BIOLOGY AND MANAGEMENT OF RICE INSECTS

BIOLOGY AND OF RICE

Edited by
E.A. HEINRICHS



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MANAGEMENT INSECTS

With contributions by

R.M. Aguda • A.T. Barrion • M. Bharathi • S. Chelliah • D. Dale
K.O. Gallagher • E.A. Heinrichs • K. Kiritani • J.A. Litsinger
M.E. Loevinsohn • K. Naba • P.A.C. Ooi • O. Parada
D.W. Roberts • M.C. Rombach • B.M. Shepard • C.M. Smith • G. Weber

IRRI
INTERNATIONAL RICE RESEARCH INSTITUTE

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FOREWORD

INSECT PESTS ARE severe constraints to rice production throughout the world. Although rice insect outbreaks are recorded in antiquity, evidence indicates that the severity and frequency of attack has increased in the last several decades. The increase appears to have accompanied crop intensification. Thus, for high yielding, green revolution varieties to achieve near their yield potential, various constraints, including those imposed by insects, must be mitigated.

Integrated pest management has been accepted as the rationale approach to the regulation of rice insect populations. Integrated pest management is an economically attractive and ecologically and sociologically acceptable means of managing rice insect populations. To most effectively implement integrated pest management programs requires first of all a proper identification of the pest complex and an understanding of the biological and ecological factors that regulate pest populations. With these building blocks as a firm foundation for properly characterizing and monitoring insect populations, various pest control tactics have been developed and integrated into rice insect management programs.

Success in the development and implementation of effective rice insect management programs has been limited in scope and has yet to be even partially achieved in many of the rice growing regions of the world. Success cannot be achieved without a development of the required skills. The authors have written this book to provide the basic information needed to develop those skills.

There has been an acute need for a book that draws together the fundamentals of rice insect taxonomy, biology, and ecology, and the various control tactics, and explains how these are integrated into a successful rice insect management program. The authors have drawn upon their extensive experience in rice entomology and have succeeded remarkably well in filling that need through the completion of this book. Its publication is evidence of our desire to promote and accelerate the development of integrated pest management systems for rice throughout the rice growing world.

KLAUS LAMPE
Director General
International Rice Research Institute

PREFACE

INSECTS ARE A MAJOR constraint in the production of rice throughout the world. They are especially severe in tropical Asia and are increasing in importance in Africa and South America. With the continued increases in the human population and losses of arable land, there is an ever increasing need to increase rice production per unit of land through the development of rice production strategies that are sustainable and are economically, environmentally, and socially acceptable. Rice entomologists are playing a major role in the development of sound rice production strategies and will continue to do so in the challenging years ahead.

Development of rice insect management strategies is promoted by the availability of literature upon which to draw. During the last three decades there has been a virtual explosion of rice entomology research papers scattered in diverse publications throughout the world, but there has not been a comprehensive treatment of rice entomology under one cover. The few books on rice entomology are out of date, very limited in scope, and are not available to most rice scientists. During my tenure at the International Rice Research Institute (IRRI) (1975-1985), I often felt the need for a reference book on rice insects. This book was produced to provide students, rice entomologists, and scientists in other rice disciplines with a comprehensive reference on rice entomology that contains the information needed to understand the principles of rice entomology and to develop research and insect management programs.

The fundamentals of rice entomology, the biology and ecology of rice insects, the various tactics for rice control, and the implementation of rice insect management systems are covered in this book. Chapter 1 discusses the global importance of rice as a major food crop and the role of insects in causing plant damage. Chapter 2 consists of a taxonomic key for the identification of rice insect pest species and their parasites and predators. This is the first taxonomic key published covering essentially all of the world's important rice insect pests and their natural enemies. Chapter 3 explains the biology, distribution, life cycle, ecology and damage caused by the major rice insect pests throughout the rice growing regions of the world. Chapter 4 is a treatment of how ecological factors determine the presence and abundance of rice insect pests in different rice cropping environments. Chapters 5-9 discuss the status of the various rice insect control tactics: host plant resistance; cultural, mechanical and physical controls; predators and parasitoids; pathogens; and insecticides, respectively. Chapter 10 covers the integration of the various insect control tactics. Chapter 11 is a case study of the development of a management strategy for the brown planthopper, *Nilaparvata lugens* (Stål), and Chapters 12 and 13 explain the development and implementation of rice insect management systems designed for Japan and Latin America, respectively.

Effective rice insect management programs are interdisciplinary in nature and involve not only entomologists with diverse expertise, but also rice breeders, plant physiologists, plant biochemists, soil scientists, economists, weed scientists, plant pathologists, and sociologists. All of these disciplines will find this book to be a valuable resource for their research program. This book will also serve as a supplement to texts in entomology and other agricultural courses in colleges and universities.

A great deal of effort has gone into the production of this book. I thank the authors for the excellence of the chapters that they contributed and extend my sincere appreciation to Jan Ray for her assistance in the preparation of the manuscript, and to Kristin Heinrichs and Wendy Heinrichs for preparing the subject and species indices. To Danny Amalin, Entomology Division, IRRI, I express my appreciation for the superb quality of his approximately 2,000 drawings of insects included in Chapters 2 and 3. Last, but not least, I owe a debt of gratitude to Dr. N.C. Brady, Director-General, IRRI (1973-1983), and Dr. M.D. Pathak, Director, Research Coordination and Training, IRRI (1962-1989) for their inspiration and encouragement and for providing me the opportunity to conduct research on rice, the most important food crop of the developing world.

Baton Rouge, Louisiana E.A. HEINRICHS

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CONTRIBUTORS

Remedios M. Aguda
Entomology Division
International Rice Research Institute
Manila, Philippines

Albert T. Barrion
Entomology Division
International Rice Research Institute
Manila, Philippines

M. Bharathi
Tamil Nadu Rice Research Institute
Aduthurai, Tamil Nadu, India

S. Chelliah
Tamil Nadu Rice Research Institute
Aduthurai, Tamil Nadu, India

D. Dale
Department of Entomology
Kerala Agricultural University
Kerala, India

Kevin O. Gallagher
Department of Entomology
University of California at Berkeley
Albany, California

EA. Heinrichs
Department of Entomology
Louisiana State University Agricultural Center
Baton Rouge, Louisiana

Keizi Kiritani
Division of Entomology
National Institute of Agro-Environmental Sciences, Yatabe, Tsukuba, Japan

James A. Litsinger
Entomology Division
International Rice Research Institute
Manila, Philippines

Michael E. Loevinsohn
International Development Research Centre
Ottawa, Canada

Kunihiko Naba
Division of Entomology
Hiroshima Prefectural Agricultural Experiment Station
Hagashihiroshima, Hiroshima, Japan

P.A.C. Ooi
CAB International Institute of Biological Control
(IBC) Malaysian Station, Batu Tiga
Selangor, Malaysia

O. Parada
Federacion Nacional de Arroceros
Bogota, Colombia

D.W. Roberts
Insect Pathology Research Center
Boyce Thompson Institute for Plant Research at Cornell University
Ithaca, New York

Michiel C. Rombach
Insect Pathology Resource Center
Boyce Thompson Institute for Plant Research at Cornell University

C. Michael Smith
Department of Plant, Soil and Entomological Science
University of Idaho
Moscow, Idaho

G. Weber
Centro Internacional de Agricultura Tropical
Cali, Colombia

I. FUNDAMENTALS

1

Rice

E.A. HEINRICHS
Louisiana State University Agricultural Center
Baton Rouge, Louisiana, USA

"So dependent upon rice are the Asian countries that throughout history a failure of that crop has caused widespread famine and death."

—Robert F. Chandler, Jr., 1979

1. IMPORTANCE OF RICE

RICE IS THE PRIMARY staple for more than two billion people in Asia and for hundreds of millions of people in Africa and Latin American (IRRI 1985). Among the major food crops it is the only one that is almost exclusively a human food. It constitutes half of the diet of the more than 1.6 billion people and 400 million rely on rice for a fourth to a half of their diet (Swaminathan 1984). Rice provides about 80% of the calories for two billion Asians and one-third of the caloric intake of one billion persons in Africa and Latin America (Chang 1984). Consumption per capita varies from 186 kg/year in Burma to a low of 4 kg/year in USA (IRRI 1988).

2. ORIGIN OF RICE

Rice an annual grass (Gramineae) is cultivated from 53° N to 40° S latitude. Rice belongs to the genus *Oryza* which includes twenty wild species and two cultigens, *O. sativa* and *O. glaberrima* (Table 1) (Chang 1985). The origin of rice is lost in antiquity. Chang (1976) (Fig. 1) has postulated that the original habitat was the supercontinent of Gondwanaland. When Gondwanaland broke up *Oryza* species drifted to what became Africa, Antarctica, Australia, Malagasy, South America, and Southeast Asia.

TABLE 1

Species of *Oryza,* chromosome numbers, and geographical distributions (from Chang 1985)

Species name (synonym)	*x =12 2n =*	*Distribution*
O. alta Swallen	48	Central and South America
O. australiensis Domin	24	Australia
O. barthii A. Chev. *(O. breviligulata)*	24	West Africa
O. brachyantha A. Chev. & Roehr.	24	West and central Africa
O. eichingeri A. Peter	24,48	East and central Africa
O. glaberrima Steud.	24	West Africa
O. gandiglumis (Doell) Prod.	48	South America
O. granulata Nees & Arn. ex Hook f.	24	South and Southeast Asia
O. glumaepatula Steud. *(O.perennis* subsp. *cubensis)*	24	South America and West Indies
O. latifolia Desv.	48	Central and South America
O. longiglumis Jansen	48	New Guinea
O. longistaminata A. Chev. & Roehr. *(O. barthii)*	24	Africa
O. meridionalis N.Q. Ng	24	Australia
O. meyeriano (Zoll. & Morrill) ex Steud.) Baill.	24	Southeast Asia, southern China
O. minuta J.S. Presl ex C.B. Presl	48	Southeast Asia
O. nivara Sharma & Shastry *(O. fatua, O. sativa f.* spontanea)	24	South and Southeast Asia and Southern China
O. officinalis Wall. ex Watt	24	South and Southeast Asia, southern China, New Guinea
O. punctata Kotschy ex. Steud.	48,24	Africa
O. rideyi Hook f.	*48*	*Southeast Asia*
O. rufipogon W. Griffith *(O. perennis, O. fatua, O. perennis subsp. balunga)*	24	South and Southeast Asia and southern China
O. sativa L.	24	Asia
O. schlechteri Pilger	–	New Guinea

Domestication of *O. sativa* occurred some 10,000 years ago in the river valleys of South and Southeast Asia and China (De Datta 1981). Rice specimens have been found in China that date from the third millenium B.C. (Grist 1975). Earliest historical references are found in Chinese writings of about 3,000 B.C. when it was stated that of the five principal food plants in the country rice was the most important.

Rice was introduced into Kyushu, Japan from China in about 100 B.C. and from there it spread reaching Hokkaido in the extreme north only in the eighteenth century. The Portuguese introduced

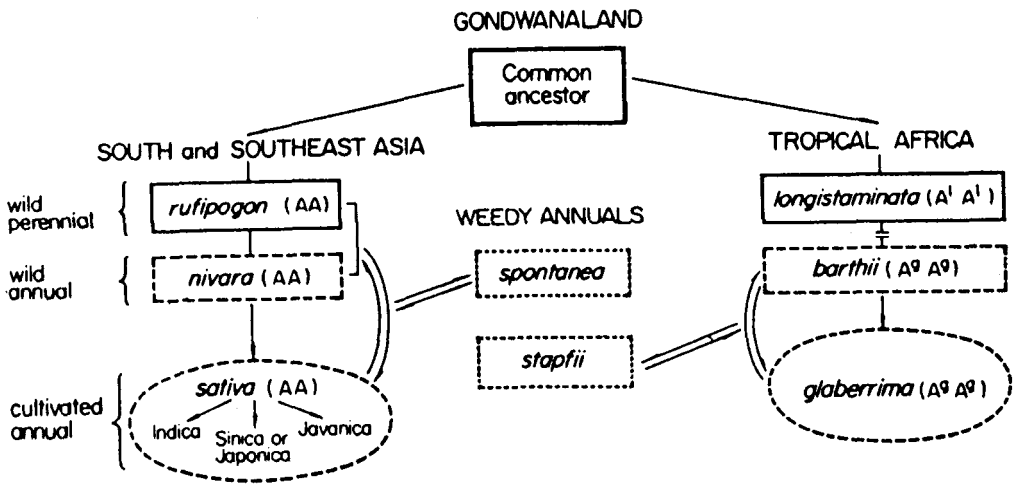


Fig. 1. Evolutionary pathway of two cultigens. Taxa boxed by solid lines are wild perennials. Taxa boxed by broken lines are annuals. Arrow with solid line indicates direct descent. Arrow with broken line indicates indirect descent. Double arrows indicate introgessive hybridization (from Chang 1985).

rice into Brazil and the Spaniards introduced rice into Central America and parts of South America. The crop was brought into Italy in the fifteenth century.

Rice cultivation in the USA dates from about 1646 when it was introduced into the James River region of Virginia and in 1685 when it was first grown in the colony of South Carolina. In 1718 it was introduced into Louisiana but did not assume importance until 1887.

3. RICE CLASSIFICATION

In Asia *O. sativa* differentiated into three subspecies based on geographic conditions; indica, javanica, and japonica (sinica). Indica refers to the tropical and subtropical varieties grown throughout South and Southeast Asia and southern China whereas japonica refers to the short and roundish grained varieties of the temperate zones of Japan, China, and Korea. Javanica designates the Indonesian bulu (awned) and gundil (awnless) rices with long panicles and bold grains growing alongside of indicas in Indonesia. A further classification for rice that refers to its habitat in terms of soil and water, is upland, rainfed shallow, deep water, floating, and irrigated. Rice area of the five types in India and China is indicated in Fig. 2. Most of the rice area in China is irrigated whereas in India less than half is irrigated (IRRI 1985). In Latin America and Africa most of the rice is upland whereas in the U.S.A. all rice is grown under irrigated conditions.

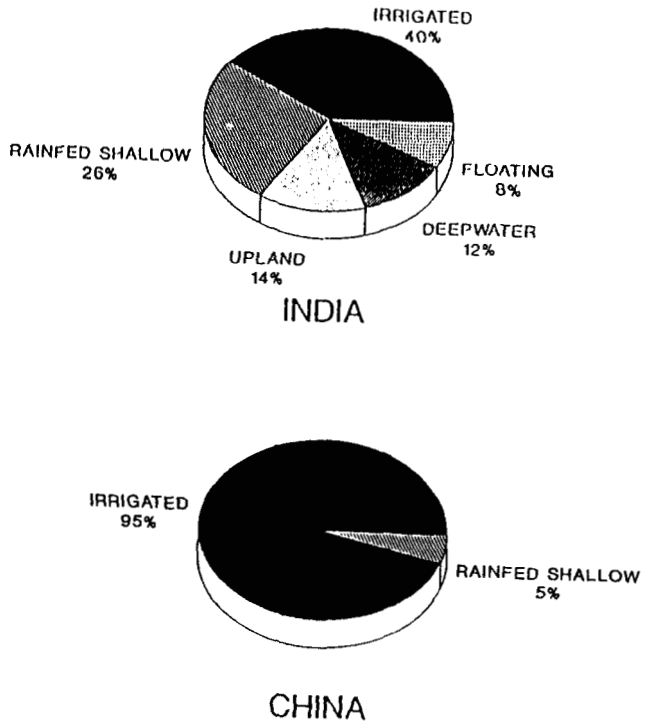


Fig. 2. Percentage area of the various types of rice culture in India and China (from IRRI 1985).

Rice is adaptable to a wide range of environmental conditions because it has an efficient system of air passage from shoot to root. This system allows rice to grow in waterlogged soils. Because of the air passage system roots respire aerobically and utilize carbohydrates to produce energy even when they are growing in an anaerobic environment.

In much of the world the rice crop is grown on soils with 5 to 10 cm of standing water. Rice also grows well on dry upland soils where it is cultivated like wheat. Rice can thus be grown in mixed and multiple cropping patterns with other crops including wheat, maize, and soybeans (Swaminathan 1984). Floating rice grows in water that is one to five m deep. It can elongate at the rate of 25 cm per day in rapidly rising water.

The rice plant passes through 10 stages during its growth cycle: (1) germination and emergence, (2) seedling, (3) tillering, (4) stem elongation, (5) panicle initiation, (6) panicle development, (7) flowering, (8) milk grain, (9) dough grain, and (10) mature grain stage (Reissig *et al.* 1986). Traditional varieties require about 150 days of growth to reach the mature grain stage whereas the

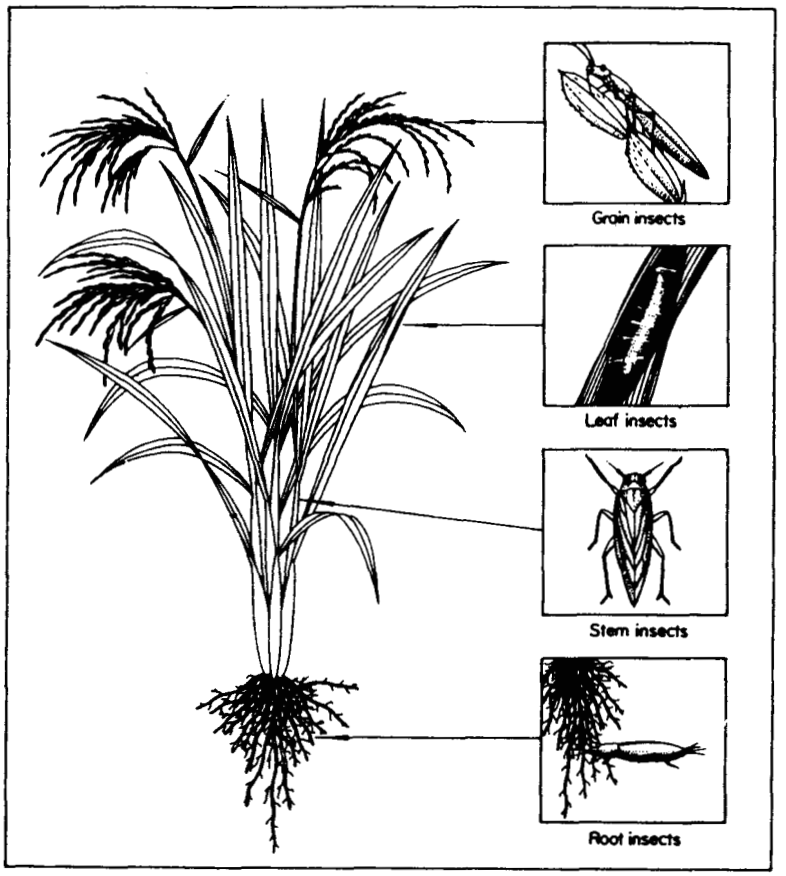


Fig. 3. Portions of the rice plant attacked by insects (from Reissig *et al.* 1986).

modern, high yielding very early maturing varieties can be harvested in as few as 90 days after sowing.

4. Damage Caused by Rice Insect Pests

4.1 YIELD LOSSES

Insect pests attack all portions of the rice plant and all stages of plant growth. Grain insects remove milk from developing grains, defoliators feed on the leaves, sucking insects feed on the leaves and stem, stem borers feed within the stem, and some species feed on the roots (Fig. 3).

Insects are important constraints to rice production and occur in all rice growing environments (see Chapter 4). Insects reduce yields substantially, especially in tropical Asia. Cramer (1967) estimated the rice yield losses caused by insects by reviewing the literature up to 1966. Because of the inadequacy of much of the data he adopted a conservative approach. Yet he estimated losses ranging from 31.5% in Asia (excluding The People's Republic of China) to 2% in Europe and Oceania (Table 2). The severity of insect damage in Asia is further indicated by the results of 117 experiments conducted on the IRRI (International Rice Research Institute) farm in Los Baños, Philippines. The average yield of insecticide-protected plots was 4.9 t/ha whereas yields of plots receiving no insecticide was 3.0 t/ha, a yield loss of about 40%. However, losses on experiment station plots are usually greater than in farmer's fields. Thus a further series of experiments coordinated by IRRI was conducted in farmers' fields in six Asian countries. The increase in yields of fields receiving fertilizer, and insect and weed control was 0.9 t/ha in the wet season and 1.7 t/ha in the dry season (Herdt 1979); 45% and 35% of those increases, respectively, were due to insect control (Fig. 4).

TABLE 2

Rice yield losses caused by insect pests on a world basis (from Cramer 1967)

Region	*yield loss* (%)
Asia (excluding People's Republic of China)	31.5
People's Republic of China	15.0
Africa	14.4
South America	3.5
North and Central America	3.4
Europe	2.0
Oceania	2.0

4.2 FACTORS AFFECTING EXTENT OF INSECT-CAUSED YIELD LOSSES

Rice insects are as old as rice itself. Historical records from Korea and Japan report on the history of rice insect pests during the last two millenia. In 701 insect outbreaks were reported in western Japan. In 875 a migratory locust outbreak occurred in the Ise District of Japan and in 1071 an

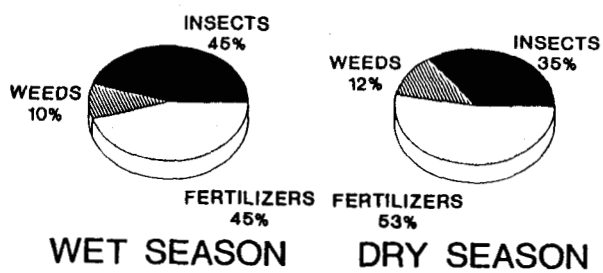


Fig. 4. Factors affecting differences in yields of farmers' fields following farmers' practices and improved production practices in six Asian countries 1974-1977 (from Herdt 1979).

armyworm outbreak occurred near Kyoto. A brown planthopper outbreak in 1733 was reported as one of the most damaging insect outbreaks in the history of rice production in Japan. About 2.6 million persons were affected and 12,000 died from Hunger (Okutani 1980).

Although rice insect outbreaks have been recorded over the last 1,300 years, they have become much more frequent and the insect pest complex has changed in the last three decades. Certain insects such as the leaf- and planthoppers have increased in severity, whereas others such as certain stem borer species have declined in importance.

Crop intensification has been suggested as a reason for the changes in the insect pest fauna in rice (Loevinsohn 1985). Loevinsohn defines intensification as "an increase in resources devoted to rice cultivation." Intensification involves (1) an increase in the number of crops grown per year, (2) an increase in the use of agricultural chemicals; fertilizer and pesticides, (3) planting of varieties responsive to fertilizers and pesticides, and (4) increased plant densities, Loevinsohn provides evidence that ecologically specialized species have been favored by crop intensification.

Changes in rice cultural practices have accompanied the widespread adoption of modern varieties. The photoperiod insensitivity and reduced growth duration of the modern varieties have made it possible to grow two and even three crops per year, where water, and temperatures are adequate. The spread of the dry season crop has caused shifts in the composition of pest fauna (Loevinsohn *et al.* 1988). Although most of the insects in the tropics have increased in severity, some species such as the white stem borer *Scirpophaga innotata* (Walker), have decreased in importance because its larvae aestivate in stubble and are destroyed by the dry season land preparation. Species dependent on standing water, such as the whorl maggot *Hydrellia philippina* Ferino, and the rice caseworm *Nymphula depunctalis* (Guenee), have become more abundant.

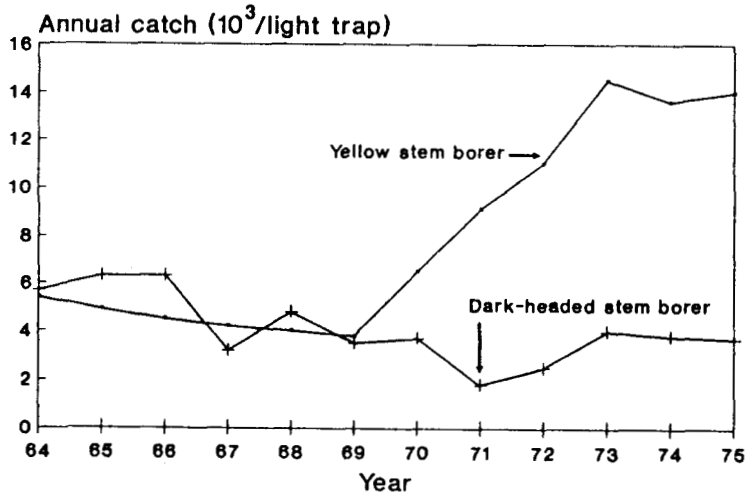


Fig. 5. Annual light trap collections indicate the replacement of the dark-headed stem borer *Chilo polychrysus* with the yellow stem borer *Scirpophaga incertulas* with the expansion of double rice cropping in Titi Serong, Malaysia, 1964-1975 (from Lim and Heong 1977).

The increase in the area planted to dry season rice as a result of expanded irrigation has reduced the area planted to alternate crops and the cover of wild grasses in fields formerly left fallow during the dry season. This change has favored specialist insect pests with monophagous feeding habits such as the yellow stem borer *Scirpophaga incertulas* (Walker) while the population of the polyphagous dark-headed borer *Chilo polychrysus* (Meyrick) has decreased (Lim and Heong 1977) (Fig. 5).

The most dramatic effects of modern cultural practices on abundance of rice insects specialists is seen in the plant sucking Homoptera; the nearly monophagous brown planthopper *Nilaparvata lugens* (Stal), and the most monophagous species of the tropical leafhopper complex, *Nephotettix virescens* (Distant). The brown planthopper rose from the status of a secondary pest to a major yield constraint beginning in the 1960s (Heinrichs and Mochida 1984). In Indonesia losses in 1976-1977 were estimated at 365,000 metric tons of milled rice; equivalent to the annual consumption of 3 million people (Dyck and Thomas 1979). Of the various changes in production practices the increased use of resurgence-inducing insecticides has been considered as the major cause of intensified brown planthopper problems in Asia (see Chapters 9 and 11).

5. Development of Integrated Pest Management Strategies

As rice scientists and farmers have gained experience in the cultivation of the modern varieties and the agronomic practices that have accompanied the 'green revolution' they have become acutely aware of the need to develop more effective and economical pest management strategies. This has resulted in a shift from a primarily unilateral approach of insect control with a strong reliance on insecticides to a multilateral approach involving a mix of control approaches.

Alternative pest control tactics have been developed and integrated into control programs. This approach known as integrated pest management (IPM) in the simplest terms is referred to as "a broad ecological attack combining several tactics for the economic control and management of pest populations" (Smith and Calvert 1978). Integrated control practices rely on combinations of biological, chemical, and cultural control methods and insect resistant rice varieties. Integrated management systems manipulate multiple plant protection tactics in an effective and coordinated way.

IPM programs are having a significant impact on minimizing the adverse effects of insecticides, and in increasing the profitability of rice production. It has been estimated that the cost savings from research leading to increased insect pest management efficiency on rice in South and Southeast Asia will be $973 million in insecticide saved by the year 2,000 (Flinn 1984).

Chapters in this book discuss the basic information required to develop sound rice insect pest management systems; an understanding of the taxonomy, biology and ecology of rice insect pests. These chapters are followed by a section dealing with the various control tactics including host plant resistance, cultural, mechanical, and physical controls, biological control agents, and insecticides. Chapters on the implementation of rice insect management systems discuss the integration of the

various control tactics and the deployment of insect pest management systems in Japan and Latin America.

During a visit to IRRI in the Philippines in the early 1960s Norman Cousins, then editor of the Saturday Review, wrote that "any genuine improvement in the human condition on this planet must be concerned with rice." Entomologists throughout the rice growing regions of the world are striving diligently to do their part in improving the quality of life by developing and implementing strategies to more effectively, safely, and economically manage rice insect pests.

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2

Taxonomy of Rice Insect Pests and their Arthropod Parasites and Predators

ALBERTO T. BARRION AND JAMES A. LITSINGER
Division of Entomology
International Rice Research Institute
P.O. Box 933, Manila, Philippines 1099

1. INTRODUCTION

RICE IS GROWN WORLDWIDE in over 124 million hectares under diverse cultural conditions and over a wide geographical range. The need for higher levels of production has caused expanded areas to be planted and more crops per year to be harvested. The greater apparency of rice in agricultural ecosystems will tend to increase species richness of both pests and natural enemies. Grist and Lever (1969) were the last to catalogue the insect pests of rice worldwide.

This chapter provides a practical and comprehensive classification of insects and spiders associated with rice worldwide. It includes both rice pests and natural enemies (predators and parasites) of rice pests. The keys are based on diagnostic characters for each species and have necessarily had to involve morphological features relevant to each taxonomic group. The richly illustrated keys can be used by individuals with minimal experience in insect morphology and taxonomy. We have maintained technical accuracy by using precise morphological and taxonomic terminology but also give non-technical synonyms. With the exception of leafhoppers and planthoppers the keys are based primarily on adults which have a greater array of morphological features.

This chapter is more complete for Asia than Africa or Latin America and South America because the keys were based on specimens in our reference collection and literature available to us. However, it is hoped that this will contribute to a better understanding of the rice ecosystem and will serve as a taxonomic guide for further studies in rice entomology.

2. KEY TO INSECTS AND SPIDERS

1 With 3 distinct body regions – head, thorax, and segmented abdomen; 6-legged; winged or wingless (insects) (Fig.1) 2

1' With only 2 body regions – cephalothorax (fused head and thorax) and unsegmented abdomen; 8-legged; wingless (spiders) (Fig. 2) 729

2(1) Wings present (with few veins or well developed) 3

2' Wingless 713

3(2) With only 1 pair of wings 4

3' With 2 pairs of wings 62

4(3) Forewings reduced to a pseudohaltere, leather-like and without venation; functional hindwings markedly expanded; head with large berry-like eyes; antennae 4- or 7-segmented; pro- and mesothorax much reduced, metathorax very large; trochanters absent; twisted winged parasites, males (**STREPSIPTERA**) 5

4' Forewings developed, membranous and with venation; hindwings reduced to club-like halteres; pro- and metathorax greatly reduced; trochanters present; fly pests, parasites, and predators (**DIPTERA**) 9

5(4) Tarsi 2-segmented; antenna 4-segmented, 3*rd* segment laterally flabellate and originates at the base of the segment; parasites of delphacids and fulgorids [Eienchidae] 6

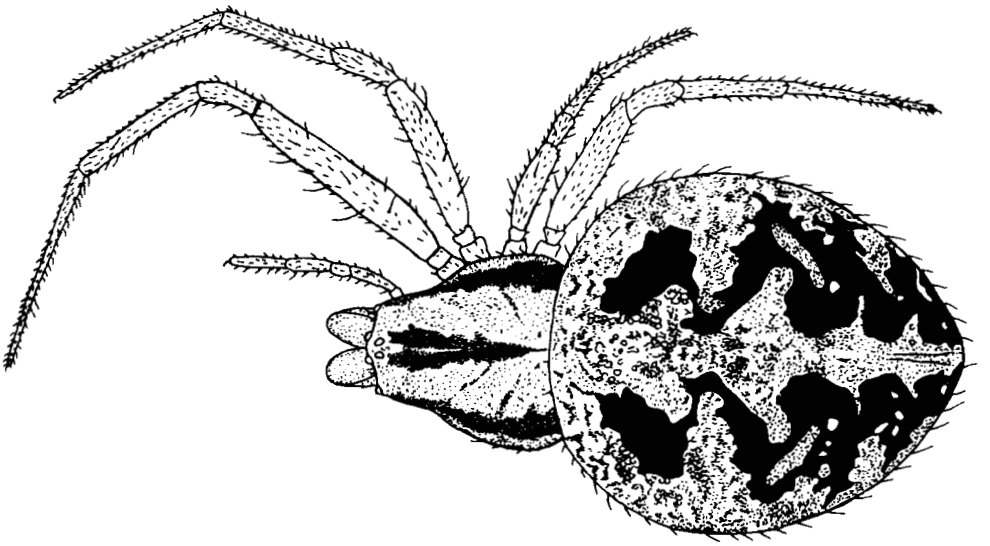
5' Tarsi 3-segmented; antenna 7-segmented, the 3*rd* to 5*th* prolong laterally, and 7*th* segment elongate; parasites of cicadellids [Halictophagidae] 7

6(5) Postlumbium (Fig. 3) prominently large and semicircular; postscutellum large, about 0.7 of entire metathorax; vein A straight to slightly convex; male cephalotheca conspicuously convex and oval (Fig. 4) ..... *Elenchus yasumatsui* Kifune & Hirashima

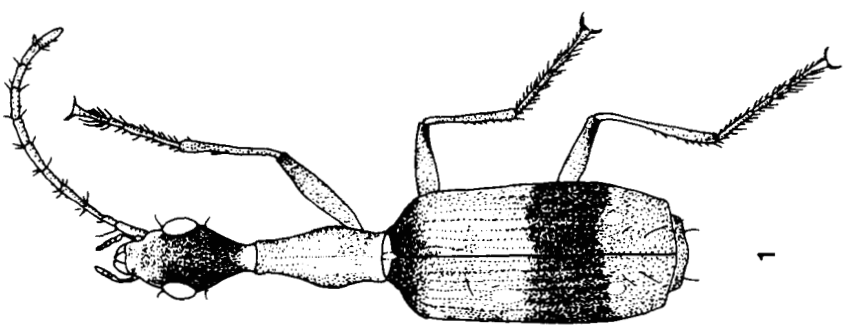
6' Postlumbium (Fig. 5) small; postscutellum subtriangular with a narrow and rounded apex, occupies about 0.4 of the metanotum; vein A straight with a bent apex; male cephalotheca globular (Fig. 6) ..... *Elenchus japonicus* Esaki & Hashimoto

7(5) Hindwing without Mf; Rf short and broad; Cu clearly shorter than 1A; 2A very short and situated near wing margin (Fig. 7); eyes with 12 facets; antennae less compact; flabella of antennal segments III to VI and VII equally slender but gradually decreasing in length, 7*th* segment narrowed medially (Fig. 8); aedeagus with almost straight, sharp, dorsal process longer than ventral protrusion; male cephalotheca conspicuously convex, transversely elongate - elliptical with ventral margin trapezoidally protruded (Fig. 9) host – *Thaia oryzivora* Ghauri ..... *Halictophagus thaiae* Kifune

7' Hindwings with long Mf; Rf long and broad; Cu and 1A almost equally long; 2A long and distinctly separated from wing margin 8

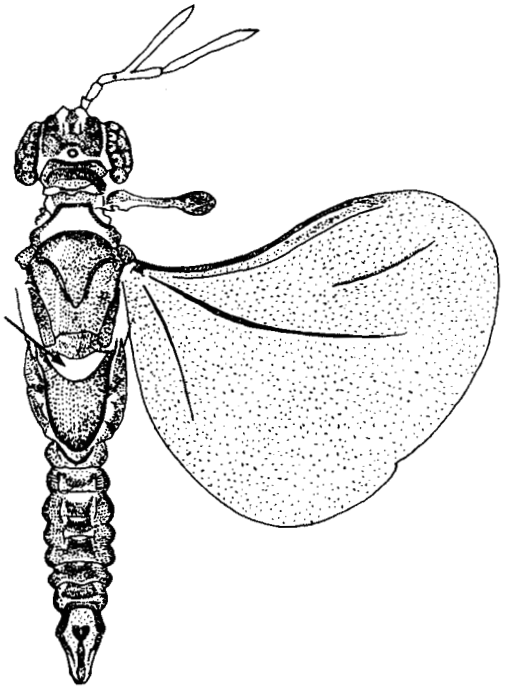


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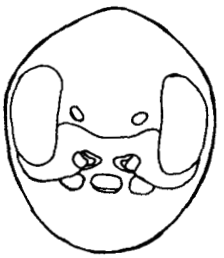


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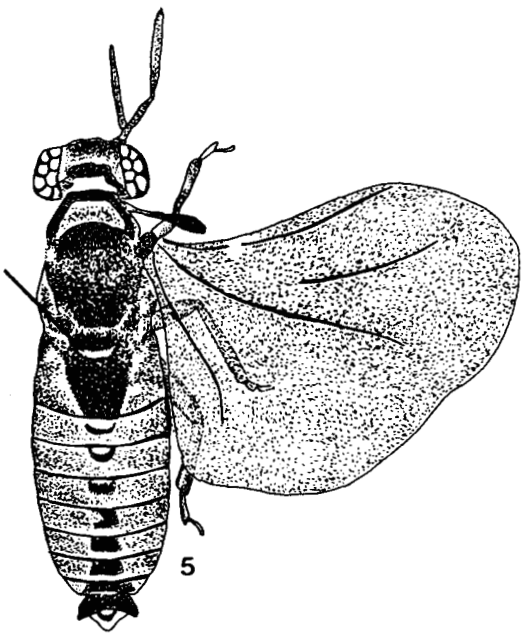
Figs. 1-2



3



4



5



6

Figs. 3-6

8(7') Basal portion of *3rd* antennal segment about as long as that of *4th;* flabella more or less thickened (Fig. 10); aedeagus enlarged in the basal half, apex with a short dorsal process and a long ventral protrusion (Fig. 11); male cephalotheca elliptical (Fig. 12); host – *Cofana spectra* . . . . . *Halictophagus spectrus* Yang

8' Basal portion of *3rd* antennal segment about twice as long as that of *4th,* flabella of antennal segment V-VII almost equal in size and shape but smaller than III and IV with a long, flat and stout flabella (Fig. 13); aedeagus enlarged in basal third, stem almost straight, hook rectangularly dorsally pointed with sharp tip (Fig. 14); male cephalotheca conspicuously convex and elongate-elliptical (Fig. 15); hosts – *Nephotettix nigropictus* and *N. virescens* . . . . . *Halictophagus bipunctatus* Yang

9(4') Third antennal segment with 4 or more freely articulated flagellomeres; maxillary palp 3 to 5-segmented 10

9' Third antennal segment usually consolidated into a compound segment, typically with a terminal to dorsal bristle-like arista; maxillary palp 1 or 2-segmented 18

10(9) Mesonotum with a V-shaped suture; ocelli absent; antennae 12-segmented with a circular pedicel, bases of funicles 2 to 10 swollen and ringed with hairs; head grey dorsally with 3 grooves above antennal sockets, front elongate-cylindrical projected forward with an apicomedian process; postscutellum globular with small bulbous median point; wings (Fig. 16) transparent except brownish bands along subcosta, and cells between R1 and R2, wing length a little longer than body length; haltere as long as abdominal segment II and III; basal tarsal segment of leg I longer than abdomen [Tipulidae] . . . . . *Tipula aino* Alexander

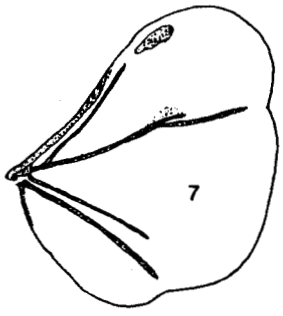
10' Mesonotum without a V-shaped suture 11

11(10') Costa continuing around wing margin with wing venation reduced, longitudinal vein Rs unbranched (Fig. 17) and without discal cell; antennae more than 10 segments with bead-like joints; maxillary palpi 3 or 4-segmented [Cecidomyiidae] 12

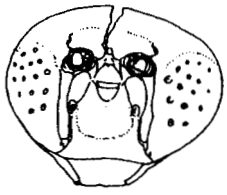
11' Costa disappearing beyond wing tip; veins equally developed and *2nd* basal cell longer than *1st* basal cell (or basal cell imperfectly separated to apically open in *2nd* basal cell); R branched; vein M branched or unbranched; antennae with 15 segments 13

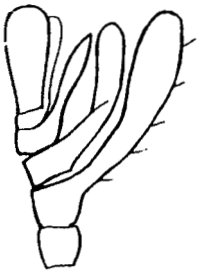
12(11) Asian rice gall midge; apical end of hypoproct rounded (Fig. 18); gonostyle thinner in apical one-third (Fig. 19); anterior margins of abdominal tergites VII and VIII without distinct pigmented areas; maxillary palpi 4- segmented . . . . . .*Orseolia oryzae* (Wood-Mason)

12' African rice gall midge; apical end of hypoproct slightly notched (Fig. 20); gonostyle very slightly tapered in apical one-third (Fig. 21); anterior margins of abdominal tergites VII and VIII with irregular narrow pigmented bands; maxillary palpi 3-segmented (Fig. 22). . . . . .



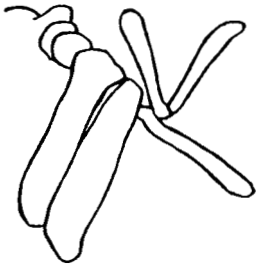

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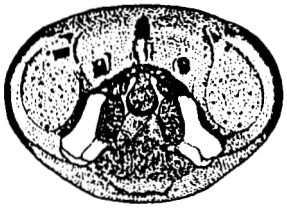

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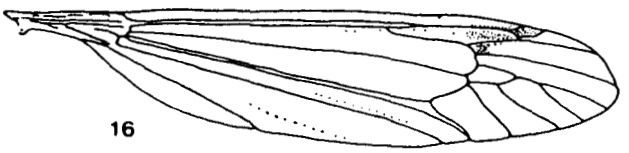

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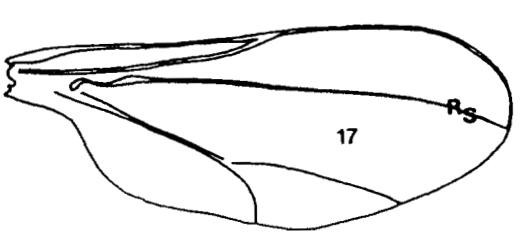

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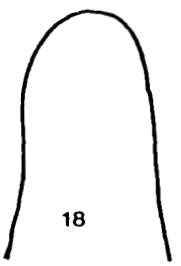

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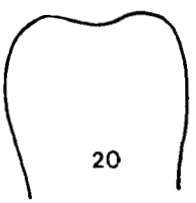
Figs. 7-15



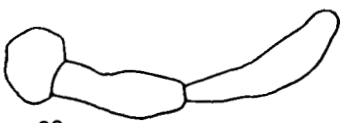


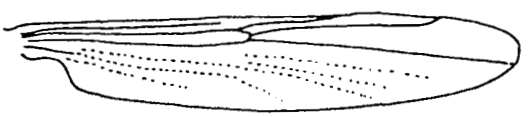


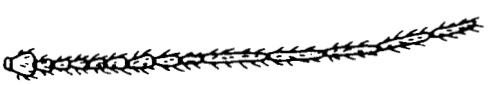












Figs.16-24

13(11') Front legs not lengthened; vein M 2-branched (Fig. 23); antennae (Fig. 24) 15-segmented, segments III-X much shorter than XI-XV; body brown with fore- and midlegs yellow; forefemora without subapical pale band; anterior part of femora II and III, tibiae II, and dorsal side of tibiae III with a series of long hard spines; ventral side of basitarsi II and III and second tarsal segment of leg III with rows of small but dense spines; apical tarsal segments of all legs with several long spines [Ceratopogonidae] . . . . . *Nilobezzia acanthopus* (de Meijere)

13' Front legs lengthened; vein M unbranched 14

14(13') Forewings (Fig. 25) with 4-5 cloudy patches on the subapex of wing membrane in between longitudinal veins R4+5 to A (or cell R5, M, Cu, and A); scutum with dark brown markings; legs yellow with dark brown bands on knees, distal part of tibiae and tarsi I-IV, tarsi V entirely black; abdominal tergites uniformly dark brown with narrow apical pale band on tergites I-VII; dorsal appendage (Fig. 26) hook or sickle shaped apex and enlarged basal portion with a rounded tip; style (= gonostylus) slender towards apex with long apical bristles (Fig. 27); small species, wing length 2.8-2.9 mm . . . . . *Chironomus kiiensis* Tokunaga

14' Forewings without cloudy patches on cells Rs, M, Cu, and A; wing length usually more than 3 mm 15

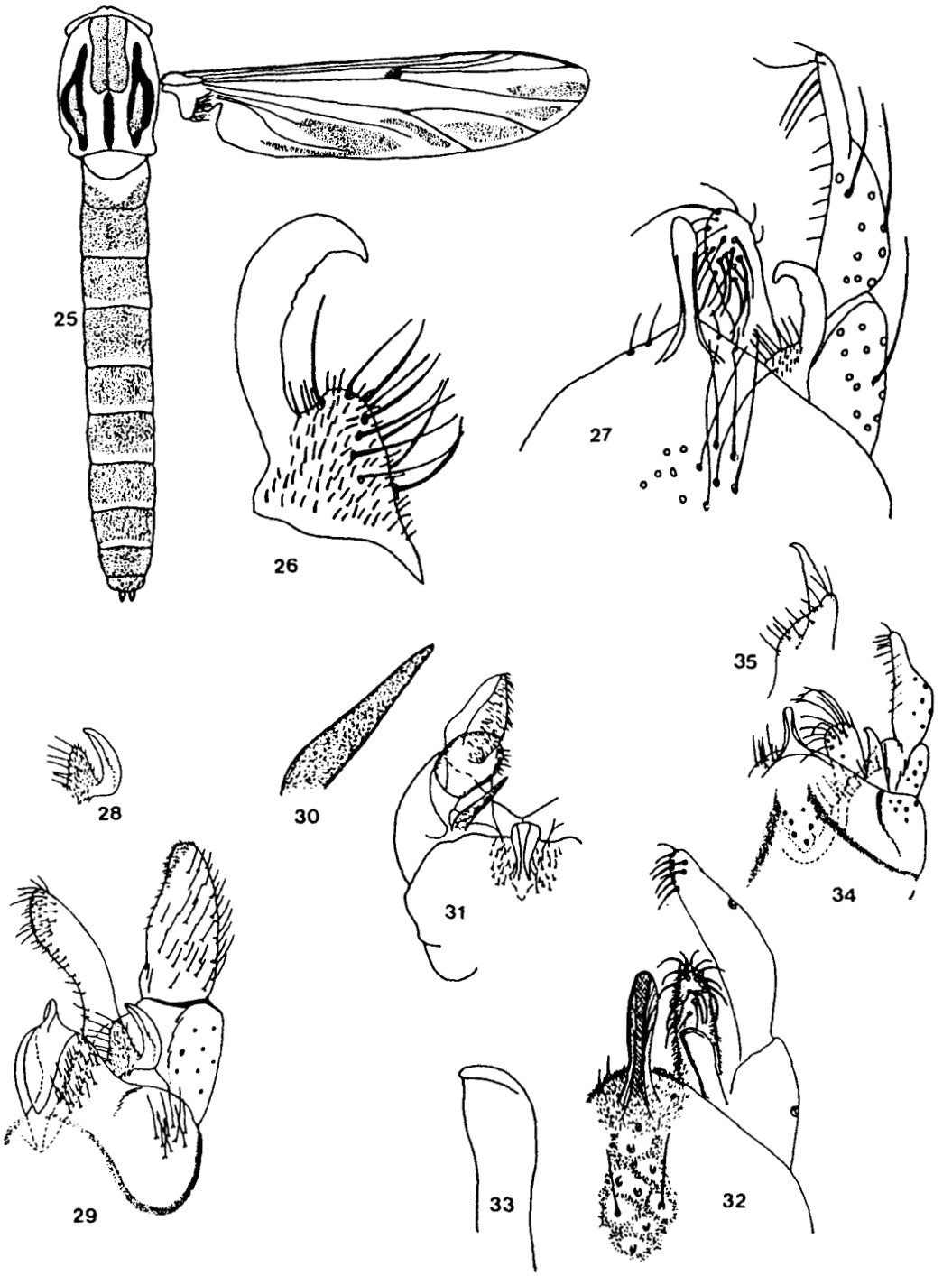
15(14') Dorsal appendage strongly C to sickle-shaped (Fig. 28) with a well developed large tubercle in its inner portion; ventral appendage large and distinctly long, slightly narrowed before base and gradually narrowly rounded apically; style almost uniformly stout except reduction towards a rounded apex; anal point 2-ridged (Fig. 29); scutellum with 13 bristles and 7 small setae; all tarsal segments apically dark and last 2 segments fuscous . . . . . *Chironomus crassiforceps* Keiffer

15' Dorsal appendage large, spine-like, slightly curved at apex or subcylindrical with a moderately enlarged apex 16

16(15') Dorsal appendage large, spine-like, straight and pointed (Fig. 30); ventral appendage greatly swollen, sounded in lateral aspect, densely hairy in the inner surface; styles short and oval; anal point short or deep in lateral aspect and laterally flanged (Fig. 31); thorax dull grey with pits of the dorsocentral bristles very distinct . . . . . *Chironomus tepperi* Skuse

16' Dorsal appendage not acutely pointed, tips slightly curved or swollen; anal point long to moderately long 17

17(16') Ventral appendage (Fig. 32) with about 17 setae, slightly pointed in the inner-apical area; dorsal appendage (Fig. 33) slightly knob-like reaching midhalf of the ventral appendage (sometimes inwardly curved at tip); anal point prominently developed, long, rounded at apex and narrowed before a little broad base; style gradually widened at midhalf in the outer margin with 7 setae along margins and 2 setae in the middle behind the former set (Fig. 32) . . . . . *Chironomus dorsalis* Meigen



Figs. 25-35

17' Ventral appendage (Fig. 34) with 10-14 setae and bluntly shaped apex; dorsal appendage (Fig. 35) straight with an inwardly curved tip; anal point small, widened basally and rounded at apex; style with a swollen basal half and narrowed apical half from the outside margins, inner apical margins with 6 setae (Fig. 34) ..... *Chironomus javanus* Kieffer

18(9') Ptilinal suture and lunule absent 19

18' Ptilinal suture and lunule present 22

19(18) Head as large as thorax and subspherical, bounded mainly by the enormous eyes; antennae with dorsal arista; R4 + 5 unbranched; big-headed fly parasites [Pipunculidae] 20

19' Entirely not as above 26

20(19) Stigma absent on wings between Sc+ R1; cross vein r-m almost midway discal cell 21

20' Stigma present between Sc + R1 23

21(20) Humeri yellowish white; wings hyaline 22

21' Humeri grey or black (Fig. 36); brown tinge present on wings; eyes not joining on front with narrow convergence point on anterior of ocelli (Fig. 37); hosts - nymphs and adults of *Nephotettix* spp ..... *Tomosvaryella oryzaetora* Koizumi

22(21) Hind trochanter trapezoidal (Fig. 38); piercer of ovipositor relatively straight (Fig. 39); genitalia of male symmetrical in dorsal outline (Fig. 40), *9th* segment glossy and broad ventrally; host — *Nephottetix* spp. ..... *Tomosvaryella subvirescens* (Loew)

22' Hind trochanter with a tubercle-like process; male genitalia moderately tapered at tip, dorsally asymmetrical (Fig. 41); ovipositor of piercer downcurved (Fig. 42); hosts — *N. cincticeps, Psammotettrix striatus* (L.) ..... *Tomosvaryella sylvatica* (Meigen)

23(20') Latero-basal half of *lst* abdominal tergum without prominent setae; in males, membranous area in the rounded genitalia absent, genitalia as long as but not as wide as *5th* abdominal segment (Fig. 43) ..... *Pipunculus roralis* (Kertesz)

23' Latero-basal half of *1st* abdominal tergum with a row of prominent setae; membranous area present in male genitalia, dorsally absent in *P. javanensis* 24

24(23') Membranous area of male genitalia caudo-ventrally present, genitalia notched dorso-apically (Fig. 44); in females, tip of ovipositor prominently upcurved extending to posterior margin of *5th* abdominal sternite starting from apex of abdomen (Fig. 45); *3rd* antennal segment dark brown; legs black with yellow patches along tibiae and tarsi ... . *Pipunculus javanensis* de Meijere

24' Membranous area dorsally present bisecting the segment; ovipositor upcurved or straight 25

Figs. 36-49

25(24') Broad longitudinal cleft present middorsally in male genitalia (Fig. 46); piercer of female's ovipositor long and nearly straight (Fig. 47); host — *Nephotettix cincticeps* . . . . . *Pipunculus orientalis* (Koizumi)

25' Narrow oblique cleft present in the right side of male genitalia (Fig. 48); piercer of female's ovipositor strongly upcurved (Fig. 49); 3*rd* antennal segment of female light yellowish brown; legs yellow except femora and distal end of tarsi . . . . . *Pipunculus mutillatus* Loew

26(19') Wing venation reduced, discal cell and crossvein m absent (Fig. 50); anterior veins very much thickened and crowded basally; oblique veins M1+ 2, M3 and Cul weak; head subglobular with oblong eyes and 1-segmented antenna (Fig. 51); thorax yellow and humpback; hindlegs long with laterally flattened femora; females with 4 scutellars and 2 pairs of equal supra-antennals; humpbacked fly parasites [Phoridae] . . . . . *Megaselia scalaris* (Loew)

26' Wing venation developed; discal cell, crossvein m and r-m present; oblique veins prominent; antennae 3-segmented 27

27(26') Arista dorsal of the cone-shaped 3*rd* antennal segment (Fig. 52); third costal section equal to or longer than the fourth; crossvein M shorter than apical portion of M3 + 4; acrostichals present; femora swollen medially and thinner apically . . . . . *Campsicnemus* sp.

27' Arista in front of *3rd* antennal segment; rest of characters not as above 28

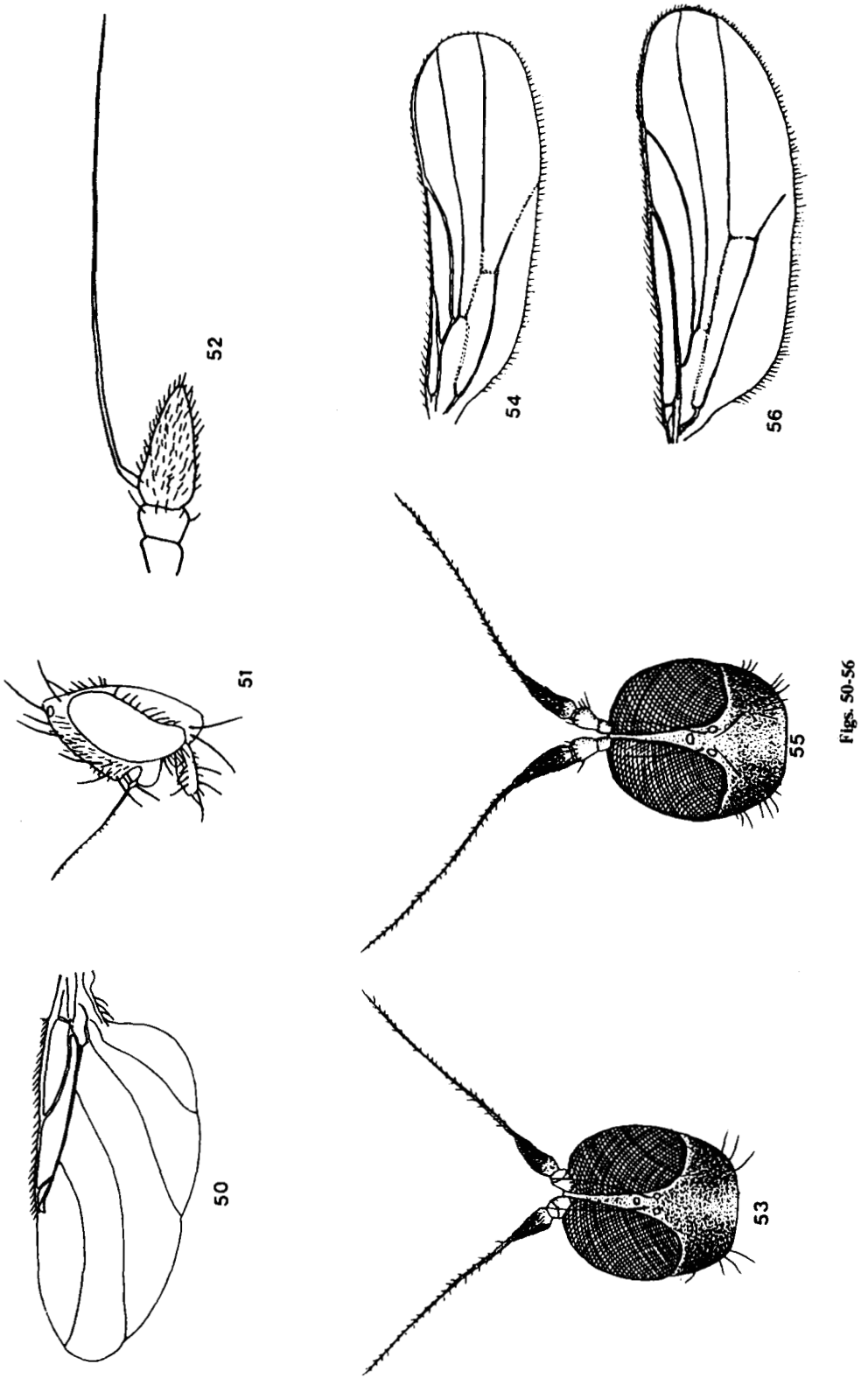
28(27') Black body with whitish yellow legs and hyaline wings; head and antenna black (Fig. 53); hind tibiae without extensor bristles; subcostal vein a little inside the basal one-third of costal length; base of vein R + Cu at midlength of subcostal vein; postical vein erased in apical half (Fig. 54) . . . . . *Drapetis (Drapetis)* sp.

28' Brownish red body with yellowish brown legs; head and antenna reddish brown (Fig. 55); hind tibiae with two extensor bristles; subcostal vein reaches midlength of costal length; base of vein R + Cu at basal one-fourth of subcosta; postical vein prominent, not erased (Fig. 56); midabdominal tergites blackish brown . . . . . *Drapetis (Elaphropeza)* sp.

29(18') Second antennal segment nearly always with longitudinal seam; lower calypter usually large and thorax nearly always with a complete transverse suture before wings 30

29' Second antennal segment without longitudinal seam; lower calypter vestigial and thorax without complete transverse suture before wings 50

30(29) Hypopleural setae absent; and vein not reaching wing margin, 2*nd* anal vein not curving forward around apex of first; terminal 3 abdominal segments with a pair each of grayish black spots (Fig. 57), sometimes absent in segment V (Fig. 58); females with a pair of small anterior plates on tergite VIII of ovipositor (Fig. 59); male trifoliate process with the stalk enlarged around middle; shoulder weak, median piece membranous and



Figs. 50-56

lateral plates developed; hypopygial prominence with 2 lateral arms widely separated and diverging outwards from tergal surface (Fig. 60), seeding maggot . . . . . *Atherigona oryzae* Malloch

30' Hypopleural and pteropleural bristles very prominent; postscutellum well developed; R5 cell narrowed or closed distally; abdominal terga with strong bristles with edges overlapping sterna; arista usually bare; parasitic flies [Tachinidae] 31

31(30') Face elevated into a very strong, broad roof-like facial keel running from epistome to lunula; eyes bare; palpi highly reduced, much shorter than 3*rd* antennal segment; sternopleuron with 2 setae; pteropleural setae absent; proboscis very long and slender, length much greater than height of head; R4 + 5 without setae, apical and fused with straight and oblique M1 and m-cu arises at about apical one-third of M (Fig. 61); parasitic on larvae of scarabaeid genera *Adoretus, Anomala,* and *Leucopholis* . . . . . *Prosena siberita* (Fabricius)

31' Face not as above, without such facial keel 32

32(31') Bend of vein M abruptly angulate (Fig. 62); M1 concave basally and convex apically; petiole (R4 + 5 + M1) slightly curved upwards producing a cleft at their junction; basal node of R4 + 5 with fine hairs ventrally, hairs shorter than r-m in length; base of costa without long hairs; palpi absent; lower calypters with only very short marginal fringe; abdomen long and slender, subcylindrical; T1+ 2 with excavation in the basal one-fifth to one-sixth; parasitic on pentatomid bug *Eysarcoris* . . . . . *Cylindromyia* spp.

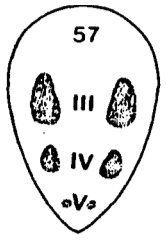
32' Not entirely as above 33

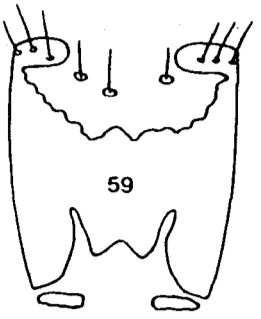
33(32') Pteropleural setae absent; eyes and prosternum bare; epistome strongly projecting, highly visible in profile; vibrissae high above level of epistomal margin 34

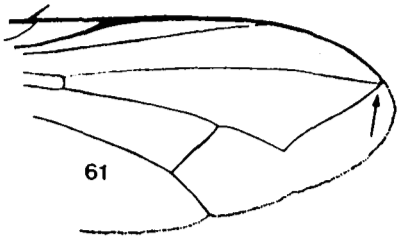
33' Pteropleural setae prominent; eyes hairy or bare; prosternum hairy or setulose and with vestiture; epistome not projecting and not visible in profile or weakly projecting; vibrissae a little over level of epistomal margin; 3 post intra-alar setae present, anterior one as close to the transverse suture as to the posterior one (Goniinae) 35

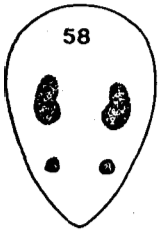
34(33) Hindcoxae with posterodorsal fine soft hairs; veins R1 and R4 + 5 bare except for fine hairs on the basal node of R4 + 5; antennae inserted a little above midlength of eye, 2*nd* segment moderately long, 3*rd* segment short and broadly rounded; parafrontal, parafacial, and wide gena hirsute; peristomal setae 8 and strongly developed; eye small and ovoid (Fig. 63) . . . . . *Cuphocera varia* F.

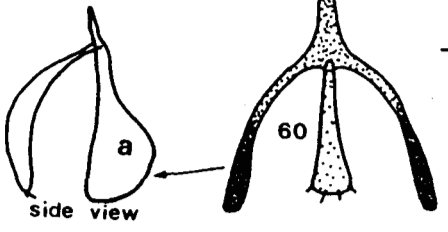
34' Hindcoxae bare posterodorsally; vein R1 setulose and vein R4 + 5 setulose up to or beyond r-m (Fig. 64); 2*nd* costal sector haired underneath; antennae very small, in line to the basal one-third of eye; eyes largely oblong; gena small; peristomal hairs less than 8 (Fig. 65); orange-yellow eyes, silvery white face; frons wider than facial region as eyes

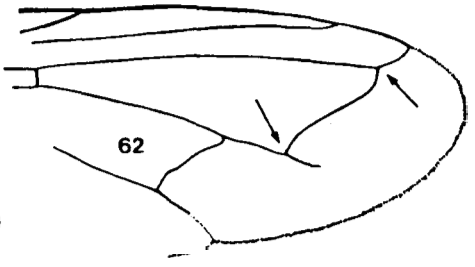


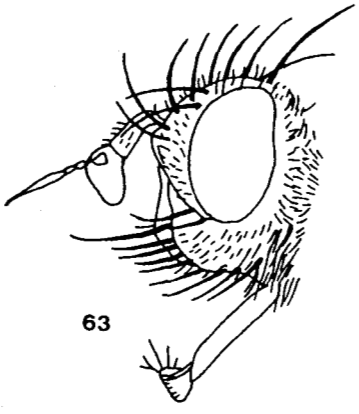


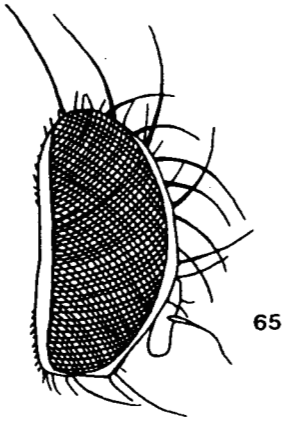


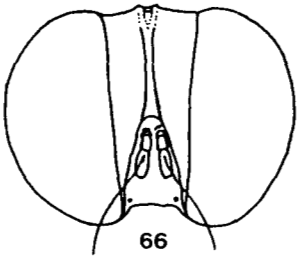


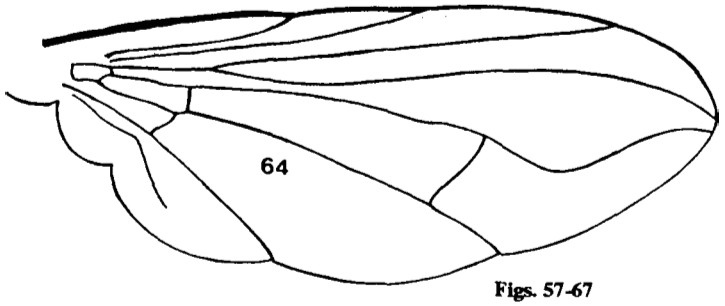




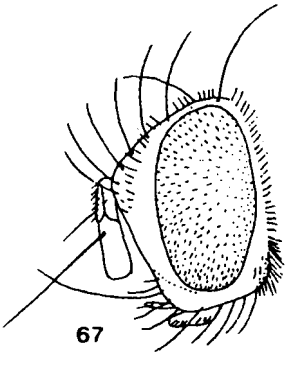








Figs. 57-67



rather converged ventrally (Fig. 66); abdomen slender, concolorous with eyes except for silvery white apices of tergites 1 + 2 and 3 and blackish tip . . . . . *Halydaia luteicornis* Walker

35(33') Pre-alar setae strong and long, longer than *1st* post intra-alar (ia) setae and *Ist* post dorsocentrals (dc); sternopleuron with 4 setae; *2nd* costal sector without hair ventrally; apical setae not enclosed by the nonconverging subapicals 36

35' Pre-alar setae weak and small, shorter than *Ist* post ia and *Ist* post dc; sternopleuron with less than 4 setae; *2nd* costal sector with or without hairs ventrally; apicals sometimes enclosed by the converging subapical setae 46

36(35) Barette completely haired; humeral callus with ***5*** strong setae, the main 3 arranged in a triangle; tibia II with a single submedian anterodorsal seta; sternopleuron with 2 setae; eyes hairy; antennae high above epistome, arista long, segment II of antennae long almost 2/3 of segment III; vibrissa long (Fig. 67); tergite V of abdomen broadest basally . . . . . *Nemorilla maculosa* Meigen

36' Barette haired only anteriorly or bare and setae on humeral callus not more than 4 37

37(36') Head shape rather abnormal (Fig. 68), strongly triangular in profile; frons almost horizontal; profrons much wider than gena; arista thickened in its entire length, with *2nd* segment elongate and 6X as long as broad; antennae inserted up high in level to the lower end of the apical one-third of height of eye; 3rd antennal segment beyond epistome, long and subcylindrical; eyes, parafacials and facial ridge all bare; cell R5 triangular with short M2 and petiole towards wing apices . . . . . *Diatraeophaga* sp.

37' Head normal, other characters not as above 38

38(37') Genal depth reduced to a narrow area smaller than the length of profrons and obliterated by the very large eyes; parafacials bare; propleural setae present; humeral callus with no more than 4 setae, 3 main ones arranged in a straight line (Carceliini) 39

38' Gena as wide as or wider than profrons; head with one or more pairs of reclinate orbital setae; vibrissae inserted above the level of the epistomal margin 42

39(38) Sternopleuron with 4 setae; frontal setae normal or mostly inclinate; apical scutellar setae horizontal; tibiae III with 2 or more anterodorsal setae; antennae long with *3rd* segment almost reaching epistome; eyes large forming narrow gena (Fig. 69); parasitic on larvae of rice skippers *Pelopidas* and *Pamara* . . . *Thecocarcelia oculata* (Baranov)

39' Sternopleuron with 2 or 3 setae; eyes bare or hairy 40

40(39') Eyes haired (Fig. 70); post dorsocentral with 4 setae; proclinate orbital setae absent; frontal setae 5; profrons twice the height of gena; parafrontal hairy unlike parafacial; antennae inserted just above midlength line of eyes; *3rd* segment not reaching epistome; vibrissa1 setae not crossing arista . . . . . *Carcelia excisa* Fallen

40' Eyes bare; post dorsocentral with 4 setae; propleural setae present though small sometimes; sternopleuron with 2 or 3 setae *(Argyrophylax)* 41

41(40') Third antennal segment reaching epistome (Fig. 71); palpi yellow; head generally dark to blackish red except silvery white tinge along parafacial and facial ridge; marginal setae of abdominal tergite IV extended beyond tip of abdomen; surstylus very small and well separated from cerci (Fig. 72); cercus tapers towards apex, in lateral view biconcave dorsally; epandrium wider than long and hairy dorsally (Fig. 73) .... *Argyrophylax nigrotibialis* Baranov

41' Third antennal segment relatively far from epistome (Fig. 74); palpi yellow; surstylus (Fig. 75) very well developed, broad and rounded at apex; cercus outwardly curved in lateral view and closely attached to surstylus; epandrium (Fig. 76) slightly hairy dorsally ..... *Argyrophylax phoeda* Townsend

41'' Similar to the above two species except genitalia; palpi black with yellowish tip (Fig. 77); marginal setae of abdominal tergite IV relatively close to tip of abdomen. .... *Argyrophylax fransseni* Baranov

42(38') Eyes densely hirsute 43

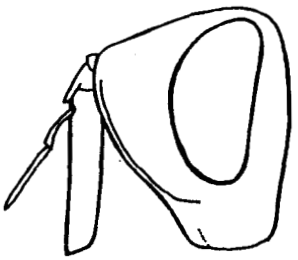
42' Eyes bare or with minute hairs 44

43(42) Parafacials entirely clothed with strong hairs (Fig. 78); antennae far from epistome, yellow-brown except segment III; head silvery white except dark brown interfrontal area with shallow, fine longitudinal grooves; abdomen same color as head, cerci triangular in apical view (Fig. 79); surstylus elongate and rounded at tip (Fig. 80); legs blackish brown with whitish yellow broad pulvilli; parasitic on rice stem borers – *Chilo* spp. and *Scirpophaga nivella* ..... *Sturmiopsis inferens* Townsend

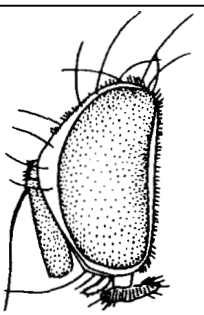
43' Parafacials bare; facial ridge rather flattened with strong setulae beyond half its length; 4 strong setae lined peristomal area; interfrontal area as long as parafrontals; antennae inserted in line to lower apical 1/3 of eye, *3rd* segment long, nearly touches epistome and vibrissa (Fig. 81); basal node of R4 + 5 with about 2-4 small setae; male abdomen with light and uneven silvery grey tinges .... *Pseudoperichaeta insidiosa* Robineau-Desvoidy

44(42') Ocellar setae very prominent, equal in size to reclinate orbital setae and inserted out of the triangle in front of anterior ocellus; yellow epistome straight; parafacials bare; eyes with few minute hairs (Fig. 82); antennae and aristae black; silvery white along parafrontals; abdomen silvery white except black T1+2 and mid- and posterior margins of tergites; legs black with silvery white femora ..... *Zygobothria ciliata* Wulp

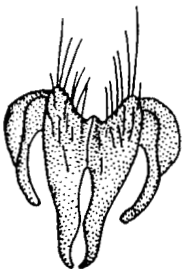
44' Ocellar setae small, weak, and wiry; parafacials with fine hairs apically; well defined hair-patch unusually small or usually large and thick with very long hairs converging into a fascicle present on each side of venter of abdominal segment IV in males; tibiae II with one submedian anterodorsal seta; aedeagus bifurcate 45



68



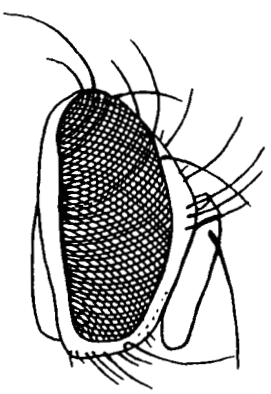
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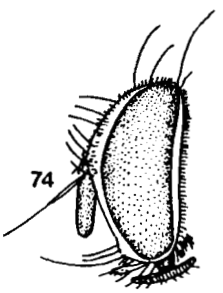
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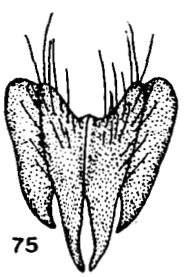
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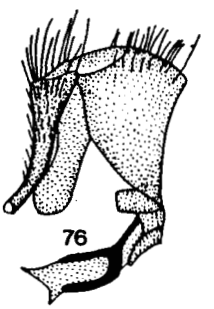
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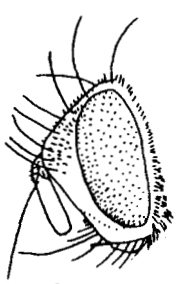
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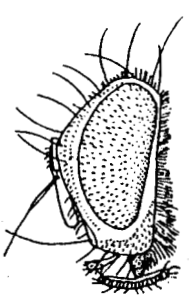
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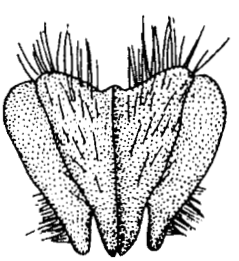
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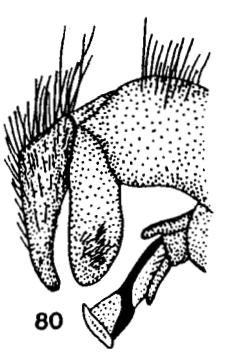
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78



79



80

Figs. 68-80

45(44') Palpi moderately short, yellowish brown; sternopleuron with 2 setae; peristomal area with 4 setae; hair-patch large, covers most of venter of abdominal segment IV (Fig. 83); upper occiput without black setulae behind postocular row in females; frons narrow; legs brownish black; abdomen black with few silvery dust; paralobes with spinules apically ..... *Palexorista lucagus* (Walker)

45' Palpi long beyond epistome, yellow; sternopleuron with 4 setae; peristomal area with 9 setae; hair-patch very small (Fig. 84), sometimes obliterated; female's upper occiput with a distinct irregular row of black setulae at the back of postocular; antennae long with 3*rd* segment nearly 3 times as long as 2*nd* segment; antennal axis high above ocular axis; parafacials with fine hairs on upper half ..... *Palexorista solensis* (Walker)

46(35') Parasites of acridid grasshoppers; scutellum with 3 pairs of strong marginal setae, apicals crossed in basal one-third, subapicals widely diverging, basals cross subapicals slightly converging and closed to distal one-third of apicals, lateral setae absent; basal node of R4 + 5 with one strong setula; eyes bare; bend of M oblique to meet R4 + 5 before apex (Fig. 85) ..... *Ceracia* spp.

46' Not parasitic on acridid grasshoppers; arrangement of marginal setae of scutellum different 47

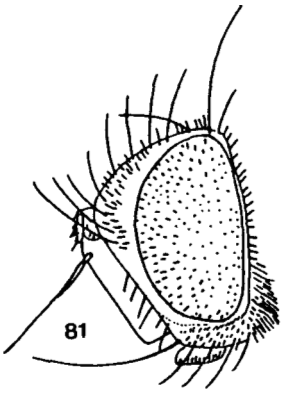
47(46') Subapical scutellar setae strongly convergent and crossed at their apices; 2*nd* costal sector haired below up to 3*rd* sector; costal margin conspicuously broken and incised at the apex of subcosta; vein R4+5 extensively setulose, R1 partly or entirely setulose; propleuron not hairy; hind tibiae with 3 dorsal preapical setae; eyes bare; proboscis normal 48

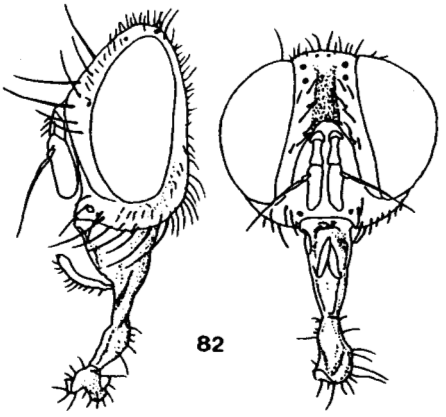
47' Subapical scutellar setae parallel or diverging; 2*nd* costal sector bare below, costal margin inconspicuously broken and not incised at apex at subcosta; T1+ 2 fully excavated 49

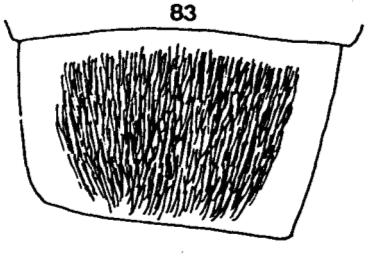
48(47) Two equally long and strongly diverging (one directed upward, the other downward) prostigmatic setae present on thorax; head silvery white except yellow interfrontal area; eyes strongly parallel-sided (Fig. 86); parafrontals with a few short hairs; antennae dark brown with brown segment II and base of segment III; peristomal area with 3 setae; palpi yellow; Sc with a bend and 2-3 hairs above bend; R1 with 13 hairs; basal node of R4 + 5 with 15-16 hairs extended to top level of bend of M .... *Peirbaea orbata* (Wiedemann)

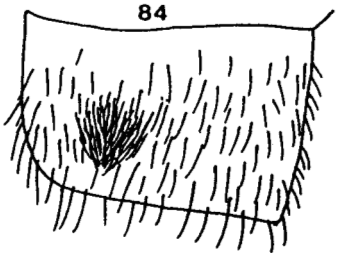
48' One strong prostigmatic seta directed upwards present on thorax; sternopleuron completely hairless laterally in front of midcoxae; eyes moderately small, widen toward genae (Fig. 87) with 2 peristomal setae; epistome curved forward; wings with strong setulae along costal margins, R1, R4 + 5 and Cul; M1 near R4 + 5 but clearly separated, bend of M not angled (Fig. 88) ..... *Ceromya silacea* Meigen

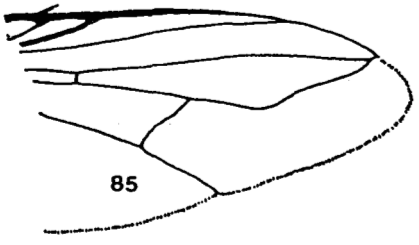
49(47') Dorsocentral with 3+3 setae, post dorsocentral with 3 setae arranged in a triangle; head grey except black occiput, reddish bottom part of parafacials; reddish brown frontal

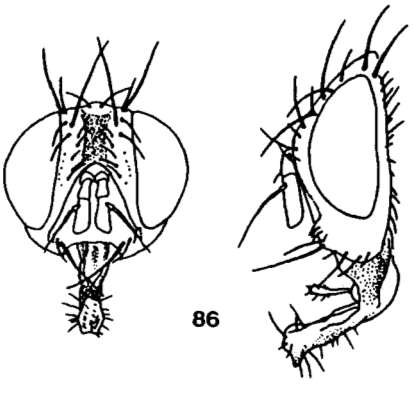


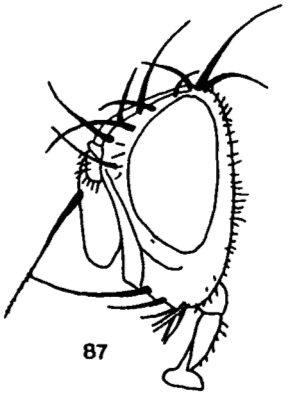


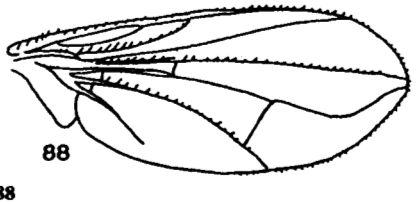












Figs. 81-88

vitta; palpi pale orange-yellow; antennae dark grey with reddish base of segment III; cerci slender, rounded at apices (Fig. 89) and distinctly divergent in rear view; abdomen orange with grey pollinose patches; legs reddish brown but pale along femora and tibiae . . . . . *Lixophaga diatraeae* Townsend

49' Dorsocentral with 3-4 setae; post dorsocentral with 4 setae; slender palp brownish yellow; ocellar setae very strong; parafacial setae absent (Fig. 90); antenna black, far from epistome, inserted almost in line to top of eye; cerci pointed at tip and surstylus with a long process (Fig. 91); legs black except white pulvilli and greyish outer femora; abdomen black with silvery white bands along apical half of tergites III to V . . . . . *Exorista xanthaspis* (Wiedemann)

50(29') Costa without breaks; subcosta perfect, nearly always separate from R1 and ending independently in costa 51

50' Costal break just before end of subcosta and or near humeral crossvein; or costa constricted, partially fractured or broken before end of R1; subcosta imperfect . . . 53

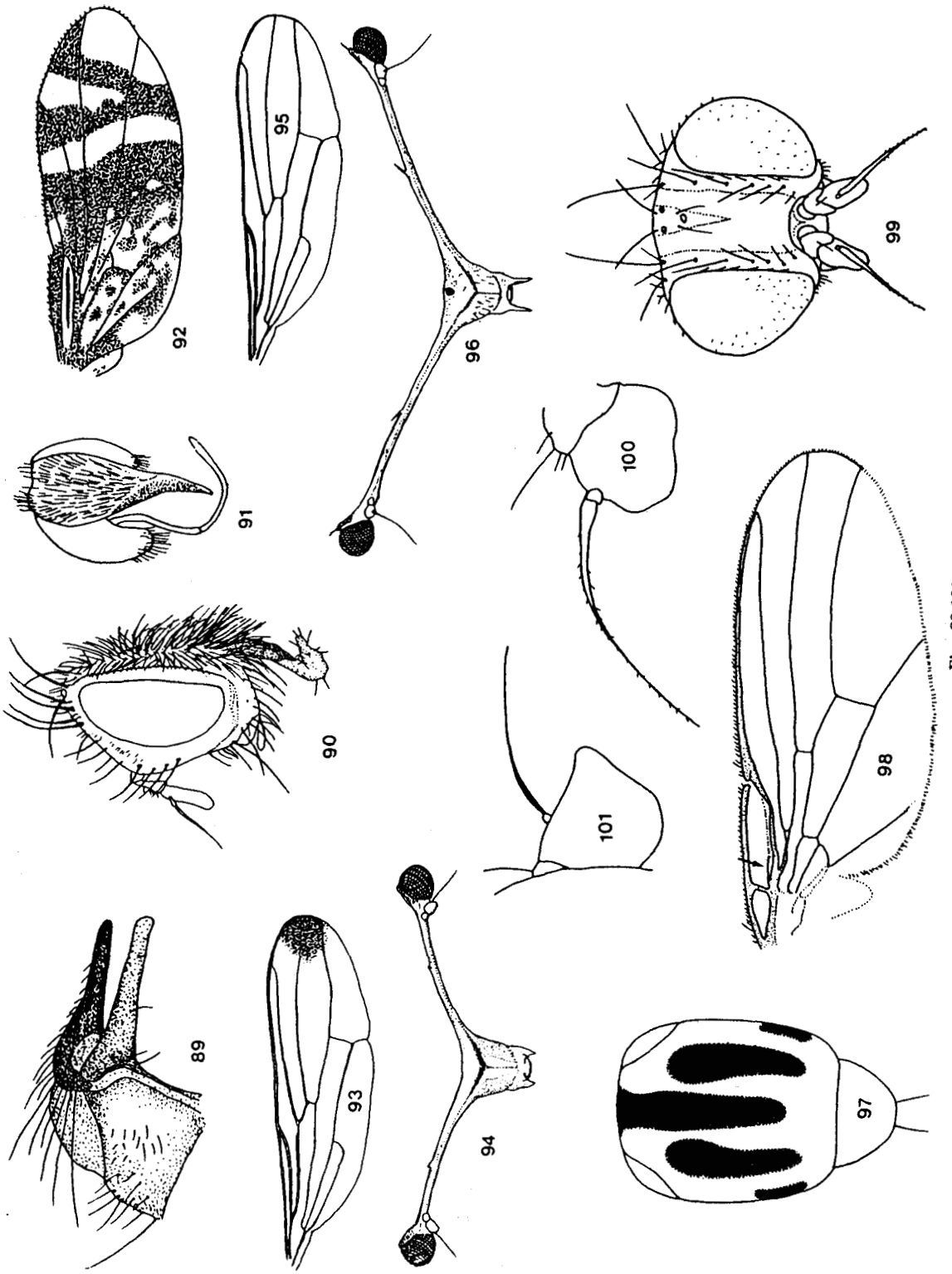
51(50) Eyes normal, close to each other and not on a stalk; wings blackened by markings leaving 3 transverse to oblique white bands towards apex and patches of irregularly arranged white spots in lower basal (Fig. 92) area; anal cell without an acute lobe; scutellum broadly rounded at apex with long setae along margins; base much wider than apex; head in dorsal view pointed forward below base of antennae; body with bluish reflections; face, genae, and antennae ochreous yellow; legs brownish with tarsi ochreous yellow except its apex [Platystomatidae] . . . . . *Poecilotraphera taeniata* (Macquart)

51' Eyes situated at the ends of long stalks; in dorsal view at least 3 times as wide as long with antennae well separated; scutellum bituberculate; front femora much swollen [Diopsidae] 52

52(51') Wings with a large, round, black apical spot (Fig. 93); frons with a dark brown stripe connecting bases of stalk (Fig. 94); yellow to pale yellow-brown with black tip; scutellum pollinose, dark to blackish brown; dorsum of thorax shining; body length (head to tip of abdomen) nearly as long as width of 2 compound eyes; species barely 6 mm . . . . . *Diopsis apicalis* Dalman

52' Wings without such black apical spot (Fig. 95); frons with a light brown stripe (Fig. 96); facial teeth rather long and more widely separated than in *D. apicalis;* scutellar spines long, yellow-brown except one-fourth to one-third apical area black; scutellum yellow; distance from eye to eye much longer than body length; species 7-9 mm in length . . . . . *Diopsis macrophthalma* Dalman

53(50') Anal cell absent; ocellar triangle conspicuously large and reddish brown; crossvein r-m beyond midhalf of discal cell; cell CuP and vein CuA + 1A absent, cell M confluent with discal cell; mesonotum with 3 broad longitudinal and 2 short subposteromarginal blackish brown bands (Fig. 97); body dark yellow, legs yellow [Chloropidae] . . . . . *Chlorops oryzae* Matsumura



Figs. 89-101

53' Anal cell present; ocellar triangle less conspicuous 54

54(53') Costa broken only near end of R1; postocellars divergent; oral vibrissae present [Agromyzidae] 55

54' Costa broken near end of subcosta and also near humeral crossvein; distinct oral vibrissae absent; postventricals divergent [Ephydridae] 56

55(54) Subcosta developed throughout its length coalescing with R1 before reaching costa; costa extending strongIy to vein M1+2; crossvein r-m slightly beyond midpoint of discal cell (Fig. 98); 3 pairs (4 + 2) of dorsocentrals and aerostichals in 6 rows; frons narrowly projecting above eyes (Fig. 99); orbital setulae sparse and reclinate; third antennal segment axe-shaped with slightly pubescent arista (Fig. 100); tibia II with 2 strong lateral bristles ..... *Agromyza oryzae* (Munakata)

55' Subcosta becoming a fold distally and ending in costa separately and basad of R1; costa ending at vein R4+5; mesonotum with 3 dorsocentrals and 4 aerostichals in irregular rows; frons not projecting above eyes; orbital setulae upright; third antennal segment with blunt angle at upper corner (Fig. 101) ..... *Pseudonapomyza asiatica* Spencer

56(54') Leg I mantis-like, enlarged femur with spines and tibiae with apical spur (Fig. 102); basal tarsal segment of leg III shorter than combined length of segments II-V; basal tarsal segment of leg I much shorter than femora I; basal ventral spine of femora I not reaching apex of basal tarsal segment of leg I; legs greyish black, tarsi of leg II slightly yellow with blackish shades and black terminal segment; sides of tergite II with a mass of hairs; abdomen brownish with silvery tinge laterally .... *Ochthera sauteri* Cresson

56' Leg I as above; basal tarsal segment of leg III as long as rest of segments (II-V); basal tarsal segment of leg I slightly longer than femora 1; basal ventral spine of femora I reaching apical end of basal tarsal segment of leg I; legs blackish brown with dense yellow-white dust, tarsi and tibiae silvery in front; tarsi of leg II all yellow; labial palp dark brown; abdomen dark olive green with white dusted triangular spots at sides of segments; sides of tergite II without mass of hairs (Fig. 103) .... *Ochthera brevitibialis* de Meijere

56" Foreleg and tibia normal, apical spur absent 57

57(56") Mesonotum without well developed setae; dorsocentrals absent; ocellars behind anterior ocellus or between posterior ocelli; *2nd* antennal segment with dorsal spine-like strong bristles (Fig. 104) ..... *Psilopa* spp.

57' Mesonotum with well developed setae; head and thoracic bristles long and strong; arista with several long dorsal hairs; 1 or 2 orbitals present and 2-3 verticals; 2-3 dorsocentrals (dc) present [Notiphilinae] 58

58(57') Midtibiae without strong dorsal bristles; dull gray to brownish black; eyes with pubescence; *3rd* antennal segment with 1 or 2 weak dorsal bristles; several facials feeble and

hair-like; 1*st* costal section without spine-like bristles apically; 2-4 dorsocentrals (dc) present 59

58' Midtibiae with 3-4 erect dorsal bristles; 1 reclinate fronto-orbital strong; 3-5 weak to moderate facial bristles; costa extending to or slightly beyond tip of 3*rd* vein; arista with many long hairs dorsally *[Notiphila]* 60

59(58) Four dorsocentral setae present; face bordered with 6 facials; frons and cheeks silvery white; mesonotum greyish with silvery white and brown tinges, scutellum silvery white to grey; antennae dark grey with light silvery tinge in the inner portion of 2*nd* segment, 7-10 aristal hairs (Fig. 105); abdomen silvery white to grey with blackish brown medians in the basal three segments; legs yellow except femora I to III; inner portion of femur I with about 10-12 spines (Fig. 106). ..... *Hydrellia philippina* Ferino

59' Four dorsocentral setae present; face golden yellow covered with silvery tinge, bordered with 4 weak to moderate facials, frons black with greyish tinge; cheeks greyish white; mesonotum and scutellum brown; antennae black with 5-6 aristal hairs (Fig. 107); head index 5:1; abdomen greyish to dark brown, legs black with greyish tinge and yellow metatarsi, inner portion of femur I armed with more than 25 small teeth (Fig. 108) ..... *Hydrellia griseola* (Fallen)

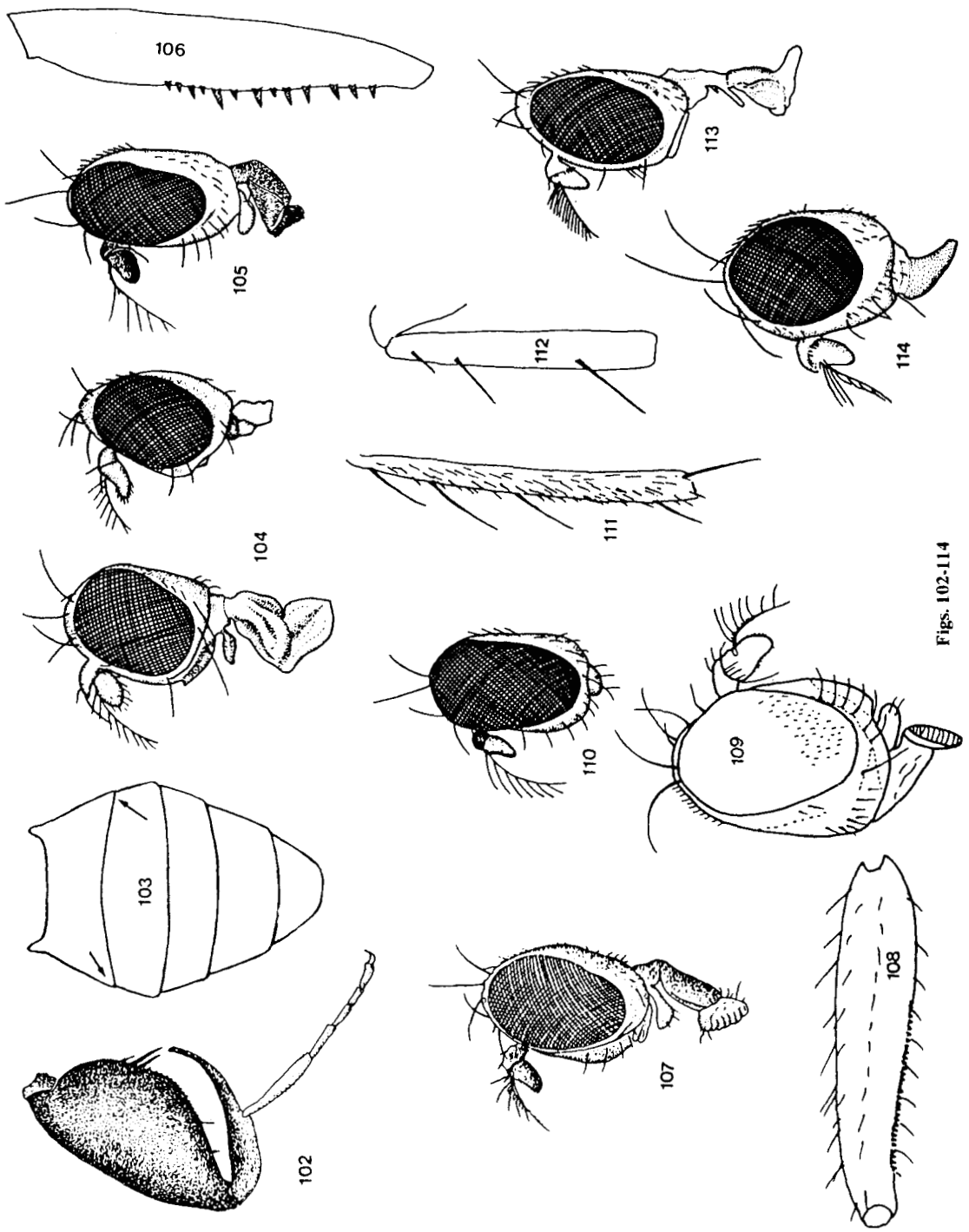
59" Two dorsocentral setae present; face and lunula silvery white with 5-6 moderate facials (Fig. 109); frons and antennae black; mesonotum and scutellum black with dense brown tinge; third antennal segment with whitish pubescence, 8 aristal hairs present; abdomen half shining black but yellow apically; tibiae and tarsi all yellow; ventral process of hypopygium thin and very slender ..... *Hydrellia tomiokai* Miyagi

59"' Two dorsocentral setae present; face golden yellow to yellowish brown with 6 hair-like facials (Fig. 110); frons blackish brown with velvety black laterals; antennae black, 3*rd* segment with brownish pubescence; 7 aristal hairs; cheeks and occiput dark grey; abdomen brown, coxae yellow, femora black, tibiae yellow except midtibiae brownish yellow, basal half of hind tibiae blackish brown .... *Hydrellia sasakii* Yuasa et Isitani

60(58') Root maggot; midtibiae with 4 extensor bristles (Fig. 111); several facial bristles weak and hair-like; 5*th* tergite in male forms a cylindrical tubercle with 2 stout upcurved bristles apically; Japanese species ..... *Notiphila sekiyai* Koizumi

60' Leaf miner; midtibiae with 3 extensor bristles (Fig. 112) 61

61(60') Antennae with 12-14 aristae tip and outer edge of 3*rd* antennal segment dark brown; ocellar bristles set relatively closer to the front of lateral ocelli; 2 strong parafacial bristles (Fig. 113); eyes moderately oblong; legs dark grey except yellow apices of femora, and brownish yellow tibiae and tarsi; abdomen silvery white with broad blackish brown spots ..... *Notiphila similis* de Meijere



Figs. 102-114

69(68') Head uniformly black (Fig. 120); anterior margin of pronotum with a pair of dark brown outwardly acute calli (Fig. 121); posterior portion straight; baso-clypeus nearly as wide as distance between eyes taken across lateral ocelli; antennal socket in a deep groove; fronto-clypeal inflection medially recurved below median ocellus; basal segments of antennae blackish brown; mirror wider than long (Fig. 122) . . . . . *Plebeiogryllus plebejus* (Saussure)

69' Head with a faint to distinct yellow band above antennal bases running towards dorsal eye margins 70

70(69') Head with clear dark yellow band in the internal margin of eye (Fig. 123); in males, mirror (Fig. 124) longer than wide, width less than 3.1 mm (sometimes with a closed cell); stridulatory file much closer to each other, with teeth number ranging from 210-292; females with 11-13 veins in the lateral field of forewings, veins IV and V mostly widely separated . . . . . *Teleogryllus occipitalis* (Serville)

70' Head with faint yellow band (Fig. 125); in males, mirror (Fig. 126) as long as wide (normally without closed cell), width greater than 3.2 mm; stridulatory file more widely separated, bears 134 teeth with a maximum of 215 in females; with 13-15 equally spaced veins in the lateral field of forewing and terminal V or VI branched from Sc . . . . . *Teleogryllus mitratus* (Burmeister)

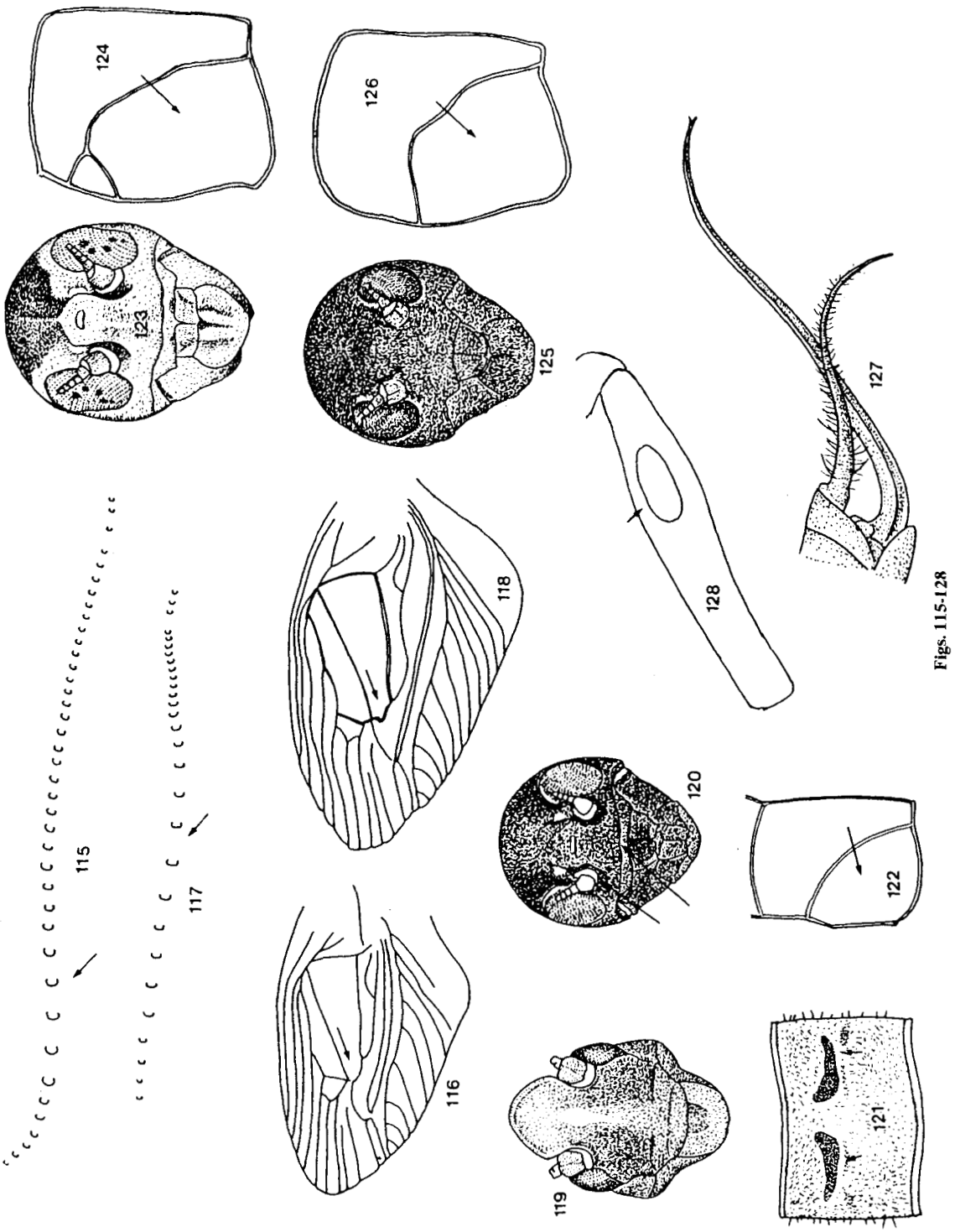
71(67') Ovipositor without differentiated apical valves; sinuated and S-shaped (Fig. 127); elytra extended almost to apex of abdomen; anterior tibia with external and internal tympanum of equal size (Fig. 128); posterior tibia serrulated between spines, long spines more than 6 pairs; pale brownish yellow gryllids; phytophagous . . . . . *Euscyrtus concinnus* (Haan)

71' Ovipositor not S-shaped; posterior tibia not serrulated; predatory gryllids 72

72(71') Elytral venation different in both sexes, male with neat anal field and mirror (Fig. 130); female elytra feebly convex, without false veins, and with 5 straight veins in the dorsal field; head without V-shaped mark dorsally; scape and pedicel pale yellow; terminal segment of maxillary palpi triangular with a broad truncated tip; *2nd* tarsal segment yellow (Fig. 129); head, thorax, wings, and legs yellow . . . . . *Anaxipha longipennis* (Serville)

72' Elytral venation similar in both sexes; male without mirror; head with a light yellow to white mark dorsally, scape and pedicel black; terminal segment of maxillary palpi black with brown tinge, and with a moderately broad and truncated tip; *2nd* tarsal segment black (Fig. 131); generally black with pale brownish red tinges in wings and abdominal dorsum, legs whitish yellow . . . . . *Metioche vittaticolis* (stål)

73(64') Fastigium projected obliquely above eyes by 2 eye lengths, deeply notched frontally in line with base of antennae (Fig. 132); face diagonal, lateral lobes of pronotun almost 2 times longer than deep, hind lateral part of lobe rounded above coxa I; ovipositor



Figs. 115-128

sword-like, as long as hind tibia; venter of tibia III with 20-21 spines; forewings as long as hindwings; hind femora slightly swollen . . . . . .*Euconocephalus varius* (Walker)

73' Fastigium not projected as above; lateral lobes of pronotum broadly rounded above coxae I, or narrowly rounded along its lower posterior margin behind coxae I and slightly indented above it; forewing shorter than the hindwing, green or brownish yellow with brownish tinge 74

74(73') Hindwings usually 1/3 longer than the forewings, wing tips more rounded, base of hind femora noticeably swollen, venter spineless; ovipositor very short but broad 75

74' Hindwings a little longer than forewings; wing tips pointed; prosternum bispinose; venter of femora with or without spines; ovipositor very long 76

75(74) Hind femora prominently attenuate; lateral lobes of pronotum longer than deep, slightly concave in the antero-dorsal 1/5 with pointed postero-dorsal tip projected relatively upward (Fig. 133); cerci (Fig. 134) very long, wide subapically prior to a tapering end; subgenital plates elongate and bifid (Fig. 135); supra-anal plate knob-like; costal margin of forewings with a brown tinge . . . . . .*Phaneroptera gracilis* Burmeister

75' Hind femora not attenuate; lateral lobes of pronotum as long as deep, partially concave along antero-dorsal 1/3 with pointed postero-dorsal tip slightly curved downwards; subgenital plate robust, elongate, and sulcate medially above and below; cerci with a long thin process at tip (Fig. 136); supra-anal plate deeply bifid (Fig. 137); costal margin of forewing uniformly green except for a pair of brownish black spots along basal 1/4; abdominal tergite X enlarged (Fig. 138) . . . . . *Phaneroptera furcifera* Stål

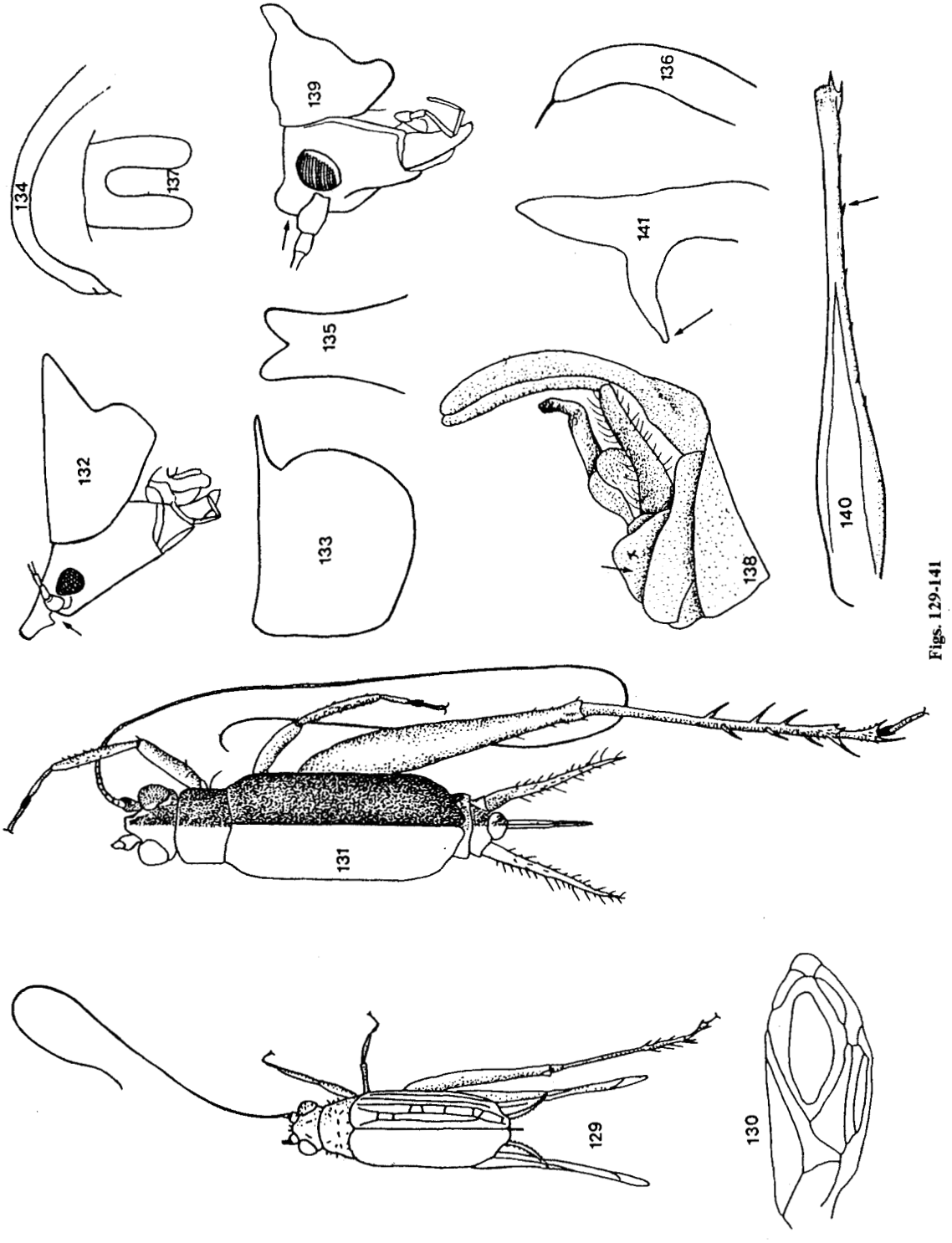
76(74') Fastigium of vertex narrow (Fig. 139); forewings unicolorous green; hind femora with 3-7 externo-ventral spines (Fig. 140); cerci with 1 internal spine, globular at apex (Fig. 141); subgenital plate with excised apex; ovipositor (Fig. 142) relatively straight, 13-16 mm in length; thorax and abdomen yellow . . . . . *Conocephalus longipennis* (de Haan)

76' Fastigium moderately wide; forewings (Fig. 143) pigmented with large dark spots, without markings along costal and precostal areas; hind femora (Fig. 144) without ventral spines; cerci (Fig. 145) of males with 1 internal spine, pointed at tip; ovipositor very short 6.6-8.2 mm (Fig. 146) . . . . . *Conocephalus maculatus* (Le Guillou)

77(63') Fastigium of vertex with a deep thin median furrow; lower basal lobe of hind femora longer than upper portion [Pyrgomorphidae] 78

77' Mediolongitudinal sulcus in the anterior of fastigium absent; lower basal lobe of hind femur as long as or shorter than upper portion 81

78(77) Pronotum rough and strongly tuberculated (Fig. 147); dorsally black with anterior tubercles and lateral lobes yellow; wings large, tegmina long with parallel sides olive green with numerous subglobular yellow spots (Fig. 148); abdomen black with reddish orange bands; body length 37-55 mm in males and 47-69 mm in females . . . . . *Aularches miliaris* (Linnaeus)



Figs. 129-141

78' Pronotum rather smooth, non-tuberculated; wings of different colors 79

79(78') Tegmina narrow but well developed with rounded tip; femora shorter than tegmina (Fig. 149); head conical, shorter than pronotum; face oblique (Fig. 150); fastigial furrow short reaching less than 1/2 distance to anterior margin of eyes; pronotum dorsally rounded with feeble median carina lightly bissected by 2 transverse sulci; hind tibia with terminal spines sharply pointed; outside spines shorter than inside . . . . . *Tagasta marginella* (Thunberg)

79' Tegmina long and narrow with tips pointed; head acutely conical 80

80(79') Fastigium (Fig. 151) of vertex longer than the length of compound eyes; head lanceolate; ratio of fastigium length to least width between eyes 2.5-3 in females and 3-3.3 in males (Fig. 152); exceptionally slender, pronotum (Fig. 153) of females with 2 wide apart sulci without cross "veins" . . . . . *Atractomorpha psittacina* (de Haan)

80' Fastigium (Fig. 154) of vertex well developed, shorter than the length of compound eyes; head conical; ratio of fastigium length/least width between eyes – 2.25 in males and 1.7-2.1 in females (Fig. 155); hindwings light purplish red; membranous area of lateral lobe prominent; sulci of pronotum with a crossvein (Fig. 156); phallic parts small; valves also small, conically short but slightly curved; small species; less than 20 mm in males and greater than 20 mm in females . . . . . *Atractomorpha crenulata* (Fabricius)

81(77') Prosternal peg absent 82

81' Prosternal peg present 89

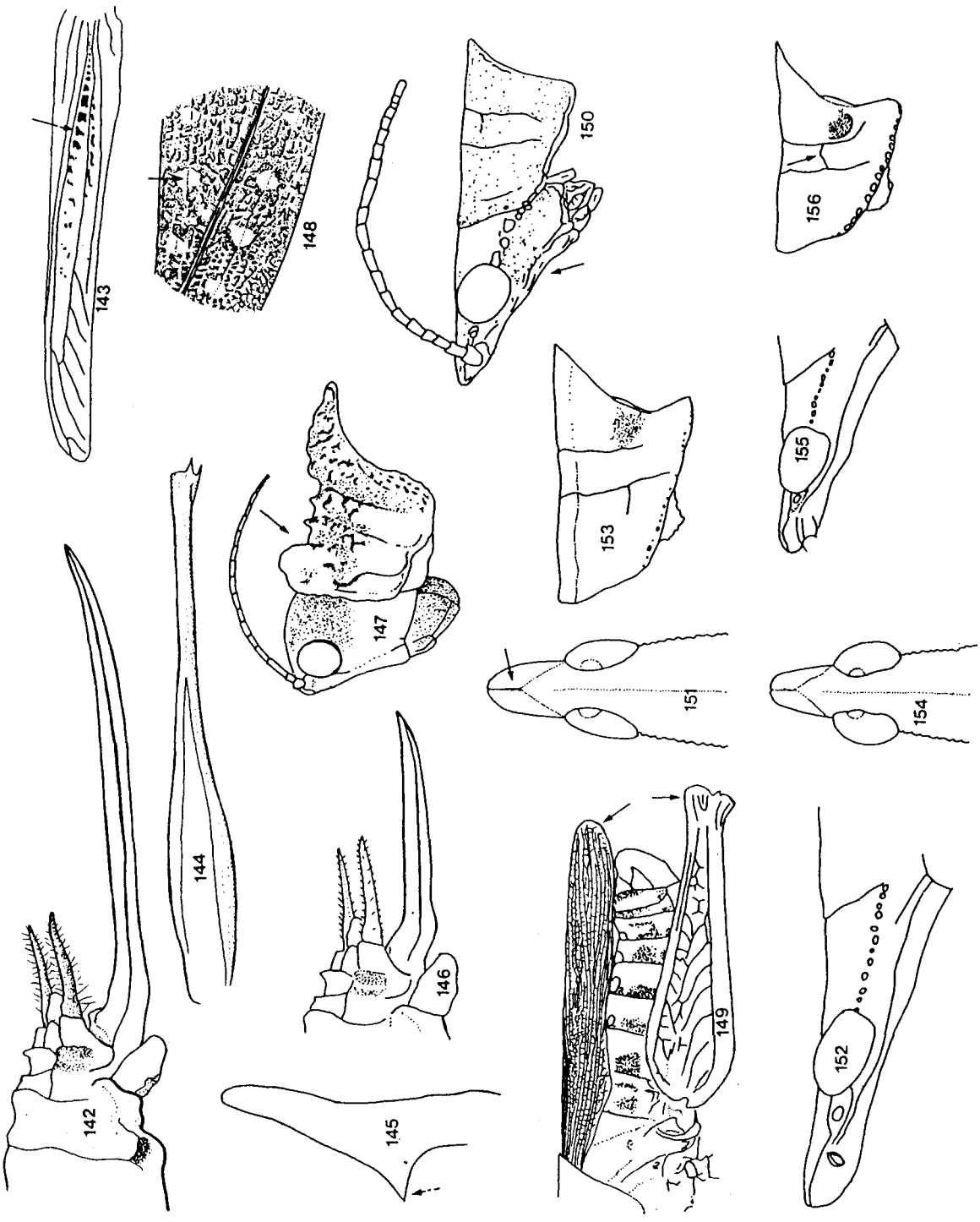
82(81) Sword-like antennae with basal segments flat and wide 83

82' Antennae filiform 84

83(82) Anterior tip of hind femora slender with a pair of spur-like processes (Fig. 157), base partially enlarged; compound eyes much closer to the anterior of head; head strongly elongated, much longer than pronoturn with a median transverse furrow; face strongly oblique (Fig. 158); tip of tegmina pointed (Fig. 159) . . . . . *Acrida willemsei* Dirsh

83' Anterior tip of hind femora moderately swollen, spur absent (Fig. 160); compound eyes midway head length; head shorter than pronotum; pronotum laterally compressed, median and lateral keels distinct; three transverse furrows present with the 2 anterior not visible dorsally; eyes, sides of vertex and pronotum and occiput with reddish brown suffusion (Fig. 161) . . . . . *Gonista bicolor* (de Haan)

84(82') Pronoturn constricted anteriorly with tubercles on median carina in front of posterior transverse furrow (Fig. 162); rod-like antennae slightly swollen in apical 1/3 and little longer than combined length of head and pronotum; fastigium of vertex angular with straight frons slightly oblique; metazonal posterior margin obtuse apically; hind femora robust with 2 black spots dorsally; general coloration chocolate brown . . . . . *Trilophidia annulata* (Thunberg)



Figs. 142-156

84' Pronotum without tubercles 85

85(84') Hindwings with blackish brown bands across middle enclosing yellow areas 86

85' Hindwings without blackish brown markings along midhalf of its length 87

86(85) Grasshoppers, barely 25 mm long; pronotum short with sides parallel anteriorly but expanded posteriorly (Fig. 163); dorsally bears a distinct light x-mark; apical half of tegmen semi-transparent, basal 1/2 of leading edge with 3 pale areas (Fig. 164); hindwings with a broad dark band enclosing basal greenish yellow area; coloration greenish brown with hind tibiae red distally ..... *Oedaleus abruptus* (Thunberg)

86' Body length ranges 26-33 mm in males and 36-52 mm in females; antero-dorsal tip of pronotum strong arched forward, posterior tip acutely angled and pointed (Fig. 165); tegmina with a white transverse band, 1/3 of distance to apex, *2nd* band indistinct (Fig. 166); hind femora ventrally and internally yellow, outer margins with series of small black spots dorsally and ventrally ..... *Gastrimargus marmoratus grandis* Saussure

87(85') Mid-tegmina lined with dense row of thickened parallel veins (Fig. 167); antennae filiform, apical 1/2 of segments black, length longer than the combined length of head and pronotum (Fig. 168); inner apical spine of hind tibiae much longer than the outer one; general coloration: brown to dark blackish brown in head dorsum and pronotum and reddish in hind tibiae ..... *Heteroptemis respondens respondens* (Walker)

87' Mid-tegmina without thickened parallel veins 88

88(87') Pronotum lower than head top (Fig. 169); median carina not clearly elevated; midsegments of antennae barely 2 times longer than broad; eyes closer to each other; hind tibiae reddish brown along mid-half and both ends with greenish bands in between, hind femora black to reddish brown but greenish dorsally and ventrally; inner 1/2 of forewings costa green; body 30 mm in length ... *Ailopus thalassinus tamulus* (Fabricius)

88' Pronotum a little higher or head in line with the median carina; head rounded anteriorly (Fig. 170); eyes widely separated; mid-antennal segments slender, nearly 5 times longer than broad; tegmina with brownish tinges on veinlets (Fig. 171); hind tibiae yellowish with brown to blackish tinges distally and proximally; body more than 34 mm long ..... *Locusta migratoria manilensis* (Meyen)

89(81') Row of thickened parallel veinlets at right angles to the main longitudinal veins in the radial area of tegmina absent 90

89' Row of thickened parallel veinlets present 106

90(89) Venter external lobe of femur III with an extended spine at apex 91

90' Venter external lobe of femur III without an extended spine apically 99

91(90) Head elongated, conical fastigium well developed, its length nearly as long as the longest eye diameter; slender species: males 20-27 mm, females 25-32 mm long [*Quilta*] 92

91' Head subconical; fastigium wider than long; more robust grasshoppers 93

92(91) Fastigium long and narrow, its length nearly subequal to eye length measured from above (Fig. 172); ratio of length of fastigium to the minimum distance between eyes taken dorsally more than 2; body length 23-27 mm in males, 27-31 mm in females . . . . . *Quilta oryzae* Uvarov

92' Fastigium broader but short, its length relatively shorter than eye length (Fig. 173); ratio of length of fastigium to the minimum distance between eyes taken dorsally less than 2; smaller species: body length 20-23 mm in males, 25-32 mm in females . . . . . *Quilta mitrata* Stal

93(91') Apical half of hind tibiae expanded; tegmina and hindwings not abbreviated; general coloration: green with brownish to bluish band latero-apically *[Oxya]* 94

93' Apical 1/2 of red hind tibiae with black spine tips expanded; head conical; pentagonal fastigium wider than long without median keel-like ridge; length of head and pronotum as long as antennae; median pronotal carina weak, weakly intersected by 3 transverse sulci; tegmina and hindwings cut short before tip of abdomen (Fig. 174) . . . . . *Caryanda diminuta* (Walker)

94(93) Supra-anal plate feebly trilobate (Fig. 175 as in *O. hyla intricata)* with a tubercle on each side of a median apical structure; cerci conical (Fig. 176), narrows apically to a small tip; inner tooth-like pair of lophi (= lobes of epiphallus wanting; female subgenital plate (Fig. 177) without longitudinal ridge ventrally . . . . . *Oxya hyla intricata* (Stal)

94' Lateral tubercles absent in the supra-anal plate 95

95(94') Valve-like (valvular) plate of cingulum prominently long, upwardly curved and swollen at apex (Fig. 178); subgenital plate (Fig. 179) of female with a median pair of widely separated spines; cerci (Fig. 180) acute; supra-anal plate of male with a rather broad triangular median lobe (Fig. 181); tegmen with a poorly developed bulge in the costa . . . . . *Oxya velox* (Fabricius)

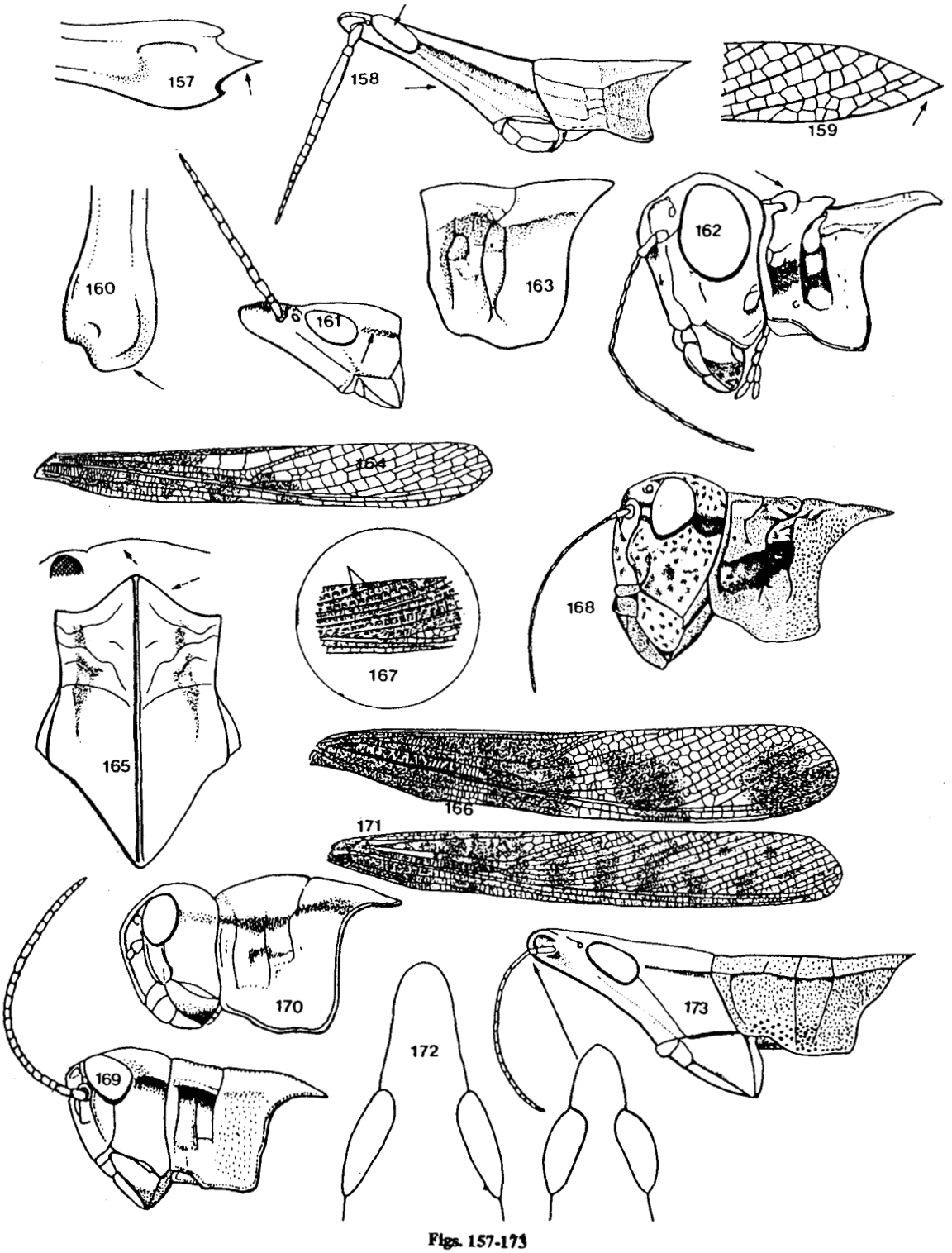
95' Valve-like plate short and fleshy 96

96(95') Supra-anal plate bears a lobe-like apical part that extends posteriorly when flat, basal folds absent (Fig. 182); tegmina short not reaching *4th* tergite of abdomen, cerci (Fig. 183) simple, conical with slightly acute tip; subgenital plate (Fig. 184) of females with lateral longitudinal ridges in the posterior 1/2 of the ventral surface; small grasshoppers barely 26 mm long . . . . . *Oxya minuta* Carl

96' Supra-anal relatively flat with or without developed basilateral folds 97

97(96') Supra-anal plate (Fig. 185) with well developed basilateral folds; cerci (Fig. 186) truncate or apically subacute; lateral longitudinal ridges of the females' subgenital plate (Fig. 187) without spines except at tip . . . . . *Oxya japonica japonica* (Thunberg)

97' Supra-anal plate without basilateral folds 98


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Figs. 157-173

98(97') Cerci conical (Fig. 188), taper towards subacute tip; supra-anal plate less triangular without basilateral folds (Fig. 189); valve-like plate of cingulum broad; apical valves of penis stout; in the females tegmina short not extended beyond apex of hind femora . . . . . *Oxya yezoensis* Shiraki

98' Cerci with a blunt to rounded apex (Fig. 190); supra-anal plate (Fig. 191) rounded triangular with basilateral folds; valvular plate of cingulum and apical valves of phallus slender; tegmina of females beyond apices of hind femora . . . . . *Oxya chinensis* (Thunberg)

99(90') Mesosternal lobes either acute or rectangular 100

99' Mesosternal lobes usually rounded; pronotum without any carinae 104

100(99) Pronotum, moderately coarse, strongly recurved (median keel raised) and distinctly cut by 3 transverse furrows (Fig. 192); frontal ridge strongly grooved below ocelli with parallel margins; tegmina and hindwings well developed, extended beyond hind knees, hind tibiae purple red with 8-9 outer and 10-11 inner yellow spines with blackened tips; coarsely punctured body, length 50-60 mm in males and 65-86 mm in females . . . . . *Chondracris rosea* (de Geer)

100' Pronotum rather flat to moderately raised 101

101(100') Hind femur long to moderately slender 102

101' Hind femur short and broad 103

102(101) Pronotum slightly tectiform to saddle-shaped (Fig. 193); posterior portion rounded (Fig. 194); face not sloping (Fig. 195); fastigium trapezoidal; median keel low, intersected by 3 prominent transverse sulci, 2*nd* and 3*rd* lateral longitudinal sulci with 2 transverse lines; gena without dark brown band; mesosternum rounded; tegmina with numerous moderately broad longitudinal bands . . . . . *Schistocerca americana gregaria* (Forskal)

102' Pronotum roof-shaped, not tectiform, laterals with 2 transverse dark brown bands bordered by pale yellow bands (Fig. 196); posterior part moderately acute; face sloping; fastigium more or less rounded; gena with a dark brown band reaching bottom of eye; mesosternum acute; tegmina (Fig. 197) without numerous brown. bands but with pale yellowish median band on its flattened dorsal surface . . . . . *Patanga succincta* (Linnaeus)

103(101') Tegmina with numerous slightly diagonal bands (Fig. 198); dorsolateral sides of pronotum with velvety dark brown bands (Fig. 199); prosternal process bent backwards almost reaching mesosternum; face reclinate, frontal ridge narrow, parallel sided, and partially depressed at ocellus; pronotum slightly constricted medially, median keel low and distinct, intersected by 3 transverse sulci; posterior margin angular; tegmina and hindwings well developed reaching beyond hind femora . . . . . *Cyrtacanthacris tatarica* (Linnaeus)

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Figs. 174-191

103' Tegmina fairly broad without dark brown fasciae (Fig. 200); prosternal process only slightly bent backwards; frontal ridge rather reclinate, surfaces finely punctated; pronotum more or less tectiform, constricted along metazona; median keel thick, convex but not well elevated, posterior margin distinctly pointed (Fig. 201); general coloration yellowish brown with bluishblack markings ..... *Valanga nigricornis* (Burmeister)

104(99') Anterior part of pronotum slightly narrowed, posterior more or less rounded at tip; frons slightly convex to moderately reclinate; combined length of pronotum and head longer than antennae; prosternal lobes short and subconical; hind femora broad, 3-4 times as long as broad, dorsal portion with dark patches (Fig. 202); general coloration dark brown ..... *Catantops pinguis* (Stal)

104' Not as above, pronotum constricted at midhalf 105

l05(104') Prosternal tubercle conical, acute apically and moderately inclined towards the back; antennae filiform, total length either longer or shorter than combined length of head and pronotum; frons straight in profile; hind femora slender with 4 broad black spots dorsally (Fig. 203); cerci of males short, gradually narrowed in the apical 1/3 and incurved apically ..... *Xenocatantops humilis* (Serville)

105’ Prosternal tubercle strongly broadened, flat laterally, and curved backwards; antennae slightly longer than head and pronotum; frons sloping behind; pronotum constricted medially; hind femora 4-5 times as long as broad; tegmina well beyond hind knee by more than a pronotal length; hind femora (Fig. 204) with 3 black spots on the dorsal margin connected to a midlongitudinal black band with a serrated appearance in the lower area ..... *Stenocatantops splendens* (Thunberg)

106(89') Spine-like apex in the lower external lobe of hind femora absent 107

106' Spine-like apex in the lower external lobe of hind femora present (Fig. 205); pronotum long, cylindrical and posteriorly expanded, with 3 transverse sulci, third very much behind middle; short conical prosternal tubercle obtuse apically; a broad dark band runs from lateral margins of fastigium to lateral lobes of pronotum to anterior margin of tegmina; valves of ovipositor strongly toothed, apex with strong recurved tooth ..... *Gesonula mundata* (Walker)

107(106) Supra-anal plate broader than long, tips acutely angular; male cerci very large, trilobed with the median piece greatly expanded (Fig. 206); subgenital plate of female also trilobed, lateral lobes shorter and less broad than the slightly acute to rounded midlobe (Fig. 207); pronotum with 2 narrow longitudinal black bands (Fig, 208); tegmina with longitudinal black stripe running from pronotum to post-cubital vein; terminal abdominal tergite black at the center edges (Fig. 209); anterior end of hind femora dark black ..... *Parahieroglyphus bilineatus* (I. Bolivar)

107' Supra-anal plate longer than broad, sides curved outwards toward apex; male cerci medium-sized 108

108(107') Apices of male cerci notched 109

108' Apices of male cerci not notched, simple 110

109(108) Ventral side of males' cerci straight in lateral view, tip acutely pointed with a blunt inwardly curved tubercle in the apical 1/4 (Fig. 210); subgenital plate of females longer than broad, semi-ovate with the median lobe pointed (Fig. 211); *2nd* and *3rd* sulci slightly wavy; hind femora moderately slender, reaching end of abdomen .... *Hieroglyphus banian* (Fabricius)

109' Ventral side of males' cerci (Fig. 212) strongly recurved in lateral view, tip blunt and curved downwards with a large tubercle above it; subgenital plate of female trilobed, median lobe longer than lateral lobes (Fig. 213) fastigium 2-3 times as broad as long, all sulci wavy (Fig. 214); apodeme (Fig. 215) widely U-shaped viewed from above; hind femora not reaching end of abdomen ..... *Hieroglyphus tonkinensis* I. Bolivar

1l0(108') Pronotum rounded along the posterior margin 111

110' Pronotum shaped otherwise, usually obtuse-angular 112

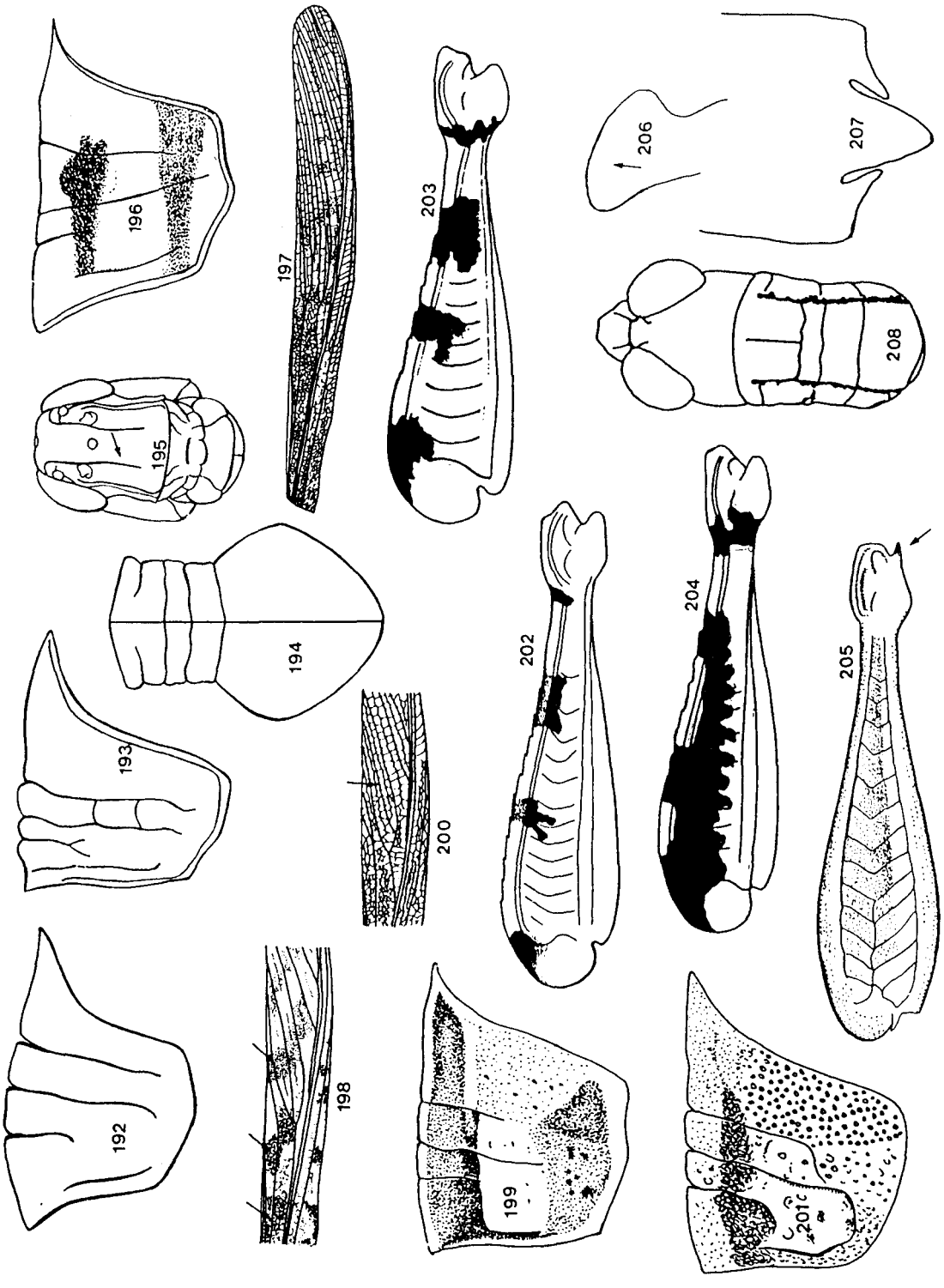
111(110) Subgenital plate of males (Fig. 216) sulcated and truncated apically; cerci (Fig. 217) simple, slightly C-shaped facing each other dorsally, tip blunt and upcurved laterally; females' subgenital plate 3-lobed with small round outer lobes much shorter than the pointed midlobe (Fig. 218); posterior of pronotum rounded (Fig. 219); integument smooth and shallowly pitted; tegmina and wings in line with tip of abdomen .... *Hieroglyphus oryzivorus* Carl

111' Subgenital plate of males notched apically (Fig. 220); cerci (Fig. 221 nearly truncated at tip with an upturned tubercle before apex (seen laterally); females' subgenital plate 3-lobed with shorter, angular outer lobes, median lobe longer and subacute (Fig. 222); tegmina and hindwings a little beyond tip of abdomen .... *Hieroglyphus daganensis* Krauss

112(110') Cerci (Fig. 223) of male subacute along apices, prominently longer than supra-anal plate with a subacute tip (Fig. 224); females' subgenital plate wide before the subacute median lobe, with two parallel slightly wavy ridges (Fig. 225); pronotum intersected by 3 black sulci; posterior sulcus deeper and wider (Fig. 226) .... *Hieroglyphus annulicornis* Shiraki

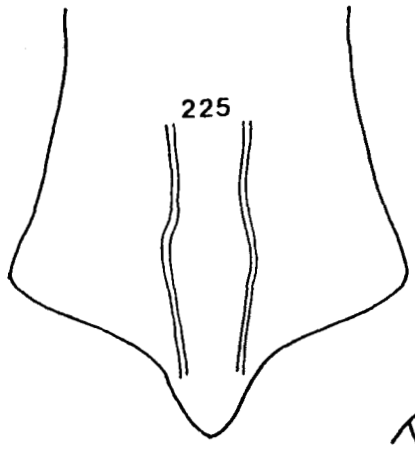
112' Cerci (Fig. 227) of males oblique, longer than supra-anal plate; subgenital plate (Fig. 228) of females with strongly rounded outer lobes and highly acute median lobe; 3 sulci of pronotum interconnected near margins (Fig. 229); three distal abdominal sternites hairy; tegmina and hindwings beyond tip of abdomen .... *Hieroglyphus nigrorepletus* I. Bolivar

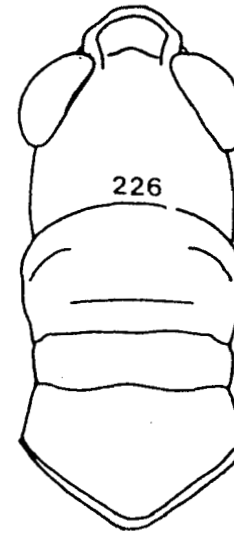
113(62') Small, usually slender insects with asymmetrical rasping and piercing mouthparts; wings short and narrow, with reduced venation and wide marginal fringe; tarsi with reversible apical bladders (last segment swollen); cerci absent; apex of abdomen rounded, point of

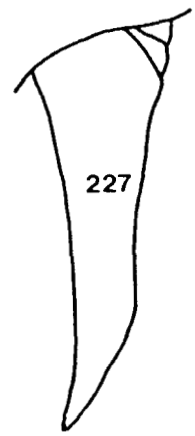

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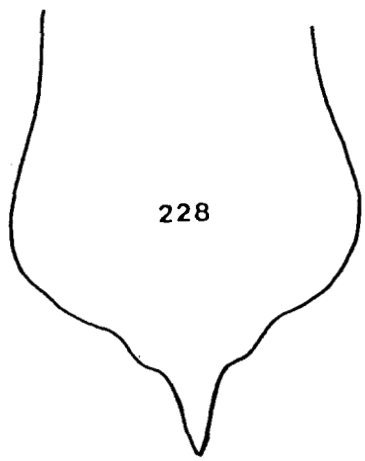
Figs. 192-208

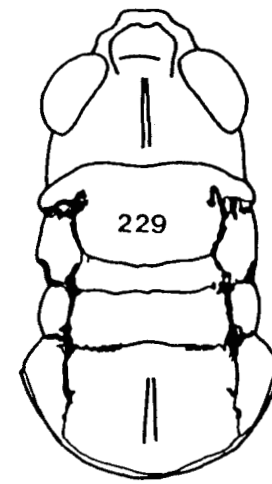
Figs. 209-224











Figs. 225-229

ovipositor dissected ventrally; narrow wings pointed apically; antennae 6- to 9-segmented (**THYSANOPTERA**); thrips [Thripidae] 114

113' Not with the above combination of characters 119

114(113) Forewings (Fig. 230) with longitudinal veins, sometimes cross vein and setae on vein; segment X of abdomen (Fig. 231) usually pointed (conical type), rarely tubular, always divided longitudinally on the ventral surface; saw-like ovipositor present in females; wing membrane with numerous microtrichia (Terebrantia) 115

114' Forewing without longitudinal veins if present; microtrichia in the wing membrane absent; segment X of abdomen tubular (Fig. 232) in both sexes without a longitudinal division dorsally and ventrally; females with a ventrally everted membranous ovipositor between segment IX and X; head long and parallel-sided; prothorax with 8 long pointed anteroangular and posteroangular setae (Fig. 233); antennae 8-segmented, brownish except lighted yellow band *3rd* segment (Fig. 234); segment III with 0-2 sense cones and 4 cones on IV; postocular seta well developed, long, about 50μ; (Tubulifera) ..... *Haplothrips aculeatus* (F.)

114" Allied to *H. aculeatus;* prothorax with 10 long cylindrical setae (Fig. 235), cup-like at tip; pelta inverted T-shaped; antennae brownish in basal 2 segments, VII-VIII and apical 1/2 of VI, III-IV-V and basal 1/2 of VI yellow; segment X of abdomen 1/2 the width of segment VII in females ..... *Haplothrips ganglbaueri* Schmutz

115(114) Forewing broad (Fig. 236), apically rounded with 4 cross veins distinct, 2 dark cross bands distinctly separated from pale areas; short setae on head and pronotum (Fig. 237); antennae 9-segmented, segment III apically shaded, sensoria on segments III and IV linear (Fig. 238); prothorax without setae post-marginally; metanota indented laterally; anteocellar setae absent; maxillary palpi 3-segmented ..... *Aeolothrips fasciatus* (Linnaeus)

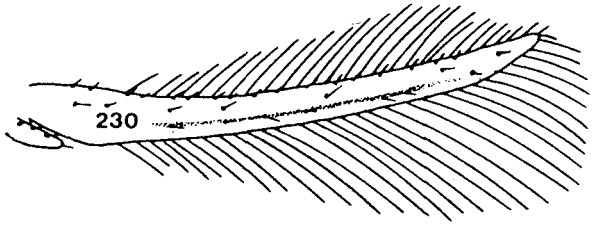
115' Forewing slender and acute apically, visible cross vein only 1; antennae with 6-9 segments 116

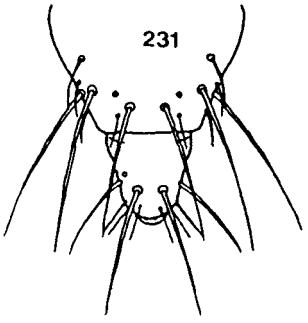
116(115') Head much smaller than pronotum, distinctly produced in front of eyes (Fig. 239); antenna segment II produced exteriorly at apex (Fig. 240); asymmetrical, III and IV with sense cones simple; trapezoidal pronotum bears 2 pairs of major posteroangular setae; sternites III-VIII of abdomen each with an ovoid glandular area in males (Fig. 241) ..... *Chirothrips manicatus* (Haliday)

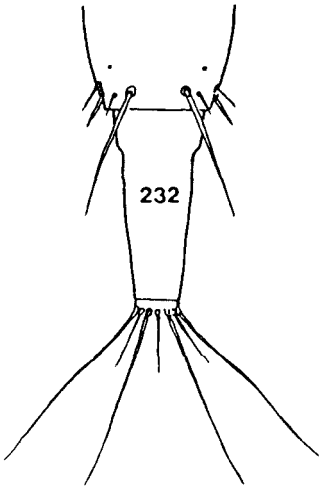
116' Head not produced in front of eyes; segment II of antennae normal 117

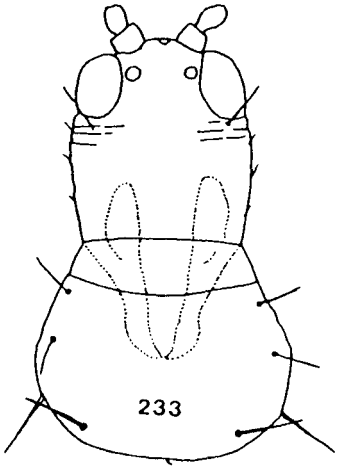
117(116') Antennae (Fig. 242) 7-segmented with forked sense cone on segments III and IV; head with 1 pair of anteocellar setae (Fig. 243); postocular seta III longer than I; forewings uniformly (Fig. 244) dark greyish brown; tibiae brown ..... *Stenchaetothrips biformis* (Bagnall)

117' Antennae 8- or 9-segmented 118











Figs. 230-234

118(117') Pronotum (Fig. 245) normal with short setae at posterior margin; metanota with a long lateral arm and 4 setae; vein series of setae in the forewing interrupted (Fig. 246); antennae (Fig. 247) 9-segmented with simple sense cone in segment 1 and a forked sense cone in III; diameter of spiracle on tergite VIII about 0.2 times the length of tergite; body yellowish green with some light brown spots... *Anaphothrips obscurus* (Muller)

118' Pronotum (Fig. 248) with long setae at the posterior margin; prothorax with 2 pairs each of long setae on anterior and posterior margins, anteromarginal setae shorter than antero-angular setae; interocellar setae in ocellar triangle; forked sense cones in antennal segments III and IV (Fig. 249); fringe cilia wavy; body dark yellowish brown; wings light yellow ..... *Frankliniella tenuicornis* (Uzel)

119(113') Both pairs of membranous wings largely covered with overlapping scales; mouthparts in a coiled proboscis; antennae many segmented; moths, butterflies (**LEPIDOPTERA**) 120

119' Not as above 180

120(119) Antennae gradually or abruptly clubbed, tip sometimes hooked 121

120' Antennae not clubbed or hooked 133

121(120) Antennae approximated at base, clubbed distally without hooked tip; some peripheral veins stalked; front wings more or less triangular, some veins especially Sc swollen at base, radius 5-branched; moths usually with brownish or greyish circular spots [Satyridae] 122

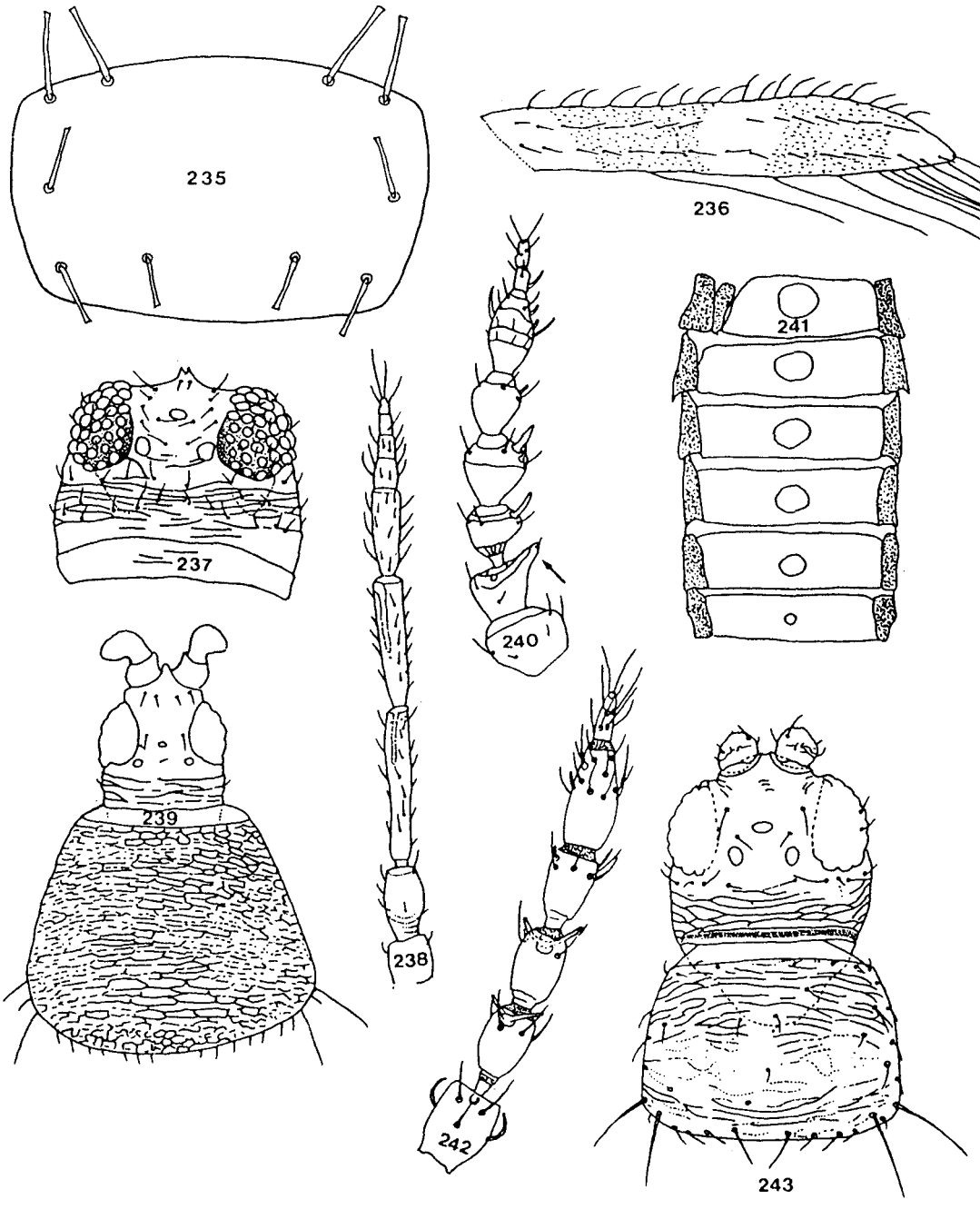
121' Antennae widely separated at base, scape with scale-tuft, flagellum dilated apically with hooked tip; ocelli absent; chaetosemata present; haustellum naked; forewings without retinaculum, veins arising separately from discal cell, CuP absent; 1A + 2A simple or forming basal fork; hindwings without frenulum, Sc connected to Rs near base by R1; moths usually with glass-windows on wings [Hesperiidae] 125

122(121) Eyes hairy; all veins basally swollen, termen of both wings entire, evenly rounded; undersurfaces of wings brighter than the dull brown uppersides (each wing) with a pale postdiscal band and a series of submarginal ocelli (eye spots) *(Mycalesis)* 123

122' Eyes smooth; tarsal claws on the mid and hind legs cleft; forewings falcate at vein 5; hindwings caudate at vein 4; uppersides of hindwings with a white dot or a white pupilled ocellus *(Melanitis)* 124

123(122) Forewings (Fig. 250) with a pair of eye spots (swollen one along veins 7-9 and the large spot almost along veins 3-5) dorsally, though a much smaller spot may be present and contiguous to the upper one, similar underneath except for the upper part bordered with a spot each anteriorly and posteriorly; hindwing bare dorsally, underneath bears 6-7 eye spots with 5 and 1 broader than rest (Fig. 251) ..... *Mycalesis gotanma* Moore

123' Uppersides of forewings with only 1 large spot, ringed pale yellow-brown between veins 2 and 3 (Fig. 252); undersides with 2 minute white dots, one under the large dorsal spot



Figs. 235-243

and the other between veins 6 and 7; hindwings bare dorsally, underneath with a small dark brown spot each between veins 1a to vein 7 . . . *Mycalesis* nr. *mineus* (Linnaeus)

124(122') Uppersides of forewings dark brown with two 1-2 mm subglobular white spots between veins 3-4 and 4-5 ringed brown to bluish violet with 4 highly wavy orange hues in the centers, a broad brown spot with violet tinge dorsad of 2 white spots (Fig. 253); undersides of forewings with 2 white spots of the upperside; hindwings with 2 brown spots ringed light brown to yellow and centered white between veins 6 and 7, and 2 and 3 . . . . . *Melanitis leda* (Linnaeus)

124' Upperside blackish brown and with unmarked forewings in males, light to pale brown in females, apical area paler than basal in both sexes; forewings of females with a round to ovoid white spot each between veins 3-4 and 4-5, lower 1/2 bordered with orange band in the inside, veins 5-7 with an inner orange and outer dark brown band; hindwing with a small white spot between veins 2-3 dorsally (Fig. 254) . . . . . *Melanitis phedima* Stoll

125(121') Vein 5 (M2) of forewings straight from its point of origin; vein 5 of hindwings distinct; antennal club not constricted before the apiculus; cell of hindwings about 2/5 wing length; uppersides of both wings with prominent orange-yellow markings (Fig. 255), 3 bands along postmedian and a contiguous one along costa and median, broadening at median; hindwing with 3 nearly contiguous bands starting from vein 2 upwards . . . . . *Ampittia maro* Fabricius

125' Vein 5 (M2) downcurved from its origin; vein 5 of hindwings wanting; antennal club constricted before apiculus 126

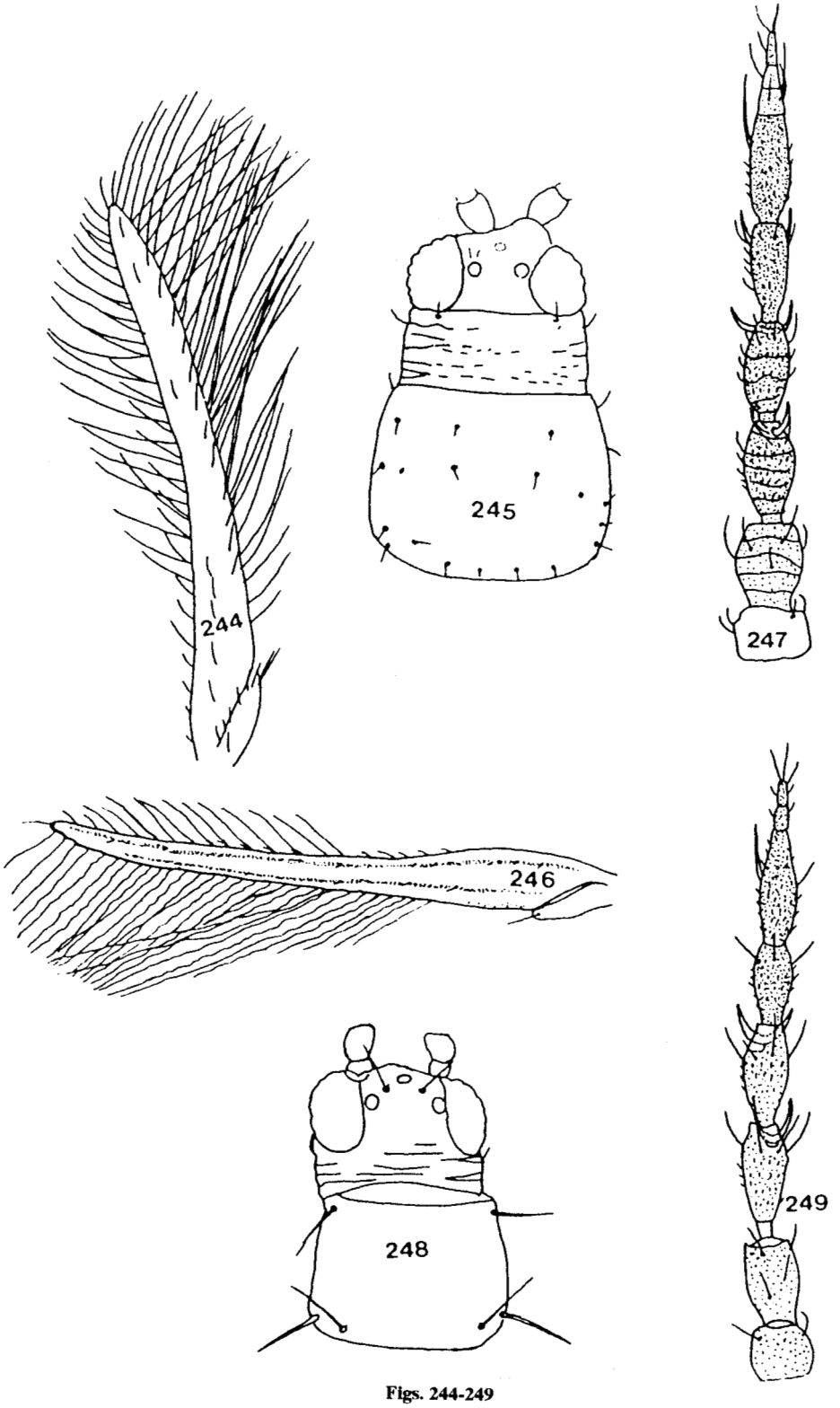
126(125') Midtibiae smooth; wings with yellow markings 127

126' Midtibiae spined or smooth; wings brown with small hyaline spots 128

127(126) Third segment of palpi short and stout; vein 2 of forewings nearer the end of the cell than to their base; uppersides of male and female forewings orange-yellow with brown markings (Fig. 256), male forewing with a narrow oblique band from midvein 1b to the origin of vein 4; termen of forewing straight; post-discal band extends from vein 1b to vein 8 and an orange spot in the cell in hindwings of male; ventral edge of male valva without a projecting shoulder . . . . . *Telicota augias* (Linnaeus)

127' Third segment of palpi long and thin; antennal club not flattened with a very fine apiculus and at an angle to the club; undersides of forewings with the lower basal portion of vein 12 (Sc) fringed with hair scales; vein 2 (Cu2) closer to end of cell, vein 4 farther from vein 3 than vein 5; post-discal band on uppersides of forewings broad running from dorsum to the costa, hindwings with 6 orange spots (Fig. 257) . . . . . *Potanthus confucius* (Fruhstorfer)

128(126') Midtibiae heavily spined; undersides of hindwings with a spot in the cell (*Pelopidas*) 129



Figs. 244-249

128' Midtibiae smooth and not spined 130

129(128) Band on uppersides of forewings meet vein 1b on the basal side of the origin of vein 2 in males, with 4 small spherical post-discal white spots and 2 rather elongate ones in the lower apical edge of the discal cell; females with broader white spots, 4 post-discals and 4 more below the apical end of the discal cell; 2 discal cells perpendicular to the nearly triangular spot above vein 1b (Fig. 258) ..... *Pelopidas mathias* (Fabricius)

129' Band on the uppersides of forewings meets vein 1b right below origin of vein 2 or nearer termen in males (Fig. 259); spots similar to *P. mathias* except for a more parallel discal spot and less oblique band between veins 3-4; females (Fig. 260) as in above species except for a more shoe-like band between veins 3-4, more rounded spot above vein 1b not perpendicular to the 2 discal cells; moths larger than *P. mtathias* .... *Pelopidas agna* (Moore)

130(128') Antennae about 1/2 length of each forewing, antennal club obtuse, uppersides of hindwings with 4 elongate to ovoid white spots; forewings with 2 elongated spots in the discal cell, 2 groups of post-discal (3 small spots lining the radial spaces and 3 broad, more rectangular spots below it, and 1 spot above vein 1b (Fig. 261) .... *Polytremis pellucida* (Murray)

130' Antennae very short, approximately 2/5 length of forewing; apiculus very short . . 131

131(130') Discal cells with 2 thin parallel white spots; 3 small post-discals and 2 broader bands in the lower apical end of cell, the 7 spots C-shaped; hindwing with 4 white spots (Fig. 262); male valva uniform in width with a straight inner edge .... *Parnara guttata* Bremer and Grey

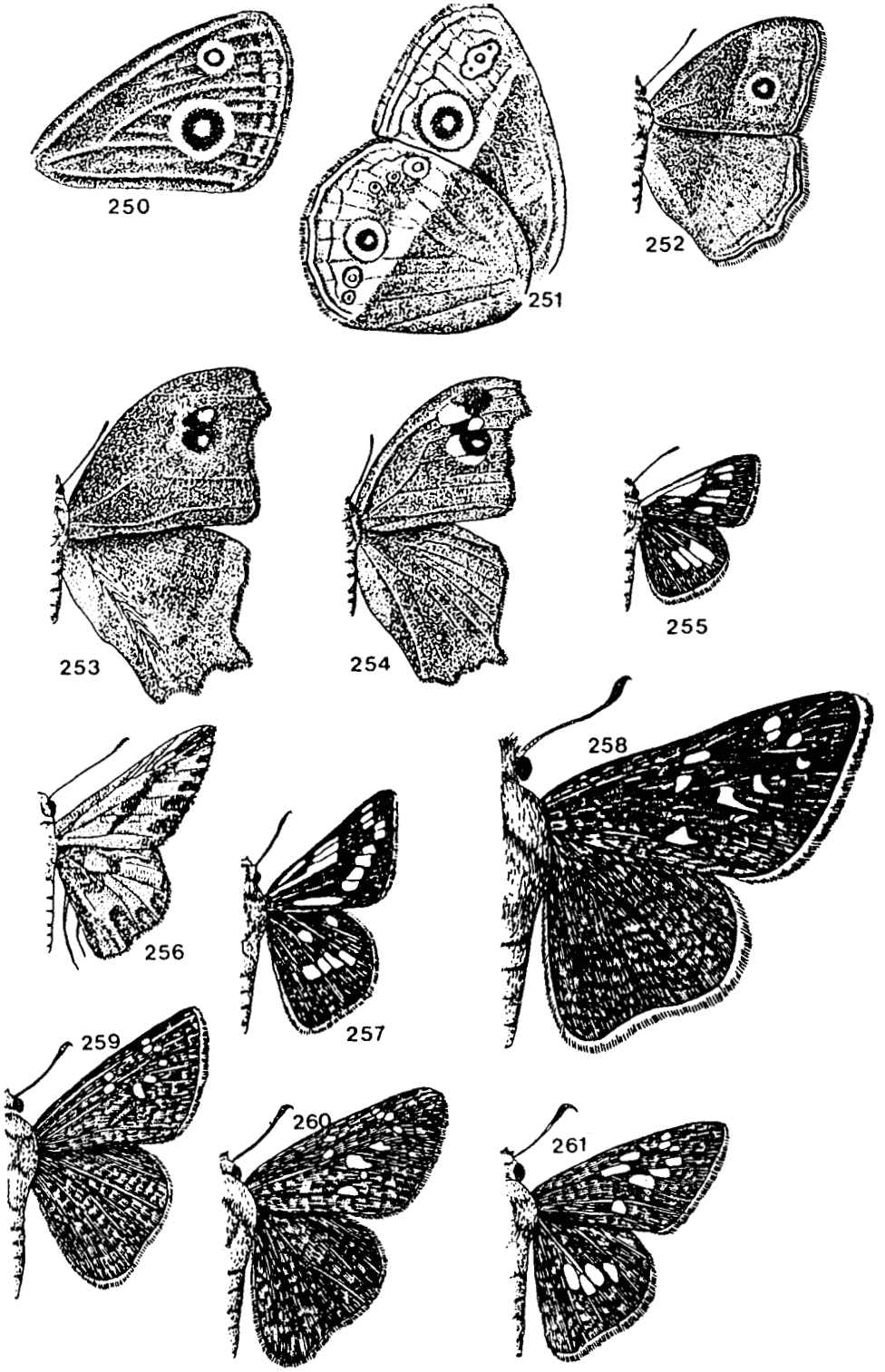
131' Discal cells without prominent spots 132

132(131') Upperside of hindwings with 2 small, irregular white postdiscal spots faint and diffuse (Fig. 263); inner margin of valva strongly convex ..... *Parnara naso bada* (Moore)

132' Hindwings with 4 white spots (Fig. 264); forewings similar to *P naso;* uppersides of wings with a more golden luster than *P. naso;* male valva recurved in its inner margin below the projecting shoulder ..... *Parnara ganga* Evans

133(120') Maxillary palpi 4-segmented (sometimes 2-3); haustellum reduced; chaetosemata usually present; forewings without areole; Sc + R1 approximated to or shortly fused to Rs beyond discal cell, M2 approximated to M3 at base in the hindwing [Pyralidae] 134

133' Maxillary palpi 1-segmented; haustellum usually strong or reduced; forewings with or without areole; chaetosemata absent 158



Figs. 250-261

134(133) Wings immaculate white with brown specks on the uppersides of both wings (Fig. 265); larvae semiaquatic, with tracheal gills and concealed inside cylindrical leaf tube; caseworm ..... *Nymphula depunctalis* (Guenée)

134' Wings never immaculate, usually brown to brownish orange; grass webworms or leaf-folders/leafrollers 135

134" Wing coloration not as above; stem borers 139

135(134') Wings fuscous (dark brown) with postmedial line undulated in both (fore and hind wings); forewings with the antemedial line outwardly curved and oblique; medial very short and dorsad of the inwardly lower half of postmedial (Fig. 266); proboscis strongly coiled in between porrect labial palpi (Fig. 267); body uniformly dark brown; body length about 12.5 mm, wing span 22-25 mm; grass webworm .... *Herpetogramma licarsisalis* (Walker)

135' Wings orange-brown with dark brown subterminal to terminal areas; antemedial, medial, and postmedial lines more prominent; body length 6-9 mm; wing span 11-18 mm; larvae yellow, with or without brown spots in the pronotal shields and sclerotized base of setae (leaffolders/leafrollers) 136

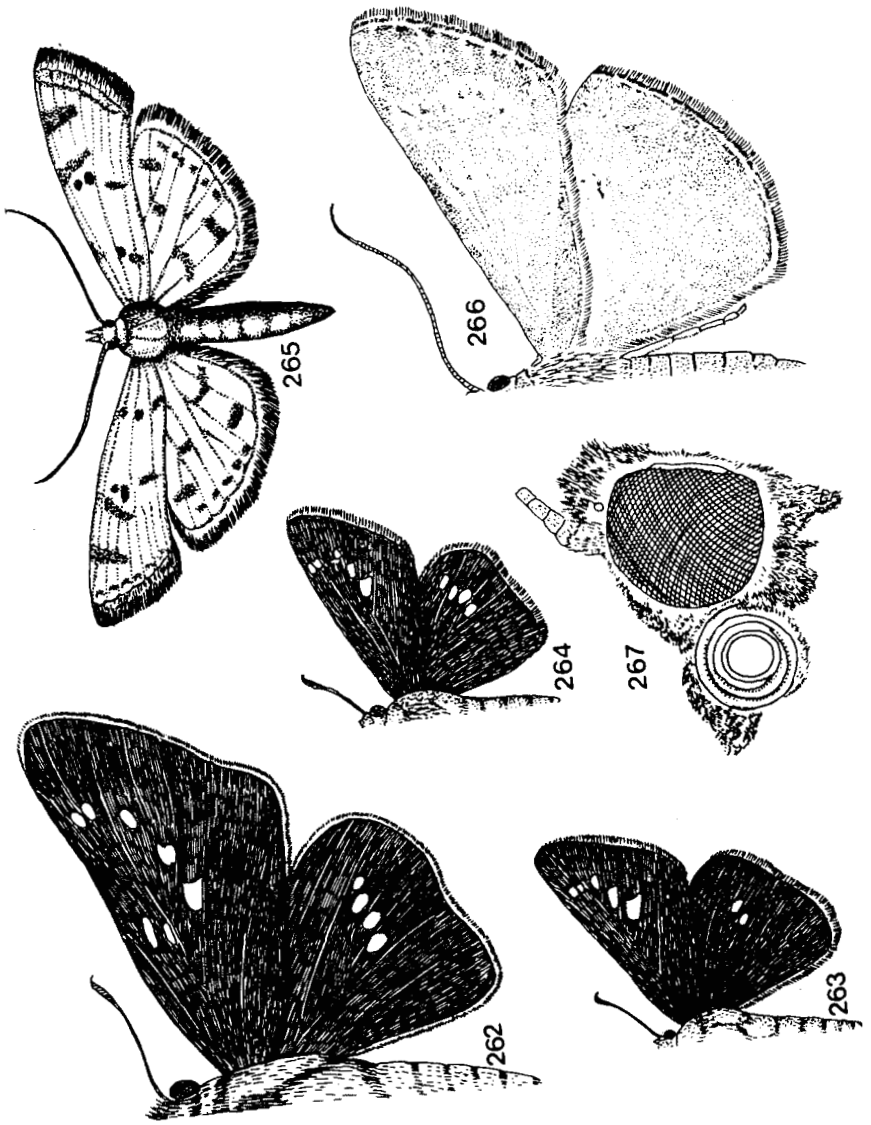
136(135') Forewings with veins R2 + R1 stalked; costal region without any strigulae; postmedial line of both wings diagonal and straight and distinctly interconnected (Fig. 268); antemedial short and replaced with androconial hair tuft in the males (Fig. 269); tip of abdomen with a longitudinal black band, broader in females and slender in males; genitalia of both sexes illustrated in insets ..... *Cnaphalocrocis medinalis* (Guenée)

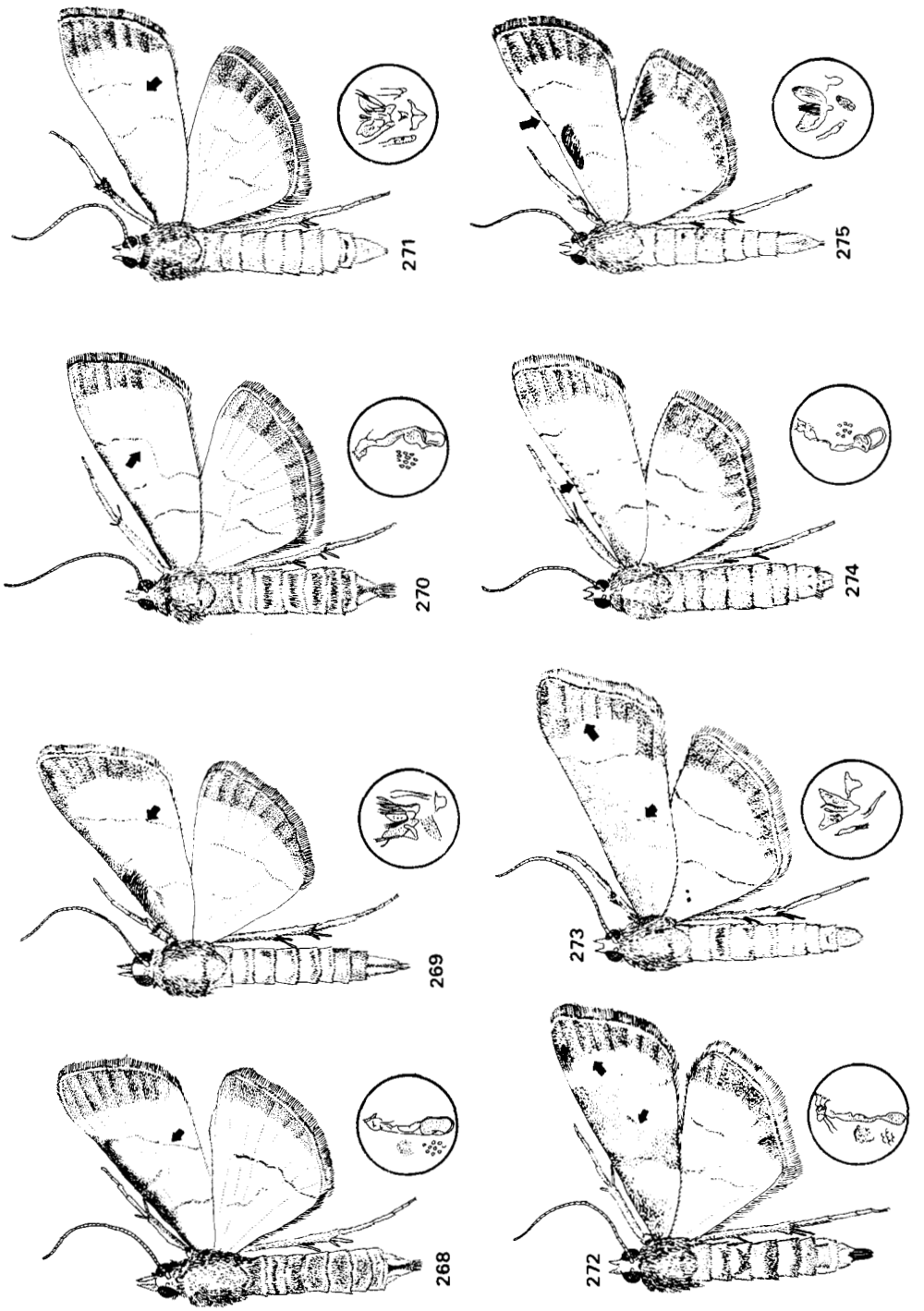
136' Forewings with veins R2 and R1 free; costal region with or without strigulae; postmedial line not as above; genitalia of both sexes illustrated in insets (Figs. 270-275) .... *Marasmia* 137

137(136') Costa of forewings with silver-yellow and minute black strigulae (Figs. 270-271); sacculus with a spur-like structure; cornuti with about 60 teeth; valva elongated to ovate; saccus knob-like; bursa copulatrix with minute teeth or scobinations in the proximal duct (ductus bursae) and none in the distal sac (corpus bursae) as illustrated in inset (Fig. 270) ..... *Marasmia ruralis* (Walker)

137' Costa without strigulae 138

138(137') Wing span 12-14 mm; forewings with a greyish brown C-shaped band covering the subterminal and terminal areas; hindwings with 2 parallel lines traversing the wing (Figs. 272-273); aedeagus with 2 robust teeth; apical one twice as long as the basal; bursa copulatrix broadly truncate basally and surrounded with composite-like granulations along the signum illustrated in inset (Fig. 272) ..... *Marasmia exigua* (Butler)


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138' Wing span more than 15 mm; postmedial line bent inwards to a point near the posterior tip of a short medial line where it runs posteriorly; postmedial line of hindwings about 1/2 the length of antemedial posteriorly (Fig. 274); abdomen of male with a small interconnected black band an penultimate segment while the female has short longitudinal black band on the tip (Figs. 274-275); genitalia of both sexes illustrated in insets ..... *Marasmia patnalis* Bradley

139(134") Proboscis absent (Fig. 276); hindwings with median nerve not pectinate on upper side 140

139' Proboscis present (Fig. 277); hindwings with a pectinate median nerve on upper side. 146

140(139) Palpi upturned (Fig. 278); forewings immaculate white, veins R2 to R4 stalked; males have 24-45 mm wing span and white anal tuft; females 19-34 mm and with orange brown tuft; American species ..... *Rupela albinella* Cramer

140' Palpi porrect (Figs. 276-277); R2 usually free 141

141(140') Forewings yellow with a black spot at lower angle of cell in the females (Fig. 279) and ochreous with minute markings in males (Fig. 280); frenulum double-bristled .... *Scirpophaga incertulas* (Walker)

141' Forewings white to ochreous white; frenulum with 1-2 bristles; anal tuft ochreous yellow, white or greyish 142

142(141') Frenulum double-bristled (Fig. 281). 143

142' Frenulum single - bristled (Fig. 282) 144

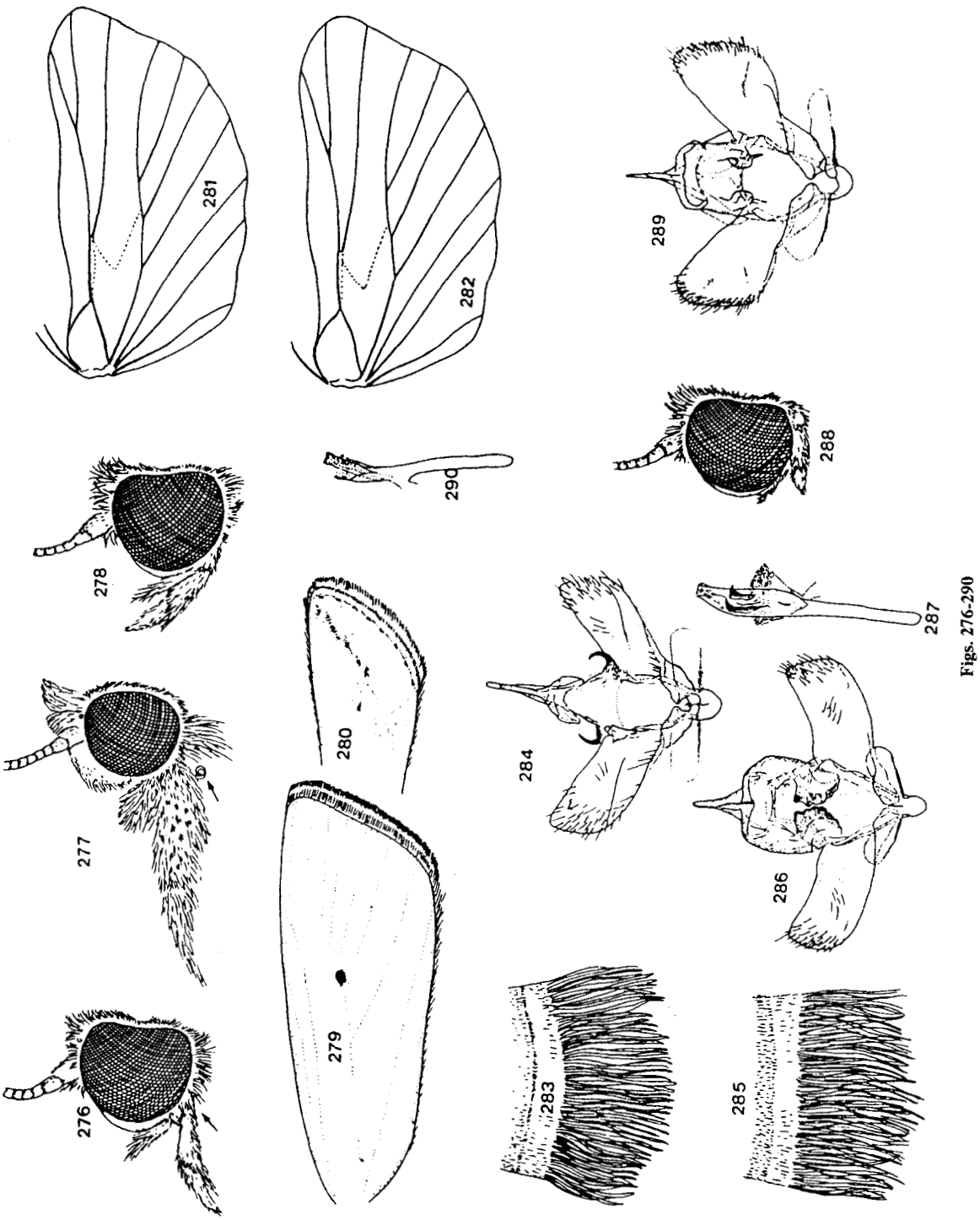
143(142) Both sexes immaculate white; anal tuft white (Fig. 283); length of labial palp 2 times diameter of compound eyes in males; subteguminal process with a spine (Fig. 284) ... . *Scirpophaga innotata* (Walker)

143' Females white; anal tuft ochreous yellow (Fig. 285); males ochreous; four fuscous spots on the submedian fold and lower angle of cell and series of small fuscous dots on the terminal area of forewings; subteguminal process large, without spine but with sinous margin (Fig. 286); 3 cornuti (Fig. 287) ..... *Scirpophaga nivella* (Fabricius)

144(142') Length of labial palps as long as diameter of compound eyes (Fig. 288); forewings white to ochreous white; subteguminal process rounded (Fig. 289); cornuti without spine (Fig. 290) ..... *Scirpophaga virginia* Schultze

144' Length of labial palps longer than diameter of compound eyes (Fig. 291); subteguminal process not as above 145

145(144') Subteguminal process flattened and rounded with smooth margins (Fig. 292); moths dark ochreous in males and white in females; length of labial palps 1.5 times diameter of compound eye; anal tuft dark grey; cornuti bear 3 spines (Fig. 293) .... *Scirpophaga gilviberbis* Zeller



Figs. 276-290

145' Subteguminal process bilobed (Fig. 294); moths of both sexes white; length of labial palps 1.3 times diameter of compound eye; anal tuft pale ochreous white; cornuti without spines (Fig. 295) ..... *Scirpophaga occidentella* (Walker)

146(139') Forewings without vein R5 (or vein 7); (Phycitinae) 147

146' Forewings with vein R5(7) (Crambinae) 148

147(146) Proboscis well developed; forewings with black suffusions along termen and tornus curved downwards (Fig. 296); fore and hindwings with M3 (vein 4) present; American species ..... *Elasmopalpus lignosellus* (Zeller)

147' Proboscis weak as in Fig. 277; forewings with a dark brown band parallel to the costal margin; tornus rounded upwards (Fig. 297); fore and hindwings without M3; median nervure with only 3 veins; African species ..... *Maliarpha separatella* (Ragonot)

148 Forewings rather narrow without metallic scales (Fig. 298); frons subrounded, slightly forward but without a corneous point at apex; ocelli absent; tufts of hair of 2*nd* abdominal segment and hind tibiae in males prominent; American species .... *Diatraea saccharalis* (Fabricius)

148' Forewings somewhat broad with metallic scales (Fig. 299); frons conically produced forward (Fig. 300) 149

149(148') Hindwings with vein M1 (or vein 6) weakly developed and slightly above middle of discocellulars; forewings with R5 (or vein 7) stalked with R4 (vein 8-9), subterminal area with wavy light brown and silvery white bands, terminal area with series of black spots and indented (Fig. 301) ..... *Acigona chrysographella* (Kollar)

149' Hindwings not as above, vein M1 well developed and R5 free 150

150(149') R1 or vein 11 free (Fig. 302) 151

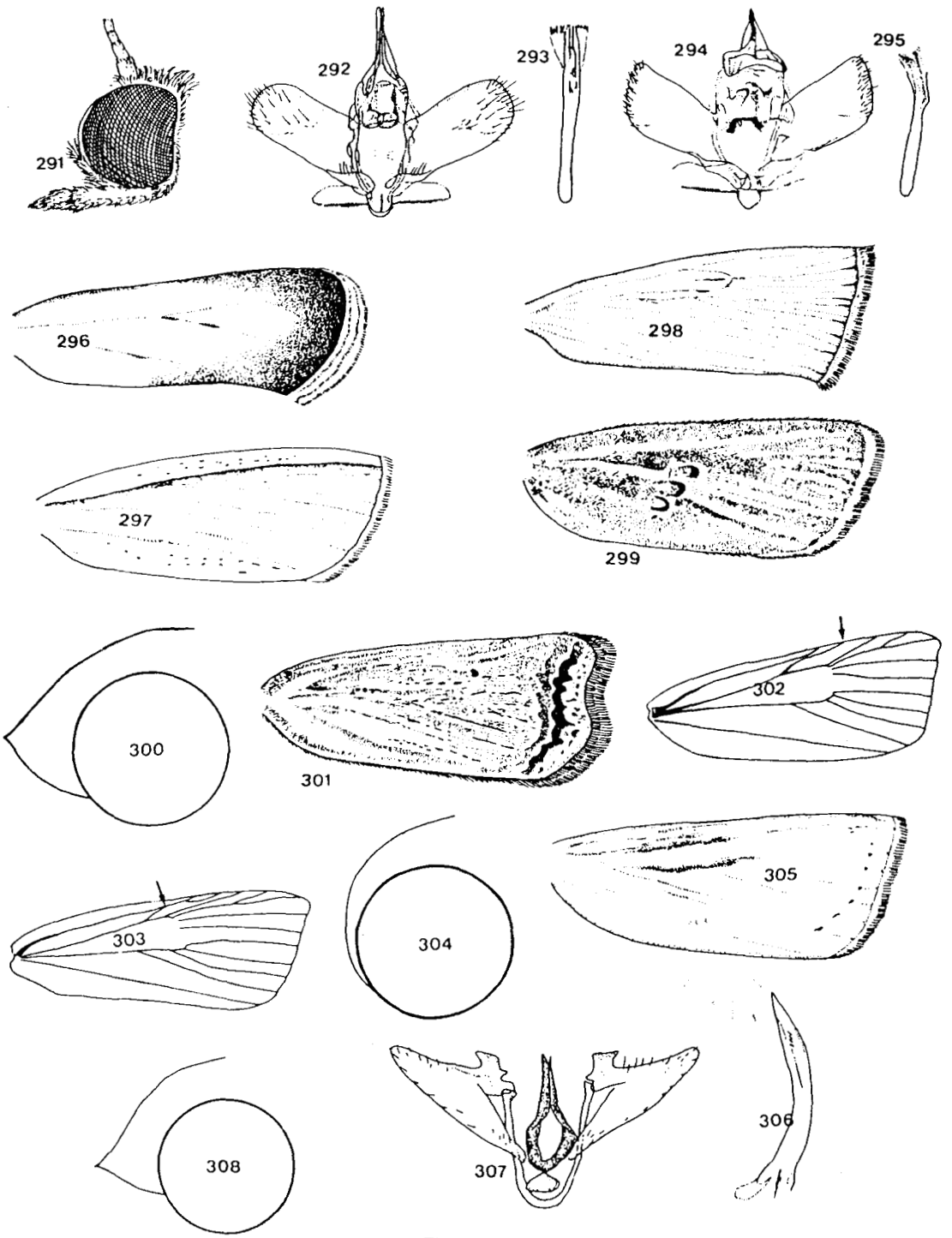
150' R1+ Sc (or vein 12) fused (Fig. 303) 155

151(150) Face broadly rounded without corneous point and ventral ridge (Fig. 304); forewings with fuscous dots on the subterminal areas (Fig. 305); labial palps 3-4 times as long as diameter of compound eyes; ocelli well developed; aedeagus curved without ventral arm, but with bulbose basal projection (Fig. 306); costa of harpe with a tooth projected upward, juxta1 arm long and tapers to points and without subbasal teeth (Fig. 307); African and European species ..... *Chilo agamemnon* Bleszynski

151' Face conical with distinct point; ventral ridge may be present or absent 152

152(151') Ventral ridge absent (Fig. 308); forewings dull yellow dusted with brown scales, terminal dots prominent, subterminal lines with series of lustrous metallic golden scales; labial palps 4 times as long as diameter of eye; costa of harpe without teeth, arms of juxta long and each bears a subapical tooth (Fig. 309); aedeagus distinctly long, hairy, apically pointed, ventral arm absent (Fig. 310) ..... *Chilo plejadellus* Zincken

152' Ventral ridge present; labial palps 3-3.5 times as long as diameter of eye 153


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Figs. 291-308

153(152') Face with vestigial ridge (Fig. 311); forewings yellow to brown dusted with fuscous scales; subterminal line a light brown line (Fig. 312); vein M1 of hindwing arises from Rs before angle of cell; costal margin of harpe with a strong median tooth; juxta bell-shaped with 2 notches basally (Fig. 313) . . . . . *Chilo partellus* (Swinhoe)

153' Face not as above; vestigial ridge well developed 154

154(153') Arms of juxta-plate symmetrical and distinctly swollen near apices; tips of harpe not tapering (Fig. 314); subapical teeth absent (male genitalia); female genitalia with heavily sclerotized ostial pouch and slightly demarcated from ductus bursae; frons with prominent ridge and corneous point (Fig. 315); forewing length 11-14 mm (Fig. 316) . . . . . *Chilo suppressalis* (Walker)

154' Arms of juxta-plate narrow and not dilated medially; subapical teeth present (Fig. 317);. female genitalia with small ostial pouch and well demarcated from ductus bursae; larger moths with forewing length 12-17 mm . . . . . *Chilo hyrax* Bleszynski

155(150') Face produced forward, smooth, or with a small point; Oriental region 156

155' Face rounded without corneous point (Fig. 304) 157

156(155) Terminal dots ill-defined to absent (Fig. 318); forewing with subterminal metallic spots roundly curved almost parallel to termen from vein M2 to inner margin; aedeagus without pointed projection (Fig. 319); costa of harpe with tooth, harpe broad and more or less triangular (Fig. 320) . . . . . *Chilo polychrysus* (Meyrick)

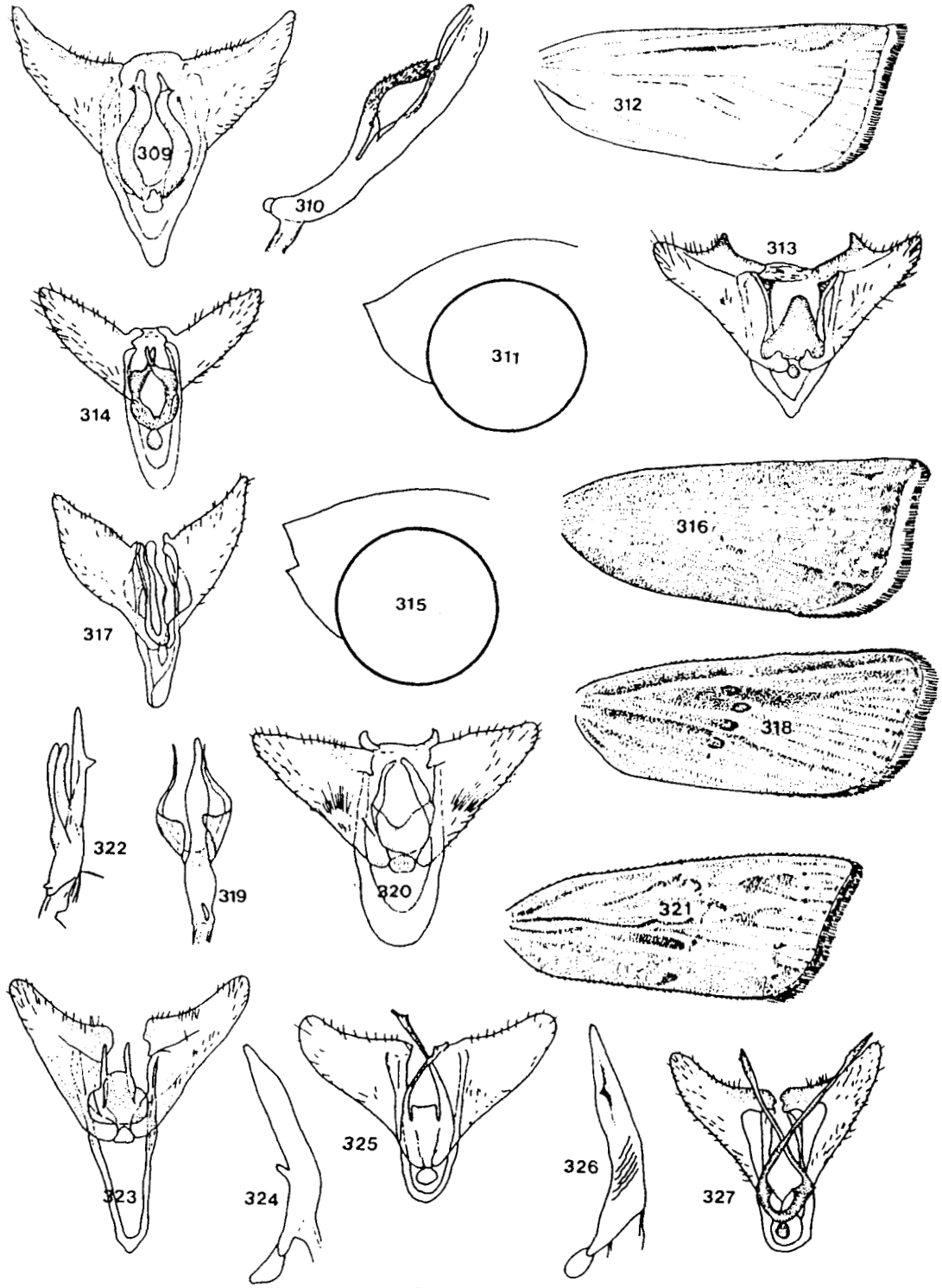
156' Terminal dots distinct (Fig. 321); forewings with subterminal metallic spots regularly curved and not parallel to termen; aedeagus with projection (Fig. 322); costa of harpe without tooth, harpe not broad (Fig. 323) . . . . . *Chilo auricilius* Dudgeon

157(155') Aedeagus with basal part curved and bears a short ventral arm (Fig. 324); arms of juxta with subapical tooth; harpe broad and blunt apically (Fig. 325); forewing length 8-13 mm and generally orange yellow to dirty yellow . . . . . *Chilo diffusilineus* (J. de Joannis)

157' Aedeagus without ventral arm (Fig. 326); juxta1 arm without tooth, harpe tapers apically (Fig. 327); forewing length 10-14 mm and ochreous yellow . . . . . *Chilo zacconius* Bleszynski

158(133') Haustellum reduced; forewing without areole; Sc + R1 swollen at base, fused with Rs to near middle of discal cell then diverges, M2 nearer to M3 than to M1 in the hindwing; dorsal black band of thorax tapers on both ends; abdomen pinkish red with black transverse median band dorsally; lateral sides with 2 longitudinal rows of paired black spots; forewings brownish white with a broad transverse black band at center, obliquely interrupted postmedially; hindwings white with a pair of gray spots in terminal area (Fig. 328) (Arctiidae] . . . . . *Creatonotus gangis* (Linnaeus)

158' Haustellum strong; forewings with areole; Sc + R1 shortly fused with Rs near base, rarely fused to about 1/2 of discal cell, M2 weak arising closer to Ml than to M3 (trifid) or strong and arising nearer to M3 than to M1 (quadrifid) in the hindwing [Noctuidael 159


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Figs. 309-327

159(158') Defoliators; moth body length 9-11 mm; wing span 16-22 mm; whitish brown to dark yellow or orange brown with or without diagonal bands 160

159' Defoliators; moth body length greater than 15 mm; body and wing coloration variable 161

159" Stem borers; moth body length 10-17 mm; forewings usually with suffused red markings radiating from wing base towards discal area 162

160(159) Triangular-shapedmoths and head always directed downwards at rest (Fig. 329); wings dull whitish yellow with a small brown short triangular-like postmedial band, subterminal to terminal area brownish with 8 tiny terminal spots; labial palps slightly porrect and broadened by scales apically (Fig. 330); frons pointed; larvae green with a pair of white longitudinal stripes dorsally, body with long hairs . . . *Rivula atimeta* (Swinhoe)

160' Moths not triangular at rest; wings orange to yellow-brown with a pair of parallel, diagonal ferruginous bands (Fig. 331); labial palps curved, hind segment small (Fig. 332); larvae green like *Rivula* but without long hairs; prolegs only present in abdominal segments V, VI, and anal region; larvae make looping movement . . . . . *Naranga aenescens* Moore

161(159') Antemedial line of forewings thin, entire and prominent, basally curved costally and continued posteriorly in the hindwing as a white diagonal band projected towards tip of abdomen; postmedial broad and basally curved; top subterminal with a broad brown spot contiguous downwards by a thinner band; hindwings dark bluish violet with 3-4 white spots in the termen (Fig. 333); labial palps upcurved, above eyes and in line with antennal bases; moth body length 16-22 mm, wing span 50 mm . . . . . *Achaea janata* (Linnaeus)

161' Antemedial line of forewings absent or less prominent; hindwings never bluish violet 162

162(161') Wings brown to grey-brown; darker in the forewings than the hindwings; forewings with a slant L-shaped band formed by an elongated reddish brown band below discal cell, above midlength of vein 1A + 2A and 1 more diagonal band radiating from apex to outer 1/3 of posterior margin (Fig. 334); subterminal with about 7 minute black dots; reniform spot traceable; hindlegs covered with a thick hair tuft . . . . *Mocis frugalis* (Fabricius)

162' Medium-sized moths without a slant L-shaped band; abdominal prolegs of larvae complete 163

163(162') Pronotal hair tuft with a pair of recurved black eyelash-like bands (Fig. 335); antennae of males bipectinate, branches of moderate length (Fig. 336); forewings with a distinct, short, transverse black bar extending distad from reniform spot; pale orbicular transversely ovate, narrowed distally (Fig. 337); hindwings nearly white except apex and part of termen; larvae are cutworms. . . . . *Agrotis ipsilon* (Hufnagel)

163' Pronotal hair tuft without recurved black eyelash bands, if present, antennae of males not bipectinate 164

164(163') Valves of male genitalia 5-7 times longer than broad; vesica long, coiled, and barbed with spines; appendix bursae of females' genitalia with a long curving "tail" at the apex 165

164' Valves broad, not as slender as in *Heliothis;* vesica different 166

165(164) Hindwings black terminal fascia interrupted by a pale patch between veins M3 + Cu2; postmedial and subterminal lines discernible (Fig. 338); apex of vesica with a normal coil valves 5 times as long as wide in males (Fig. 339); females' lumen surface of appendix bursae clothed with spicules; larval coloration varies from green to brown with whitish short stripes; cremaster spines basally separated by twice basal diameter of spine . . . . . *Heliothis (Helicoverpa) armigera* (Hubner)

165' Hindwings black terminal fascia not interrupted; postmedial and subterminal lines wanting (Fig. 340); apex of vesica curved tail-like; valves 6-7 times as long as broad in males (Fig. 341); spicules on lumen surface short and compactly set; small signum of bursae dorsad to 3 elongate signa; larval color as above; cremaster spines closer to each other, separated by a basal diameter of spine . . . . . *Heliothis (Helicoverpa) punctigera* Wallengren

166(164') Eyes not hairy; indentation between valvula and cucullus small or wanting (*Spodoptera*) 167

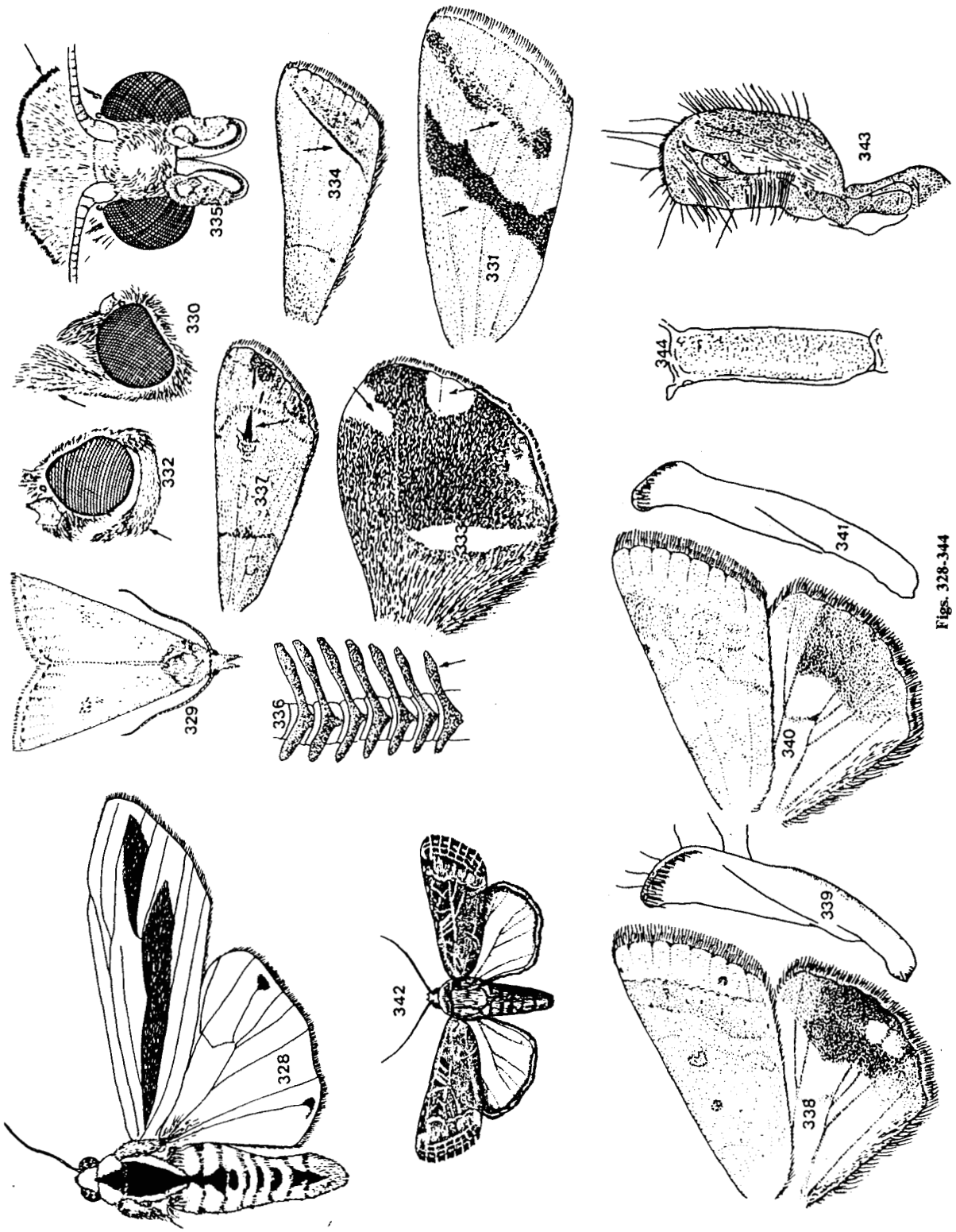
166' Eyes hairy; indentation between valvula and cucullus prominent to very wide (*Mythimna*) 175

167(166) Reinform spot oblique and arrow head-like; orbicular oblique with black edges and dark brown center; subbasal line angled and oblique; antemedial slightly waved and curved inwards toward the base in the lower half, subterminal with 7 transverse bIack bars, 2nd bar from top the smallest and basal one bifurcated or split into 2 black bars (Fig. 342); moths with dark purplish brown forewing. . . . . *Spodoptera litura* (Fabricius)

167' Wing patterns or marks not as above 168

168(167') Western Hemisphere species; females' forewings dark brown without any contrasting markings, superficially rounded at apex with an ovate, oblique and black centered orbicular spot; males' usually brown with subterminal line of forewing fading out midway to inner margin; harpe short and straight; valves broad about 1/4 longer than wide (Fig. 343); ductus bursae long and cylindrical (Fig. 344) . . . . . *Spodoptera frugiperda* (J.E. Smith)

168' Not restricted to the Western Hemisphere; wing patterns different 169


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Figs. 328-344

169(168') Indentation between cucullus and valvula absent in male's genitalia 170

169' Indentation present 171

170(169) Central margin of harpe broad with strong curved processes on distal and proximal ends, distal process slightly beyond margin of valvula; valva half as broad at the valvular region; sacculus and transtilla broad (Fig. 345); females' corpus bursa a globular sac; heavily sclerotized ductus bursa ribbed with minute sclerotized tubercles; signum scobinate and transverse . . . . . *Spodoptera pecten* Guenée

170' Central margin of harpe slender, curved distal process not reaching margin of valvula; transtilla not clear (Fig. 346); males' forewings without pale diagonal band running from near costa between orbicular and reniform spots toward inner apical angle of wing; apical tibial spurs of middle legs very slender with reduced specialized setose (Fig. 347); females with circular or shortly ovate orbicular spot, never oblique and smaller than the reniform; larvae with pale spiracles rimmed black; dorsum pale with a narrow medial dark stripe enclosing a broken pale middorsal line . . . . . *Spodoptera exigua* (Hubner)

171(169') Indentation broad and shallow between the broadly rounded cucullus and valvula; transtilla elongate and thumb-like pedunculi very prominent with thick fan-like hair tuft; valvula clothed with a dense patch of hairs mid-dorsally; harpe with a strongly sclerotized apical spine, distal process curved and 2 proximal processes on either side of it present (Fig. 348); aedeagus with a long sclerotized spine distally; ductus bursa not sclerotized but ribbed longitudinally . . . . . *Spodoptera abyssinia* Guenée

171' Indentation deep to moderately deep; other characters not as above; reniform spot prominently black 172

172(171') Ventral margin of males' genitalial valve incised near apex (Fig. 349); cucullus twice as broad as long; distal and proximal processes of harpe sharply pointed and hardly curved, tip of distal process slightly beyond incision line (Fig. 350); aedeagus with a single cornutus, smooth and tapered apically, and about 1/2 as long as aedeagus; sclerotized ductus bursa 2 times longer than ostium bursa; reniform spot prominently black as in succeeding species; in both sexes, the band between postmedial and subterminal fasciae narrow, reddish brown shading between veins M2 and Cul reduced (Fig. 351) . . . . . *Spodoptera triturata* (Walker)

172' Ventral margin of males' genitalial valve incised well below apex; cucullus as long as broad or a little longer than wide 173

173(172') Foretibiae with a thick mass of long hair and scales on outer side partly reaching apex of tarsus; outer spur of tibiae II slightly shorter than inner spur in males; basal 1/2 of inner spur with specialized, non-squamose densely setose area (Fig. 352); male genitalial valves elongate and narrow except in mid-valvula, the broadest (Fig. 353); anal

angle in the indentation present between cucullus and valvula; transtilla slender; small finger-like labis present; harpe bears a finger-like apical spine reaching anal angle 174

173' Foretibial hairs and scales lightly produced and never up to *1st* tarsal segment; both spurs on tibiae II very broad and lanceolate, specialized setose areas broad and well developed (Fig. 354); females' forewings with elongate-ovate, strongly oblique orbicular spot, reniform spot wanting (Fig. 356); males' forewings with a pale diagonal band between orbicular and reniform spots running from near costa to inner apical wing margin, genitalia1 valves narrowed towards saccus, cucullus blunt to squarish on top, harpe curved from the central region (L-shaped), distal end acutely pointed and downwardly curved at apex (Fig. 355). . . . . *Spodoptera exempta* (Walker)

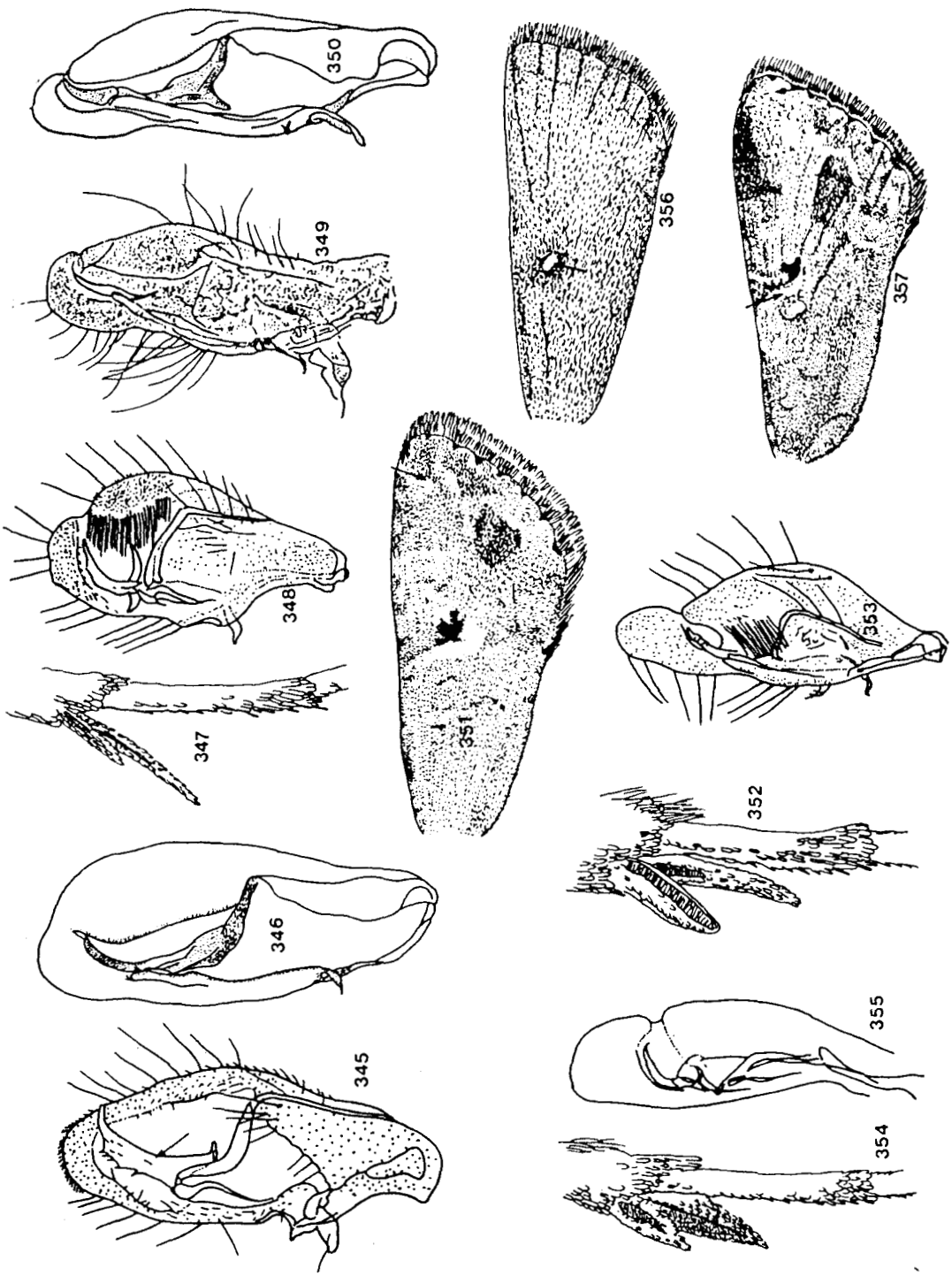
174(173) Males: Medial band reduced to small spot between the reniform and the orbicular, terminal area a small patch near apex; females: white subterminal fascia very slender and terminal area marked with reddish brown irrorations (Fig. 357); Oriental, Indo-Australian and Pacific species . . . . . *Spodoptera mauritia acronyctoides* Guenée

174' Males: medial with a conspicuous white band, space between subcostal vein and Cu2 white except the brown margins and central reddish area of the orbicular spot; and a large fuscous black reniform spot joined to brown costa by a vague median band; veins M1 to M3 with a small but conspicuous fuscous spot; terminal area immaculate white at apex; terminal row with interneural fuscous spots (Fig. 358); African species . . . . . *Spodoptera mauritia mauritia* Boisduval

175(166') Moths pale brown with slight traces of orbicular and reniform spots (Fig. 359); postmedial curved represented by a series of black spots on veins, excurved from radial branches to vein 5 and oblique from vein 4 to outer margin; and marginal series of black specks fairly prominent; light brown oblique band radiates from apical area to bottom of forewings, hindwings pale suffused with reddish brown tinge; cucullus and valvula with a wide anal angle, the former with a long spur apically and moderately slender base opposite anal angle (Fig. 360); female genitalia with a long less rigid arm encircling the bursa copulatrix . . . . . *Mythimna separata* (Walker)

175' Moths brown ochreous or reddish brown without traces of paired orbicular and reniform spots; apex of discal with a whitish spot on entire median of cell bisected by a whitish stripe 176

176(175') Discal cell bisected by a whitish stripe; forewings slight reddish brown with lustre, postmedial line with a series of reddish black spots on veins 2 and 3 running inward-upward to costal margin; antemedial line a reddish black spot below fork of vein 2 (Fig. 361); meson of thorax with whitish stripe on a reddish brown background; hindwings pure white; cucullus sausage-like, more than 4 times as long as wide; sacculus not prolonged to midpoint of cucullus (Fig. 362) . . . . . *Mythimna venalba* (Moore)



Figs. 345-357

176' Discal cell with only a whitish spot on tip; cucullus kidney-shaped to large and normal 177

177(176') Moths brownish-ochreous mottled with fuscous scales; males with prominent ventral lateral tuft on the base of abdomen; females as in males with hair fringes underneath discal cell; wing veins whitish speckled with grayish brown scales; reniform spot, a small white spot at lower angle of cell; antemedial line only a single blackish brown spot below median vein; postmedial with a series of concolorous spots on veins evenly excurved from costal margin to inner margin (Fig. 363); sacculus with a horn-like projection, outcurved, somewhat slender and pointed; cucullus large and normal (Fig. 364) .... *Mythimna loreyi* (Duponchel)

177' Moths ochreous ground; apex of forewings rounded, veins white and their interspaces with fine red-brown streaks; median vein more prominent at lower cell angle beyond a slight fuscous fascia; undersides of wings both without series of specks; inner margins of saccullus toothed, highly sclerotized; cucullus kidney-like shaped (Fig. 365) .... *Mythimna roseilinia* (Walker)

178(159') Asian species; forewing with a pale red horizontal band radiating from wing base to mid termen (Fig. 366); male clasper with a strong furcated projection .... *Sesamia inferens* (Walker)

178' African species; forewings without the radiating pale red band (Fig. 367) and male claspers not as above; melanism notable in adult moths 179

179(178') Juxta broad trapezoid (Fig. 368), costal spine short and bifid apically (Fig. 369); forewing more ochreous with minimal fuscous suffusion, fringe ochraceous white and lightly infuscate at middle and tip; postmedial fascia fuscous black and slightly dentated; pectus pinkish ..... *Sesamia calamistis* Hampson

179' Juxta flask-shaped with a long neck (Fig. 370), costal spine long, curved with a strong sub-apical tooth (Fig. 371); forewing with more fuscous suffusion; postmedial fascia curvely dentated extending from vein R2 (10) to Culb (2); pectus white .... *Sesamia botanephaga* Tams & Bowden

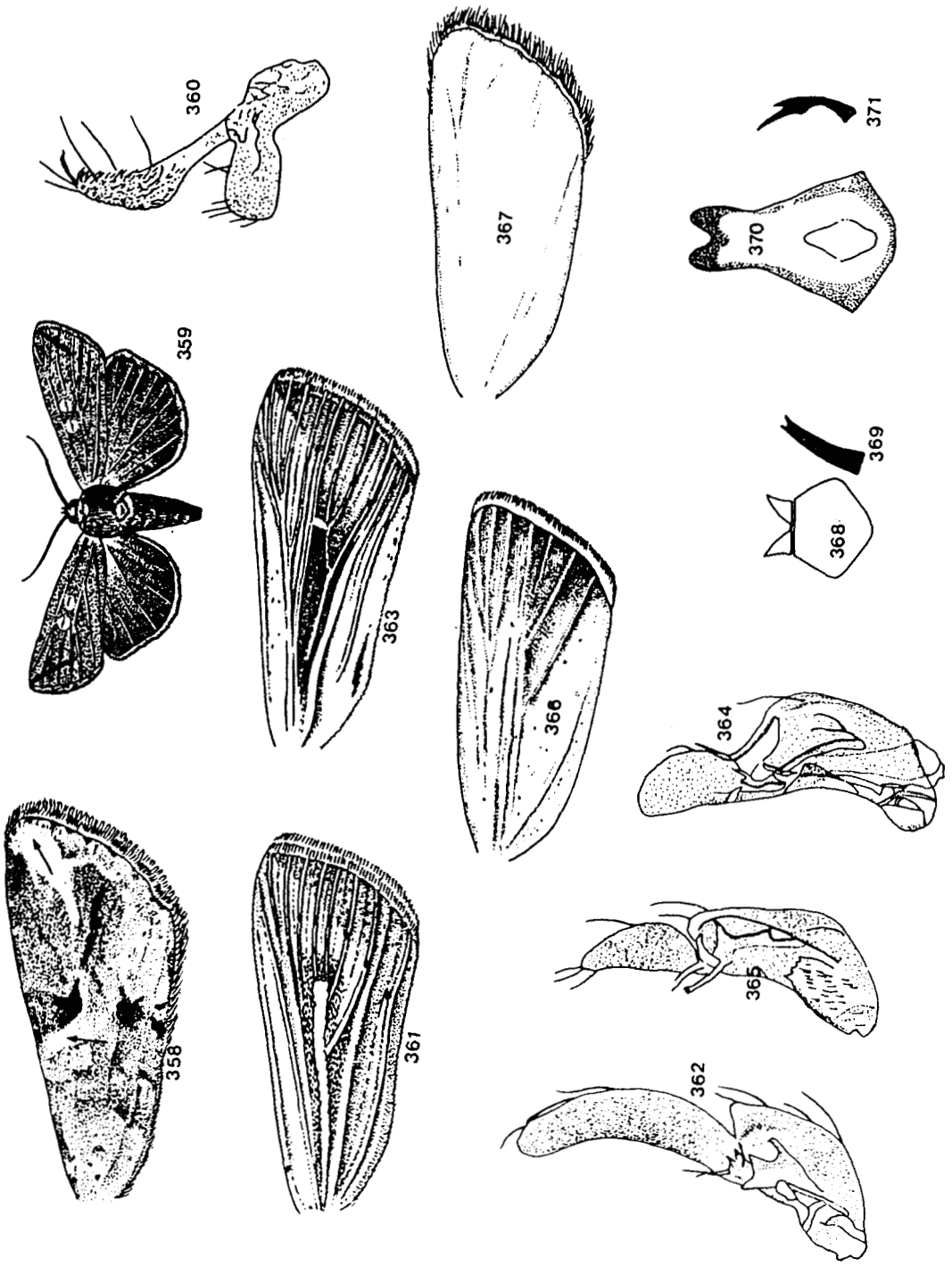
180(119') Beak arising from front or hind part of head; front wings thickened at base and membranous at tips (hemelytra), tips overlapping at rest (**HEMIPTERA**) 181

180' Mouthparts not beak-like, usually mandibulate 344

181(180) Forewing in the form of tegmina of more or less uniform texture, without sharp differentiation into corium and membrane and usually held roofwise over abdomen; labium inserted close to prosternum without an intervening sclerotized gula 182

181' Forewing in the form of hemelytra with thickened corium and apical membrane, usually folding flat on the abdomen with widely overlapping apices; labium inserted far from prosternum with an intervening sclerotized gula 228

182(181) Tarsi 1- or 2-segmented; abdomen with or without siphunculi 183



Figs. 358-371

182' Tarsi 3-segmented; abdomen never with siphunculi 194

183(182) Tarsi, when present, usually 1-segmented and bearing a single claw; with a combination of dorsal ostioles, ventral circuli, triocular pores and usually with 1-18 pairs of cerarii; anal ring usually with an outer and inner row of pores; tubular ducts not invaginated at inner end; siphunculi absent; all forms wingless except males; mealybugs [Pseudococcidae] 184

183' Tarsi usually present, and 2-segmented (sometimes 1-segmented, but rarely atrophied); claws paired; antennae 1-to 6-segmented (commonly 5-to 6-segmented), last segments bear an elongate processus terminalis; both sexes either winged or apterous; when winged, hindwing with 2 oblique veins; abdomen without or with a pair of siphunculi; foliar and root aphids [Aphididae] 185

184(183) Antennae 6- or 7-segmented; quinquelocular pores numerous and evenly distributed dorsally except at middle with almost a single row of triocular pores; 4 pairs of cerarii confined in the 6*th* and posterior segments of abdomen; anal lobe cerarii each with 2 or 3 lanceolate setae, triocular pores absent (Fig. 372); anal ring not joined at anterior end ..... *Brevennia rehi* (Lindinger)

184' Antennae 8-segmented; quinquelocular pores absent; 16 pairs of cerarii present but without ocular and preocular pores; anal lobe cerarii with a pair of conical setae surrounded by a dense cluster of triocular pores and 6 auxiliary setae; anal ring with a double row of pores (Fig. 373) ..... *Pseudococcus saccharicola* Takahashi

185(183') Apterae with or without siphunculi, or with first two tarsal segments fused (showing single segment appearance); antennae shorter than 1/4 of body length and 5-segmented. Alate either without siphunculi, or with annular rhinaria borne on 6-segmented antennae; median veins of wing unbranched (Fig. 374) 186

185' Apterae always with siphunculi; first 2 tarsal segments distinctly separated. Alate forms always with siphunculi but without annular rhinaria; median veins of fore wings 1 to 2 branches. Antennae of both forms 6-segmented, processus terminalis of ultimate antennal segment longer than base of segment 187

186(285) Siphunculi distinct, conical in shape and with a rim; anal plate not displaced dorsally (normal); abdominal segment VIII bears 2 dorsal hairs. First and second tarsal segments in apterae appear 1-segmented; antennae 5-segmented (Fig. 375); prominent dorsal groups of facetted wax glands present on abdomen. Alatae with many annular rhinaria on antennal segments III-V (Fig. 376); segment III and V of antennae each prominently longer than segment IV ..... *Tetraneura nigriabdominalis* (Sasaki)

186' Siphunculi absent; anal plate of both apterae and alatae displaced dorsally; abdominal segment VIII with 6-8 dorsal hairs; second segment of hind tarsus shorter than the ultimate rostral segment. Apterae hairy along antennae and dorsal body, Alatae with a few rounded or irregularly-shaped rhinaria on antennal segments III-V (Fig. 377); and

such characters absent in apterae (Fig. 378); venter of abdomen without multifaceted wax plates ..... *Geoica lucifuga* (Zehntner)

187(185') Siphunculi very short, conical, and lightly colored compared to the cuticle; segments I-VI of abdomen each with 1-2 spinal hairs, 2-3 marginal pairs and a lateral pair; body dorsum including head (Fig. 379) with long, stout, and pointed hairs in apterae (alatae with abdominal hairs borne on brown sclerites); antennae 5-segmented with processus terminalis about 1.75-2.25 times base of segment V and segment III with 2-4 spinal hairs; cauda rounded with long hairs and a neck-like median (Fig. 380) ..... *Sipha flava* (Forbes)

187' Siphunculi longer than wide at base; antennae usually 6-segmented 188

188(187') Lateral abdominal tubercles usually absent from abdominal segments I-VII and variably occurring on segments II-VI; spiracles of abdominal segments I and II near each other with their pigmented areas nearly contiguous; frontal tubercles well developed; antennal hairs capitate; ultimate rostral segment (Fig. 381) constricted near base and 0.7-0.8 times larger than the *2nd* segment of the posterior tarsus; genital plate of females subspherical with a pair of moderately long setae (Fig. 382); cauda with 8-9 hairs (Fig. 383) ..... *Macrosiphum (Sitobion) avenae* (F.)

188' Lateral abdominal tubercles usually present on abdominal segments I and VII, and larger than those on II to VI; spiracles of abdominal segments I and II far apart; frontal tubercles never well developed; alatae usually without a dorsal patch; antennal hairs never capitate 189

189(188') Cauda pale and not pigmented 190

189' Cauda pigmented brownish; concolorous at least to apices of siphunculi 192

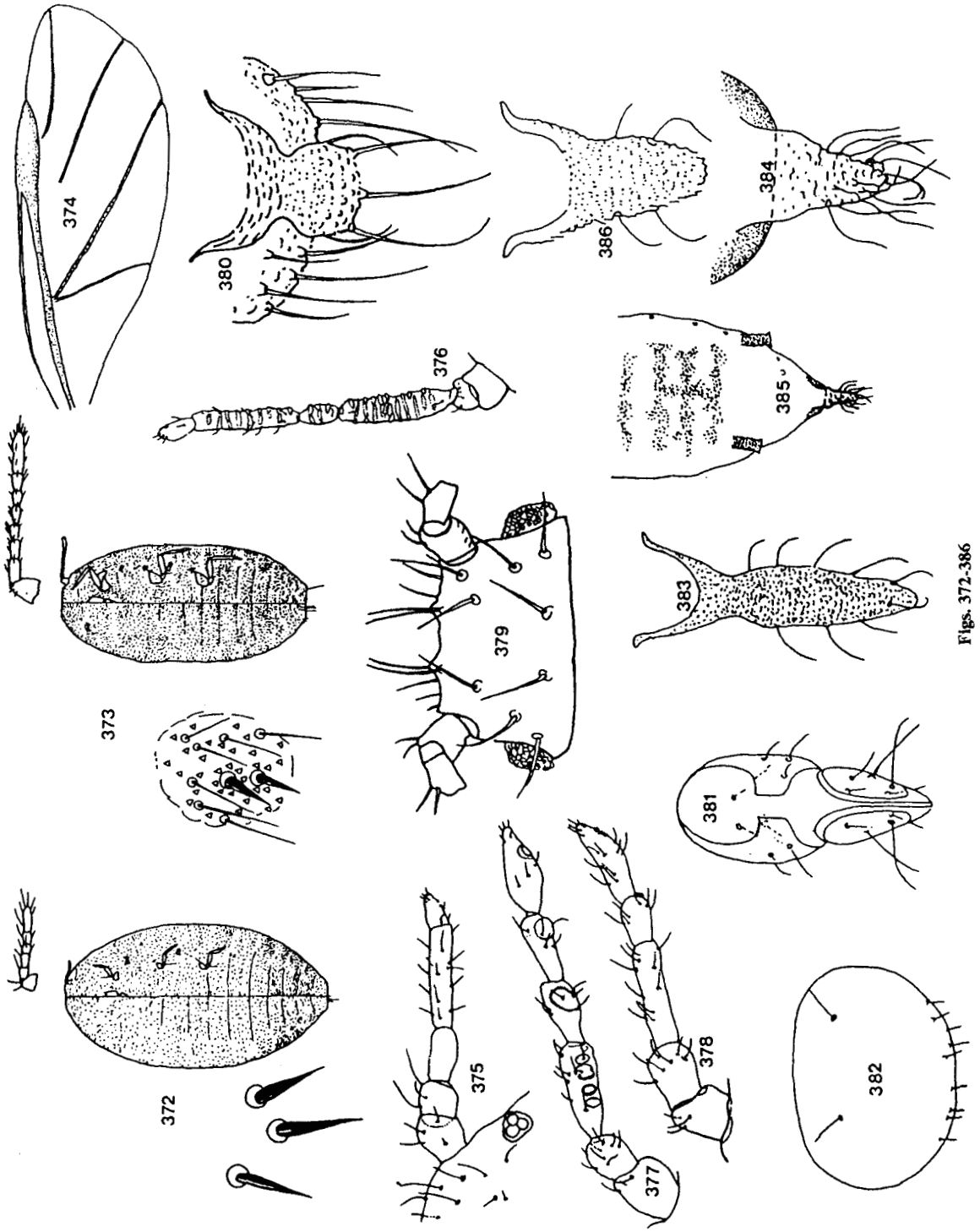
190(189) Cauda with 9-17 hairs (Fig. 384); antennae 2/3-3/4 times body; brownish black siphunculi shorter than greyish-yellow cauda (Fig. 385); alatae with dark crossbars on abdomen (Fig. 385) ..... *Melanaphis sacchari* (Zehntner)

190' Cauda with fewer hairs about 4-6 only (Fig. 386) 191

191(190') Cauda pale with 4 hairs only; siphunculi uniformly dark, rough-imbricate, and much longer than whitish cauda (Fig. 387); femora and first 2 antennal segments darkly pigmented; segment IV of antennae pale but with a small brown apical ring; alatae with median vein of forewing twice-branched; reddish brown aphids ..... *Hysteroneura setariae* (Thomas)

191' Cauda with 4-6 hairs; siphunculi more slender, smooth, and dark apically (Fig. 388); femora and first 2 antennal segments pale; antennal segment IV uniformly dusky brown; alatae with median vein of forewing single-branched; green aphids ..... *Schizaphis graminum* (Rondani)

192(189') Aphids colonizing roots and stem bases; cauda with 4 hairs (Fig. 389); siphunculus sculptured, cylindrical with apices colored brown similar to cauda (Fig. 390); segment



Figs. 372-386

VIII of abdomen with 4-8 hairs dorsally; hairs on body and legs long and fine similar to antennal hairs; antennae 5-segmented (rarely with 6 segments), antennal hairs much longer than maximum diameters of segments (Fig. 391); greyish black aphids with reddish tinge in the abdomen ..... *Rhopalosiphum rufiabdominalis* (Sasaki)

192' Aphids common on the aerial parts; segment VIII of abdomen with only 2 dorsal hairs; antennae of alatae and apterae 6-segmented with antennal hairs shorter than maximum diameters of segments 193

193(192') Processus terminalis prominently long and usually 3-4 times base of antennal segment VI; dorsum of abdomen with circular bead-like cuticular arrangement (Fig. 392); siphunculi over twice length of cauda, very smooth, and distinctly clavate in the dusky apical 1/2 and pale in the basal half (Fig. 393); brown aphids .... *Rhopalosiphum nymphaeae* (L.)

193' Processus terminalis short, only 1.7-2.5 times base of antennal segment VI; antennae short, less than half body length, median of vertex elevated (Fig. 394); apterae with antennal hairs longer than maximum diameters of segments; marginal tubercles located above midlength of spiracles 1 and 2 and after *7th* spiracle; siphunculi uniformly dark and spinulose, up to 1.6 times longer than black cauda (Fig. 395); green to dark olive green aphids ..... *Rhopalosiphum maidis* (Fitch)

194(182') Tegula lacking; midcoxa short and not widely separated; antennal pedicel rarely thicker than scape, without wart-like sensillae; hind tibia long with rows of articulated small spines, without tibial spur (Fig. 396); leafhoppers [Cicadellidae] 195

194' Tegula present on mesothorax; midcoxa elongate and widely separated; pedicel enlarged, often bulbous with numerous wart-like sensillae; hind tibia with a large movable spur (Fig. 397); planthoppers [Delphacidae] 219

195(194) Adultleafhoppers 196

195' Fourth and fifth instar nymphs of leafhoppers 208

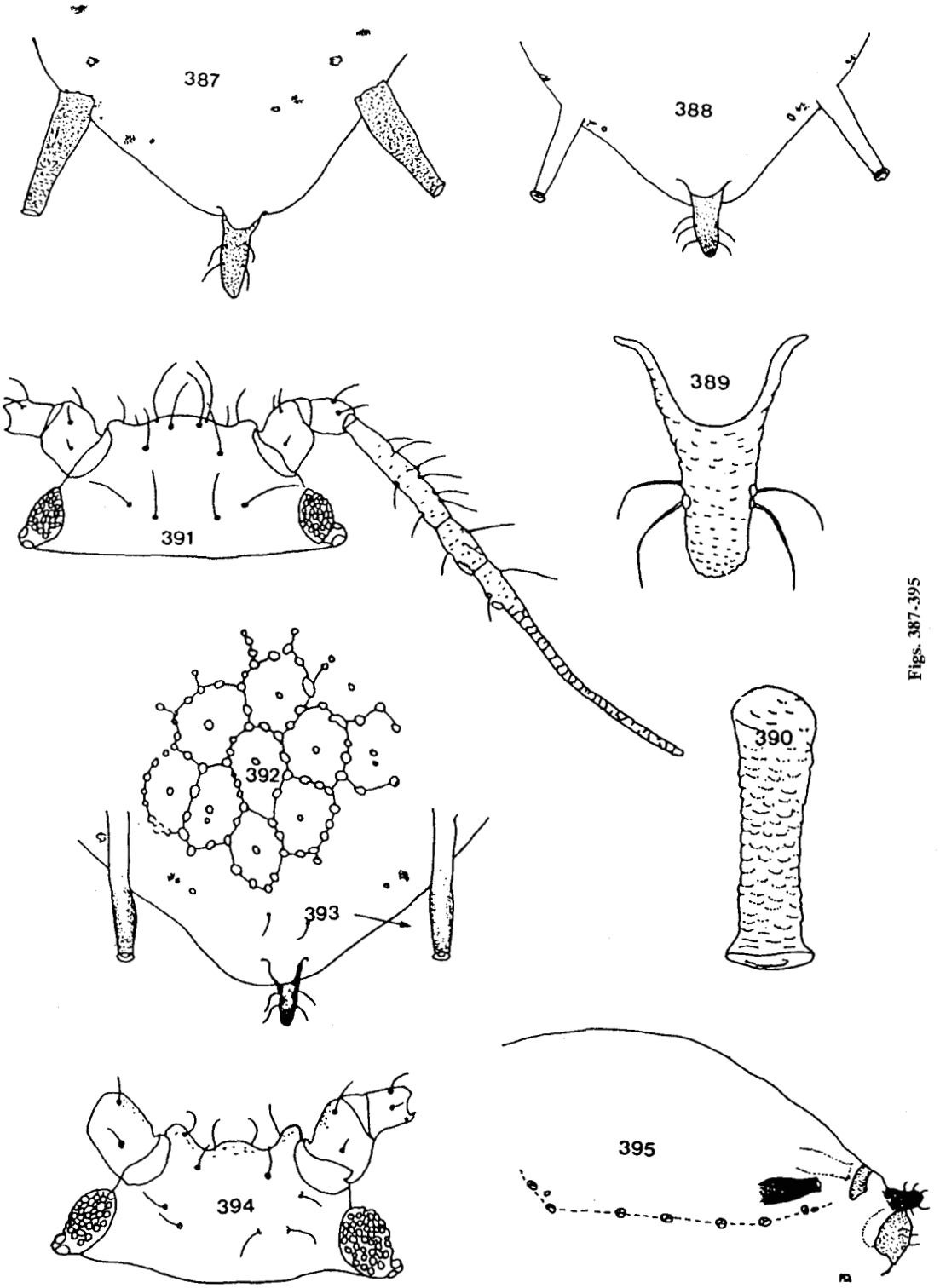
196(195) Opaque green leafhoppers with black markings on head, face, pronotum, tegmen, and other body parts; vertex sharply ridged 197

196' Color highly variable but never green 202

197(196) Vertex without black submarginal band or with band partially developed or with traces only behind ocelli 198

197' Vertex with a black submarginal band fully developed (entirely contiguous) 199

198(197) Vertex slightly longer medially than next to eye (11:10), its cephalic margin rather rounded or slightly bulging; comma-shaped transverse black band behind ocelli in males (Fig. 398); absent in females (Fig. 399) ... *Nephotettix malayanus* Ishihara & Kawase



Figs. 387-395

198' Vertex much longer medially than next to eye (11:8), its anterior margin markedly pointed; marginal and submarginal bands absent in both sexes (Fig. 400) ..... *Nephotettix virescens* (Distant)

199(197') Anterior margin of pronotum without black markings 200

199' Anterior margin of pronotum with black markings 201

200(199) Anterior margin of vertex rounded at center (Fig. 401) ..... *Nephotettix cincticeps* (Uhler)

200' Anterior margin of vertex angularly projecting or distinctly pointed in center (Fig. 402) ..... *Nephotettix parvus* Ishihara & Kawase

201(199') Marginal black band of vertex rather broad and contiguously developed between ocelli (Fig. 403); inner margin of clavus with a black band ..... *Nephotettix nigropictus* (Stål)

201' Marginal black band of vertex much reduced and present only in midcephalic margin (Fig. 404); African species ..... *Nephotettix modulatus* Melichar

202(196') Forewing maculate (spotted) or with zig-zag band 203

202' Forewing not as above 204

203(202) Forewing with a black to dark brown longitudinal zig-zag band (Fig. 405); vertex and pronotum whitish ..... *Recilia dorsalis* (Motschulsky)

203' Forewing with dusky markings (Fig. 406); vertex with a broad transverse band between the compound eyes and a thin band running along the margin below the ocelli (Fig. 407); pronotum and mesonotum with grey and white patterning ..... *Scapitoideus morosus* Melichar

204(202') Ocelli on disc of vertex closer to hind margin than to anterior margin; frontoclypeus swollen; head with a median apical black spot (Fig. 408); large pale whitish leafhopper ..... *Cofana spectra* (Distant)

204' Ocelli either on or closer to anterior margin of vertex or on face; frontoclypeus not swollen 205

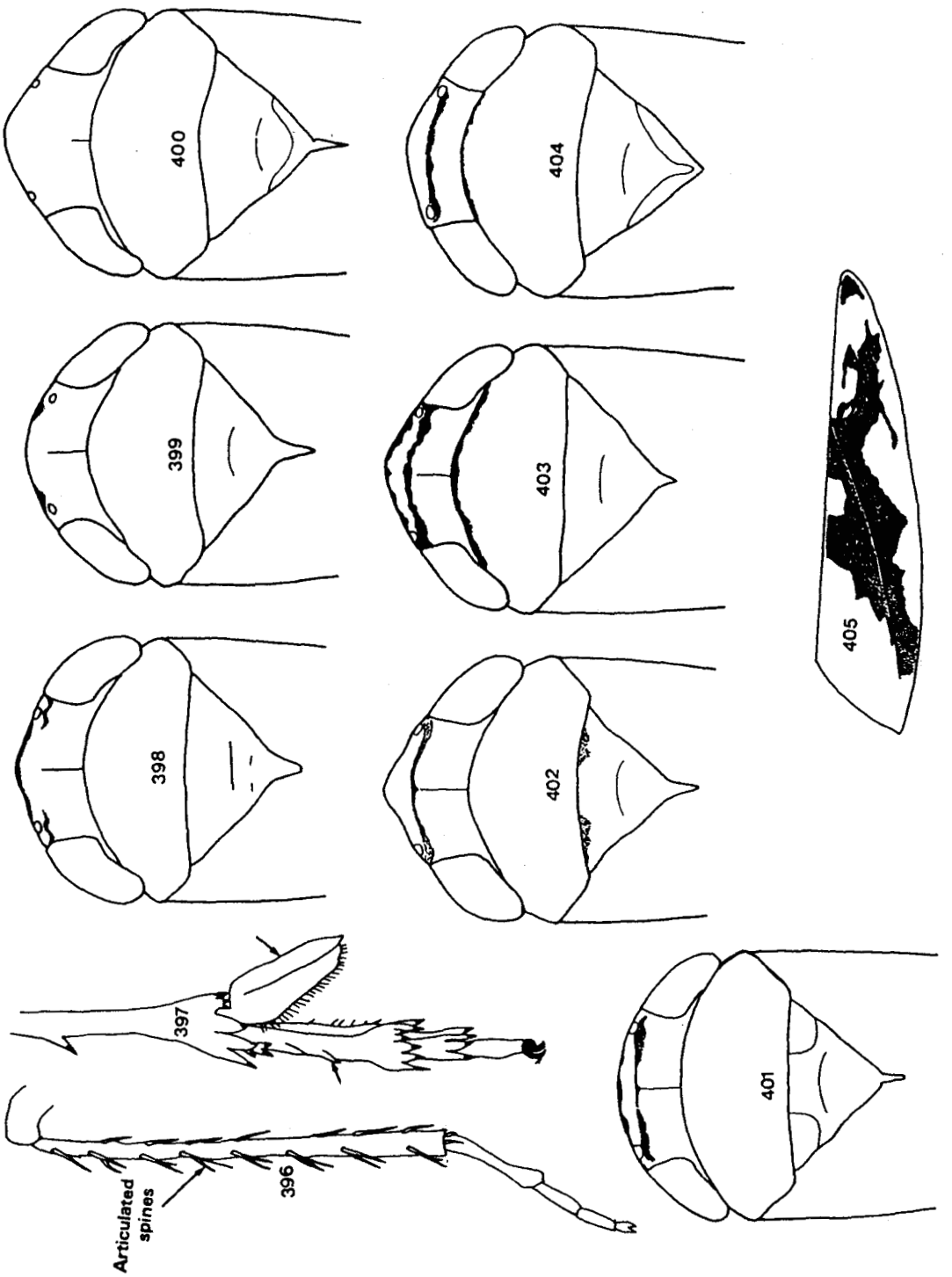
205(204') Vertex without spots; pronotum with paired light triangular markings (Fig. 409) 206

205' Vertex with spots; Fronotum without such markings 207

206(205) Processes of aedeagus broader; median ridge of *7th* sternite exserted in females (Fig. 410) ..... *Thaia oryzivora* Ghauri

206' Processes of aedeagus narrow; median ridge of *7th* sternite not exserted in females (Fig. 411) ..... *Thaia subrufa* (Motschulsky)

207(205') Vertex with a black median spot touching the anterior margin (Fig. 412) ..... *Empoascanara maculifrons* (Motschulsky)



Figs. 396-405

207' Vertex with 2 black spots of the anterior margin (Fig. 413); head and thorax golden yellow; forewing unspotted or without a dark fuscous or black longitudinal stripe along discal cell (Fig. 414) . . . . . *Cicadulina bipunctata* (Melichar)

208(195') Ocelli prominent on crown of vertex between eyes; anterior margin of vertex bulging and rounded; body with bluish tinge (Fig. 415) . . . . . *Cofana spectra* (Distant)

208' Ocelli along the anterior margin of pointed or rounded vertex (Fig. 416); dorsal body surface with spines 209

209(208') Spines present only on the dorsal posterior margin of the last 2-3 abdominal segments; entire dorsum of abdomen may be black or orange except penultimate segment with 2 black spots; pronotum with a pair of L-shaped bands (Fig. 417) . . . . . *Cicadulina bipunctata* (Melichar)

209' Not as above 210

210(209') Body with spines including head, thorax, abdomen and wing pads 211

210' Body with abdominal spines only 212

211(210) Wing pads without spines; prominent black spot present in mid-anterior portion of vertex (Fig. 418) . . . . . *Empoascanara maculifrons* (Motschulsky)

211' Body clothed with spines including wing pads (Fig. 419) . . . . . *Thaia* spp.

212(210') Head an thoracic markings more suffused and less prominent 213

212' Black or dark markings present on the body dorsum 214

213(212) Frontal view of head with 2 curved but parallel orange bands running between 2 compound eyes (Fig. 420) . . . . . *Scaphoideus morosus* (Melichar)

213' Frontal view of head without such bands; subdorsal band prominent in the abdomen (Fig. 421) . . . . . *Recilia dorsalis* (Motschulsky)

214(212') Pale green to yellow leafhopper; body with minimal markings; last abdominal segment with a dark spot on apical 2/3 (Fig. 422) . . . . . *Nephotettix virescens* (Distant)

214' Greenish leafhoppers with dark body markings 215

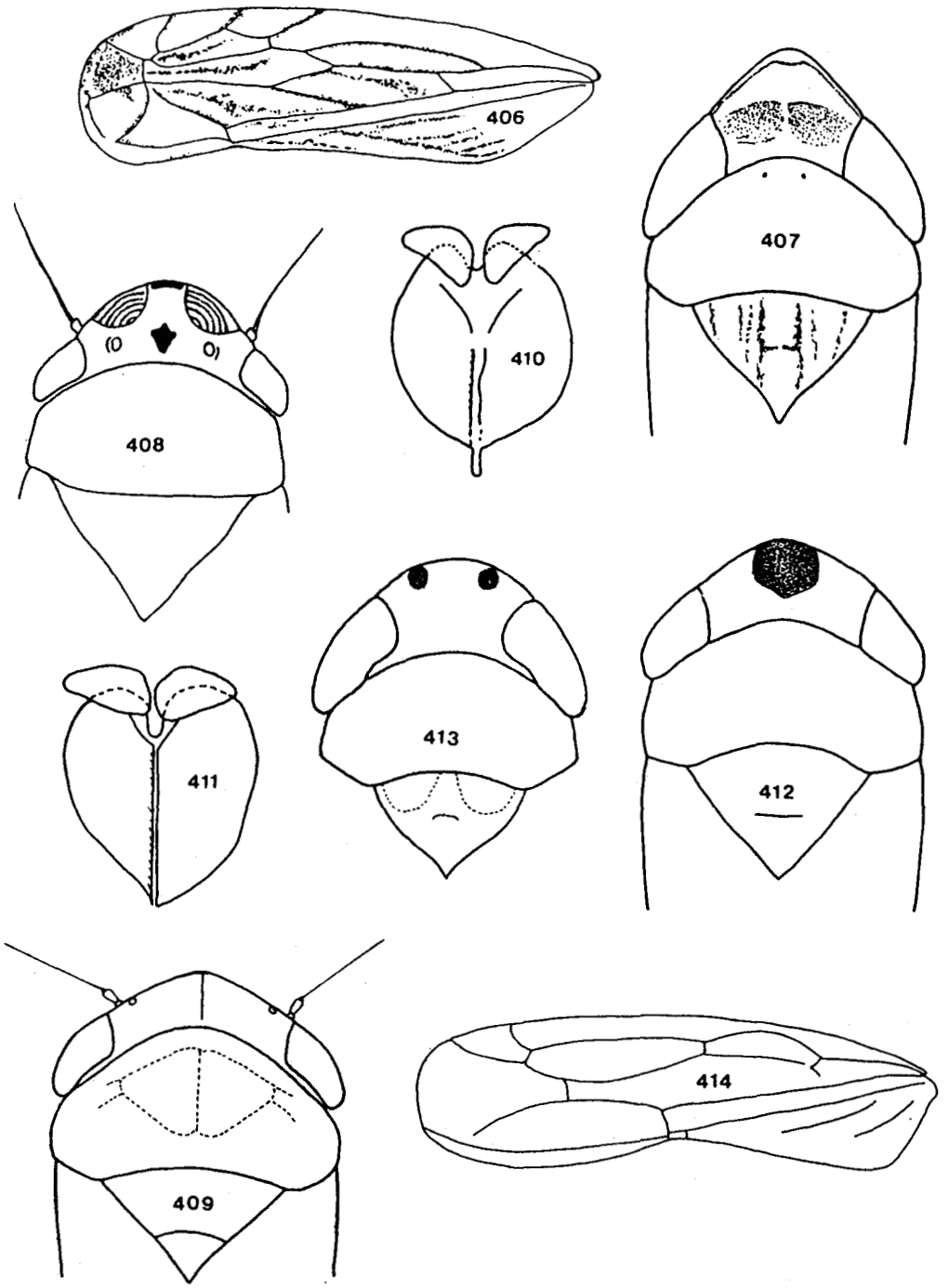
215(214') Markings on last abdominal segment absent; anterior margins of vertex with 2 black spots (Fig. 423) . . . . . *Nephotettix malayanus* Ishihara & Kawase

215' Markings on last abdominal segment distinct 216

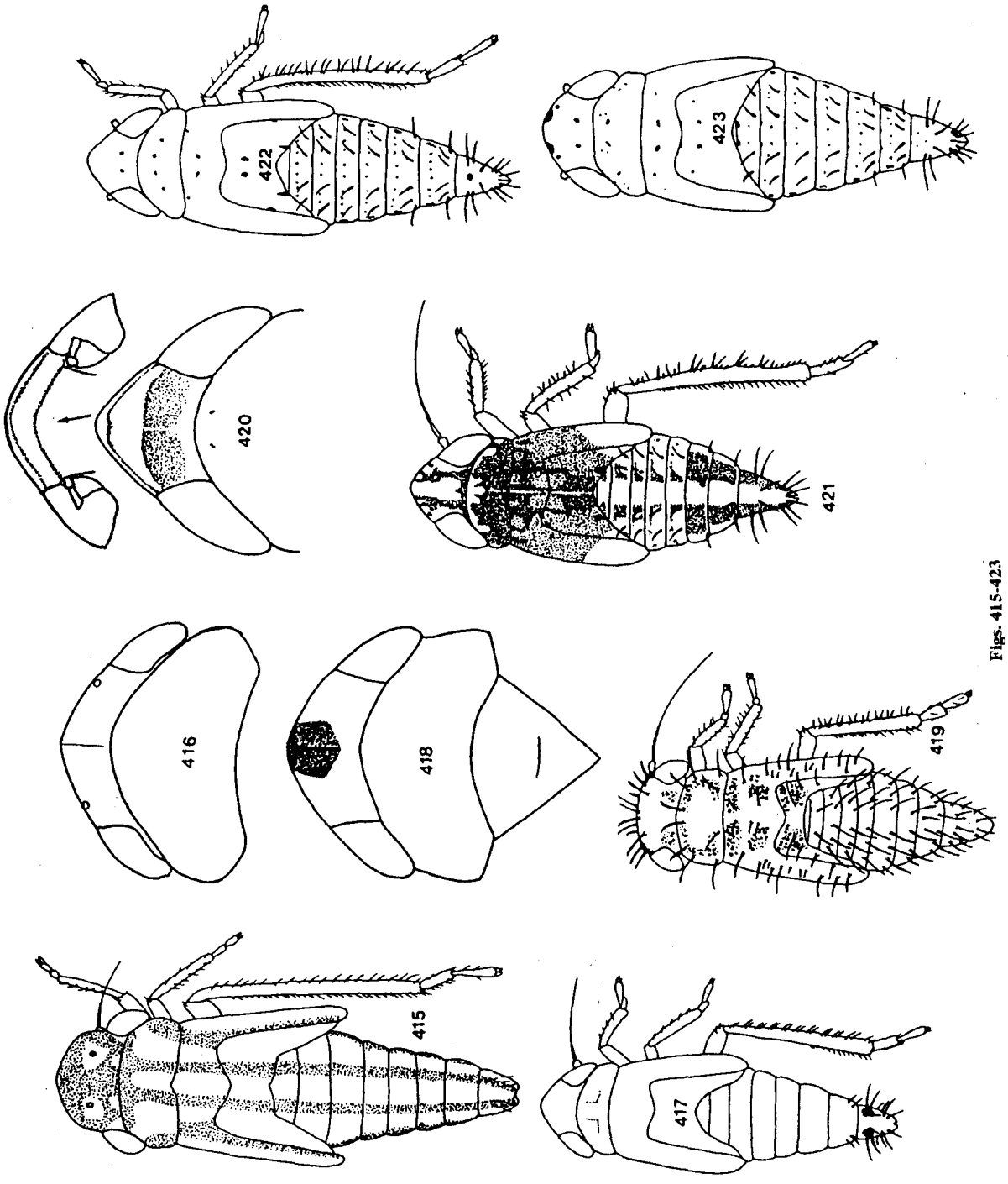
216(215) Bead-like band present on the last abdominal segment (Fig. 424); body markings variable . . . . . *Nephotettix cincticeps* (Uhler)

216' Not as above 217

217(216') Abdominal dorsum with light markings; median stripe on the last abdominal segment poorly developed; sub-marginal band below ocelli pale; cheek unshaded, clypeus with black median band (Fig. 425) . . . . . *Nephotettix parvus* Ishihara & Kawase



Figs. 406-414



Figs. 415-423

217' Abdominal dorsum with dark markings; median stripe on the last abdominal segment distinct; clypeus with partial or entire black band 218

218(217') Vertex with 3 pairs of bands (Fig. 426); face entirely black . . . . . *Nephotettix nigropictus* (Stål)

218' Vertex with fewer bands; upper median of clypeus and upper portion of cheek (below compound eyes) with black spots (Fig. 427) . . . . . *Nephotettix modulutus* Melichar

219(194') Adult planthoppers 220

219' Fourth and 5*th* instar planthopper nymphs 224

220(219) Prominent fixed spines on basal segment of post-tarsi; frons not excavated; median carina not intercepted (Fig. 428); mesonotum with 4 pale brown longitudinal markings (Fig. 429); posterior margin of male pygofer with no central process ventrally; parameters not bifurcated apically (Fig. 430) . . . . . *Nilaparvata lugens* (Stål)

220' No prominent spines on basal segment of post-tarsi 221

221(220') Vertex quadrate, as long as broad, slightly narrower than eye; lateral pronotal carinae concave and incomplete (Fig. 431); genae black, with yellowish brown lateral carinae; mesonotum black with white-tipped scutellum; parameres simple and club-shaped (Fig. 432) . . . . . *Laodelphax striatellus* (Fallen)

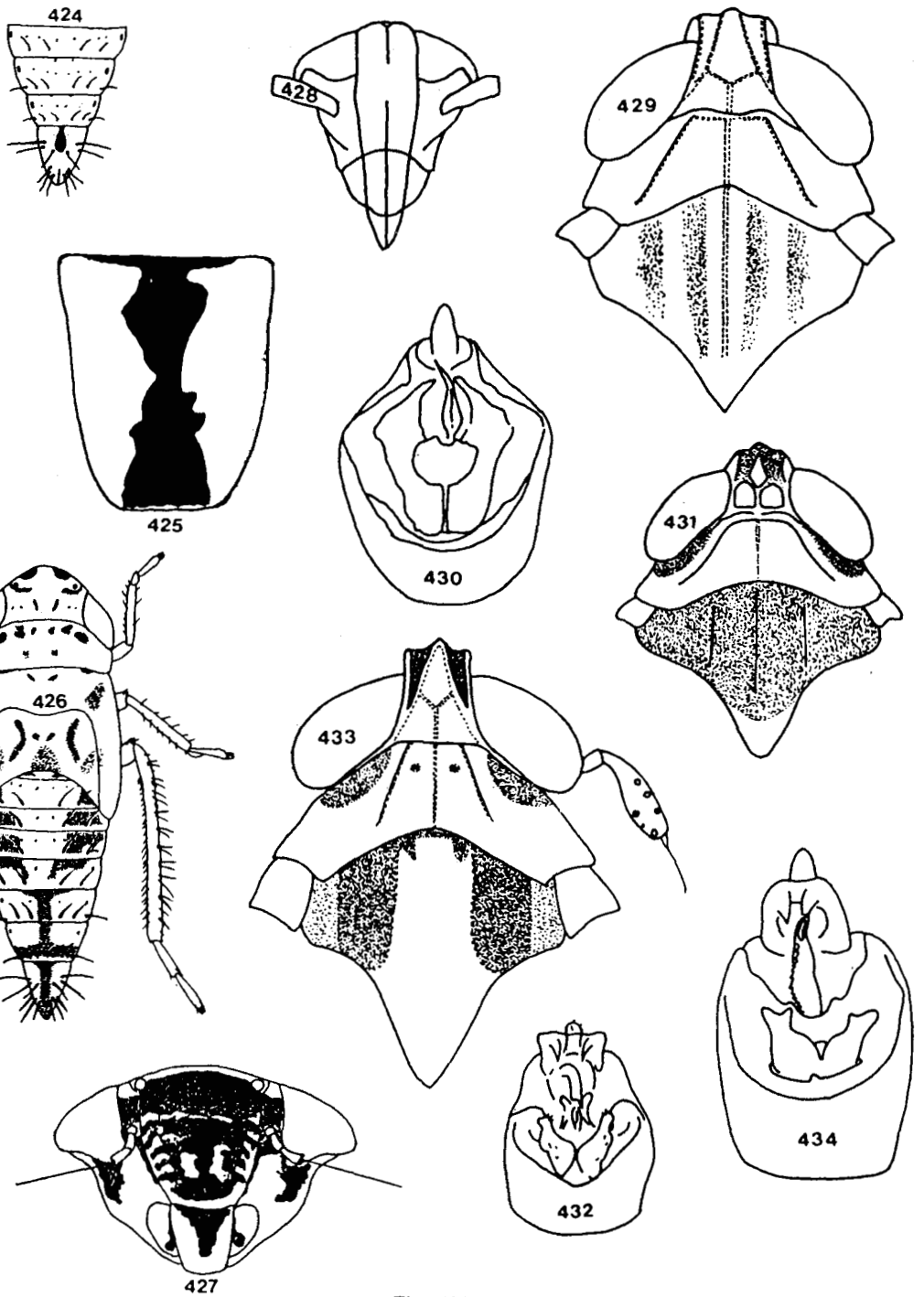
221' Vertex longer than broad at base with prominent whitish yellow areas on vertex, pronotum and mesonotum 222

222(221') Pronotal carinae rarely straight and almost reaching posterior margin; mesonotal carina more or less strongly divergent; mesonotum whitish medially with outer sides of lateral carinae dark brown (Fig. 433); forewings with black pterostigma; parameres broad basally and bifurcated apically with no large spine; ovipositor moderately long and never deeply curved dorsally in its basal half (Fig. 434) . . . . . *Sogatella furcifera* (Horvath)

222' Pronotal carinae usually straight, never reach posterior margin; mesonotal carinae parallel in the anterior half and weakly divergent; ovipositor long and slender, deeply curved dorsad in its basal 1/2 and straight or weakly recurved distally; Latin American species 223

223(222') Clavus without spot (Fig. 435); apex of style broad with the inner margins pointed and with a marked carina; infuscation at apex of tegmen confined to the apical cells posterior to M3 + 4; ovipositor large and more prominently serrated (Fig. 436); body 3-4 mm long . . . . . *Tagosodes orizicolus* (Muir)

223' Clavus with a spot (stigmata) between the common claval vein and the commissural margin, in folded wing spots form a saddle-shaped stigmata (Fig. 437); apex of style small, slender and curved inward; ovipositor (Fig. 438) relatively narrower and not prominently serrated; body 2 mm long . . . . . *Tagosodes cubanus* (Crawford)



Figs. 424-434

224(219') Vertex plate about as long as wide; head narrow; dorsal portion of body (thorax and abdomen) with tinge of grey and white markings 225

224' Vertex plate wider than long, head broad; dorsal portion of body with brown pigmentation 227

225(224) Thoracic and abdominal dorsum uniformly marked with various amounts of grey and white markings on a creamy white background; dorsal white band indistinct (Fig. 439) . . . . . *Sogatella furcifera* (Horvath)

225' Thorax and abdomen not as above; dorsal white band distinct 226

226(225') Tip of vertex truncated; lateral margins of pronotum broad; subdorsal portion of abdomen with 6 pairs of bands (Fig. 440) . . . . . *Tagosodes cubanus* (Crawford)

226' Tip of vertex partly emarginate; lateral margins of pronotum acute and pointed downward (Fig. 441); sub-dorsal portion of abdomen with 7 pairs of bands . . . . . *Tagosodes orizicolus* (Muir)

227(224') Post-clypeus pale yellow; head width large (0.56-0.70 mm) (Fig. 442); apices of abdominal segments with whitish dome-shaped indentations (Fig. 443) . . . . . *Nilaparvata lugens* (Stål)

227' Post-clypeus dark brown; head width small (0.52 mm) (Fig. 444); median area of abdomen whitish with darker margins (Fig. 445) . . . . *Laodelphax striatellus* (Fallen)

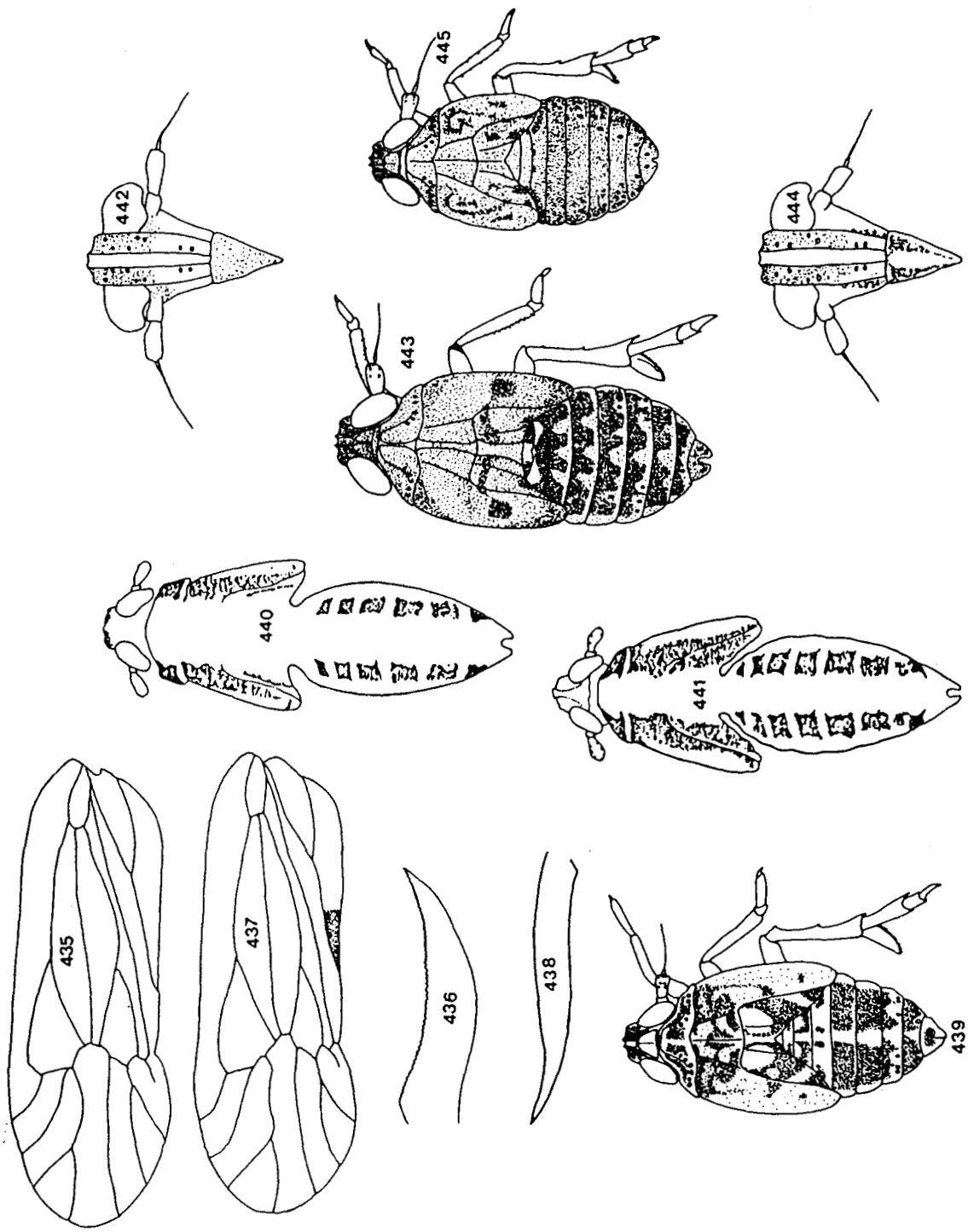
228(181') Antenna entirely concealed beneath (except in *Ochterus),* and shorter than head; arolium absent 229

228' Antennae exposed or visible above, as long as or longer than head; arolium present or absent 236

229(228) Ocelli present; flat and almost entirely black; all legs slender, not raptorial and legs II and III without fringes of swimming hairs; beak slender reaching hind-coxae, enlarged basal segment black and thin, slender apical segments brownish red; depressed antero-lateral margin of pronotum brownish yellow along apical margins and yellowish basally; posterior margin bordered yellow-orange, median area convex (recurved) (Fig. 446); hemelytra with 2 yellow spots (base of membrane and at mind-length of embolium-exocorium) and a moderately long yellow band at base of embolium-exocorium (Fig. 447) [Ochteridae] . . . . . *Ochterus marginatus* (Latreille)

229' Ocelli absent 230

230(229') Fore-tarsi 1-segmented, scoop-like (palae) with a row of hairs; beak short, hidden and unsegmented; head slightly overlaps with pronotum, yellow and moderately rounded at tip (Fig. 448); pronotal disk brownish grey with procurved base; scutellum with a yellow transverse band at mid-half; forewing brownish grey except transparent membrane and base of clavus; membrane inwardly curved, tip truncated and apical margin brown; base



Figs. 435-445

of clavus lightly punctated (Fig. 449); nymphs and adults root feeders; aquatic [Corkidae] ..... *Micronecta quadristrigata* Breddin

230' Fore-tarsi not scoop-like; beak segmented 231

231(230') Body very strongly convex above; hind tarsi without claws; forelegs not raptorial 232

231' Body flattened or slightly convex; hind tarsus with claws; front leg raptorial, femur usually thickened; membrane of elytra with veins 235

232(231) Hind leg short, with 2 claws; hind tibia cylindrical, without long hairs; abdomen without fine laminate ventral keel on segments 2-6; small insects usually less than 4 mm long [Pleidae] 233

232 Hind leg long, oar-shaped, with 1 claw; flattened hind tibiae with fringe of long hairs; abdomen with a broad median ventral keel; hemelytral commissure with an elliptical pit at anterior end; usually more than 4 mm long [Notonectidae] 234

233(232) Body 2.2 mm long and 1.4 mm wide; head rugose-punctate with a brown longitudinal median ridge between eyes, not reaching apex of pronotum; pronotum reticulate punctate except smooth postero-median area (Fig. 450); scutellum with traces of reticulate punctations; hemelytra reticulate punctate with brown pits at each punctate; propleuron carinate yellow at base of coxa I and with a small protrusion at its hind part; mesopleural lobe strongly rounded cephalad and slightly indented posterad below mid-half ..... *Paraplea sobrina* Stål

233' Body 1.6 mm long and 0.8 mm wide; head nearly smooth with a moderately broad median longitudinal brown band between eyes almost reaching apex of pronotum, center area with a yellow spot; pronotum smooth to shallowly punctate (Fig. 451); scutellum smooth; hemelytra reticulate punctate with whitish pits; propleuron straight without tubercle at hind of coxa I; mesopleural lobe weakly rounded cephalad and widely procurved at mid-half ..... *Paraplea liturata* (Fieber)

234(232') Eyes strongly convergent, touching each other postero-dorsally or with a very narrow gap (0.03 mm) in between (Fig. 452); head rounded in lateral view; terminal antennal segment pale yellow (Fig. 453); tibia I slender, thin and strongly flattened, without spines; apical 1/2 of tibiae with a brown median band; tarsus I 0.6 times length of tibiae (Fig. 454) ..... *Anisops* sp.

234' Eyes moderately convergent with a clear separation (0.07 mm) postero-dorsally (Fig. 455); head pointed in lateral view; terminal segment of antenna brown (Fig. 456); tibia I slightly concave and cylindrical with spines; apical half of tibia without band; tarsus I 0.7 times length of tibia (Fig. 457) ..... *Anisops kuroiwae* Matsumura

235(231') Tarsi 2-segmented; apex of abdomen with a pair of flat, retractile airstraps; margins of pronotum and wings yellowish, thin, and rather flap-like; head snake-like in front and triangular dorsally (Fig. 458); eyes small, slightly convex in the inner posterodorsal side,

elongate and 3 times longer than height seen laterally; proboscis hidden beneath; venter of abdomen elevated medially, basal 2 segments narrow and slightly converging mid-ventrally; clavus and corium brownish and finely punctated; membrane hyaline with 6 rectangularly closed cells (Fig. 459); apical lower end of corium with globular dense mass of short brown setae [Belostomatidae] . . . . . *Diplonychus rusticus* (Fabricius)

235' Tarsi l-segmented; eyes prominent and transverse; proboscis visible in front (Fig. 460); apex of abdomen with a non-retractile, cylindrical siphon; venter with static sense organs; body long, narrow and cylindrical with nearly contiguous coxae II and III; front leg sickle-shaped with a strong midfemoral tooth (Fig. 461) [Nepidae] . . . . . *Ranatra diminuta* Montadon

236(228') Tarsal claws anteapical (especially on forelegs); tip of last tarsal segment more or less cleft 237

236' Tarsal claws apical; tip of last tarsal segment entire 243

237(236) Ocelli present; long-legged; hind femora extending beyond apex of abdomen; mid-coxae closer to hind- than forecoxae; medial margins sinuate [Gerridae] 238

237' Ocelli absent; short-legged; hind femora not reaching apex of abdomen; mid-coxae equidistant between hind- and forecoxae; medial margins straight [Veliidae] . . . 242

238(237) Body comparatively short and oval; inner margin of eyes convex; posterior end of abdomen produced to a spine-like point; body entirely black dorsally and ventrally except orange-brown band at midapex of pronotum, eye margins, and hind vertex; basal half of femur I yellow (Fig. 462) . . . . . *Rhagadotarsus* sp.

238' Body long and thin, inner margins of eyes concave; pronotum with a yellow median longitudinal stripe 239

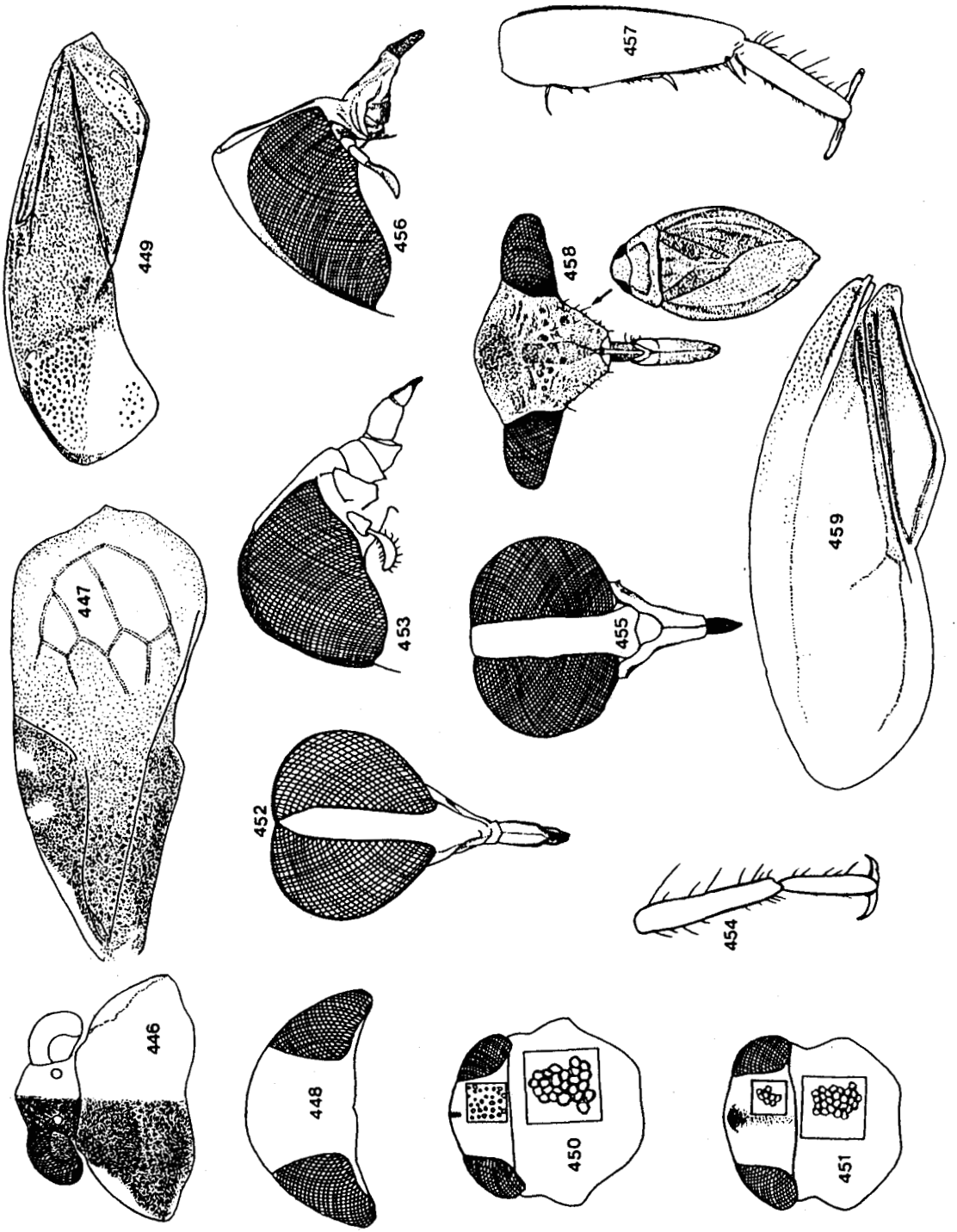
239(238') Hindtibia at least 4 times as long as the first tarsal segment; 1*st* antennal segment longest but shorter than segments 2 + 3 (Fig. 463); head and pronotum with whitish markings, venter light brown with 2 dark brown patches at anterior 1/2 of mesosternum; pronotum with a mid-longitudinal band (Fig. 464); hemelytra brown with dark brown embolial region; mid-leg with brown femora at anterior l/2 and dark brown at posterior 1/2 and with a spine at distal end; 1*st* tarsal segment of leg II 4 times as long as the 2*nd* . . . . . *Gerris adelaides* Dohrn

239' Hidtibia not as above; 1*st* antennal segment equal or longer than segments 2 + 3 240

240(239') Anterior lobe of pronotum with a large subglobular to quadrangular yellow spot (Fig. 465) . . . . . *Limnogonus parvulus* (Stål)

240' Anterior lobe of pronotum with a pair of longitudinal yellow-brown spots 241

241(240') Posterior lobe of pronotum with a longitudinal yellow line (Fig. 466). . . . . *Limnogonus fossarum* (Fabricius)



Figs. 446-459

241' Posterior lobe of pronotum without a longitudinal yellow line (Fig. 467). . . . . *Limnogunus nitidus* (Mayr)

242(237') Apical ventral sternite of male abdomen angled at corner, base not evenly rounded; paramere thin immediately above curved point and broadens just below it (Fig. 468); general shape short but broad, usually black with small grey areas (Fig. 469); abdomen of females laterally compressed at base . . . . *Microvelia douglasi atrolineata* Bergroth

242' Apical ventral sternite of male abdomen rounded at corner, base evenly rounded, paramere nicely sickle-shaped, still wide at curvature point and tapers apically, uniformly broad towards base (Fig. 470); greyish to brown (Fig. 471); abdomen of females not markedly compressed laterally at base . . . . . *Microvelia douglasi douglasi* Scott

243(236') Head long and slender, as long as thorax and dilated distally; elongate thorax with nonsulcate mesosternum and mid-coxa closer to fore-coxa than to the hind-coxa; eyes situated a little below mid-length of head; body long, slender and cylindrical (Fig. 472) Fig. 472 [Hydrometridae] 244

243' Head not more than twice as long as wide, not dilated distally; eyes near base of head; bodyshortandstout 245

244(243) Tergite X cylindrical and longer than IX, with a longer apicomedian spine; wing tips extended to 2/3 of tergite VII; wings with the white band below 2*nd* longitudinal vein with few patches inside 2 closed rectangular cells, outer closed cell with an oblong white spot at midbase; vein touching costal area short, 0.54 times basal length of outer cell (Fig. 473) . . . . . *Hydrometra orientalis* Lundbland

244' Tergite X nearly as long as IX, with apex widened laterally and relatively short apicomedian spine; wing tips a little beyond segment VIII; white band of wing above the 2*nd* longitudinal vein; outer cell with a white band along entire basal half, vein touching costal area long, as long as bottom length of outer cell (Fig. 474). . . . . *Hydrometra lineata* Eschscholtz

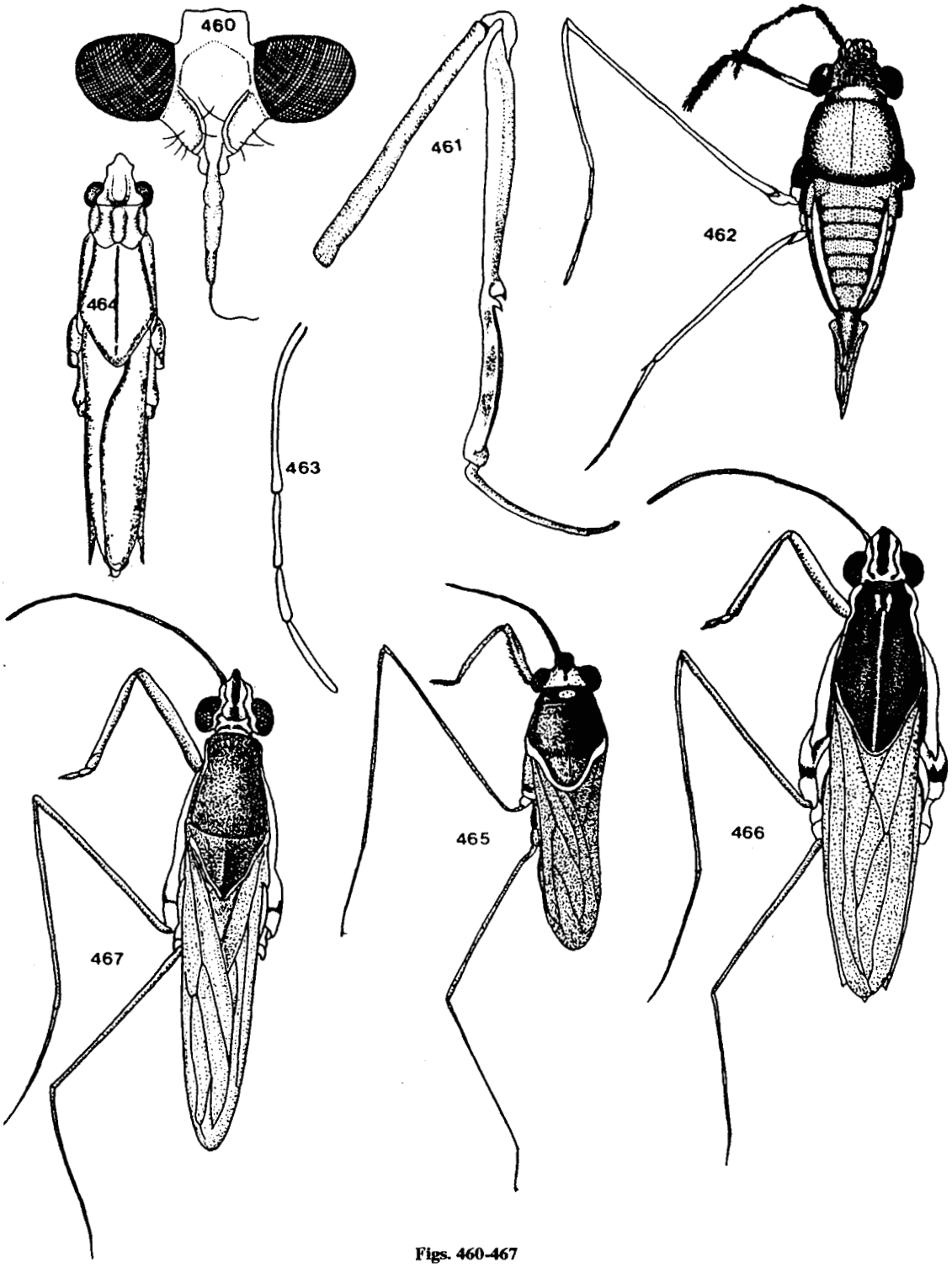
245(243') Antennae 5-segmented 246

245' Antennae 4-segmented 275

246(245) Tarsus 2-segmented; hemelytra with clavus and membrane similar in texture and without veins; venter of head with a longitudinal groove for beak reception; pronotal pits in a transverse row; sides of pronotum constricted at mid-half producing an elongated lobe; body and wings with white hairs; scutellum with a median longitudinal carina forming 2 lobes; legs without ventral spines, corium veins hardly visible, membrane light brownish black with 3 white spots (Fig. 475) . . . . . *Hebrus bergrothi* Horvath

246' Tarsus 3-segmented; hemelytra distinct from clavus and usually with veins 247

247(246') Tibiae with numerous stout spines, usually in 2 rows (Fig. 476); apices of mid and hind coxae fringed with nearly contiguous rigid setae; forelegs fossorial; tarsi 3-segmented; usually small, slightly depressed, black oval to elliptical; burrower bugs [Cydnidae]. 248



Figs. 460-467

247' Tibiae witbout numerous strong spines (Fig. 477); apices of mid and hind coxae not fringed with closely set rigid setae; abdominal venter sometimes moderately elevated but not prominently keeled or tectiform to flattened; frenum, if present hardly extended beyond 3/4 marginal length of scutellum [Pentatomidae] 249

248(247) Small sized bugs, 5 mm long; vertex rounded and hairy, peg-like spines along apical margins of vertex absent (Fig. 478) . . . . . *Geotomus pygmaeus* (Dallas)

248' Medium sized bugs, 6-7 mm long, vertex notched mid-anteriorly and with 10 peg-like spines along margins (Fig. 479) . . . . . *Aethus indicus* (Westwood)

249(247') Phytophagous bugs; all femora with a dorsal spine apically (Fig. 480); tip of abdomen with 4 spines (Fig. 481); lateral angle of pronotum with laterally projected spines (Fig. 482); tylus longer than juga; head with 6 rows of longitudinal punctations; 2*nd* antennal segment as long as 3*rd;* African species . . . . . *Diploxys fallax* Stål

249' Phytophagous bugs without dorsal spine at apex of femora 250

249" Predatory bugs without dorsal spine at apex of femora 274

250(249') Pronotal spine more or less prominent 251

250’ Pronotal spine absent 268

251(250') Tylus slightly beyond juga; head long; body dorsally flat and convex underneath; 3*rd* antennal segment longer than the 2*nd*; 2*nd* abdominal segment impressed medially not obtusely convex, devoid of a tubercle; mesosternum not carinated; lateral margins of head prominently trenchant; frenum not passing midscutellum; tibiae feebly planosulcate; fulvous species *(Eysarcoris)* 252

251' Tylus and juga in the same line 256

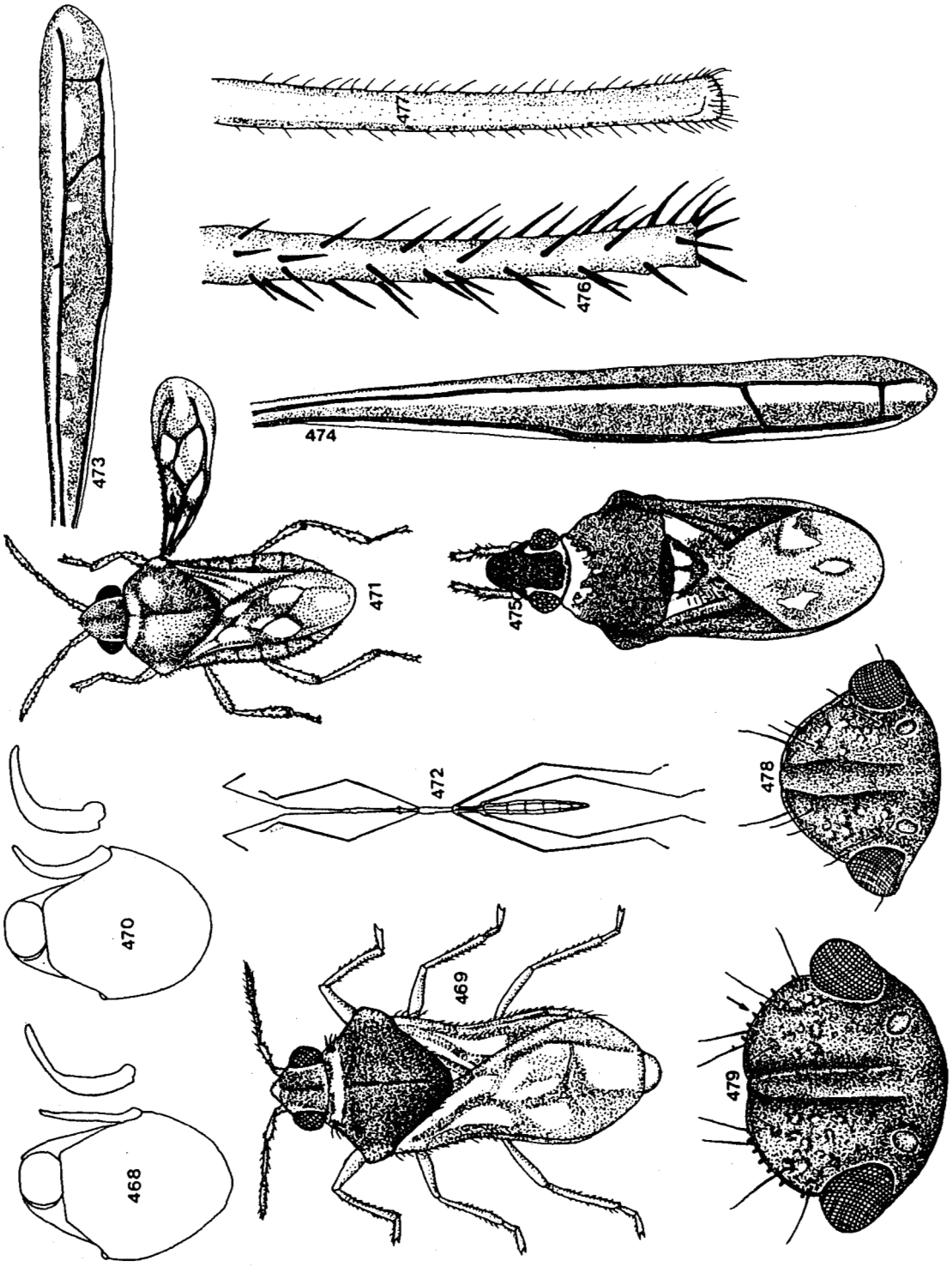
252(251) Lateral angle of pronotum prominent or partially developed; head blackish; tylus and juga with nearly contiguous punctuations; body length 5.8-6.7 mm 253

252' Lateral angle of pronotum not prominent; head brownish with punctations rather sparse and separated; body length 4-5.8 mm 255

253(252) Lateral angle blackish, robust, and with a blunt end, lateral to slightly upward; tylus with a mid-longitudinal yellow dagger-like band; base of scutellum with large ovoid and obliquely set spots; midscutellum with a transverse groove; a pair of black spots above calli present (Fig. 483) . . . . . *Eysarcoris montivagus* Distant

253' Lateral angle less developed to sharply pointed but never projected upward; tylus without a yellow dagger-like band 254

254(253') Lateral angle of pronotum not sharply pointed; tylus almost entirely black, calli slightly concave and bear no black spots behind; midscutellum not deep; second antennal segment shorter than the 3*rd* segment; yellow spots on the basal outer edge of scutellum not as oblique as in *E. montivagus;* body length 5.82 mm (Fig. 484). . . . . *Eysarcoris guttiger* (Thunberg)



Figs. 468-479

254' Not as above; pronotum's lateral angle blackish and acute or sharply pointed, directed laterally; tylus and juga in same line producing a broad tip; body length 6-6.5 mm (Fig. 485) ..... *Eysarcoris panvus* Uhler

255(252') Body 5-5.8 mm long and 3 mm wide; head darker than *E. capitatus* with blackish punctations along jugal margins, area between ocelli and compound eyes, and edge of tylus; tylus with a thin yellow longitudinal stripe; calli triangular-like with black outer base; second antennal segment shorter than *3rd;* base of scutellum with 3 yellow spots, median slightly concave and tip relatively narrow but rounded (Fig. 486). .... *Eysarcoris ventralis* Distant

255' Body barely 4.3 mm long; head yellowish brown with light blackish brown well separated punctations; margins of juga black; calli not well defined; tip of scutellum broadly rounded with nearly parallel sides (Fig. 487) ..... *Eysarcoris capitatus* Distant

256(251') Scutellum short, not as long as abdomen; body length 9-12 mm dorsally flat and ventrally convex; American species *(Oebalus)* 257

256' Scutellum very long, reaching tip of abdomen, almost rectangular but not covering lateral portion of forewing; anterolateral process of pronotum toothed or elongately spinelike with tip projected in different directions; body length 6.5-11 mm; Asian and African species *(Scotinophara)* 258

257(256) Tylus exerted slightly beyond juga (Fig. 488); margin of pronotum not clearly separated from disc; each pronotal corner with small teeth-like tubercles; second antennal segment shorter than *3rd;* scutellum dark yellow along margins forming a Y-shaped appearance (Fig. 489); body elongated, body length 9 mm ... *Oebalus poecila* (Dallas)

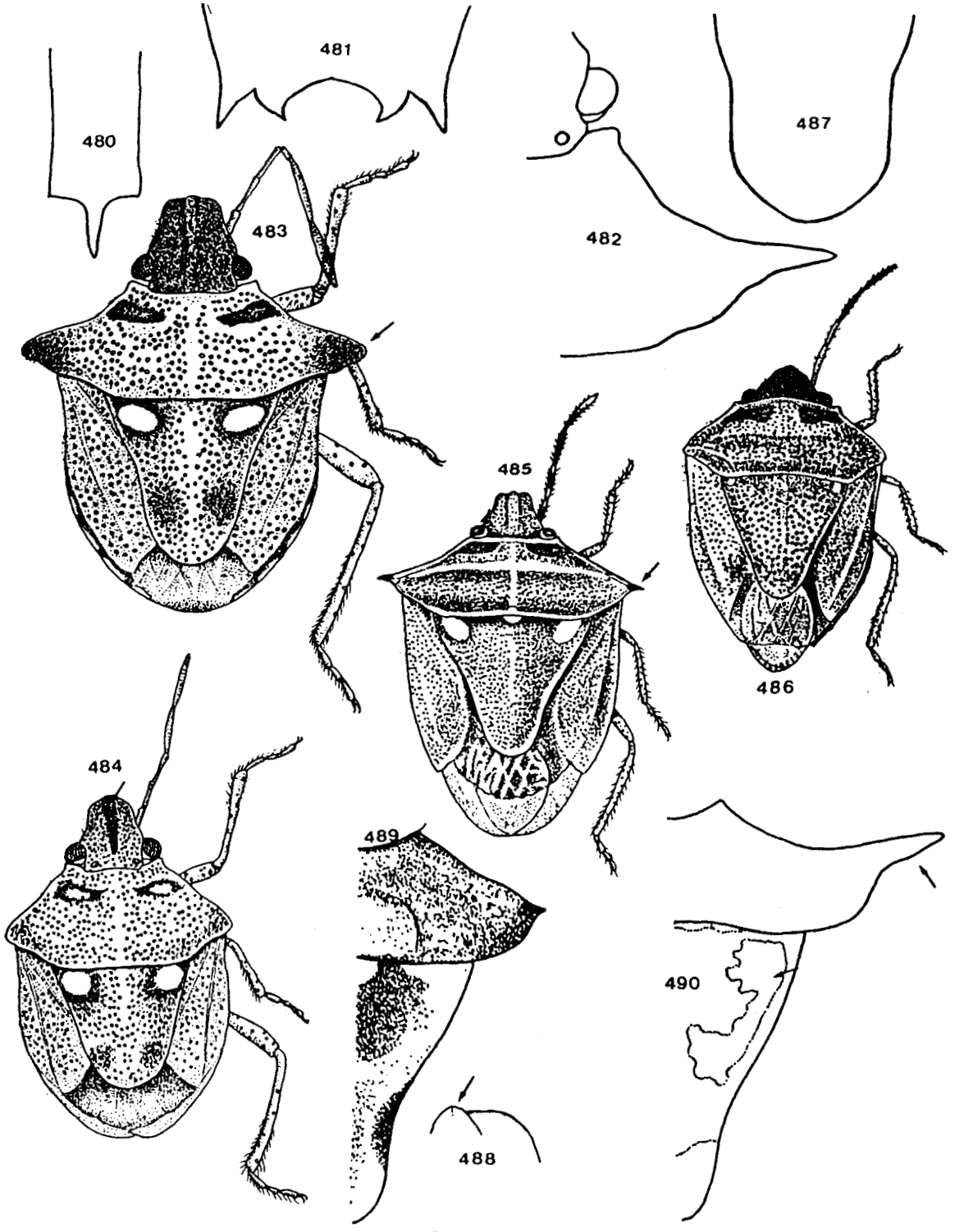
257' Tylus and juga in the same line; head long; pronotal shoulders with long latero-forward directed spines; scutellum much longer than wide at base with knob-like yellow bands in the outer basal half margin, apex yellow; body length 12 mm (Fig. 490). .... *Oebalus pugnax* (Fabr.)

258(256') Anterolateral margins of pronotum between anterior and humeral processes serrate or dentate; anterior portion of pronotum irregularly rounded but with a distinct transverse depression behind 259

258' Anterolateral margins of pronotum between anterior and humeral processes not as above 261

259(258) Midanterior part of pronotum not swollen, anterolateral margins serrate or dentate with a small anterior process shorter than the humeral processes; head and anterior part of pronotum same color as the rest of the body (Fig. 491); femora without a pale annulation apically; clasper with a slight hook at apex and straight margin below it (Fig. 492). .... *Scotinophara serrata* (Vollenhoven)

259' Pronotum tumescent at the midanterior part; anterolateral margins minutely serrate; anterior processes distinct and usually longer 260



Figs. 480-490

260(259') Transverse depression on pronotum obscure; anterior part less swollen; brownish ochraceous, anterior pronotum, head, and base of posterior tibiae black; rest of posterior tibiae dark brown; pronotal anterior processes straight and spinous (Fig. 493) ..... *Scotinophara parva* Yang

260' Transverse depression between humeral processes distinct; anterior part of pronotum swollen; humeral process triangular; anterior processes of pronotum distinctly curved forward (Fig. 494); tips of clasper inwardly curved, base with acute tubercle (Fig. 495); black or rarely reddish brown, only posterior tibiae black. .... *Scotinophara scotti* Horvath

261(258') Postocular anterior margins of pronotum broad and oblique; anterolateral margins insinuate 262

261' Postocular anterior margins of pronotum straight to slightly sinuate; anterolateral margins of pronotum anteriorly excavate 263

262(261) Pronotal disk not excavated anteriorly and a transverse depression behind excavation weak; scutellum without a pair of distinct oblique depressions; tip of anterolateral spine of pronotum projected posterad but not extended beyond anterior angle of pronotum (Fig. 496); clasper with a large tubercle medially (Fig. 497) .... *Scotinophara coarctata* (F.)

262' Disk of pronotum excavated anteriorly and a transverse depression behind it prominent; scutellum with a pair of oblique depressions before midlength; tylus as long as lateral lobes (Fig. 498); *3rd* antennal segment slightly less than twice as long as the *2nd* (Fig. 499); apical segment as long as segments II & III combined. .... *Scotinophara inermiceps* (Breddin)

263(261') Anterolateral margins of pronotum straight and laminate; anterior processes of pronotum long and directed forwards; dorsum longly pilose; anterior pronotum rather gibbous (Fig. 500) ..... *Scotinophara horvathi* (Distant)

263' Anterolateral margins of pronotum totally or partially carinate, excavate on anterior half and insinuate below; anterior pronotum not swollen; dorsum shortly pilose .. 264

264(263') Anterior processes of pronotum projected horizontally 265

264' Anterior processes of pronotum projected anteriorly 267

265(264) Black species; humeral processes of pronotum distinct, as long as or slightly shorter than the apical ones, the latter spinous and extended beyond outer margin of eye; rostrum reaching midpoint of hind coxae; scutellum twice as long as width at narrowest point (7:6:12); apex of antenniferous tubercle slightly bifid (Fig. 501); clasper slightly emarginate apically (Fig. 502) ..... *Scotinophara lurida* (Burmeister)

265' Brownish or ochraceous species; other characters not as above 266

266(265') Tylus shorter than juga (Fig. 503); femora black with a pale ring near tip; rostrum extended beyond hind coxae to abdomen; clasper acute-triangular in the inner apex (Fig. 504); scutellum nearly 1/3 times longer than width at narrowest point; apex of antenniferous tubercle blunt ..... *Scotinophara obscura* (Dallas)

266' Tylus as long as juga (Fig. 505); femora without subapical ring; scutellum not reaching abdominal tip with apex subtruncate; hemelytra without distinct pale line (Fig. 506); antennae piceous, body beneath widely black ..... *Scotinophara latiuscula* Breddin

267(264') Anterior processes of pronotum long, nearly as long as 1*st* antennal segment; humeral processes as long as anterior processes of pronotum; pronotum gibbous anteriorly with a pale central carinate line and a transverse impression (Fig. 507); clasper slightly broad distally, base with a small tooth-like structure (Fig. 508) ..... *Scotinophara bispinosa* (F.)

267' Anterior processes of pronotum short; less than the length of the 1*st* antennal segment; humeral process shorter than anterior (Fig. 509); ochraceous with black head; transverse impression on pronotum wanting; clasper narrow medially, wide on ends (Fig. 510) ..... *Scotinophara ochracea* (Distant)

268 (250') Abdominal sternite III with an anteriorly projected tubercle reaching midcoxae (Fig. 511) 269

268' Venter of abdominal segment III without a tubercle 272

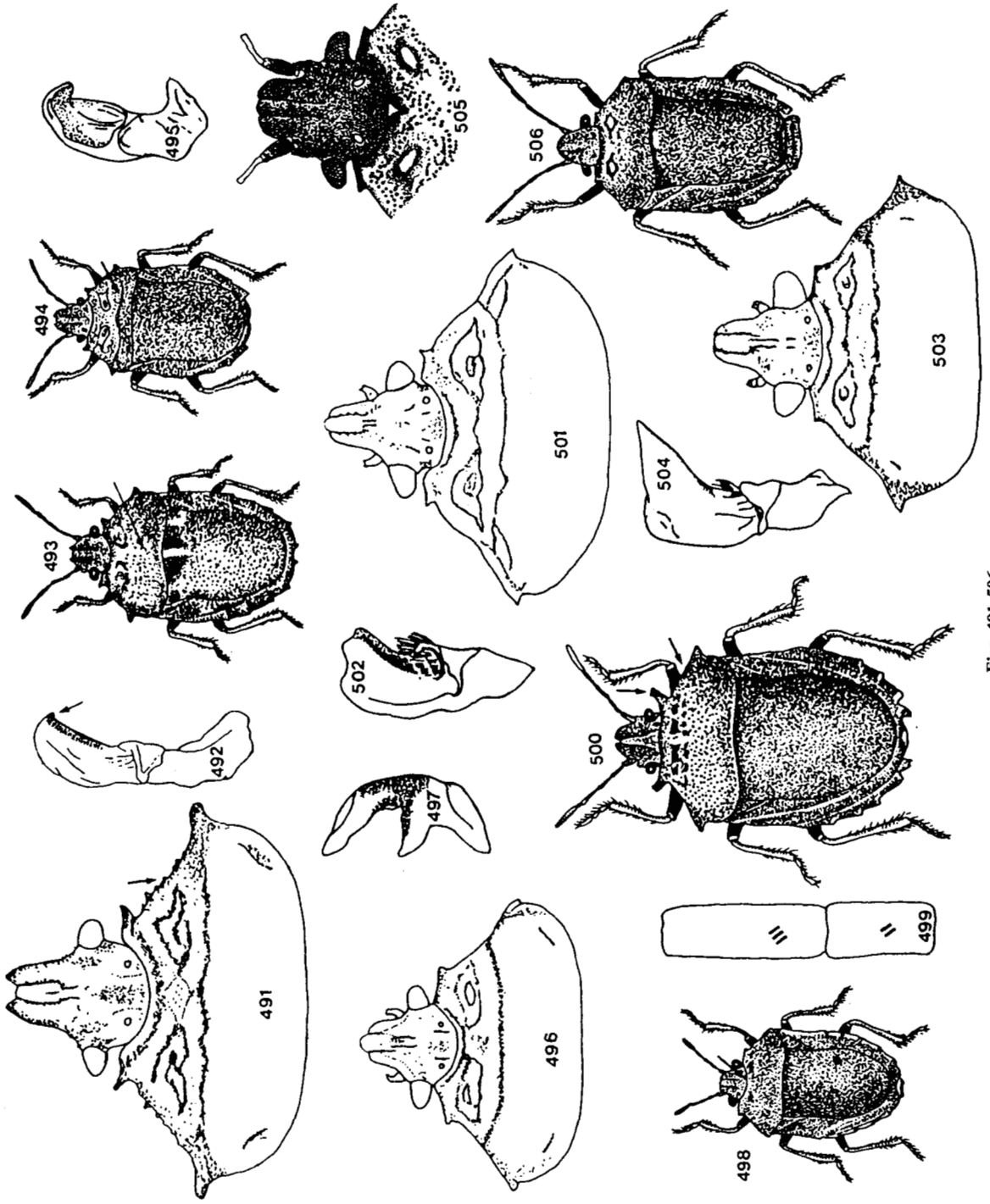
269(268) Body yellow, surface semi-translucent and smooth, with fine to minute black punctures; 2 *nd* antennal segment as long as 3*rd;* scent gland spout long and thin (Fig. 512); spiracles black; pronotum with a transverse white to reddish band (Fig. 513); body length 8-11 mm ..... *Piezodorus hybneri* (Gmelin)

269' Body more or less oval, distinctly colored yellow to orange-yellow in the pronotum and scutellum; corium with yellow spot 270

270(269') Tylus and juga in same line; head with 3 pale ochraceous longitudinal stripes and a small spot of same color before the compound eye; scutellum extended to 5*th* abdominal segment, apex narrow, frena reaching near apex; callus near each other and with a black longitudinal band in between; pronotum with a wider yellow patch behind calli (Fig. 514); last ventral segment moderate in males and abdominal segments not contracted ..... *Menida formosa* (Westwood)

270' Tylus slightly exserted beyond juga; head with 5 pale ochraceous longitudinal stripes; 6*th* abdominal segment contracted medially; last ventral segment very large in male and bell-shaped *(Pygomenida)* 271

271(270') Top of scent gland with a broad black band; posterior margin of metapleuron black between yellow metacoxae and lateral margin of abdomen (prominent in males); ventral yellow bands on abdomen relatively thin and narrow; black bands along margins of scutellum in the apical 1/3 and midbasal 1/3 less prominent (Fig. 515) ..... *Pygomenida varipennis* (Westwood)



Figs. 491-506

271' Top of scent gland with a broad yellow band; posterior margin of metapleuron yellow from metacoxae to lateral margin of abdomen; ventral yellow bands on the abdomen long and broad; black spot along margins of scutellum in the apical 1/3 and midbasal 1/3 somewhat broad and distinct (Fig. 516) . . . . . *Pygomenida bengalensis* (Westwood)

272(268') Green coloration with or without yellow marks on the head and anterior portion of pronotum; scutellum devoid of prominent spots; humeral area of pronotum rounded (Fig. 517); apical 3 segments of antennae with light brown tinge (Fig. 518); scent gland spout short; rostrum fine reaching hind coxae; moderately large 11-18 mm long . . . . . *Nezara viridula* (Linnaeus)

272' Allied to *N. viridula;* humeral area (Fig. 519) of pronotum rather pointed and produced beyond bases of wings; apical 3 segments of antennae (Fig. 520) blackish except distal and proximal ends of segments V & VI and basal 2/3 of segment IV; East Asian species . . . . . *Nezara antennata* Scott

272" Yellowish orange to brownbodied bugs; scutellum with yellow or black spots 273

273(272") Pronotum (Fig. 521) with 4 black longitudinal bands, interrupted along apical 1/3; scutellum with 2 black median longitudinal bands with interruptions along basal 1/3; corium with 3 elongated black spots; tylus longer than juga; 2*nd* antennal segment as long as segment III . . . . . *Antestia anchora* (Thunberg)

273' Pronotum and scutellum without black bands; lateral angle of pronotum more produced than *A. anchora;* tylus and juga in the same line, mid-juga more heavily punctated than tylus; head and pronotum punctated blackish brown; antennal segment III twice as long as segment II (Fig. 522); tip of scutellum ivory yellow (Fig. 523) . . . . . *Starioides degenerus* (Walker)

274(249") Uniformly metallic blue with luster except brownish membrane; lateral angle rounded without spine; pronotum, scutellum, clavus, corium and embolium with widely separated punctations; 4*th* antennal segment shorter or as long as the distance between eyes, segment II > III (Fig. 524) . . . . . *Zincrona caerulea* (Linnaeus)

274' Brownish with reddish brown legs, blackish antennae, and white tip of scutellum (Fig. 525); and entire margin of embolium; humeral spine very distinct (Fig. 526); pronotum, scutellum, corium and clavus with punctations close to each other; 4*th* antennal segment noticeably longer than the distance between eyes; segment II nearly as long as III . . . . . *Andrallus spinidens* (Fabricius)

275(245') Ocelli absent; beak 4- segmented; hemelytra with or without cuneus; membrane with 1 or 2 closed cells or 2 to 3 basal cells where 7 or more longitudinal veins originate 276

275' Ocelli present, if absent prosternum bears a median transverse stridulatory groove; beak 3- or 4-segmented; hemelytra1 membrane different 282

Figs. 507-520

276(275) Cuneus absent; membrane of hemelytron with 2 or 3 basal cells from which 7 or more longitudinal anastomosing veins originate; black corial spot touching inner posterior margin of cornium (Fig. 527); body elongate; antennae inserted at middle of head; femora slender, anterior femora with 1-2 small spines; collar as thick as anterior lobe of pronotum; rostrum thin and long; hind margin of pronotum with black fascia, scutellum reddish; African species [Pyrrhocoridae] . . . . . *Dysdercus superstitious* (Fabricius)

276' Cuneus present; membrane of hemelytron with 2 closed cells [Miridae] 277

277(276') Rostrum reaching mid-coxae only; 1*st* antennal segment as long as vertex; vertex without bristles; eyes slightly far from anterior margin of pronotum 278

277' Rostrum reaching hind-coxae 279

278(277) Second antennal segment about twice as long as pronotal width as base (1.5 : 0.8); apex of 1*st* antennal segment pale, rest black; hemelytra and legs brownish yellow; bases of tibiae black; median line of scutellum black (Fig. 528); aedeagus spiked including rounded vesical spiculum (Fig. 529); right clasper branched, one lobe with setae, the other with serrate margin (Fig. 530) . . . . . *Cyrtorhinus fulvus* Knight

278' Second antennal segment slightly longer than pronotal width at base; III as long as pronotal width at base; end of 1*st* antennal segment greenish yellow; hemelytra and legs greenish; longitudinal median line of scutellum black (Fig. 531); all tibiae yellow; aedeagus less spiked with vesical spiculum not evenly rounded (Fig. 532); right clasper with a subapical spine in the under lobe (Fig. 533) . . . *Cyrtorhinus lividipennis* Reuter

278" Second antennal segment nearly as long as pronotal width at base; forewings in part brownish yellow with black clavus, outer wing edges pale, hyaline to sub-hyaline, closed wings appearing to be blackish down middle with white borders; 1*st* antennal segment yellow (Fig. 534); 2*nd* segment, head, thorax, and abdomen usually entirely black . . . . . *Cyrtorhinus mundulus* (Breddin)

279(277') Arolia present, divergent toward their apices; claws toothed at base; head pointed in front; pronotum punctate; 1*st* antennal segment cylindrical; body with short pubescence; hemelytra opaque, abdomen and membranous wings not seen from above 280

279' Arolia absent, replaced by pair of straight hairs 281

280(279) Pronotum lustrous black with minute hairs, yellow collar and light brown postero-lateral margins; head blackish brown with yellow areas along eye margins, areas near eyes and juga; first antennal segment reddish brown (Fig. 535); proboscis reaching coxa III (Fig. 536); abdomen reddish pink; apex of scent gland plate flat; corium and clavus glossy blackish brown, corium with whitish yellow bands at base, dorsal margins and before apex opposite apical end of clavus . . . . . *Proboscidocoris tibialis* Poppius

Figs. 521-534

280' Pronotum dull blackish brown with brown shoulder, collar and behind collar; head entirely yellow-brown; first antennal segment brown (Fig. 537); abdomen dull straw-colored; apex of scent gland plate strongly bulged; hemelytra dull brown with a broad yellow band at base of corium, dorsal margins of corium whitish yellow . . . . . *Proboscidocoris sp.*

281(279') Pseudarolia present arising from base or inner margins of claw; vertex with round green spots contiguous to eyes; pronotum with greenish tinge apically; collar absent; head and pronotum black (Fig. 538); 2*nd* antennal segment shorter than head width across eyes; aedeagus with a short pointed outer theca with basal half lightly sclerotized (Fig. 539); left clasper rounded and with long hairs basally, cleft medially and each lobe with acute structures (Fig. 540); general color pale yellow-brown to stramineous with black head, pronotum, pleura and genital segment; legs whitish yellow . . . . . *Tytthus chinensis* (Stal)

281' Pseudarolia absent; claws (Fig. 541) toothed or thickened at base; vertex without spots; pronotum punctated, collar present; antennal segment blackish brown, segment I1 more hairy than I and 3.4 times longer than 1*st*, twice longer than 3*rd*, and longer than head width taken across eyes (Fig. 542); head, pronotum, scutellum and thorax yellowish brown; wings yellowish with corium and clavus finely punctated; sides of abdomen reddish brown; legs yellow with brownish bands in the dorso-apical areas of femora . . . . . *Deraecoris vittatus* (Reuter)

282(275') Beak 3-segmented; hemelytra with cuneus and embolium, cuneal fracture well developed, membrane without closed cells; adults with well developed metapleural scent gland openings; male genitalia strongly asymmetrical; small (1.48-3.6 mm), elongate oval species 283

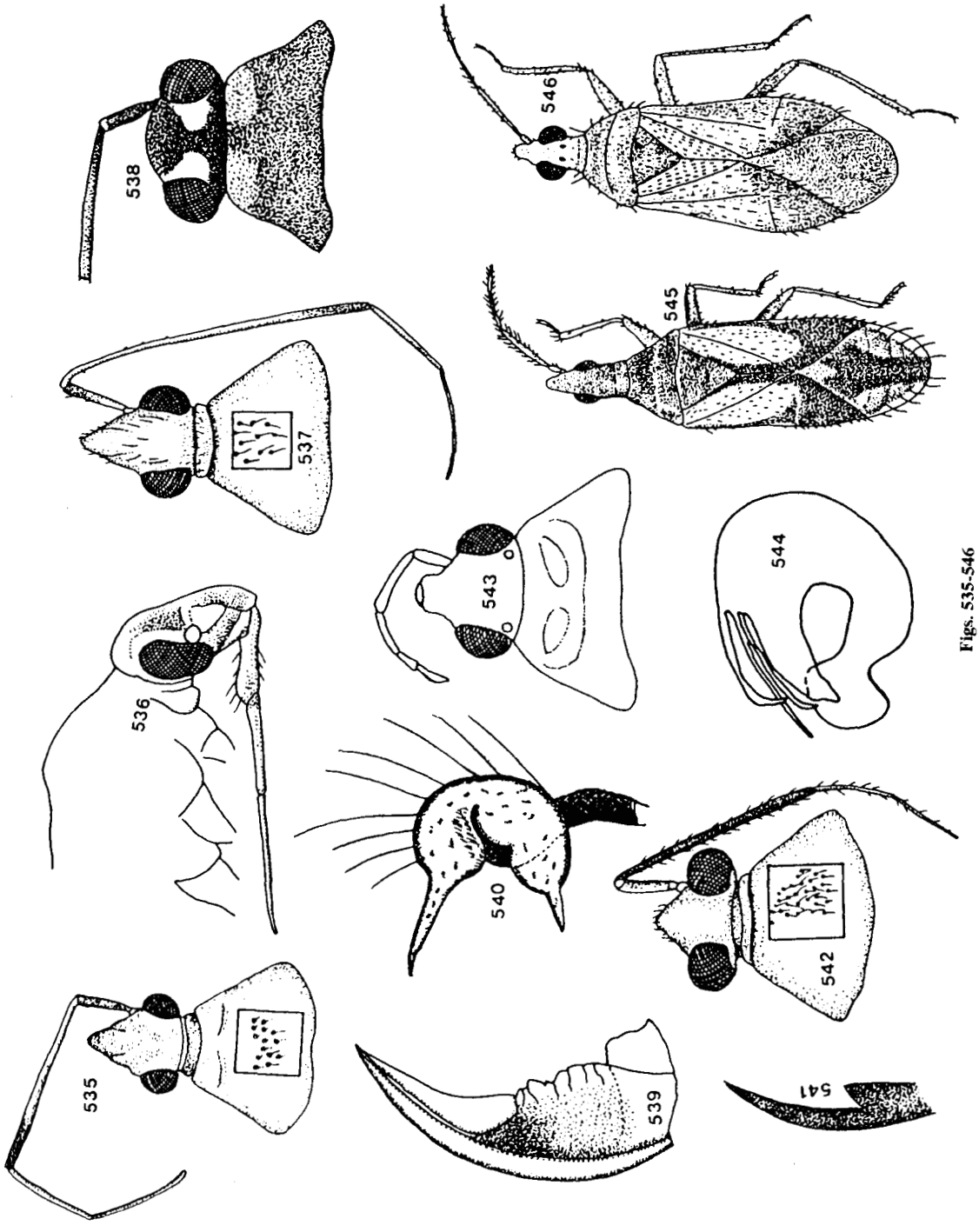
282' Beak 3- or 4-segmented; hemelytra without cuneus; 5 mm or more in length 286

283(282) Metapleural scent gland opening curved forward, often reaching anterior margin of metapleuron 284

283' Metapleural scent gland opening directed backward, continued as a fine carina which curves forward to anterior margin of metapleuron 285

284(283) Pronotal collar "absent" (hidden), lateral margins of pronotum wide; head and pronotum dull punctate; pronotal disc with shallow callosities separated by few punctures (Fig. 543); anterior male tibiae with a row of peg-like teeth; 4*th* antennal segment hardly longer than 3*rd*; aedeagus (Fig. 544) with 3 branches of flagellum; brown to dark brown except corium, tibiae and femora pale white and cuneus and connexivum light brown; 1.5 mm long . . . . . .*Orius tantillus* (Motschulsky)

284' Pronotal collar prominently lying completely in front of anterior apical angles of pronotum, lateral margins narrowly carinate and not broadly reflexed; 1*st* and 2*nd* antennal segments very stout, apical 2 segments thinner than scape and pedicel; inner portion of corium, apical half of clavus and innermost base and dorsal part of membrane light colored (Fig. 545) . . . . . *Montandoniola moraquesi* (Puton)



Figs. 535-546

285(283') All tibiae straight, anterior femora with slender hairs; tibia II and III without long hairs, pubescence not longer than diameter of segment; beak reaching anterior coxae; pronotal collar wide, disc without prominent callus; 2*nd* antennal segment much longer than interocular width; apices of corium and embolium oblique and subequal in width (Fig. 546); apex of metasternum with a bifurcate spine concealed by coxa III . . . . . *Amphiareus* sp.

285' Tibia I curved inwards (bowed), anterior femora armed with spines; beak short, not reaching anterior coxae; pronotal disc with a W-shaped callus; apical width of corium 2 times or more wider than apical width of embolium; apical margin of corium and embolus strongly curved outward-upward (Fig. 547) . . . . . *Physopleurella armata* Poppius

286(282') Prosternum with a median transversely striated stridulatory groove extending anterior of fore-coxae; head usually with a transverse suture near eyes; beak 3-segmented [Reduviidae] 287

286' Prosternum not as above 308

287(286) Ocelli absent; tibiae I concave almost at mid-ventral half and with rows of inner lateral spines; femora I with ventral spines; scutellum with a long basal and short apical upwardly directed spines 288

287' Ocelli present, without combination of above characters 291

288(287) Lateral spines on the apex of basal one-third of pronotum nearly as long as pronotum; apical spine of scutellum parallel with the basal spines 289

288' Lateral spines on the apex of basal one-third of pronotum about half the length of pronotum; apical spine of scutellum outwardly and upwardly curved 290

289(288) Legs yellow except apices of femora brownish black with red-orange tinge (Fig. 548); bases of tibia lightly red-orange, apical end blackish similar to tarsi; pronotum 1.9 times longer than head, brownish black medially and reddish marginally in dorsal view; pronotal lateral spines yellow with brownish tips (Fig. 549) . . . . . *Polytoxus fuscovittatus* (Stål)

289' Legs blackish with basal half of femur I (Fig. 550) and base of II and III yellowish; pronotum 2 times longer than head, bluish postero-medially and with a pair of brown longitudinal bands in the antero-median area, margins reddish; pronotal lateral spines yellow basally and blackish in the apical half . . . . . *Polytoxus selangorensis* Miller

290(288') Hemelytra with vein M at apical margin of discal cell roundly bent near base, (Fig. 551); proboscis not reaching apex of prosternum; 2*nd* antennal segment slightly longer than basal spine of scutellum and anterior lobe of pronotum . . . . . *Polytoxus* sp. A

290' Hemelytra with vein M at apical margin of discal cell angulate, small vein arising at angle and extending for short distance into cell (Fig. 552); proboscis reaching apex of prosternum; *2nd* antennal segment as long as basal spine of scutellum, subequal to length of anterior lobe of pronotum ..... *Polytoxus* sp. B

291(287') Femora, head, pronotum, scutellum, and abdominal margins spinose (Fig. 553); head with 2 dorsally long horn-like spines on bases of antennae; antero-dorsal half of pronotum with 2 long erect spines, posterior half with 6 (2 laterals each behind transverse groove and 4 in a row before posterior margins); scutellum with 3 spines; leg I barbed with long and short spines dorsally and ventro-laterally in femora and ventro-laterally in tibiae, brownish yellow ..... *Polididus armatissimus* Stål

291' Not as above: abdominal margins without spines 292

292(291') Apex of scutellum broad with 2 or 3 spines 293

292' Apex of scutellum triangular or subtriangular 294

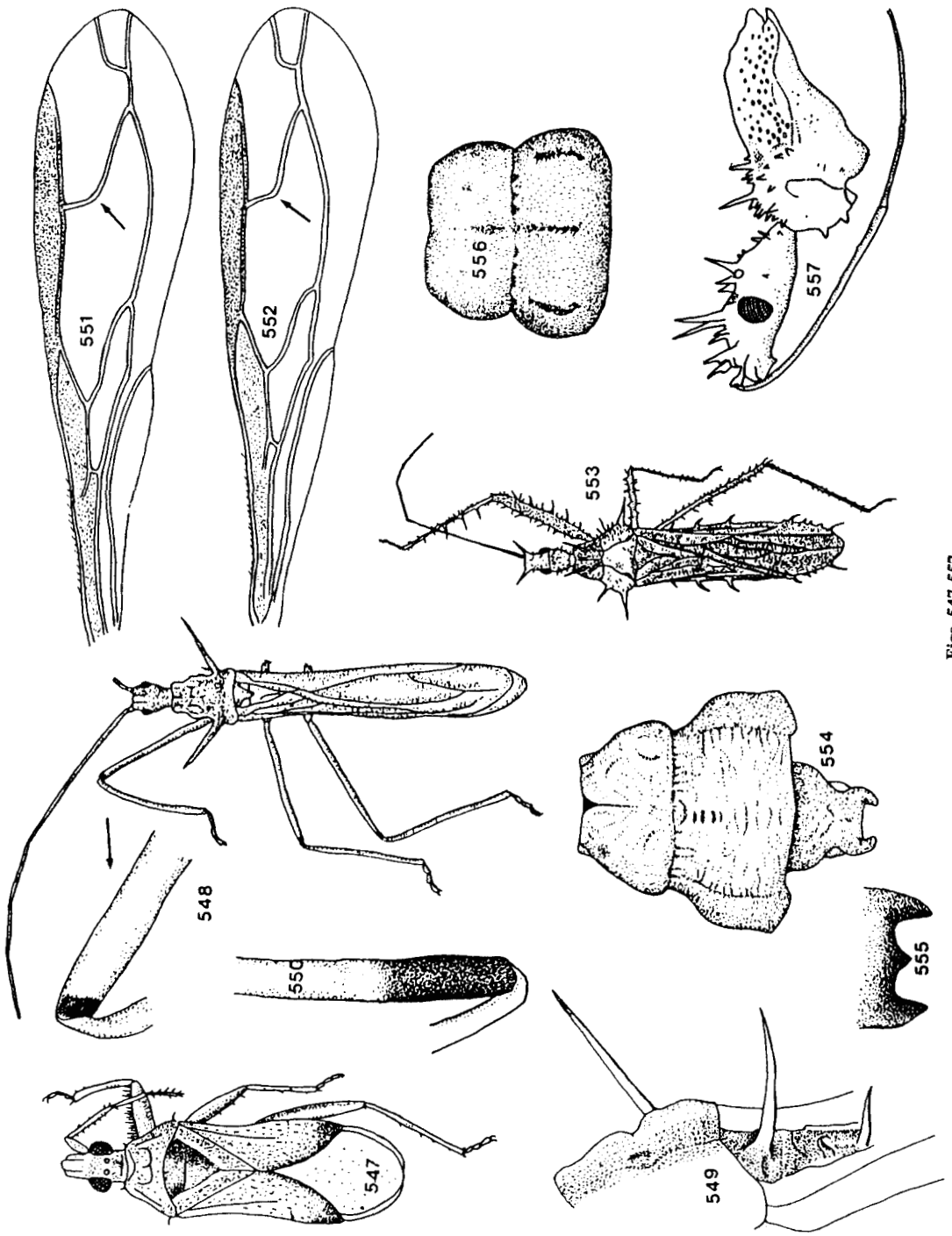
293(292) Apex of scutellum with 2 converging spines (Fig. 554), constricted along lateral mid-half and with a deep cavity at center in between lateral carinae: head with a ridge-like tylus and small and low juga; body black except whitish eyes and ocelli and band on the *2nd* basal one-fourth antennal segment III, pinkish red to pale orange-red base of embolium and lateral margins of abdomen, venter of abdomen with 4 pinkish red transverse bands on sternites II-V; tibiae I and II with very short spongy membrane ..... *Scadra* sp.

293' Apex of scutellum with 3 spines, inner one very small and outer ones nearly parallel with each other (Fig. 555); pronotum clearly bilobed with a cross groove at middle, posterior lobe with sublateral longitudinal grooves (Fig. 556); body black except reddish abdominal margins, entire abdominal venter I to V red except black bases, rest black; legs I and II blackish brown including coxae and trochanter, apices of tibiae slightly swollen and bent downwards, ventrally with a moderately concave spongy membrane; ventral apical one-third of all femora with a small blunt tubercle ..... *Ectrychotes crudelis* (Fabricius)

294(292') Hemelytra with a quadrangular cell at the inner end of corium near base of membrane 295

294' Hemelytra without a quadrangular cell at the inner end of corium near base of membrane 298

295(294) Head with 6 anteocular spines (Fig. 557) and 6 postoculars; anterior lobe of pronotum with 4 long and a number of small spines; postero-median margins with short spines, overhanging on top of scutellum; femora I hirsute with a long and 2 short blunt spines dorsally; venter of tibiae I with 2 rows of short blunt teeth; yellow-brown to brownish orange with blackish membrane and hindpart of head ..... *Scipinia horrida* Stål



Figs. 547-557

295' Head, pronotum, and legs without such spines; body coloration commonly red and black and structure of hemelytra different 296

296(295') Abdomen with broad lateral and thin apico-sternal white bands; red with black legs, antennae, proboscis, membrane, claws and base of corium, scutellum, ante-ocular area up to base of antennae and post-ocular except for a red and yellow band in between ocelli, antero-median part of anterior lobe and apical half of posterior lobe of pronotum (Fig. 558), meso-pleuron and part of meta-pleuron; ocelli small, set closer to eyes than to each other; pronotal humps small; cells of membrane almost equal in diameter (Fig. 559) ..... *Rhinocoris fuscipes* (Fabricius)

296' Abdomen, head (except white underneath) and legs entirely black; anterior lobe smooth and with humps, posterior lobe coarse; pronotal humps large and more rounded; inner cell larger than the dorsal one 297

297(296') Entire pronotum black dorsally and laterally, humps of anterior lobe wide apart (Fig. 560); scutellum with yellow carina and apical spine; quadrangular cell (Fig. 561) small twice longer than wide (10:5); prosternum and all coxae black; 1*st* antennal segment 2.7 times longer than 2*nd* ..... *Rhinocoris* sp. A

297' Pronotum red or with posterior lobe blackened in between the 2 longitudinal grooves near humeri (Fig. 562); scutellum red including apical tip; quadrangular cell (Fig. 563) large 1.5-1.7 times longer than wide; prosternum and coxae I reddish; 1*st* antennal segment 2.8 times longer than 2*nd* ..... *Rhinocoris* sp. B

298(294') Hemelytra with a 6-sided discoidal cell; body depressed to moderately flat 299

298' Hemelytra without a discoidal cell 303

299(298) Segment I of proboscis longer than combined length of II and III slightly beyond hind-margins of eyes; head one-third shorter than 1*st* antennal segment, ventro-lateral and postero-lateral areas of post-ocular region lined with spines and postero-median with a pair of tubercles directed posterad; pronotum nearly as long as 1*st* antennal segment and subtriangular with a broad V-shaped anterior part (Fig. 564); dull brown with femora I-III and antennal segment I mottled yellowish white; tibiae brownish along mid-half and both ends but yellow in between; body elongate and depressed ..... *Pygolampis* sp.

299' Segment I of proboscis not reaching hind-margins of eyes, short or just as long as combined length of II and III 300

300(299') Femur I with a single row of 31-34 (11 moderately large and 20-23 small ones) ventro-apical teeth; discoidal and outer cell of membrane, central part of clavus, and inner part of corium castaneous (Fig. 565); first antennal segment length less than half of segment II; eyes indented behind at mid-half (Fig. 566). 301

300' Femur I with 2 rows of ventral spines 302

301(300) Subgenital plate markedly narrowed in the basal one-third, concave basally and cleft apically, plate with about 30 hairs (Fig. 567); paramere with subtruncate flat inner process, subapical longest setae slightly longer than paramere diameter (Figs. 568-569); inner process slightly serrated; tip of scutellum curved upwards; 1*st* antennal segment 0.42 length of 2*nd* (Fig. 566); outer distal margin of discoidal cell bisected by the middle vein of membrane a little below mid-half (Fig. 570) . . *Oncocephalus pacificus* Kirkaldy

301' Subgenital plate broadly recurved medially, gradually narrowed basally and nearly straight posteriorly, plate with about 40 hairs (Fig. 571); paramere's subapical longest seta as long as paramere diameter (Fig. 572); inner process flat with angled sides (Fig. 573), evenly serrated with minute teeth; tip of scutellum projected forward; 1*st* antennal segment 0.46 length of 2*nd;* outer distal margin of discoidal cell bisected by the middle vein of membrane at mid-half (Fig. 574) . . . . . *Oncocephalus impudicus* Reuter

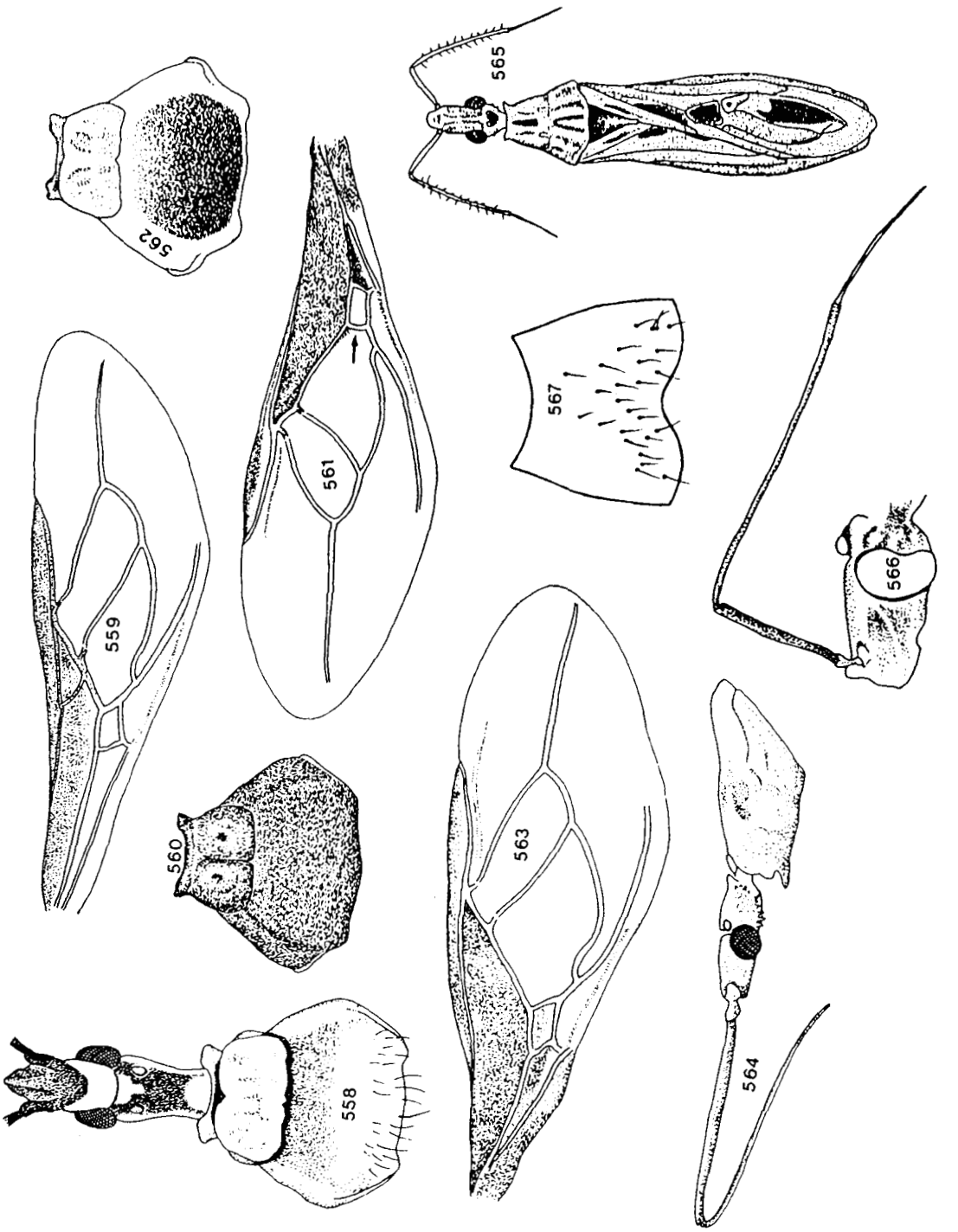
302(300') Pronotum 1.8-1.9 times longer than its greatest width, 1.3 times longer than 1*st* antennal segment and 1.2 times longer than head (Fig. 575); head with a pair of tubercles in between antennal bases, and spines along ventrolateral and posterolateral portion of head; back of head with 2 small tubercles in between the groove; proboscis without spines; femur I moderately and uniformly swollen with 2 outer and 3-6 inner large teeth and a number of small ones in between; apex of femur III almost at tip of abdomen; discoidal cell rectangular; straw-colored except legs with brown striae . . . . . *Sastrapada entomophaga* Miller

302' Pronotum about as long as broad (Fig. 576), 2 times longer than 1*st* antennal segment and one-sixth longer than head; without tubercles between antennal bases, 3 spines on each ventro-lateral part of ante-ocular area (Fig. 577); back of head smooth without spines; proboscis with spines in segments I and II; femur I broadest medially with 3 outer and 4 inner prominently long spines and a number of small ones in irregular row in between the big spines; apex of femur I about 1-2 segments short at tip of abdomen; discoidal cell subglobular yellow-brown. . . . . *Staccia diluta* Stål

303(298') Pronotum constricted near mid-half, swollen anterior part with blackish band medially, laterally and near margins; posterior half brown and with a black humeral spine; head with a porrect tubercle in between bases of antennae and a pair of setae near antennal base; lustrous eyes strongly diamond-like; ocelli with orange ring (Fig. 578); legs banded dark brown in apical half and yellow in basal half; venter of femur with 2 spines in leg I and one each in II and III; tarsus I with simple claw (Fig. 579) and 2-segmented; margins of abdomen spinous . . . . . *Lisarda* sp.

303' Pronotum constricted below mid-half, anterior lobe and subglobular and posterior lobe more or less transverse 304

304(303') Tibia I with spongy furrow, II normal; head long and porrect; antennae far in front of slightly oblique eyes by a little less than 1 eye diameter (Fig. 580); anterior lobe of pronotum with 2 longitudinal grooves on each side of the median groove, submedian



Figs. 558-567

grooves fused medially before transverse groove forming elongate mark; lateral grooves curved towards pronotal margins (Fig. 581); outermost cell of membrane large; brownish yellow with black eyes, posterior lobe of pronotum, scutellum, forewings except yellow apex of membrane and clavus and base of corium, and reddish brown sides of head, thorax and abdomen (Fig. 582) . . . . . *Sirthenea flavipes* Stål

304' Tibiae I and II with spongy furrow; head of moderate length and slightly curved downwards; general color black 305

305(304') Spongy furrow (Fig. 583) occupies barely half length of tibiae; forewings without ovoid or subglobular yellow spots 306

305' Spongy furrow occupies almost apical three-quarters of tibiae; forewings with ovoid or subglobular yellow spots 307

306(305) Apical half of corium yellow (Fig. 584) except blackish brown base; base of forewings blackish brown; inner area of cells of membrane brownish black with slight violet tinge, large middle cell with a bifurcated vein arising at its distal end with a common point; basal cell small and long, width of cell at distal end 0.5 times that of cell above it; antennal segments I and II black, segment II slightly shorter than anterior lobe of pronotum; proboscis black (Fig. 585) . . . . . *Pirates atromaculatus* (Stål)

306' Corium, embolium, and base of clavus yellow; inner area of cells of membrane light to dark brown, large cell of membrane bifurcated distally not at a common point, distal oblique vein 5 times longer than distal lateral width of cell below (Fig. 586); antennal segments I and II brownish black, segment II a little longer than anterior lobe of pronotum; proboscis reddish brown (Fig. 587) . . . . . *Pirates sparsus* Miller

306" Basal half of corium, clavus and scutellum dark cinnamon brown; membrane with an arched (bow-like) transverse band near base and a rounded subapical spot (Fig. 588); segment II of antennae about as long as anterior lobe of pronotum. . . . . *Pirates arcuatus* Stål

307(305') Corium with a large ovoid yellow spot and a small light yellow spot in the subtriangular inner basal cell of the membrane area; 2*nd* antennal segment slightly shorter than length of anterior lobe of pronotum; lateral edge of abdomen with large black areas in between yellow spots (Fig. 589); proboscis segment II one-fourth longer than ante-ocular area. . . . . *Ectomocoris biguttulus* Stål

307' Corium without large yellow spot; inner basal cell of membrane with a large yellow spot at center (Fig. 590); 2*nd* segment of antenna one-third longer than anterior lobe of pronotum; proboscis segment II 1.14 times longer than anteocular area (Fig. 591); lateral edge of abdomen with narrow black spot in between yellow spots . . . . . *Ectomocoris atrox* Stål

308 Beak 3-segmented and long; front legs not raptorial; arolia absent 309

308' Beak 4-segmented 310

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Figs. 567-585

309(308) Membrane of hemelytra with 4 elongated closed cells; head not pointed viewed dorsally; eyes converging frontally; pedicel longer than segment III or IV; pronotum convex above scutellum and narrowed anteriorly; scutellum large and pointed; black except whitish membrane (Fig. 592) [Saldidae] ..... *Saldula ornatula* Reuter

309' Membrane of hemelytra without closed cells; corium with dark brown thickened veins forming 3 whitish cells; head acute frontally; eyes not convergent; pedicel shorter than segment III or IV; pronotum straight at base with shallow suture in the apical one-third scutellum small, truncated apically and with a cavity before apex; light brown with dirty white membrane (Fig. 593) [Mesoveliidae] ..... *Mesovelia vittigera* Horvath

310(308') Arolia absent; front leg enlarged, raptorial and with spines; hemelytra with many marginal veins [Nabidae] 311

310' Arolia present; front legs and hemelytra variable 315

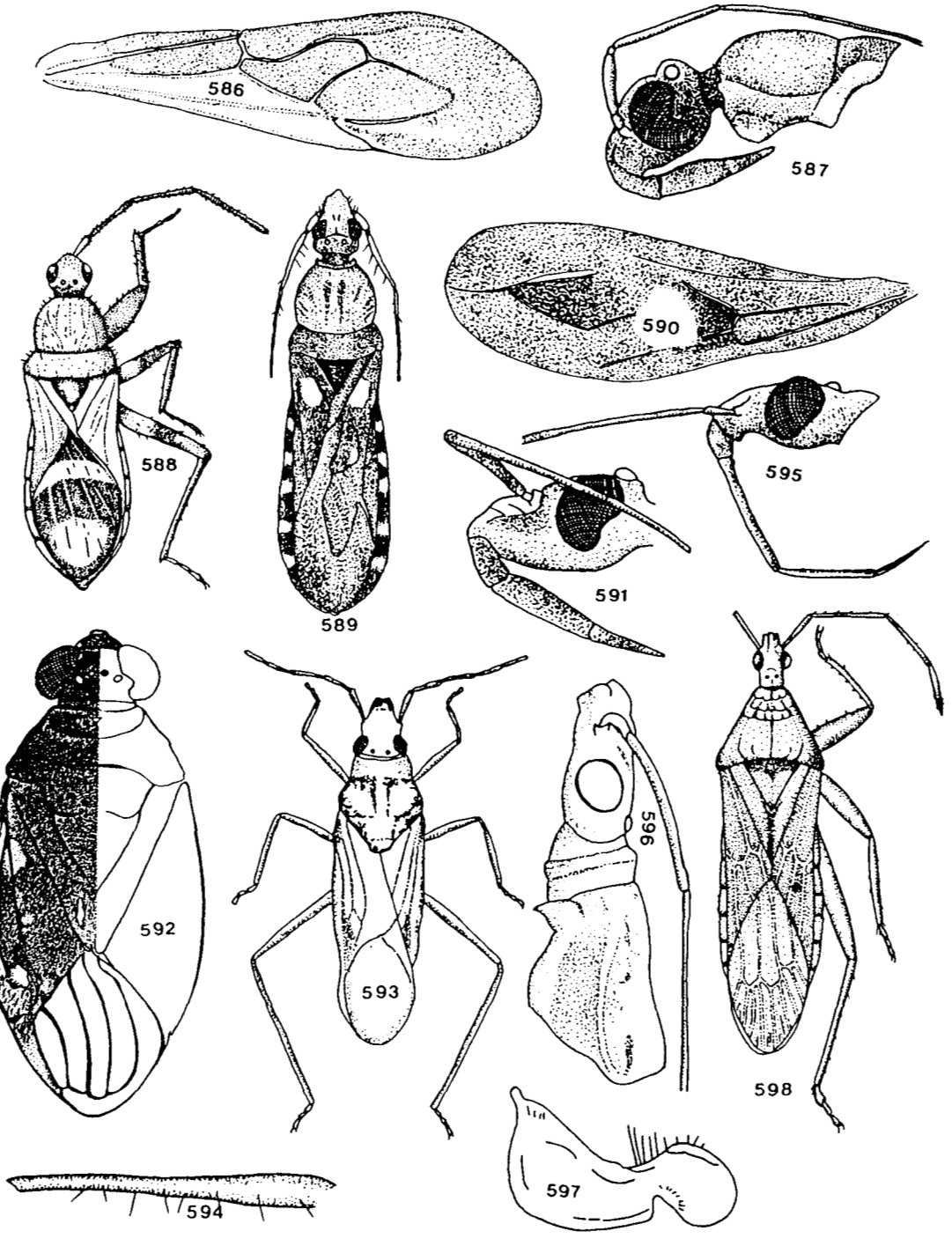
311(310) Mid- and hind-femora with spines much longer than femora width (Fig. 594); femora I and II with 5 ventral and 5-6 inner lateral spines; tibiae I and II with 9-10 long thin spines, venter of II with 13-18 black short spines in a row; head with a pair of long trichobothria between ocelli and inner margins of eyes, black with yellowish white marks behind base of antennae, sides and front of ocelli; ocelli elevated and near each other; segment II & IV of proboscis as long as segment II of antenna (Fig. 595); collar black dorsally and white ventrally; generally blackish brown with three longitudinal white to yellow marks 6 mm long ..... *Arbela nitidula* (Stål)

311' Mid- and hind-femora without such type of spines; tibiae I and II with 2 close rows of short, dark and tooth- like ventral spines 312

312(311') Basal one third of pronotum with prominently transverse and zig-zag punctations; connexivum beneath abdomen not ventrally deflexed, not demarcated by deep longitudinal furrow; segment I & II of antenna slightly longer than head and prothorax; anterior lateral side of prothorax pointed posteriorly (Fig. 596); ocelli not elevated and wide apart; scutellum with a brownish black median longitudinal band; femora I with 9-10 brown patches laterally; tibiae I and II with two rows of black small spines ventrally; dull straw-colored to pale brown-yellow with pleuron brownish red. ..... *Stenonabis tagalicus* Stål

312' Posterior lobe of pronotum weakly and shallowly punctate; connexivum ventrally deflexed beneath, very distinctly demarcated from abdominal sterna by a deep longitudinal furrow; sterna without ventro-lateral rows of shiny hairless areas 313

313(312') Shaft of males' left genital clasper subglobular with a narrow cleft opposite base of blade; tip of clasper with a protrusion (Fig. 597); tegmina uniformly pale; antennal base near eyes; ocelli behind eyes, tip of head (juga and tylus) short; membrane cells almost of equal level at apex (Fig. 598) ..... *Nabis sinoferus* Hsiao



Figs. 586-598

313' Shaft of males' left genitalia clasper elongate to subglobular but without protrusion at apex of blade; blades acute 314

314(313') Tegmina nearly uniformly pale straw in color; legs feebly marked; shaft of males' claspers subglobular with a shallow and narrow concavity opposite base of blade; tip of blade moderately acute (Fig. 599) ..... *Nabis capsiformis* Germar

314' Tegmina slightly darker straw in color; membrane cells at different levels towards apex (Fig. 600); shaft of males' claspers elongate with a wide concavity opposite base of blade, tip of blade strongly acute (Fig. 601) ..... *Nabis stenoferus* Hsiao

315(310') Membrane of hemelytra with only 4 or 5 veins [Lygaeidae] 316

315' Membrane of hemelytra multi-veined; scent glands present 330

316(315) Head triangular; eyes moderately small; front femora usually with spines; phytophagous 317

316' Head transverse; eyes very large; front femora without spines; entomophagous . . 327

317(316) Abdominal suture between sternites IV and V (3*rd* visible inter-segmental suture) curved anteriorly close to the lateral margin but not completely reaching the margin. (Subfamily Rhyparochrominae) 318

317' All ventral abdominal intersegmental sutures straight and extended to the lateral margins; abdominal spiracles of segment VII laterally or ventrally located, the rest situated dorsally 324

318(317) Sides of postocular portion of head parallel for some length; segment I of antennae exceeding tylus by more than half its length; head rarely longer than wide across eyes, dorsal surface with 4-7 pairs of scattered trichobothria; corium without a costal spot posterior to middle; pronotal collar narrower at sides; pronotum impunctate anteriorly (Fig. 602); femora solid color, with 2 strong ventral teeth; tibiae with only one (Fig. 603) ..... *Pamerana nigritula* (Walker)

318' Sides of postocular part of head narrowed or rounded proximally; head width across eyes equal to or greater than length; segment I of antennae exceeding tylus by less than half its length 319

319(318') Hindwing with vein R strongly curved anteriorly, without reaching margin, head, pronotum, and abdomen usually yellow-brown to dark brown; aedeagus without spines and processes except for holding sclerites; total length 3-3.5 times maximum width 320

319' Hindwings vein R reaching anterior margin; aedeagus with spines and processes but without holding sclerites, total length 3.5-5.6 times maximum width 323

320(319) Pronotum uniformly black; inner angle of corium with distinct whitish or pale spot; clavus without the regular rows of punctures; apex of scutellum yellow (Fig. 604); proboscis reddish brown except yellow segment II, short and barely beyond coxa I;

femora reddish brown in apical half-one-fourth, bear 7 spines (4 inner and 3 outer) (Fig. 605) ..... *Pachybrachius pacificus* Stål

320' Pronotum never uniformly black; spot in the inner angle of corium not distinct . . . 321

321(320') Pronotum black except the dark brown posterior one-third; spot in the inner angle of corium not clear; femora yellow; antennae dark yellow; apex of scutellum brown, clavus with ***3*** regular rows of punctures (Fig. 606); proboscis long and yellow nearly reaching coxa II; femora yellow with 5 teeth (Fig. 607); female venter yellow. . . . . *Pachybrachius inortatus* (Walker)

321' Pronotum uniformly brown or black reddish brown; femora and antennae yellowish; femur I with or without band; proboscis may or may not reach coxa II; spermathecae with or without apical bulb and multi-coiled; female venter never yellow 322

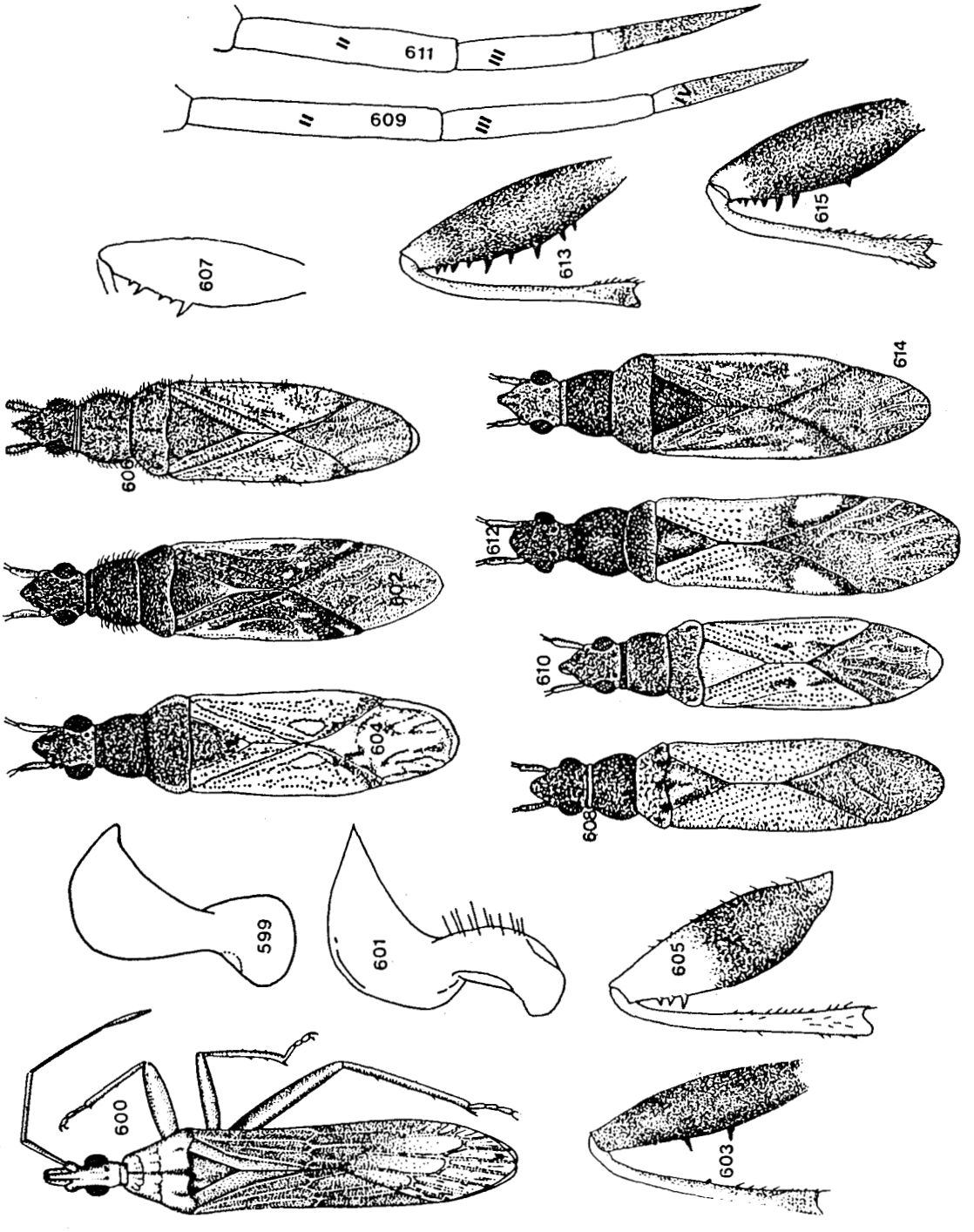
322(321') Collar yellowish brown; scutellum brownish along sides; pronotum dark reddish brown; hind part with 4-5 black patches and evenly punctured surfaces (Fig. 608); fore-femora with or without a broad, complete fuscous band in the apical half; segments II and IV of antenna subequal; basal segment of proboscis usually ending noticeably before base of head, 3*rd* segment about one-fourth longer than 4*th* (Fig. 609); coloration; dark brown to castaneous; spermatheca with 8-10 and 4-6 loose coils; apical bulb absent . . . . *Pachybrachius nigriceps* (Dallas)

322' Collar dark brown; pronotum blackish brown, hind part without black patches and less irregular punctures (Fig. 610); fore-femora yellow without fuscous band; segment II of antenna longer than IV, basal segment of labium reaching head; 3*rd* segment of labium rarely longer than the 4*th* (Fig. 611); spermatheca short, coiled portion with 4 loose coils, apical bulb present ..... *Pachybrachius sobrinus* (Distant)

323(319') Corium with a prominent transparent to white spot in between its brown band (Fig. 612); fore-tibiae unarmed in males with more evenly scattered spines (Fig. 613); fore-femora solid color either castaneous or black for at least distal half or meso- and meta-thoracic femur black; sides of ante-ocular part of head between eye and antennal base parallel; head surface between eyes flat; posterior lobe of pronotum with 4 luteus spots, 2 medians and 1 each near lateral angle; fore-coxae armed with 1 spine in both sexes; fore-trochanter spineless in males . . . . . *Paraeucosmetus pallicornis* (Dallas)

323' Corium with 2 nearly interconnected transparent spots; costal margin of corium narrowly pale with a post-median inter-costal grayish brown spot and entirely black venter (Fig. 614); head about as wide as long across eyes; pronotal collar distinct with a deep constriction; head, pronotum, and scutellum sparsely covered with long erect hairs; posterior lobe of pronotum solid black; fore-tibiae in males shallowly curved towards proximal end and armed with variously developed spines around mid-half; femora with 6 spines at apex (Fig. 615) ..... *Horridipamera nietneri* (Dohrn)

324(317') Flat bugs with macropterous and brachypterous forms; scutellum whitish but not head and thorax; corium and clavus not pitted or at most with weak, scattered punctures;


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Figs. 599-615

apical coria1 margin concave; dorsal abdominal gland openings at the posterior margins of terga IV and V only; fore-femora (Fig. 616) with 2 paired large tubercular process; fore-coxal cavities open; antennae clavate, segment II as long as III (Fig. 617) . . . . . *Dimorphopterus cornutus novaequineae* Ghauri

324' Not as above, corium and clavus pitted 325

325(324') Compound eyes (Fig. 618) borne on a tubercle; wing (Fig. 619), corium with a blackish brown costal band, punctured basal and lateral margins, and a long and short row of punctures below it; membrane with 2 median and 1 laterally projected dark brown bands; antennal segments long except base, IV longer than rest of segments, II as long as III . . . . . *Ninus insignis* Stål

325' Eyes not as above; corium transparent without dark brown bands 326

326(325') Head, thorax, and antennae hairy; ridge on pronotum and scutellum absent (Fig. 620); corium with a row of punctures; antennal segment III shorter than II, IV slightly swollen (Fig. 621); body dark brown . . . . . *Cymonius turaensis* (Paiva)

326' Head, thorax, and antennae not hairy; mid-anterior half of pronotum and mid-scutellum with a whitish longitudinal ridge; tylus sharply pointed and much longer than juga bisected by base of antennae; segment III of antennae twice as long as segment II (Fig. 622); corium (Fig. 623) uniformly punctured throughout . . . . . *Cymodema basicornis* (Motschulsky)

327(316') Head with an inverted broad T-shaped black to brown band; antennae dorsally whitish yellow with blackish base of IV, basal half of III, basal two-thirds of II and basal half of I; pronotum with a small yellow apico-median and postero-median spot; yellow area of humeri extended to hind level of eyes (Fig. 624); enclosing 16 brown punctures mostly on margins; posterior half of pronotum brownish; scutellum, pronotum, and head almost equal in length; body length 4.4 times longer than pronotum or head length . . . . . *Geocoris jucundus* (Fieber)

327' Head almost uniformly yellow to brownish yellow with a black patch between ocelli and hind part of eyes or entire hind part of head 328

328(327') Posterior part of head black; high above ocelli and concave in between (Fig. 625) . . . . . *Geocoris ochropterus* (Fieber)

328' Posterior part of head black only in between ocelli or hind part of eyes 329

329(328') Scutellum (Fig. 626) with a transverse dark yellow band at base; pronotum yellowish around margins and broadly brownish red medially; yellow area of humeri extended to the entire oblique apical margins of pronotum enclosing 5-8 punctures almost medially (Fig. 627); eye height 0.5 times eye length and as long as 3rd antennal segment . . . . . *Geocoris* sp.

329' Scutellum uniformly black (Fig. 628); narrow posterior margins and broad lateral area of protonum yellow; humeri area yellow extended to lower half of the oblique antero-

lateral area of pronotum enclosing 13 punctures (Fig. 629); eye height 0.6 times eye length and slightly longer than *3rd* antennal segment . . . . . *Geocoris flaviceps* (Burmeister)

330(315') Head narrower and shorter than pronotum; bucculae long, behind level of antennifers; hind coxae more or less rounded or square [Coreidae] 331

330' Head nearly as wide and as long as pronotum, bucculae very short, rarely reaching level of antennifers; hind coxae more or less elongated [Alydidae] 332

331(330) Pale brown with a pair of tiny white spots on the forewings; humeri longer, protruded laterally and sharply pointed; 10-12 mm long (Fig.630) . . . . . *Cletus punctiger* (Dallas)

331' Dark to light brown with a pair of small white spots on the forewings; body more coarsely punctate; humeral spine sharply pointed; 8-8.5 mm long (Fig. 631) . . . . . *Cletus trigonus* (Thunberg)

332(330') Hind femora somewhat stout, with several or many spines on ventral surface; humeral angle drawn out into a spine; rostrum reaching mesothoracic coxae *(Riptortus)* 333

332' Hind femora elongated, unarmed, never stout, head long, jugae porrect produced into front of tylus and longer than it; pronotum long; lateral angles unarmed *(Leptocorisa)* 335

333(332) Meso- and meta-pleuron with paired semi-globular white spots (Fig. 632); tips of antennal segments I, II and III brownish (Fig. 633); body somewhat rust brown . . . . . *Riptortus pedestris* (Fabricius)

333' Meso- and metapleuron with rectangular-like whitebands 334

334(333') Antenna solid brown (Fig. 634); body rust brown . . . . . *Riptortus pilosus* (Thunberg)

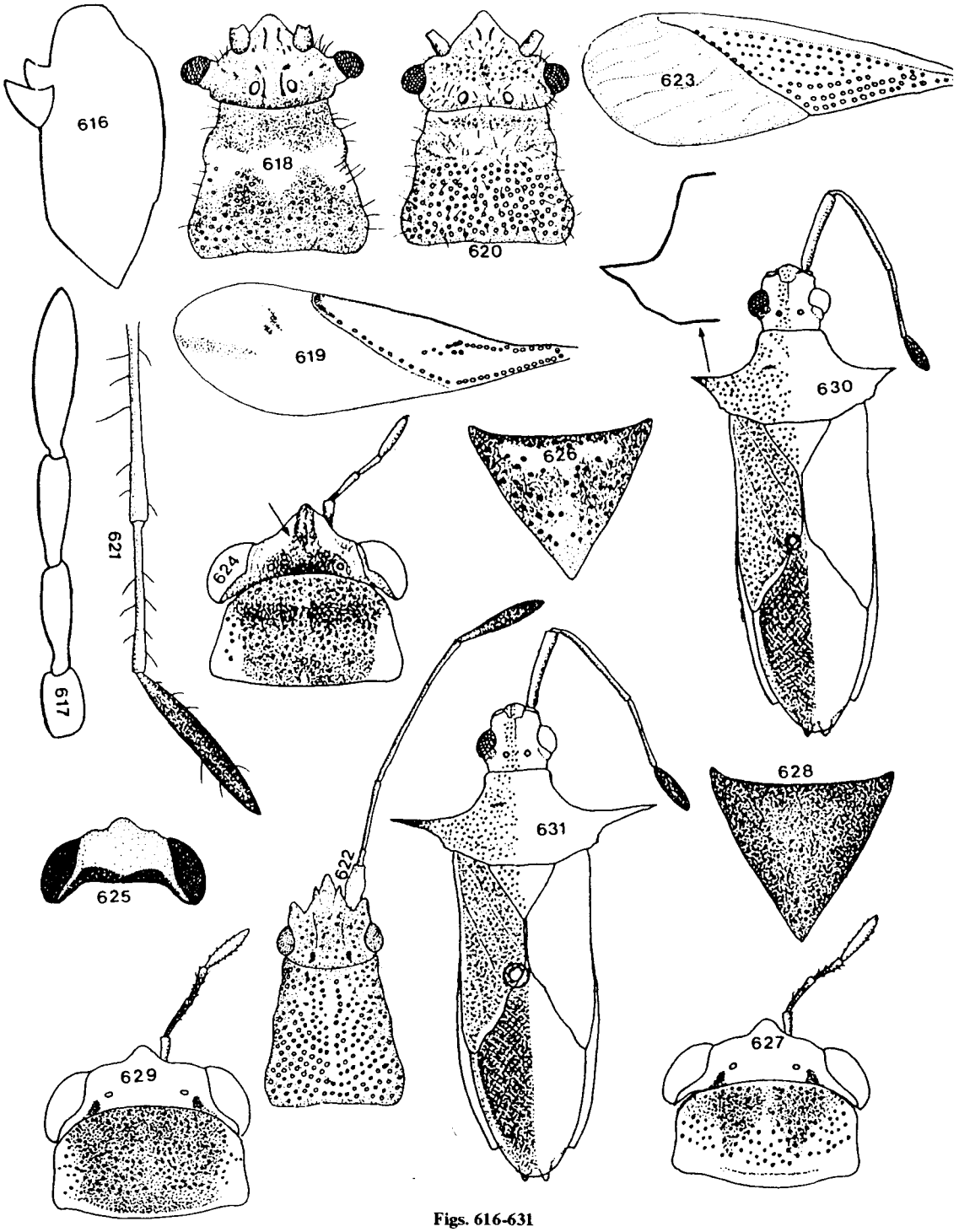
334' Apical half of antennal segments II and III and entire length of segment I dark reddish brown (Fig. 635); lateral side of whole insect with a broad longitudinal white band (Fig. 636) . . . . . *Riptortus linearis* (Fabricius)

335(332') Rostrum extended beyond apices of *2nd* coxae 336

335' Rostrum never beyond 2*nd* coxae 337

336(335) Lateral dark line well developed (Fig. 637); venter of abdomen with a median dark streak extended from 1*st* to *6th* segment of rostrum but reaching only midway between *2nd* and *3rd* coxae (Fig. 637); basal quarters of apical antennal segments never pale; parameres large (Fig. 638); body length 15 mm . . . . *Leptocorisa solomonesis* Ahmad

336' Lateral black line faintly represented by 2 blackish brown dots; one on sides of antenniferous tubercles and on collar, never beyond pronotal collar (Fig. 639); disc of pronotum never blackly punctured, sometimes with greenish tinge; anterior tip of head cleft (Fig. 640); paraclypeae distinctly elongated, pointed and cylindrical . . . . . *Leptocorisa palawanensis* Ahmad



Figs. 616-631

337(335') Endocorium and clavus black 338

337' Endocorium and clavus pale to light brown 339

338(337) Abdominal tergites solid color; hemelytra dark black except the costal margins above the membrane; claspers (Fig. 641) with truncated apices and reaching well beyond pygophore; paraclypeae short, thick basally and pointed at apices ..... *Leptocorisa biguttata* Walker

338' Abdominal tergites V-VI1 black (or basal one-third) (Fig. 642); apical segments of antennae pale distally and proximally; paraclypeae cylindrical, pointed and knob-like at apices; base of clasper narrow, strongly and obliquely truncate (Fig. 643) ..... *Leptocorisa costalis* (Herrich Schaffer)

339(337') Ventro-lateral brownish black spots present in the abdomen (Fig. 644); claspers basally broad, tapering to a flat point with curved extremities; in females, proximal margin of abdominal sternite VII deeply notched ..... *Leptocorisa oratorius* (Fabricius)

339' Ventrolaterals of the abdomen and claspers not as above 340

340(339') Body length almost 13 mm; paraclypeae short 341

340' Body length usually more than 14 mm 342

341(340) Tibiae and antennae dark; paraclypeae thin medially and robust basally; apices of parameres pointed to each others' base at resting position (Fig. 645); proximal margin of abdominal tergum VII truncated ..... *Leptocorisa pseudolepida* Ahmad

341' Tibiae and antennae pale to light brown; paraclypeae (Fig. 646) thick medially and thin basally, blunt and straight; claspers with strongly pointed apices, blades very short (Fig. 647) ..... *Leptocorisa luzonica* Ahmad

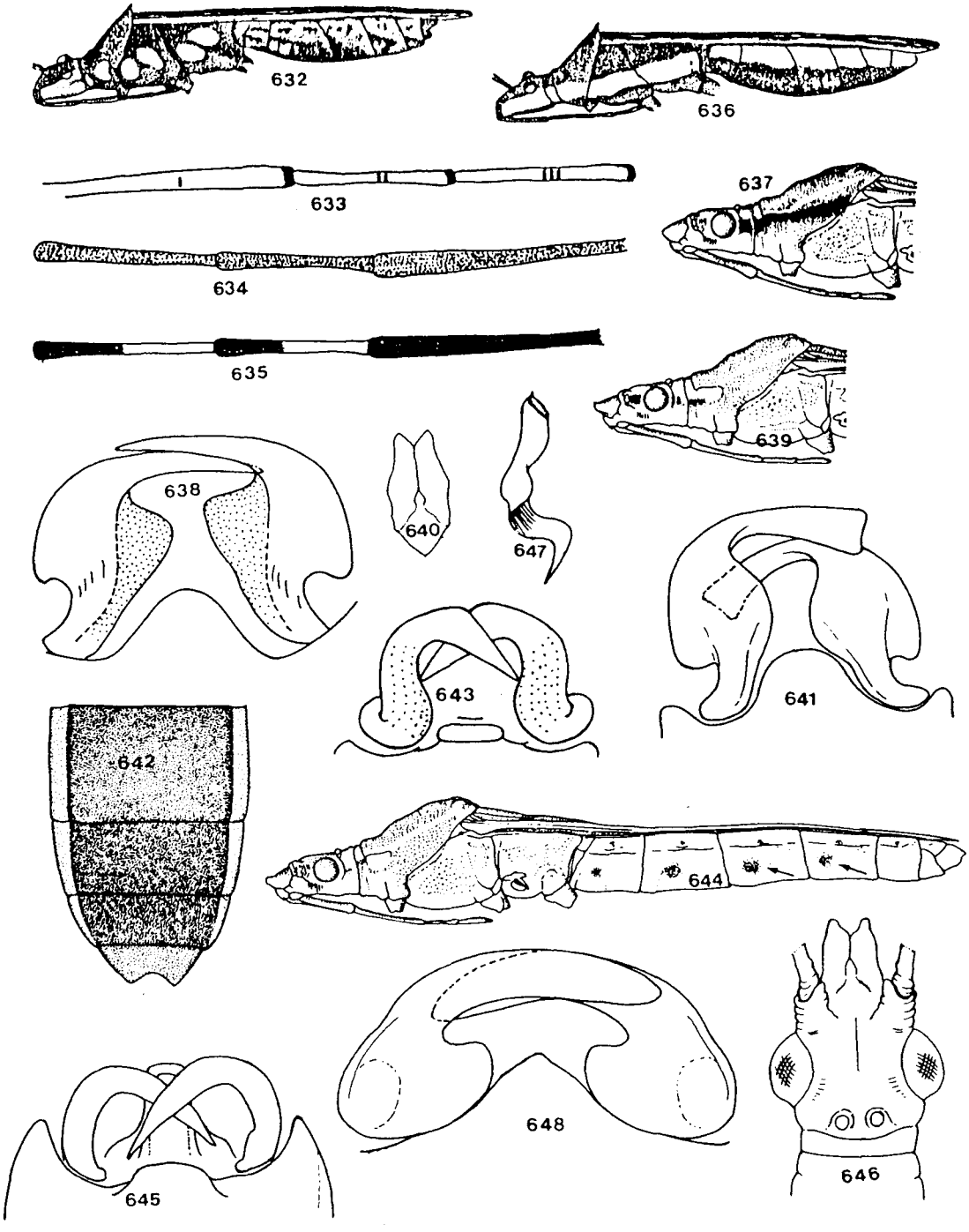
342(340') Segment I of antennae longer than 3 times the length of 1*st* rostral segment; body pale yellow-brown; claspers (Fig. 648) with very long cylindrical and pointed blades ..... *Leptocorisa tagalica* Ahmad

342' Antennal segment I shorter; parameres different 343

343(342') Callosities near pronotal posterior angles large and dark; basal joint of antennae dark brown to black; lateral black line runs from bases of antenniferous tubercles to collar sides; claspers truncated apically (Fig. 649); body length 16.8 – 18.0 mm ..... *Leptocorisa chinensis* Dallas

343' Callosities small and pale; basal joint of antennae pale and solid color; lateral black line only a black dot on the sides of collar; claspers bifid at apices (Fig. 650); body length 15-16 mm ..... *Leptocorisa acuta* (Thunberg)

344(180) Cerci sclerotized, unsegmented and modified into terminal forceps; forewing reduced to small tegmina, hindwing large, membranous, semicircular, and fan-like; abdomen long and freely movable; legs short and cursorial with 3-segmented tarsus (**DERMAPTERA**) 345


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Figs. 632-648

344' Cerci normal; wings and abdomen not as above 348

345(344) Tarsal segment 2 prolonged into a narrow lobe beneath the distal segment; usually blackish to reddish species 346

345' Notasabove 347

346(345) Black to dark reddish brown; antenna black except segments XIV-XVII (Fig. 651); yellow; elytra black, inner apical part of 1*st* pair protruded; pronotum slightly transverse (Fig. 652); branch of male forceps broad and with inner margins toothed or arched; pygidium of females transverse, distal part not narrowed ..... *Chelisoches morio* (Fabricius)

346' Yellowish brown to reddish light brown; antenna solid light brown (Fig. 653); elytra yellow with dark reddish brown bands on both lateral sides; pronotum longer than broad (Fig. 654); 3*rd* abdominal segment with a black small tubercle; pygidium of females short, distal part narrowed ..... *Proreus simulans* (Stål)

347(345') Hind-margin and angles of pronotum broadly rounded (Fig. 655); sides of abdominal segments slightly blunt and not keel shaped; parameres with external apical angle sharp ..... *Euborellia philippinensis* Srivastava

347' Hind-margin of pronotum rather square (Fig. 656); sides of 7*th* and 9*th* abdominal segments keel shaped; external apical angle of parameres broadly rounded ..... *Euborellia annulata* (Fabricius)

348(344') Two pairs of wings subequal; sterna II and III of males with complex accessory genitalia **(ODONATA)** 349

348' Wings not subequal 362

349(348) Large dragonflies, 27-42 mm long; discoidal cell divided longitudinally into triangles and supratriangles; wings held horizontally in repose, hind-wings broader than fore-wings and rounded anally in both sexes; triangles of wings different, pointed rearward in the fore-wings, and elongated lengthwise and nearer to arculus in the hindwing; eyes globular, touching or moderately separated 350

349' Moderately small 18-32 mm long, slender bodied damselflies; fore- and hind-wings similar in shape and venation; discoidal cell quadrangular, not longitudinally divided; eyes wide apart 358

350(349) Hind-wings very greatly broadened basally; 2 cubito-anal cross-veins present; 2*nd* cubito-anal of the hind-wing forms a prominent subtriangle; stigma trapezoidal; vein M2 strongly wavy; entire basal area of hind-wings somewhat yellow (Fig. 657); slightly swollen basal segments of abdomen with extra transverse carinae ..... *Pantala flavescens* Fabricius

350' Hind-wing moderately broadened basally; other characters not as above 351

351(350') Distal ante-nodal nervure of forewings complete; A2 opposite anal crossvein; prothorax with a very large, erect notched posterior lobe fringed with long hairs 352

351' Distal ante-nodal nervure of fore-wings incomplete 353

352(351) Triangle of hind-wing crossed (Fig. 658); wings smoky transparent with light brown coloration at apices, basal wing spot large reaching 2 *nd* ante-nodal and tornal angle of wing in males; pterostigma dark reddish brown covering 2 1/2 cells; frons reddish frontally; prothorax and thorax reddish brown similar to legs; distal ends of femora and inner surfaces of tibiae blackish brown; abdomen basally broad, tapers apically, strongly keel shaped and bright scarlet red; lamina of male genitalia naked or with few long golden hairs on its outer surface; borders of segment VIII markedly dilated and bordered broadly with black apical border with small ventral plate; short triangular vulvar scales bent slightly ventrally and apically to body axis in females' genitalia . . . . . *Orthetrum testaceum* (Burmeister)

352' Triangle of hind-wing free from crossveins; wings smoky transparent with slight marks at apices and borders of wings; pterostigma black with yellow-brown median, covers 2 cells (Fig. 659); frons yellow, very deeply notched to form two triangular facets in front; prothorax bright yellow, thorax and abdomen greenish yellow with black marks; segments IV to VI with a broad oval dorsal black spot on basal one-third continued finely along mid-dorsal carina to join with very broad apical black rings on IV and V; males' genitalia with a mass of long hairs; females' vental plate of segment VIII with a small convex notch the ends of which project slightly ventral wards; 9*th* ventral plate keel shaped basally and swollen at apex . . . . . *Orthetrum sabina* (Drury)

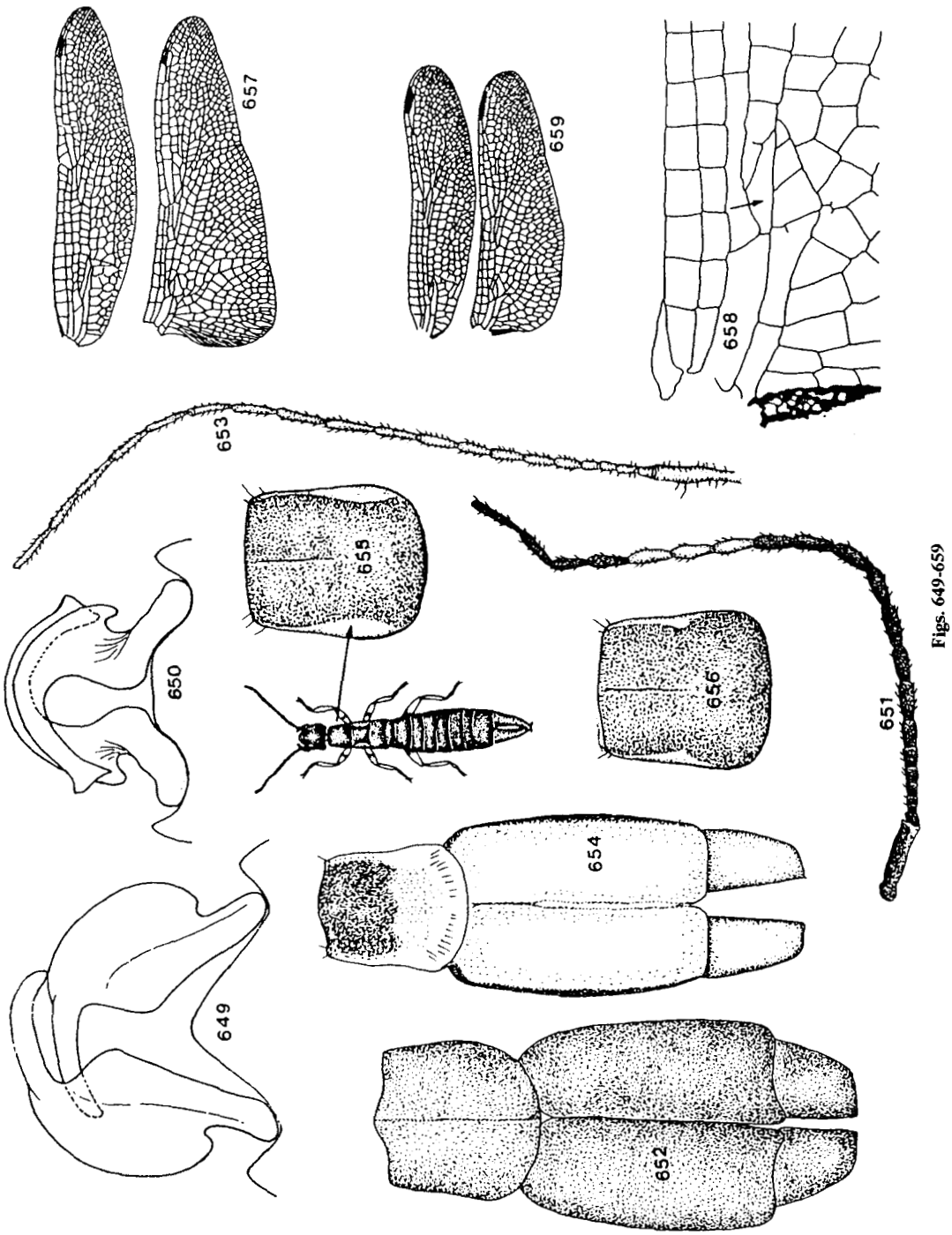
353(351') Prothoracic lobe large and fringed with long hairs; eyes contiguous for a short distance; frons non-metallic dorsally; costal border offore-wing (Fig. 660) straight, discoidal field begins with a row of 2 cells; fore-wing triangle crossed; subtriangle with 3 cells; hindwings discoidal cell entire . . . . . *Diplacodes trivialis* Fabricius

353' Prothoracic lobe small and usually naked 354

354(353') Borders of discoidal field strongly converging at wing margins; antenodal crossveins of fore-wings and hind-wings with $12\frac{1}{2}$ and 10, respectively; discoidal cell of fore-wing broader, with its costal side 0.5 the length of basal; 2 rows of cells above radial planate; no supplementary nervure; IR2 between R2 and R3; A2 smooth; stigma reddish, short with 2 crossveins below (Fig. 661); frons red dorsally . . . *Trithemis aurora* Burmeister

354' Borders of discoidal field parallel or widely divergent at wing margins 355

355(354') Wings with small basal yellow marking; usually 1 row of cells above radial planate; stigma long with 2 crossveins underneath; discoidal field widens at edge of wing; fore-wings with $9\frac{1}{2}$ – $10\frac{1}{2}$ ante-nodal nervures; eyes shortly contiguous (Fig. 662); face and frons red . . . . . *Crocothemis servillia* (Drury)



Figs. 649-659

355' Wings broadly black or dark reddish brown from basal half - two-thirds with half — two-thirds transparent area before or after stigma in males; females with a large spot at nodus and apex broadly darkened as in *N. tullia tullia* 356

356(355') Basal half of male fore-wings broadly black and opaque area in apical one-half (Fig. 663); females with large black spot at nodus and apex broadly darkened (Fig. 664) . . . . . *Neurothemis tullia tullia* (Drury)

356' Wings dark reddish brown from base up to part of stigma 357

357(356') Hind-wings with one cubito-anal crossvein; brown area in both wings reaching pterostigma (Fig. 665) abbreviated in hind-wing on posterior side and rounded externally . . . . . *Neurothemis palliata* Rambur

357' Hind-wings with 2 cubito-anal crossveins; brown area broadly squared at the base of stigma in both wings (Fig. 666) . . . . . *Neurothentis terminata terminata* Ris

358(349') Arculus well beyond Ax_2; labrum metallic blue 359

358' Arculus slightly beyond Ax_2 360

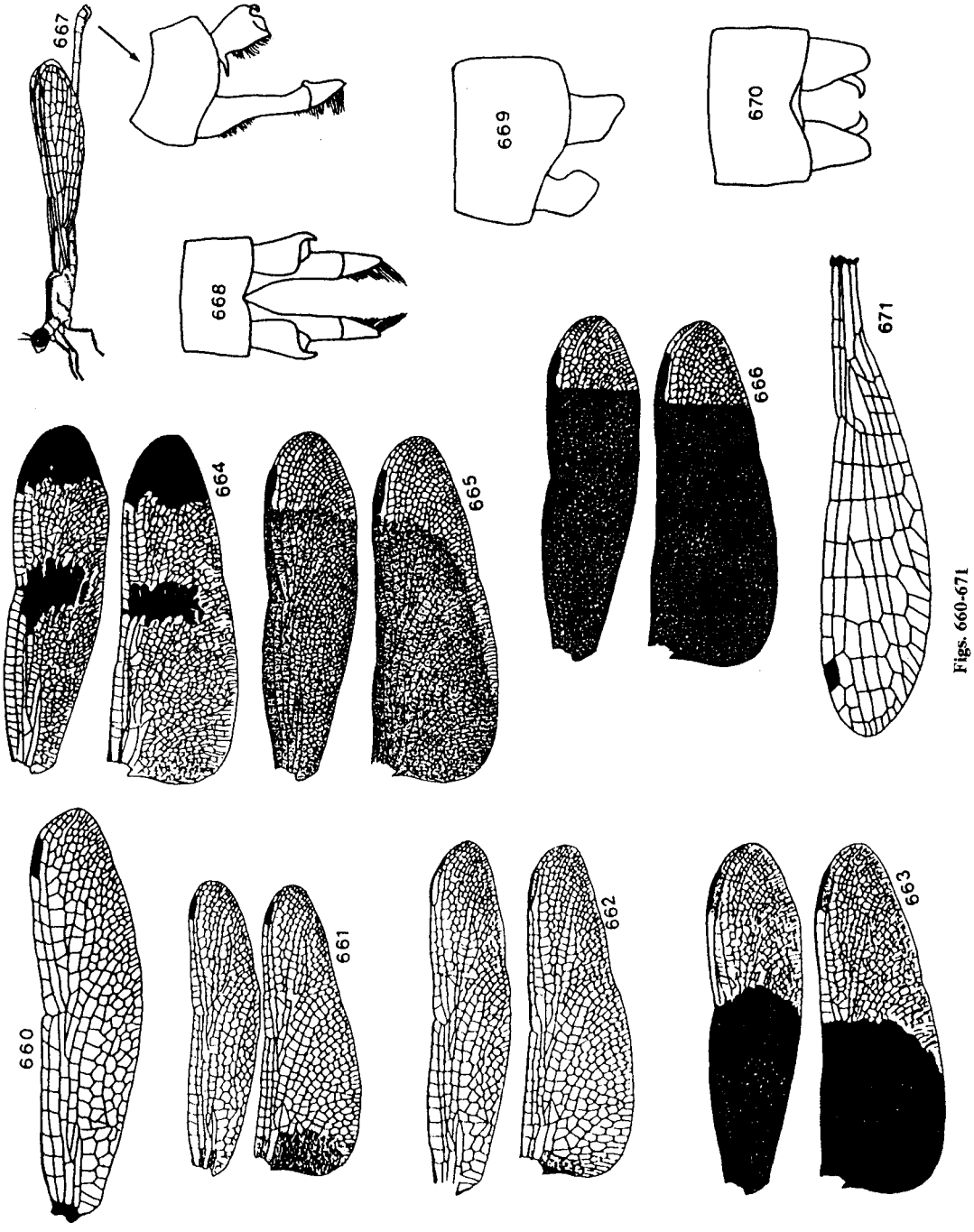
359(358) Superior anal appendages shorter than inferiors and 3-spined (2 apically and 1 basally) (Fig. 667); inferior part parallel-sided laterally and with hairs at inner side (Fig. 668); lower sides of prothorax bluish green and blue on the anterior and posterior lobe; median of posterior lobe slightly developed; fore-wing with 5-6 postnodal nervures and 4 in the hind-wing . . . . . *Agriocnemis femina femina* (Brauer)

359' Superior anal appendages longer than inferiors and without spines or tubercles (Fig. 669), inferior part with inwardly curved tips (Fig. 670); anterior lobe, lower sides and extreme part of posterior lobe apple green; posterior lobe trilobate with midlobe produced backwards; fore-wings (Fig. 671) with 6-7 postnodal nervures, and 5-6 in hind wings . . . . . *Agriocnemis pygmaea* (Rambur)

360(358') Anal bridge arising from the hind border of wing, more or less below the point where it meets anal crossing (a short nervure at base of wing extending from Cu2 + IA *(1st* anal) to the anal bridge or hinder part of wing); pterostigma of male fore-wings and hind-wings different in shape and size with 8 postnodals in the fore-wings (Fig. 672); segment X of males with a pair of apical tubercles dorsally (Fig. 673); postocular spots present; thorax with distinct black markings; body black and green, segment VIII of male abdomen bright blue and reddish to dull green in females; abdominal length 25 mm . . . . . *Ischrura senegalensis* (Rambur)

360' Anal bridge arising from the hind border at the point where anal crossing meets it 361

361(360') Segment VIII of females with an apical ventral spine; pterostigma of fore-wings almost twice the size of that in the hind-wings but both blackish grey; costal and distal borders broadly white covering three-quarters of cell; fore-wings with 9 postnodal nervures and 8 in the hind-wings; abdomen of males extremely slender and comparatively long, I-III



Figs. 660-671

pale azure blue, IV-VII pale yellow and VIII-X blue; X with an X-shaped black dorsal spot and broadly blue on sides; anal appendage black, superiors 0.5 length of segment X and apex inwardly curved (Fig. 674); inferior part small, rounded tubercles (Fig. 675); females' anal appendages very small, conical and black; vulvar scales not conspicuous and pale blue ..... *Aciagrion occidentale* Laidlaw

361' Segment VIII of females without an apical ventral spine; pterostigma of forewings very oblique, diamond shape, brownish black with outer angle and costal border narrowly white, tinted with blue on the upper surface of wing; fore-wings with 14 postnodal nervures (Fig. 676) and 12 in the hind-wings; abdominal dorsum dark metallic blue, venter brown to brownish yellow; abdominal segment IX and X with inverted yellow V-shaped marks laterally ..... *Pseudagrion pilidorsum pilidorsum* Brauer

362(348') Wing veins with marginal branching; wings broad with blunt to slightly rounded apices; Rs slightly wavy and inner series of gradates of both wings converged with Rs; subcosta and radius in hind-wings of male fused below stigma; male stigma heavily developed, narrow in the fore-wings, and wider and often brown-pigmented, never fused with radius in the hind-wings (Fig. 677); adults green with conspicuous orange-yellow mid-dorsal stripe; larvae trash-carriers, head with 6 prominent reddish brown stripes, middle 4 forming Y-shape; body with 3 longitudinal brownish stripes (**NEUROPTERA**) [Chrysopidae] ..... *Chysopa basalis* Walker

362' Wing veins without marginal branching; larvae not trash-carriers 363

363(362') Fore-wings form a highly chitinous or leathery non-folded, rigid plate called elytra (**COLEOPTERA**) 364

363' Fore-wings elongate membranous without hamuli and shed off by basal sutures, or fore-wings and hind-wings coupled by hamuli (hook structures) during flight; some species wingless with characteristic node forms 485

364(363) Notopleural suture in the prothorax absent; wings without an oblongum; hind-coxae movable, separated from the meta-sternum and never dividing basal abdominal sternite into 2 lateral lobes 365

364' Notopleural suture present; wings with an oblongum; hind-coxae fused to the meta-sternum dividing the basal abdominal sternite into 2 lateral lobes 426

365(364) Posterior coxae not reaching elytra; meta-sternum with a transverse suture; terrestrial beetles with legs adapted for crawling or running 366

365' Posterior coxae reaching elytra; meta-sternum without a transverse suture; hind-leg hairy and adapted for swimming; coxa III large without longitudinal plates, metasternal-metacoxal suture arched [Dytiscidae] 419

366(365) Antennae arising in front of head above bases of mandibles; head width across eyes always wider than thorax; inner lobe of maxillae with movable hook at its end; clypeus

extended laterally beyond the base of antennae; elytra with white to light yellow markings or spots; tiger beetles [Cicindellidae] 367

366' Antennae arising more laterally on sides of head between eyes and bases of mandibles; head width across eyes always narrower than thorax; inner lobe of maxillae without a movable hook; clypeus not extended laterally beyond base of mandibles; elytral pattern variable; ground beetles [Carabidae] 385

367(366) Elytra with 6-8 white to yellow sub-globuiar spots; middle of elytra with 3-4 spots arranged in a longitudinal row parallel to each other (also parallel transversely); humeri, lateral, and sutural margins without marks or spots; sides of pronotum with or without white hairs; scape with 2 setae near apex 368

367' Elytral marks variable, never in a longitudinal row parallel to each other; humeri, lateral and sutural margins with marks or spots, if not dots present and very close to each otlier in the humeri lateral and sutural areas; apex of scape with 1-2 setae 373

368(367) Sub-apical area of labrum with 7 long setae; sides of pronotum without white hairs; elytra with 6 globular to sub-globular spots 369

368' Sub-apical area of labrum with 6 long setae; sides of pronotum with or without hairs; elytra with 6-8 sub-globular spots 370

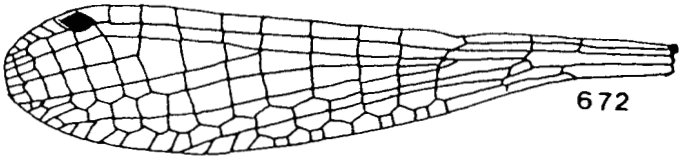
369(368) Right side of labrum with 3 sub-apical and 1 sub-median long hairs, sub-basal area with a narrow transverse yellow band; head and pronotum slightly coarse, striped near eyes; longitudinal mid-groove almost 0.5 times width of sub-posterior area of pronotum, posterior one-fifth with longitudinal stripes (Figs. 678-679); median elytral yellowish spot markedly oblique and larger than the rest, sub-apical spot smallest in males (Fig. 680) and sub-humeral spot the smallest in females (Fig. 681); length 15-17 mm . . . . . *Cicindela* sp. A

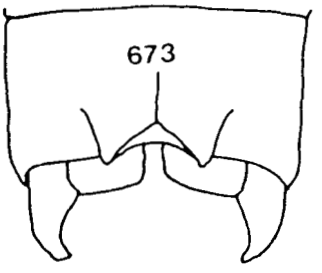
369' Left side of labrum with 4 sub-apical long hairs in a row; each side of the labrum with a broad rectangular yellow spot, apex of labrum with 3-5 teeth in some females; head striped farther behind eyes; front pronotum shallowly V-shaped, posterior one-fifth without longitudinal stripes (Fig. 682); elytral white spots usually globular and equidistant (Fig. 683); length 13.5-16 mm . . . . . *Cicindela sexpunctata* Fabricius

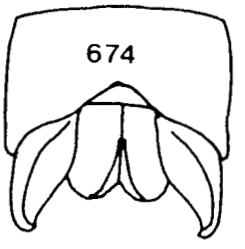
370(368') Sides of pronotum with white setae; males with 8 spots on elytra, basal spot very small roughly one-third of middle spot and transverse (Fig. 684); females (Fig. 685) with 6 spots without the subbasal; subhumeral spots in both sexes slightly oblique; labrum with 3 teeth, black with a rectangular yellow spot on each side in females; yellow band of labrum in males almost contiguous except for a moderately broad blackish brown apical and basal median band . . . . . *Cicindela* sp. B

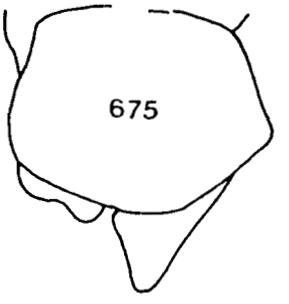
370' Sides of pronotum without white hairs; both sexes with 6 spots 371

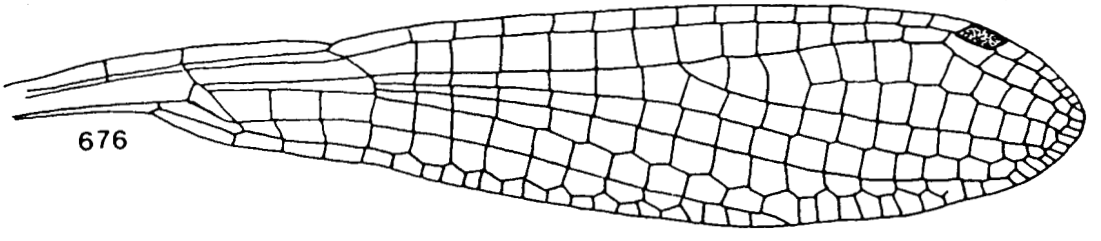
371(370') Apical spots on elytra noticeably large almost equal in size to the median spots (Fig. 686) but larger than the subhumeral spots in the females; median spot the largest in

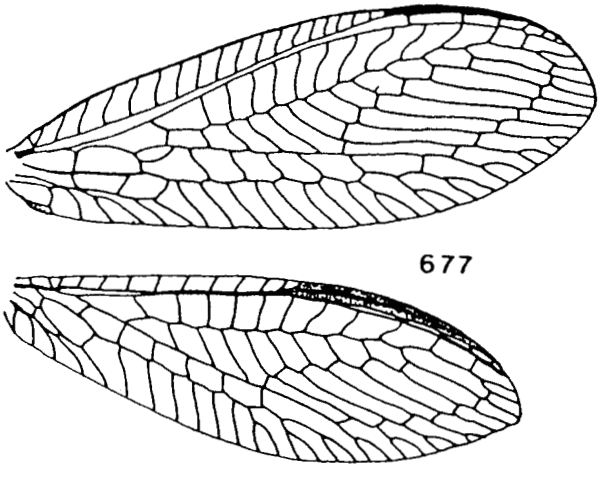












Figs. 672-677

males; distances between spots unequal; posterior part of pronotum with transverse rope-like stripes; labrum bluish with light yellow marks on each side, broad and prominent in males (Fig. 687) . . . . . *Cicindela* near *sexpunctata* Fabricius

371' Apical spots on elytra smaller than the median, equal to or a little smaller than subhumeral spots 372

372(371') Elytral spots same distance from each other, subhumeral slightly oblique and oblong (Fig. 688); pronotum as long as wide and with 2 transverse ridges posteriorly (Fig. 689); next to last sternite of males with a moderately wide and deep median apical cleft; longitudinal light groove of terminal sternite near the left side of the apical cleft of the preceding sternite; length 16 mm . . . . . *Cicindela* sp. C. *(sexpunctata* grp.)

372' Median spots closer to the subhumeral than to the subbasal spots (Fig. 690); pronotum with midlongitudinal part with short transverse striae and oblique in the posterior part (Fig. 691); penultimate sternite of males with a moderately deep cleft medio-apically; longitudinal groove of terminal sternite slightly on the right side of the apical cleft of the preceding sternite; length 14.8 mm . . . . . *Cicindela* sp. D *(sexpunctata* grp.)

373(367') Small to moderately small tiger beetles, 7-12 mm long 374

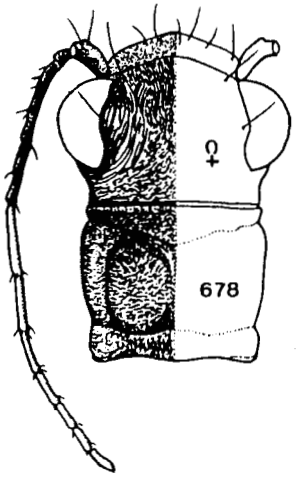
373' Large tiger beetles, 13-20 mm long 380

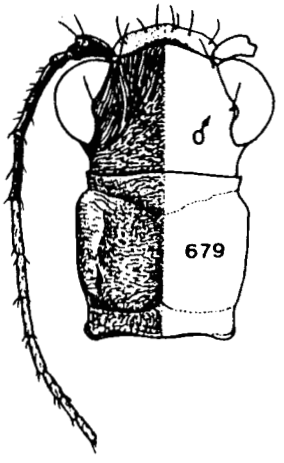
374(373) Humeri without yellow marks or spots; sides of pronotum with white hairs, apical width slightly less than median width 375

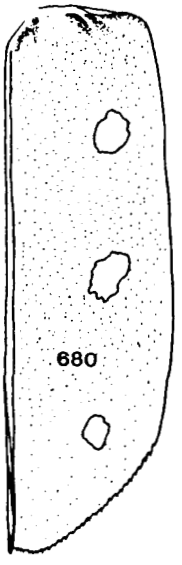
374' Humeri with yellow mark or spot; sides of pronotum with or without hairs; apical width prominently narrower than median width 376

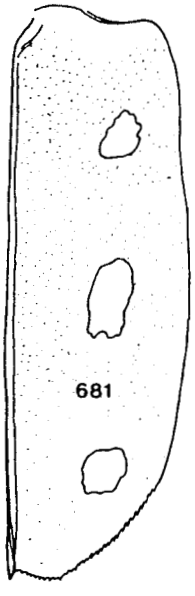
375(374) Elytra black with 2 small yellow spots in each elytron, a pale sub-median closer to the sutural margin and an oblique apical (= apical lunule without a leg), distinctly punctated but not confluent, some discal areas not pitted; apical spine of elytra developed and slightly beyond level of apical teeth (Fig. 692); labrum black, raised medially with **7** sub-apical setae (4 in the left and 3 in the right), apico-median with a tooth and wavy towards sides producing a small inner and wider outer concavities; sub-apex of scape with only 1 seta (Fig. 693); pronotum (Fig. 694) cylindrical and as long as wide, slightly rough striae converging to the median line; length 8 mm . . . . . *Cicindela* nr. *kaleea* Bates

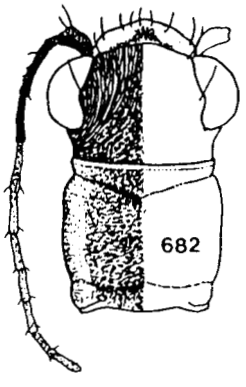
375' Elytra dull black with 3 small spots near middle of elytra and an apical lunule, in some specimens the spot in the midbasal one-third absent but a wide unpitted area around the globular spot in the apical one-third present (Fig. 695); median tooth of apex of labrum in a deep cavity, blunt elevations on each side of the tooth and moderately obliquely square towards lateral sides; subapex of labrum with 6 white hairs; middle of frons with fine zigzag stripes running backwards to the vertex; supraorbitals with 13-14 well separated longitudinal ridges; length 8-9 mm . . . . . *Cicindela kaleea* Bates

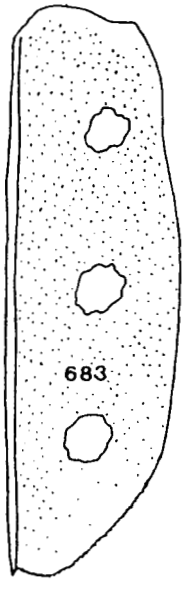




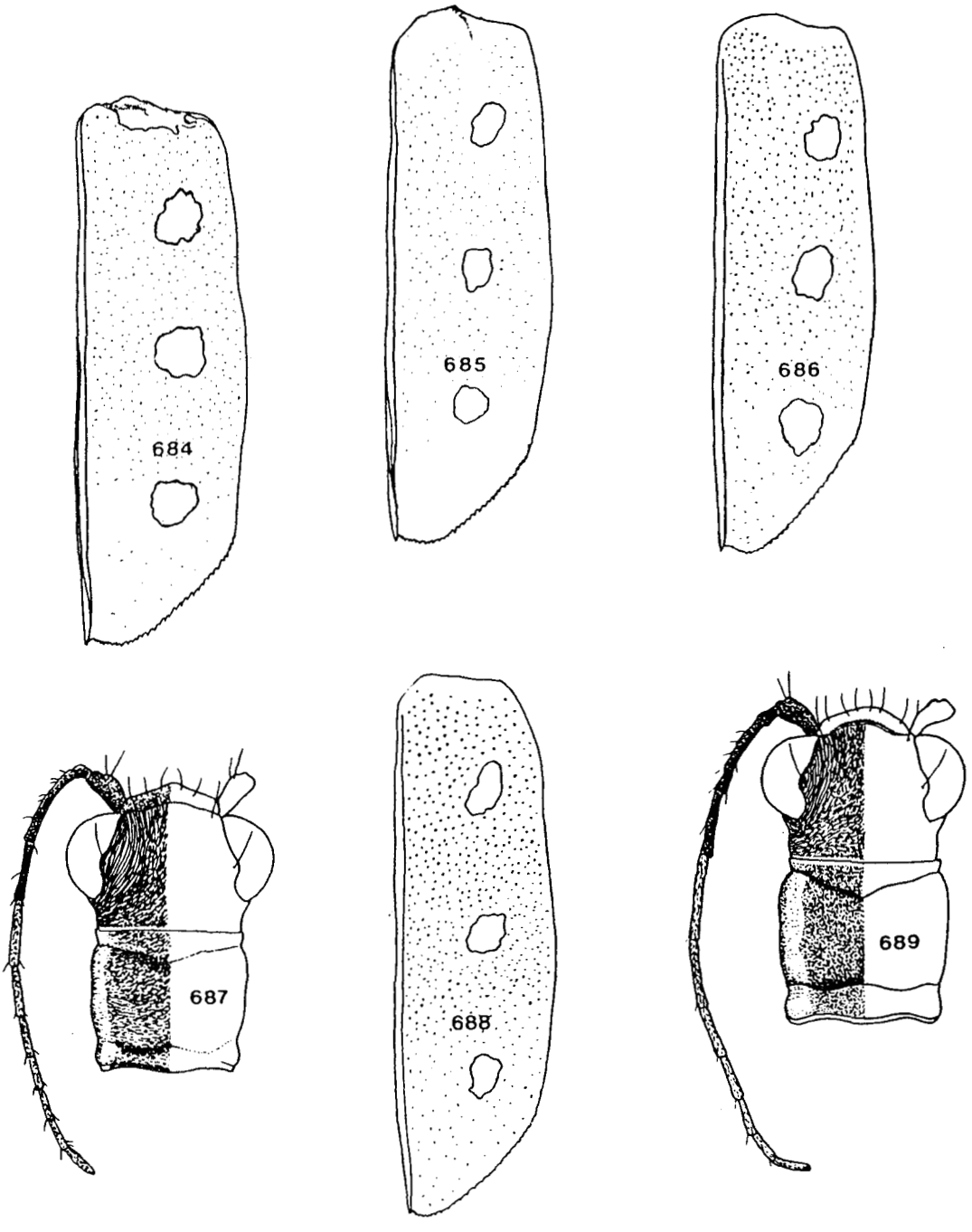








Figs. 678-683



Figs. 684-689

376(374') Basal half of elytra with 2 pairs of parallel yellow stripes near sutural margins, base with a pair between humeri and margins near scutellum; humeri with a yellow band extended up to the apical lunule, sometimes interrupted along mid-half but usually connected to an oblique band directed to the sutural margins (Fig. 696); labrum yellow with apical area brown, 3-5 teeth with 4 white hairs subapically (Fig. 697); length 9-11 mm . . . . . *Cicindela striolata* Illiger

376' Subsutural area without parallel yellow stripes 377

377(376') Marginal band with a "foot" and a "knee" 378

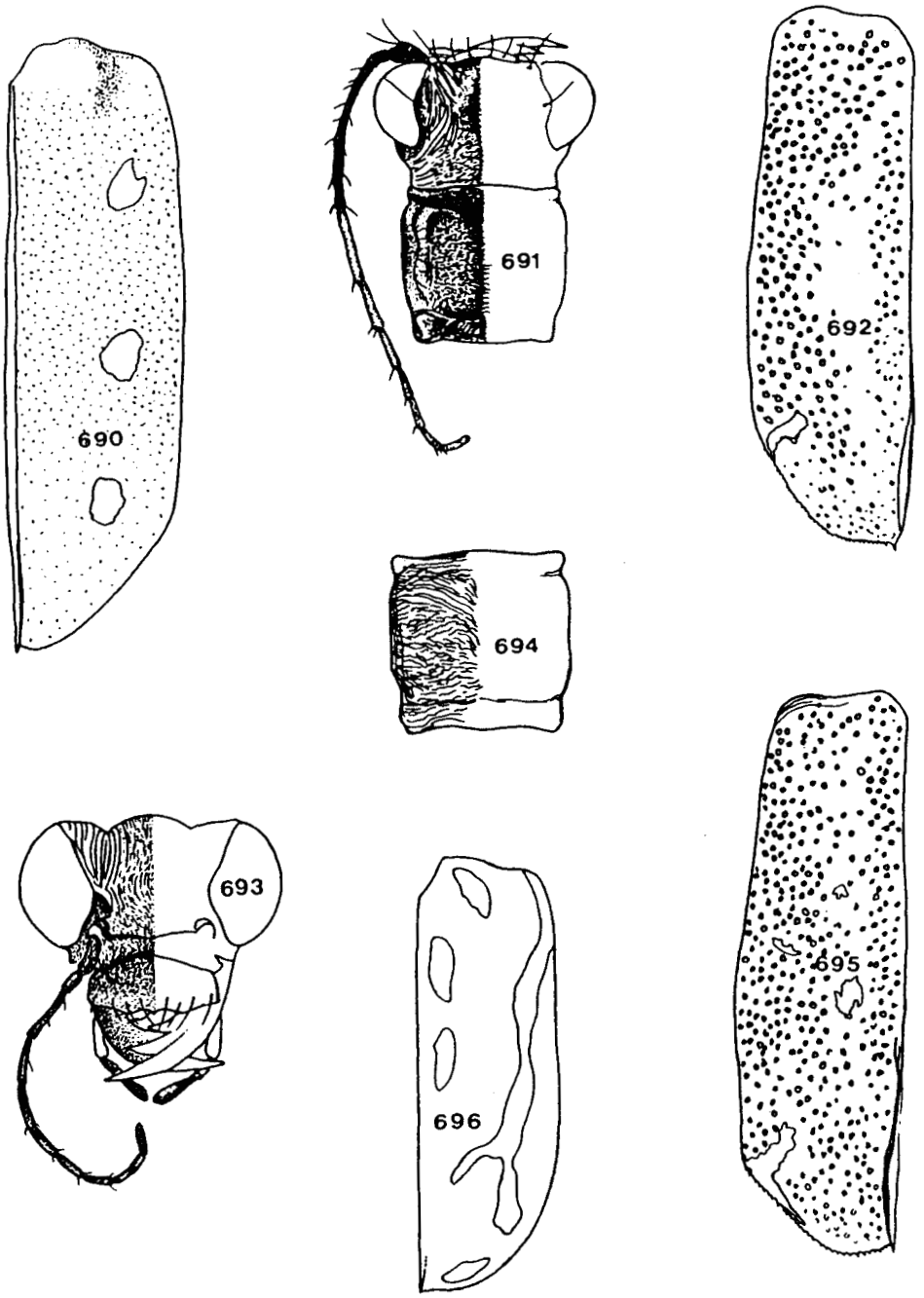
377' Marginal band reduced to spots 379

378(377) Humeral lunule and its slightly oblique, broad and strongly C-shaped spot occupying more than half of width of elytron, distinctly separated from the marginal lunule; band connecting marginal lunule to its "knee" deeply concave towards base and slightly pointed on opposite end (apex); foot of marginal lunule square, enlarged at tip and concave towards the knee; marginal lunule narrowly separated from apical lunule; arm of apical lunule directed towards "foot" broadly connected to it; apex of elytron distinctly higher than sutural spine (Fig. 698); length 8-11 mm . . . . . *Cicindela elisae* Motschulsky

378' Humeral lunule and its spot normal C-shaped with tips almost on top of each other occupying about half of elytra1 width and thinly connected marginally to the marginal lunule; rounded "knee" connected to the marginal lunule by a straight transverse band and J-shaped from "knee" to "foot"; tip of foot rounded; marginal lunule well separated from the apical lunule; arm of apical lunule water-drop like and very thinly to almost unnoticeably connected to it; apex of elytra lower than the sutural spine, elytra of females broadened along marginal lunule (Fig. 699); labrum (Fig. 700) yellow except black apex and base, apico-median with a sharp moderately long black tooth and 15 sub-apical white hairs in 2 rows; length 10-12 mm . . . . . *Cicindela sumatrensis* Herbst

379(377') Elytron dull black with 6 sub-globular yellow spots (Fig. 701); 5 along lateral margins and 1 small globular spot at mid-half close to the sutural margin; humeral spot well isolated from the sub-humeral spot; apex of elytra with serrations small and very close to each other towards the prominent sutural spine and apical lunule short (Fig. 702); labrum pointed apico-medially and lined with 14 hairs (Fig. 703); females with a more pronounced apex of elytra and oblique toward the sharply pointed sutural spine, pronotum dark blue, without hairs along lateral margins, nearly glabrous and rounded latero-medially (Fig. 704); length 9-10 mm (note: this is a new Philippine tiger beetle very similar to *C. ferriei)* . . . . . *Cicindela* nr. *ferriei* Fleutiaux

379' Elytron with 3 ovoid yellow spots in an oblique row towards the humeral spot, middle spot thinly connected to the subapico-median spot; lateral margins with 2 smaller thinly connected spots parallel to the median and subapico-median spots (note: these 4 spots



Figs. 690-696

are well separated in the males); apical lunule complete with enlarged tips and relatively thin connections (Fig. 705); labrum largely yellow with brownish apical margins, 3 teeth with a large middle tooth and slightly concave towards lateral margins; sub-apical margins with 6 long white hairs; pronotum hairy laterally, subapical and subbasal transverse groove deep (Fig. 706); length 12 mm . . . *Cicindela lacrymosa* (Fabricius)

380(373') Apical lunule complete and inverted J-like; marginal and humeral lunule present or reduced to spots 381

380' Apical lunule absent with only a spot near base of apical serrations; marginal without distinct knee or reduced to spots; humeral and sub-humeral spots distinctly separated 382

381(380) All lunules complete; humeral spot slightly oblong; basal part of inverted H-like marginal lunule sharply pointed and apical lunule small Y-shaped with a moderately enlarged inner arm directed towards the "foot" (Fig. 707); length 13 mm . . . . . *Cicindela specularis* Chaudoir

381' Elytra with 6 prominently yellow spots and an apical lunule; 3 spots in a mid-diagonal row towards humeral spot and 2 along lateral margins (a small dot below middle towards base and an oval large one above middle towards apical lunule); lower humeral spot strongly oblique and the spot in the apical one-third near sutural margin transverse-oblique (Fig. 708); both ends of apical lunule square, margins of elytra opposite lunule evenly toothed (Fig. 709); pronotum smooth between transverse grooves and stripes near eyes with a narrow smooth area in between (Fig. 710); labrum with a very sharp tooth near mid end (Fig. 711); length 13-13.5 mm . . . . . *Cicindela* nr. *lacrymosa* (Fabricius)

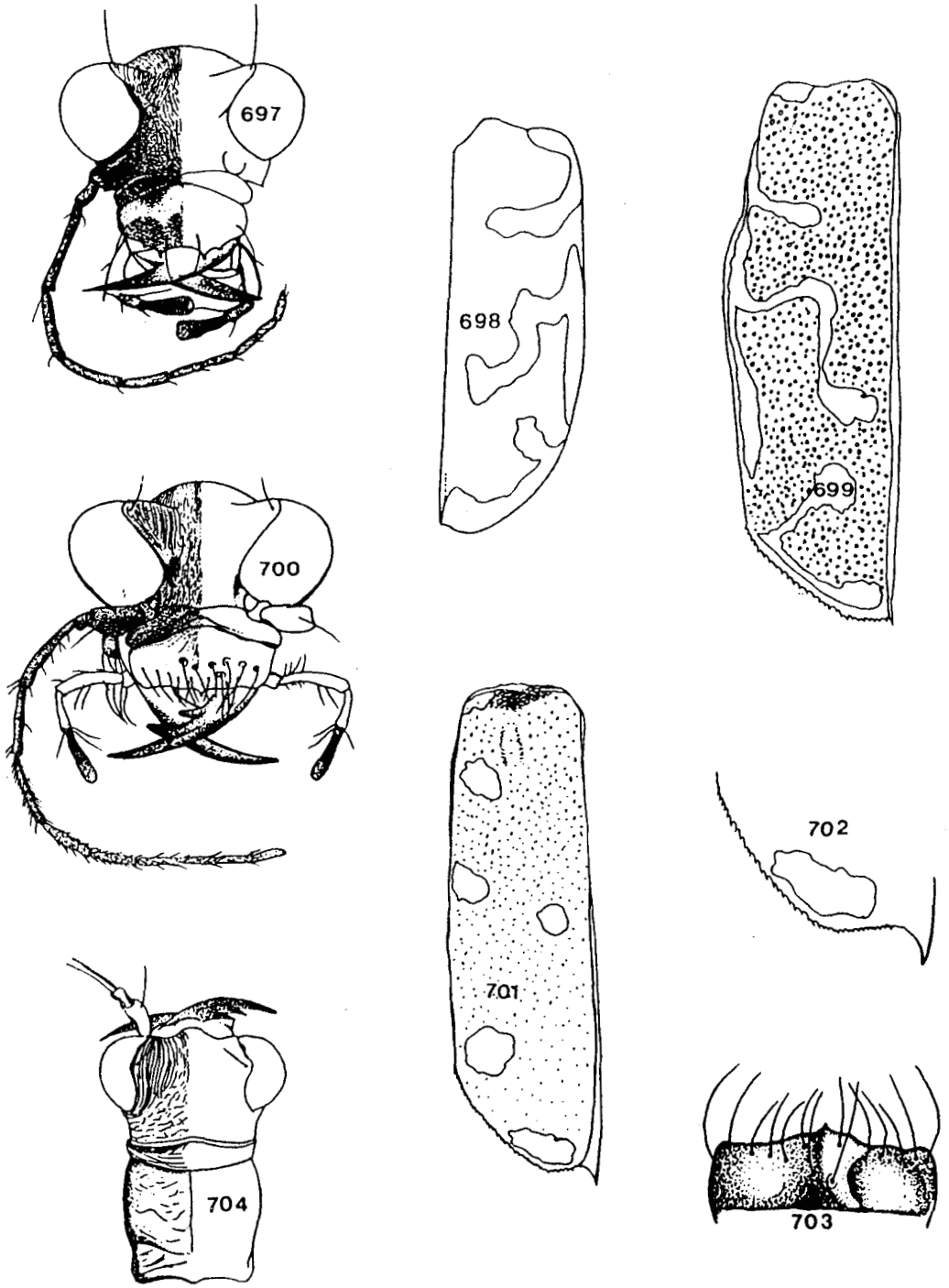
382(380') Elytra with 3 oval or round spots and a large key-shaped marginal lunule with an expanded band towards lateral margin and an oblique band towards the sutural margin (Fig. 712); length 15-18 mm . . . . . *Cicindela japana* Motschulsky

382' Elytra pattern rather different; elytra with 5 spots, middle area usually with 2 spots opposing each other in an oblique position 383

383(382') Discal spot slightly above mid-half towards apex near the sutural margin, small and globular about 2-2.5 times its diameter away from marginal band; rest of the spots unequal in size except the biggest marginal band; lower humeral spot longitudinal in position; humeral and subapical (in the apical one-fourth) transverse and discal spot slightly oblique (Fig. 713); length 17 mm . . . . . *Cicindela ferriei* Fleutiaux

383' Disd spot ovoid-elongate and very close to the marginal middle band; length 18-20 mm 384

384(383') Marginal middle band transversely oblong with a pointed inner tip directed towards subglobular discal spot; subhumeral spot button-like; subapical spot subovate and transverse (Fig. 714); length 20 mm . . . . . *Cicindela japonica* Thunberg



Figs. 697-704

384' Marginal middle band subglobular without a pointed inner tip; discal mark elongated with a pointed outer tip directed towards middle marginal band; subhumeral spot oblongate; subapical spot slightly pentagonal (Fig. 715); length 18 mm . . . . . *Cicindela chinensis* De Geer

385(366') Abdomen with 7 or 8 sterna visible; mandibles with a setigerous puncture in scrobe (Fig. 716); elytron truncate at apex 386

385' Abdomen with 6 visible sterna; mandibles without a setigerous puncture in scrobe; elytra usually not truncate at apex 391

386(385) Costae on elytra weak, faint and vaguely connected before apex (Fig. 717); black except brownish yellow pronotum with some brown marks apicomedially and medially; pronotum and elytra hairy; head moderately hairy, few white bristles behind eyes latero-ventrally, and with closely punctate to network-like punctations in the frons and vertex; labrum slightly rounded apically with 5 bristles (Fig. 718); length 6-7 mm . . . . . *Brachinus* sp.

386' Costae on elytra strong, distinct and separate apically; length 13-22 mm 387

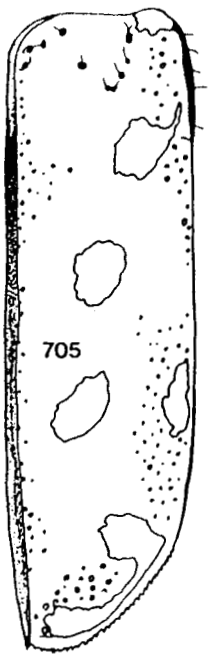
387(386') Elytra without transverse yellow spots or marks at midhalf and humeri; pronotum with or without a pair of lateral longitudinal bands 388

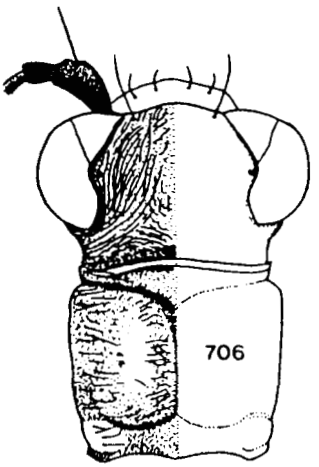
387' Elytra with prominent transverse yellow bands at midhalf and at humeri, pronotum with a pair of yellow bands or entirely yellow with anterior and posterior margins black interconnected by a median longitudinal black band 389

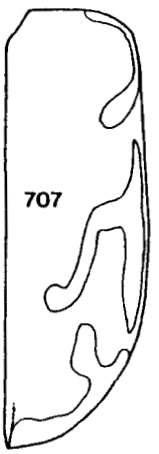
388(387) Moderately small species; length 13-15 mm; pronotum entirely black; black band of vertex entire extended to rearside of eyes and dorsally a little above level of supraorbital setae (Fig. 719); knees or apices of femora little, brownish red, and groove 3 with a long subapical setae; costae I straight basally; all costae of elytra very prominent producing clear grooves (Fig. 720); proepisterna uniformly black . . . . . *Pheropsophus* sp. A

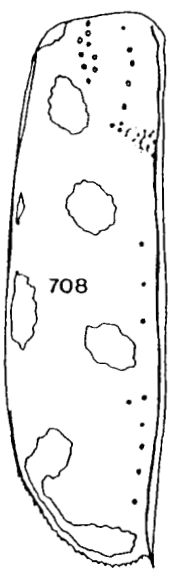
388' Relatively large species, length 19-22 mm; pronotum black with a pair of longitudinal yellow bands; vertex with a black median band, its anterior part high in front of supraorbital setae reaching midhalf level of eyes (Fig. 721); knees with prominent black band, entire ventro-apical half blackish brown and inner apical one-fourth dark brown in males; groove 2 with a long subapical seta; costae I slightly diverging basally; all costae of elytra prominent producing shallow grooves (Fig. 722); central area of proepisterna yellow . . . . . *Pheropsophus* sp. B

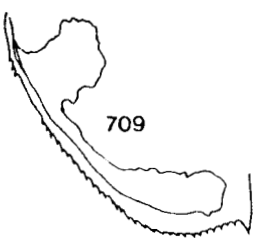
389(387') Median transverse band of elytra zigzag-like and not reaching costae 2 or very small and narrow reaching only groove 2 and interrupted between costae 4, 5, 7 and 8; humeral spot extended to groove 5 (Fig. 723); entire length of epipleura yellow; pronoturn black with a broad oblong yellow band on each side of median longtitudinal groove; propleuron entirely yellow except black spot near coxa I, anterior and dorsal margins;

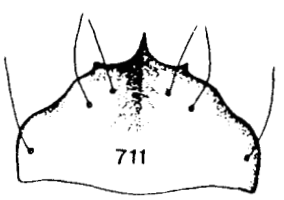


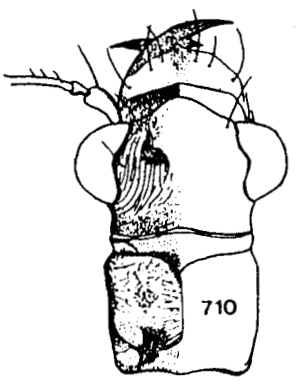




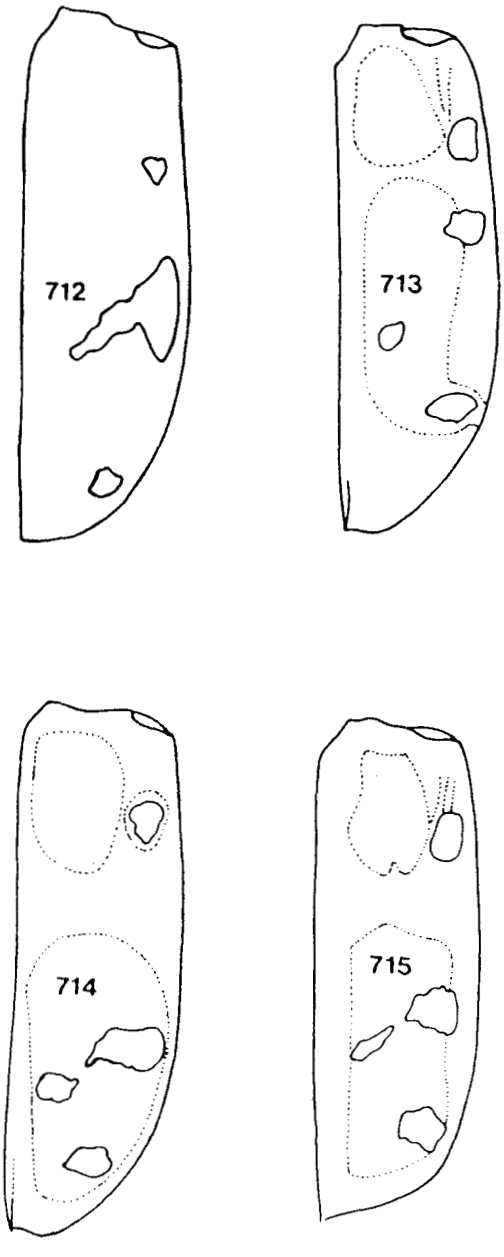








Figs. 705-711



Figs. 712-715

vertex with a broad median black band, its apical end strongly concave and above midlevel of eyes (Fig. 724); length 17-20 mm . . . . . *Pheropsophus javanus* (Dejean)

389' Median transverse band of elytra broad reaching costae 2 390

390(389') Humeral spot large and subglobular containing the subbasal setae in groove 5 (Fig. 725); pronotum with a narrow yellowish lateral band not reaching anterior and posterior apices, widens only medially opposite midlateral setae (Fig. 726); propleuron reddish brown with a yellow band along dorsal margin becoming subtriangular subposteromarginally; vertex with a broad median band reaching entire median of frons, constricted at middle and subbasal area (Fig. 726); length 12-21 mm . . . . . *Pheropsophus occipitalis* (MacLeay)

390' Humeral spot small and elongate, below the subbasal setae in groove 5 (Fig. 727); pronotum brownish yellow with a black I-shape band; vertex with a median band narrowed at basal half, not reaching frons (Fig. 728); length 16 mm. . . . . *Pheropsophus jessoensis* Morawitz

391(385') Prothorax long, swollen at middle, narrowed anteriorly and posteriorly with or without setae in the lateral groove; elytra reddish similar to prothorax; with a broad black or blue transverse band along apical half or before apex with a pair of white spots on the apical margins of the band (some species with another pair along the posterior margin of band or with blue to black band on base of elytra 392

391' Prothorax subcylindrical with almost parallel sides and dorsal surfaces glabrous; shining black to dull and punctated; prothorax usually wider than long 399

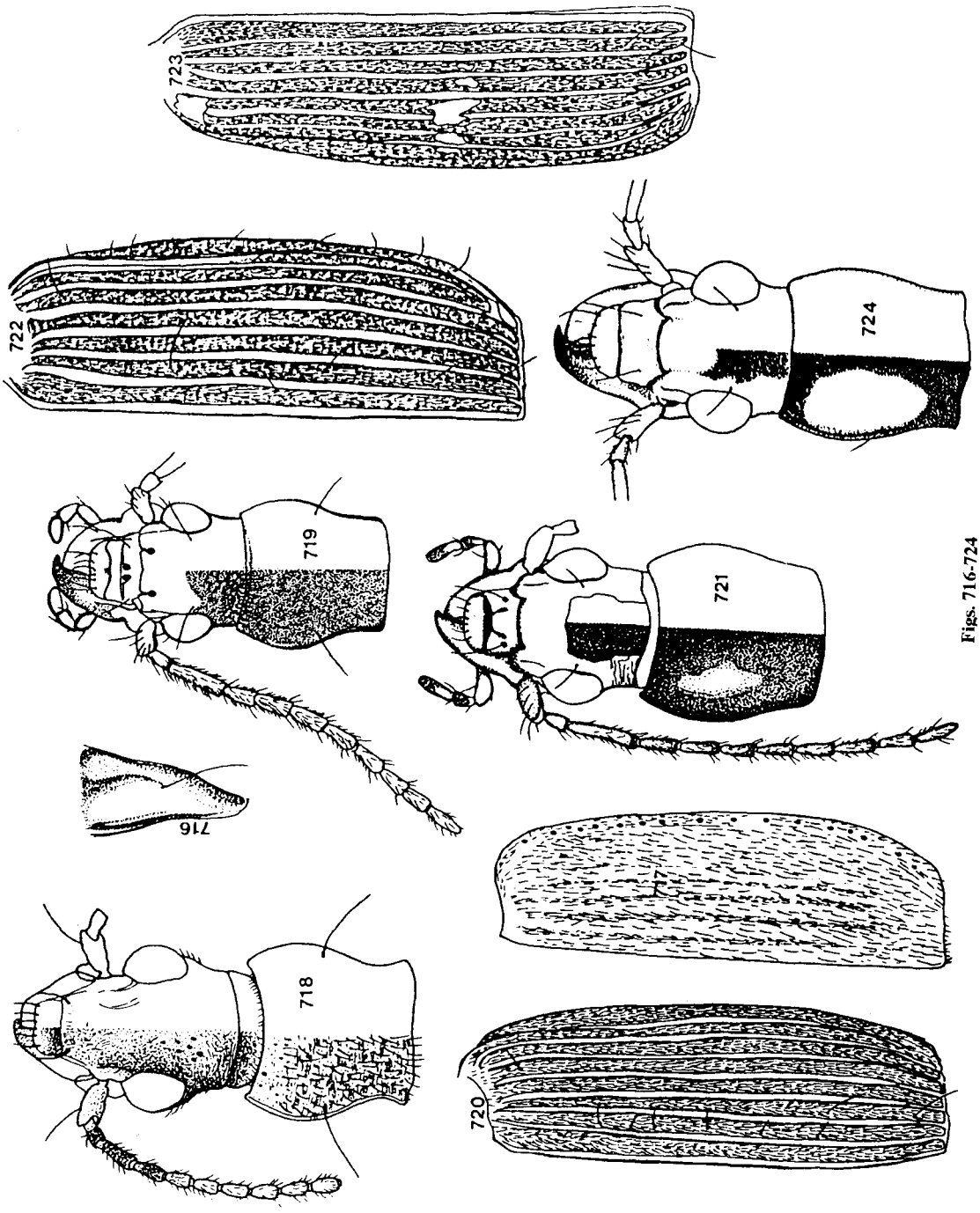
392(391) Fourth tarsal segment simple, not bilobed; head impunctate; prothorax smooth or transversely striated; head, prothorax and elytra blackish 393

392' Fourth tarsal segment bilobed; head slightly to heavily punctate; pronotum strongly punctate 395

393(392) Prothorax without lateral setae, apical third less punctate than the rest, lateral side ungrooved and not bordered; head punctate except smooth vertex and hind area of eyes; subapical hair of scape longer than entire length of scape (Fig. 729); shiny black species with brownish epipleura and apices of elytra; intervals 5 and 6 with a longer blackened area closer to apex; apical portion of elytra obliquely truncate (Fig. 730); length 5.5-6mm . . . . . *Eucolliuris* sp.

393' Prothorax with 1 or 6 setae on each side; elytra with a pair of white spots subapically 394

394(393') Prothorax red and fairly long with transverse striations, swollen below midhalf but constricted before base; lateral side with 1 seta; apical half or more of elytra black with silvery white spots below midhalf of black band in intervals 5 and 6, basal half red (Fig.



Figs. 716-724

731); head black and straightly narrowed up to neck; femur I black except yellow basal third and with few scattered spines; length 7-8.3 mm ..... *Archicolliuris bimaculata* (Redtenbacher)

394' Prothorax black and moderately short, shiny and smooth with 6 setae on each side, base with 4 transverse grooves (Fig. 732); elytra shiny black with reddish brown tinge: and a silvery white spot in interval 4 before apex of each elytron (Fig. 733); femur I light brown and uniformly clothed with many hairs around its entire length; length 6 mm ..... *Odacantha* sp.

395(392') Prothorax without a pair of lateral setae; elytra with 1-2 bluish black bands and 4 white spots 396

395' Prothorax with a pair of lateral setae; elytra with 2 bluish black bands and 2 white spots 397

396(395) Elytra with 2 blackish blue bands, a small one at base and a broad one right below midhalf with band length of each elytron as long as width of elytron; all 4 spots along margins of the band; anterior spots on interval 5 twice as large as posterior spots on intervals 4 and 5; prothorax somewhat rugose on apical and basal areas and apical angles rectangular (Fig. 734); length 6.6-7.8 mm ..... *Ophionea indica* (Thunberg)

396' Elytra with 1 black band near middle, basal band absent; white spots on elytra nearly similar in size; half of anterior spots sunken in the band and interval 5 widens along that area to accommodate the spot; posterior spots on intervals 4 and 5 within the band; prothorax distinctly and closely transversely rugose forming small transverse meshes (Fig. 735); length 7-7.1 mm ..... *Ophionea nigrofasciata* Schmidt-Goebel

397(395') Elytra (Fig. 736) with 2 pores each on interval 5 of each elytron and 10 on interval 3, white spot on interval 4 slightly bean-shaped and small; sides of back of head straight and with few hairs; apical part and margins of prothorax above setae with short fine hairs; 2 long setae noticeably below hind margins of eyes (Fig. 737); length 7 mm ..... *Ophionea interstitialis* Schmidt-Goebel

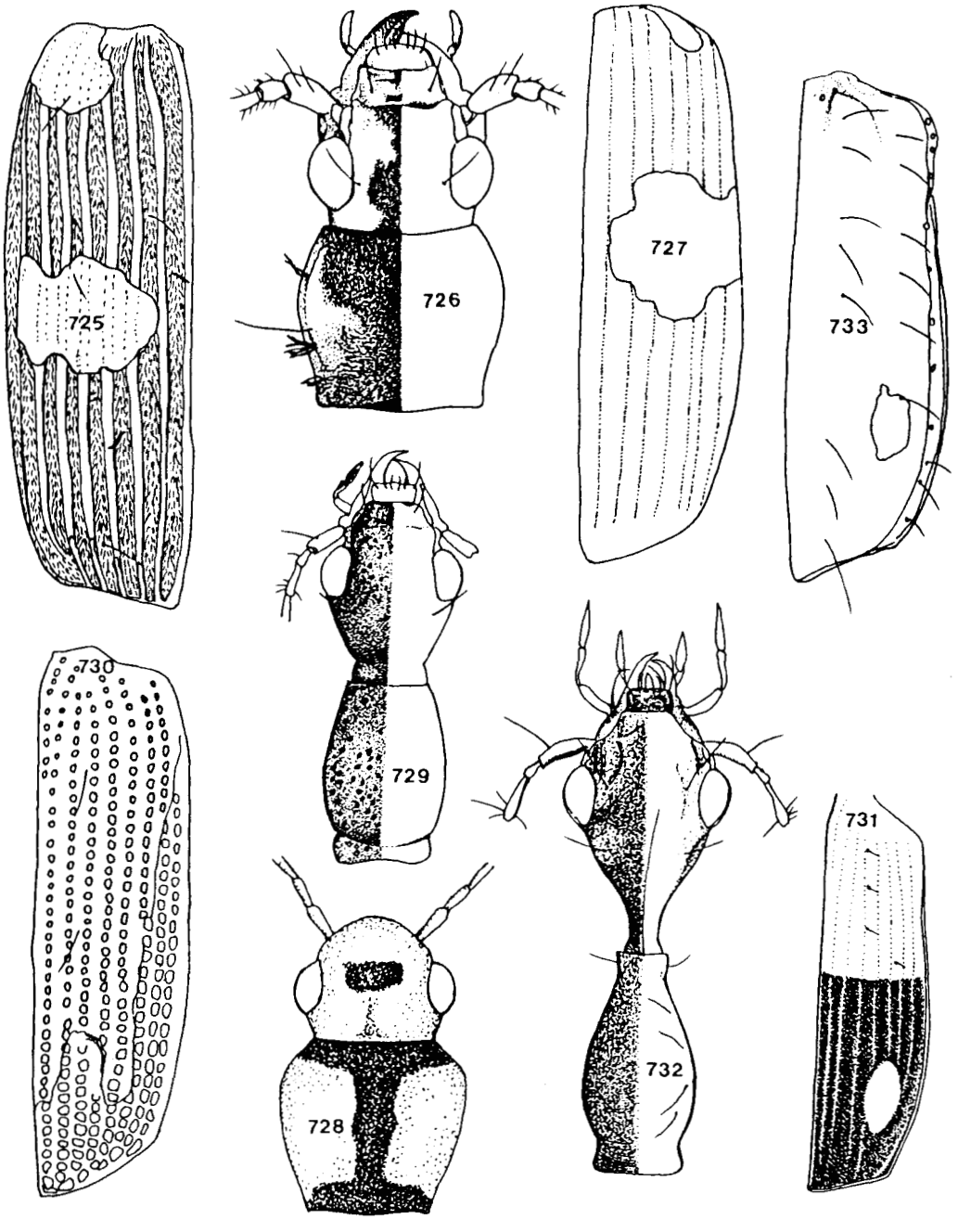
397' Elytra without pores on interval 5 and with less than 10 pores on interval 3 398

398(397') Silvery white spot long, more than 0.5 times length of posterior band; interval 3 with 9 pores; back of head behind eyes moderately rounded (Fig. 738); prothorax swollen a little above the posterior constriction; length 7 mm .... *Ophionea ishii hoashii* Habu

398' Silvery white spot small, noticeably less than half length of posterior band; interval 3 with 8 pores (Fig. 739); back of head behind eyes less rounded but not straight; prothorax swollen below the setae (Fig. 740); length 6.4-7 mm ..... *Ophionea ishii ishii* Habu

399(391') Prothorax subcylindrical or quadrate but with a small tooth in postero-lateral margin opposite the last pair of setigerous punctures; tibia I normal or with laterally developed claw-like teeth 400

399' Prothorax broad and usually wider than long 404



Figs. 725-733

400(399) Tibia I with laterally extended claw-like teeth; tarsal segment IV simple; pronotum with bordered lateral margins and a median longitudinal groove 401

400' Tibia I simple without laterally extended claw-like teeth; tarsal segment IV bilobed; pronotum not bordered but heavily punctured 403

401(400) Pronotum quadrate with a small tooth in the postero-lateral margin transversely opposite the last pair of setigerous punctures (Fig. 741); frons with 2 deep longitudinal grooves and a moderately elevated lateral lobe between eyes and sides of clypeus; clypeus truncate with a small rounded lobe on each lateral side; supraorbital groove with 2 setae; antennae bead-like and slightly beyond level of posterior setigerous puncture; elytra with rectangular meshes, ridge 3 with 4 pores (Fig. 742); apex of tibia I with 3 claw-like teeth, middle tooth with a subtooth at base; reddish brown, length 5.5 mm . . . . . *Clivina* sp.

401' Pronotum slightly cylindrical, uniformly black, glabrous and shiny, and wider than abdomen; frons with a small rounded horn in the middle; uniformly black species 402

402(401') Subapical transverse groove of pronotum concave medially and narrowed down to the apicolateral angle, posteromedian margin almost unnoticeably indented; base of pronotum without a short longitudinal groove on opposite sides of the median longitudinal groove (Fig. 743); elytra with moderately shallow and more widely separated grooves; apices of ridges 2-6 punctated similar to ridge 1 and enclosed by ridges 1 and 7; ridge 5 reaching base of elytra (Fig. 744); labrum with a longitudinal median groove; apico-median margins of clypeus straight; length 16 mm . . . . . *Scarites* sp. A

402' Subapical transverse pronotal groove gradually narrowed down to the apicolateral angle with more convex-like pits; posteromedian margin with deep cleft and with a short longitudinal groove on opposite sides of the long median longitudinal groove (Fig. 745); elytral grooves deep and closer to one another, apices with few but wide pits; ridge 5 aborted before base and closed by ridge 6 and 7 (Fig. 746); labrum with a median longitudinal groove; apicomedian portion of clypeus slightly concave; length 12 mm . . . . . *Scarites* sp. B

403(400') Head, prothorax and abdomen including elytra metallic green, closely punctated and finely hirsute (Fig. 747); brown labrum trilobe-like with 2 setae in each lobe; apices of femora I-III black; apical one-fifth of scape blackish and larger than the slightly bent and brownish basal half; margins of frons in front of eyes parallel-sided; pronotum 2 times longer than broad; apico-lateral corner of elytra with a small acute tooth (Fig. 748); length 9-11 mm . . . . . *Drypta gerliculata* (Mug)

403' Head and prothorax brown, elytra black along sutural, basal, and lateral margins with a brown band covering ridge 3-7; head less punctate behind the eyes; pronotum slightly longer than broad and densely punctate (Fig. 749); elytral punctations on the intervals and none on the ridges; brown labrum trilobed with lateral lobes rather acute lateral;

apices of femora I-III reddish brown; apical one-half to one-third of scape blackish brown; margins of frons in front of eyes converging apically; apico-lateral corner of elytra rounded (Fig. 750); length 7-9 mm . . . . . *Dryptajaponica* (Bates)

404(399') Labrum strongly notched apicomedially; mentum emarginate with 2 setae near mid-emargination; clypeus straight to moderately emarginate; margin of elytra without an internal plica towards apex 405

404' Labrum and clypeus truncated apically or labrum strongly rounded at apex; mentum with tooth, straight or emarginate; margins of elytra with or without internal plica towards apex 406

405(404) Supraorbital setae one pair; clypeus straight to weakly emarginate; pronotum glabrous and strongly bordered laterally; latero-apical one-third with a pair of setae, basal one-third with a pair of long longitudinal grooves (Fig. 751); elytra uniformly black, groove 5 and 6 fused before apex and not reaching base of elytra; groove 7 fused with groove 8 becoming part of apical groove up to tip of groove 4; groove 1 with a setigerous pore basally and converging towards groove 2 (Fig. 752); labrum with 4 setae; length 15-20 mm . . . . . *Diplocheila polita* (Fabricius)

405’ Supraorbital setae 2 pairs; clypeus moderately emarginate; pronotum very finely punctate with light transverse striae and shallow longitudinal lateral grooves (Fig. 753); elytral grooves 1 and 2 fused basally to a setigerous pore, grooves 3 and 4 and 5 and 6 separately fused at their apices before apical groove; groove 7 separated from 8 towards apex (Fig. 754); labrum with 6 setae; length 14 mm . . . . . *Submera latifrons* (Dejean)

406(404') Midlateral sides of pronotum angular and bear a lateral seta on each side; pronotum triangular posteriorly; head with 2 pairs of supraorbital setae 407

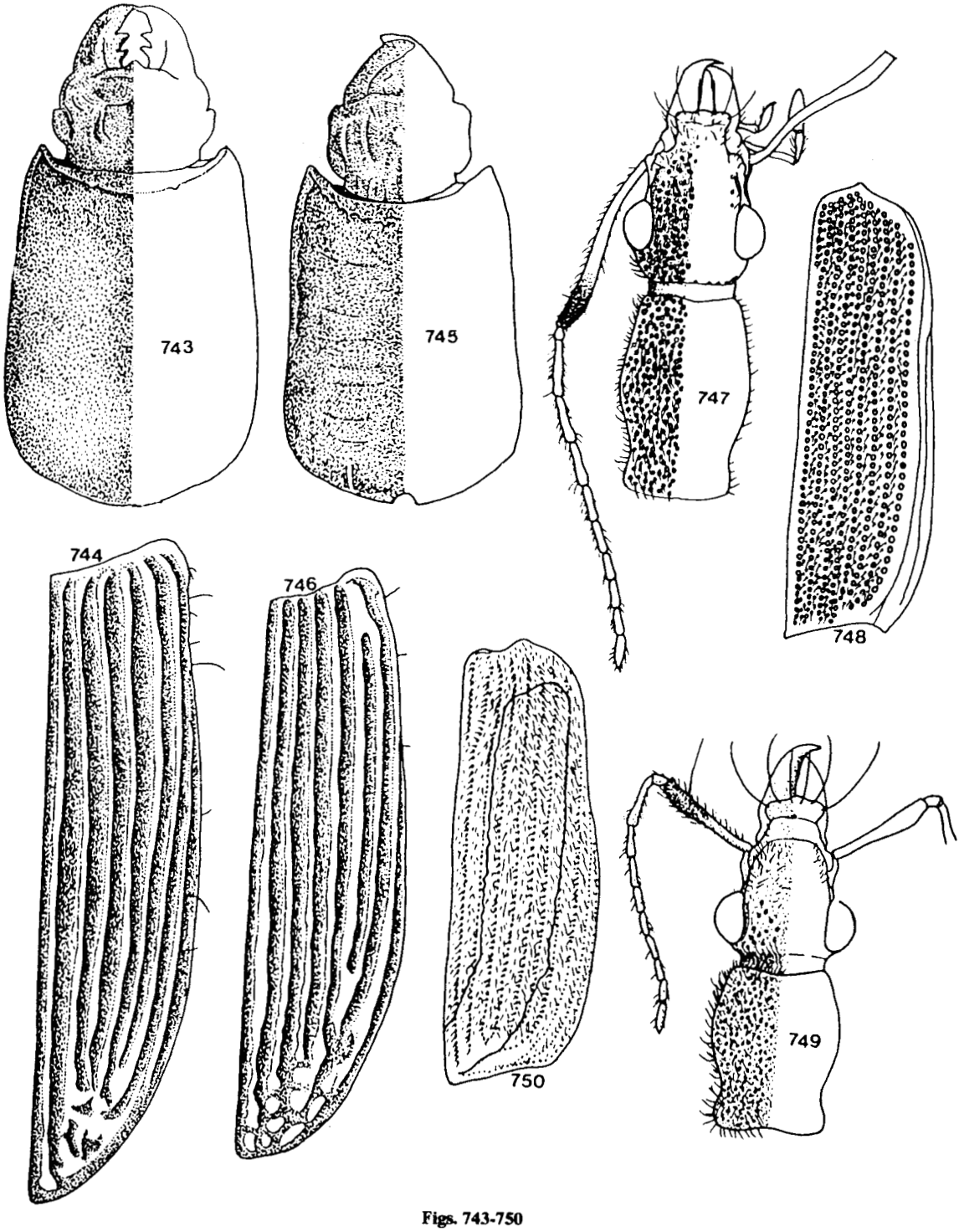
406' Lateral sides of pronotum more or less rounded; pronotum truncate posteriorly; head with 1 pair of supraorbital setae 408

407(406) Entire body black with lateral margins of pronotum and elytra yellow; head, prothorax, and elytra very finely reticulated (Fig. 755); antennae blackish brown except brown segments III and IV; hirsute except basal 4 segments; elytra subtruncate apically and striae lightly and sparsely punctulate (Fig. 756); length 5.3 mm . . . . . *Pentagonica* nr. *erichsoni* Schmidt-Goebel

407' Body black except red pronotum; antennae black except brown to dark brown basal 4 segments (Fig. 757); elytral striations faintly punctulate (Fig. 758); length 6 mm . . . . . *Pentagonica ruficollis* Schmidt-Goebel

408(406') Elytral margins without an internal fold toward apex; antennal segments III-XI hirsute with a long seta toward apex, basal one-third of segment III and entire segment I and II not hairy 409

408' Elytral margins with an internal fold toward apex; antennal segments IV-XI with pubescence 410



Figs. 743-750

409(408) Anterior marginal line of pronotum deep and entire, posterolateral corner angulated and posterior one-third with dense close fine pits (Fig. 759); head reddish brown between eyes; labrum with 6 subapical setae and hairs apico-laterally (Fig. 759); groove 2 of elytra with a setigerous pore basally, entire groove complete, grooves 3 and 4 fused towards apex similar to 5 and 6, 7*th* groove extended up to tip of 3 and 4; apices of elytra brownish with slight emargination; scutellar striae absent; shiny black beetles with margins of pronotum and elytra yellow (Fig. 760); length 8.6 mm . . . . . *Anoplogenius microgonus* Bates

409' Anterior marginal line of pronotum fine and interrupted at middle, posterolateral angle rounded and moderately punctated in between the angle and the median longitudinal groove (Fig. 761); groove 2 very short reaching level of bulging of groove 1; elytra brownish black concolorous to the head and pronotum with 4 yellowish spots, in grooves 5-8 near the humeri and base and 7-9 subapically (Fig. 762); scutellar setae present; length 6.5 mm . . . . . *Egadroma quinquepushdata* (Wiedemann)

410(408') Elytra with yellow marks or lateral margins of elytra yellow 411

410' Elytra uniformly black without yellow marks 417

411(410) Elytra with 3 yellow marks, in the humeri, 2 transversing groove 4 to midlateral margins of elytra and 1 along sutural margin subapically covering suture up to groove 4 (Fig. 763); pronotum black rough medially with brownish red margins; head metallic blue-green with brownish clypeus and yellow-brown rectangular labrum (Fig. 764); length 13 mm . . . . . *Chlaenius xanthospilus*

411' Elytra with 2 subapical marks or entire lateral margin yellow 412

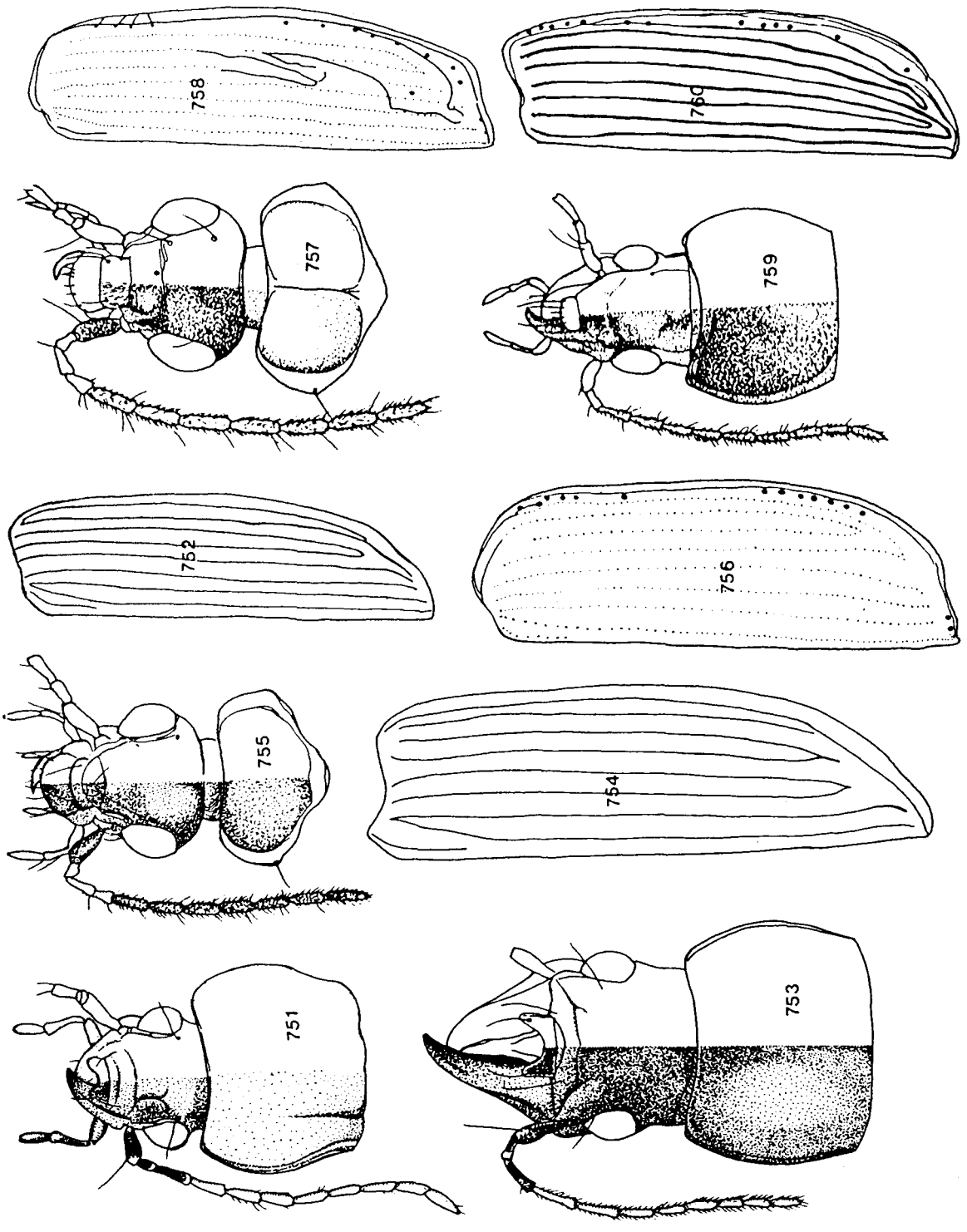
412(411') Entire elytral margins yellow 413

412' Elytral margins black with yellow marks subapically 414

413(412) Yellow elytral margins broad covering groove 7 to margins of elytra and epipleura, the band slightly narrows apically to the sutural margin (Fig. 765); pronotum (Fig. 766) broadest medially and constricted just above lateral setae, disc slightly rough with widely spaced moderately shallow pits; head (Fig. 766) moderately fine with network-like marks behind eyes dorsally and 2-3 fine convex grooves between eyes radiating from supraorbital area; labrum rectangular and yellow with 6 subapical setae (Fig. 766); head and pronotum metallic blue-green, elytra black and legs yellow except black to reddish brown coxae; length 15 mm (Fig. 767) . . . . . *Chlaenius circumdatus* Brulle

413' Yellow elytral margins narrow not reaching groove 7, the band broadens towards apex; lateral margins of pronotum gradually rounded with thin and narrow yellow band (Fig. 768); length 11 mm . . . . . *Chlaenius inops* Chaudoir

414(412') Apical one-third of elytra with a broad V or U-shaped yellow band, top of band with a foot extended to groove 3 (Fig. 769); elytra almost entirely clothed with short brown hairs; pronotum with reddish brown lateral margins, disc clearly punctate with the



Figs. 751-760

posterior area more closely punctate than the anterior; head very finely punctate; labrum slightly emarginate at midapex and with a black spot posteromedially (Fig. 770); length 9-14 mm (Fig. 771) ..... *Chlaenius virgulifer* Chaudoir

414' Subapical band of elytra not U-shaped 415

415(414') Elytron with a moderately large subapical yellow spot covering grooves 3-8 (Fig. 773), and entire elytra punctate; yellow spot short between grooves 3-5 and longest between 5-6; pronotum with a deep lateral longitudinal groove on each side of median groove posteriorly; basal third of pronotum more punctate than the anterior; head smooth between eyes except for some very fine transverse striae; anterior and posterior area with fine punctations; median area of clypeus with moderately dense fine punctations (Fig. 772); antennae blackish brown except yellow-brown scape; elytra black, head and pronotum metallic blue-green; legs with black tibiae and knees, reddish brown tarsi and yellowish brown to red femora; trochanters dark reddish brown; length 12-13 mm .... *Chlaenius bioculatus* Motschulsky

415' Subapical mark on elytron small and represented by short longitudinal bands or 2 contiguous bands 416

416(415') Yellow marks of elytron on intervals 4, and 6 to 8 with the 6*th* interval having the longest band (Fig. 774); pronotum with moderately deep, evenly distributed and uniform punctations (Fig. 775); head smooth behind, finely punctated and relatively smooth up to frons except oblique striations near supraorbital area; clypeus smooth and with very fine pits; labrum reddish brown, narrows behind, and widens opposite latero-subapical setae; antennae IV-VIII black, IX-XI brown, III brown except blackish ends, scape and pedicel brownish yellow; elytra dull black, prothorax black with metallic blue-green luster laterally and head lustrous blue-green; length 14.5 mm ..... *Chlaenius* sp. A

416' Yellow marks of elytron on intervals 4, and 7 to 8, with the 6*th* interval without band or reduced to 3 small dot-like forms (Fig. 776) or contiguous on interval 4 to 6 and a spot on interval 8 (Fig. 777); pronotum with more prominent carina between pits; head with light punctations, short median longitudinal striae between eyes and oblique striae on top of it present; clypeus with small evenly scattered pits; labrum black and reddish apical margin (Fig. 778); antennal scape and pedicel yellow-brown, segment III dark brown with black ends, IV to VI blackish and VII to XI brownish yellow (Fig. 778); femora and dorsum of tibiae yellow, knees, venter of tibiae and entire tarsi black; length 13mm ..... *Chlaenius* sp. B

417(410') Pronotum noticeably punctated, punctations dense apically and posteriorly and sparse or well separated medially, lateral groove wide and less elongated (Fig. 779); head smooth with sparse fine punctations, labrum moderately emarginate with setae almost midway its length; elytra1 striae 3 and 4, and 5 and 6, fused, separated at apices (Fig. 780); length 12.6 mm ..... *Chlaenius* sp. C

Figs. 761-771

417' Pronotum with very few scattered fine punctations; striae 6 separated from 5 which is fused to 7 apically 418

418(417') Pronotum lustrous metallic green with 2 rows of sparse punctations aligned to the median longitudinal groove, discal area with light, widely scattered shallow punctations and about one-fourth wider than long (3:4); head concolorous with pronotum, smooth and finely punctated behind head, and with 2-3 light grooves along supraorbital area; labrum red (Fig. 781); elytra with striae 5 zigzagging towards apex, separated from 6 and 7 (Fig. 782); length 15 mm ..... *Chlaenius quadricolor* Fabricius

418' Pronotum metallic blue to shining black, almost as long as wide (19.5 : 21); pronotal disc moderately punctated and with light transverse striations along the median groove; head concolorous with pronotum, finely punctated up to clypeus and slightly rough behind eyes (Fig. 783); labrum red with 3 small black spots basally; elytra1 striae 3 and 4 fused apically with tip joining striae 7, striae 5 and 6 separated and vaguely connected to striae 7 (Fig. 784) ..... *Chlaenius* sp. D

419(365') Small, 2.75-4.3 mm long; elytra testaceous, marking consisting of zigzag double, clear lines, sometimes the lines becoming thick and coalescent 420

419' Moderately large to large; 10-37 mm long; elytra mostly black with yellow longitudinal markings; if pale yellow-brown, pronotum and elytra with transverse black band 421

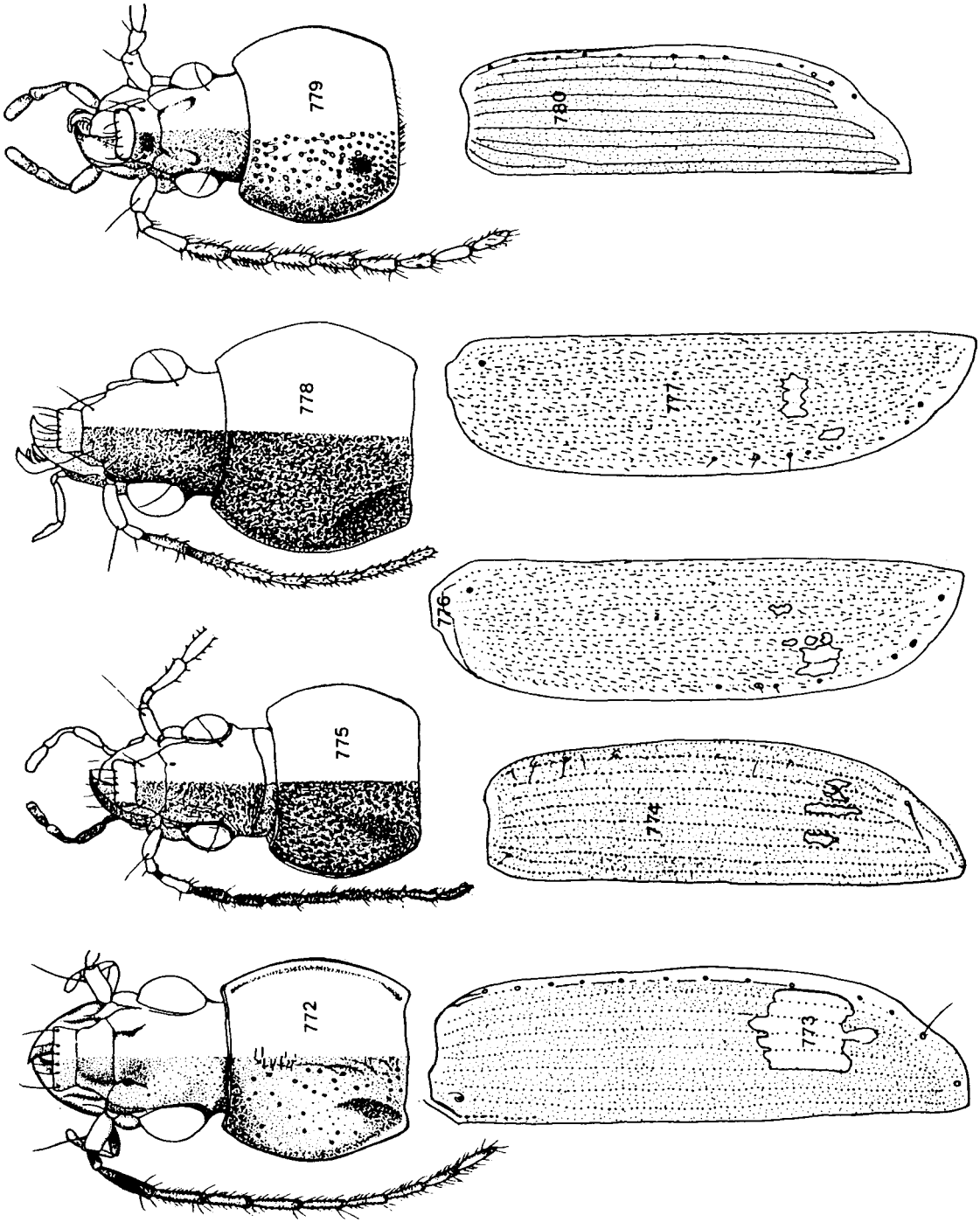
420(419) Elytral markings (Fig. 785) fine undulating, zigzag double lines, clear and thick but never coalescent; pronotum (Fig. 786) testaceous with transverse black markings in the middle along the anterior and posterior margins, and a narrow median transverse black patch on the disc; male penis with a broad, twisted plate, broader in front of the arch and deeply emarginate at apex ..... *Laccophilus sharpi* Regimbart

420' Elytral markings as above but generally thick and coalescent; pronotum (Fig. 787) testaceous without any black markings anteriorly and posteriorly; penis moderately strongly curved medially, almost uniformly wide and notched at the apex on the ventral side ..... *Laccophilus parvulus* Aube

421(419') Prolateral sides of tarsi III armed with a double layer of comb-like teeth, retrolateral sides clothed with golden brown fringe of hairs; body black with yellow bands on sides of pronotum, elytra, or apical part of frons; body length 24-40 mm 422

421' Prolateral and retrolateral sides of tarsi III lined with golden yellow-brown fringes of hairs; body black or yellow with black punctations; body length 10-14 mm 424

422(421) Anteapical inward dilatation of the yellow band of the elytra drop-like (Fig. 788); its inner rounded part separated by half its length from the main yellow band; two longitudinal rows of shallow and faint punctations in the black part of elytra evenly separated and rather sparse, median punctures within 2 rows made up of four punctures square form; body length 35-40 mm ..... *Cybister japonicus* Sharp


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422' Anteapical inward dilatation hooked inward (half arrow-like); puncture arrangement not in line with each other transversely, but in oblique pattern four points form a rectangle 423

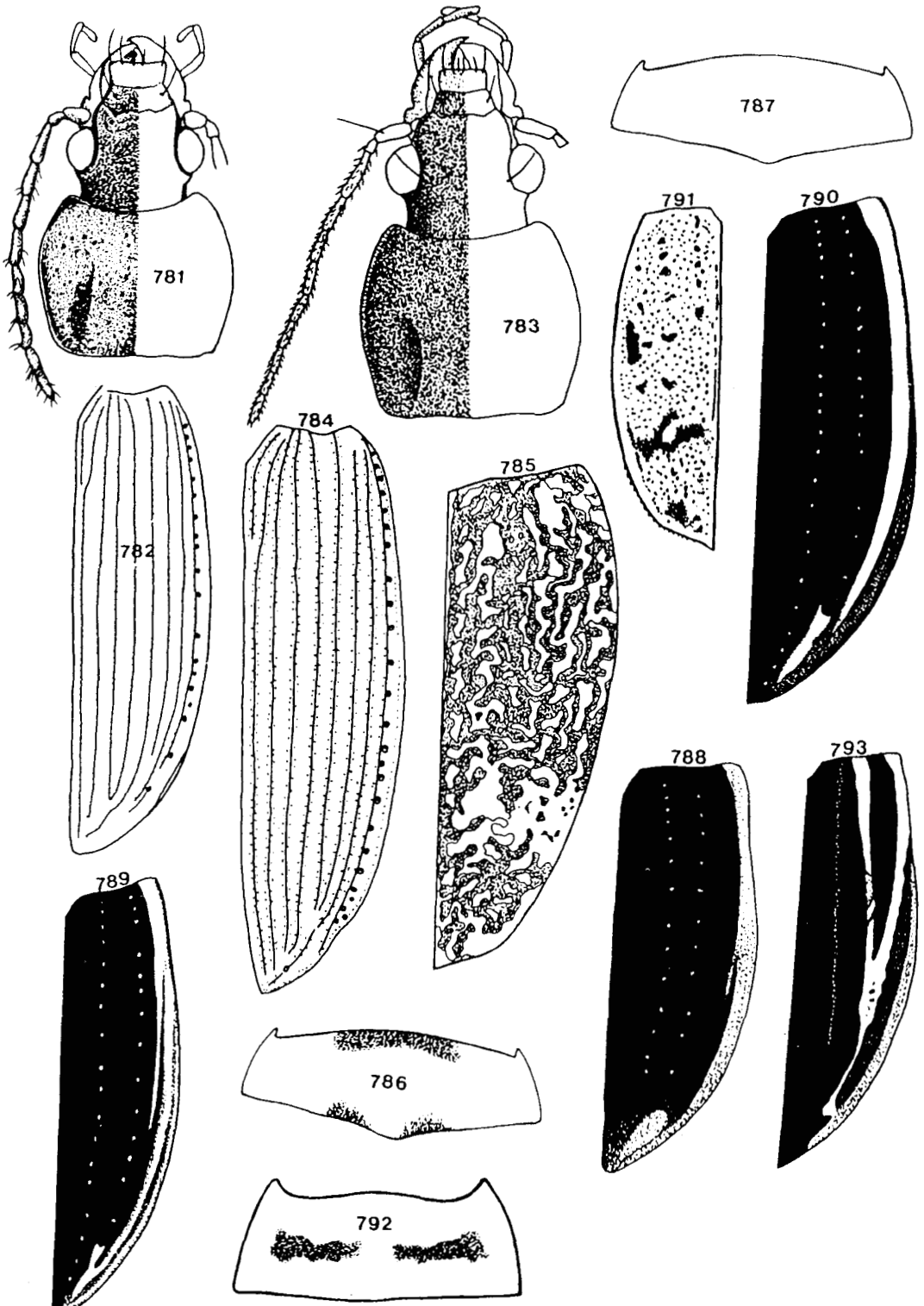
423(422') Elytra and pronotum very smooth; pronotal lateral yellow band one-third narrower than the basal yellow band of elytra; lateral band of elytra (Fig. 789) trifurcated slightly below midhalf, space in between trifurcation reddish brown, anteapical inward dilatation half arrow-like and connected to the tip of the lateral band before the suture; row of punctures adjacent to suture with 17 pits, row closer to the yellow band with 12; anteromedian part of pronotum with a very shallow (almost unnoticeable) cleft, posteromedian at base of scutellum slightly procurved; body length 26 mm .... *Cybister trifunctatus orientalis* Gschwendtner

423' Elytra with broken fine longitudinal striae except smooth unstriated area near suture and proximal one-third; punctations near suture with 23 pits and 14 in other row adjacent to the yellow band excluding two more pits in the anteapical inward, broad hook-like band; elytral yellow band narrowed proximally and broad towards base of elytra, two times broader than that of lateral pronotal band; punctures form an oblique rectangle transversely (Fig. 790); pronotum with irregular network-like irrorations; anteromedian of pronotum with a small noticeable cleft, posteromedian with a very fine indentation (almost unnoticeable); body length 38 mm .... *Cybister trifunctatus* subsp. A

424(421') Lateral border (Fig. 791) of elytra serrated below midhalf but not reaching apex of suture; tip of suture tapers to a point; elytra with deep black punctations, a black spot lateromedially laterad of a small longitudinal groove; and a transverse zigzag-like band on the top of the posterior one-third; base of elytra reddish brown towards scutellum; pronotum (Fig. 792) rebordered laterally with a transverse black median band broken at middle by eight minute globular to ovate blackish brown spots; head yellow except for black back and a transverse oblong black spot dorsad of black hindpart of head; apex of frons strongly recurved medially ..... *Eretes sticticus* Linnaeus

424' Lateral border of pronotum not serrated; lateral area of pronotum not rebordered; posterior claws unequal, apical spurs of hindtibiae pointed; suture between the metapisternum and metasternal wing straight 425

425(424') Elytra smooth and without punctate-like marks, black with yellow humeral and subhumeral stripes narrow and joined together posteriorly after the middle (Fig. 793); pronotum with a broad yellow band laterally, as broad as the distance from elytral margin to subhumeral stripe; frontal half of head yellow; antennae yellow except VI-XI blackish brown; mesotarsi of male with two rows of sessile palletes; tarsal claws of legs I and II always widely diverging; tibiae I enlarged submedially to as much as half its length, with three long setae apicolaterally, five (3 moderately large and 2 hair-like setae) at venter of enlarged tibial area and spineless in between the two groups of setae ..... *Hydaticus vittatus* (Fabricius)



Figs. 781-793

425' Elytra brown with black interconnected punctate-like marks, contiguous medially (Fig. 794); lower humeral area and lateral margins yellowish; scutellum black; pronotum (Fig. 795) brownish red with blackish shades midanteriorly and midposteriorly; head concolorous with pronotum; antennae uniformly brownish yellow; mesotarsi as in *H. vittatus;* tarsal claws usually parallel to each other; tibiae I with its width of enlarged area a little over half of tibial length, apicolateral with three setae, venter of enlarged area with 4 (3 moderately large and 1 hair-like setae) and with small spines in between the two groups of setae ..... *Hydaticus rhantoides* Sharp

426(364') Head prolonged into a distinct beak or snout; basal segment of geniculate antennae often received in grooves on snout; labrum absent; tarsi 4-4-4; front tibiae usually without series of teeth externally or prolonged distally into a stout spur; size and shape variable [Curculionidae] 427

426' Not with the above combination of characters 432

427(426) Tarsi simple; body covered with waterproof coat of scales; rostum long; larvae are root feeders 428

427' Tarsi bilobed; body without prominent waterproof coat of scales; rostrum short or long; 1arvae may or may not be root feeders 429

428(427) Pronotum (Fig. 796%) longer than wide, almost rectangular; body covered by varnish-like coat of scales, bead-like scales along eye margins, back of head, apical one-third of rostrum, coxae I to III, venter of prothorax, and between coxa II and last 4 abdominal sternites except the penultimate segment; eyes partly hidden dorsally, twice longer than broad; space between eyes convex; antennal groove straight; space not reaching eye (Fig. 797); tibia II (Fig. 798) medially curved with a prominent upcurved spine and a small one opposite it; ash-grey; adults 3-3.5 mm, temperate species .... *Lissorhoptrus oryzophilus* Kuschel

428' Pronotum wider than long, rounded along lateral sides; body covered by small leaf-like scales on elytra and somewhat circular scales in pronotum; eyes prominently visible dorsally, one-fourth higher than wide; space between eyes with a pit (Fig. 799); elytra1 grooves fine and straight; tibiae straight, II curved towards tip with a single spur (Fig. 800); black adults 5 mm or more, Oriental species .... *Hydronomidius molitor* Faust

429(427') Rostrum short, as long as wide or a little longer than wide; larvae not root feeders 430

429' Rostrum much longer than wide and more or less cylindrical; larvae are root feeders 431

430(429) Rostrum short, a little longer than wide, dorsomedian longitudinal ridge present and highest above the area between antennal base and anterior eye margin; mandible with deciduous cusp leaving a scar; antennal groove curved below front of eye margins; scape long almost reaching collar of pronotum; eyes visible above; globular (as wide as high);

pronotum cylindrical longer than wide (Fig. 801); antennae dark reddish brown, segment II as long as III; black ..... *Tanymecus* nr. *boettcheri* Voss

430' Allied to *T.* nr. *boettcheri;* prothorax less cylindrical; dorsomedian longitudinal ridge highest above antennal base or a little above it; scape of antennae not reaching hind margin of eyes (Fig. 802); antennae entirely black, segment I1 longest next to pedicel, and 2.2 times longer than segment III (Fig. 803) ..... *Tanymecus indicus* Faust

430" Rostrum nearly as wide as long, deeply grooved medially from apical one-fourth to basal one-eighth, side grooved as in *Tanymecus;* head and thorax covered with circular scales, glossy and hairy; eyes subspherical, slightly bulging, rimmed with white scales; antennae 12-segmented with 4 compact into club, 1*st* funicular segment one-third shorter than combined length of segments II and III; prothorax about one-fourth wider than long, wider behind than in front; elytra tapers apically with 6 dotted lines up to shoulder (Fig. 804); tips of tibiae without spur except brush of hairs (Fig. 805) .... *Hypomeces* nr. *squamosus* Fabricius

431(429') Elytra with a pair of whitish oblong spots on the apical one-third of stria 2 and 3 (Fig. 806) ..... *Echinocnemus* squameus Billberg

431' Elytra without any white spots (Fig. 807); rostrum shorter than *E. squameus* .... *Echinocnemus oryzae* Marshall

432(426') Antennae lamellate (at least three); with ten or fewer segments; front coxae prominent; pygidium exposed in most species [Scarabaeidae] 433

432' Antennae not lamellate 440

433(432) Tarsal claws of leg III unequal in length, inner claw smaller; tibiae III with 2 long spurs at apex 434

433' Tarsal claws of leg III equal in size, toothed or bifid; foretibiae with 2-3 outer tubercles 438

434(433) Black beetle with shiny pronotum and elytra; pronotum very smooth; lateral and anterior parts strongly margined; head roughly carinate, lightly punctated in between eyes; anterior clypeus with a pair of upcurved “horns” (Fig. 808); 6 large mandibular teeth visible dorsally; tibiae I strongly serrated with 7 teeth in the outer part 1,2 and 4 the longest, inner apical part with one long tooth; outer claw of tarsi very broad and scoop-like in males; elytra (Fig. 809) each with 11 fine striae, striae 4, 5, and 6 enclosed by 3 and 7 striae; scutellum not punctated, triangular apically; length 17 mm .... *Heteronychus lioderes* Redtenbacher

434' Brownish red or blackish brown beetles; body may or may not be hirsute; clypeus without horns at apex 435

435(434') Uniformly hirsute; head, thorax, and elytra clothed with spike-like decumbent white hair, hair underneath rather fine; moderately flat beetles; clypeal (Fig. 810) margins strongly round, thin edges upcurved; pronotum partly rough, almost rectangular, 2.3

times wider than long; scutellum not triangular; semi-punctated, lateral edges curved and basal end curved medially; basal end of elytra deep between shoulder and a hump before scutellum; outer edge of tibiae I with 3 blunt tubercles, 1 and 2 nearer each other, 2 and 3 wide apart, and a moderately long spur in inner side (Fig. 811); legs dark brownish red ..... *Adoretus ranunculus* Burmeister

435' Not hairy as above; elytra brown; pronotum reddish brown 436

436(435') Head black except dark brown clypeus; vertex slightly raised; clypeus punctated, rounded with elevated edges, basal area in front of eyes straight or shortly angled; transverse ridge above clypeus prominent, elevated near eyes; pronotum with black patches anteriorly, smooth, 2.2 times wider than long, margined with a broader anteromedian than rest, laterally rounded, slightly straight to concave anteriorly and concave posteriorly (Fig. 812); elytra brown, punctated with 2-3 longitudinally low ridges between 3-5 irregular rows of black striae; scutellum rounded apically with base nearly straight; outer part of tibia I (Fig. 813) with 3 black-tip blunt tubercles, inner tip with a short spur; outer claw of leg I bifurcated; legs yellow with blackish brown patches on femora, and tibial tubercles ..... *Adoretus luridus* Blanchard

436' Reddish brown beetles with brownish yellow to reddish brown elytra; body finely punctated; clypeus broadly angled posteriorly; venter of body clothed with long fine hairs 437

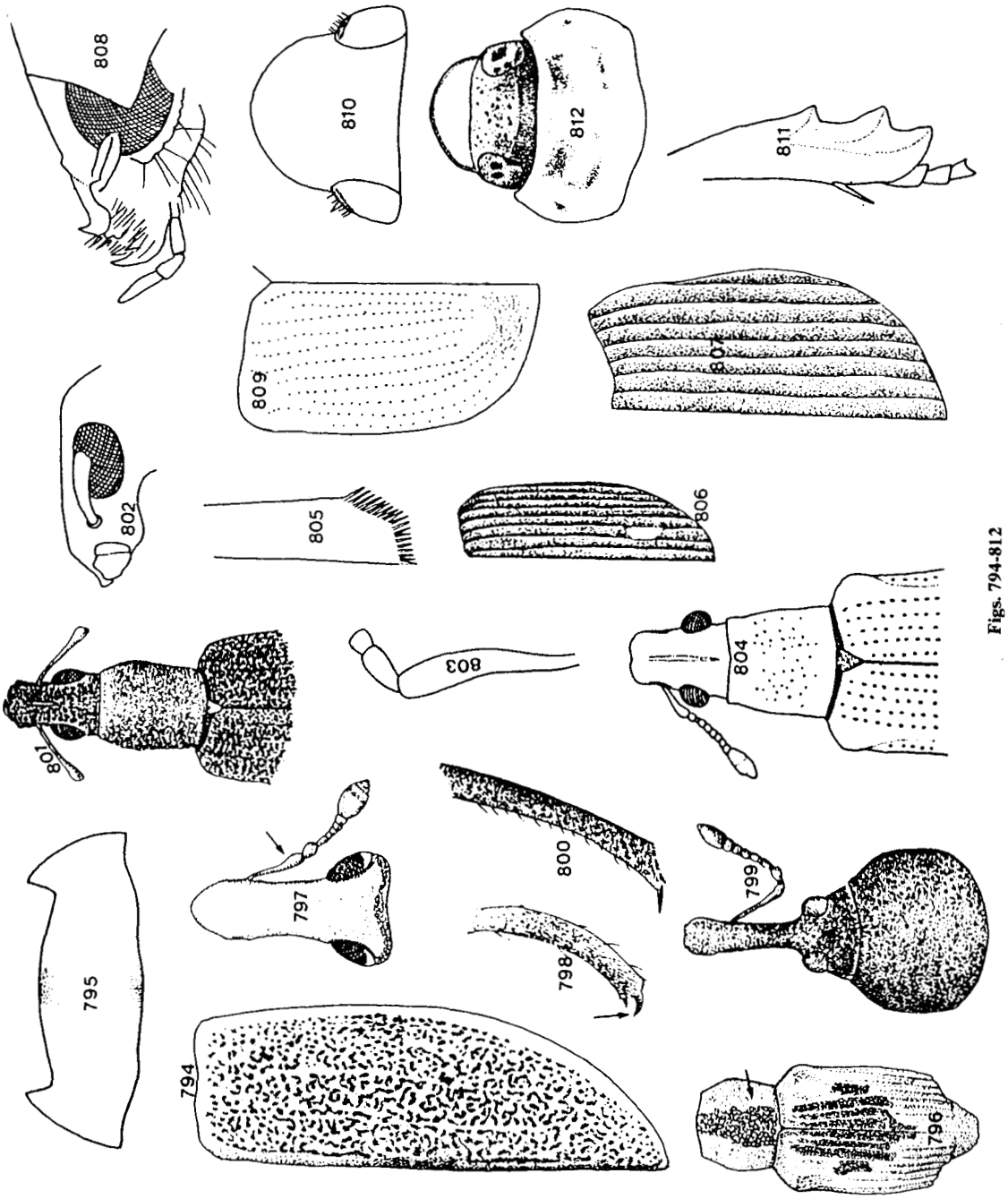
437(436') Elytra reddish brown, same color as head and thorax; glossy bodied beetle, head subtruncate anteriorly; pronotum much broader behind the anterior, midlateral half slightly bulging (Fig. 814); tibiae I with one long blunt tubercle on outer end and a small inner one (Fig. 815); tibiae III with at least 3 rows of spurs in the outer median half . . . . *Anomala sulcatula* Burmeister

437' Elytra brown or brownish yellow, dark reddish brown on shoulder extended below to lateral margins and on the apical hump (Fig. 816); tibiae I with 2 tubercles (Fig. 817); tibiae III with 2 rows of spurs in the anterior and posterior end of the outer median half ..... *Anomala humeralis* Burmeister

438(433') Anterior and posterior margins of pronotum margined (Fig. 818); pronotum less convex, apico-lateral half widely margined and higher than "eye bar", median half deeply lobed and bulged posteriorly viewed from above (Fig. 819); clypeus with upcurved margins, cleft median area (Fig. 820); tibiae I with 3 tubercles on the outer side and a spur on the inner end opposite 2*nd* and 3*rd* tubercles; stridulatory file present in the anterior edge of the elytra1 epipleuron; ridge of shoulder incurved posteriorly (Fig. 821) ..... *Holotrichia* spp.

438' Pronotal margins not margined except lateral edges 439

439(438') Body black and slightly shiny, surfaces covered with spherical to ovoid whitish yellow spots (Fig. 822); clypeus partly cleft anteriorly and broadly angled posteriorly (Fig. 823); lateral end of pronotum lobed behind midhalf and posterior tip pointed (Fig. 824); body length barely 30 mm ..... *Leucopholis irrorata* (Chevrolat)


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Figs. 794-812

439' Body brownish red, not glossy, uniformly clothed with spike-like setae (Fig. 825); clypeus broadly margined and raised medio-apically (seen frontally) (Fig. 826), not cleft, lateral margin of pronotum lobed a little behind median, posterior tip rounded (Fig. 827); body length more than 30 mm ..... *Leucopholis* sp.

440(432') Aquatic insects; maxillary palpi antenna-like, long, as long as or longer than the short antennae; vertex with a Y-shaped impressed line, antennal cupule preceded by five segments; front coxal cavities open behind; procoxae not concealing prosternum; tarsal segmentation 5-5-5; with or without median sternal keel [Hydrophilidae] 441

440' Terrestrial insects; maxillary palpi short; vertex without Y-shaped impression; antennae 8-11 segmented without cupule; pronotum variable either hexagonal, constricted on both ends or widest to globular at middle; head subglobular to strongly transverse; tarsal segmentation 4-4-4,5-5-4 or 5-5-5 445

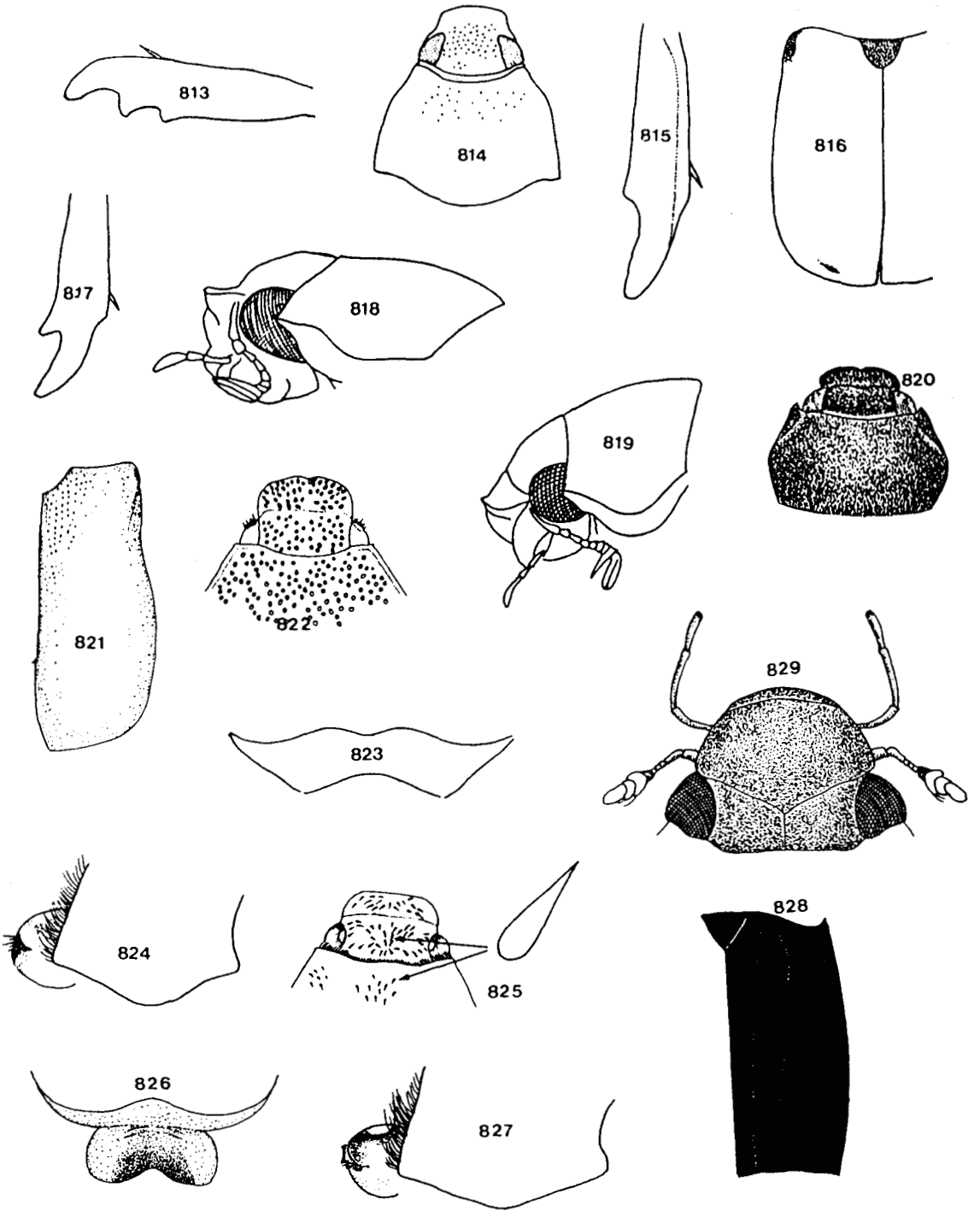
441(440) Large aquatic beetles, 28-35 mm long; head including eyes, pronotum, scutellum, and elytra entirely black; elytra with two rows of longitudinal pits narrowing on both ends; median sternal keel very long reaching grooved prosternum 442

441' Small aquatic beetles, 5-12 mm long; elytra never entirely black; median sternal keel absent, if present not beyond coxae I and not contained in the prosternum; groove in prosternum absent 443

442(441) Bases of two longitudinal rows of punctures widely separated, distance between them as long as distance from side of scutellum to subsutural punctations (Fig. 828); median sternal keel reaching midhalf of sternite III; venter of body including head and thorax black with few red-brownish tinges on apices of femora and sides of abdomen; junction of Y-shaped impression about in level midhalf of eye, leg of Y shorter than eye length taken laterally (14:18) (Fig. 829); length 32-35 mm .... *Hydrophilus acuminatus* Motschulsky

442' Bases of two longitudinal rows of punctures much nearer each other than the distance of subsutural punctations to side of scutellum (Fig. 830); median sternal keel reaching almost apex of sternite III; venter of body brownish red; junction of Y-shaped impression above midhalf of eyes, leg of Y longer than eye length taken laterally (20:17) (Fig. 831); length 28 mm ..... *Hydrophilus* nr. *bilianeatus cashmirensis* Redtenbacher

443(441') Median sternal keel completely absent; head, pronotum, scutellum and elytra punctated; junction of Y-impression in line with apical third of eye, leg of Y long and as long as eye length taken laterally; back of head behind eyes with a transverse groove; elytra with 10 long punctated grooves and *6th* and *7th* not fully reaching basal margin across humeri and a small incomplete one after the first near sutural line; in between long grooves 1-2 lines (usually one) of punctures; head longer than pronotum; generally yellow-brown with black abdomen and metapleuron; length 5.5 mm (Fig. 832) .... *Berosus* sp.


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Figs. 813-829

443' Median sternal keel present but short, not reaching apical half of coxae I; prosternum entire and without a groove; pronotum with two rows of punctations along lateral sides, discontinued medially; apical half of clypeus reddish brown; frons with punctations near eye margins; lustrous black beetles; length 9-12 mm 444

444(443') First antennal segment short, only reaching anterior eye margins (Fig. 833); prosternum gradually produced or narrowed forward with a straight floor (seen laterally); median sternal keel slightly notched subapically and without bristles; apex of clypeus moderately notched medially; frons with two transverse concave punctations and almost medially erased; scutellum 1.22X longer than wide; body form less convex; length 12 mm . . . . . *Sternolophus rufipes* Fabricius

444' First antennal segment beyond midhalf of eye (Fig. 834); prosternum rounded forward with its floor slightly oblique at apex and straight posteriorly; subapex of median sternal keel with bristles in the notch; apex of clypeus straight; frons with transverse punctations medially, concave on booth ends with closer punctures and sparse medially but prominent; scutellum nearly as wide, as long; body strongly convex; length 9 mm . . . . . *Sternolophus* sp.

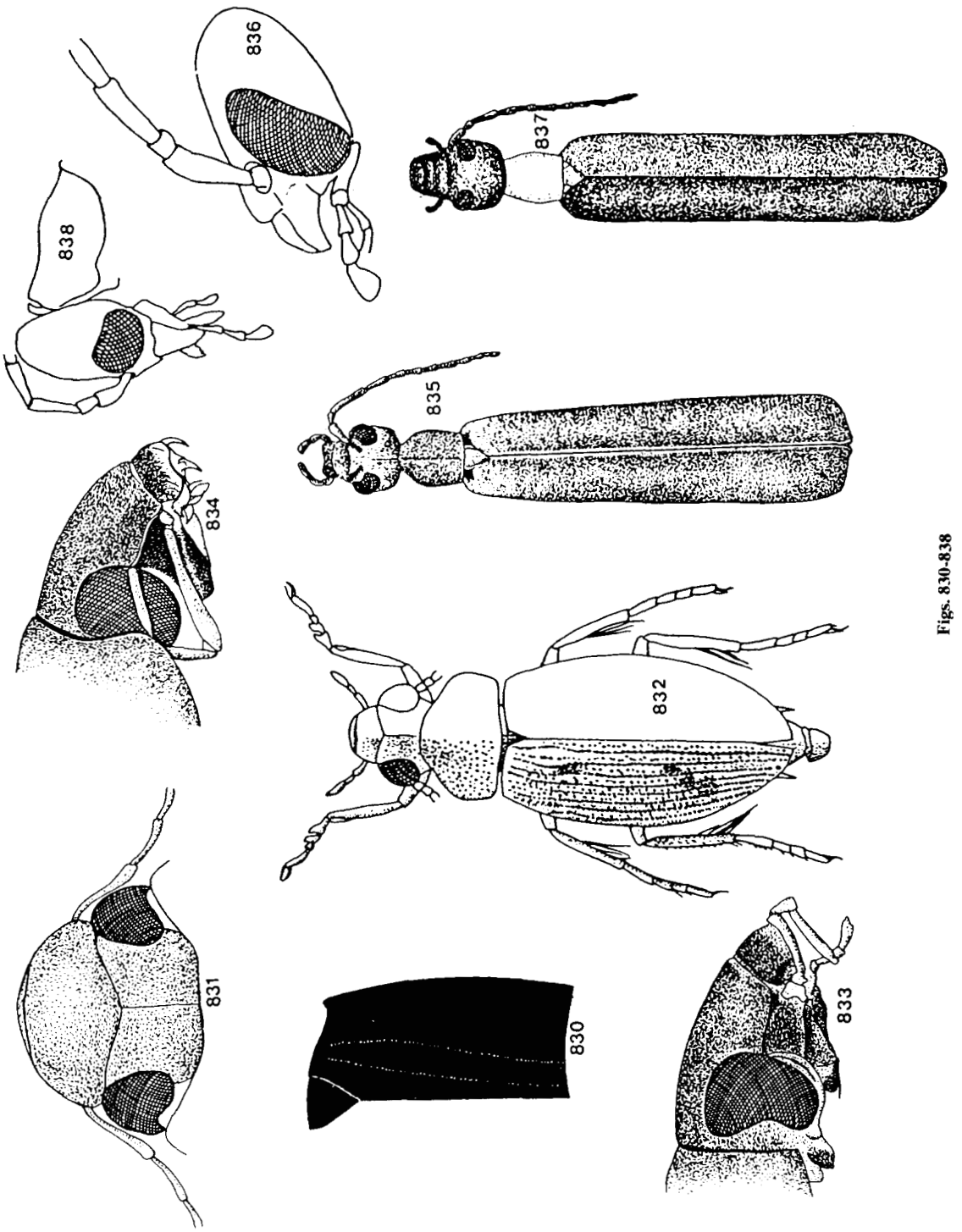
445(440') Tarsal formula 5-5-4, heteromerous with bipartite claws; a sclerotized blade-like process beneath each claw; body cylindrical and moderately soft; eyes nearly transverse with emarginate margins near antennae [Meloidae] 446

445' Tarsal formula variable 5-5-5, 5-5-4, 4-4-4 but without such claws 447

446(445) Body uniformly black, clothed with thick white hair; eyes oblique with base of antennae below top level (Fig. 835); antennae same color as body except brownish scape, pedicel, and dorsal half of segment III all covered with white hair dorsally and black hair laterally and ventrally; scape nearly 3 times as long as pedicel, segment III much longer than segment IV, one-third shorter than combined length of IV and V (Fig. 836) . . . . . *Cylindrothorax* sp.

446' Body black except orange-brown pronotum; eyes transverse with antennal base almost in line with anterior level of eyes (Fig. 837); edges of pronotum markedly grooved elevating outer rims, lateral and posterior edges dark brown, anterior one-third with a transverse deep region (Fig. 838); elytra with bluish lustre; antennae entirely black, scape twice as long as pedicel, segment III as long as IV . . . . . *Cylindrothorax melanocephala* Fabricius

447(445') Tarsal segmentation 3-3-3 (each tarsus with 3 segments, actually 4-segmented each with the basal two segments expanded and densely pilose beneath, 2*nd* produced into a long lobe underneath, 3rd minute and concealed, 4*th* long); head deplexed strongly or deeply sunken into the prothorax; body broadly ovate and highly convex in form; entire abdomen covered by elytra; 5-6 visible sternites, basal sternites with a curved femoral line running backwards from inner end of coxae; antennae 8-11 segmented with a 3-segmented club [Coccinellidae] 448



Figs. 830-838

447' Tarsal segmentation 5-5-5 or 5-5-4; body form usually elongate, not strongly convex; head not deeply sunken into prothorax 460

448(447) Clypeus expanded laterally; antennae 8-segmented; postcoxal line complete, tarsal claws simple, slightly thickened at base; body oval to rounded oval and moderately convex above; elytra with three longitudinal black vitta and a yellow longitudinal vitta in between 449

448' Clypeus not expanded laterally; anterolateral angle of clypeus produced forward; antennae 11-segmented; postcoxal line incomplete; tarsal claws usually cleft; genae extending into eyes; mandibles bifid at apex; body broadly oval to elongate oval with or without spot or broad longitudinal bands 450

449(448) Discal and sutural black vittae both broad, reach base of elytra and confluent basally, discal band distinctly more than 2 times wider than the width of yellow and sutural bands taken separately; head yellowish or red testaceous with blackish area on vertex in the male and entirely blackish in the female; pronotum yellowish brown; punctations in the head and pronotum fine and sparse and muchstronger and closer in the elytra (Fig. 839) ..... *Brumoides lineatus* (Weise)

449' Sutural and discal black vittae both narrow; discal band rarely more than twice wider than the yellow and sutural bands and never confluent with the sutural band; only sutural band reaches base of elytra; coloration similar to *B. lineatus* (Fig. 840) .... *Brumoides suturalis* (Fabricius)

450(448') Tibial spurs absent in all legs 451

450' Tibiae II and III with spurs 456

451(450) Elytral epipleura wide, concave and strongly descending externally 452

451' Elytral epipleura moderate, feebly concave and almost horizontal; body broadly elongate oval and less convex; prosternum without carinae; abdominal lines incomplete; pronotum reddish yellow with one or two pairs of quadrate to subovate black spots; elytron normally with a pair each of transverse black humeral, median, and a spot each of post-median and subapical; sutural band narrow and broadens postmedially (Fig. 841); paramere short and moderately stout, about as long as basal piece; infundibulum long ..... *Harmonia octomaculata* (Fabricius)

452(451) Elytra with longitudinal streaks; pronotum with black marks 453

452' Elytra uniformly yellow to reddish yellow without black marks 455

453(452) Sutural band black; thin and narrow on both ends but gradually widened medially; discal band absent; posterior one-third of pronotum black medially and a pair of spherical spots above it (sometimes entire basal half black without spots above but with 2-3 dentations anteriorly); elytra orange-brown (Fig. 842); siphonal capsule moderately stout, its outer arm moderately stout and inner arm short and truncated at tip; sipho

relatively curved and shorter than *M. hirashima* and *M. yasumatsui;* paramere noticeably subglobular in apical half; apex of medium lobe broadly truncate . . . . . *Micraspis discolor* (Fabricius)

453' Sutural and discal bands prominent 454

454(453') Discal band very broad and curved, 2-3 times broader than sutural band, and not reaching distal and proximal ends of elytra; posterior half of pronotum black and apical half yellow; general color yellowish brown (Fig. 843) . . . . . *Micraspis inops* (Mulsant)

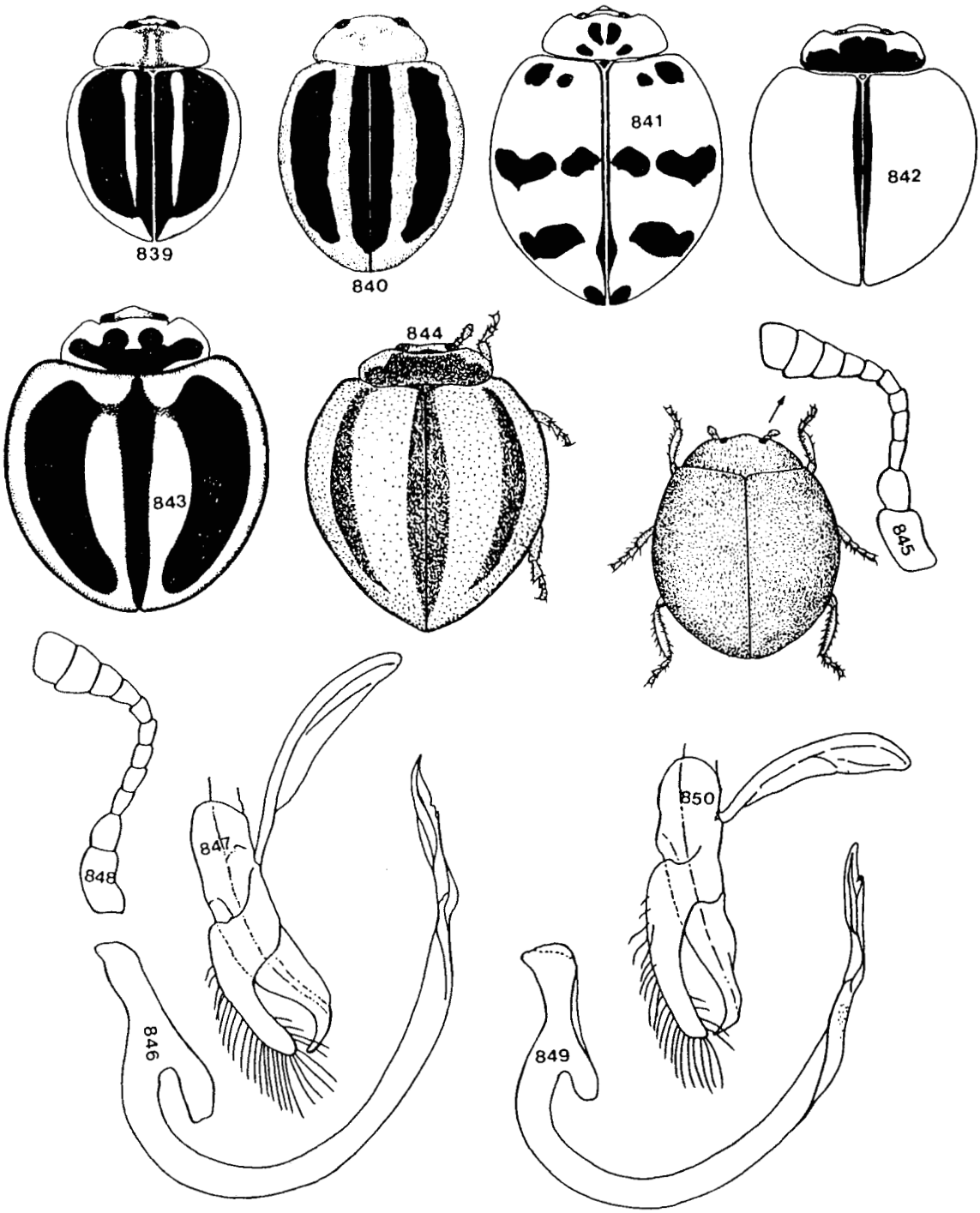
454' Discal band narrower than median area of sutural band; both bands narrower than the reddish yellow background of elytra, reach proximal end but not distal end of elytra; pronotum blackish except yellow lateral margins; general color reddish yellow (Fig. 844) . . . . . *Micraspis vincta* (Gorham)

455(452') Body short oval, about four-fifth times as wide as long; head slightly narrower than half the pronotal width and interocular distance slightly shorter than 0.5 head width; apical side of terminal antennal segment strongly obliquely truncate (Fig. 845); prosternal carinae more broadly separated; sipho relatively stout and weakly curved with a slender and longer sclerite in the apical end; siphonal capsule very long and slender inner process, the latter rarely shorter than the outer process (Fig. 846); tegmen comparatively slender (Fig. 847); apex of median piece strongly bending dorsally and sharply pointed at apex in side view, very narrow, parallel-sided with a truncated tip; reddish with yellowish brown head, antennae, pronotum, scutellum, legs and abdomen except for a black median area . . . . . *Micraspis hirashimai* Sasaji

455' Body nearly hemispherical, slightly longer than wide; head distinctly broader than half the pronotal width; interocular distance nearly half as broad as the head width; apical side of 11*th* antennal segment weakly obliquely truncate (Fig. 848); sipho (Fig. 849) relatively slender and weakly curved; siphonal capsule slender with outer process much longer than the inner one; tegmen (Fig. 850) slender and long, about two-fifths as long as sipho; median piece slender, gradually narrowed apically with a truncate tip; lateral lobes of tegmen also long and slender, more than three-fifths of tegmen weakly arcuate laterally; orange-brown, head yellowish brown to orange-brown with darker antennae and mouthparts, underside of thorax and abdomen entirely brown and legs yellow-brown . . . . . *Micraspis yasumatsui* Sasaji

456(450') Body slightly depressed and ovate (Fig. 851); prothoracic hypomeron with distinct fovea; pronotum yellow with a pair of subquadrate spots separated by a thin yellow line posteromedially; elytra yellow with external margination complete and uninterrupted, and with two interconnected sometimes interrupted anchor-like black bands (Figs. 852-853); humeral black markings never divided into two separate markings; prosternum with distinct narrow lateral ridge reaching the apex; postcoxal line incomplete; legs yellow to yellowish brown without black markings . . . *Propylaea japonica* (Thunberg)

456' Body moderate to strongly convex, rounded or broadly elongate oval; patterns on elytra entirely different 457



Figs. 839-850

457(456') Femur III long extending well beyond the outer margin of elytra; tarsal claw with a slender tooth at middle; tibiae II and III with two spurs; femoral line on first abdominal segment complete; body elongate oval; elytron with 6 spots 4 above median (1 each in discal and suturo-basal, humeral and above humeral) and 2 below median (1 large knob-like submedian and a smaller subovate subapical); pronotum largely black except yellow lateral and anterior margins, apical part of black band slightly 4-lobed with 3 clefts and a pair of small ovate yellow spots (Fig. 854); sipho with four hooked-lobes on sides of ventral and dorsal part; median piece of tegmen slender with a point apex and longer than paramere; length 4-4.6 mm . . . . . *Hippodomia variegata* (Gocze)

457' Femur III short, not reaching the outer margin of elytra; body rather rounded and convex; frons narrow, about 0.5 as long as head; pronotum covering large part of eyes and widest near base; prosternal process with parallel carinae 458

458(457') Black basal band of pronotum transversely long and narrow and connected by a short very narrow longitudinal constriction to a transverse oval black discal spot; elytra with a black sutural stripe dilated behind scutellum and before apex; each elytron with two wavy post-humeral and median black bands, and a rounded black subapical spot; all the bands and spot not connected to the sutural stripe (Fig. 855) . . . . . *Menochilus sexmaculatus* (Fabricius)

458' Pronotum almost entirely black except for a yellow patch along its antero-lateral half; elytra together with 7 spots, each elytron actually with 4-5 spots 459

459(458') Elytra with a black trilobed or slightly Y-shaped subhumeral marking, postmedian black band wavy and confluent with sutural margin, sutquadrate black spot at three-fourths the external margin, and one black spot each on both ends of the sutural margin (Fig. 856); each elytron with 5 spots; prosternum with a pair of carinae which hardly extend beyond the level of the front coxa; abdominal lines forked V-shaped-like in the external part; tibia III with distinct apical spur . . . . . *Coccinella repanda* Thunberg

459' Elytra1 spots globular to subglobular and well separated from each other except almost contiguous spots behind scutellum; each elytron with 4 spots; sutural band absent except at base (Fig. 857) . . . . . *Coccinella septempunctata* Linnaeus

460(447') Elytra very short exposing a considerable portion of abdomen, exposed abdominal tergites laterally margined; tarsal segmentation 5-5-5; generally orange-red with blue-black elytra, blackish head and apical two segments of abdomen 461

460' Abdominal tergites entirely covered by the long, well developed elytra 462

461(460) Pronotum subglobular (Fig. 858); all legs blackish brown; femur uniformly blackish brown (Fig. 859); terminal segment of palpi blackish brown; black basal area of elytra not very close to the pronotum (Fig. 860) . . . . . *Paederus tamulus* Erichson

461' Pronotum elongate-ovate (Fig. 861); all legs brownish yellow except apex of femur III (Fig. 862); terminal segment of palpi brown; brown basal area of elytra close to pronotum (Fig. 863) . . . . . *Paederus fuscipes* Curtis

462(460') Tarsal segmentation 5-5-5 463

462' Tarsal segmentation 5-5-4 482

463(462) With click mechanism formed by a long prosternal process; labrum visible; head black; small and transversely ridged between eyes; pronotum with an inverted W-shaped brown band, posterolateral angle with a sharp tooth (Fig. 864); scutellum slightly oblong and deeply sunken between elytra; elytra blackish brown basally, yellow-brown towards margin with black patches in the discal area; median base of elytron protruded basally (Fig. 865); antennae extended to the tooth of pronotum; body clothed with yellow hairs; length 7 mm [Elateridae] ..... *Aeoloderma brachmana* (Candeze)

463' Without click mechanism, posterolateral angle of pronotum without a sharp tooth; 11-segmented antennae shorter than body; tarsus pseudotetramerous with 4*th* segment small and hidden in the bilobed 3*rd* segment; leaf beetles (Chrysomelidae] 464

464(463') Head with frons inflexed, mouthparts hypognathous; pronotum and elytra without broadly expanded margins Hispinae 465

464' Head with frons not inflexed, mouthparts prognathous 471

465(464) Body cylindrical, narrow, elongated, and parallel-sided, unarmed with distinct spines; head irregularly punctured; basal joint of antenna long, thick, and apically compressed and dilated externally; prothorax subquadrate longer than broad, sides straight and parallel, posterior angles acute; scutellum black, impunctate and apically rounded; elytra parallel-sided, more than 4 times longer than broad with ten regular rows of striae and finely serrated towards tip; small beetles 4.5-5 mm long, dorsally metallic green with lustre, black ventrally (Fig. 866) ..... *Leptispa pygmaea* Baly

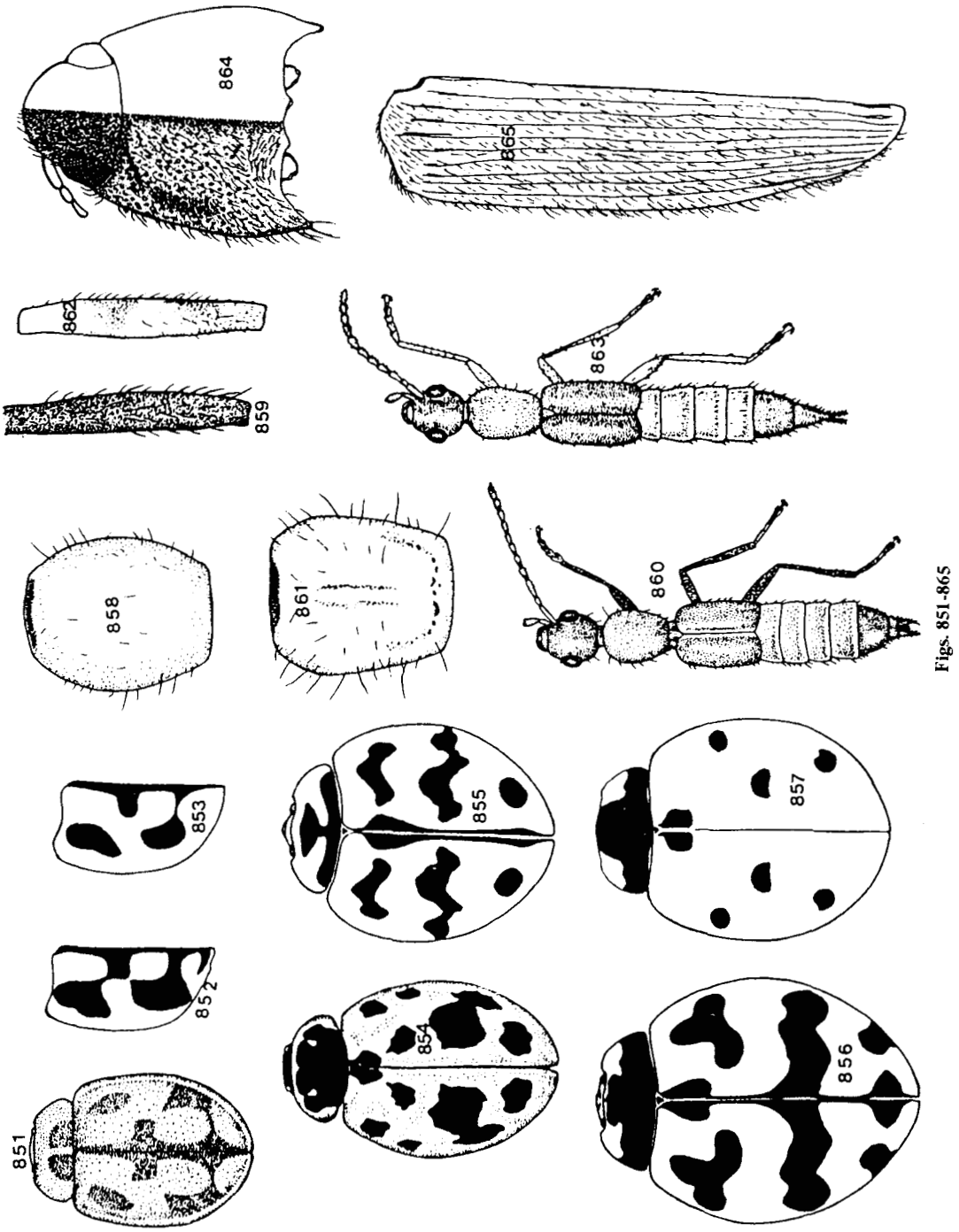
465' Body margins with spines dorsally and laterally 466

466(465') Anterodorsal margin of pronotum spineless; lateral edges each with 4 short spines, 2 anterolaterals nearly contiguous basally and 2 more below middle widely separated (Fig. 868); pronotum (Fig. 868) constricted behind 4*th* lateral spine, cylindrical to somewhat rounded dorsally, not quadrate as in *Dicladispa* and *Dactylispa;* elytra with 4 small, short spines in laterobasal half (Fig. 867); segment III of antennae nearly as long as basal and 4*th* segments ..... *Trichispa sericea* (Guerin)

466' Anterodorsal margin of pronotum without spines; prothorax with a group of long and prominent spines behind anterolateral angles and a single spine behind middle; elytral margin not produced; antennae 11-segmented; segment III longest; body narrow and subparallel *(Dicladispa)* 467

466" Not as above, anterior margin with a spine or group of spines on each side 469

467(466') Oriental species; basal segment of 11-segmented antennae with a short ventro-apical tooth; pronotum with 4-branched stout spines laterally before middle and a simple one below middle; posterolateral angle without a prominent thin seta; spines more or less straight; elytral punctations in regular rows, extreme apex without a long spine; lustrous



Figs. 851-865

blue-black hispid except dark brownish to black legs and antennae, and reddish femora; body length 3.7-4.8 mm (Fig. 869) ..... *Dicladispa armigera* (Oliver)

467' African species; each side of pronotum with 4-6 robust spines 468

468 Pronotum with 4 spines, one 3-branched before middle and a simple one below middle, lightly punctated, posterolateral angle with a short thin setae; elytra with relatively deep irregular punctations, spine on apico-lateral area large with a broad base, extreme apex with a prominent spine at median (Fig. 870) ..... *Dicladispa viridicyanea* (Kraatz)

468' Pronotum with 5 long spines, one 4-branched before middle and a single spine just behind the tetramerous spine; a small, short, horizontal spine present posterolaterally (Fig. 871); antennae without spines; elytra coarsely punctated, body oblong, bluish-black including legs and antennae, shiny except opaque pronotal disc ..... *Dicladispa striacollis* Gestro

469(466') Antenna lacking spines, segment III a little shorter than length of segment IV and V together; lateral margins of pronotum with 3 spines, median apical two very close to each other basally, 3rd spine below middle; anterodorsal part of pronotum with 2 double-branched spines; elytra coarse and clothed with numerous spines, lateral ones longer and more slender than the short but robust inner ones (Fig. 872); African species ..... *Dactylispa bayoni* Gestro

469' First antennal segment with a long simple or 4-branched spine, segments 11-VI with or withoutspines 470

470(469') Basal segment of antennae with a 4-branched spine, apicodorsally, 2*nd* with two, 3*rd* to 6*th* with one each (Fig. 873); pronotum constricted behinde simple spine, with 10 spines, 4 double-branched with 2 each of anterodorsal and lateral margin, and 2 simple ones below the laterals; head rugose with grey hairs around eyes; black with glossy punctate-striate elytra (Fig. 874) ..... *Hispa stygia* (Chapuis)

470' Basal segment of antennae the largest, with a simple spine (Fig. 875), segment II small and rounded, increased in size thereafter with 5 apical segments thick and elongate club-like covered by brown pubescence; prothoracic spine close to *H. stygia* except for a subacute tooth in the anterolateral edge; head broad and rugose, convex eyes rimmed with silvery hairs; bluish black hispid ..... *Hispellinus moestus* (Baly)

471(464') Pronotum broader than long or as broad as long, sides strongly constricted behind middle, narrower than elytra without distinct lateral margins; head usually constricted behind emarginate eyes; antennae filiform, insertions separated by entire width of frons, elytra rarely more than 3 times as long as broad, punctures at least regular with interspaces between rows at least as wide as punctures; occiput abbreviated (Criocerinae) *(Oulema)* 472

471' Pronotum as wide as elytra, usually with lateral margins; prosternum without antennal grooves; antennal insertions nearly approximate 473

472(471) Basal segment of antennae yellow, rest of segments black; pronotum as broad as long, lateral sides medially constricted, disc with a double row of coarse punctures and impunctate basally; basal groove prominent (Fig. 876); dorsum yellowish brown except black lateral margins of elytra and scutellum . . . . . *Oulema atrosuturalis* (Pic)

472' Basal segment of antennae reddish; pronotum (Fig. 877) reddish brown, punctures moderately dense and scattered, relatively dense at middle forming 2 light longitudinal rows, basal grove not prominent; elytra blue with yellow thorax . . . . . *Oulema oryzae* (Kuwayama)

472" All segments of antennae uniformly black; pronotal punctures sparse, central ones arranged in 3 rows, rest impunctate (Fig. 878); body entirely blue or green with metallic green elytra; pronotum, femora, tibiae, and tarsi reddish yellow, apices of tibiae and tarsi darkened . . . . . *Oulema melanopa* (Linnaeus)

473(471') Femora III slender, adapted for walking (Galerucinae) 474

473' Femora III thicker than I and II, enlarged for jumping (flea beetles) (Alticinae) 477

474(473) Pronotum longer than wide, slightly constricted below middle producing a minute process, gena slightly shorter than smaller diameter of eye; anterior coxal cavities open behind; elytral epipleuron wide basally, elytron (Fig. 879) yellow-brown with a midlongitudinal black band not reaching apices and outer margins black; head black; antennae dark brown to black except segments VIII and IX yellow . . . . . *Medythia nigrobilineata* (Motschulsky)

474' Pronotum wider than long, anterior and posterior lateral angles with thin setae; anterior coxal cavities closed behind 475

475(474') Anterior and posterior pronotal margins concave or procurved, not subquadrate dorsally; elytral epipleuron suddenly narrowed at end of basal one-third and distinctly narrower at middle; basal segment of tarsi III long and slender, one-fifth longer than remaining segments combined 476

475' Pronotum subquadrate or rectangular, anterior margin straight, midposterior area strongly indented; basal segment of tarsi III short and not slender, nearly as long as 2*nd* segment (Fig. 880); African species . . . . . *Sesselia pusilla* Gerstacher

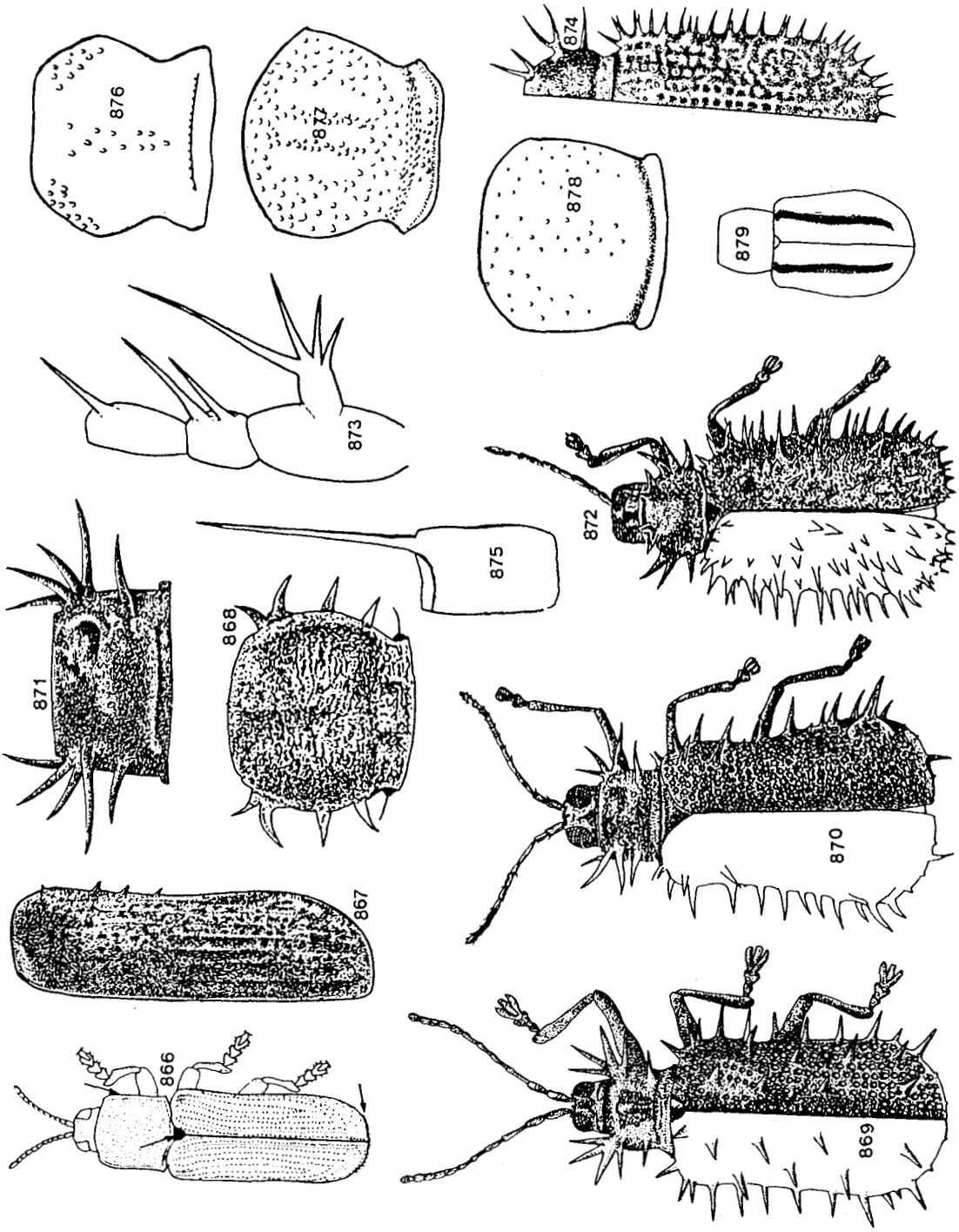
476(475) Elytra (Fig. 881) black with 2 broad subglobular yellow spots before and behind middle; abdomen reddish brown . . . . . *Monolepta signata* Olivier

476' Elytra (Fig. 882) yellow with 2 transverse blackish brown bands, basal one runs from suture to suture, the submedian band not reaching lateral wing margins; body and legs yellow except brownish black head, apical antennal segments, mesopleuron and mesosternum . . . . . *Monolepta bifasciata* (Hornstedt)

477(473') African species of *Chaetocnema* 478

477' Oriental species 481

478(477) Body length more than 3 mm; head and pronotum moderately punctated; space between antennal base as long as or slightly longer than scape; antennal segments III-VII



Figs. 866-879

far more slender than the apically dark colored four segments; pronotum rounded on all sides; inner striae of elytra rather oblique (Fig. 883) . . . . . *Chaetocnema kenyensis* Bryant

478' Body length, a little over 2 mm 479

479(478') Pronotum approximately one-third wider than long, densely punctured, narrows toward anterior and broadens below middle, anterior and posterior lateral angles more or less rounded; vertex lightly punctated; antennae without very slender segments similar to *C. kenyensis* ; elytral striae in regular rows, *1st* or *2nd* stria incomplete (Fig. 884) . . . . . *Chaetocnema abyssinica* Jacoby

479' Pronotal punctures moderately dense and coarse to almost smooth; posteromedian part of pronotum margined or unmargined 480

480(479') Posterior edge of pronotum margined, middle strongly concave; head almost smooth (Fig. 885) . . . . . *Chaetocnema pulla* Chapuis

480' Posterior edge of pronotum not margined; middle mildly concave; head punctated (Fig. 886) . . . . . *Chaetocnema pallidipes* Fairmaire

481(477') Interantennal space carinate or swollen medially, not punctated; vertex impunctate or with few punctures; elytron with interstices flat mesally and weakly swollen laterally; punctations rather irregular; pronotum with a punctured, faintly impressed line along basal margin (Fig. 887); anterior femora reddish to pitchy brown with a pale apex . . . . . *Chaetocnema basalis* Baly

481' Interantennal space flat and strongly punctured; vertex prominently punctured, elytral punctations in 15 regular rows (Fig. 888) . . . . . *Chaetocnema concinnipennis* Baly

482(462') Claw toothed with a fleshy appendage beneath; body clothed with long erect setae; head quadrate, strongly transverse; pronotum reddish yellow and hexagonal; neck absent; antennae 10-segmented, brown except three reddish yellow basal segments; legs I and II brown and III bluish; elytra deep blue with a transverse reddish yellow band medially, apical end of elytra with a small reddish yellow band; apex of sutural area of elytra open V-shaped (Fig. 889) [Melyridae] . . . . . *Apalochrus rufofasciatus* Pic

482' Claw simple; body without long erect setae; pronotum not hexagonal 483

483(482') Head strongly deflexed and moderately globular, free from anterior margin of pronotum; neck distinct; pronotum globular medially and constricted anteriorly and posteriorly; elytral humeri obsolete; metathoracic wings vestigial; femur clubbed; penultimate tarsal segments bilobed (Anthicidae] 484

483' Head not deflexed, wider than long and deeply sunken in the concave anterior pronotal margins; sides of frons strongly produced over the antennal insertions; eyes deeply indented in between frontal flange and anterolateral part of pronotum; pronotum subquadrate with a wide lateral margin and double convex posterior margin (Figs. 890-891); clypeus with a V-shaped cleft anteromedially (Fig. 890); body clothed with yellow-brown clavate setae arranged in 9 bands in each elytron with 3-4 rows in each

band (Figs. 892-893), area in between bands smooth and blackish; basal 3 abdominal sternites immovably connected [Tenebrionidae] ..... *Gonocephalum* spp.

484(483) Elytra without any oblique white markings (Fig. 894); entire body and legs uniformly brown ..... *Formicomus* sp.

484' Elytra with oblique white markings (Fig. 895); basal one-half of antennae brownish and blackish towards apex; basal portion of femur II and III pale; body black .... *Formicomus braminus* La Ferte Senectere

485(363') Front and hindwing similar in size, shape, and venation and extended well beyond tip of abdomen at rest, hamuli and crossveins absent; wing scales (= stumps) present; veins M and Cu multibranched; fontanelle usually present; antenna moniliform; tarsi 4-segmented (**ISOPTERA**) 486

485' Frontwing different from the hindwing in size, shape, and venation, and as long as or slightly beyond tip of abdomen at rest, hamuli present; with or without crossveins in the 4 membranous wings; wing scales absent; veins M and Cu not multibranched; fontanelle absent; antenna usually elbowed, clubbed or filiform; tarsi 3-5 segmented (**HYMENOPTERA**) 488

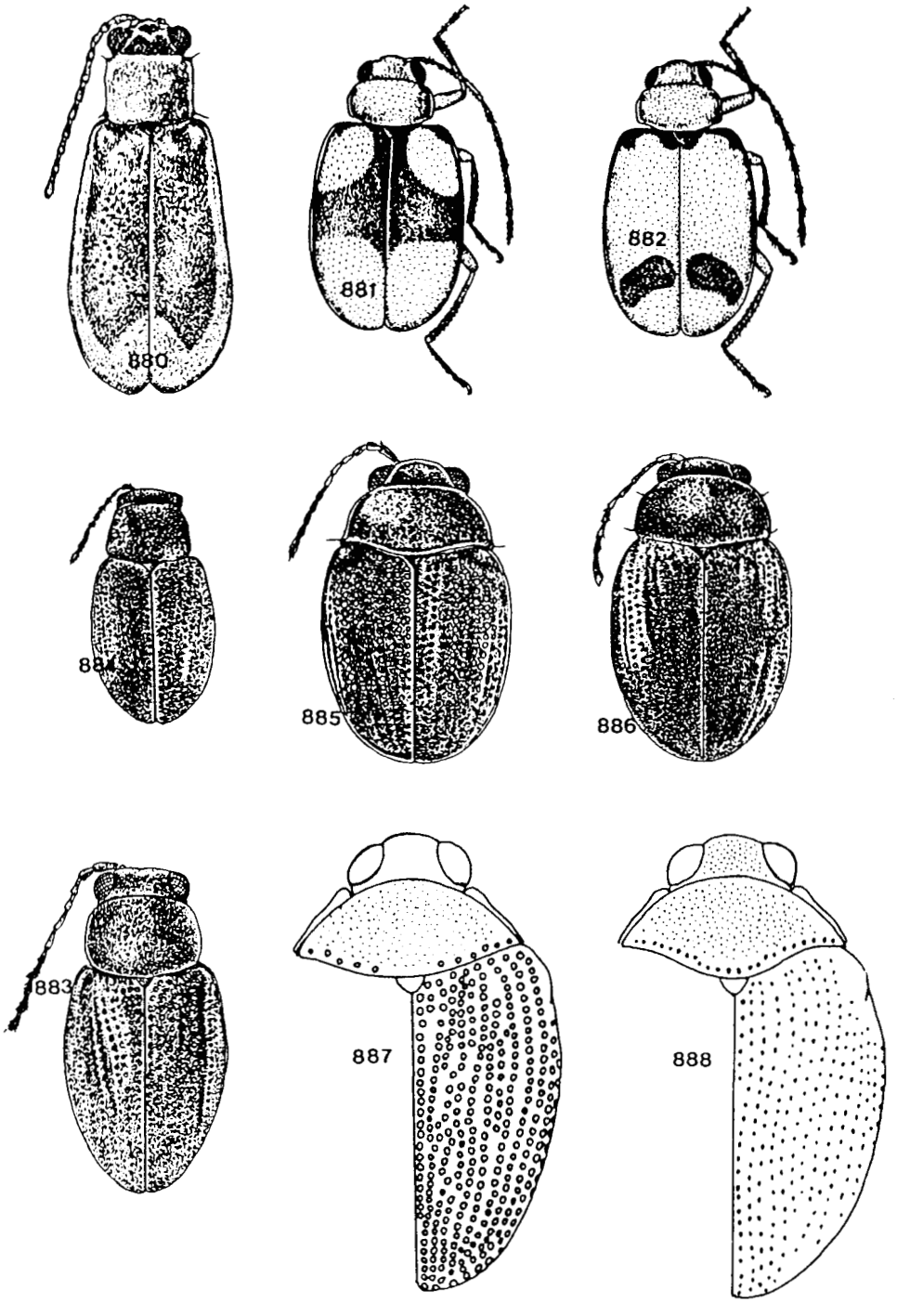
486(485) Anterior wing scales covering at least the base of the posterior scales; wings slightly reticulate, veins Sc + R and radial sector with 2 thin longitudinal lines near apex, radial sector with 5-7, medius trifurcate apically; cubitus of frontwing with 8 branches and 11 in the hindwing (Fig. 896); pronotum large and cleft at its median anterior margin; ocelli present [Rhinotermitidae] ..... *Coptotermes formosanus* Shiraki

486' Anterior wing scales short, not reaching to base of posterior scales; wings not entirely reticulate [Termitidae] 487

487(486') Radial and median sector 4-branched at apices, cubitus multidichotomously branched (Fig. 897); head ovoid with ocelli and a small fontanelle; small clypeus moderately truncate apically, labrum dome-shaped; pronotum very wide along anterior margin and narrow posteriorly (Fig. 898); African species .... *Macrotermes natalensis* (Haviland)

487' Radial and Sc + R (Fig. 899) almost fused at wing apex, unbranched, medius with 3 oblique branches in apical one-third; cubitus with 15 branches, tridichotomous at middle; ocelli and fontanelle prominent; prothorax cleft along midanterior and mid-posterior part (Fig. 900); Oriental species ..... *Macrotermes gilvus* (Hagen)

487' Sc + R and radial sector fused towards apex and merged with tip of medius, medius branch at midhalf with a pentadichotomous branch, cubitus with 14 single-branch veins in the frontwing (Fig. 901); head subovoid with indistinct fontanelle, clypeus moderately large, slightly cleft along apical margin to straight, deeply sunken in the concave frons; labrum longer than wide, partly dome-shaped; pronotum (Fig. 902) subtruncate with a minute cleft at midanterior margin, anterolateral angle slightly elevated, posterior margin moderately indented ..... *Microtermes* sp.



Figs. 880-888

488(485') Hind tibial spur or spurs present, one (the medial when there are 2) modified into a calcar through development of a comb of hairs or teeth on its inner tarsal margin; a corresponding strigil or brush is developed on the slightly emarginate basitarsus; if both spurs are non-simple or lacking, then at least some body hairs are plumed and the hind basitarsus widened, or first 1 or 2 segments of metasoma forming a node 489

488' Hind tibia with 1 or 2 spurs (absent in a few Ichneumonidae), but none modified for pruning; sometimes a dense brush of enlarged hairs developed on the basitarsus and apex of tibia 519

489(488) Lateral pronotum and mesopleuron (or prepectus) overlapping and with considerable free movement, lower portion of pronotal lobe rounded (pronotum and prepectus fused in Dryinidae, but the antennae 10-segmented), spiracle cover lobe of pronotum not margined with close fine hairs (prepectus visible); hindwings without closed basal cells 490

489' Lateral pronotum and mesopleuron meeting with carinate margins and with very little free movement between them, lower portion of pronotal lobe tapering to a point 503

490(489) Antennae 10-segmented in both sexes; females usually wingless with chelate foretarsi [Dryinidae] 491

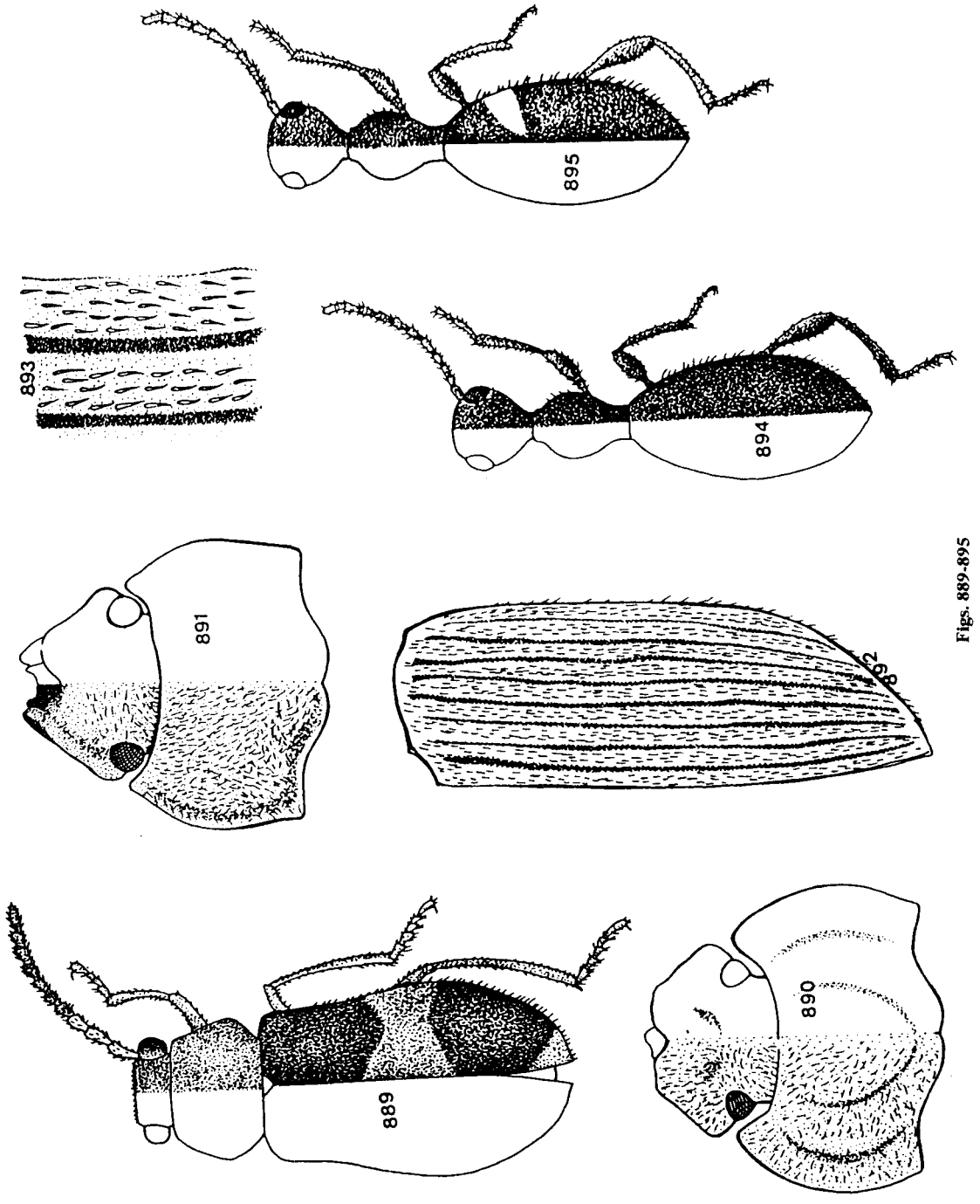
490' Antennae 13-segmented, apical segments globular; foretarsi of both sexes simple, not chelate, apterous forms absent; head depressed to slightly convex; lateral ocelli near posterior margin of head; face with a ridge in between antennal sockets; thorax without humps or node-like patterns, smooth propodeum quadrate and margined laterally and posteriorly; legs short, blackish brown with yellow tarsus; wings hyaline, pubescence outside closed cells, stigma prominent (Fig. 903) [Bethylidae]; larval parasite of *Cnaphalocrocis* and *Marasmia* leaffolders . . . . . *Goniozus* nr. *triangulifer* Kieffer

491(490) Both sexes fully winged; notaulices completely distinct, and jointed posteriorly in male; female with testaceous head, antennae, and pronotum; abdomen similarly testaceous except tergites 1, 2 and 4 partly brown; propodeum and petiole black; forewing transparent without dark transverse bands; maxillary palpi 3-4 segmented and labial palpi 2-segmented; segment 1 and 4 of foretarsus equal in length; enlarged claw with subapical tooth and 4-5 lamellae; segment V of foretarsus with a single row of 9-12 lamellae, apex with a group of 6-11 lamellae (Fig. 904); aedeagus of male with a deeply cleft apicomedian process (Fig. 905); hosts - *N. lugens, S. furcifera, L. striatellus, P. saccharicida,* and *Nephotettix* spp. . . . . *Echthrodelphax fairchildii* Perkins

491' Female apterous; male winged; other characters not as above 492

492(491') Enlarged claw without subapical tooth, with or without small tooth at the end of the longitudinal furrow 493

492' Enlarged claw with subapical tooth 496



Figs. 889-895

493(492) Pronotum not crossed by a transverse depression, if so, impression very weak; labial palp 2-segmented 494

493' Pronotum with a prominent transverse depression 495

494 Maxillary palpi 2-segmented; enlarged claw with *3* bristles at end of longitudinal furrow; segment V with a row of 6 minute lamellae on distal half, apex with 6 lamellae (Fig. 906); segment I of foretarsi longer than segment IV (11:9); black except testaceous antennae and yellow legs (Fig. 907); hosts — *Nephotettix cincticeps* and *N. nigropictus* .... *Tetrodontochelys sakaii* (Esaki & Hashimoto)

494' Maxillary palpi 3 to 4-segmented; enlarged claw as above but with 5 peg-like hairs; segment V with a row of 16-20 lamellae and a group of 8-10 lamellae at apex, proximal region with an inner serrate margin (Fig. 908); segment I of foretarsi as long as segment IV; reddish testaceous with black petiole, brown vertex and abdomen; hosts - *N. virescens, N. nigropictus,* and *Recilia dorsalis* ..... *Tetrodontochelys lucens* Olmi

495(493') Maxillary palpi 3-segmented; labial palpi 2-segmented; enlarged claw with a bristle and 3 peg-like hairs at end of longitudinal furrow; segment V of front tarsi with innerside proximally not serrate, with 2 rows of 12 lamellae and a group of 6 lamellae at apex (Fig. 909); 1*st* segment of tarsi I the longest, two times longer than *4*th and slightly longer than 5*th;* black species except yellow malar space, clypeus, mandibles, and front of vertex, and brownish antennae and legs; host — *N. lugens* ..... *Gonatopus yasumatsui* Olmi

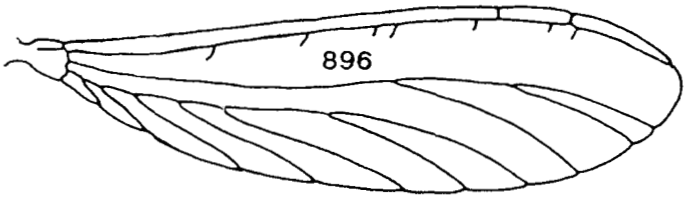
495 Maxillary palpi 6-segmented; labial palpi 3- segmented; enlarged claw with 6 peg-like hairs, innerside not proximally serrate but with 18-19 lamellae in 2 rows, apex with 14 lamellae in a group (Fig. 910); 1*st* segment of tarsi I two-thirds of 4*th,* 5*th* segment four times longer than 1*st;* head brownish red with yellow mandibles, clypeus and front vertex; antennae brown with segments **1** and 2 yellow; thorax and abdomen blackish brown; host —*Nephotettix virescens* ..... *Gonatopus lucidus* (Rohwer)

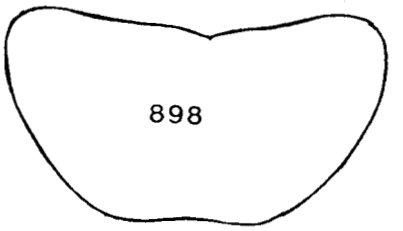
496(492') Pronotum without or very weak transverse depression; labial palpi one-segmented; maxillary palpi 2-segmented 497

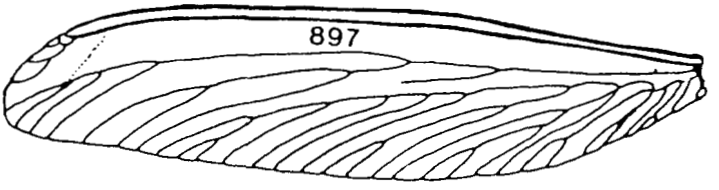
496' Pronotum clearly with a prominent depression; labial palpi 2-segmented; maxillary palpi 2- to 4-segmented 499

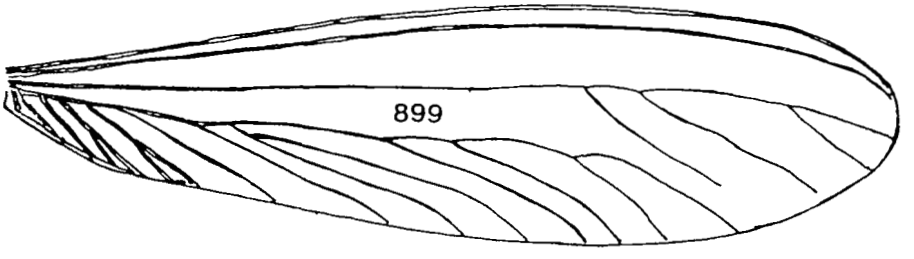
497(496) Female with abdomen entirely testaceous to occasionally brown; propodeum yellow testaceous; enlarged claw with 3-6 lamellae, segment V with 2 rows of 7-10 lamellae and a group of 2-7 lamellae at apex (Fig. 911); male with dorsal process of gonoforceps distally broadened and serrated (Fig. 912); hosts — *N. lugens, Laodelphax striatellus* and *Sogatella furcifera* ..... *Haplogonatopus apicalis* R.C.L. Perkins

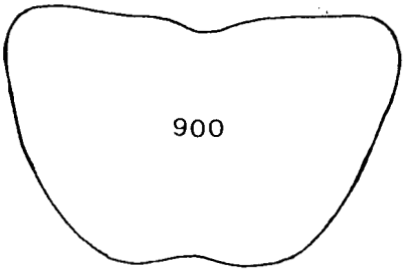
497' Female abdomen fully black; male dorsal process of gonoforceps distally serrated or not serrated 498

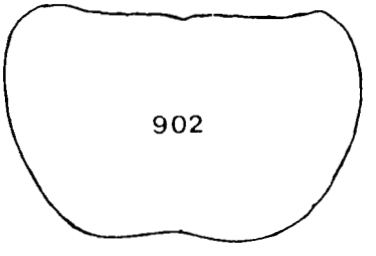


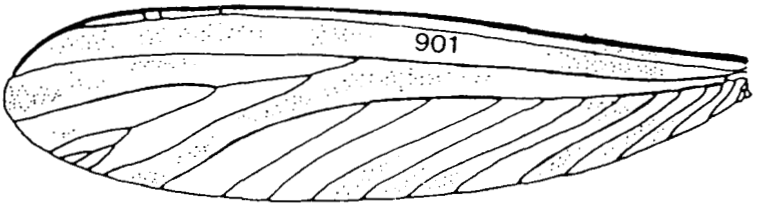












Figs. 896-902

498(497') Dorsal process of gonoforceps distally serrated but not broadened (Fig. 913); segment V with 12 lamellae (Fig. 914); host - *L. striatellus* ..... *Haplogonatopus atratus* Esaki & Hashimoto

498' Dorsal process of gonoforceps long and slender, apex without a serrated margin (Fig. 915); segment V with 11 lamellae, enlarged claw with 4 (Fig. 916); host - *L. striatellus* ..... *Haplogonatopus oratorius* (Westwood)

499(496') Legs testaceous; thorax and propodeum red testaceous with yellow scutum; maxillary palpi 2-4 segmented; sides of metanotum rounded; metathorax + propodeum with a weak tract of median furrow; enlarged claw with subapical tooth and 6-7 lamellae, segment V of foretarsus with 2 rows of 19-20 lamellae and a group of 5-8 lamellae at apex (Fig. 917); basal segment of foretarsus as long as 4th; dorsal process of gonoforceps of male slender, pointed at apex and with a subapical point (Fig. 918); hosts - *N. lugens* and *Sogatella* sp. ..... *Pseudogonatopus sarawaki* Moczar

499' Legs mostly yellow; thorax, propodeum, and abdominal coloration more or less different (except red testaceous in *P. nudus);* sides of metanotum rounded or protruding; dorsal process of gonoforceps of male different 500

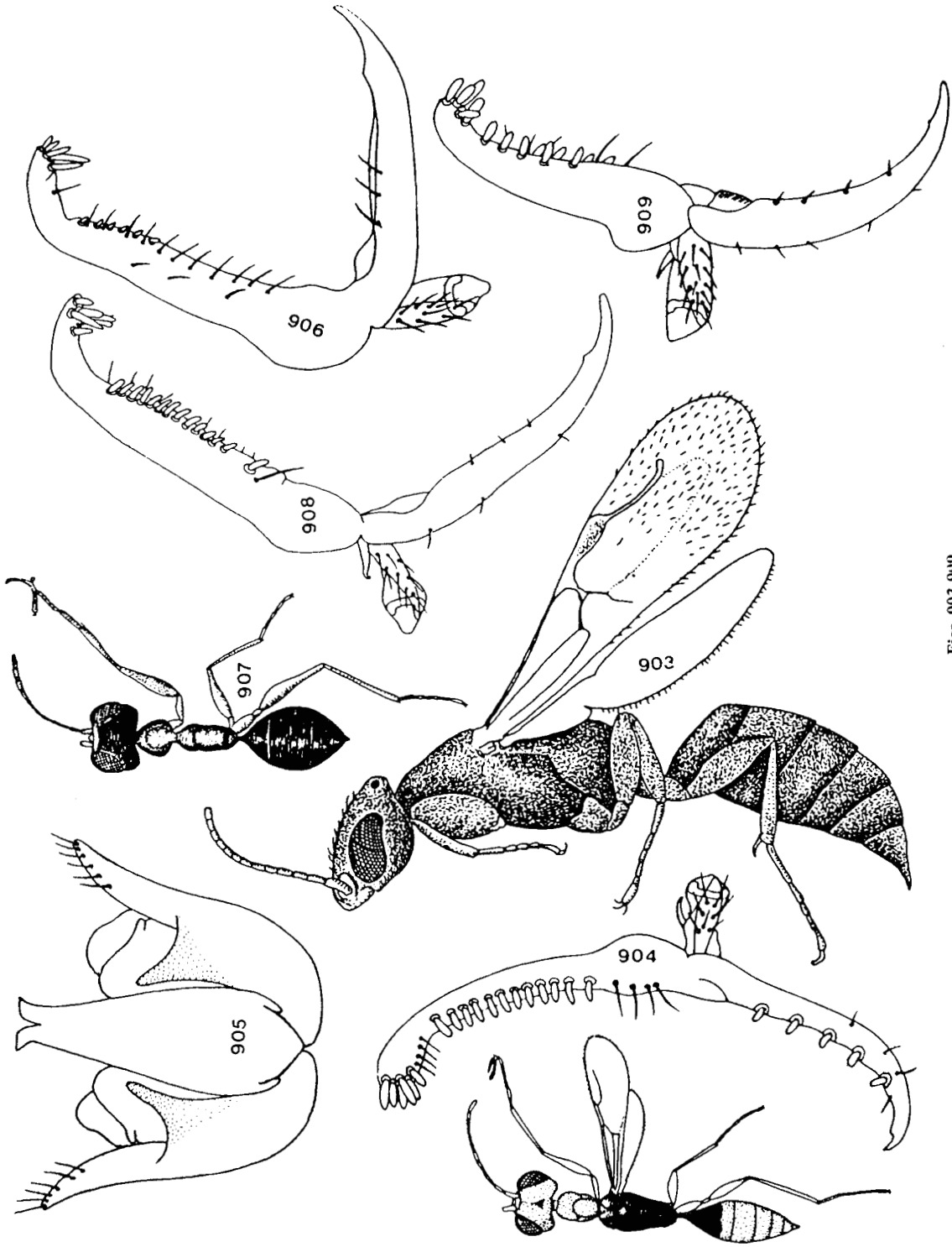
500(499') Sides of metanotum protruding, metathorax + propodeum without median furrow; maxillary palpi 4-segmented; enlarged claw with a subapical tooth and 6 lamellae; segment V of foretarsus with 2 rows of 14 lamellae and a group of 6 lamellae at apex (Fig. 919); basal segment of foretarsi as long as 4*th* segment; general coloration reddish testaceous except black petiole and brown-red abdomen (Fig. 920); hosts - *N. lugens* and *Sogatella furcifera* ..... *Pseudogonatopus nudus* R.C.L. Perkins

500' Sides of metanotum rounded; body color black to brownish black 501

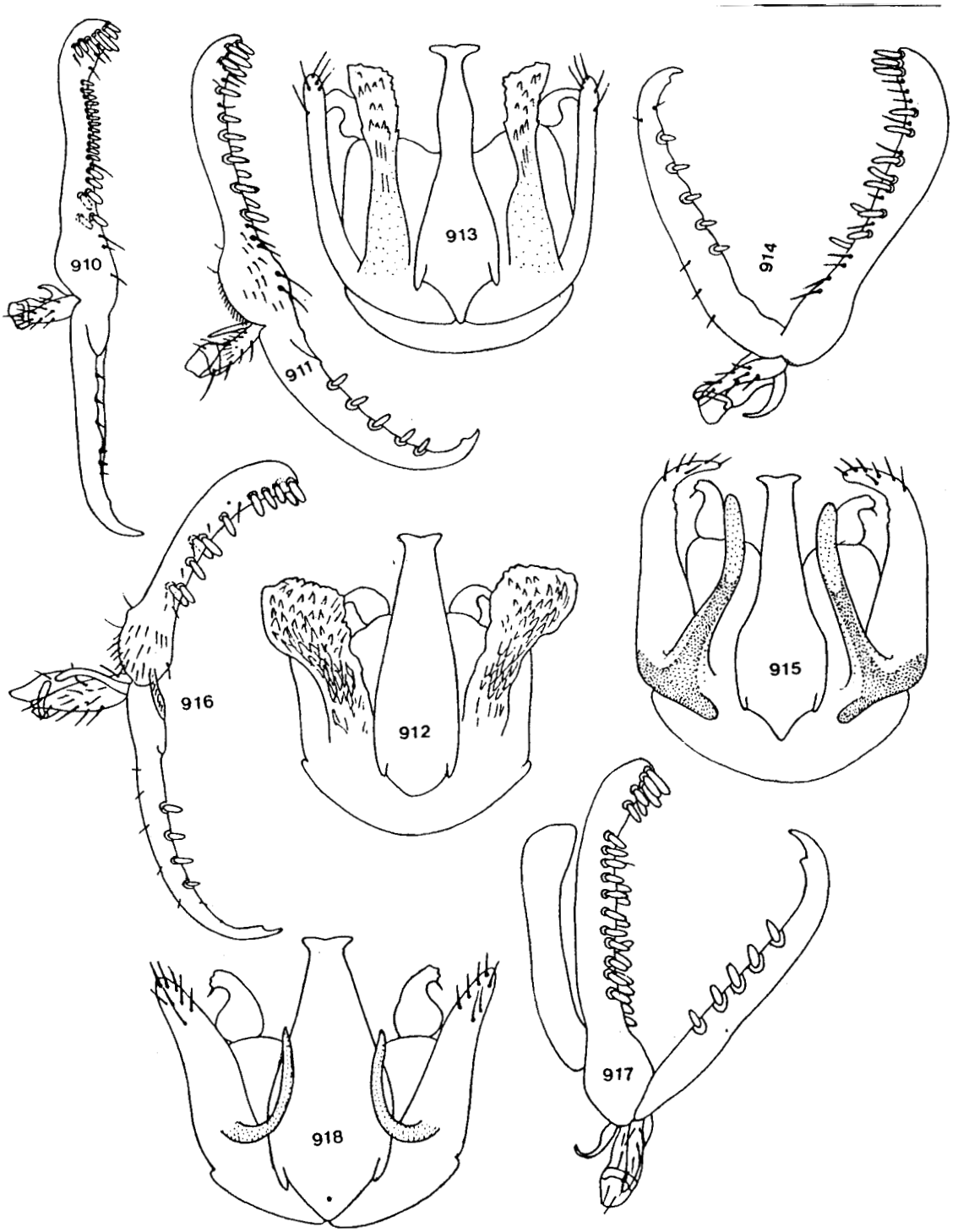
50l(500') Head, thorax, and propodeum brownish black; abdomen black; (Fig. 921); maxillary palpi 2-segmented; mandible tetradentate (Fig. 922); metathorax and propodeum weakly granulated; enlarged claw with subapical tooth and 4-5 lamellae, segment V of foretarsus with 2 rows of 10-12 lamellae and a group of 5 more at apex (Fig. 923); basal segment of foretarsi one-fifth longer than 4*th* (20:16); dorsal process of gonoforceps in male broad and long, rounded at apex and with a lateral point (Fig. 924); hosts - *S. furcifera* and *L. striatellus* ..... *Pseudogonatopus fulgori* (Nakagawa)

501' Not as above 502

502(501') Body uniformly black except brown head; propodeum without a yellow area at apex; metathorax and propodeum dull and granulated (Fig. 925); maxillary palpi 4-segmented; enlarged claw with a subapical tooth and 5 lamellae; segment V of foretarsi with 2 rows of 13 lamellae, apex with a group of 7 lamellae (Fig. 926); segment I of foretarsus 1.24 times longer than 4th (21:17); dorsal process of gonoforceps of male very short and pointed (Fig. 926); hosts - *N. lugens, S. furcifera,* and *Nephotettix* spp. ..... *Pseudogonatopus flavifemur* Esaki & Hashimoto



Figs. 903-909



Figs. 910-918

502' Thorax and propodeum black; propodeum with a yellow patch at apex; abdomen brownish black and head brown; metanotum and propodeum with a tract of median furrow and indistinctly sculptured; maxillary palpi 2-4 segmented; enlarged claw with 4-9 lamellae; segment V of foretarsus with 2 rows of 20-25 lamellae, apex with a group 7-10 more lamellae (Fig. 927); dorsal process of gonoforceps broadly long, pointed and blade-like (Fig. 928); hosts – *S. furcifera, N. lugens* ..... *Pseudogonatopus hospes* R.C.L. Perkins

503(489') Segments 1 or 2 of metasoma nodiform and sharply marked off from the rest; posteroventral corners of thorax each with a metapleural gland [Formicidae] 504

503' Segment 1 of metasoma not node-like; metapleural glands absent 509

504(503) One petiole (node) present 505

504' Two petioles present 508

505(504) Head and thoracic dorsum with prominent long grooves (deeply carinated) transverse in the pronotum and mesoscutum and longitudinal in the mesoscutellum; anterolateral angle of pronotum toothed (Fig. 929); right mandible with 5-teeth; clypeus with 7 blunt teeth; frontal carina widely separated; antenna 12-segmented; veins Rs + M reaching wing apices; first discoidal cell 5-sided; second discoidal cell trapezoidal; cubital cells 1 and 2 almost equal in size (Fig. 930); gaster attached to the alitrunk by a single node, top of node thinly flat and concave at middle; black ants ..... *Odontopouera* sp.

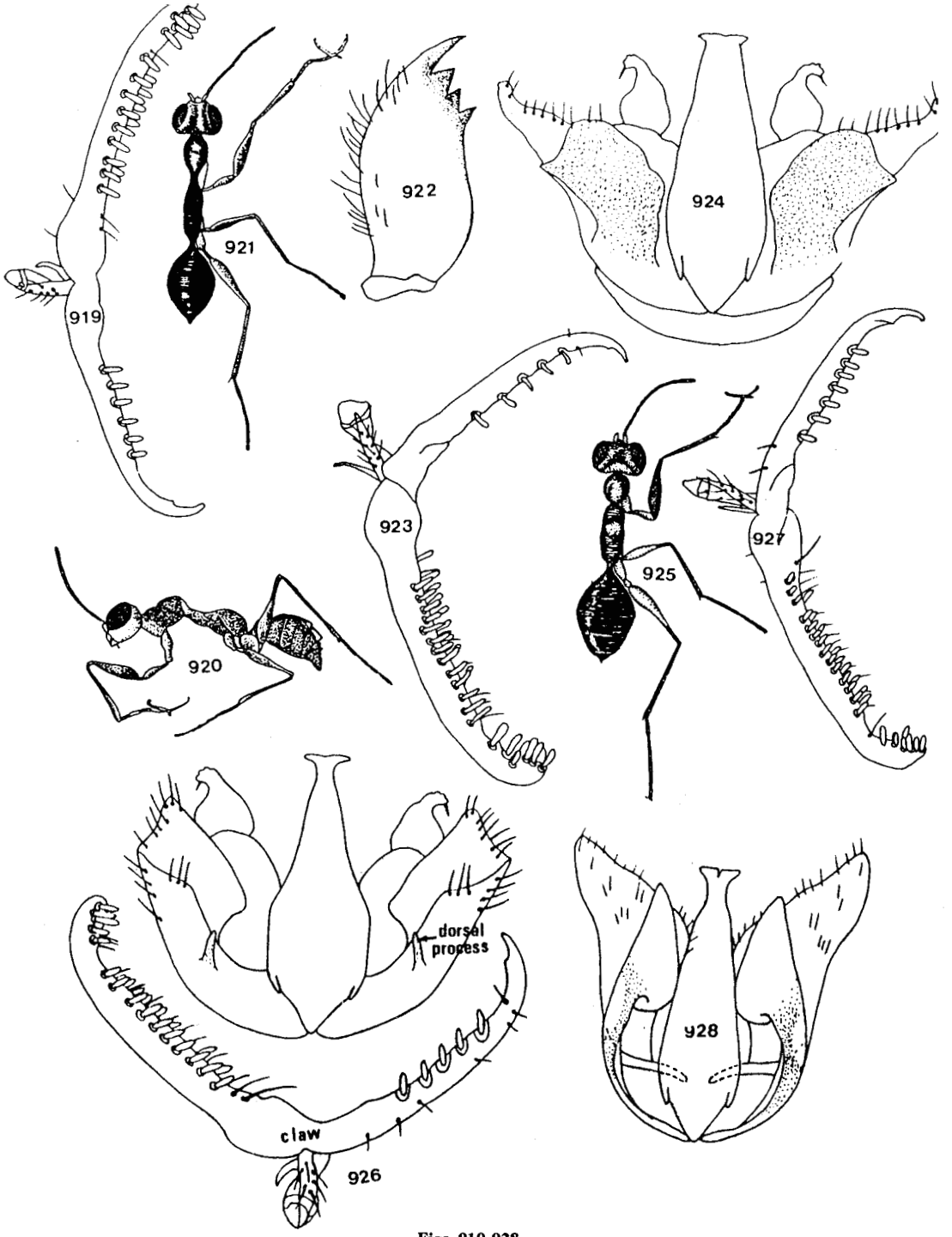
505' Head and thorax smooth to moderately punctated; venation variable 506

506(505') Pronotum with anterolateral teeth, propodeum and petiole with a pair each of spines (Figs. 931-932); petiolar spines projected sidewards or curved posteriorly (Fig. 933); antennae 12-segmented (Fig. 933); first abdominal segment very broad, almost twice as long as the total length of remaining segments; veins Rs and M diverging originating from a common point at little beyond 7; inner tip of Cul curved downwards; Cu straight basally, hump-like above tip of A and straight towards wing apex (Fig. 934); black ants clothed with fine white hairs ..... *Polyrachis* spp.

506' Not as above 507

507(506') Head (sometimes finely carinated along sides), thorax, and abdomen (Fig. 935) clothed with moderately long hairs, smooth and shiny black; frontal carina weakly raised; stigma thin; veins Rs and M moderately diverging after a square plate junction at base of crossvein r or after a small extension past base of same crossvein; apical half of Cu convex and appears fused to tip of A above wing notch; discoidal cell very large; Cu-a close to midhalf of M+Cu; M and Cu not reaching wing margins (Figs. 936-937); antenna brown except black scape; petiole narrowed at tip in lateral view, subtruncate in posterior view; abdominal segment II (T2) usually longer than either I or III (Fig. 938) ..... *Camponotus* spp.

507' Head, thorax, and abdomen dull black clothed with short hairs, noticeably punctated with transverse carinae in the propodeum and the petiole; frontal carina small but well



Figs. 919-928

expanded; stigma rather large; Rs and M stems from different points; 1*st* discoidal cell small and subrectangular; Cu-a close to apex of M + Cu; M and Cu slightly erased towards their apices and parallel to each other (Fig. 939); antennae blackish red to brown, black towards scape; petiole rounded at apex; abdominal tergite I as long as II (Fig. 940) ..... *Diacamma* sp.

508(504') First discoidal cell strongly triangular towards its base, vein M straight almost reaching wing margin, Rs with a short extension after fusion with R1 prior to wing apex, very long almost meeting Cu near wing notch; 1*st* cubital cell narrowed towards median cell, Sc + R unparallel to Rs + M (Fig. 941); propodeal spiracle elongated; nodes subglobular with flat top; pedicel a little longer than wide ..... *Pheidologeton* sp.

508' First discoidal cell trapezoidal, vein M very short and Rs not reaching wing margin and never fused to R1; vein A short not meeting Cu; 1*st* cubital cell narrowed on both ends with Sc+ R parallel to Rs +M (Fig. 942); propodeal spiracle subglobular; 1*st* node divided at middle dorsally; pedicel globular ..... *Solenopsis geminata* (Fabricius)

509(503') Posterior lateral lobes of pronotum not reaching back to and terminate below tegula; hairs on body unbranched; notaulices wanting or feebly developed; jugal lobe in hind-wings; one interradial crossvein present in forewings [Sphecidae] 510

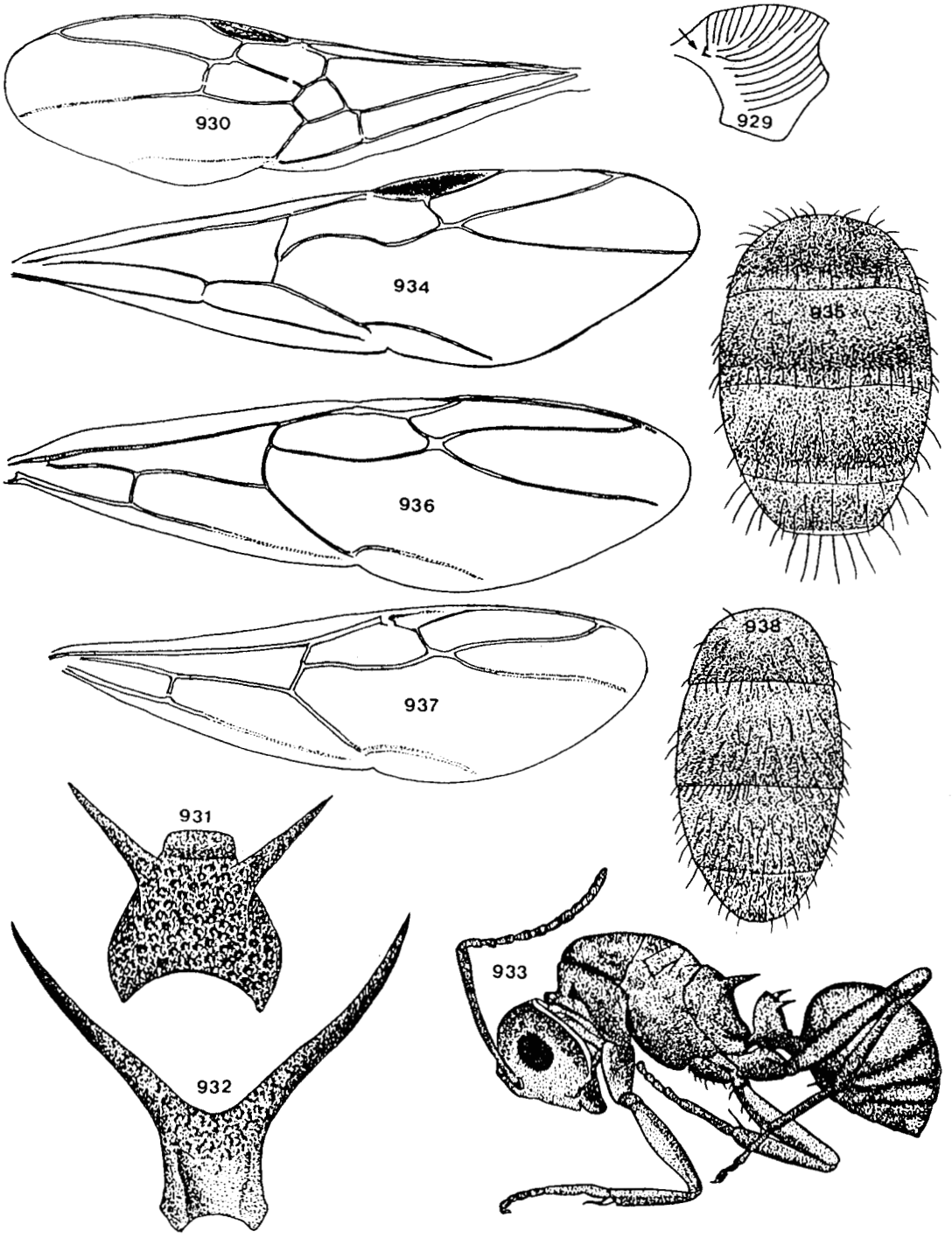
509' Posterior lateral lobes reach above tegula, usually angulated; forewing longitudinally folded at resting position, 3 marginal cells present; tegula with or without raised margin; tarsal claws bifid to simple [Vespidae] 512

510(509) Gaster with a long yellow petiole, longer than gaster or femur III (Fig. 943); pronotum with a pair of yellow lobes; mesoscutellum and metanotum yellow similar to apical one-third of femur and tibia of legs I and II, trochanter III, base of femur III, basal one-half of tibia III and basal tarsal segment of leg III; midtibia with 2 spurs; forewing with 6-sided 2*nd* cubital cell, apex of cubital protruded and rounded (Fig. 944); hindwing with 2 distinct 2*nd* anal veins well separated from 1A, jugal lobe without notch .... *Sceliphron madraspatanum conspicillatum* (Costa)

510' Gaster subsessile; 2 posterior ocelli more or less distorted (not round and convex), flattened and reduced; posterior border of pronotum straight viewed dorsally; tarsal claws without tooth; pygidium of female very polished 511

511(510') Abdomen and hind femur black; fore tibia without dorsal spines, 2*nd* antennal segment glabrous and polished, segment III not nearly twice as long as segment IV (Fig. 945); wings dark fuscous brown; disc of propodeum wrinkled in female; male antennal segment III as long as or a little shorter than IV (Fig. 946); clypeus gently rounded in its entire margin to very weakly but broadly emarginate sides; gaster smooth and polished; pygidium broad with arcuate sides ..... *Larra carbonaria* (Smith)

511' Abdomen polished and reddish except 3 black apical segments; fore tibia with dorsal spines; 2*nd* antennal segment pilose, III nearly twice as long as IV (Fig. 947); wings clear; disc of propodeum with a faint median carina, basally with separate punctures and densely reticulate in female; male antennal segment III noticeably longer than IV (Fig.



Figs. 929-938

948); clypeus produced medially into a polished and distally impunctate and very shallow emarginate lobe; gaster impunctate in female and banded with silvery file in male; pygidium very smooth with delicate punctures ..... *Larra sanguinea* Williams

512(509') Tarsal claws bifid; tegula with raised margins, apical half dark brown; mandibles long with visible serration, projected downwards; yellow except black vertex, mesoscutum (Fig. 949), anterior and posterior margins of mesoscutellum, apical and median part of propodeum, subapical area of tergite I, midhalf of II, basal two-thirds of IV and most lateral part of thorax except yellow band in propleuron and mesopleuron; tergite II with a pair of ovoid yellow spots behind black band (Fig. 950); discoidal cell 3 not rectangular with an oblique recurrent vein 2 connected to base of 2*nd* cubital cell; antennal segment III as long as combined length of IV and V .... *Eumenes campaniformes* (Fabricius)

512' Tarsal claws simple; tegula without raised margins 513

513(512') Reddish brown; apical part of abdominal tergite II with a prominent yellow band, with or without yellow spots towards base; mesoscutum without parallel yellow stripes; mesopleuron with or without yellow band 514

513' Yellowish black to brown; basal portion of abdominal tergite II broadly yellowish to light brownish yellow or with apical margin narrowly banded yellow; mesoscutum always with a pair of yellow parallel longitudinal stripes 515

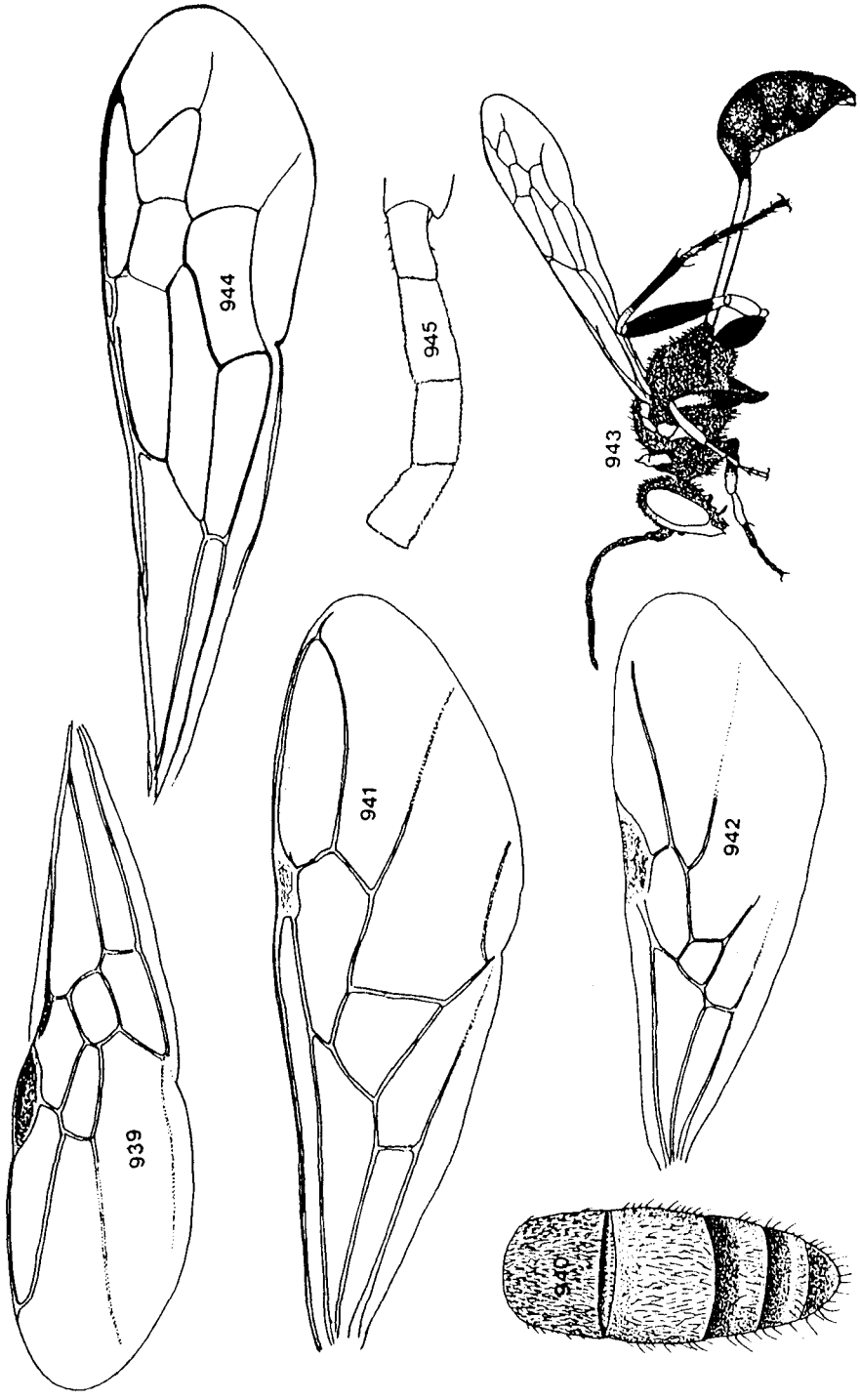
514(513) Propodeum with a pair of basal convergent carinae running from posterolateral angle of metanotum toward muscle slit base; muscle slit narrow and pointed (Fig. 951); basal portion of abdominal tergite II with a pair of prominent yellow spots obliquely cutoff at the base (Fig. 952); tergite I swollen posterolaterally and anterodorsally (Fig. 953); mesopleuron with a yellow band running parallel to the yellow band on sides of pronotum ..... *Ropalidia marginata sundaica* van der Vecht

514' Propodeum without such carinae; muscle slit broad and rounded anteriorly; basal portion of tergite II usually without yellow spots or highly reduced (Fig. 954), apical portion with a broad yellow fascia; tergite I parallel-sided at base anterodorsally, swollen posteriorly but narrowed towards apex in posterior one-quarter (Fig. 955); mesopleuron without yellow band ..... *Ropalidia fasciata* (Fabricius)

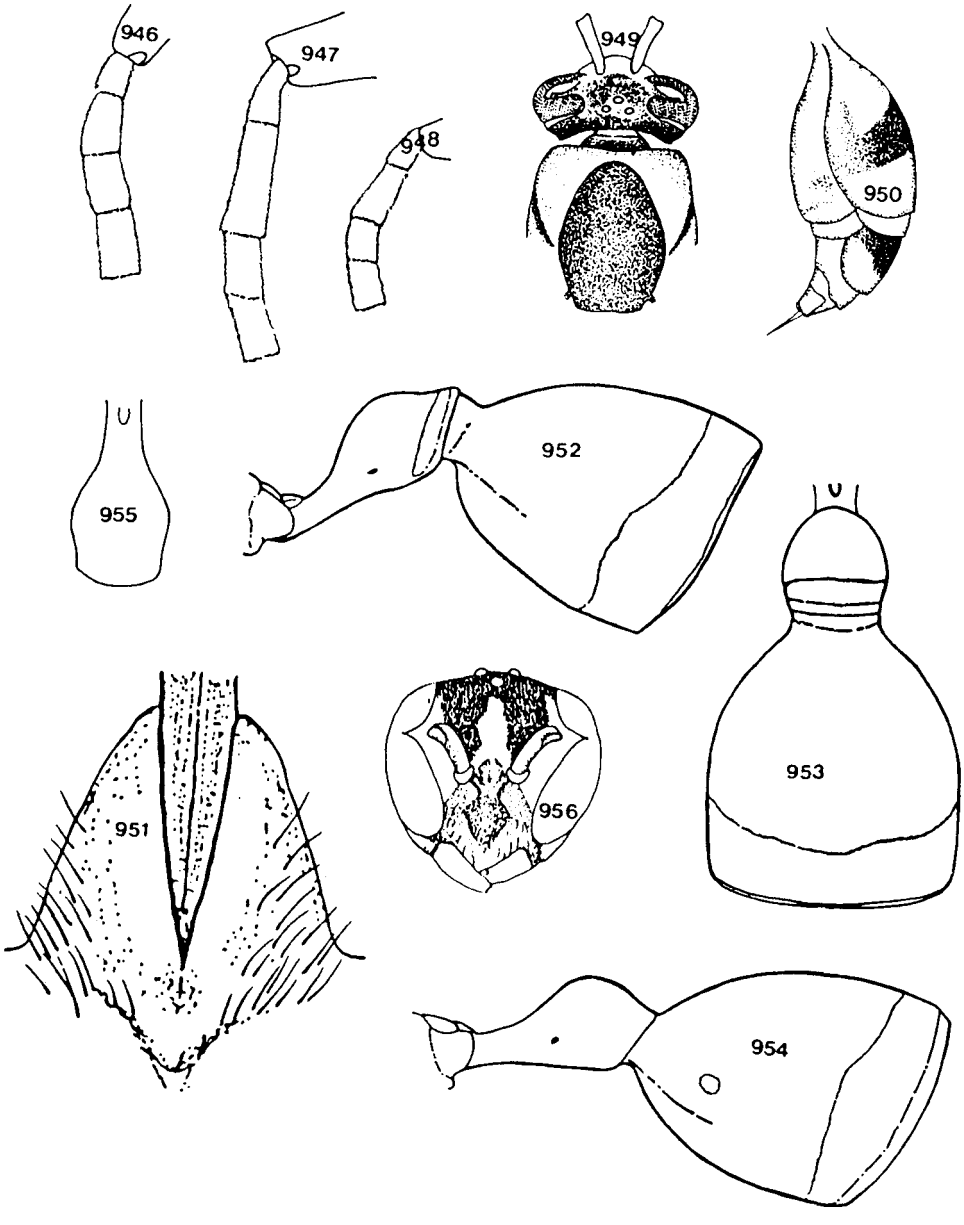
515(513') Mesoscutum without parallel longitudinal stripes 516

515' Mesoscutum with parallel longitudinal stripes 517

516(515) Clypeus yellow V-shaped, pointed apicomedially with brown patches in the central area and brown V-shaped mark below antenna (Fig. 956); vertex black, reddish brown behind and below ocelli up to eye margins and black near antennal base; pronotum reddish brown except thin yellow apical margin; hump-like mesoscutellum and metanotum with a pair each of yellow spots; propodeum without yellow markings; abdomen black except apices of tergite I and II yellow (Fig. 957); legs yellow to reddish brown, blackish brown in femora II and III .... *Ropalidia* nr. *philippinensis* (Saussure)



Figs. 939-945



Figs. 946-956

516' Clypeus cleft medially producing 2 prominent teeth and entirely yellow (Fig. 958); dorsum of head black with a deep and broad pit behind ocelli; yellow bands at the back and front of eyes towards emargination and a triangular yellow band above antennal base (Fig. 959); entire pronotum yellow with brown tinge along margins; mesoscutellum and metanotum with transverse rectangular yellow bands; abdominal tergite I reddish brown with a black base and yellow anterior, tergites III-VII yellow, II red and black with a pair of yellow spots near basolateral and yellow entire apical margin (Fig. 960) . . . . . *Ropalidia* sp. A

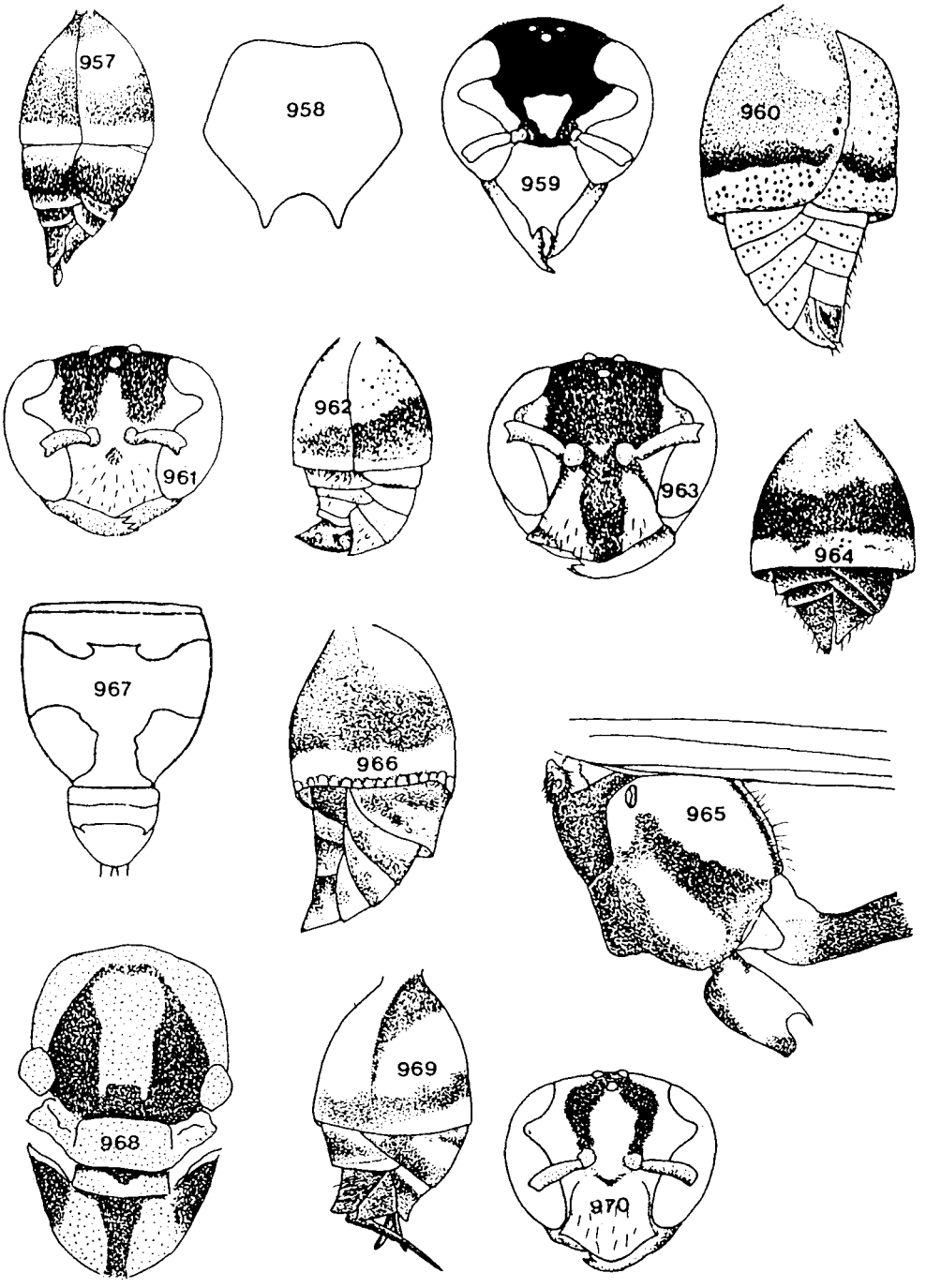
517(515') Clypeus uniformly yellow, clothed with fine hairs and a small black spot at base of antennae; yellow band emanating from antennae directed to but not touching the ocelli; vertex black with a thin oblique yellow stripe between eyes and lateral ocellus (Fig. 961); yellow part of pronotum reaching tegula; mesopleuron with a large yellow band; metapleuron with a yellow band at middle; abdomen yellowish except a broad subapical brown band in tergite II, a thin narrow band on apex of tergite III, and entire terminal segment (Fig. 962); coxae II and III mostly yellow on apical one-half . . . . . *Ropalidia flavopicta flavobrunnea* van der Vecht

517' Clypeus with a broad median longitudinal black band (Fig. 963) and sparsely haired; yellow spot present above antennae; vertex black without yellow oblique stripe between eyes and lateral ocellus (Fig. 963); tergites III and rest of apical segments brown, II yellow apically and basally but black submedially (Fig. 964); mesopleuron with a small yellow band, metapleuron and coxae II and III black . . . . . *Ropalidia* sp. B

517" Not with the combination of characters above 518

518(517") All legs black except yellow apice of femora I-III and parts of all coxae; yellow band on propodeum hook-shaped along spiracular area (Fig. 965); tergite I short, posterior two-thirds high or swollen in lateral view and yellow basally with a lateral protruding yellow band (Fig. 966); tergite II with a broad nearly medially contiguous dorsobasal lateral spot (Fig. 967); apices of rest of tergites yellow; clypeus with a median dark spot similar to (Fig. 961); mesoscutum with a yellow median band; metanotum yellow with a median dark band (Fig. 968) . . . . . *Ropalidia cyathiformis* (Fabricius)

518' Femora I to III yellow with black bands along the basodorsal one-half; tibia and tarsus of leg I brownish yellow, tibia II blackish brown in basodorsal two-thirds, and tarsus II, tibia and tarsus of leg III blackish brown; propodeum entirely yellow without a hook-shaped area near spiracles; tergite I moderately long, yellow apicoposteriorly and extended to the spiracles, II with alternating brown and yellow transverse bands, III median transverse yellow band constricted in the middle (Fig. 969), metanotum entirely yellow, mesoscutum with a pair of yellow longitudinal bands; clypeus yellow, front of head with an ovate black band running from ocellar region to below antennal base (Fig. 970); submedian yellow band of tergite II broad and transversely uninterrupted . . . . . *Ropalidia* sp. C



Figs. 957-970

519(488') Pronotum with at least a lateral spiracle cover lobe reaching back to tegula, or, if wingless, lobe margined with close fine hairs; lateral pronotum vertically grooved for reception of fore femora 520

519' Pronotum not reaching back to tegula (almost so in some Leucospidinae, in which tegula is lengthened, and in some Mymaridae); forewing with venation very reduced, without fully formed cells; pronotum separated from tegula by prepectus 637

520(519) Spiracle cover lobe of pronotum without close fine hairs along its margin 521

520' Spiracle cover lobe of pronotum margined with close fine hairs, anal lobe of hindwing notched; hindwing without jugal lobe; apex of wing with close pseudovenation; tibia II with 1 spur; eyes emarginate; stout bodied and densely haired wasps [Scoliidae] . . . 596

521(520) Lateral area of pronotum without a vertical groove for reception of femora I; scutellar cup elevated and well developed; mesonotum with parapsidal furrows; abdomen without hairy ring on tergite 2; antennae 13-segmented in the female and 15-segmented in male [Cynipidae] 522

521' Lateral pronotum vertically grooved for reception of front femora; scutellar cup absent; costal cell present or absent 523

522(521) Third antennal segment the longest, as long as combined length of scape and pedicel; segment 4 to 9 rather stout and equally long; segments 10 to 15 slightly shorter than each of 4 to 9; segments 9-13 light brown (Fig. 971); scutellar cup very close to the posterior end of thorax, sides with setae and network-like subglobular to rectangular marks (Fig. 972); radial cell subtriangular with unequal "arms" (15:25), inner angle of cell rounded opposite vein (Fig. 973); hosts – *Hydrellia* and *Notiphila* pupae . . . . . *Eucoilidea* sp. A

522' Third antennal segment shorter than 4*th,* seventh antennal segment longest, as long as each of segments 8 to 15 and 1.45 times longer than 3*rd;* 4th to 6*th* almost subequal in size and length (Fig. 974); segments 1-4 yellowish brown; scutellar cup far from posterior end of thorax, sides with indistinct network-like marks (Fig. 975); radial cell triangularly thinner than *Eucoilidea* sp. A and with equally long arms, inner angle of cell rounded opposite small crossvein above horizontal vein (Fig. 976); hosts – *Hydrellia* and *Notiphila* pupae . . . . . *Eucoilidea* sp. B

523(521') Costal cells absent, but distinct marginal vein from base or a pterostigma; hindwing with at least one closed basal cell (except in Aphidiinae) 524

523' Costal cells present, or venation greatly reduced; hindwing without closed cells . . 604

524(523) Forewing with 1 or without recurrent vein; hindwings with median cell not extending to base of marginal vein [Braconidae] 525

524' Forewing with 2 recurrent veins (rarely one); hindwing with median cell elongated beyond base of marginal vein [Ichneumonidae] 557

525(524) Mandibles widely separated, tips not touching when closed; head transverse with posterior margin of vertex emarginate; wings hyaline with dark brown stigma and veins, radial cell large, ending before apex of wing; recurrent nervure received in 1st cubital cell at a far distance from its apex; radial cell of hindwing petiolate (Fig. 977); antenna with 41-42 segments in both sexes; prothorax honey-yellow in females and yellowish brown in males; host – *Chlorops oryzae;* Japanese species ..... *Coelinidea oryzicola* Watanabe

525' Mandibles in usual position, tips touching when closed (Fig. 978) 526

526(525') Clypeus semicircularly emarginate at apex forming a circular opening with the mandibles (Fig. 979) 527

526' Clypeus not emarginate at apex, not forming such an opening with the mandibles; if very rarely with a long narrow opening (e.g. some Opiinae), then first orbital and first discoidal cells separated 535

527(526) Abdomen petiolate, basal segment with 3 constrictions, longest one occurs before widened apex (Fig. 980); brownish yellow to dark brown; wings hyaline; legs pale yellow, ovipositor as long as 2*nd* and following abdominal segments together; body length 3-4 mm; host – *Chilo suppressalis* ..... *Spathius helle* Nixon

527' Abdomen sessile 528

528(527') Occiput not margined 529

528' Occiput margined 532

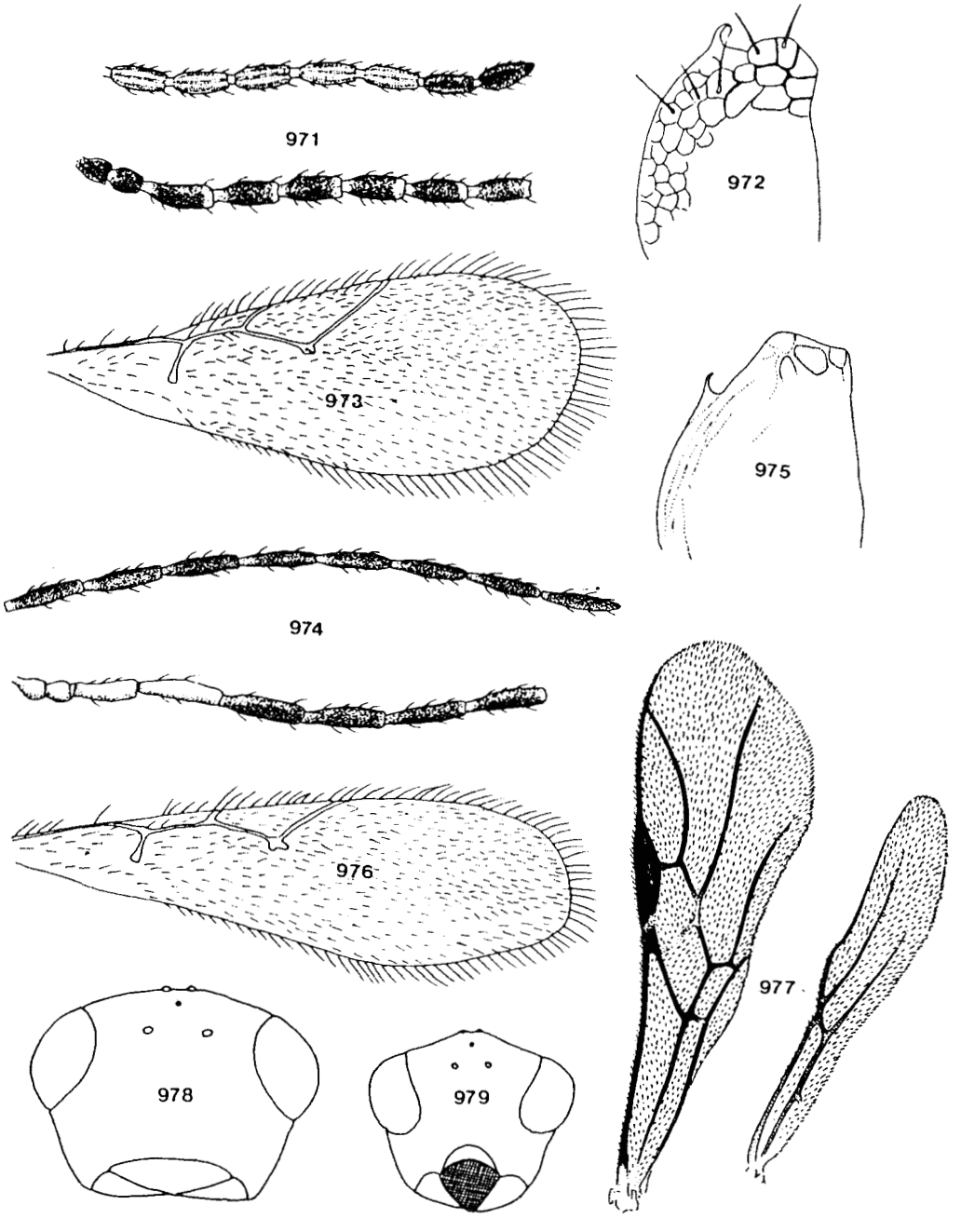
529(528) Second tergite of abdomen with oblique furrows 530

529' Second tergite of abdomen without oblique furrows 531

530(529) Large species, 9-13 mm long; abdomen elongated, with elevated median area of tergite II smooth and strongly defined (Fig. 981); reddish yellow with 6*th* abdominal tergite black; wings yellowish, subhyaline with apical margins fuscous, forewing with three blackish brown spots; ovipositor very long, 2 times as long as body (Fig. 982); hosts – *Sesamia inferens, Scirpophaga incertulas* ..... *Stenobracon nicevillei* (Bingham)

530' Smaller species, 5-6 mm; abdomen oblong with median raised area of 2*nd* tergite weakly defined and rugose with a V-shaped mark (Fig. 983); yellowish brown to brown, females generally darker than males; wings fuscous to subhyaline; ovipositor short, as long as half of abdomen (Fig. 984); hosts – *S. incertulas, Sesamia inferens, Chilo suppressalis* ..... *Tropobracon schoenobii* (Viereck)

531(529') Head and thorax yellowish red; abdomen black with a white band on each tergite; plate of first tergite parallel-sided, 3 times as long as apical breadth (Fig. 985); ovipositor as long as hind femur (Fig. 986); body length 3.5-4 mm; hosts similar to *T. schoenobii* ..... *Bracon chinensis* (Szepligeti)



Figs. 971-979

531' Body reddish yellow with black markings; plate of l*st* tergite narrowed basally, less than 2X as long as apical breadth (Fig. 987); head almost parallel-sided behind eyes, transverse with immargined occiput (Fig. 988); ovipositor as long as half of abdomen (Fig. 989); body length 3.5-4 mm; hosts - *C. suppressalis, S. inferens* . . . . . *Bracon onukii* Watanabe

532(528') Second cubital cell distinctly smaller than the l*st* (inner) cubital (Figs. 990-992); 2*nd* intercubitus prominent; submedian cell of forewing with nearly parallel margins; nervulus straight, emanates from about one-third basal length of l*st* discoidal cell; transverse Cu1 less oblique or slightly straight; brachial cell angled in its basoapical border; propodeum quadrate (Fig. 990) or narrowed posteriorly (Figs. 991-992); tergites 1-3 yellow brown to dark reddish brown; host – *C. suppressalis* . . . . *Rogas* spp.

532' Uniformly yellowish brown except a pair of light reddish brown longitudinal bands that converge posteriorly in the median mesoscutum; head in top view not quadrate; width as long as mesothorax; lateral ocelli 2 ocellar diameters away from eyes; transverse cubital I noticeably oblique; median of propodeum with a long longitudinal carina extending to tergites I and II; tip of abdomen more or less rounded dorsally (Fig. 992) . . . . . *Rogas narangae* Rohwer

532" Second cubital cell as long as first cubital; inner end of 1*st* intercubitus and 2*nd* intercubitus usually pale; apical end of 1*st* brachial cell rounded and 4.7 times longer than wide; postnervellus long; abdomen sessile with tergites 2 + 3 divided by 1 or 2 transverse furrows; ovipositor about two-thirds as long as abdomen 533

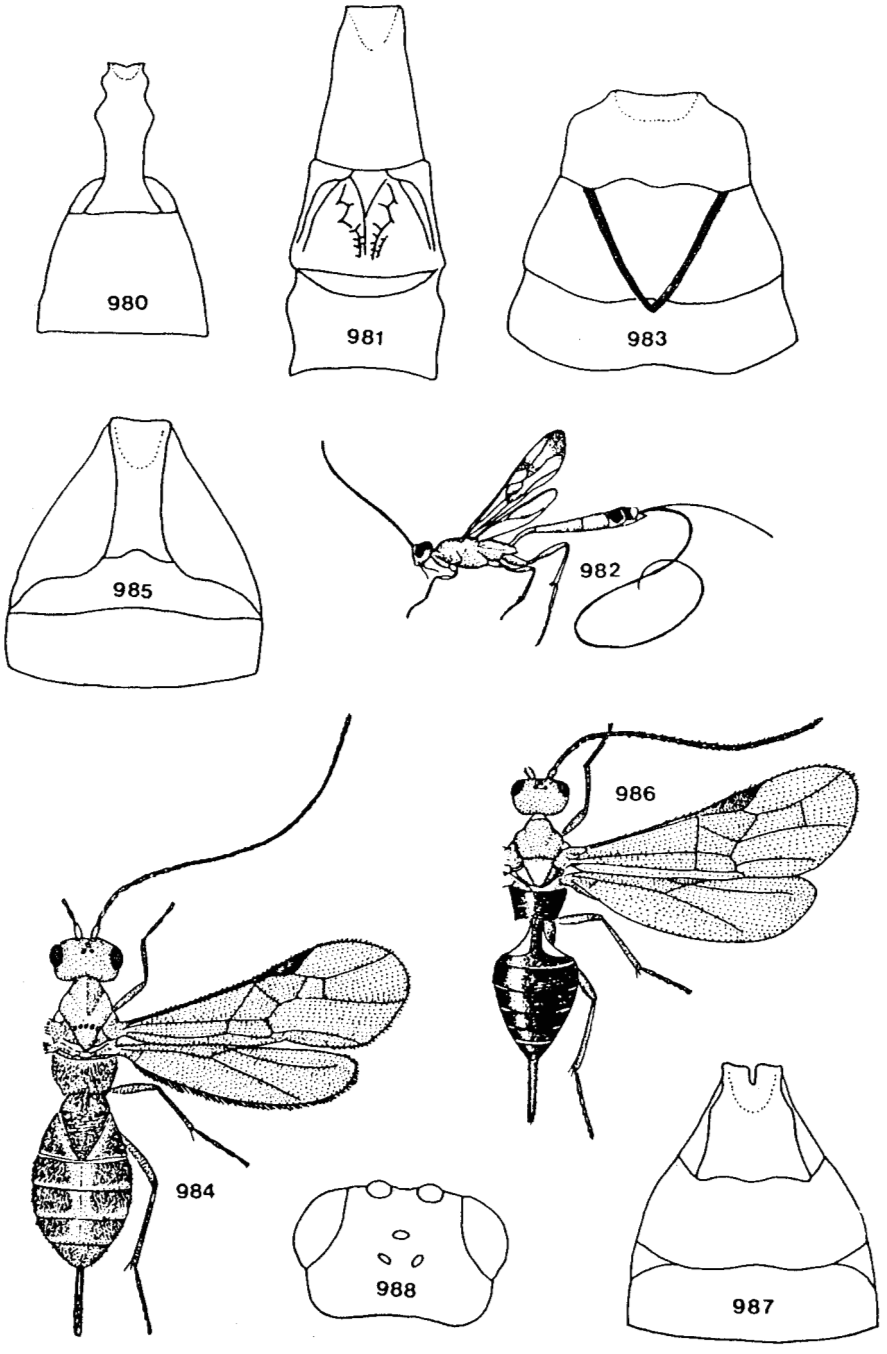
533(532") Abdomen with tergites 2 + 3 divided by 2 transverse furrows into three parts, the middle one being short and fusciform (Fig. 993); dark brown to black; head not transverse, area behind eyes unparallel (Fig. 994); legs honey-yellow; wings subhyaline with pale yellow stigma; body length 3.5-4 mm; host – *S. incertulas* in Java and Thailand . . . . . *Rhaconotus schoenobivorus* (Rohwer)

533' Tergites 2 + 3 divided by a single transverse furrow into 2 parts 534

534(533') Antenna with 44-47 segments; mesonotum a little longer than its maximum width; propodeum ill defined dorsally, with only fine sculpture between basal and inner carina; hairs on vertex, pronotum, and mesonotum conspicuous; tergites evenly carinate longitudinally except the broadly transverse tergite (Fig. 995) . . . . . *Rhaconotus scipophagae* Wilkinson

534' Antenna with 30-32 segments; mesonotum shorter than its maximum width; dorsal areas of propodeum very distinct provided with scaly reticulation; hairs on vertex, pronotum, and mesonotum not conspicuous; 1*st* and 2*nd* tergites entirely carinate longitudinally, 3*rd* and 4*th* uncarinated in the apical half, 3*rd* sometimes smooth, 5*th* carinated only on side (Fig. 996) . . . . . *Rhaconotus oryzae* Wilkinson

535(526') Forewing with 2 cubital cells 536



Figs. 980-988

535' Forewings with 3 cubital cells 551

536(535) Abdomen inverted bath tub-like (broadly convex), apical end slightly wide to strongly rounded; segmentation absent 537

536' Abdomen not as above, normal in form 538

537(536) Abdomen almost parallel-sided, with a pair of broad pale yellow markings towards base (Fig. 997); body length 6-8 mm; host – *Chilo suppressalis* in East Asia .... *Chelonus munakatae* Munakata

537' Entire dorso-basal segment of abdomen yellow, tip of abdomen broader than base (Fig. 998); body length 5-5.8 mm; hosts – *C. medinalis* & *Marasmia* spp. in Southeast Asia ..... *Chelonus* sp.

538(536) Female antennae "aberrant", scape slender and very long with an apophysis in the basal third, entire length a little over one-third of antennae; funicular segment VII with an apico-ventral protrusion (Fig. 999); *1st* metasomal tergite petiolate with deep dorsopes (Fig. 1000); notauli complete, rugose posteriorly; ovipositor straight and its sheath slender; emergence hole of cocoon subterminal and irregularly round; host – *Medythia nigrobilineata* in East Asia ..... *Streblocera okadai* Watanabe

538' Antennae of both sexes normal 539

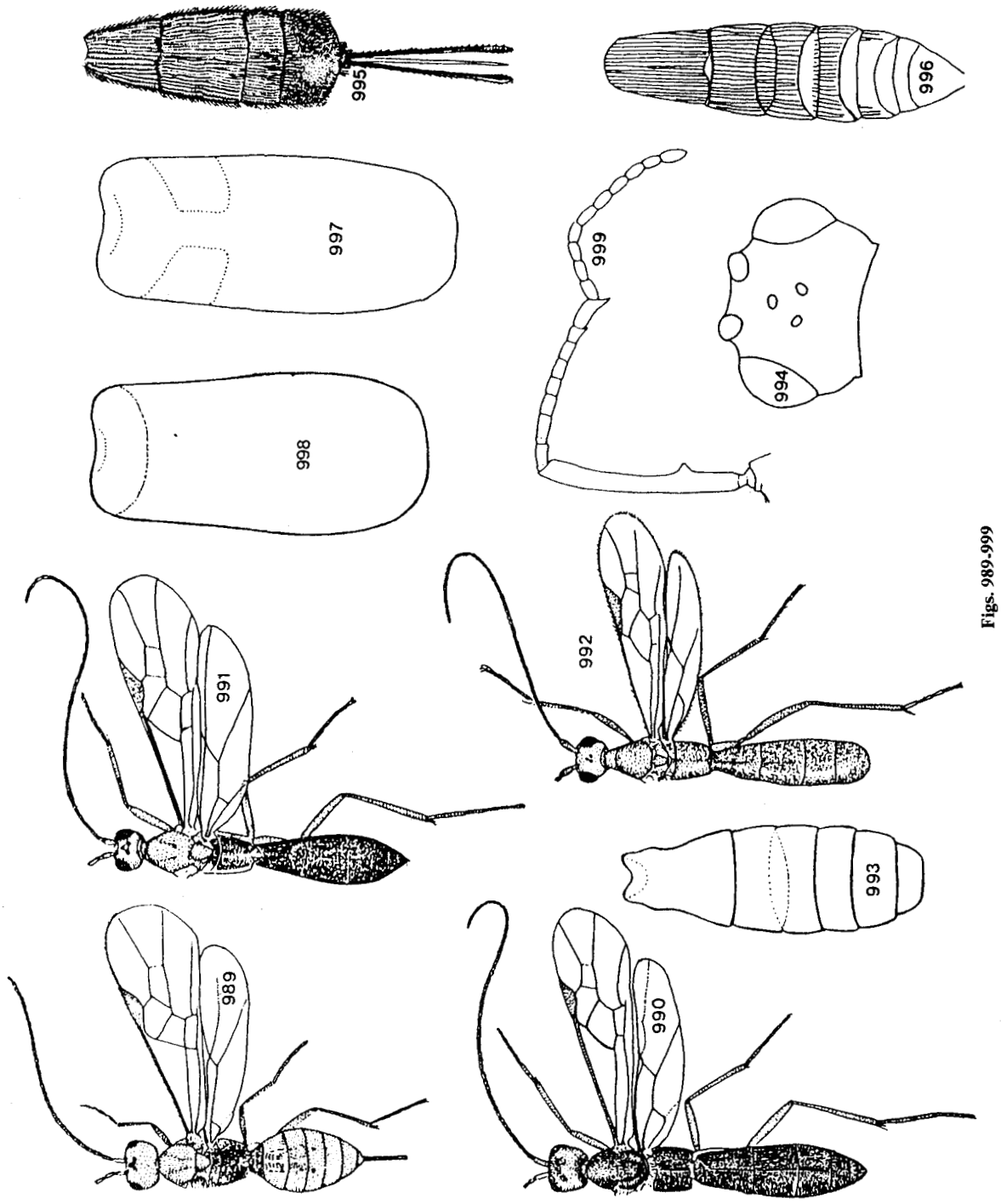
539(538') Radial cell closed 540

539' Radial cell not clearly defined, radius weakly developed 541

540(539) Radius concave; median cell large indistinct or vague medius; first discoidal cell 5-sided and subtriangular towards large stigma; subdiscoideus incomplete (Fig. 1001); head slightly transverse with occipital carina complete; eyes slightly convergent with scattered minute hairs; ocellar triangle not well raised and lateral ocelli closer to compound eyes than to each other (Fig. 1002); propodeum with a strong transverse carina; first abdominal tergite sessile and striate longitudinally (Fig. 1003); ovipositor curved ventrad; antennae with 21-22 segments; antennal sockets opposite midlength of eyes (Fig. 1004); host - *M. nigrobilineata* in East Asia ..... *Centistes medythiae* Maeto & Nagai

540' Radius straight; median cell relatively small with prominent medius; first discoidal cell 4-sided and subtrapezoidal; cubitus faint, similar radiella and cubitella of hindwing; subdiscoideus complete (Fig. 1005); head subglobular with occipital carina dorsally interrupted; eyes smooth; ocellar triangle nearer each other than to the compound eyes; propodeum very finely punctated and smooth; orange bodied except hyaline wings and blackened ocellar triangle; hosts – *Cnaphalocrocis medinalis, Marasmia* spp .... *Orgilus ashmeadi* Viereck

541(539') Hypopygium relatively large with a series of striae medially; head twice as long as broad, minutely punctate except coarsely punctate face; metanotum with median small cup-



Figs. 989-999

shaped area surrounded by a ridge; propodeum with indistinct areola and costulae (more or less obscured by coarse rugose sculptures); tergite I of abdomen twice as long as wide basally and rugosely punctate; tergite II transversely rectangular; and much wider than long (Fig. 1006); ovipositor sheath as long as hindtibia; black except legs with coxae, 2*nd* and 3*rd* abdominal tergites reddish yellow; wings hyaline brown with moderately large pterostigma (Fig. 1007); leg III black except reddish middle tibia, most of femur, trochanter and coxa (Fig. 1008); hosts *C. polychrysus, S. incertulas* . . . . . *Exoryza* (= *Apanteles) schoenobii* (Wilkinson)

541' Hypopygium usually short, sides evenly sclerotized, without a series of longitudinal creases near middle; tergite II at least half as long as III and subrectangular; ovipositor sheath short and mostly concealed by hypopygium 542

542(541') First tergite of abdomen very narrow, parallel-sided and 3 times as long as broad (Fig. 1009); head particularly vertex, frons, and temples smooth and impunctale; mesoscutum with numerous and distinct punctures anteriorly; propodeum rugulose, subopaque with weak costulae and indistinct areola; ovipositor sheath black, approximately one-third as long as abdomen, distinctly curved downward; coxae I to III black, all femora, apical half of hind tibia, and hind tarsus basally brownish black (Fig. 1010); hosts — *Cnaphalocrocis medinalis, Marasmia* spp. . . . . *Cotesia* (=*Apanteles*) *angustibasis* (Gahan)

542' First tergite variable and without the combination of above characters 543

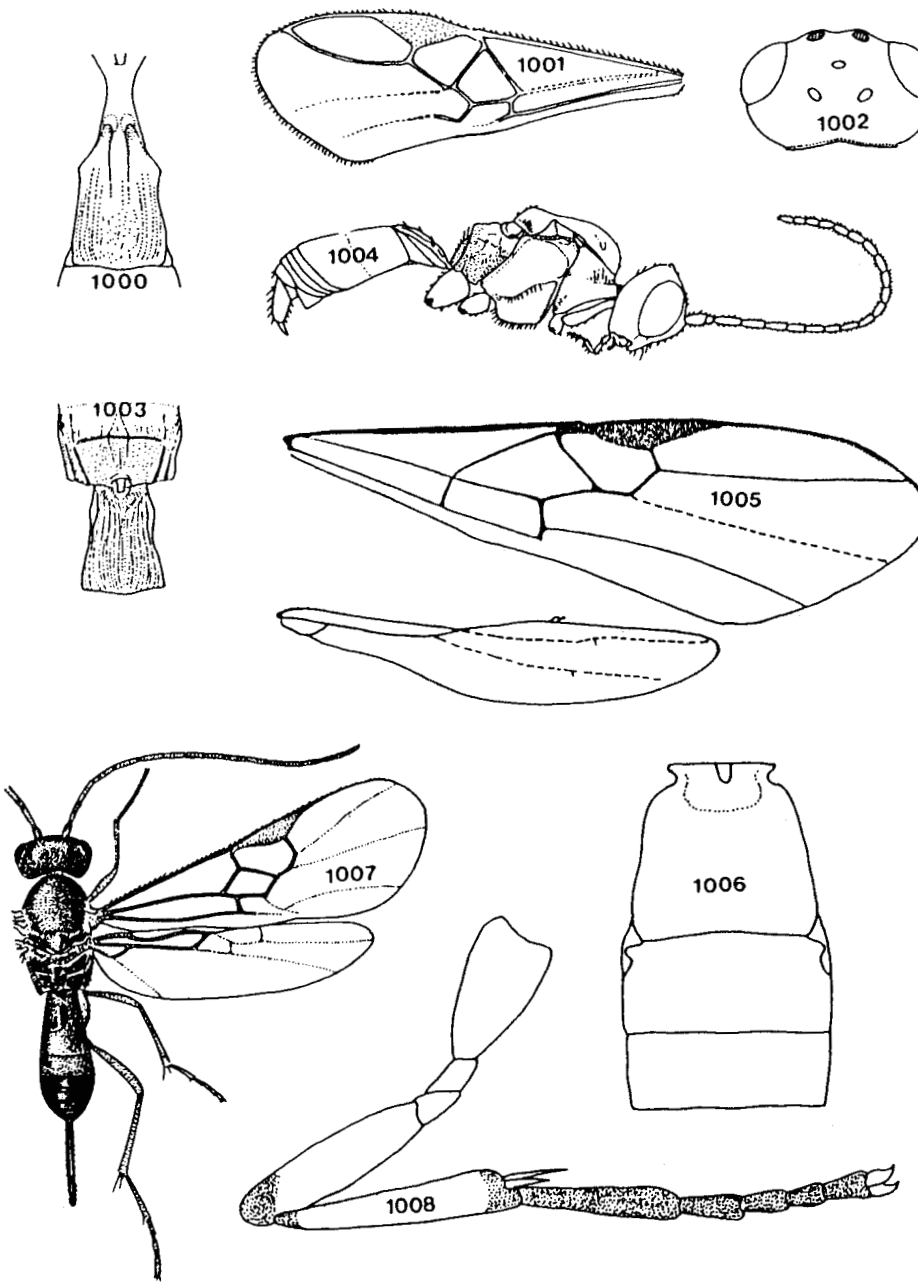
543(542') Areola strongly V-shaped at apex (Fig. 1011); head mostly punctate; mesonotum rather irregularly strongly punctate with rugose fine striae along sides of notauli; first tergite as broad at base as at apex, widest in apical third, with an excavated area reaching apex of tergite just beyond the strongly tumescent median; second and third abdominal tergites reddish yellow; ovipositor sheaths as long as or slightly longer than the hind femur; hind femur mostly reddish yellow with a fuscous mark at extreme apex (Fig. 1012); hosts — *C. medinalis, Herpetogramma* (= *Pachyzancla*) *stultalis* . . . . . *Cotesia* (=*Apanteles*) *opacus* (Ashmead)

543' Areola not V-shaped 544

544(543') Areola large, subquadrate with an open extreme base, carinae and costulae strong; first abdominal tergite (Fig. 1013) slightly swollen at midlength and lightly rugose, unsculptured and smooth apically; tergite II trapezoidal, basal area of tergite (2 + 3) only about half as long as the rest of the segment beyond it; ovipositor sheaths (Fig. 1014) shorter than hind femur, apical attenuation as long as 4*th* segment of tarsus, very thick, curved and strongly tapering from base to apex; all femora, tibiae, and tarsi red testaceous; antennae dark red-brown to black; costal veins testaceous; stigma light brown; host — *Spodoptera litura* . . . . . *Cotesia* (= *Apanteles*) *prodeniae* (Viereck)

544' Areola absent; if present not subquadrate; l*st* and 2*nd* tergite of different shape and sculpture; ovipositor length variable 545

545(544') Areola and costulae present 546



Figs. 1000-1008

545' Areola and costulae absent 547

546(545) Solitary cocoon white; host – *Cnaphalocrocis medinalis;* vannal lobe feebly concave beyond its widest part and without projecting hairs; tergite I of male more or less narrowed behind, and very mildly narrowed in the female; tergite 2+3 black; stigma hyaline 1*st* transverse cubital very narrow; ovipositor about three-quarters as long as hind tibia (Fig. 1015) ..... *Cotesia cyrpris* Nixon

546' Cocoons white, gregarious and clustered together to form a narrow elongate mass covered with rather loose silk; vannal lobe evenly convex beyond its widest part and with distinct hair fringe throughout, Cul strongly triangular apically, radius far from cubitus (Fig. 1016); tergite I parallel-sided and without longitudinal carina, slightly turned over and down, slightly excavated basally and partially swollen medially and apical two-thirds indefinitely sculptured; tergite II smooth, apex evenly and strongly rounded (Fig. 1018); ovipositor sheath (Fig. 1017) strongly down-curved, longer than hind tibia, its attenuation almost as long as two-thirds of hindtarsus ..... *Cotesia baoris* (Wilkinson)

546" White cocoons either solitary or gregarious; tergite I (Fig. 1019) barely tumescent medially; 2*nd* tergite smooth and unsculptured; propodeum smooth with open areola; fore and mid legs, hind femur completely darkened; and basal half of hind tibiae red testaceous; antennae dark brown; stigma and wing veins brown; wings slightly infumated evenly throughout; ovipositor sheaths as long as or slightly longer than hind tibia; hosts – hesperiid and rice leaffolder larvae ..... *Cotesia agilis* (Ashmead)

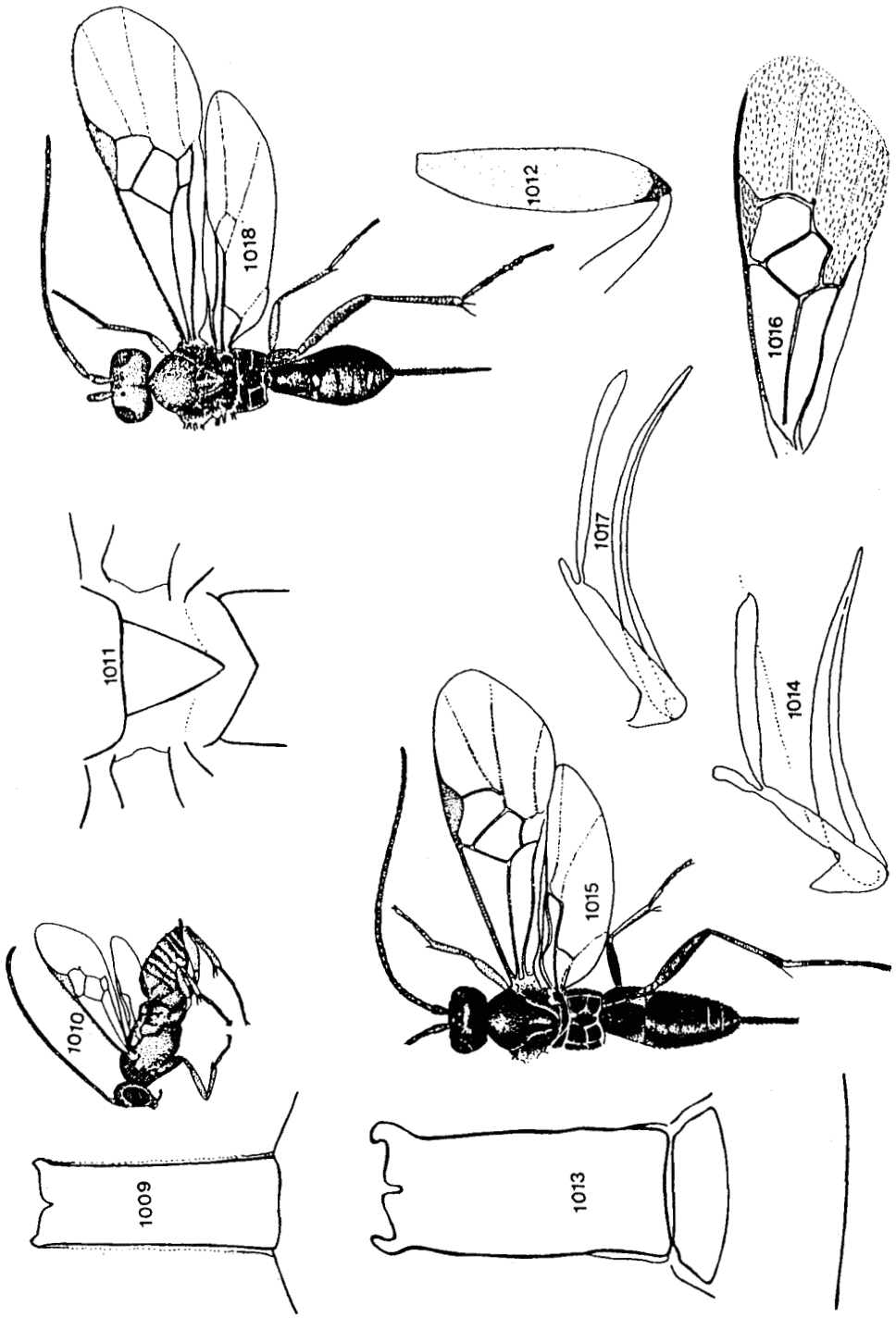
547(545') Thorax dorso-ventrally flattened; head in lateral view not usually prominent below antennae, largely impunctate; propodeum evenly rugolose; 1*st* tergite constricted subbasally and broadened apically; 2*nd* tergite punctated with ovoid-shaped mark; legs and antennae red testaceous; tegulae, stigma, and costal veins (Fig. 1020) testaceous; tergite I of abdomen widened behind, apicolateral corners weakly and roundly constricted, posteromedian margin of tergite I slightly cleft (Fig. 1021); ovipositor sheath short ... . *Cotesia flavipes* Cameron

547' Thorax not dorso-ventrally flattened; head in lateral view usually prominent below antennae 548

548(547') Hind coxa roughened and rugose; tegulae red testaceous 549

548' Hind coxae smooth, at most closely punctate; tegulae of different coloration ... 550

549(548) Solitary parasitoid; scutellum densely rugose-punctate all over without any smooth interspaces anteriorly; fore and middle coxae invariably black; tergite III covered all over with fine setae except for small midbasal area; tergites I and II with subquadrate network like punctures except narrowed and smooth base (Fig. 1022); cocoons pale cream; hosts – *Plutella xylostella, Spodoptera litura* .... *Cotesia plutellae* (Kurdjumov)



Figs. 1009-1018

549' Gregarious parasitoid; punctures of scutellum at least on anterior half, wide enough apart to leave smooth shiny interspaces fully equal to width of punctures; pterostigma hyaline and shorter than R1; r and r-m meeting at a distinct angle (Fig. 1023); fore and middle coxae yellowish brown; tergite I wider at apex than base, black and rugulose, II aciculate with diverging sulci (Fig. 1024); tergite III with a single transverse row of few fine setae . . . . . *Cotesia ruficrus* (Haliday)

550(548') Propodeum without a transverse basal carina; hypopygium acute; ovipositor very short; first tergite gradually narrowed towards base, 1*st* and 2*nd* reticulate – rugose with median basal one-third of 1*st* and median apex of 2*nd* smooth, apex of first somewhat cleft and that of second uniformly pitted (Fig. 1025); legs with coxae reddish yellow and dark brown tarsus; tegulae, stigma, and veins yellowish brown (Fig. 1026); hosts – *Mythimna unipuncta, Naranga aenescens* . . . . . *Cotesia kariyai* (Watanabe)

550' Propodeum with a strong basal transverse carina and a longitudinal median carina; hypopygium obtuse; ovipositor sheath about half the length of hind tarsus; 1*st* tergite smooth in the excavate basal one-third, rugulose laterally, narrowed immediately after the base then widens apically with rounded apicolateral margins and slightly emarginate apex; 2*nd* tergite with median disk sculpture, apical margins without uniform pits and smooth laterally (Fig. 1027); legs including coxae brownish yellow except hind coxa dark brown to black with extreme apex and ventral side reddish yellow; scape, flagellum, tegulae and costal veins dark brown; hosts – *Busseola fusca, Chilo ignefuscalis, C. zonellus, Sesamia calamistis, S. cretica* in Africa . . . . . *Cotesia sesamiae* (Cameron)

551(535') Second cubital cell small and triangular-like 552

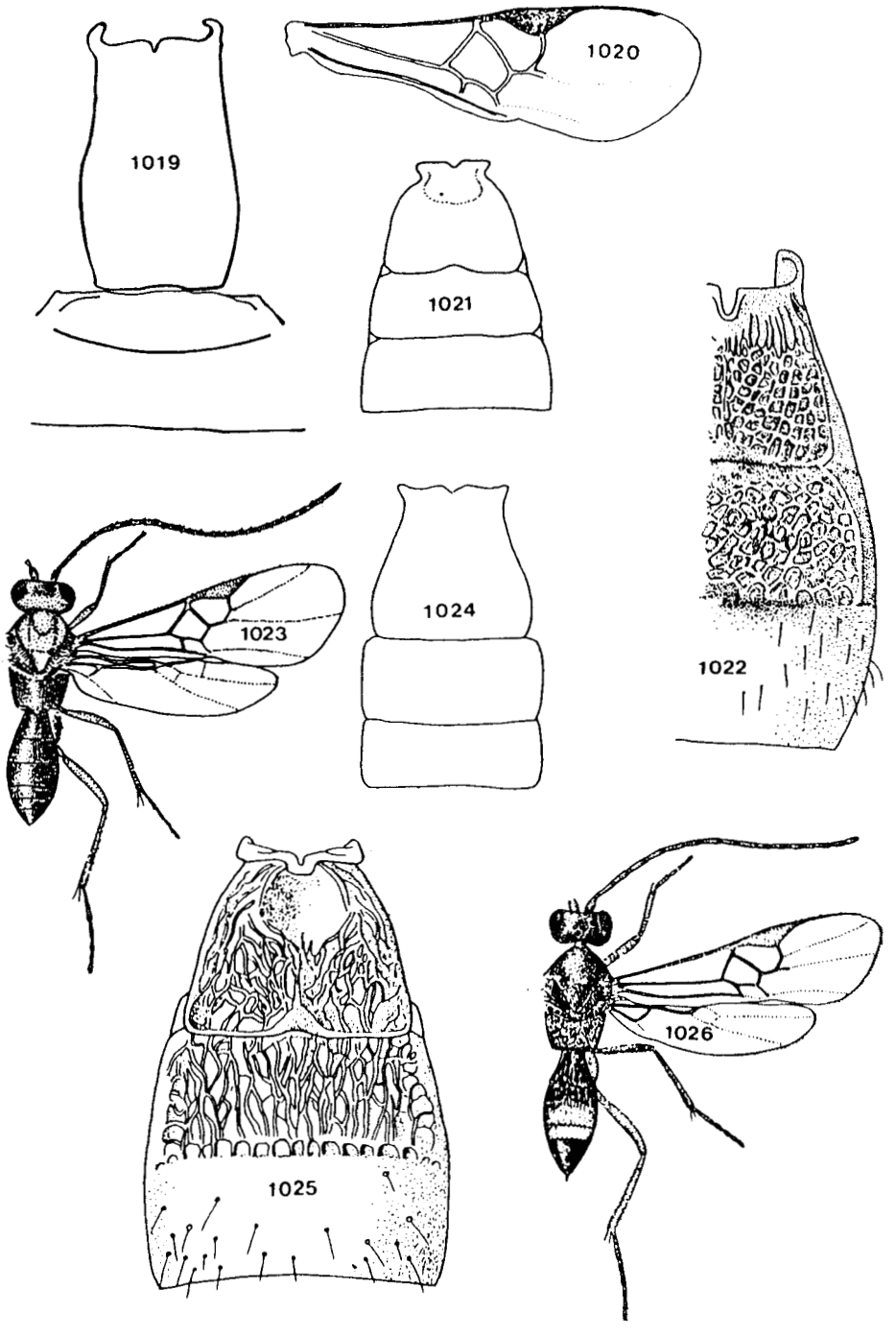
551' Second cubital cell moderately large and subrectangular 555

552(551) Ovipositor sheath entirely hairy, arising distally from valvifer, a little shorter than half as long as abdomen, and half as long as hind tibia (Fig. 1028); hypopygium rather large and sclerotized evenly across middle and not folded; radius, cubitus, and subdiscoideus all effaced, Cul strongly curved outward (Fig. 1029); black with three basal tergites yellowish red; legs reddish yellow; host – *Chilo suppressalis* . . . . . *Hygroplitis russatus* (Haliday)

552' Ovipositor sheath with only few hairs distally 553

553(552') Prepectal carina present; notauli deep; radial cell open with base of radius effaced; submediellan cell triangular-like towards base; cubitella more or less straight; abdomen oblong elongate, black except yellow lateral patches in the basal part; hind tibia darkened in the apical half (Fig. 1030); hypopygium short and evenly sclerotized ovipositor sheath very short; host – *S. litura* . . . . . *Snellenius manilae* (Ashmead)

553' Prepectal carina absent; notauli less developed to absent; hypopygium usually moderately small and elongated medially; ovipositor sheath arises proximally from second valvifer, radius almost entirely effaced; submediellan cell rounded or angled distally 554



Figs. 1019-1026

554(553') Nervellus strongly rounded; abdomen almost completely darkened except yellow patches along lateral margins of basal tergites (Fig. 1031); host – *S. litura* . . . . . *Microplitis tuberculifer* (Wesmael)

554' Nervellus oblique forming an angulated corner at apex of submediellan; abdomen not dark colored except apical three tergites and apical margins *6th* tergite (Fig. 1032); host – *S. litura* . . . . . *Microplitis pallidipes* Szepligeti

554'' Nervellus similar to *M. pallidipes;* wings hyaline; body typically black; tibia III light colored at middle and dark on both ends (Fig. 1033) . . . . . *Microplitis* sp.

555(551') Eyes hairy (Fig. 1034); entire body black including legs and with white hairs; forewing with brown infuscation after stigmal vein; hindwing with similar infuscation along costal area, basal one-fourth and apical one-fourth (Fig. 1035) . . . . . *Cardiochiles philippinensis* Ashmead

555' Bases and wing tips of both pairs of wings brownish (Fig. 1036) . . . . . *Cardiochiles* sp.

555'' Eyes bare; body not black; wings hyaline except brown veins and stigma 556

556(555'') Ovipositor very long, almost twice as long as the abdomen; abdomen slender, brownish black dorsally with longitudinal striae and yellowish brown edges; venter entirely orange-brown; basal two tergites very slender and flattened; middle lobe of mesonotum more bulging than lateral lobes and prominently separated from the latter by the deeply pitted notauli; coxa III evenly swollen with a brown patch apico-dorsally (Fig. 1037); hosts – *Cnaphalocrocis medinalis, Marasmia* spp. . . . . *Macrocentrus philippinensis* Ashmead

556' Ovipositor very short, moderately exerted beyond tip of abdomen; tergite I of abdomen rather rough with a slightly raised median longitudinal carina, carina narrow basally and widens apically; tip of abdomen much broader than basal tergites (particularly I) and curved slightly downwards; notauli absent; all legs including coxae yellow (Fig. 1038); host – *Hydrellia philippina* . . . . . *Opius barrioni* Fischer

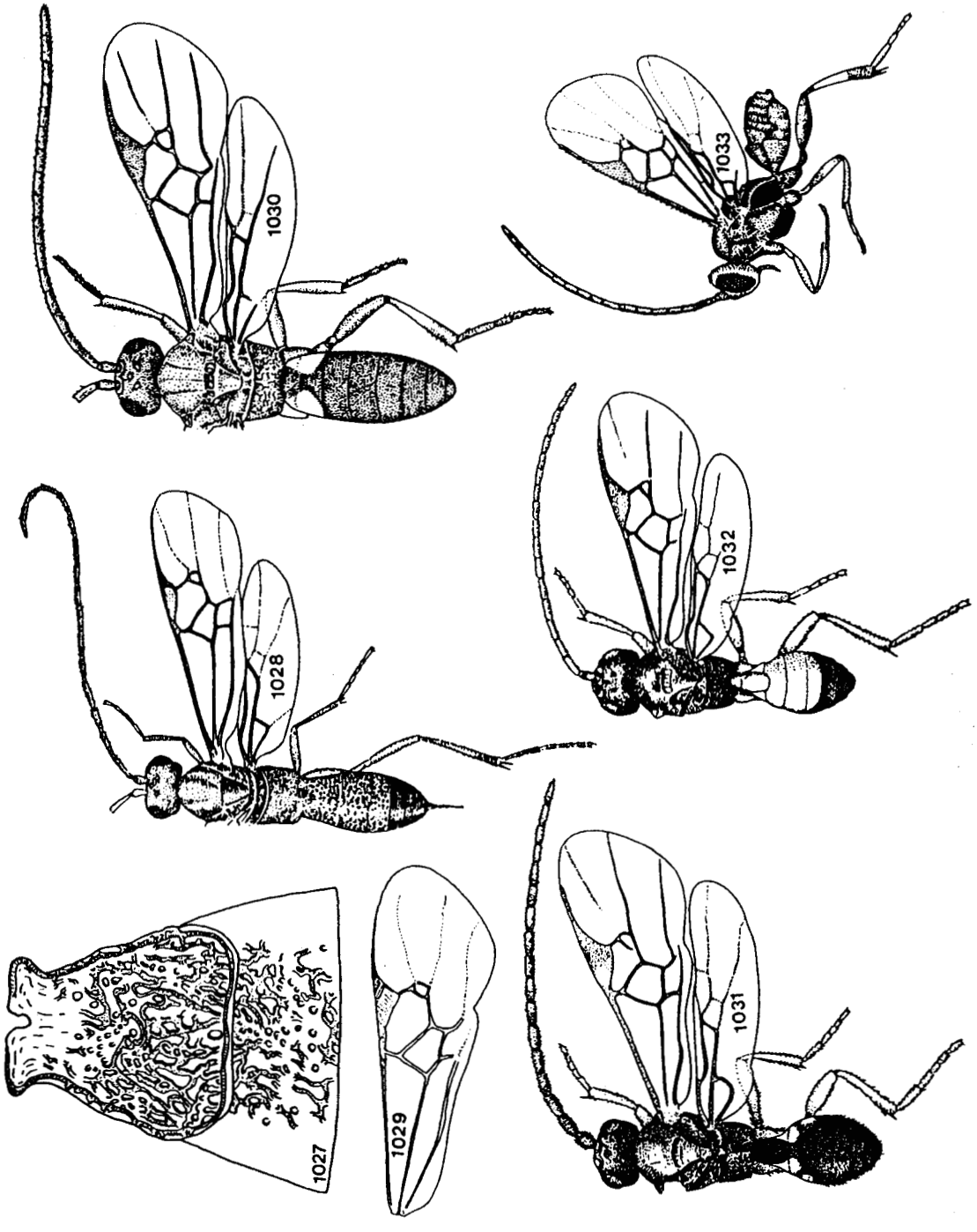
557(524') Abdomen flattened, segment III and following segments wider than deep 558

557' Abdomen strongly compressed in apical half, segment III and following segments thicker (in terms of height) than wide; spiracle of tergite I distinctly distad of the middle; ovipositor with a preapical dorsal notch 582

558(557) Spiracle of tergite I at or basad of the middle; flagella of female antennae without a white ring medially 559

558' Spiracle of tergite I distad of the middle; flagella of female always with a median white ring 570

559(558) Tergite VII with a white apico-median transverse band; tergite I fused with its sternite, sclerotized portion reaches apical one-third of tergite; second recurrent vein opposite intercubital vein; areolet of forewing absent; sternaulus long and rather distinct . . 560



Figs. 1027-1033

559' Tergite VII without a white marking; tergite I not fused with its sternite, sclerotized portion of the sternite reaches basal one-third of tergite; areolet of forewing present; sternaulus weak or absent 561

560(559) Tergites II and III entirely black; tergite I, black and reddish apico laterally (Fig. 1039); leg coloration similar to *A. a. schoenobii;* hosts – *S. incertulas, S. innotata* .... *Amauromorpha accepta metathoracica* Ashmead

560' Tergite III and apical one-third – half of tergite II red (Fig. 1040); tergite I red, sometimes blackish in part; mid and hind coxa red except apex narrowly black; fore coxa and all trochanters black; hind femora black to blackish brown basally; hind tarsus black and tibia pale basally; male with subtegular ridge and a pair of marks on face white; tergite IV and V of male entirely red; hosts – *S. inferens, C. suppressalis, S. innotata,* and *S. incertulas* in India, Malaysia, Thailand, Sabah, Taiwan, China .... *Amauromorpha accepta schoenobii* (Viereck)

561(559') Ovipositor with a preapical dorsal notch (Fig. 1041); epomia absent; tergite I twice as long as wide, II-IV without tubercles, II and III only slightly longer than wide or subequal; tergites black except apices of I-III narrowly (in females) or broadly (in males) brownish red; mandibles yellow; clypeus obscurely reddish in females and yellow in males; hindlegs of female entirely blackish brown to black and reddish brown in the males; host – *C. suppressalis* in Japan and China .... *Lampronota mandschurica* (Uchida)

561' Ovipositor without a preapical dorsal notch; epomia present; tergite I as long as wide or slightly longer than wide, II-IV each with a pair of tubercles, II and III broader than long 562

562(561') Mandibles twisted apically, lower tooth hidden when mandibles are closed; propodeum more or less areolated; body and legs yellow with or without black markings 563

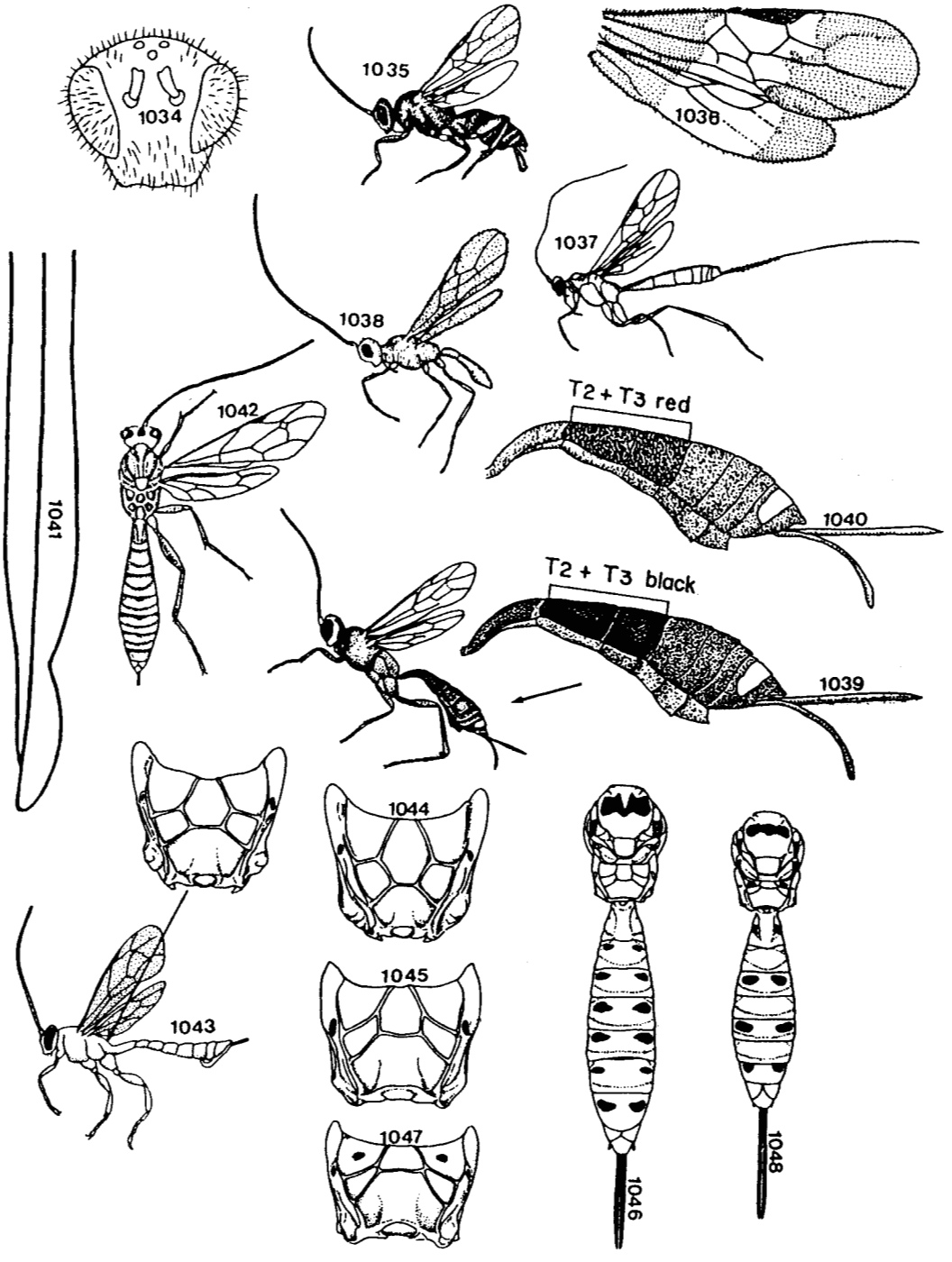
562' Mandibles not twisted towards apex; propodeum usually with only a pair of dorso-median short longitudinal carinae; body mainly black, legs variously colored but not mainly yellow 568

563(562) Abdomen entirely without paired black spots (Fig. 1042) 564

563' Abdomen with paired black spots; mesoscutum with black spots; propodeum with or without black spots 565

564(563) Areola receives costulae behind center, 0.82-1.35 times as long as wide; midapical transverse carina half the length of median longitudinal carina below level of spiracle (Fig. 1043); ovipositor sheath 4.8 times as long as wide with base and median equal in width; hosts – *C. suppressalis, S. inferens, C. medinalis, P. mathias, Telicota augias* ... . *Xanthopimpla flavolineata* Cameron

564' Areola receives costulae near center, 1.05-1.45 times as long as wide, midapical transverse carina nearly a median longitudinal carina length below level of spiracle (Fig.



Figs. 1034-1048

1044); ovipositor sheath 3.9 times as long as wide, base wider than middle; host — *S. inferens* ..... *Xanthopimpla enderleini* Krieger

565(563') Propodeum without black spots; areola with apically wide and basally narrow margin (Fig. 1045); mesoscutum with a broad transverse trilobed black band above median; apicomedian band with a yellow V-shaped cleft; tergite I and apical two tergites without paired black spots (Fig. 1046); hosts — *C. suppressalis, O. nubilalis* ..... *Xanthopimpla modesta modesta* Smith

565' Propodeum (Fig. 1047) and mesoscutum with black spots 566

566(565') Abdominal tergites I, III, V and VII with paired black spots (Fig. 1048); areola (Fig. 1047) relatively small, 2.4 times broader posteriorly than apex, apical part narrowed; midtransverse carina almost midway level of spiracle; mesoscutum with a transverse black band in the subapical one-half and more or less trilobe (Fig. 1048); tegula not black; ovipositor sheath 1.8 times as long as hindtibia, its tip strongly convex above without transverse ridges; host — *C. suppressalis, P. guttata, O. nubilalis, C. sacchanphagus* ..... *Xanthopimpla punctata* (Fabricius)

566' Tergites I to VII except VI with paired black spots 567

567(566') Mesoscutum with a pair of broad latero-median and smaller postero-median black spots; tegulae without black spot; spots on tergite I outside longitudinal carina (Fig. 1049); 1*st* lateral area of propodeum (Fig. 1050) with an oblique ovoid black spot; hosts - *S. nivella, C. suppressalis, O. nubilalis, C. infuscatellus, C. sacchariphagus, C. auricilius, S. inferens* ..... *Xanthopimpla stemmator* (Thunberg)

567' Mesoscutum with a black broadly hooked, claw-like lateral spot and a median longitudinal cup-like band, longitudinal above constricted median and broadly transverse below constriction; tegulae black posteriorly (Fig. 1051); 1*st* lateral area of propodeum with a black subquadrate spot (Fig. 1052); spots on tergite I half inward the longitudinal carina; hosts — *C. suppressalis, S. nivella* ..... *Xanthopimpla pedator* (Fabricius)

568(562') Eyes with a strong emargination opposite antennae (Fig. 1053); notauli indistinct, mesopleural sulcus without median angulation; tergites I-IV or I-V orange-red; flagella and pedicel of antennae reddish brown; mid- and hind coxa and hind femora red, femora apically black, trochanters, hind tibia and hind tarsus yellowish white with bases and apices of tibia and apices of tarsal segments blackish brown; hosts — *C. suppressalis, C. auricilius, S. incertulas, S. innotata, S. inferens, Naranga aenescens* ..... *Itoplectis narangae* (Ashmead)

568' Eyes with a weak emargination opposite antennae; notauli distinct; mesopleural sulcus distinctly angulated medially 569

569(568') Hindtarsal segment V longer than II; ovipositor stout, its ventral valve with vertical ridges very near apex (Fig. 1054); basal flagellar segments and pedicel of antennae somewhat brownish beneath; all trochanters yellowish white; host — *C. suppressalis* . . . . . *Scambus annulitarsis* (Ashmead)

569' Hindtarsal segment V shorter than II; ovipositor slender (Fig. 1055); its ventral valve with strongly slanted ridges subapically; basal flagellar segments and pedicel yellow underneath; coxa, trochanter, and hind femur of female reddish brown, fore and midcoxa and all trochanters yellowish white in male; host — *C. suppressalis* . . . . . *Gregopimpla kuwanae* (Viereck)

570(558') Face occupied largely by a yellow flat to concave escutcheon-shaped plate bounded by a carina on all sides, and a yellow thin apico-median tubercle between antennal bases projected towards vertex or ocellar area; a broad yellow patch between antennal area and emarginate area of eyes; scutellum brown in apical half and yellow posteriorly, parallel-sided with small tubercles postero-laterally; wing with a brown infuscation in the 3*rd* cubital part or radial cell (Fig. 1056); abdomen with black and yellow bands (Fig. 1057); coxae I and II yellow, III black to reddish brown; hosts — *S. litura, H. armigera* . . . . . *Metopius rufus browni* Ashmead

570' Face and abdomen not as above 571

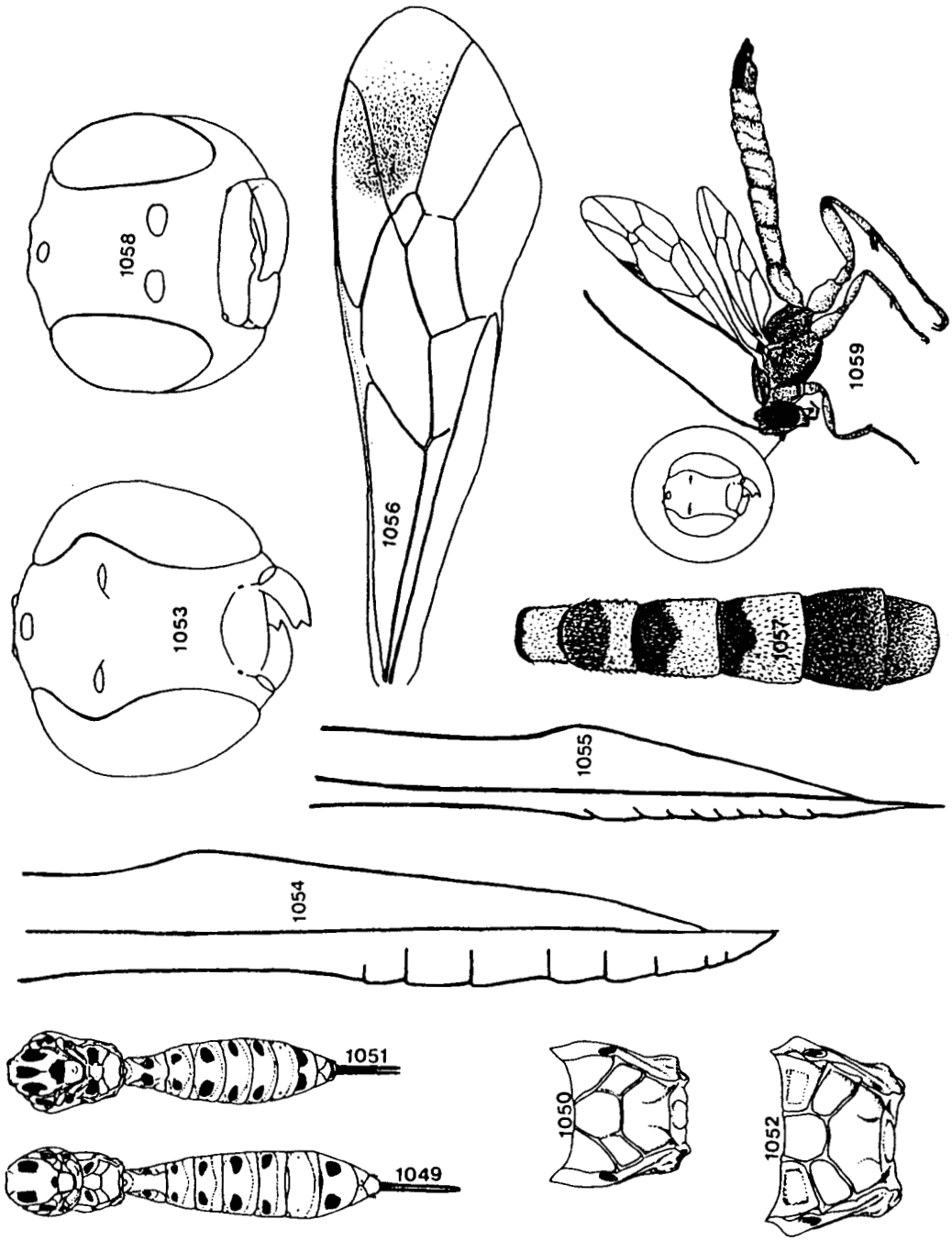
571(570') Ovipositor not or slightly exserted behind apex of abdomen; sternaulus absent or weak; abdomen with or without apico-median spot 572

571' Ovipositor conspicuously exserted behind apex of abdomen; sternaulus present, at least about one half as long as mesopleuron; abdomen with an apico-median spot 573

572(571) Clypeus with a pair of apico-median teeth; head globular in front; malar space short (Fig. 1058); spiracle of propodeum subglobular; scutellum not carinate laterally; abdomen without an apico-median white spot; flagella of female antenna subcylindrical and apically broadened; thorax and tergites I-IV red; mid- and hind coxa including trochanter and base of femur reddish brown; hind femur blue-black except basal part; hind tibia and tarsus blackish brown, segments pale at base; host — *C. suppressalis* . . . . . *Centeterus alternecoloratus* Cushman

572' Clypeus without apico-median teeth; head transverse in front; malar space very long (Fig. 1059); spiracle of propodeum elliptical; scutellum carinate laterally; flagella of female antennae strongly flattened and broadened posteromedially; head, thorax, propodeum, tergites, and legs yellowish brown to reddish brown; abdomen with an apicomedian white spot; apical II or III tergites, apices of hindfemora and tibiae broadly black including narrow part of basal hind tibia and apical one-third-half of hindtarsal segment I; host — *S. incertulas* . . . . . *Ischnojoppa luteator* (Fabricius)

573(571') Areolet of forewings large; thorax including propodeum without red marks 574



Figs. 1049-1059

573' Areolet of forewing small; thorax at least behind the level of scutellum and propodeum conspicuously reddish 576

574(573) Mesoscutum polished; with strong punctations; tergite black, (not rufous), in male, basal half of tergites I and II (sometimes III too) white; hind tibia white basally flagella of female antennae reddish basally beneath; frons of male with a small lateral white spot; forewing of female clouded apically, crossveins of areolet almost parallel to each other and faint similar to 2*nd* recurrent vein (Fig. 1060); host - *C. suppressalis* ..... *Agrothereutes lanceolatus* (Walker)

574' Mesoscutum mat, with indistinct punctures; hind tibia not white basally 575

575(574') Scutellum mat, with dense punctures; tergite II and III of females mat and very densely punctured; tergites usually black (Fig. 1061); hindlegs black, tarsus of male white medially; female flagella black with median white rings (Fig. 1062); host - *C. suppressalis* ..... *Gambrus wadai* (Uchida)

575' Scutellum polished or subpolished with few indistinct punctures; tergites II and III of female polished to subpolished with weak sparse punctures, II-III or I-IV red; hindlegs, tibiae, and tarsi slightly paler with apices of femora and tibiae black, and apices of tarsal segments slightly darkened; flagella of female antennae tricolored, red basally, white medially, and blackish apically (Fig. 1063); host - *C. suppressalis* ..... *Gambrus ruficoxatus* (Sonan)

576(573') Frons without a semicircular carina above each antennal socket; mandibles broad apically with teeth subequal in length; ovipositor thicker and tip usually blunt; upper margin of pronotum moderately swollen; propodeal apophyses or sublateral crests present as teeth in females 577

576' Frons with a semicircular carina above each antennal socket 580

577(576) Mesoscutum dull, striate or aciculate along margins and grooves; scutellum flat to weakly arched, dull or subpolished, distinctly and closely punctate; lateral carina of scutellum extending to beyond its basal half 578

577' Mesoscutum smooth or subpolished; scutellum smooth and convex; lateral carina not as above 579

578(577) Subtegular ridge and tegulae always entirely black; scutellum red or black; pronotum coarsely trans-striate medially and irregularly wrinkled above; mesoscutum finely aciculate along margins of each lobe, median of midlobe rugulose and lateral lobes subpolished; anterior half of thorax black and posterior half light colored (Fig. 1064); forewing with a fuscous band extending from base of stigma to lower margin; middle, hind trochanters, coxa, and femur never black, usually reddish (Fig. 1065); female abdomen (Fig. 1066) with apices of tergites I and II, entire VII, and narrow apex of VII whitish yellow, hosts - *S. nivella, C. sacchariphagus, Bactra venosata* ..... *Goryphus basilaris* Holmgren

578' Subtegular ridge, tegulae, and scutellum whitish yellow; female forewing without a brown tinge below stigma (Fig, 1067); face finely longitudinally striate; upper margin of pronotum with fine oblique striae; mat mesoscutum finely punctured; tergites I and II with white apices, VII and VIII broadly yellowish white, II to V alternately blackish to reddish brown (Fig. 1068); host — *C. suppressalis* . . . . . *Goryphus apicalis* Holmgren

579(577') Forewings (Fig. 1069) with a small brown spot below stigma; scutellum yellow; first tergite slender, apical part slightly widened; areolet pentagonal with side parallel; apices of tergite I, II and VII broadly white, rest of I reddish brown like propodeum (Fig. 1070); antennae dark brown without white marks of flagellar segments V-IX; forelegs pale yellow, middle leg pale brown with apical tarsal segments dark brown; hindlegs reddish brown except trochanter, *1st, 2nd* and *5th* hind tarsal segments dark brown and rest of hind tarsus white (Fig. 1071); hosts — *Oulema melanopa, O. oryzae* in Taiwan . . . . . *Goryphus lemae* (Sonan)

579' Forewings with 2 brownish bands; hindwing apices dark brown (Fig. 1072); scutellum reddish brown along apical margins; first tergite not slender and dark orange; apices of tergites I to IV and VI1 yellow similar to fore, middle coxae, and trochanters; propodeum and rest of tergite I dark orange; legs largely dark orange, all tarsal segments, hind trochanter, apex of femur, base and apex of tibia blackish (Fig. 1073); antenna black with white marks above each of flagellar segments V-IX; host — *Scirpophaga incertulas* . . . . . *Goryphus mesoxanthus mesoxanthus* (Brulle)

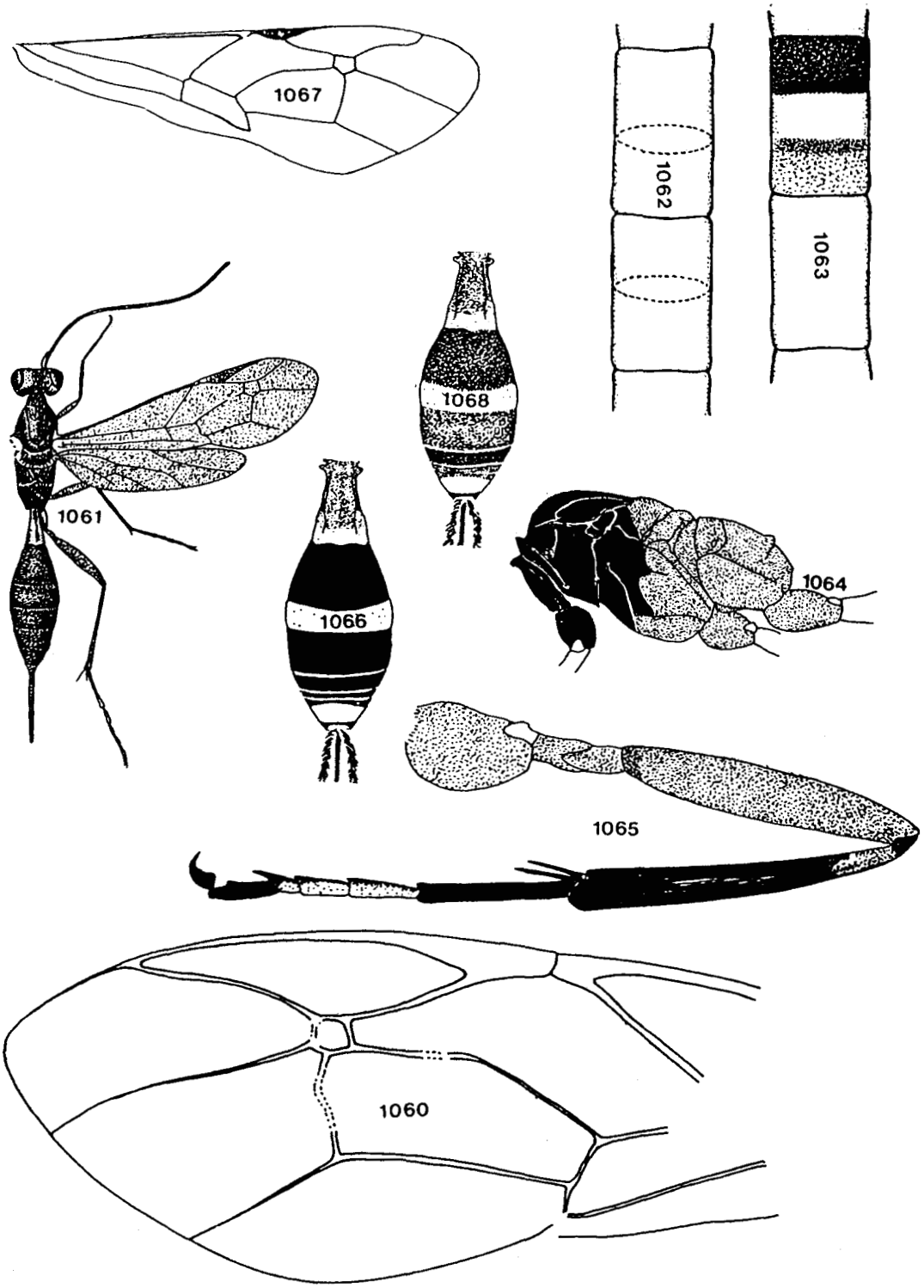
580(576') Forewing with a broad band below stigma covering distal one-third of discocubital cell, inner basal part of radial cell, almost entire areolet, distal two-third of 2*nd* discoidal cell and inner apical part of *2nd* brachial cell; wing apices along distal ends of *3rd* cubital, *3rd* discoidal and 2*nd* brachial cells with brown tinge (Fig. 1074); antennae dark brown and thin mesonotum with fine punctations; palpi white and tarsi yellowish; hosts — *Chilo infuscatellus, Bactra venosata* in East Asia . . . . . *Isotima chilonis* (Uchida)

580' Forewing tinge different from above; tergite I black or red; apical transverse carina of propodeum absent or weakly indicated laterally; mesoscutum black; apical margin of tergite II of female and apical margins of I-III of male white; forecoxa and trochanters of female fuscous; hind trochanters, tibiae, and tarsi black; hosts — *Scirpophaga innotata, s. incertulas, Sesamia inferens* in South and Southeast Asia 581

581(580') Tergite I black (Fig. 1075); hosts — *S. innotata, S. incertulas* in Java (Indonesia) and Philippines, and *Sesamia inferens* in Malaysia . . . . . *Isotima dammermani* (Rohwer)

581' Tergite I red (Fig. 1076); host — *S. incertulas* in India and Indonesia . . . . . *Isotima javensis* (Rohwer)

582(557') Discocubital cell of forewing (Fig. 1077) with a conspicuous hairless area bearing two scleromes (a sclerotized streak and spot); mesoscutum light brown; apical tergites light brown, not marked with black; only one intercubital vein present and second recurrent



Figs. 1060-1068

vein conspicuously basad of the intercubital vein; host – *S. inferens,* Taiwanese and Japanese species . . . . . *Enicospilus sakaguchii* (Matsumura & Uchida)

582' Forewings without such structure or appearance 583

583(582') Areolet present on forewing 584

583' Areolet absent on forewing 587

584(583) Eyes rather strongly emarginate; temple narrow; tegula black; head subquadrate; interocellar distance 1.1-1.2X the ocello-ocular distance; thorax longer with speculum shiny; lower outer angle of 2*nd* discoidal cell acute 585

584' Eyes weakly or not all emarginate; temple moderately wide; clypeal margin present or indistinct 586

585(584) Scape and pedicel yellow (Fig. 1078); mesopleuron below subtegular ridge finely transtriate; foreleg entirely yellowish brown with black coxa; III brownish black with black coxae (Fig. 1079); propodeum flattened and abruptly narrowed apically, median propodeal carinae indistinct; host – *Pamara bada* . . . . . *Casinaria ajanta* Gupta & Maheshwary

585' Scape and pedicel black (Fig. 1080); mesopleuron below subtegular ridge irregularly and coarsely wrinkled; median carina wavy and present; fore trochanters and base of forefemur blackish brown usually up to middle, tarsal segments largely black; midtibia blackish apically and tarsi wholly black; leg III uniformly black (Fig. 1081); propodeum large and elongate; tergite I long and straight; postpetiole bulbous; hosts – *Pelopidas mathias, P. cinnara* . . . . . *Casinaria pedunculata pedunculata* (Szepligeti)

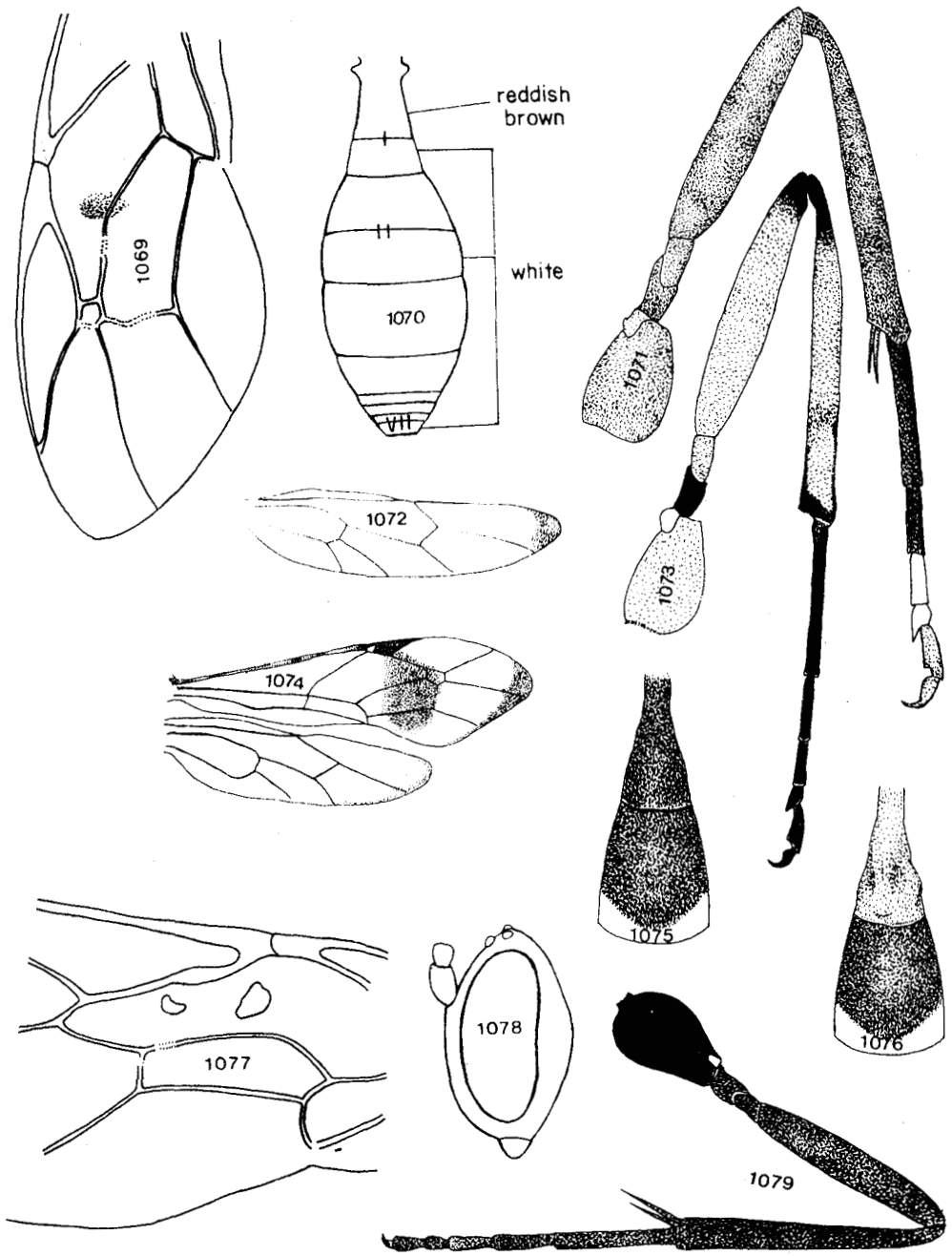
586(584') Tergite I of abdomen without baso-lateral pit or groove in front of spiracle; propodeum extending backward over middle of hindscoxa; male clasper with a preapical dorsal notch; tergites almost entirely black; mandibles, scape and pedicel yellow; midcoxa and hindcoxa black; hindfemur, tibia and tarsus blackish brown; trochanter yellow; face black, clypeus confluent with the face (Fig. 1082); host – *C. suppressalis* . . . . . *Venturia* sp.

586' Tergite I of abdomen with a baso-lateral pit or groove in front of spiracle; tergite II-V red with bases of II and III blackish; mid- and hindcoxae, hindfemur, and hindtibia red, tibia slightly darkened at apex; trochanters light brown; hindtarsus reddish brown, each segment pale basally; areolet of forewing present (2 intercubital veins present) (Fig. 1083); host – *S. incertulas* . . . . . *Diadegma akoensis* (Shiraki)

587(583') Clypeus separated from face by a groove 588

587' Clypeus confluent with face 591

588(587) Ventral margins of tergite I subparallel to each other (Fig. 1084); occipital carina almost complete above; lateral ocellus distance from eye about 1.0 (in female) or 0.5 (in male) its diameter; mesoscutum light brown and yellow, most often with 3 blackish stripes



Figs. 1069-1079

(sometimes with one or with no black stripes); scutellum yellow; hindtibia darkened on both ends; hosts − *C. suppressalis, Scirpophaga* spp., *C. medinalis, Marasmia* spp. . . . . *Trathala flavoorbitalis* (Cameron)

588' Ventral margins of tergite I bowed inward to touch or almost touch each other; occipital carina broadly incomplete above 589

589(588') Second discoidal cell of forewing pointed at base (Fig. 1085); hindfemur about 3.1 times as long as deep; male clasper with an apical small peculiar projection; mesoscutum and scutellum entirely black; tergites III- VI alternately black and reddish brown (Fig. 1086); hindtibia blackish brown; hosts - *Scirpophaga* spp., *C. medinalis, Marasmia* spp. . . . . *Temelucha stangli* (Ashmead)

589' Second discoidal cell of forewing truncate at base (Fig. 1087); hindfemur about 4.3-5.2 times as long as deep; male clasper without an apical projection 590

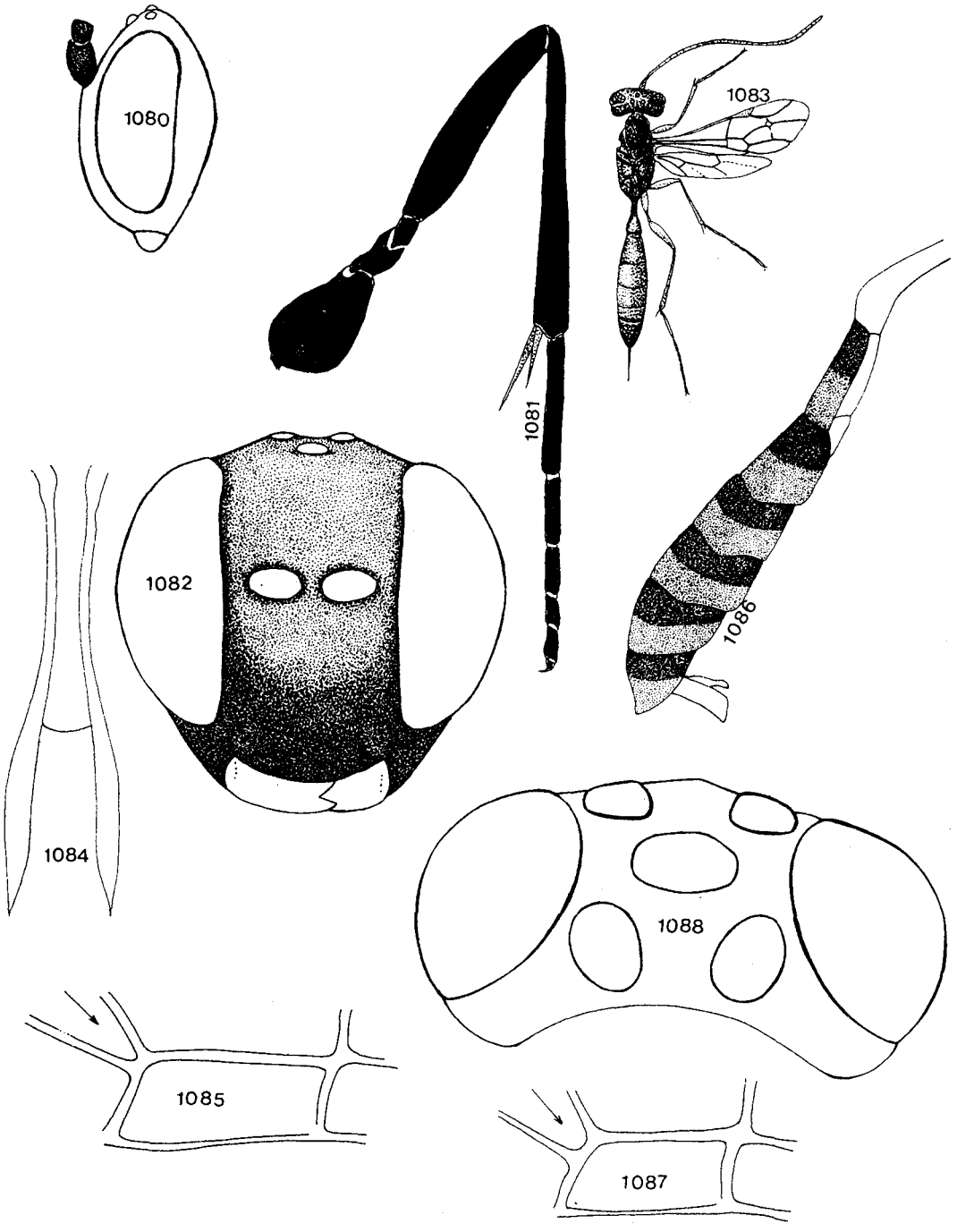
590(589') Lateral ocellus very close to eye, separated by about 0.5 (in female) or 0.1-0.2 (in males) its diameter (Fig. 1088); mesoscutum light brown and yellow, usually with three dark brown stripes; scutellum yellow; hindtibia scarcely darkened at apex; hosts - *C. suppressalis, Naranga diffusa, Bradina admixtalis, C. medinalis* . . . . . *Temelucha biguttula* (Munakata)

590' Lateral ocellus rather far from eye, separated by about 1.5 (in female) or 1.0-1.1 (in male) its diameter (Fig. 1089); mesoscutum, scutellum, and hindtibia colored as in *T. **bi**guttula**;*** general color yellowish orange; hosts - *C. suppressalis, C. medinalis, Marasmia* spp. . . . . *Temelucha philippinensis* (Ashmead)

591(587') Eyes with conspicuous long hairs, strongly emarginate and, distinctly convergent ventrally; wings without discoidella; mesopleuron without smooth shiny area, with horizontal striae; face yellow including temple, but with frons and ocellar areablack; top of propleuron, subtegular area, scutellum, coxae I-III and legs (except leg IV brownish black with apical two-thirds of tibiae, entire trochanter and basal one-third of femora blackish brown) all yellow; scutellum rather convex with two longitudinal carinae towards posterior half; tergite I without lateral groove; tergite II without a thyridium; ovipositor about 2-3.8 as long as apical length of abdomen (Fig. 1090); hosts − *Cnaphalocrocis medinalis, Marasmia* spp., *Ostrinia jumacalis* . . . . . *Trichomma (Trichomella) cnaphalocrosis* Uchida

591' Eyes bare, weakly or strongly emarginate and not convergent ventrally; lateral groove in tergite I and thyridium in tergite II present; face, subtegular area, and scutellum black 592

592(591') Eyes strongly emarginate; area of vertex behind eyes narrow; mesopleuron without smooth area, coarsely punctate; scutellum flat, somewhat deep medially; lower outer angle of second discoidal cell forms a right angle; tip of mediellan cell well rounded with a short protruberance apically; radiella concave or rounded (as seen on top) . . . 593



Figs. 1080-1088

592' Eyes weakly emarginate or not at all; area of vertex behind eyes moderately wide; scutellum convex; tip of mediellan cell not well rounded, radiella straight and cubitella deeply concave before apex 595

593(592) Median propodeal carinae distinct and usually very strong; notaular region similarly sculptured as the rest of mesoscutum; mesopleuron finely and closely rugose; tegulae black; face rugulose; male genital claspers broad and flat apically (Fig. 1091); subgenital plate (Fig. 1092) of male oblo-elongate, more or less uniformly colored; host – *Achaea janata* ..... *Charops ganges* Cushman

593' Median propodeal carinae absent or weakly present in the apical region of the propodeum (Fig. 1093); middle femora wholly yellow 594

594(593') Leg III black except yellow trochanter, base of tibia, and ends of femur (Fig. 1094); tarsal claw with 5 teeth (Fig. 1095); black mesopleuron reticulate rugose; forecoxa and tegulae yellow; abdomen largely reddish brown; male genital clasper with a slender apical process (Fig. 1096); subgenital plate (Fig. 1097) of male broadly subglobular to ovoid with a tapering point tubercle-like, plate dark colored except lateral periphery and tubercle light colored; hosts – *S. innotata, C. medinalis, Marasmia* spp. . . . . *Charops brachypterum* (Cameron)

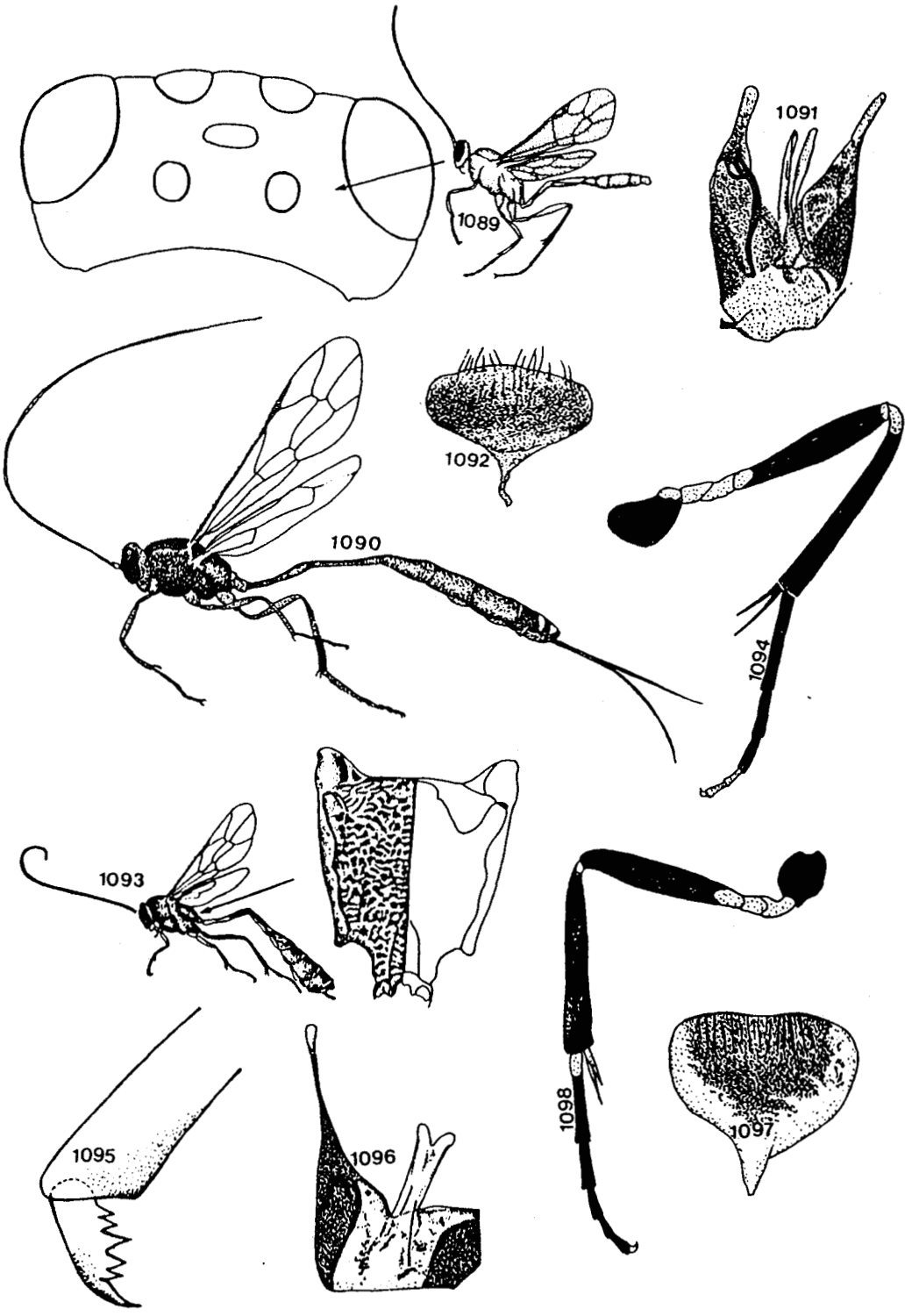
594' Hindfemur yellowish brown; base of tarsus I yellow (Fig. 1098); petiole wholly reddish; mesopleuron closely rugose; male genital clasper with a moderately slender apical process, midlength of process a little broader (Fig. 1099); subgenital plate (Fig. 1100) almost wholly dark colored except light colored margins; subtriangular with slightly convex top; hosts – *S. incertulas, S. innotata, Naranga aenescens, Spodoptera mauritia, Mythimna loreyi, Pelopidas mathias* ..... *Charops bicolor* (Szepligeti)

595(592') Abdomen reddish brown except black tergites I & II (although apices are reddish brown usually); trochanter III yellow; apical half of basal tarsal segment of leg III dark; thorax and head black; wings with 2*nd* recurrent vein erased at midhalf (Fig. 1101) . . . . *Eriborus vulgaris* (Morley)

595' Entire abdomen black; tarsal claws with small pectines basally; hind tarsal segment III about as long as segment V (Fig. 1102); scape black with brownish yellow tinge beneath; mid- and hind coxa black; hind femur red; hind tibia and tarsi reddish brown to yellowish brown, tibiae blackish at apex and tarsal segments I-IV apically and entire of segment V slightly darkened; trochanters yellowish brown to reddish brown with hind trochanter blackish basally; hosts – *C. suppressalis, Sesamia inferens* . . . . *Eriborus sinicus* (Holmgren)

595" Abdomen uniformly black dorsally; tarsal claws entirely pectined from base to apex; hindtarsal segment III slightly longer than segment V (Fig. 1103); coloration as in *E. sinicus;* hosts – *S. inferens, S. incertulas* ..... *Eriborus terebrans* (Gravenhorst)

596(520') Forewings with 2-3 closed cubital cells and a single recurrent vein attached to the base of second cubital cell 597



Figs. 1089-1098

596' Forewings with two closed cubital cells and two recurrent (1*st* and 2*nd*) veins attached to the base of the second cubital cell 598

597(596) Scutellum with a squarish yellowish orange band; metascutellum with a transverse rectangular yellowish orange mark; head, thorax, legs and abdomen clothed with black hairs; clypeus punctated but light medially, convex, pointed apically and without transverse ridges; mandibles without grooves and serrated with 2 inner teeth; antennal base very close to eyes with a distance of 0.25 diameter of antennal base (Fig. 1104); wings with bluish lustre basally and reddish brown towards apex; l*st* recurrent vein in the basal one-fourth of 2*nd* cubital cell (Fig. 1105) 36 mm long .... *Scolia* nr. *scutellaris* Gribodo

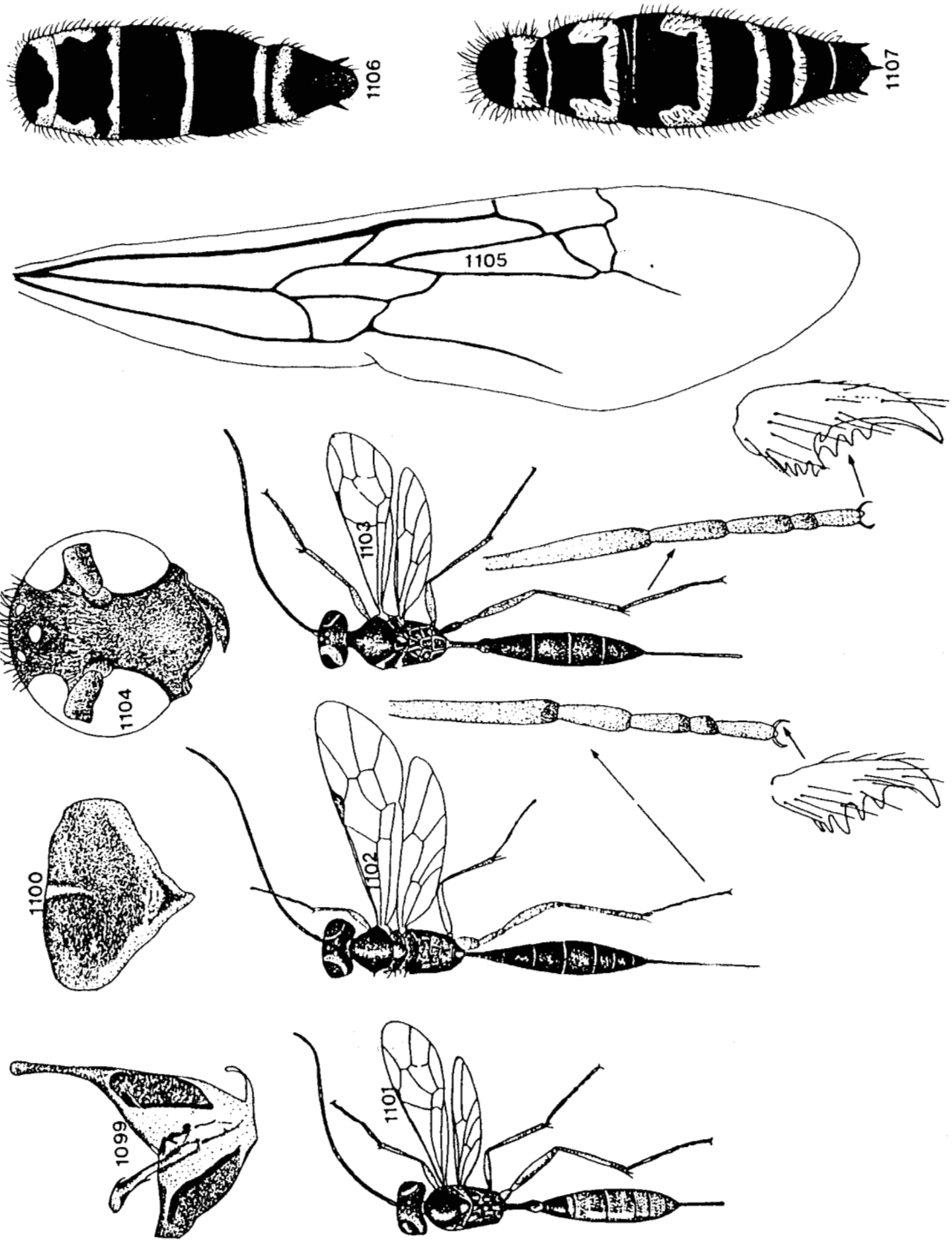
597' Scutellum and metascutellum black; head with yellowish white hairs arising from each punctate; clypeus not convex, mostly smooth without punctures except laterals below antennal base; anterior margin with transverse ridges and light longitudinal carinae medially above it; mandibles without serrated teeth; antennal base distant from eyes; female tergites I-IV (Fig. 1106) with a thin yellow band and a row of yellow hairs at apices, rest black; median yellow band narrow but broadens laterally in tergite I, II with an additional pair of subglobular yellow spots toward margins; apices of sternites with yellowish white hairs and yellow patch along apico-laterals of II and III; male tergites I-V with yellow narrow apical bands; bands in I-III widen laterally and become spot-like; apices of sternites II-III with yellow bands, erased medially in IV and reduced to spot laterally in V (Fig. 1107); male 100 mm long and female 14 mm long ..... *Scolia* sp.

598(596') Abdomen uniformly black, apices of tergites with black hairs; head with black or whitish and reddish orange hairs 599

598' Abdomen black with tergite apices lined with yellowish hairs and bands behind it or white hairs 600

599(598) Hairs on head and pronotum black; vertex punctated above lateral ocelli; eye margins and entire clypeus well punctated; with deep pits in the entire area between eye emargination (Fig. 1108); distance between first and second recurrent vein 1.3 times that space between first and second transverse cubital; 2*nd* transverse cubital oblique in the apical four-fifths and vertical in the basal one-fifth; bulge of cell R in line with 2*nd* transverse cubital; extension of Cu as long as the distance between two recurrent veins; (Fig. 1109); radiella far away from cubitella and their tips diverge apically, venation reaches midhalf of hindwing (Fig. 1110); 27 mm long ..... *Campsomeris* sp. A

599' Hairs on back of head and entire pronotum reddish orange; vertex smooth; shiny, impunctate including ocellar area, seven small transverse pits with white hairs above lateral ocelli (Fig. 1111); eye margins hardly punctate; midclypeus smooth and impunctate; distance between two recurrent veins 0.7 of distance between transverse cubital 1 & 2; midlength of transverse cubital slightly pointed outward; bulge of cell R beyond level of 2*nd* transverse cubital; extension of Cu long, two-fifths longer than



Figs. 1099-1107

distance between two recurrent veins; radiella and cubitella parallel-sided and parallel to each other; 17 mm long . . . . . *Campsomeris collaris quadrifasciata* Fabricius

600(598') Apices of abdominal tergites II to IV with white hairs; tibial spur of leg III white 601

600' Apices of abdominal tergite I-V with yellow bands and hairs; tibial spurs white to blackish brown 602

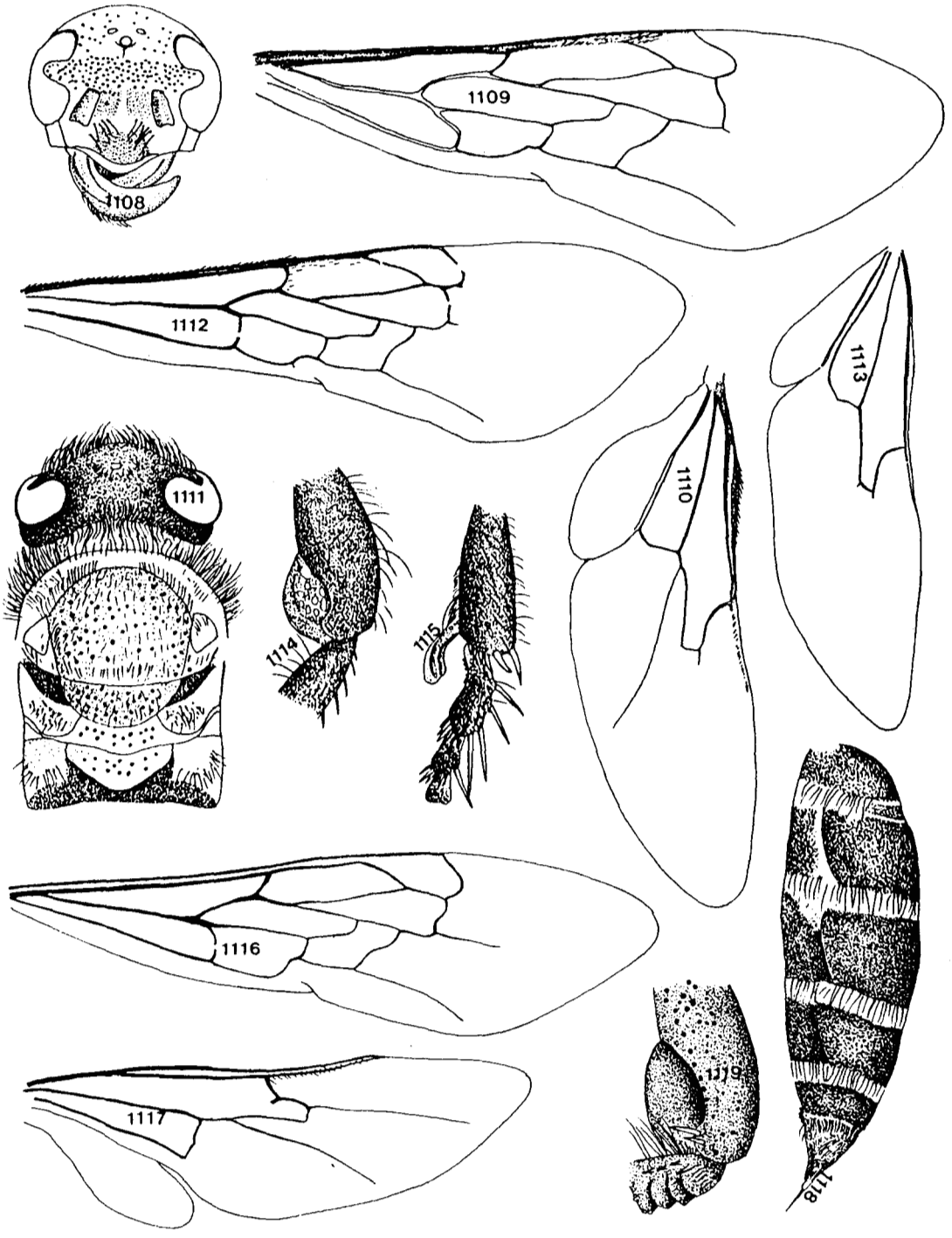
601(600) Apical distance between first and second recurrent veins longer than the apical distance between transverse cubital 1 and 2; first recurrent vein with an angled corner; subdiscoideus straight; vein R rounded at its bulging point with its tip directed slightly downwards below level of wing apex; tip of Cu beyond second cubital cell short, barely one-fifth the apical distance of two recurrent veins (Fig. 1112); radiella and cubitella of hindwings not traceable (Fig. 1113); mandibles narrow apically with short inner basal hairs; apex of hindfemur with a reddish brown enlargement in the inner side, central plate lined with subglobular marks (Fig. 1114); basal tarsal segment of leg III with 2 long white subapical ventral setae (Fig. 1115) . . . . . *Campsomeris* sp. B

601' Apical distance between 2 recurrent veins as long as apical distance between transverse cubital 1 & 2; first recurrent vein with a rounded corner; subdiscoideus downwardly curved apically; bulging point of vein R well beyond slightly S-shaped 2*nd* transverse cubital and tip directed towards wing apex; extension of Cu beyond 2*nd* cubital cell, one-fifth longer than the distance between two recurrent veins (Fig. 1116); radiella and cubitella prominent (Fig. 1117); mandibles broad and tip moderately acute; abdomen entirely black similar to *Campsomeris* sp. B, lined along apices of tergites with white hairs (Fig. 1118); brown plate at inner-apical part of hind femur (Fig. 1119) without globular marks; basal tarsal segment of leg III with five long white setae . . . . . *Campsomeris* sp. C

602(600') Hairs on head, thorax, legs and apices of tergites yellow to dark yellow or brownish yellow; clypeus, scutellum, and metascutellum without yellow bands; mandibles prominently open, tips touching each other; yellow band on apex of tergite II straight basally, without U- or V-shaped pattern; tergite III with a hat-like yellow mark apically, elevated medially and low laterally (viewed posteriorly) (Fig. 1120); apical distance between 2 recurrent veins as long as apical distance between 2 transverse cubitals (Fig. 1121) . . . . . *Campsomeris* sp. D

602' Hairs on body and legs white to whitish yellow; clypeus and scutellum with yellow areas; mandibles on top of each other and closed; yellow bands on tergite II-V all U-shaped 603

603(602') Tergite II with a wide V-shape mark; III concave medially, yellow band much wider than black band (Fig. 1122); scutellum with a pair of yellow subrectangular spots; metascutel-



Figs. 1108-1119

lum without yellow marks; clypeus with small black median spot; distance between antennal base and eyes 0.36 diameter of antennal base . . . . . *Campsomeris* nr. *aurulenta* (Smith)

603' Tergite II with a wide U-shape band; I with an additional black band on top of yellow band; III widely concave medially, black band much wider than yellow band (Fig. 1123); scutellum and metascutellum with a broad transverse yellow band; clypeus with a large median black spot; distance between antennal base and eyes 0.2 diameter of antennal base . . . . . *Campsomeris annulata* (Fabricius)

604(523') All tibiae with 2 spurs, reduced to a calcar and a simple spur in the fore tibia; wing simple with well sclerotized long marginal vein extended to wing base; stigmal vein moderately long and concave; antennae 11-12 segmented [Ceraphronidae] 605

604' Mid and hind tibia with only 1 spur 607

605(604) Forewing with 2 broad brown bands, dark at midhalf and light at apex (Fig. 1124); thorax, legs and scape yellow; head brownish yellow; abdomen brownish black similar to funicular segments VI-VIII (Fig. 1125); 0.9-1 mm long . . . . . .*Ceraphron* sp. A

605' Forewing without brown bands 606

606(605') Brown except black head, propodeum, flagella of antenna, pedicel and apical half of scape (Fig. 1126), and apical one-half of abdomen; all legs brownish yellow; forewing a little longer than abdomen (6057) and with 2 light yellow brown bands running parallel with the marginal vein, in between with a row of setae (Fig. 1127); funicle segment I (Fig. 1126) as long as combined length of II and III; 2-3 mm long . . . . . *Ceraphron* sp. B

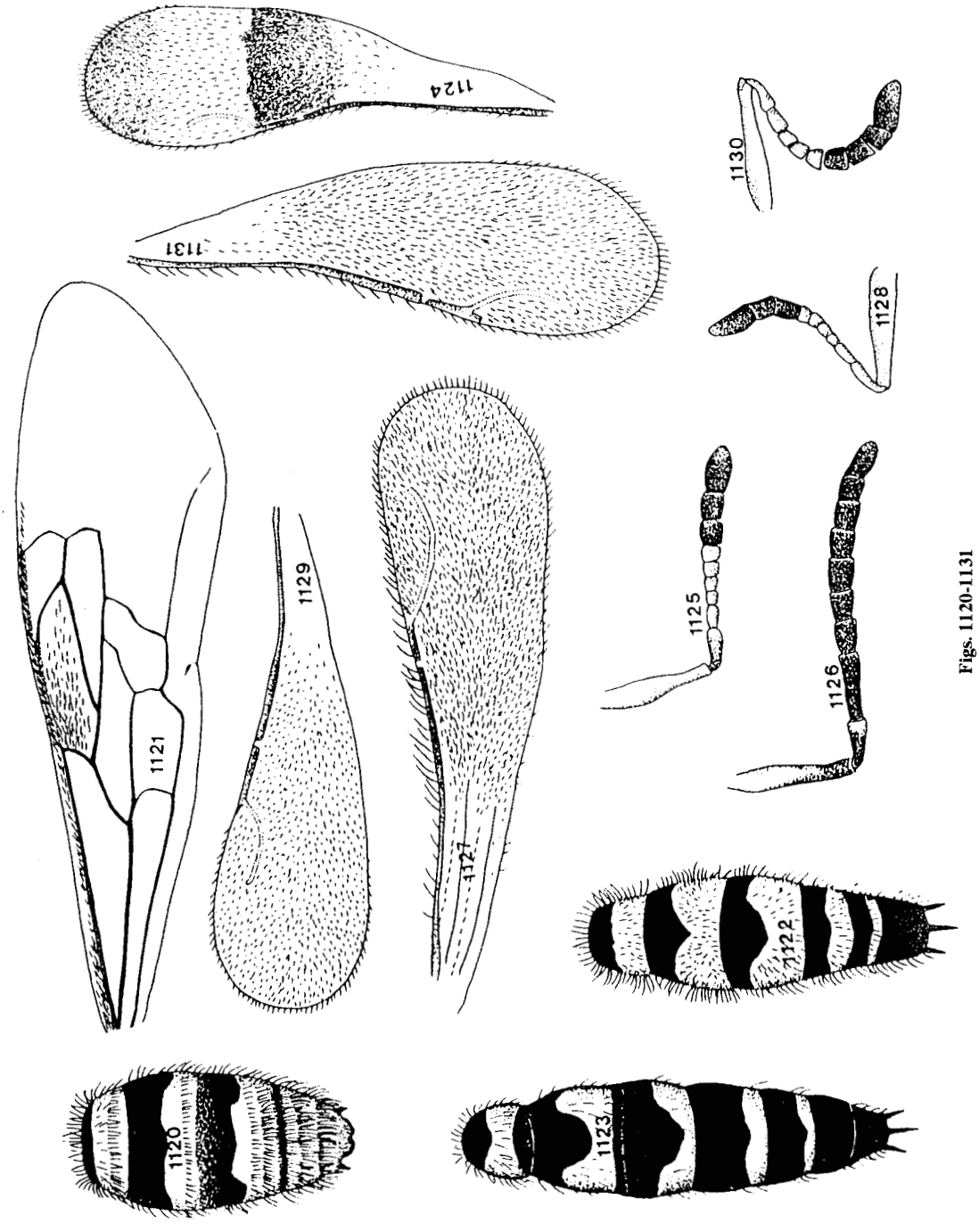
606' Entirely black except abdomen with brownish tinge; antennal scape yellow, pedicel and funicles I-IV brownish yellow, funicle I shorter than combined length of II and III, rest of segments blackish brown (Fig. 1128); legs I-III yellow; forewing without yellow-brown band parallel with the marginal vein and one-fourth longer than abdomen, stigmal vein faint and short (Fig. 1129); 1.2 mm long . . . . . *Aphanogmus fijiensis* (Ferriere)

606' Similar to *A. fijiensis;* 1*st* funicle nearly as long as combined length of II and III, terminal 4 segments blackish brown (Fig. 1130); stigmal vein moderately long and with few hairs near wing base (Fig. 1131) . . . . . *Aphanogmus* sp.

607(604') Venation absent or reduced to submarginal vein with a slightly knobbed apex; egg-larval parasites of *Orseolia oryzae* [Platygasteridae] 608

607' Forewing with distinct, though sometimes short marginal and stigmal veins [Scelionidae] 609

608(607) Antennal scape and legs light orange-yellow; apical four antennal segments pale brown, broad, and subquadrate, basal four smaller in size (length and width) than apical segments and light orange-yellow; coxae yellow except brown coxa I; lateral posterior part of thorax with dense greyish pubescence (Fig. 1132); 0.9-1.0 mm long . . . . . *Platygaster oryzae* Cameron



Figs. 1120-1131

608' Antennal scape and legs yellow; funicular segments brownish black, long and slender; slightly more than twice as long as broad; coxae brownish black except yellow coxa III; posterior part of thorax with greyish white pubescence; body length more than 1 mm (Fig. 1133) . . . . . *Platygaster foersteri* (Gahan)

609(607') Gaster with lateral margins rounded; wide latero-tergites of metasoma loosely attached to sternite (not incised) forming no depressed submarginal ridge; 2*nd* tergite (T2) of metasoma the longest; antenna 12-segmented in male and 10-11 in the female [Telenominae] 610

609' Gaster with lateral margins carinated; narrow laterotergites incised to form impressed submarginal ridge; metasoma usually subequally segmented with 3*rd* segment (T3) often the longest; lateral ocelli usually nearer to the inner orbits than to median cells [Scelioninae] 633

610(609) Frons predominantly sculptured particularly in the lower half; eyes bare and usually glabrous; parapsidal furrows often present 611

610' Frons smooth and shining, lack sculpturing in the lower half of frons; eyes usually hairy; parapsidal furrows absent 616

611(610) Fan-like carina prominent in the head emanating near mandibular base, extended dorsad to the frons and cheeks, and branches ventrad on either sides of insertions; central keel, submedian and orbital carinae developed (Fig. 1134); lateral side of thorax strongly pitted (Fig. 1135); acetabular field and anteroventral portion of mesepisternum setose; lateral sulci on 2*nd* sternite (S2) broadly separated posteriorly but more nearly straight and setigerous punctures widely separated; antennae with yellow scape (similar to coxae), black radicle; hosts – *Scotinophara latiuscula, S. coarctata* . . . . . *Psix lacunatus* Johnson & Masner

611' Fan-like carina absent; cheeks and frons without ridges; postmarginalis of wings usually longer than stigmalis; metasoma uniformly black; scutellum of females with semi-decumbent hairs not interfering the sculpture 612

612(611') Tergite I of abdomen without any sublateral setae; notauli present 613

612' Tergite I of abdomen with sublateral setae; notauli absent 614

613(612) Scutellum coarsely sculptured; slightly more roughly punctured than mesoscutum and scrobiculate towards edges; broad, well convex mesoscutum strongly reticulate – sculptured and clothed with short hairs; notauli sharply defined posteriorly; gaster longer than broad, 1*st* tergum with deep longitudinal costate on basal half, 2*nd* tergum 1.4 times wider than long and midbasal two-thirds longitudinally striated, the rest of tergites smooth and shining (Fig. 1136); female antenna (Fig. 1137) reddish yellow, 5-segmented club broad and long with 2*nd* and 3*rd* club segments transverse, and conical apical

segment; scape subequal to next three segments; length 1.3-1.5 mm; egg parasites of *Nezara viridula* L., *N. antennata* and *Piezodorus rubrofasciatus* in E. Asia . . . . . *Trissolcus mitsukurii* (Ashmead)

613' Scutellum smooth without microsculpture; mesoscutum covered with leather-tough microsculpture; notauli (Fig. 1138) narrow but visible; dorsellum with dorsal transverse row of deep pits along scutellar-metanotal suture and venter with longitudinal carinae; episternal foveae well-developed with a line of 4-5 dorsoventrally elongate deep pits running from dorsal tip of acetabular carina toward mesopleural pit; mesopleural carina absent ventrally (Fig. 1138); tergum II with weak wrinkles reaching well beyond basal costae and short irregular subapical line of setae; antenna dark brown to black with light yellow-brown radicle and scape; malar region narrow; length 0.9-1.2 mm; egg parasite of *Nezara viridula* in N. America . . . . . *Trissolcus thyantae* Ashmead

614(612') Second tergite with prominent rugulae beyond basal costae; scutellum with distinct tough leather-like microsculpture; bases of setae with pustules or blisters; head in lateral view, with wide gena highly bulging posteriorly; vertex broadly rounded; episternal foveae only a pair of circular pits dorsad of acetabular carina apex (Fig. 1139); 2 *nd* tergum highly rugulose eyes hairy and diverging posteriorly (Fig. 1140); hosts – *Nezara viridula, Piezodorus guildinii* in Americas . . . . . *Trissolcus basalis* (Wollaston)

614' Second tergite smooth; bases of setae not strongly raised 615

615(614') Vertex abruptly rounded up to occiput; orbital furrow dorsally and ventrally constricted; hyperoccipital carina absent; frons with rough thick leather-like microsculpture (Fig. 1141); anteroventral portion of mesepisternum coriaceous, median longitudinal carina well developed; scutellum smooth (Fig. 1142); episternal foveae 2-3 poorly delimited depressions; host – *Nezara viridula* in Americas . . . . . *Trissolcus hullensis* (Harrington)

615' Vertex sharply angled up to occiput; orbital furrow narrow and fading ventrally; hyperoccipital carina present; frons with granulose microsculpture (Fig. 1143); scutellum coarsely rugose-areolate, antero-ventral mesoepisternum rugulose; episternal foveae only 2 shallow pits (Fig. 1144); egg parasite of *Nezara* in N. America . . . . . *Trissolcus solocis* Johnson

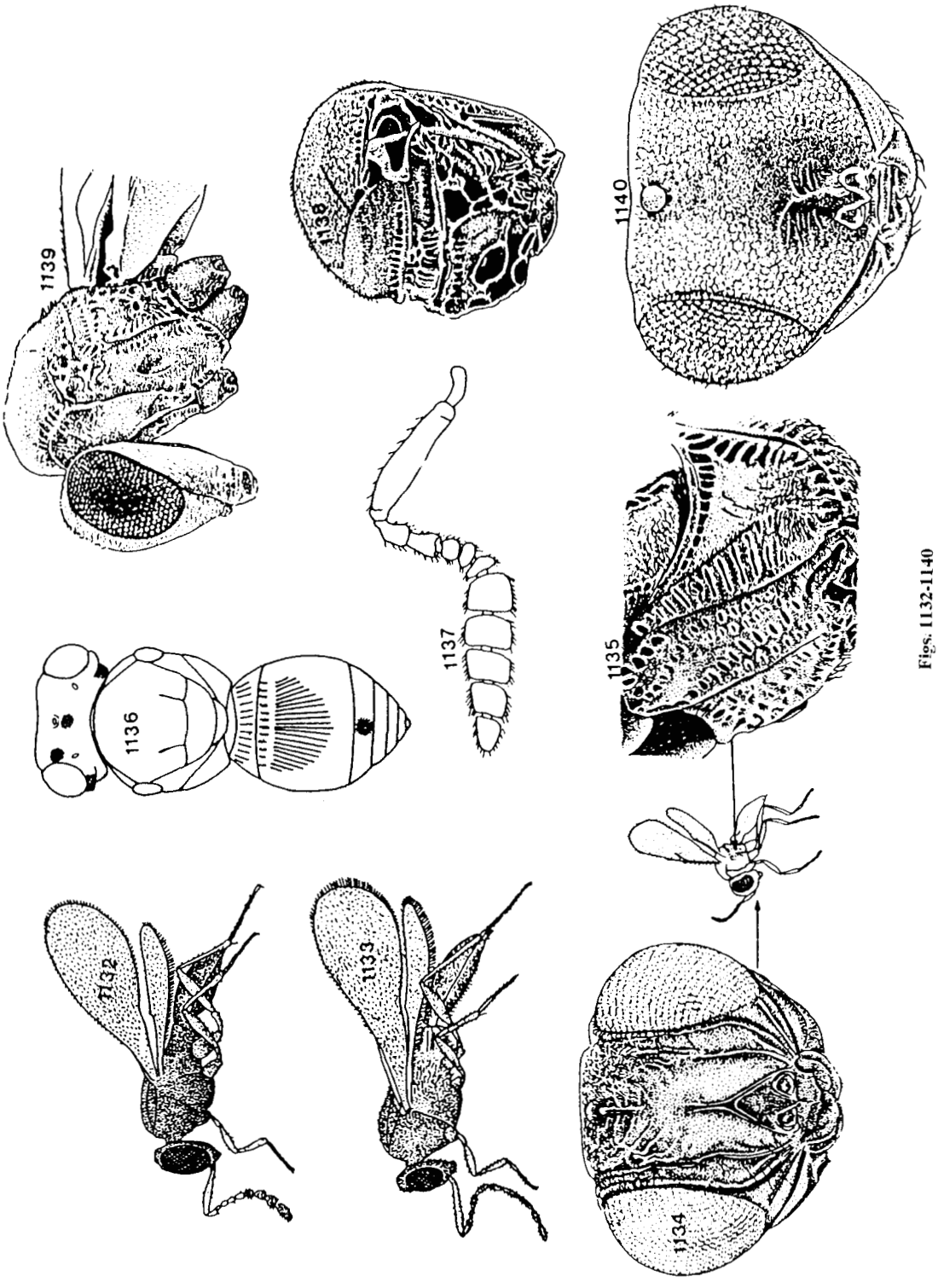
616(610') Hosts – stem borer eggs 617

616' Hosts—eggs of pentatomid bugs in the genera *Nezara, Scotinophara, Eysarcoris) Oebalus* and eggs of lepidopterans, *Melanitis, Spodoptera and Mythimna* 624

617(616) Small telenomines, body length 0.5-1.1 mm 618

617' Moderately large telenomines, body length 1.5-1.8 mm 620

618(617) Tergite I uniformly smooth, unsculptured, its costae absent or reduced to an imperceptible row of minute foveae basally; tergite II (Fig. 1145) with emarginate apex; lower midhalf of abdomen evenly tapering towards apex and somewhat flattened; metasoma



Figs. 1132-1140

long and slender, clearly concave in dried specimens; antenna of males yellow except apical 3-4 segments, funicles 4 to 9 subglobular and bead-like, funicles 1 to 3 about twice as wide as the rest (Fig. 1146); female scape 4.9 times as long as broad, 1*st* funicle 1.6 times as long as broad, 2*nd* and 3*rd* subequal and subquadrate, club 4-segmented with each segment a little longer than broad and conical-ovate apical segment (Fig. 1147); penis sheath not narrowed before the apex (Fig. 1148); female 0.8-0.85 mm long and male small, 0.5-0.6 mm long (Fig. 1149); hosts — *Scirpophaga incertulas, S. innotata* .... *Telenomus rowani* (Gahan)

618' Tergite I strongly and evenly costate at apical margin; thorax hardly longer than its greatest width; head markedly transverse; shortest distance between the eyes clearly greater than their width as seen from above 619

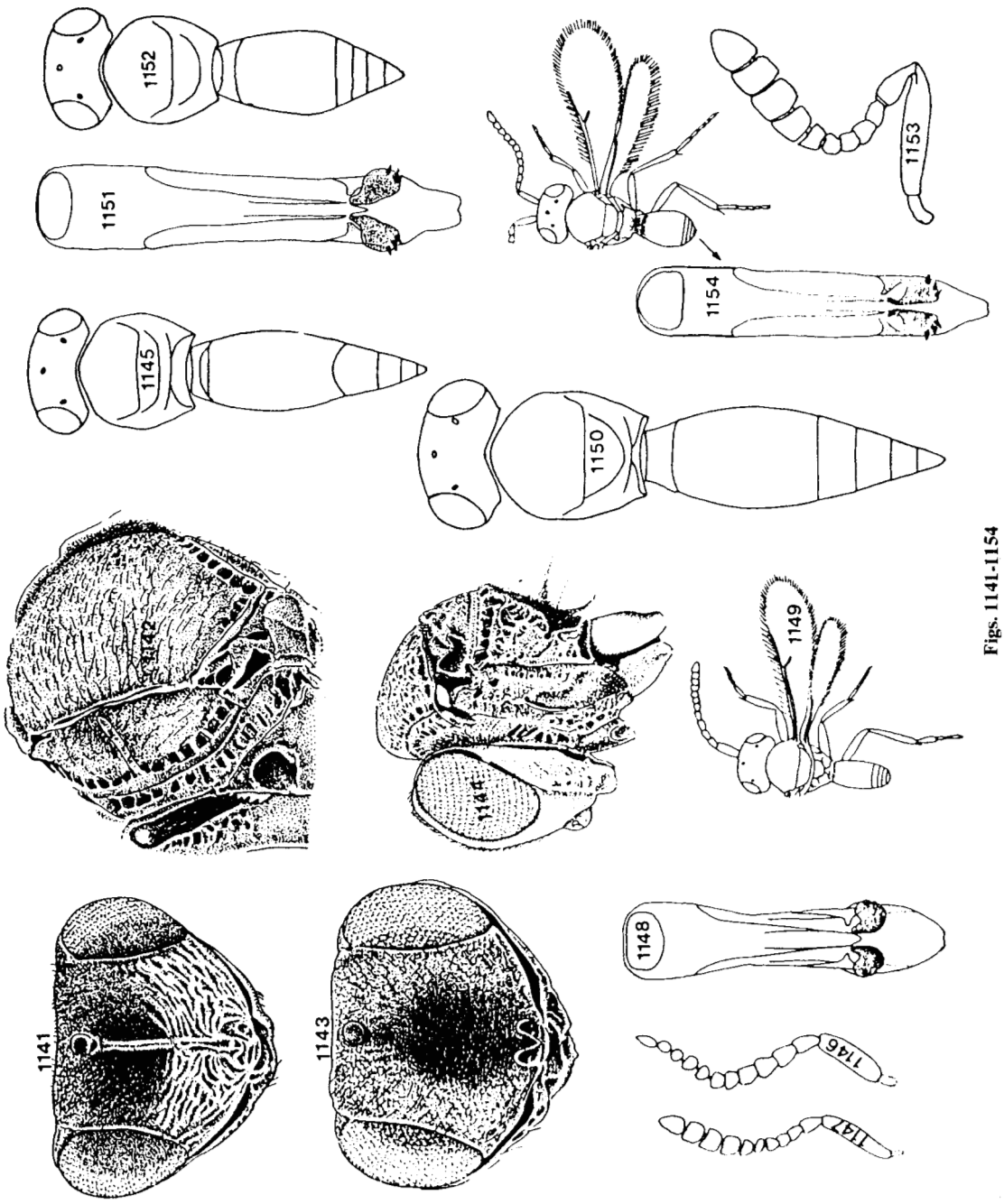
619(618') Abdomen nearly three times as long as its greatest width (Fig. 1150); hind tibia slightly less than twice as long as its metatarsus; forecoxa of male prominently darkened, without conspicuous darkening along inner border of apical appendages; basal segment of hind tarsus long and slender, equally thin as the rest, and almost as long as the apical three segments; penis sheath narrowed before apex (Fig. 1151); male 0.9 mm long and female 1-1.1 mm long; hosts — *S. incertulas, S. auriflua* and *Chilo sacchariphagus* ..... *Telenomus dignoides* Nixon

619' Abdomen about twice as long as wide, narrowed to a sharp point at apex; tergite I with sharply defined longitudinal costae right across; tergites 3 and 4 strongly transverse (Fig. 1152); pedicel longer than combined length of funicular segments I and II (Fig. 1153); hind tibia slightly more than twice as long as its metatarsus; legs bright yellow; genitalia distinct on account of thickening which appears as a dark band along inner side of apical appendage (Fig. 1154); 0.7-0.8 mm long; hosts — *Scirpophaga innotata, S. incertulas, Chilo suppressalis, C. polychysus, C. auricilius* .... *Telenomus dignus* (Gahan)

620(617') Eyes bare; transverse, head, and body dark brown with yellow legs except brown coxa I and apical tarsomeres; antennal segment II >III, IV to VI weakly rounded and transverse, VII trapezoidal, VIII-X transverse, XI longer than wide and apically globose (Fig. 1155); wings narrow without a basal vein but with long marginal setae, stigmal vein shorter than postmarginal vein; legs short and stout, 5*th* tarsomeres of all legs dilated, 5*th* middle tarsomere with four strong ventral spines (Fig. 1156); mesoscutum weakly and evenly convex; scutellum bulging, smooth with long sparse setae; submarginal foveae absent; tergite I of abdomen with 2 pairs of lateral setae, 1 pair of sublateral with basal margins finely punctured; tergite 2 without longitudinal costae but with transverse striations basally (Fig. 1157); 1.7 mm long; host — *S. innotata* in S. E. Asia .... *Telenomus transversus* Bin & Johnson

620' Eyes setose; combination of characters not as above 621

621(620') Mesoscutum flat or strongly depressed 622



Figs. 1141-1154

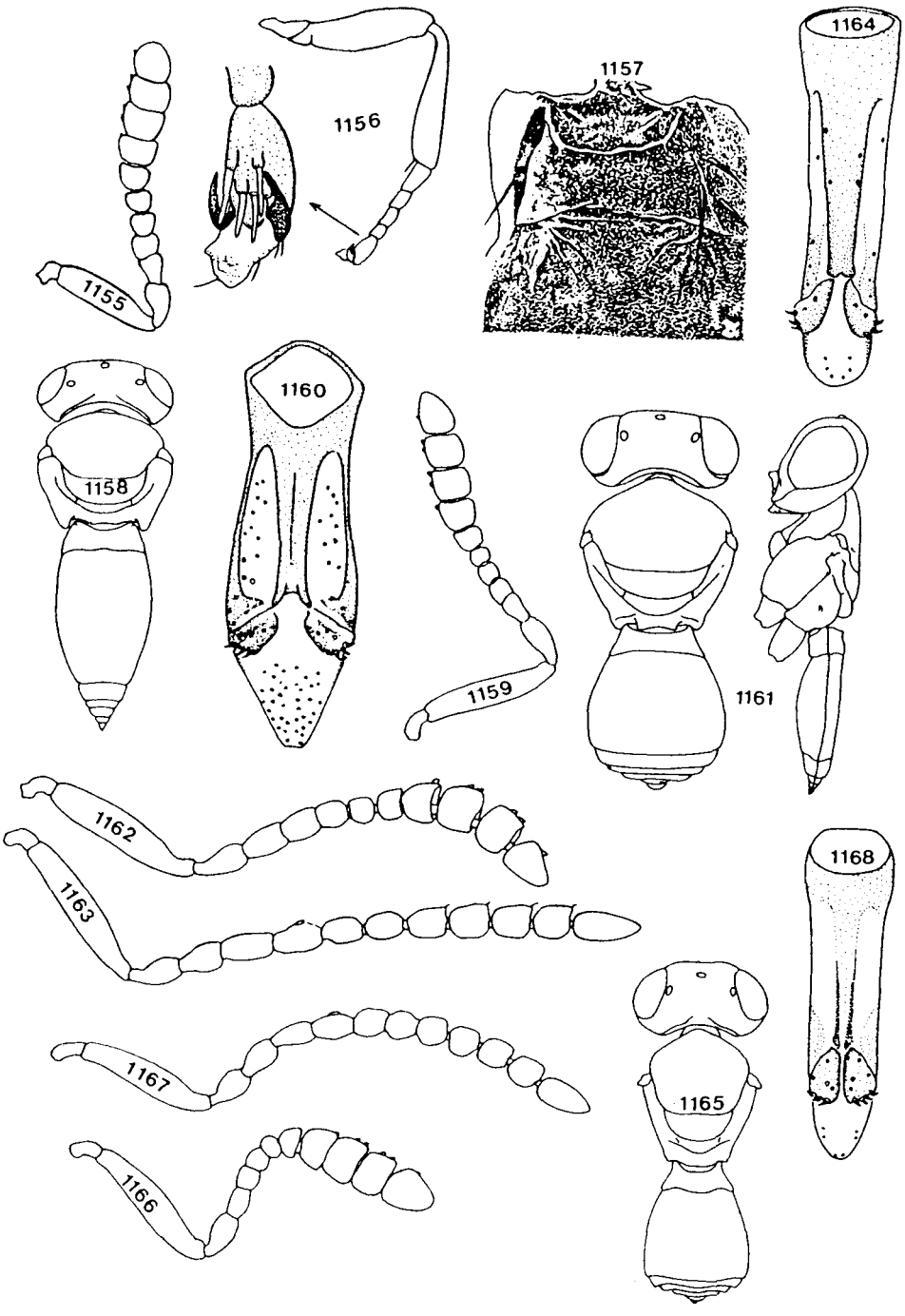
621' Mesoscutum evenly convex; head more transverse-ovate (Fig. 1158); female antennal segment II much longer than any of III-XI, VI strongly transverse and subglobular, VII < VIII, VIII-X transverse (Fig. 1159); in male, II much longer than any of III-XI, IV and V slightly longer and with basiconic sensillum and wider than III, VI-X transverse; 5*th* tarsomere of legs without strong setae ventrally; abdomen elongated, tergite II much longer than wide and tip pointed; tergite I with 3 pairs of lateral setae, 2 pairs of sublateral setae and costae reduced to a median row of foveae similar to tergite II (Fig. 1158); genitalia with a narrow median plate and small digital teeth (3/digitus), penis valves strongly sclerotized and sheath tapers apically (Fig. 1160); 1.7 mm long; host – *S. melanoclysta* in Africa ..... *Telenomus versicolor* Bin & Johnson

622(621) Head strongly reflexed; lateral angles of clypeal margins sharply pointed; labral margins excised medially; temples narrow, weakly bulged and with a narrow band of coriaceous sculpture along posterior orbits reaching dorsal occipital carina (Fig. 1161); mesoscutum strongly depressed; scutellum strongly transverse; episternal foveae present but very shallow; acetabular field large entering mesopleural furrow but not reaching intercoxal space; antennae of female (Fig. 1162) with segment II and III equal in length, IV (longest) > V, VI globular to quadrate, VIII > VII, VII to X transverse; segment V with a prominent tyloid-sensillum and VIII-XI each with a long seta in the expanded ventro-apical angle in the male (Fig. 1163); tergite I with 2-3 pairs of lateral setae, wrinkles of tergite II fan-like medially reaching one-third of its length (T2); digital teeth small with 3 teeth/digitus; penis sheath strongly rounded at apex (Fig. 1164); 1.8 mm long; hosts – *Diatraea rufescens* and *D. saccharalis* in South America .... *Telenomus alecto* (Crawford)

622' Head not strongly reflexed; occipital carina complete with or without median interruptions; temples with or without a band of coriaceous sculpture 623

623(622') Temples with a band of coriaceous sculpture along posterior orbit reaching half the distance from occipital carina; head moderately transverse (Fig. 1165); occipital carina complete without median interruptions; acetabular field reaching mesopleural furrow; female (Fig. 1166) antennal segment V and VI globular, male (Fig. 1167) with segment III > II, IV = V, V with a tyloid sensillum ventrally, VI-XI clearly transverse; tergite I with 2 pairs of lateral setae and costae in basal half, tergite II nearly as broad as long (Fig. 1165); genitalia with small digital teeth, median plate forms two indistinct converging rods, penis sheath narrow and pointed apically (Fig. 1168); 1.5 mm long; host – *Chilo sacchariphagus* in S. Asia ..... *Telenomus globosus* Bin & Johnson

623' Temples without such band; head subglobular, occipital carina indistinct medially (Fig. 1169); mesoscutum strongly depressed (Fig. 1170); acetabular field not reaching mesopleural furrow; antenna in female with segment, VI strongly transverse (Fig. 1171); male (Fig. 1172) with segment II=III, IV< V, V with a distinct basiconic sensillum, VI-XI globose; abdomen subelongate, broadens below lower end of broad tergite II, tergite I with 2 pairs of lateral setae and costate in entire length of laterals and basal half



Figs. 1155-1168

of middle area (Fig. 1170); genitalia with large digital teeth; median plate forms an elongate trapezoidal plate; penis sheath short and strongly long rounded to moderately tapered apically (Fig. 1173); 1.6 mm long; hosts — *Maliarpha separatella* and *Eldana saccharina* in Africa . . . . . *Telenomus applanatus* Bin & Johnson

624(616') Egg parasitoids of noctuids *(Mythimna* and *Spodoptera)* and satyrid *(Melanitis);* first funicular segment as long as or slightly longer than pedicel 625

624' Egg parasitoids of pentatomid bugs *(Nezara, Piezodorus, Scotinophara, Eysarcoris, Oebalus);* first funicular variable, in some, as long as pedicel 627

625(624) Head and pronotum of male reddish yellow, antenna deep brown except yellowish brown scape, leg yellow except fusco-testaceous femur and tibia of leg III and apical tarsal segments yellow or black; female, black with chestnut brown antenna and fuscous legs; head transverse with well convex frontal region, broad and flat vertex; male antennal segment I 3.2 times as long as II, II a little longer than III, III = IV; VI-VI11 subquadrate, IX = X, XI < X, XII conically elongate; female club 4-segmented; segment VI very short and strongly transverse, proximal three segments slightly transverse (Fig. 1174); forewings rather broad and hyaline, ciliated, stigmalis one-fifth of postmarginalis; tergite I of abdomen transverse with longitudinal costae all over; II nearly as long as broad with short striae basally; 0.6-0.7 mm long; egg parasitoid of armyworm *Mythimna unipuncta* in E. Asia . . . . . *Telenomus cirphivorus* Liu

625' Not as above, egg parasitoids of different hosts 626

626(625') Large species with short and stout body, at least 0.9 mm long; head transverse, vertex convex, finely and evenly scaly-reticulate with sparse short hairs; preoccipital carina present and distinct even in the median area; antenna honey yellow except dark brown club, pedicel as long as first funicular segment; VI subglobular, VII and proximal three segments of club transverse (Fig. 1175); forewing pale, venation yellowish and not sharply outstanding; stigmalis rather long 0.6 times of postmarginalis; fringes of hind wing a little more than half maximum width of wing (Fig. 1176); hosts — unknown noctuid moth and *Melanitis leda* in Asia . . . . . *Telenomus Iucullus* Nixon

626' Very small species, length 0.5 mm; head strongly transverse; vertex without a posterior declivous surface; preoccipital carina not distinct (Fig. 1177); antenna uniformly blackish, funicles I-IV very small, bead-like and much narrower than pedicel and VI-VI11 similar in size, female segment III distinctly longer than IV, VI strongly transverse (Fig. 1178); male with segment III-V of same length (Fig. 1179); forewing greyish; stigmalis short; fringes of hindwing longer than or fully as long as maximum wing width; genitalia slightly narrow medially, with stout digiti and digital teeth, 3/digitus, median plate very wide basally and strongly concave at apex near digiti, penis sheath moderately long, subrounded at apex; genitalia in general short and broad (Fig. 1180); hosts — *Spodoptera litura* and *S. mauritia acronyctoides* in Asia . . . . . *Telenomus remus* Nixon

627(624') Oriental species of *Telenomus* parasitizing *Nezara* or *Scotinophara* 628

627' Non-oriental (Palearctic, Nearctic and Neo-tropical) species of *Telenomus* attacking a wider genera of pentatomid bugs 629

628(627) Small species, 0.8 mm long; postscutellum with a semi-triangular strongly rugose median dilation; ocellar region without punctures (Fig. 1181); 1*st* funicular segment shorter than pedicel, 3*rd* at least not elongate; club clearly 5-segmented (Fig. 1182); stigmalis rather short; fringe about two-thirds maximum wing width; abdomen longer than wide (11:7) with tergite I sculptured to its extreme apex; striations on tergite II reach basal; genitalia feebly sclerotized, narrowed medially above digiti and below basal ring, digiti stout with 3 small digital teeth each, median short and broad with nearly straight apex, penis sheath acutely rounded (Fig. 1183); general coloration black except yellow legs and scape, and uniformly brown funicles; hosts – *Scotinophara lunda, S. coarctata* and *S. latiuscula* in S. and S.E. Asia . . . . . *Telenomus triptus* Nixon

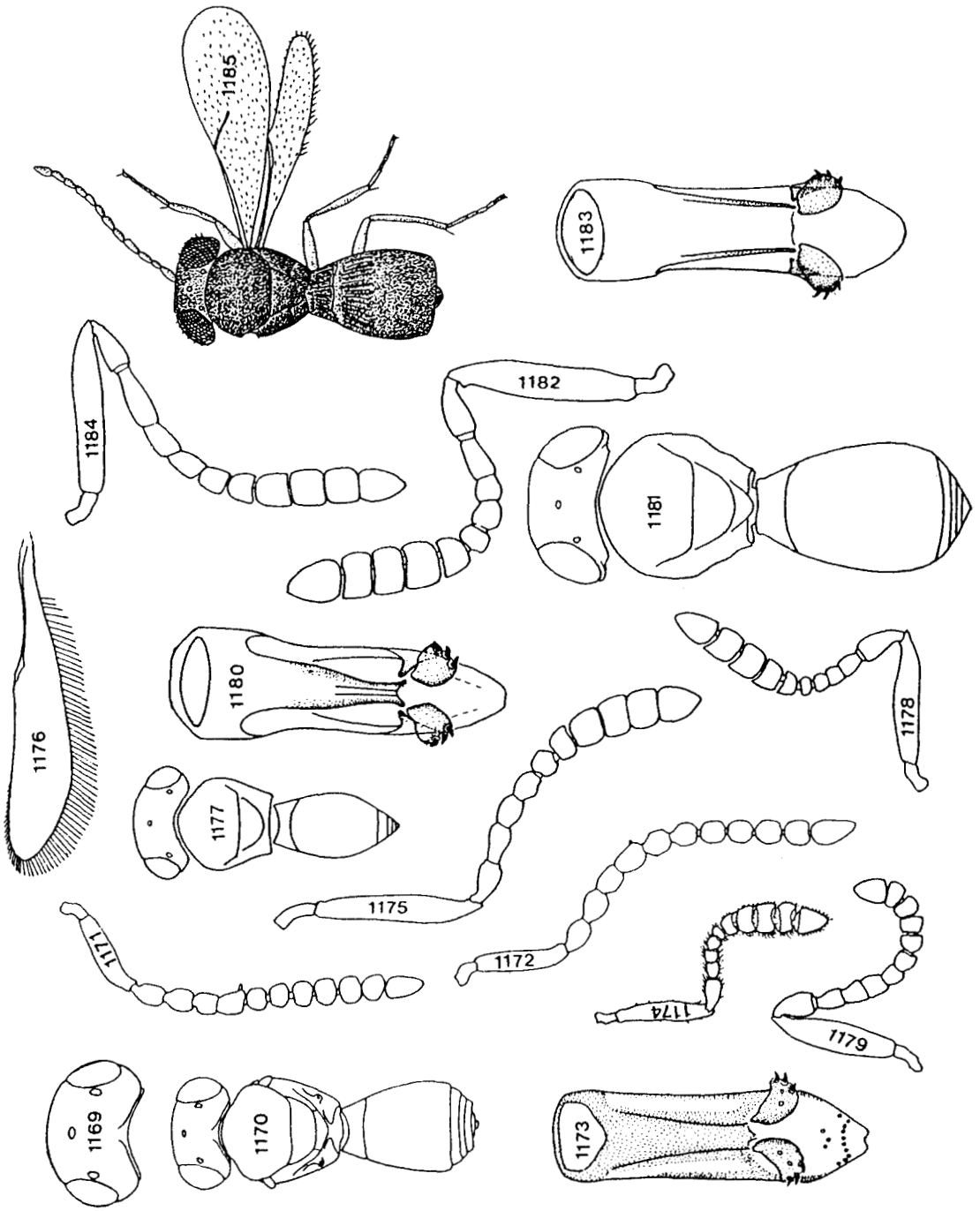
628' Moderately large species, 1.05 mm; postscutellum with a median subglobular strongly rugose swelling; ocellar region with 3-4 punctures; antenna slender without a clearly differentiated club; 1*st* funicular segment as long as pedicel, II and III elongate (Fig. 1184); fringe about half maximum wing width; stigmalis of forewings long; abdomen 1.5 times as long as wide with tergite I evenly striate (Fig. 1185); black with unicolorous dark brown antennae, yellow legs except blackened coxae I-III and infuscated femur; host - *Nezara vindula* and *S. latiuscula* in Asia . . . . . *Telenomus cyrus* Nixon

629(627') Ocellar setae 2-3 pairs either widely separated or weakly developed; shallow postocellar grooves behind lateral ocelli; hyperoccipital carina absent; temples drop-off sharply to occipital carina, coriaceous sculpture along posterior orbits extending 0.33 distance to occipital carina (Fig. 1186); metapleural carina well developed in the posterior half of sclerite; antenna 11-segmented in the female, pedicel < 1*st* funicle, 4*th* funicle quadrate; V < VI; VII-VIII transverse; clava 5-segments; head and body black with all coxae black to dark brown; body length 1.2-1.3 mm; host – *Nezara viridula* in Asia and Europe . . . . . *Telenomus chloropus* Thomson

629' Ocellar setae absent, if present postocellar grooves wanting 630

630(629') Hyperoccipital carina present; frontal depression well developed; frons slightly bulging between antennal insertions and inner orbits; 1*st* funicle distinctly longer than pedicel in the female (Fig. 1187); funicular segments I to III much longer than wide and VI-IX slightly longer than wide in the male; scutellum with submarginal foveae smaller than dorsellar punctures; head and body black; yellow forecoxa with blackish base, mid-and hind coxa dark brown concolorous to antennal segments II-XI; scape brownish yellow; genitalia (Fig. 1188) with moderately broad digiti, 3 teeth/digitus; penis sheath rounded; body length 1.10 mm in male and 1.1-1.4 mm in the female; host – *Nezara viridula* in America . . . . . *Telenomus cristatus* Johnson

630' Hyperoccipital carina absent; frontal depression usually weakly developed 631



Figs. 1169-1185

631(630') Polyphagous egg parasitoids in American region; head and body dark brown to black; vertex smoothly rounded, angled or rounded behind lateral ocelli; mesoscutum strongly convex,- coriaceous-pustulate without longitudinal sculpture (Fig. 1189); setal bases pustulate in the smooth scutellum; submarginal foveae subequal in size to dorsellar punctures; dorsellum broadly triangular overlapping propodeum; abdominal tergite I with 2-3 pairs of sublateral setae (Fig. 1190); antenna of female 11-segmented, segment II<III; VI (4*th* funicle) transverse, VII < VIII; wing clear; genitalia slender, digiti and teeth (3/digitus) large; median plate with parallel sclerotized rods near digiti; penis sheath short and almost broadly rounded (Fig. 1191); body length 0.9-1.4 mm in female, 0.9-1.6 mm in male; hosts — *N. viridula, Oebalus pugnax, Mormoidea poecilia* . . . . . *Telenomus podisi* Ashmead

631' Not as above 632

632(631') Egg parasitoids of *Nezara antennata* in E. Asia; vertex rather narrow and well convex; antennae and coxae nearly black throughout, pedicel slightly longer than broad, shorter than 1*st* funicular segment, 2*nd* funicular segment about as long and broad as first; *3rd* 1.7 times as long as broad and 0.9 times as long as 2*nd;* 4*th* - 9*th* slightly longer than broad (Fig. 1192); abdominal tergite II about as long as broad and weakly longitudinally striated basally; body length of male 0.9 mm and 1.2 mm in the female . . . . . *Telenomus nakagawaii* Watanabe

632' Egg parasitoids of *Scotinophura, Piezodorus* and *Eysarcoris* in E. Asia; vertex rather flat and broad; postero-lateral part behind eye angulate and very narrow (Fig. 1193); pedicel 2.2 times as long as the 1*st* funicular segment; 3*rd* funicular oblong, 4*th* globular and club with 5 segments in female (Fig. 1194); male with funicular segment I to III much longer than IV to IX; black except for dark brown antenna with yellowish brown to yellow scape and apex of pedicel; legs including coxae uniformly yellow; penis sheath short and apically rounded (Fig. 1195); body length 0.9 mm in male and 1.1 mm in female . . . . . *Telenomus gifuensis* Ashmead

633(609') Small scelioninae, body length barely 1.6 mm; egg parasitoids of rice bug *Leptocorisa oratorius;* head with reticulate sculpture all throughout except transverse interconnected rectangular sculptures in frontal area above antennal bases (Fig. 1196); deep ridge at the back of head and strongly rounded at front; mesothorax and scutellum with rough peg-like structures (Fig. 1197); otherwise finely punctated, parapsidal furrows absent; antenna brownish yellow with yellowish scape and distal end of pedicel; pedicel inverted, cone-shaped and much longer than 3*rd;* 4*th* - 6*th* quadrate; 7*th* - 12*th* form the club, also quadrate except cone-shaped apical segment (Fig. 1198); wing hyaline with small hairs; veins brown; abdomen broadly ovoid; barely longer than wide, l*st* tergite 4 times broader than long; black with yellow legs . . . . . *Gryon nixoni* Masner

633' Relatively large species, body length 3-4 mm; egg parasitoids of grasshopper . . . 634

634(633') Submarginal veins in hindwing incomplete, short, usually stump-like; wing smoky, forewing with a longitudinal hyaline streak just below middle and veins dark brown; lower part of frons between eye and antennal insertion with some short carinae converging towards mouth; hosts - *Oxya velox* and *O. japonica* 635

634' Submarginal veins complete, reaching fore margin at frenal hooks; hosts — grasshoppers or lepidopteran eggs 636

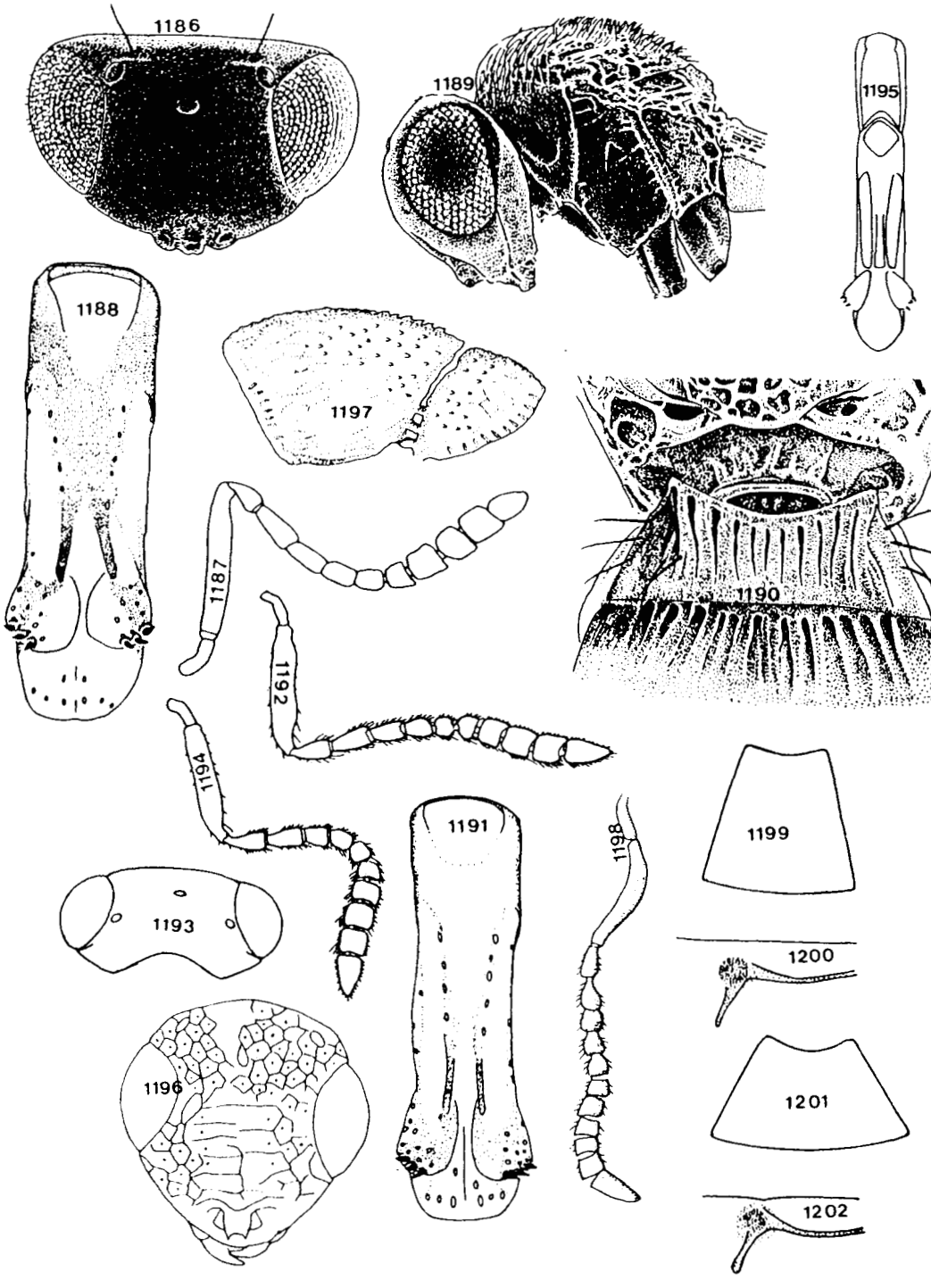
635(634) First tergite of abdomen subquadrate, a little longer than broad at base (Fig. 1199); scutellum not armed; legs reddish yellow; veins dark brown; stigmal vein slender, finely defined and not apically rounded (Fig. 1200); 2*nd* tergite hardly impressed on basal half; in male the 1*st* joint of flagellum thickened, being twice as long as thick; 3*rd* the longest but not conspicuously enlarged; basal half of scape reddish yellow in male with the rest fuscous ..... *Scelio muraii* Watanabe

635' First tergite of abdomen transverse, being distinctly shorter than broad at base (Fig. 1201); scutellum armed; legs yellow; veins darker, almost black; stigmal vein stout, sharply defined and apically rounded (Fig. 1202); 2*nd* tergite clearly impressed on basal half; in male first flagellum slender, not distinctly thickened; 3*rd* joint conspicuously enlarged; female scape reddish yellow and only fuscous at extreme apex ..... *Scelio tsuruokensis* Watanabe

635" First tergite of abdomen transverse similar to *S. tsuruokensis* but short and truncate anteriorly (Fig. 1203); 2*nd* broader and a little longer than 1*st*, 3*rd* twice as long as 2*nd*; each segment longitudinally striate from base to end with 11 striae on first and 15 finer ones of second; legs red except black coxae and brown midposterior femur of female; wing slightly infuscated, covered with brownish cilia except hairless base; hindwing large and quite hyaline; scutellum unarmed; metanotum with a row of large grooves separated by transverse carinae; propodeum hollowed posteriorly and with a large tooth on each side; antenna of female scape 4 times as long as pedicel and pedicel nearly as long as first flagellum; male's 3rd flagellum globular (Fig. 1204); host — *Locusta migratoria migratorioides* in Africa ..... *Scelio zolotarevskyi* Ferriere

636(634') Antennal scape very long, dilated dorso-ventrally and triangular in the females (Fig. 1205); body black, flat and highly depressed dorso-ventrally; antennae pale orange concolorus to legs except blackened clubs; abdomen with punctures and striations, tip end not strongly pointed (Fig. 1206); larval parasite of lepidopteran leaffeeders; body length 3 mm ..... *Platyscelio abnormis* Crawford

636' Antennal scape slender but not dilated as above (Fig. 1207); genae strongly developed behind mid-inner portion of eye, making eyes rather oblique in lateral view; body uniformly black except brownish legs; hindcoxae and antennae excluding darkened club brownish black; entire body clothed with short white hairs; abdomen very long and



Figs. 1186-1202

slender, 5.5 times longer than thorax and strongly pointed at tip (Fig. 1208); egg parasitoids of *Conocephalus longipennis;* body length 4 mm ..... *Macroteleia crawfordi* Keiffer

637(519') Tarsi 3-segmented [Trichogrammatidae] (Fig. 1209) 638

637' Tarsi 4- or 5-segmented (Fig. 1210) 662

638(637) Antennal club of female 1-segmented; funicle 2-segmented; marginal vein curved distally away from anterior border of front wings to extend up to stigmal vein; setae of disc usually in vein tracks 639

638' Antennal club of female with more than one segment 654

639(638) Antennal club of male 3-segmented bearing 2 funicular segments; vein track of radial sector (RS1) absent; forewing with long marginal fringe; stigmal vein elongate *(Trichogrammatoidea)* 640

639' Antennal club of male 1-segmented with unsegmented flagellum but with 2 slight constrictions below in the region of funicular segments; forewing with short marginal fringe; vein track RS1 present *(Trichogramma)* 644

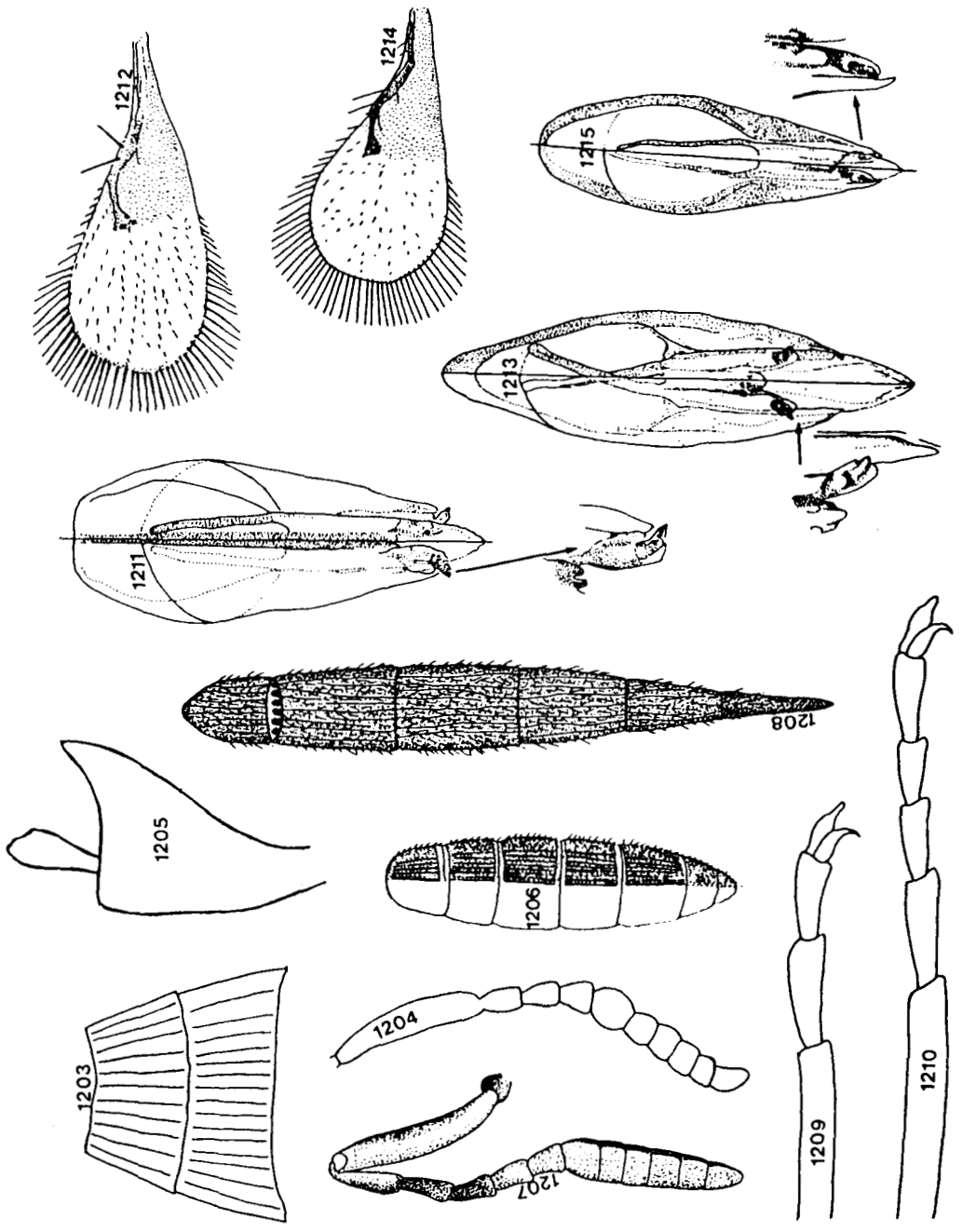
640(639) Chelate structure of male genitalia large and protruding extended beyond apical ends of gonoforceps; median ventral projection (MVP) indistinct; lateral tubercles prominent in between of ventral ridges highly chitinized (Fig. 1211); forewing with rounded outer margin, long fringe setae about width of remigium (Fig. 1212); ovipositor of female slightly longer than hind tibiae (egg parasite of *Chilo* sp. and *Diopsis thuracica)* (Ghana) ..... *Trichogrammatoidea simmondsi* Nagaraja

640' Chelate structure small or large, far below or at most near gonoforceps 641

641(640') Chelate structures distinctly far below gonoforceps, median ventral projection distinct although short, lateral tubercles not distinct; aedeagus apodeme nearly 0.8 times length of tibia III (Fig. 1213); ovipositor as long as tibia 111, width of plate about half the length; basal infuscation in line with stigma, remigium with sparse and long setae, fringe setae long, more than one-third width of remigium (Fig. 1214); flagella of male antenna with 22-26 long hairs; orange color except bright red eyes; light brown thorax and abdomen; S. and S.E. Asia ..... *Trichogrammatoidea nana* (Zehntner)

641' Chelate structures rather near gonoforceps; other characters not as above 642

642(641') Median ventral projection, lateral tubercles, and central ridges indistinct; aedeagus with apodemes subequal in length, together 0.6 length of tibia III (Fig. 1215); ovipositor slightly longer than tibia III, width of plate less than half the length; antennal flagella nearly 1.5 times scape, with moderately long 25-32 hairs, the longest more than 2 times width of flagellum; basal infuscation light, in line with stigma (Fig. 1216); ochreous with bright red eyes, yellowish brown thorax and dark reddish brown abdomen; egg parasite of *Heliothis armigera* ..... *Trichogrammatoidea armigera* Nagaraja



Figs. 1203-1215

642' Median ventral projection present; lateral tubercles distinct or indistinct 643

643(642') Median ventral projection distinct with distinct lateral tubercles (Fig. 1217); basal infuscation not reaching stigma; fringe setae short (Fig. 1218); flagellar hairs of antennae about 30, all long . . . . . *Trichogrammatoidea lutea* Girault

643' Median ventral projection not conspicuous with lateral tubercles distinct (Fig. 1219); basal infuscation in line with stigma; fringe setae long (Fig. 1220); antennal flagella with 22-26 long hairs . . . . . *Trichogrammatoidea bactrae* Nagaraja

644(639') Median ventral projection absent or inconspicuous 645

644' Median ventral projection present 647

645(644) Dorsal expansion of gonobase (DEG) with a broadly rounded posterior extremity, extruding slightly beyond level of gonoforceps and base constricted; median ventral process not conspicuous; aedeagus slightly longer than apodeme; chelate structure near tips of gonoforceps (Fig. 1221); ovipositor longer than tibia III; antennal flagella with about 35 nearly blunt hairs of moderate length, the longest 2.5 times width of flagella; light yellow except blackish cheeks, sides of thorax, scutellum, legs and abdomen; (egg parasites of hesperiids) . . . . . *Trichogramma hesperidis* Nagaraja

645' Dorsal expansion of gonobase horseshoe-shaped basally; fringe of forewings one-fifth width of wings; aedeagus distinctly longer than apodeme, both together as long as or longer than tibia III 646

646(645') Ovipositor markedly extruded beyond tip of abdomen; female with white thoracic ventral region; antennal hairs of male long, the longest 4 times maximum width of flagella; male genitalia elongate, chelate structure far below tip of gonoforceps, aedeagus about 3 times longer than apodeme (Fig. 1222) . . . . . *Trichogramma pallidiventris* Nagaraja

646' Ovipositor slightly exserted, longer than tibia III which is as long as aedeagus with short arm (Fig. 1223); male genitalia elongate ovate, chelate structure in line with MVP (Fig. 1224); thoracic venter of female never white; antennal hairs of male long, the longest 3.5 times maximum width of flagella . . . . . *Trichogramma japonicum* Ashmead

647(644') Antennal hairs very long, longest hair 3.5-4 times maximum width of flagellum . . . 648

647' Antennal hairs moderately long, longest hair 2 to 2.5 times maximum width of flagellum 649

647" Antennal hairs very short, the longest as long as maximum width of antenna; flagella unsegmented (Fig. 1225); longest marginal setae of forewing one-quarter wing width (Fig. 1226); dorsal expansion of gonobase triangular tapering at tip and extended to chelate structure (Fig. 1227); aedeagus longer than apodeme (Fig. 1228); ovipositor longer than hind tibia (egg parasite of *Chilo diffusilineus)* . . . . . *Trichogramma mwanzai* Schulten & Feijen

648(647) Dorsal expansion of gonobase basally narrow, highly chitinized, triangular and constricted basally (Fig. 1229); longest antennal hair 3.5 times maximum width of flagellum; aedeagus (Fig. 1230) slightly longer than apodeme, both together slightly shorter than tibia III, ovipositor longer than tibia III (Fig. 1231); fringe on tornus nearly one-eighth of wing width; brownish yellow with black thorax and abdomen (Americas) . . . . . *Trichogramma semifunatum* (Perkins)

648' Dorsal expansion of gonobase broadly triangular at base with conspicuously rounded sides, median ventral process (MVP) below chelate structure (Fig. 1232); longest hair of antenna 4 times maximum width of flagellum; forewings much longer than body; aedeagus and apodeme equally long (Fig. 1233); together shorter than tibia which is as long as ovipositor (Fig. 1234); dull yellow body with brownish head, pronotum and abdomen . . . . . *Trichogramma evanescens* Westwood

649(647') Longest antennal hair 2.5 times maximum width of flagellum 650

649' Longest antennal hairs not more than 2 times maximum width of flagellum 651

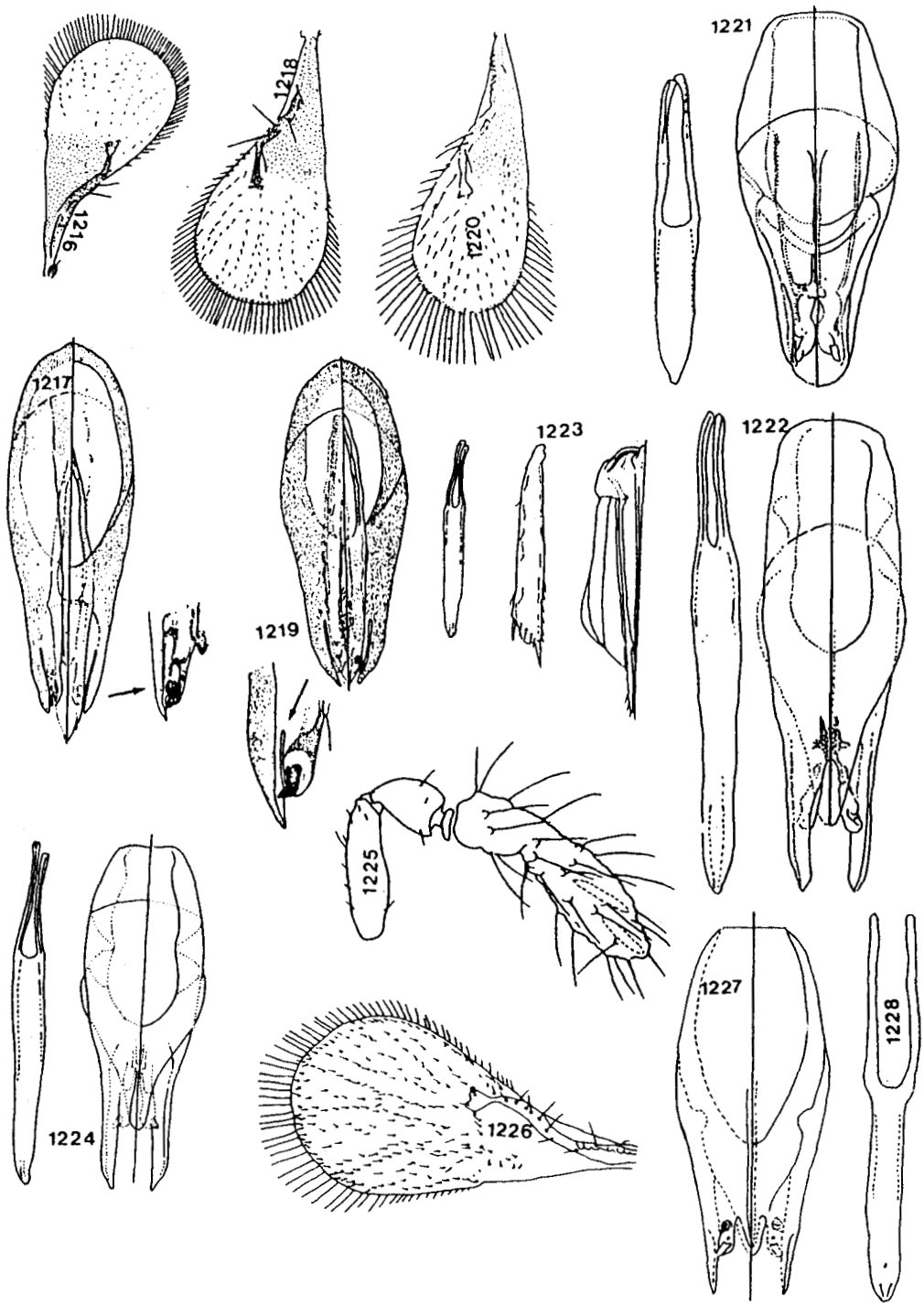
650(649) Antennal flagella of male with 50 or more hairs; dorsal expansion of gonobase with broad lateral lobes basally; median ventral projection very large, slightly below chelate structure (Fig. 1235); apodeme longer than aedeagus (Fig. 1236) (E. Asia) . . . . . *Trichogramma dendrolimi* Matsumura

650' Antennal flagella of male with less than 35-40 hairs; dorsal expansion of gonobase with narrow lateral lobes basally; small median ventral projection sharp, ovate to long ovate (Fig. 1237); apodeme as long as aedeagus (Fig. 1238), together shorter than tibia III; ovipositor longer than tibia III (Fig. 1239) . . . . . *Trichogramma chilonis* Ishii

651(649') Aedeagus as long as apodeme, both together equal to 1.2 length of gonobase (Fig. 1240); median ventral projection sharp and triangular (Fig. 1241), ovipositor slightly longer than tibia III; fringe on tornus of forewing about one-sixth of wing width (Fig. 1242); yellow with dark brown abdomen; terminal segment of male antenna narrowed apically (Fig. 1243); egg parasite of *Mythimna separata)* (China) . . . . . *Trichogramma leucaniae* Pang & Chen

651' Aedeagus longer than apodeme, other characters not as above 652

652(651') Aedeagus much longer than apodeme (Fig. 1244); dorsal expansion of gonobase highly sclerotized, with large lateral lobes, sharp, and triangular central lobe; median ventral projection almost in line with chelate structure (Fig. 1245); wing infuscation darker than *T. leucaniae* (Fig. 1246); male antennal hairs long, apical half of terminal segment large (Fig. 1247); egg parasite of *Mythimna separata* in China . . . . . *Trichogramma ivelae* Pang & Chen



Figs. 1216-1228

652' Aedeagus just longer than apodeme; dorsal expansion of gonobase moderate to highly chitinized (America) 653

653(652') Chelate structures nearer to gonoforceps; median ventral projection below level of chelate structures (Fig. 1248); aedeagus longer than apodeme (Fig. 1249), both shorter than tibia III which is a little shorter than ovipositor (Fig. 1250); adult yellow except anterior terga of abdomen dark pigmented in female and entire abdomen in male . . . . . *Trichogramma perkinsi* Girault

653' Chelate structures far below level of gonoforceps; median ventral projection nearly in line with chelate structures (Fig. 1251); apodeme as long as aedeagus (Fig. 1252), combined length shorter than tibia III which in turn is shorter than ovipositor (Fig. 1253); adult yellowish brown with fuscous head, thorax, and abdomen . . . . . *Trichogramma frasciatum* (Perkins)

654(638') Marginal fringe of forewing at least half maximum wing width; discal ciliation usually in rows but sparse; female antenna 2-segmented (ring and funicle) *(Oligosita)* 655

654' Forewing with a narrow smoky or brownish tinge across wing beneath stigmal vein (Fig. 1254); scape as long as combined lengths of pedicel and funicle (Fig. 1255); gaster pale yellow except tergites latero-dorsally dark brown . . . . . *Paracentrobia yasumatsui* Subba Rao

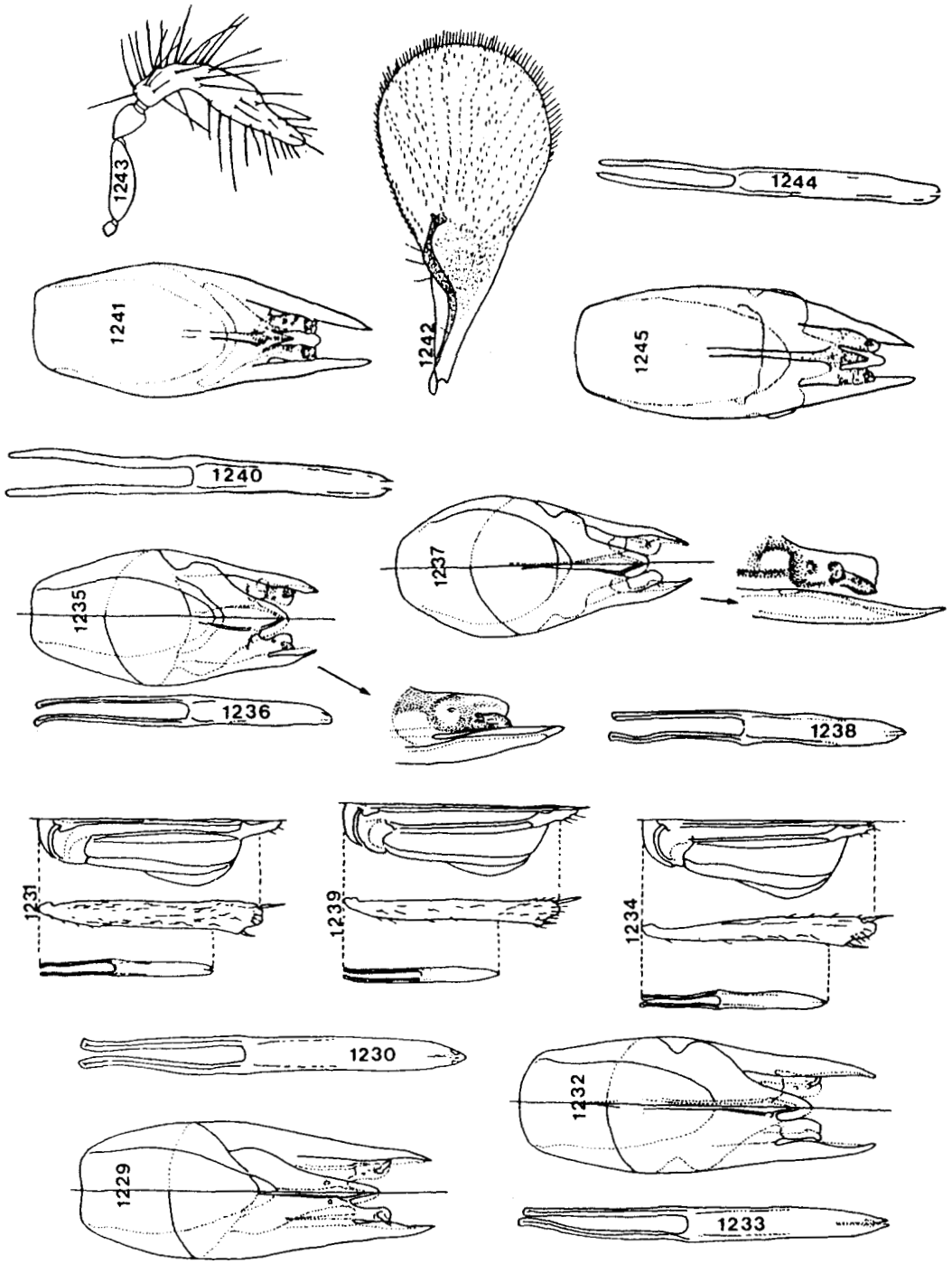
654" Forewing with a rounded brown tinge below stigmal vein (Fig. 1256); scape a little longer than combined length of pedicel and funicle (Fig. 1257); tergites I-IV of abdomen uniformly brown . . . . . *Paracentrobia andoi* Ishii

655(654) Marginal fringe of forewings one-third or one-half the maximum width of wings 656

655' Marginal fringe of forewings slightly shorter or longer than maximum width of wings 657

656(655) Discal cilia short, fine, and very sparse, at least 10 rows visible; short hairs absent along margins; infuscation distinct, a little beyond stigmal vein at middle, 15 small setae arranged in 3 rows at middle of infuscation below marginal vein; marginal vein with 3 long setae, stigmal vein knob-like with subtruncate apex and 4 distal sensilla and a long seta above midlength of stigma; forewing broad and rounded; fringe about one-third maximum wing width; pedicel about half of scape (Fig. 1258); femur III with 13 transverse striations and 3 ventral setae (Fig. 1259); orange-bodied species with light yellow-brown legs, antennae and mesoscutum . . . . . *Oligosita consanguinea* Girault

656' Discal cilia long and coarse; marginal fringe of forewings about half maximum width of wings, always greater than one-third (Fig. 1260); pedicel 3 times as long as funicle segment, the latter prominently wider than long; scape broadened basally, funicle and



Figs. 1229-1245

basal 2 clubs bisected medially by a transverse row of long setae (Fig. 1261); host unknown but collected from ricefield ..... *Oligosita brevicilia* Girault

657(655') Pedicel as long as the short and clavate scape (Fig. 1262); funicular segment longer than broad; forewings with distinct and large substigmal cloud; yellow except fuscous tips of coxae and midfemora, and dark brown basal half of abdomen ..... *Oligosita manii* Viggiani

657' Pedicel usually much shorter than scape 658

658(6571) Pedicel almost as long as the narrow funicle; club as long as the combined length of pedicel, ring, and funicle segments; cilia on discal area very sparse, a single complete row lining the apical end of wing and 10 more cilia irregularly scattered at the distal end (Fig. 1263) ..... *Oligosita shibuyae* Ishii

658' Pedicel at least twice as long as funicle 659

659(658') Marginal fringe of forewing as long as or longer than the maximum width of wings; discal cilia moderately sparse 660

659' Marginal fringe of forewing more than 0.7 maximum width of wing but not as long as wing 661

660(659) Marginal fringe of forewing distinctly longer than maximum wing width (Fig. 1264); pedicel more than twice the length of funicle, the latter slightly wider than pedicel (Fig. 1265); sheath of ovipositor not exserted ..... *Oligosita naias* Girault

660' Marginal fringe and maximum width of forewing equally long (Fig. 1266); funicle half the length of pedicel (Fig. 1267); sheath of ovipositor clearly exserted ..... *Oligosita yasumatsui* Viggiani & Subba Rao

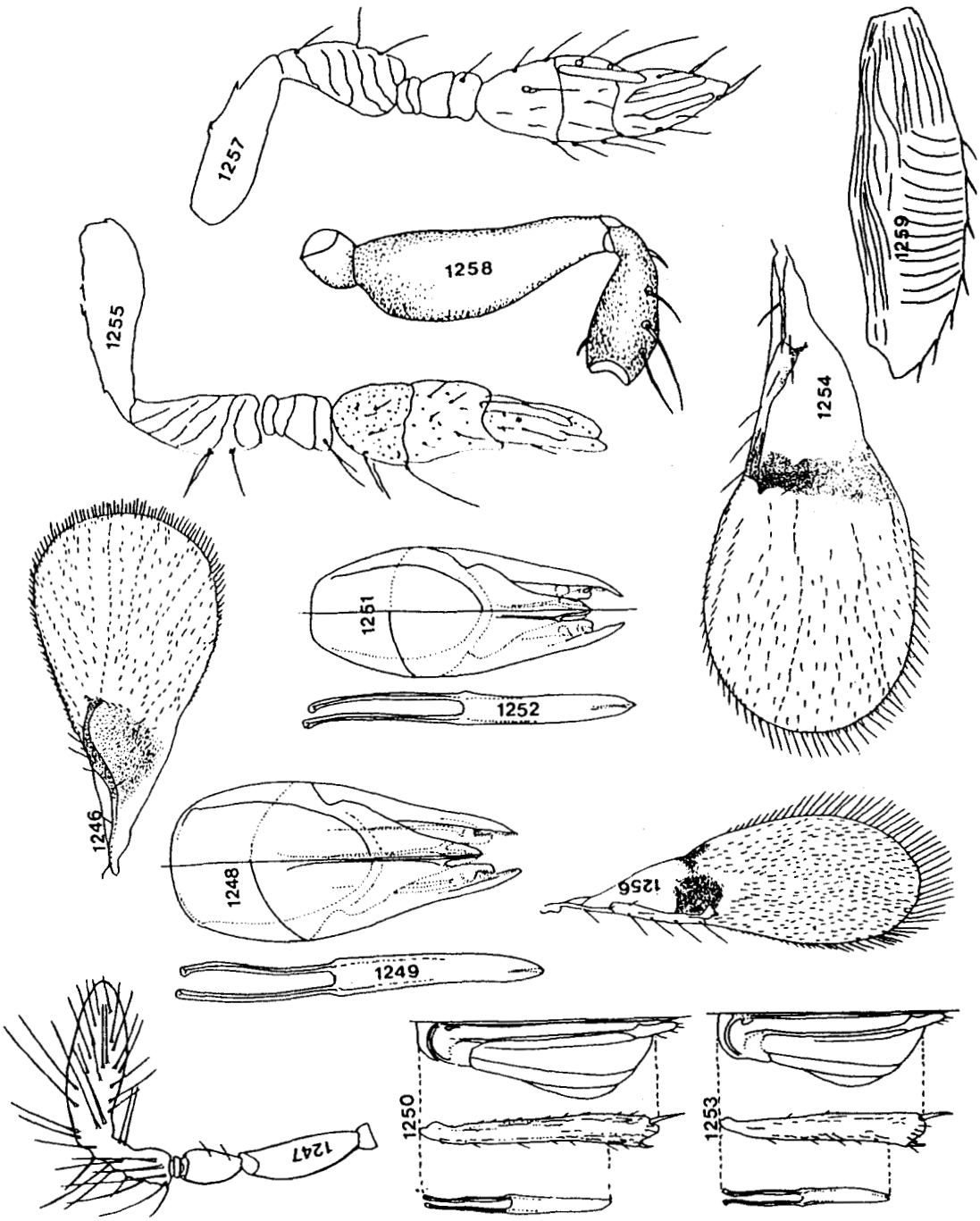
661(659') Marginal fringe of forewing only slightly shorter than maximum wing width; discal ciliation rather thick opposite subtriangular stigmal vein, moderately scattered towards distal end (Fig. 1268); pedicel more than 2 times longer than funicle (Fig. 1269) ..... *Oligosita aesopi* Girault

661' Marginal fringe almost as in *O. aesopi;* funicle subglobular and less than half of pedicel (Fig. 1270); discal ciliation more evenly scattered towards distal end, without dense ciliation opposite the knob-like stigmal vein (Fig. 1271) ..... *Oligosita nephotettica* Mani

662(637') Basal part of hindwing reduced to thread-like stalk composed of the sub-marginal vein; wing disc ribbon-like; forewing with a long marginal fringe; antennal sockets wide apart [Mymaridae] 663

662' Hindwing never stalk-like basally 682

663(662) Gaster with more or less distinct petiole, convexly rounded or subglobular basally; mesopostphragma not projecting into the gaster; tarsi 4- or 5-segmented 664



Figs. 1246-1259

663' Gaster broadly connected to the propodeum (hindpart of thorax); mesopostphragma plainly projecting into gaster; a pair of distinctly separated plates (= postscutellum) behind scutellum; antennae 9-segmented in the females (6 funicular segments, solid club) and 13-segmented in the males; tarsi Csegmented *(Anagrus)* 674

664(663) Tarsi 5-segmented 665

664' Tarsi 4-segmented 672

665(664) Petiole long and slender (Fig. 1272); propodeum prominently carinated; antenna II-segmented with 8 funicular segments and undivided club (Fig. 1273) . . .*Ooctonus* sp.

665' Petiole short, wider than long; antennae of male 13-segmented (Fig. 1274) and female 11-segmented, with 8 funicular segments (Fig. 1275); marginal vein not elongated, venation not reaching basal one-third of wing; gaster subsessile *(Gonatocerus* spp.). 666

666(665') Anal plate with 4 long hairs (Fig. 1276) 667

666' Anal plate with more than 4 long hairs (Fig. 1277) 669

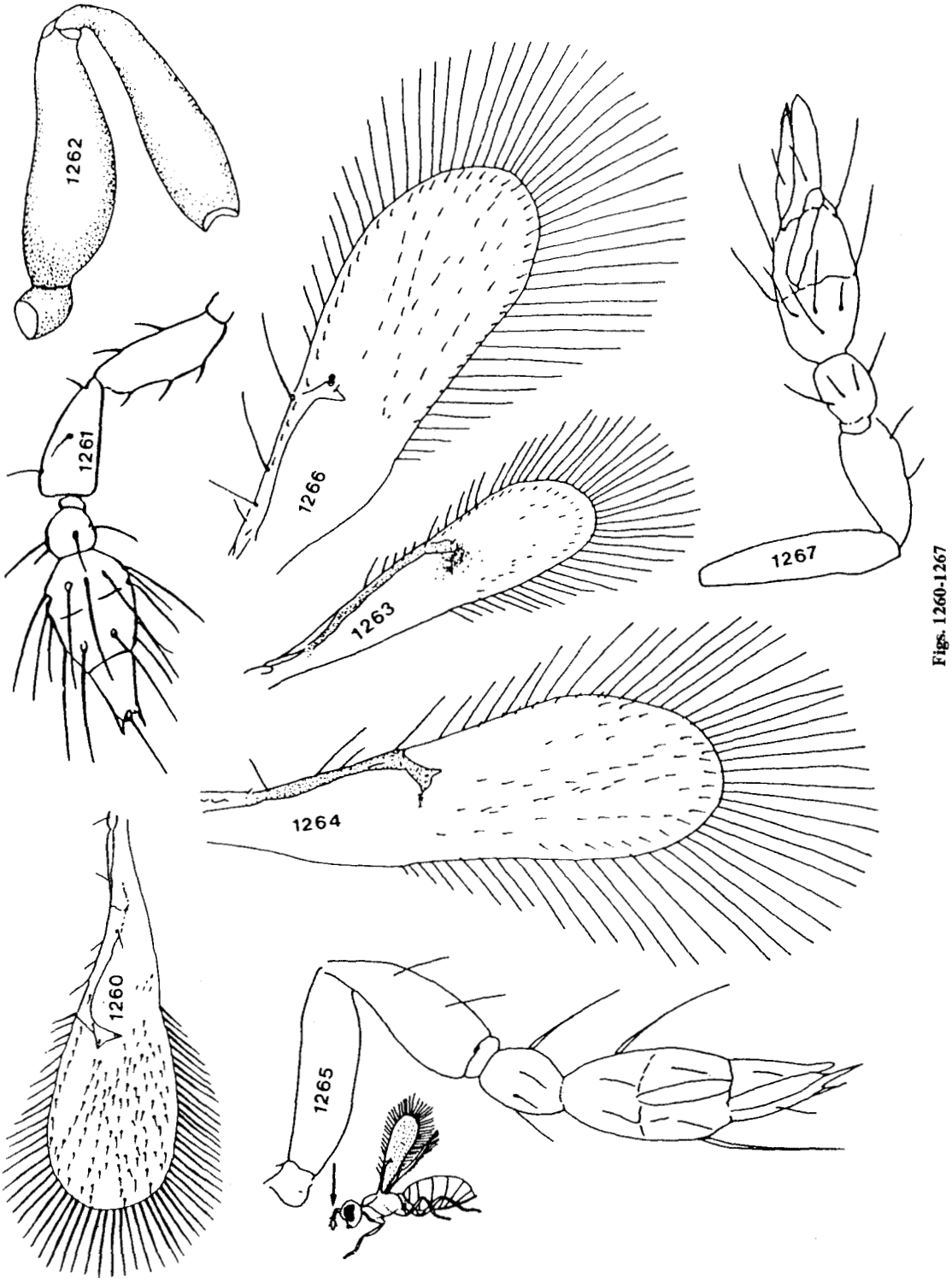
667(666) Apical 4 funicular segments distinctly longer than the basal four 668

667' Apical 4 funicular segments as long as or slightly shorter than the basal 4, *4th* to *6th* segments cylindrical equally long and without sensory ridge; segments VII and VIII with a pair of sensory ridges each (Fig. 1278); median of mesoscutum with a subglobular brown band in apical half (Fig. 1279); forewing (Fig. 1280) 4.5 times as long as wide; anal plate large, tapers apically and pygostyle indented subbasally inside (Fig. 1231) . . . . . *Gonatocerus uttardecanus* Mani & Saraswat

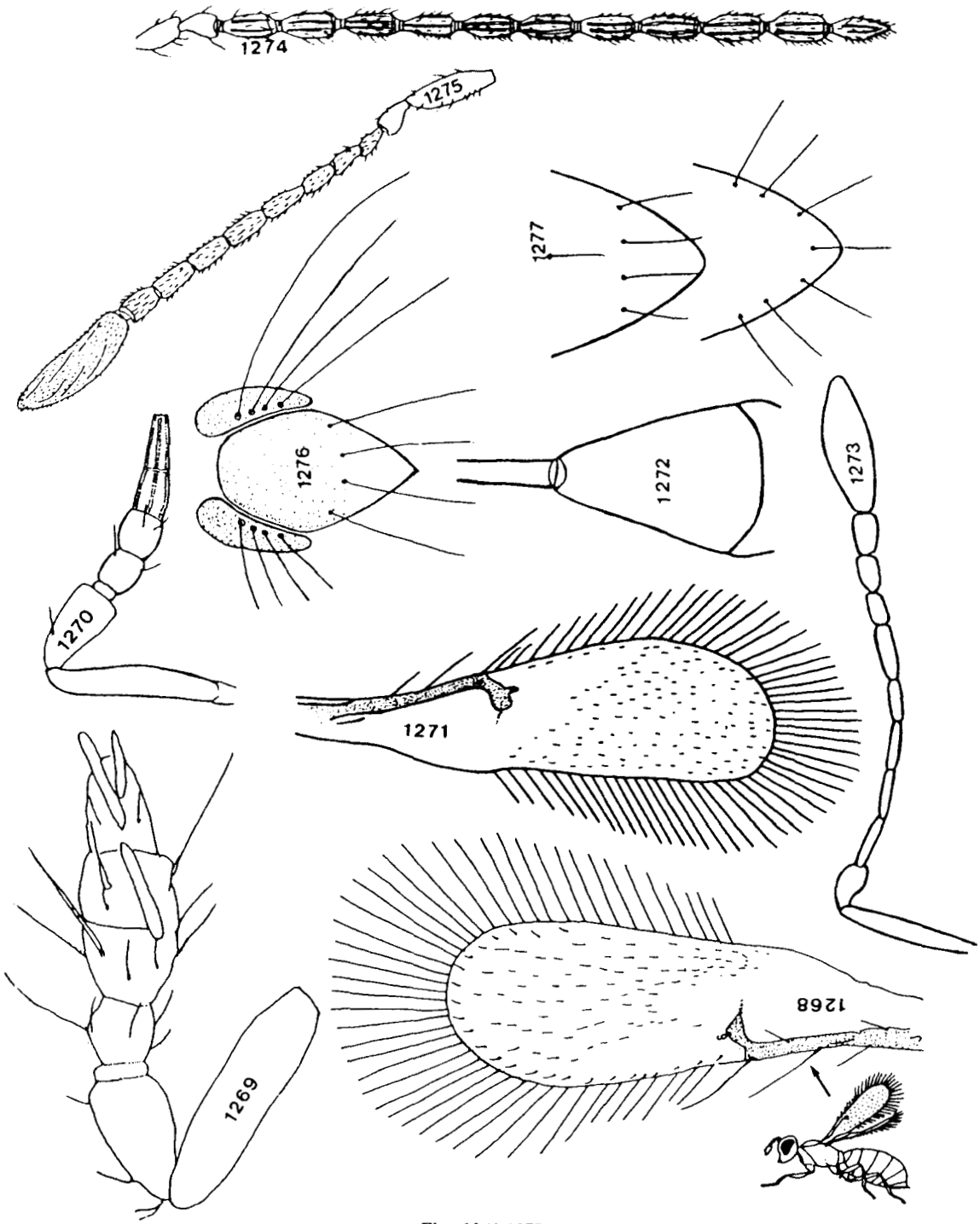
668(667) Funicular segments V-VIII longer than basal 4 segments, cylindrical to subcylindrical, equally long and with a pair each of sensory ridges (Fig. 1282); entire median area of mesoscutum occupied by a brown band except lateral margin near parapsidal furrow (Fig. 1283); forewing 3 times longer than wide (Fig. 1284); anal plate short hairs in 2 rows, apex of plate pointed; pygostyle without indention (Fig. 1285); postphragma very flat . . . . . *Gonatocerus narayani* (Subba Rao & Kaur)

668' Funicular segments V to VIII globular, each with sensory ridges except segment VI, and segment VIII with a cavity (Fig. 1286); mesoscutum moderately produced and rounded apicomedially with a brown band above tip of parapsidal furrow (Fig. 1287); forewing rather concave along anterior margin, about 4 times as long as wide; marginal vein 7.4 times as long as wide; proximal sensillum midway of distal sensilla and distal macrochaeta (Fig. 1288); 4 anal plate hairs in a transverse row in apical one-third (Fig. 1289) and cleft at apex . . . . . *Gonatocerus devitatacus* Mani & Saraswat

669(666') Anal plate triangular with 7 long hairs mostly along margins (Fig. 1290); apicomedian band of mesoscutum reaching only pair of setae (Fig. 1291); forewing slightly constricted near stigmal vein, nearly 4 times as long as wide, marginal vein 14 times as long as wide; stigmal vein bears 3 distal sensilla (Fig. 1292); pedicel as long as funicular



Figs. 1260-1267



Figs. 1268-1277

segment III, F6 = F7, and club nearly as long as radicula and scape (Fig. 1293); abdomen light yellow except blackish brown tergites V and VI ..... *Gonatocerus munarus* Mani & Saraswat

669' Anal plate suboval or ovoid; funicular segments of various lengths 670

670(669') Anal plate ovoid with 5 hairs in 3 transverse rows (Fig. 1294); basal funicular segment of antennae shortest in both sexes; 0.7 as long as 2*nd,* 2*nd* and 3*rd* subequal, 4*th* to 8*th* equally long, a pair of sensory ridges only in segments V to VIII in the female (Fig. 1295) and all segments in male except scape and pedicel (Fig. 1296); lateral sides of mesoscutum behind parasidal furrow entirely yellowish brown to brown (Fig. 1297); forewing 4 times as long as wide; proximal sensillium just below distal macrochaeta (Fig. 1298); ovipositor highly exserted ..... *Gonatocerus cicadellae* Nikolskaya

670' Anal plate subovoid; basal **3** funicular segments equally long 671

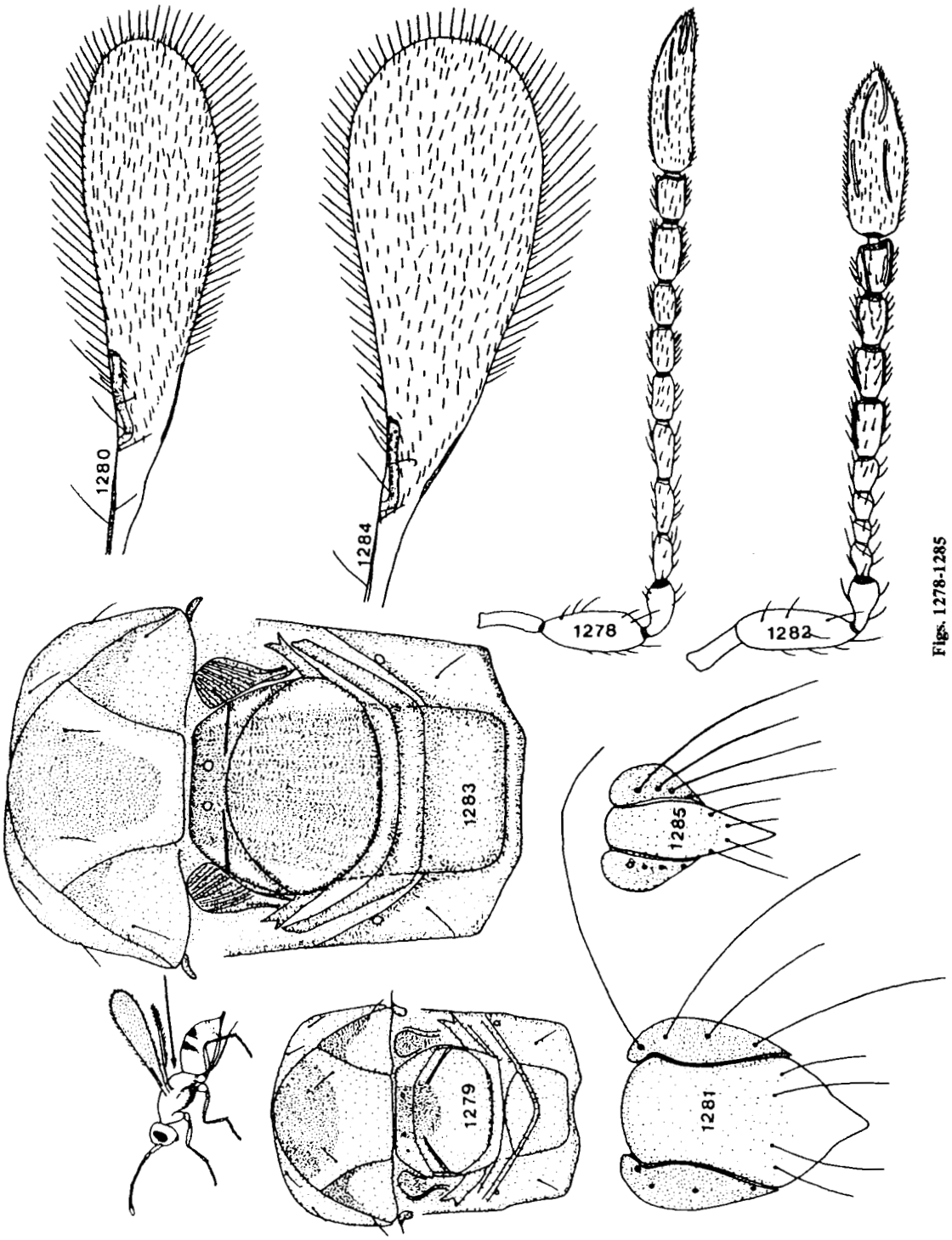
671(670') Anal plate bluntly conical with 5 long hairs in 2 transverse rows medially (Fig. 1299); female antenna with 4*th* and 6*th* funicular segments globular and equal in length, 6*th* the shortest, paired sensory ridges in segments V, VII, and VIII (Fig. 1300); shortest funicular segment I (F1) as long as scape, club = F3 = F4 = F8 = F10 in male (Fig. 1301); discal hairs a little beyond base of marginal vein in origin (Fig. 1302); abdomen with alternating yellow and brown transverse bands (Fig. 1303) ..... *Gonatocerus cincticipitis* Sahad

671' Anal plate narrowly conical with a subacute apex (Fig. 1304); female funicular segments IV, V, and VI globular and equally long, paired sensory ridges only in VII and VIII segments (Fig. 1305); funicular segment X (F10) as long as club, and longer than F6 to F8 in the male (Fig. 1306); discal hairs emanate from base of marginal vein and form a prominent oblique line to posterior margin; abdomen with four brown interrupted transverse bands (Fig. 1307) ..... *Gonatocerus miurai* Sahad

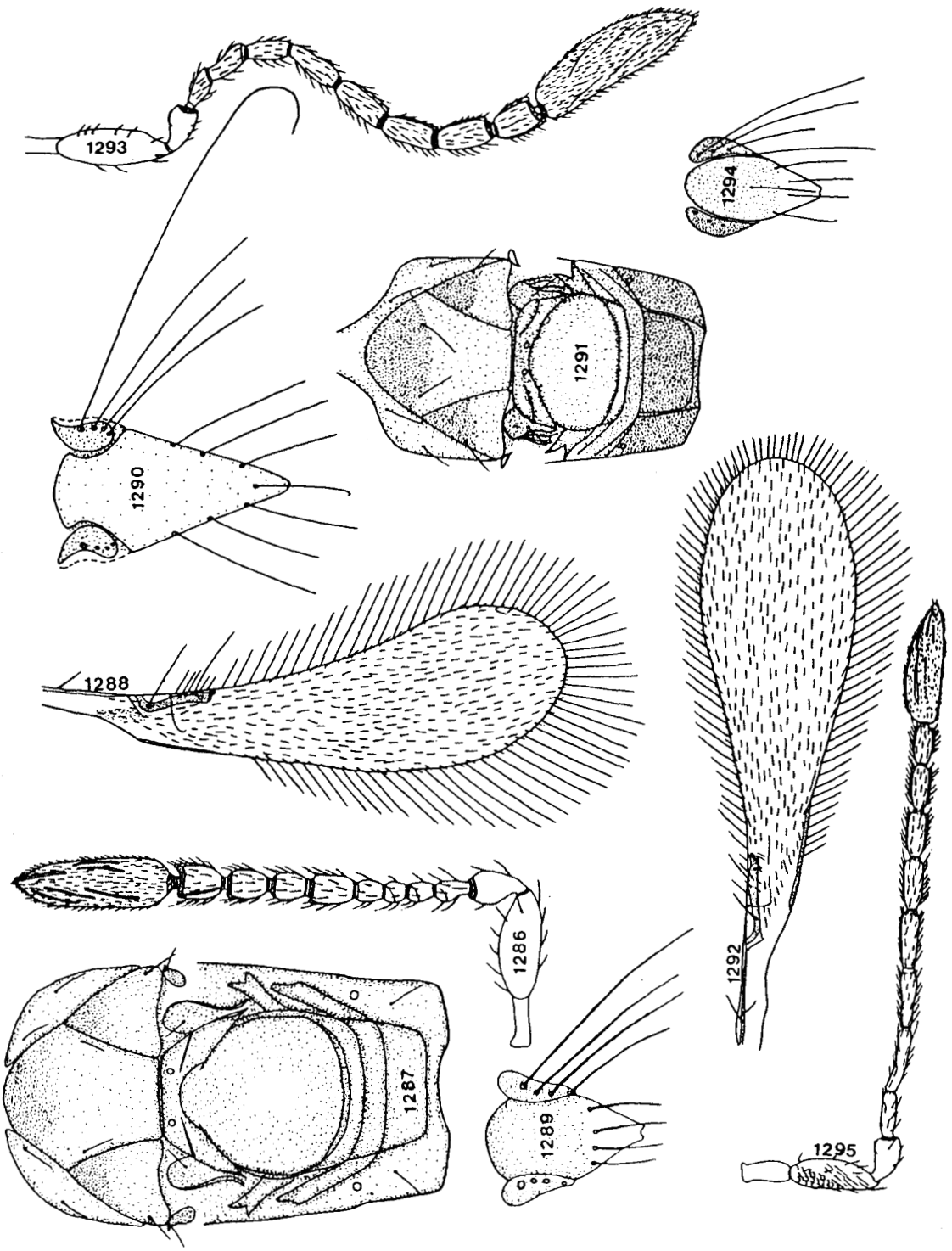
672(664') Hindwing with few marginal cilia, abbreviated, filiform and highly reduced; forewing (Fig. 1308) strongly petiolated and oar-shaped, distal half of broad part dark brown with one clear row of setae traversing middle from shaded to light area and 2-3 short rows of setae dorsad it in shaded portion; marginal fringe 4 times maximum width of wing; scape medially thin, enlarged on both ends, 1*st* funicle as long as pedicel, II the longest, segments III to VI short and together with undivided club slightly longer than the very long 2*nd* segment (Fig. 1309); basal tarsal segment 2 times length of 2*nd* ..... *Mymar taprobanicum* Ward

672' Not with the combination of above characters; forewing hyaline with normal discal cilia 673

673(672') Scape without scale-like structures; marginal vein thickened (Fig. 1310); prothoracic spiracles in normal position ..... *Polynema* sp.



Figs. 1278-1285



Figs. 1286-1295

673' Scape with prominent scale-like structures, pedicel broad, funicles I to III long and in decreasing length, and in increasing diameter towards club (Fig. 1311); marginal vein thin (Fig. 1312); prothoracic spiracles positioned towards middle of the body, on the line between pronotum and mesoscutum ..... *Stephanodes imbricatus* (Narayanan & Subba Rao)

674(663') Funicular segment I long, usually 2 times as long as wide; scape smooth without transverse ridges 675

674' Funicular segment I very short, subglobular; scape transversely carinated 677

675(674) Funicular segment I slender and longer than pedicel (Fig. 1313); antennae long and narrow; ovipositor hardly exserted (Fig. 1314), ratio of ovipositor and exserted part 20:1; disc of forewing narrow, nearly parallel sided, with 1 row in basal two-thirds and 2 rows in the apical one-third (Fig. 1315) ..... *Anagrus optabilis* (Perkins)

675' Funicular segment I shorter or as long as pedicel 676

676(675') First funicular (Fig. 1316) segment as long as pedicel; ovipositor highly exserted; apical 2 segments of tarsi III as long as the exserted part of ovipositor; disc (Fig. 1317) of forewing slightly dilated in the apical one-third, ciliation in an irregular row towards basal half and in 2-3 irregular rows in apical one-third . . . *Anagrus perforator* Perkins

676' First funicular segment distinctly shorter than pedicel (Fig. 1318); ovipositor just moderately exserted, length of exserted part as long as apical segment of tarsus III; ratio of ovipositor and exserted part 5.4:1; proximal two-thirds of forewing parallel after marginal vein, distal one-third gradually expanded and curved with long marginal cilia, a long midlongitudinal line of discal hairs from distal end of marginal vein to wing apex present, accompanied by another irregular short line of 6-8 hairs dorsad of long line (Fig. 1319) ..... *Anagrus panicicolae* Sahad

677(674') Distal end of forewing disc dilated 678

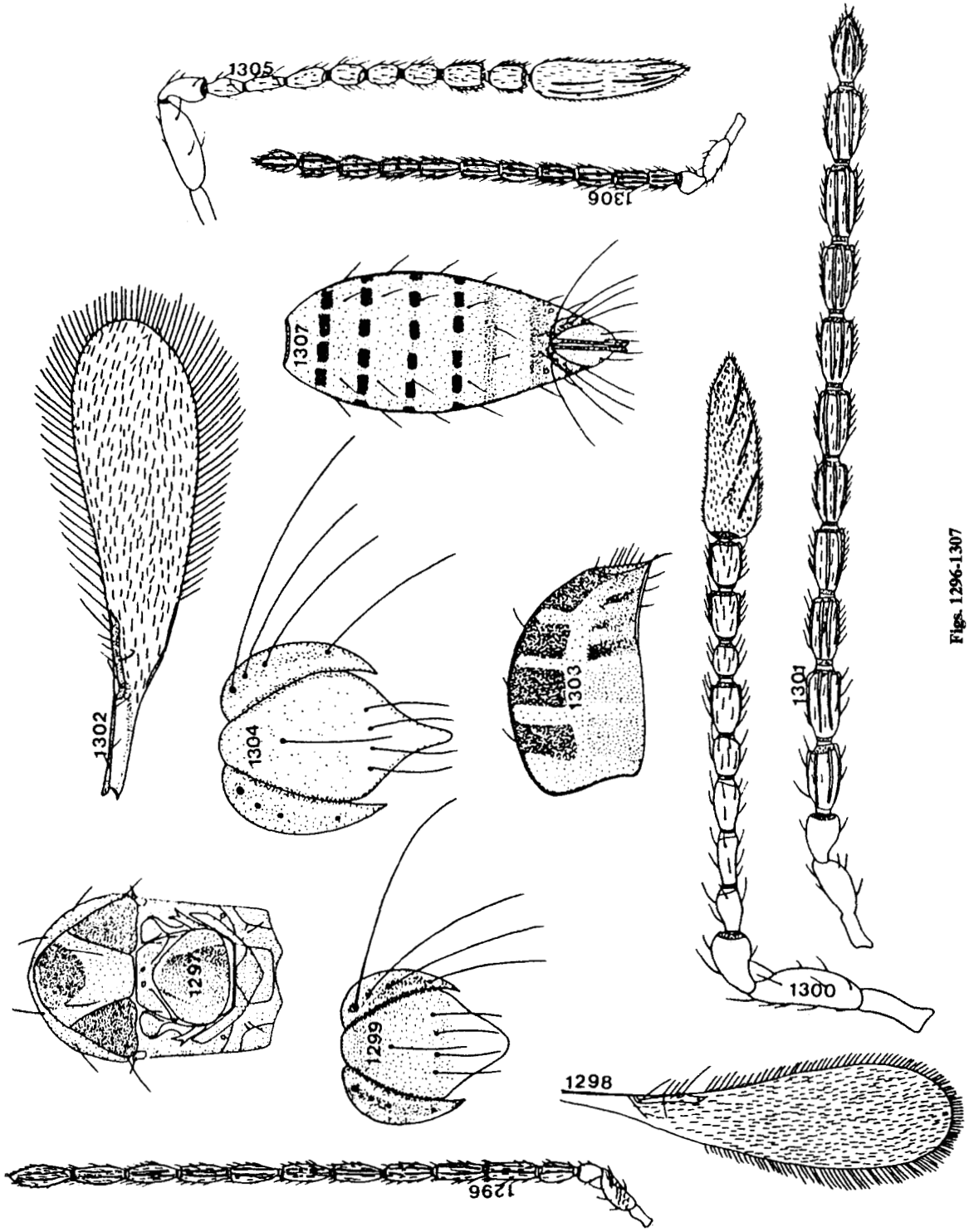
677' Distal end of forewing disc not dilated; 2*nd* funicular (E) segment longest 680

678(677) Marginal vein with 2 long setae; forewings with 3-4 rows of discal hairs with distinct small bare space at the widest part (Fig. 1320); gaster conical; ovipositor moderately exserted; 1*st* funicle very small and subglobular, F2 longer than F3 and the longest (Fig. 1321) ..... *Anagrus flaveolus* Waterhouse

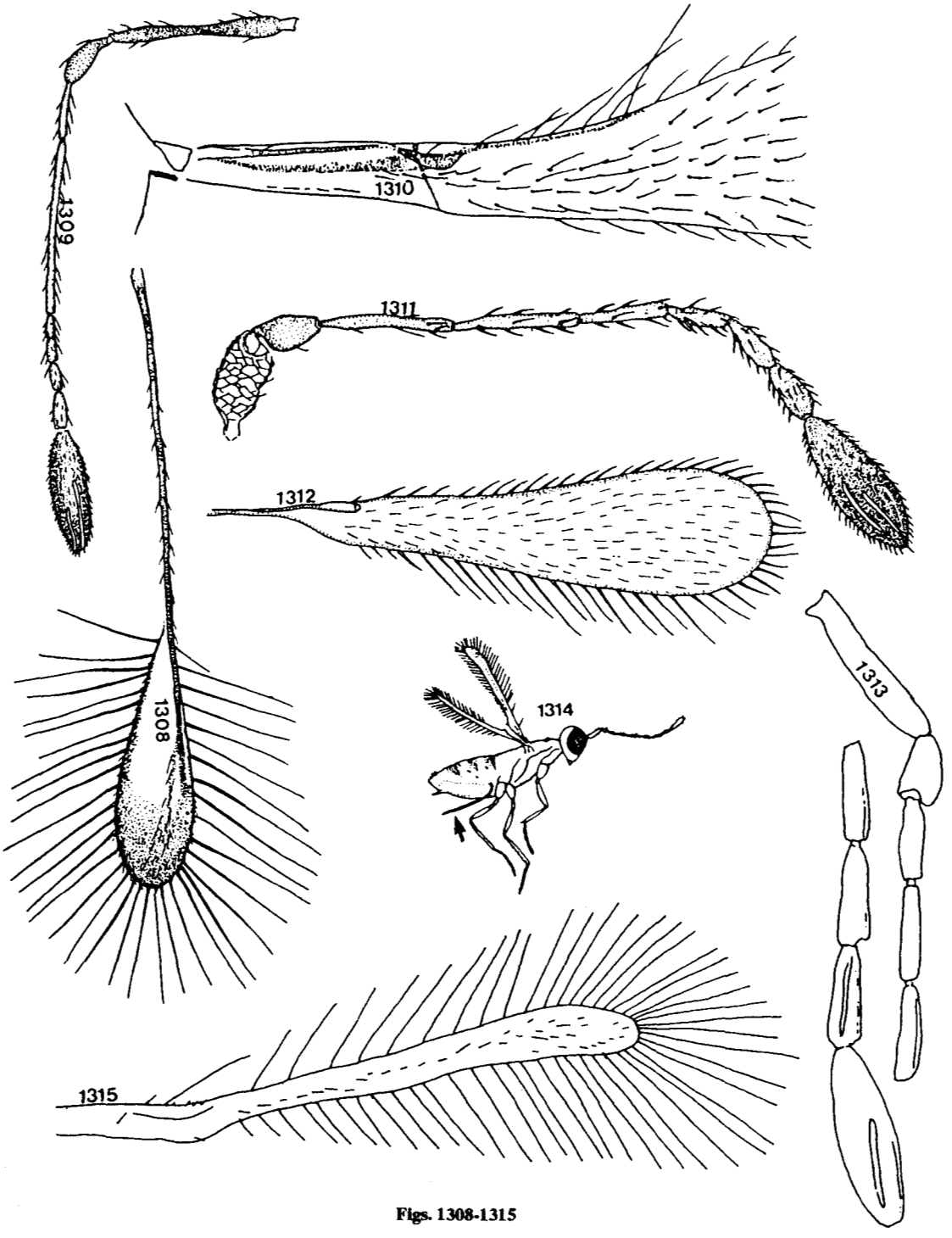
678' Marginal vein with only 1 long seta 679

679(678') Forewing with 8-9 irregular rows of discal hairs and without bare or hyaline space at its widest part (Fig. 1322); 3*rd* funicular segment with only 1 sensory ridge (Fig. 1323); ovipositor moderately exserted, ratio of ovipositor and its exserted part 9.2:1 ..... *Anagrus incantatus* Haliday

679' Forewing with 2 regular rows (rarely 3) of discal hairs and with hyaline space in its widest part, ciliation moderately more towards proximal end (compared with the distal



Figs. 1296-1307



Figs. 1308-1315

end) (Fig. 1324); ovipositor clearly exserted beyond tip of abdomen; club with 1 sensoria (Fig. 1325) ..... *Anagrus* sp. A

680(677') Funicular segment II the longest; segments IV to VI subequal in length and diameter (Fig. 1326); discal ciliation 2 lines, forms a long clear hyaline area distally; marginal fringe almost 3 times the maximum width of wing (Fig. 1327); ovipositor short to slightly exserted ..... *Anagrus frequens* Perkins

680' Funicular segment II as long as segment IV; may or may not be as long as segment VI; ovipositor short or long 681

681(680') Ovipositor long, prominently exserted beyond tip of gaster; ovipositor length a little over twice the length of apical segment of ovipositor sheath; 2*nd* funicular segment as long as 4*th* but shorter and much more slender than the broad 6*th* segment (Fig. 1328); 1 row of discal ciliation visible along clear area (Fig. 1329) ..... *Anagrus* sp. B

681' Ovipositor short, slightly exserted beyond tip of gaster; funicular segments II, IV, and VI subequal; distant end of forewing with a hyaline area; marginal fringe a little longer than the maximum wing width (Fig. 1330) ..... *Anagrus armatus* (Ashmead)

682(662') Tarsi 4-segmented 683

682' Tarsi 5-segmented 700

683(682) Clava enlarged, entire with apex strongly and obliquely truncate; antenna 8-segmented (Fig. 1331); sensillae of forewings at apex of stigmal vein arranged symmetrically, basal one-third of front wings with few hairs, tip of marginal vein weakly hyaline prior to stigmal vein (Fig. 1332); this grey to black polyembryonic parasite oviposits in eggs and emerges during the host larval stage (Encyrtidae) — host *C. medinalis, Marasmia* spp., *Hedylepta indicata* ..... *Copidosomopsis nacoleiae* (Eady)

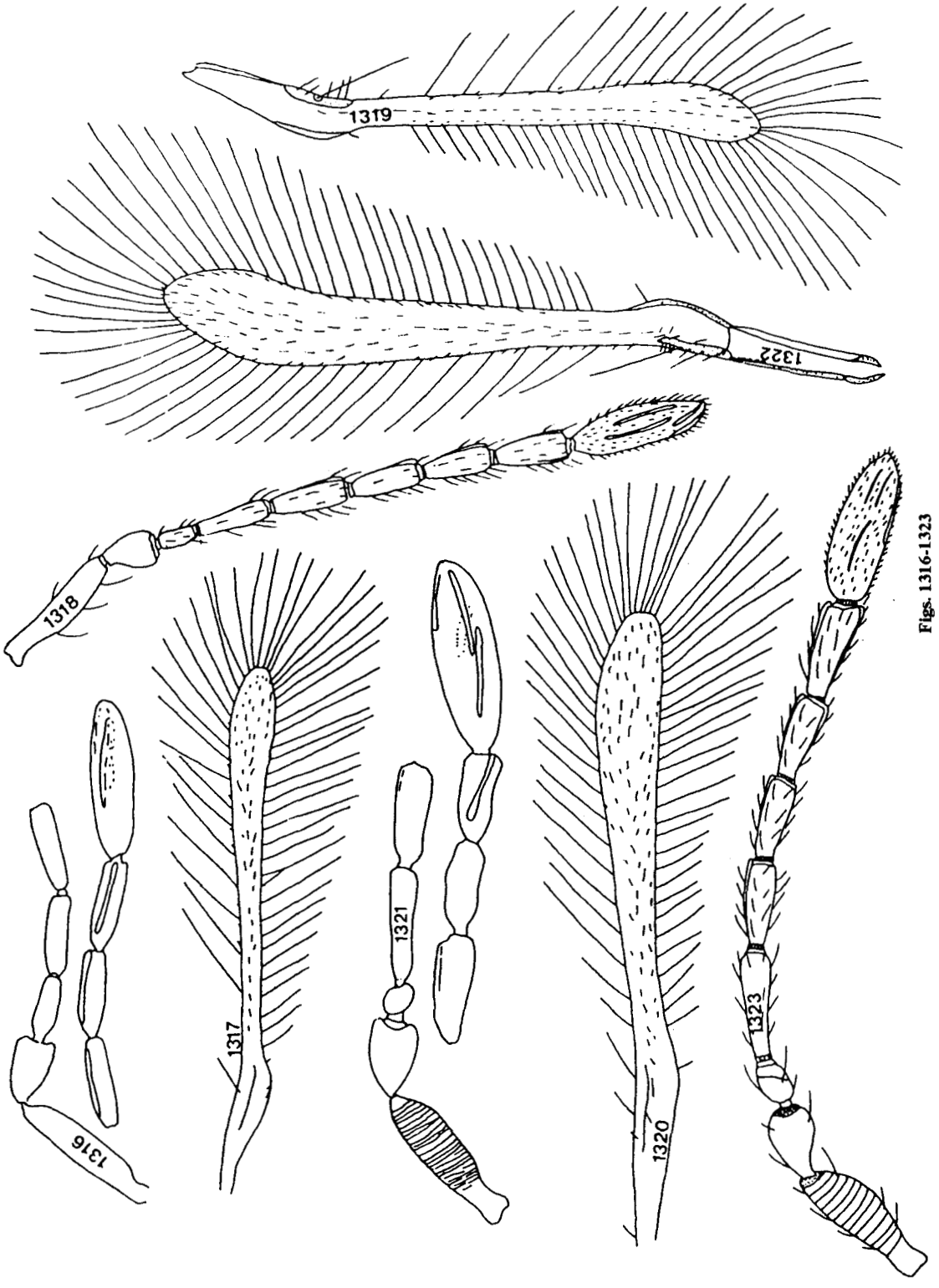
683' Not as above 684

684(683') Hind coxa enlarged laterally compressed, and disc-like; long bristles on hind tibia form diamond-like configurations; antennae with three funicles and a conspicuous anellus, usually ramose in males; marginal vein very long; body compressed laterally [Elasmidae] 685

684' Hind coxa not greatly enlarged, if so, not compressed or disc-like and with different pattern; hind tibia without diamond-like arrangement of bristles; gaster distinctly constricted at junction with the propodeum [Eulophidae] 687

685(684) Head, thorax, and abdomen yellow except blackened ocellar triangle, dorsal part of coxae, mid and lateral edges of scutellum, lateral edge of propodeum, abdominal tergites II and III, middle of V-VI and edges of IV to VI in the female (Fig. 1333) and entire tergites II to IV and apical half of male ..... *Elasmus albopictus* Crawford

685' Color pattern not as above 686



Figs. 1316-1323

686(685') Uniformly dark colored (Fig. 1334); forewing long and very narrow and evenly rounded distally (Fig. 1335) ..... *Elasmus corbetti* Ferriere

686' Not entirely black; venter, mid-and lateral sides of abdomen orange (Fig. 1336); antenna yellowish brown with very short funicular joints; hind coxae black with tip yellow, femur III with blackened dorsum and venter (Fig. 1337); body length 1-1.3 mm ..... *Elasmus philippinensis* Ashmead

686" Blackish green on head, mesonotum, and propodeum; postscutellum yellow; antenna brown except yellow scape; abdomen reddish yellow along the sides; legs yellow except greenish black coxae II and III and black striped upper part of hind femora (Fig, 1338); forewing slightly widened distally, wing tip with its apical half rounded (Fig. 1339) ..... *Elasmus claripennis* (Cameron)

687(684') Forewing with interruption between submarginal vein and parastigma; tarsus usually 4-segmented [Eulophidae] 688

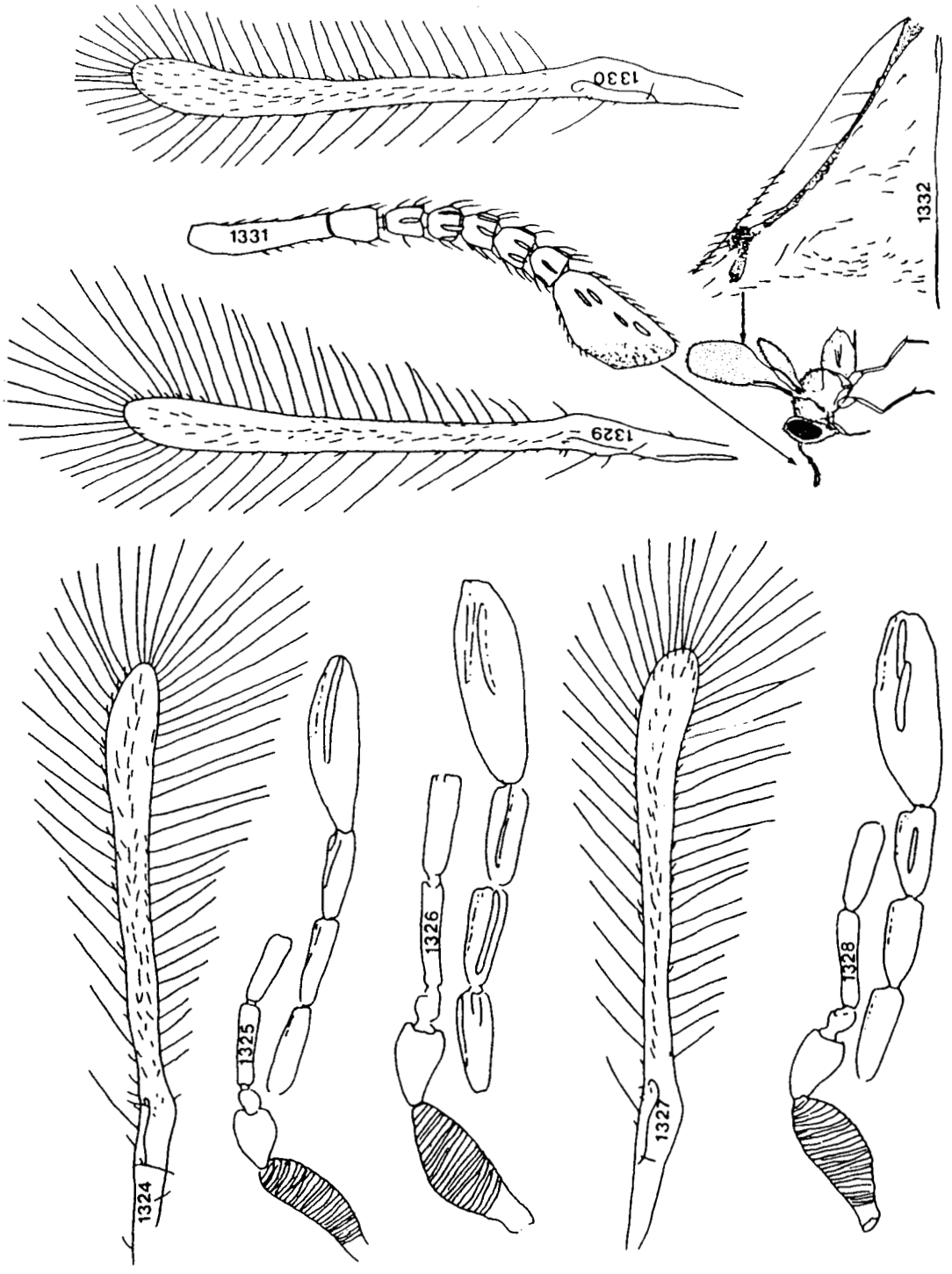
687' Forewing with submarginal vein smoothly joining parastigma 697

688(687) Notaular depression shallow and not defined, hind midlobe broad and weakly emarginate with deep impressed line; pronotum strongly arched with smooth and laterally obtuse-angular collar; scutellum less convex, reticulation on basal half more elongate and weak anteriorly; dorsellum large and impressed laterally; forewing with bare costal cell, pilose basal vein, small speculum, densely hirsute wing disc, very small stigma, postmarginal vein more than twice as long as stigma vein; petiole slightly transverse, reticulate with an elevated median carina in anterior half; head transverse; temples converging behind eyes; eyes moderately hairy; antennal scape slightly swollen in apical one-third and 5 times as long as broad; funicles longer than wide; gaster much shorter than thorax; 1.2 to 1.4 times as long as broad, broadest subposteriorly; 1*st* tergite very large about 0.80 of gaster (Fig. 1340); black with dark faint greenish tinge along sides of thorax, propodeum and anterior part of tergite I (pupal parasite of *Parnara guttata*) ..... *Pediobius mitsukurii* (Ashmead)

688' Similar to *P. mitsukurii;* pronotum without dorsally prominent extension towards anteriorly rounded head; petiole not wider than long; antennae with slender scape viewed dorsally and subglobular funicles; abdomen noticeably ovoid; forewing with at least 2 transverse rows of hairs in the anal region, hindwing with few hairs toward basal area (Fig. 1341) ..... *Pediobius atamiensis* (Ashmead)

688" Notaular line complete; axillae angularly produced; scutellum with two longitudinal submedian grooves; pronotum without cross-carina; middle lobe of mesoscutum with hairs, median area never bare, usually with a median groove; malar sulcus present; stigmal vein long; funicle 3-segmented in female 689

689(688") Oriental species; body shining green with bluish lustre to uniformly-brownish black or pale yellow 690



Figs. 1324-1332

689' African species 692

690(689) Antenna with 4 ring segments; body pale yellow except patches of metallic green with brassy and golden reflections in the thorax and sides of abdomen (Fig. 1342); scape of male antenna enormously expanded beneath (Fig. 1343), innerly convex and outerly concave . . . . . *Ooletrastichus formosanus* Timberlake

690' Antenna with one ring segment; blackish brown with greenish reflections or metallic blue with lustre 691

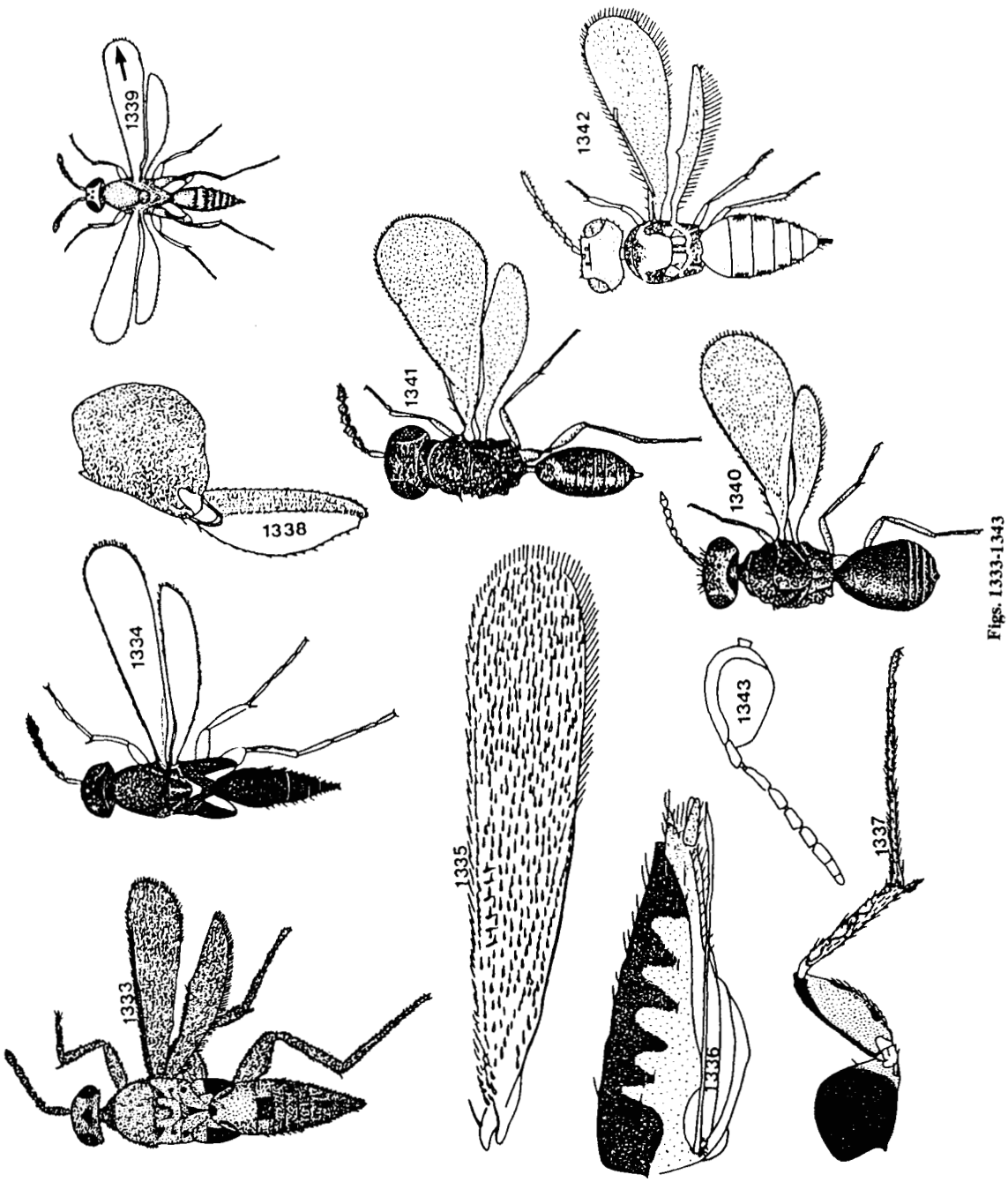
691(690') Body uniformly brownish black with greenish reflections in the head and thorax; legs whitish yellow except brownish coxa I and femur I; antenna blackish brown except yellow-brown scape, funicular segments not slender (Fig. 1344); club of male antenna black, broad and much wider than any antennal segment (Fig. 1345) . . . . . *Tetrastichus howardi* (Olliff)

691' Body metallic blue or shining green with bluish lustre; antenna brown except yellow scape with brown sensoriae in male; legs yellow except greenish coxae I and IV; ocelli in a low triangle, front ocellus never reached by scape; thorax smooth and shining, abdomen elongate, pointed behind with a slightly exserted ovipositor; female antenna (Fig. 1346) 3 equally long funicular segments 3 times as long as broad; male; 1*st* funicular segment smaller than the rest, funicle and club clothed with short hairs, sensorial organ of scape narrow and elongate and nearly as long as scape (Fig. 1347); abdomen ovoid, slightly longer than thorax . . . . . *Tetrastichus schoenobii* Ferriere

691" Very similar to *T. schoenobii;* shiny green with bluish lustre; legs uniformly whitish yellow with dark brown last tarsal segments (Fig. 1348); 3 equally long funicular segments only twice longer than broad; abdomen narrow and pointed behind, ovipositor more exserted than in *T. schoenobii* (Fig. 1349) (pupal parasite of *Hydrellia philippina)* . . . . . *Tetrastichus* sp.

691'" Body dark brown or black with slight blue-green lustre; scape, trochanters, apices of femora, entire tibia and tarsus pale yellow; head transverse wider than mesonotum; clypeus emarginate medially and mandibles sharply bidentate (Fig. 1350); mesoscutum with 3 pairs of bristles in inner basal half of parapsidal furrow (Fig. 1351); forewing hyaline and broader apically; submarginal vein with 2 setae, stigma vein about one-fifth of marginal vein (Fig. 1352); antenna with segment I > II = III (Fig. 1353); sensoria about two-thirds of scape (Fig. 1354) host : *S. inferens* . . . . . *Tetrastichus inferens* Yoshimoto

692(689') Head, thorax, and abdomen shiny and very finely reticulated; costal cell of forewing 12-13 times as long as broad, ventral area limed with many setae; submarginal vein with 7 large bristles dorsally (Fig. 1355); marginal vein as long as stigmal vein; propodeum smooth with median carina; 1*st* funicular segment the longest, nearly 3 times as long as broad, slightly shorter than club; male antenna with 5 funicular segments and clava with a basal whorl of long setae (Fig. 1356); sensorial organ near apex of scape, less than half



Figs. 1333-1343

length of scape; color pattern of pronotum, mesonotum, and scutellum light to dark brown; larval-pupal parasitoid of African gall midge, *Orseolia oryzivora* . . . . . *Tetrastichus pachydiplosisae* Risbec

692' Larval-pupal parasite of diopsid rice stemborers 693

693(692') Head, thorax, and abdomen irregularly reticulated; large part of coxae reticulated or unreticulated; ovipositor slight to clearly exserted 694

693' Head, thorax, and abdomen regularly reticulated; large part of coxae usually reticulated; ovipositor moderate to fully exserted 695

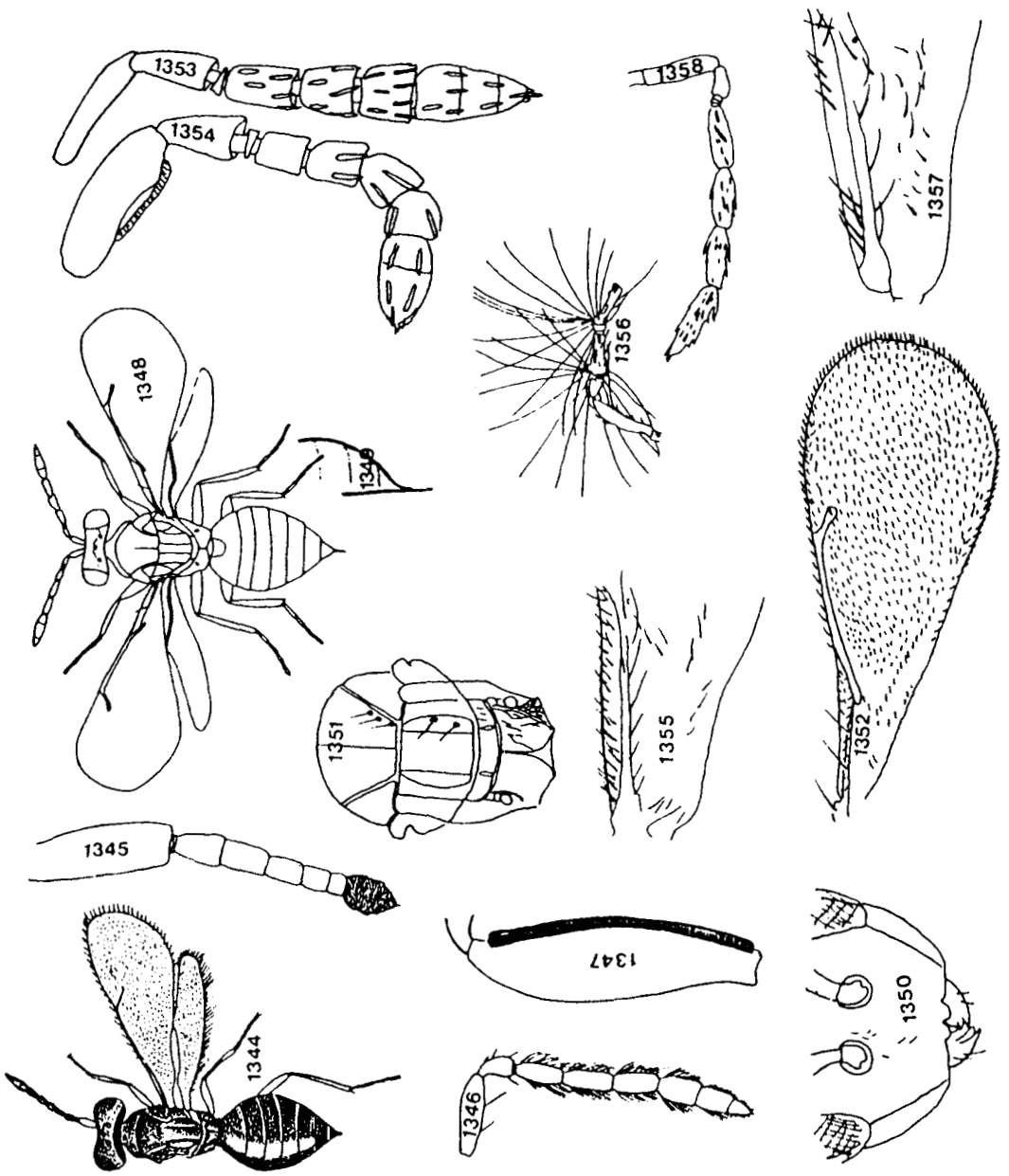
694(693) Yellow-bodied species with dark brown pronotum, anterior midlobe of mesoscutum, propodeum, and stylus; ocellar triangle brown concolorous to scape and pedicel; abdomen with irregular brown areas along margins and posterior tergites; malar space 0.8 times length of eyes; groove present between ocellar triangle (lateral ocellus) and eye margins; hindcoxae not reticulated; forewings 2.8 times as long as broad, not reaching tip of gaster, costal cell without bristles at middle (Fig. 1357), dorsum of submarginal vein with 4 bristles; gaster oblong-lanceolate; funicular segments without dense row of marginal hairs (Fig. 1358); ovipositor clearly exserted . . . . . *Tetrastichus flavobruneus* Schulten & Feijen

694' Blue-green with glossy green abdomen; malar space less than 0.8 times eye length; most of hind coxa reticulated; forewing reaches tip of gaster, nearly 3X as long as broad, costal area with few evenly dispersed hairs; dorsum of submarginal vein with 5 bristles (Fig. 1359); gaster elongate; ovipositor slightly exserted; male antenna with 6 funicular segments, rimmed basally by a whorl of 8-11 long bristles (Fig. 1360) . . . . . *Tetrastichus confusus* Schulten & Feijen

695(693') Malar space very wide, as long as eye length; forewing as long as broad, extended to tip of gaster, dorsum of submarginal vein with four bristles costal area with about 12 setae, sparsely set distally (Fig. 1361); ocellar triangle elevated, without groove between lateral ocellus and eye margin; base of antenna rimmed dorsally with 4-5 long hairs, funicle I a little over half of 2*nd* funicle (Fig. 1362); head and thorax bluish green, abdomen reddish brown with blue-green lustre; ovipositor slightly exserted . . . . . *Tetrastichus nisbeci* Schulten & Feijen

695' Malar space less than eye length; other characters not as above 696

696(695') Male with 6 funicular segments, each with a basal incomplete row or whorl of 8-11 bristles; sensorial process 0.8 of scape length (Fig. 1363); malar space one-half eye length; postspiracular carina well developed; body blue-green except yellow parts below and between antennal sockets, genae; scape yellowish white with brown upperside distally, pedicel brown to light brown, flagella uniformly brown; costal area with 6-7 setae evenly spaced towards distal end, submarginal with 6 setae; basal area of forewing



Figs. 1344-1358

below submarginal without hairs (Fig. 1364); ovipositor clearly exserted; relatively large species, male 1.6 mm and female 2.9-3.6 mm ..... *Tetrastichus variabilis* Schulten & Feijen

696' Male with only 5 funicular segments, each lined at basal one-third or one-fourth with an incomplete ring of 6-8 long bristles (Fig. 1365); sensorial process a little over half of scape; scape as long as eye length; malar space 0.7 of eye length; basal area of forewing with setae, 4-5 in the submarginal and 6 in the base of costal area (Fig. 1366); body generally metallic green with green to dark green abdomen ..... *Tetrastichus diopsisi* (Risbec)

697(687') Mesoscutum with complete notaular lines; male antennal funicle not ramose 698

697' Mesoscutum with notaular lines incomplete or absent; male antennal funicle with rami or lateral branches 699

698(697) Abdomen subsessile; hind tibia with small spurs, shorter than basitarsus; head broader than mesoscutum; eyes finely pubescent, large in facial view; face triangular in frontal view (Fig. 1367); mandibles hexadentate with 2 large teeth (Fig. 1368); antenna 11-segmented with 2 rings and 3-segmented club; scape beyond vertex; propodeum highly carinated, not oblique, with 4 setae in the hind lateral margin of propodeum; scutellum flat and carinated distally; axillae well developed (Fig. 1369); yellow with blackish antennae, grey eyes, brown patches on scutellum and abdominal tergites, midtergites of IV and V usually with broad brown spots (Fig. 1370) ..... *Stenomesius japonicus* (Ashmead)

698' Abdomen subpetiolate; hind tibia with long spurs, longer one exceeds basitarsus; propodeum oblique; scutellum without longitudinal furrows; body black except yellow area at base of gaster; abdomen broadest submedially (Fig. 1371) ..... *Euplectrus* sp.

698' Abdomen ovoid, basal half yellow with 2 pairs of black spots laterally, latero-median spots one-third - half that of subbasal lateral spots (Fig. 1372) ..... *Euplectrus chapadae* (Ashmead)

699(697') Hind tibia with 2 apical spurs; toruli of antennae below middle of face; flagella somewhat flattened; costal cell wide, postmarginal vein more than 2X as long as stigmal vein; propodeum weakly sculptured, convex and plicae present but without median carina (Fig. 1373); abdomen black with or without subbasal white band (Fig. 1374) ..... *Sympiesis* spp.

699' Hind tibia with 1 apical spur; toruli near middle of face; costa cell narrow; scape well beyond front ocellus; male (Fig. 1375) antenna with 3 long rami; female with 2 anelli (rings), 4 funicular segments with 2*nd* segment the longest and nearly 3X length of pedicel, club 3-segmented ..... *Hemiptarsenus* sp.

700(682') Hind femur strongly enlarged with teeth in the ventral edge, thoracic dorsum rough, with dense piliferous, umbilicate punctations; prepectus small; funicle 7-segmented plus

a ring segment; forewings not folding; ovipositor not upwardly curved over dorsum [Chalcididae] 701

700' Hind femur more or less normal, ventral edge without serrated tooth 705

701(700) Coxae without an inner ventral tooth in either sex 702

701' Coxae without an inner ventral tooth in the females 704

702(701) Preorbital carina of frons distinct, widely abbreviated near malar ridge; postorbital carina indistinct; scrobe area polished, moderately deep reaching front ocellus (Fig. 1376); genae flat below eyes; right mandibles with 3 apical teeth; mesoscutellum rounded at apex; scutellum gently declined posteriorly with apical part narrowly explanate and reflexed, apical margin rounded (Fig. 1377); hind tibia mostly black, slightly reddish basally with yellow spot subbasally and apically; femur III (Fig. 1378) black except apical yellow spot, outer ventral margin with 10-12 teeth; dorsum of tergite 2 with dense minute punctures ..... *Brachymeria excarinata* Gahan

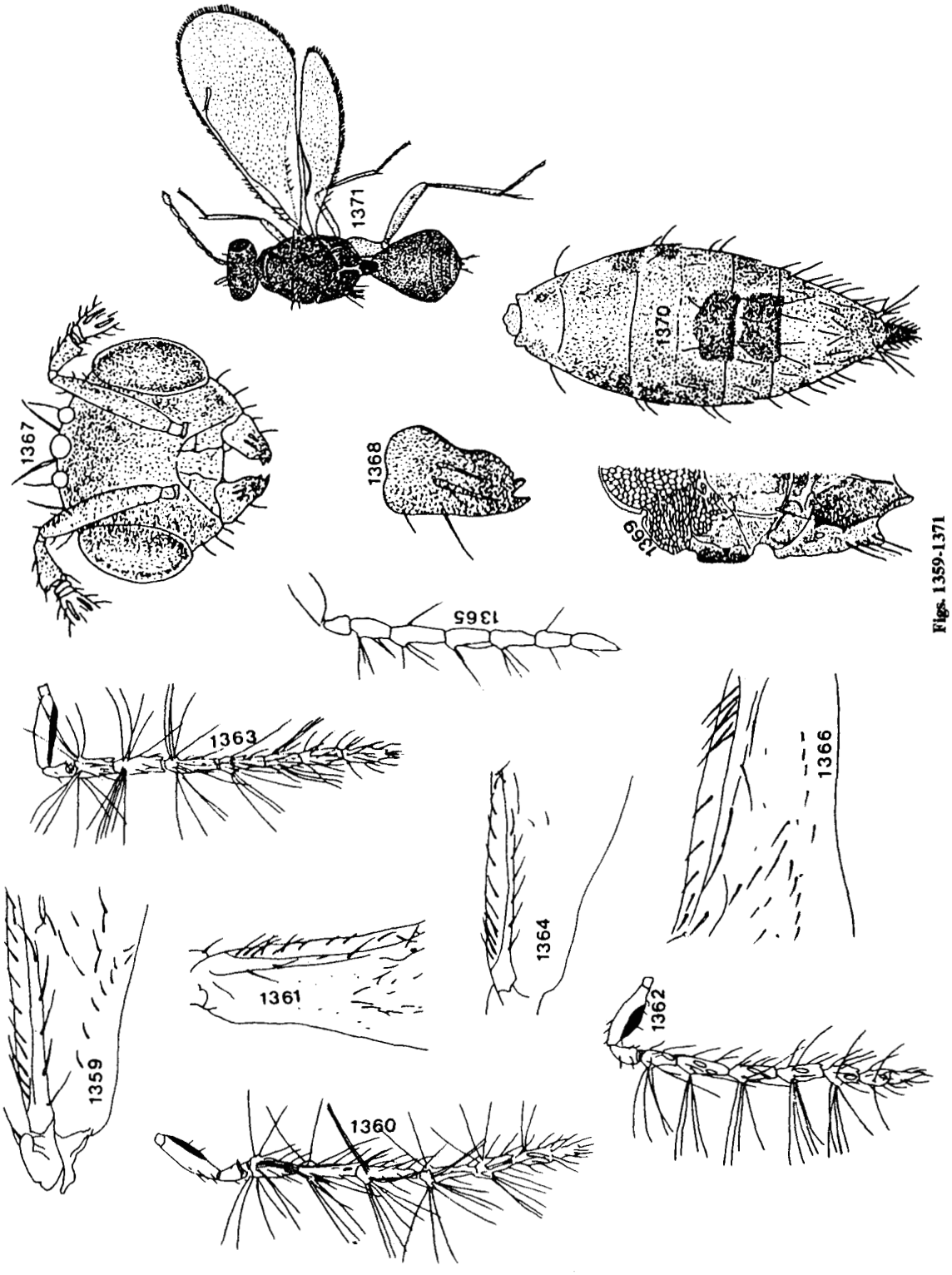
702' Frons without preorbital carina but with or without postorbital carina 703

703(702') Head 3 times wider than thorax; lateral ridges of scrobe produced in front of antennal toruli; vertex distinctly deeply pitted; postorbital carina present reaching genotemporal margin; genal angle acute in front and nearly rectangular behind; scutellum cleft medially in dorsal view; hind femur and tibia III yellow with a black broad patch at middle (Fig. 1379); abdomen a little shorter than pronotum; tergite VI with 6-7 transverse rows of distinct and deep pits ..... *Brachymeria megaspila* Cameron

703' Head width nearly as long as thorax; lateral ridges of scrobe not produced in front of antennal toruli; postorbital carina not well developed to almost absent; front genal angle slightly acute and obtusely rounded off behind (Fig. 1380); scutellum in dorsal view not divided medially; hindcoxa black with brownish red distal part, femur reddish brown except yellow apex with a pale black patch on outer side, tibia yellow with black ventral carina and brown base; abdomen a little shorter than 1.5 times length of pronotum, mesoscutum, and scutellum combined; tergite VI with 5-6 transverse rows of indistinct punctures ..... *Brachymeria jayaraji* Joseph, Narendran & Joy

704(701') Lateral ridges of scrobe produced in front of antennal toruli; smooth median area prominent below scrobe, the latter reaching front ocellus; postorbital carina distinct, extended to posterior margin of genotemporal part; front genal angle acute to slightly rounded, hind angle rectangular but broadly rounded (Fig. 1381); scutellum weakly bilobed medially; femur III (Fig. 1382) shiny black with clear yellow apical part, tibia III creamy yellow with entire inner half reddish black; abdomen shortly ovoid with smooth first tergite ..... *Brachymeria lasus* (Walker)

704' Lateral ridges of scrobe not produced in front of antennal toruli; area below scrobe with punctures and without a smooth median raised portion; scrobe not reaching front ocellus (Fig. 1383); scutellum parallel-sided towards base and rounded apically; hind



Figs. 1359-1371

femur (Fig. 1384) black with yellow distal ends; tibia III yellow with reddish black base; abdomen black with first tergite faintly rough ..... *Brachymeria albotibialis* (Ashmead)

705(700') Mesopleura large, convex and without any vertical grooves; midtibia with a strongly produced straight apical spur 706

705' Mesopleura usually grooved and at least partly impressed 708

706(705) Midcoxa closer to forecoxa; mesoscutum flat and convex dorsally, without impressions; thorax finely reticulate, mesonotum more glossy than scutellum and wider than long; scutellum rounded; antenna (Fig. 1385) yellow, inserted at base of face near clypeus, scape short, pedicel elongate 0.4X length of scape and more than twice as long as broad, funicle 1-3 small, subquadrate, 4-6 longer than broad and each longer than basal 3, club-3-segmented and a little longer than 4-6; head transverse, frontally rounded with narrow vertex; abdomen triangular, shorter than thorax; hypopygium reaching more than 0.7 along gaster; body black with metallic luster on head and thorax [Encyrtidae] ..... *Ooencyrtus malayensis* Ferriere

706' Midcoxa closer to hind coxa; mesoscutum impressed posteriorly, longer than broad without distinct shoulders; tibial spur of midleg very long, as long as combined length of basal 3 segments and strongly hirsute; forewing with an oblique bare linea-clava; marginal vein longer than submarginal; antenna with 5 funicles and an anellus, clava with obsolete second suture [Eupelmidae] 707

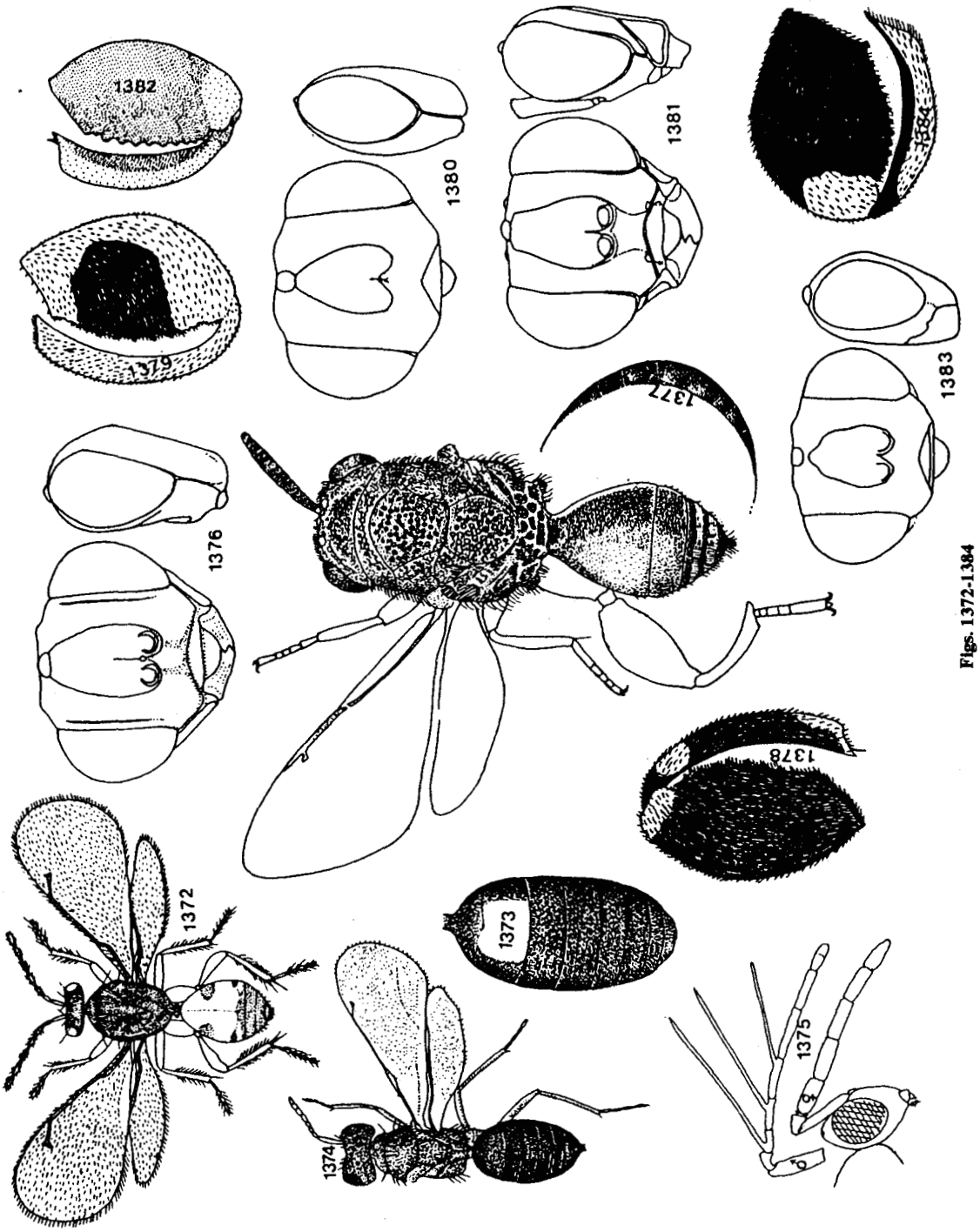
707(706') Brown infuscation of forewing originates at apex of speculum; mesoscutum white medially; head and pronotum black, triangular area of pronotum sometimes whitish (Fig. 1386) ..... *Neanastatus cinctiventris* Girault

707' Infuscation starts halfway between oblique speculum and stigma, stigmal area to wing tip infuscated; mesoscutum black with 2 whitish bands (Fig. 1387); vertex of head and triangular area of pronotum yellow ..... *Neanastatus oryzae* Ferriere

708(705') Pronotum large and long, nearly quadrate and as broad as mesoscutum; notaular grooves complete; propodeum sloping, median longitudinal groove present; marginal vein normal, without infumation below; female (Fig. 1388) with 5-segmented funicle; funicular segments each with a ring of bristles near the base and apex in male (Fig. 1389), club with many bristles; gaster with 4*th* tergite (Fig. 1390) the longest; body non-metallic [Eurytomidae] ..... *Eurytoma* spp.

708' Pronotum short, if long then with a punctated thorax, usually with metallic lustre; male antenna with 5-7 funicular segments; forewing bare in basal one-third or with 13-segmented antenna and pilose forewing; notauli often complete; hind coxa hardly larger than forecoxa [Pteromalidae] 709

709(708') Hind tibia with two spurs; fore femur golden yellow and unpigmented; head same color as thorax, black with green metallic luster; abdomen pale to dark yellow with somewhat



Figs. 1372-1384

broken median and clearly broken brown marginal stripes (Fig. 1391); antenna with 2 anelli in both sexes, female antenna with very long funicle segments and long erect hairs, scape to anelli yellow and funicle to club dark brown . . . . . *Propicroscytus mirificus* (Girault)

709' Hind tibia with only one spur; head and thorax reticulately punctated; scutellum without frenum; occipital ridge near foramen far behind and below lateral ocelli; forewing not very hairy, with fringe, postmarginal vein longer than stigmal vein 710

710(709') Striae one clypeus confined to clypeal region; temples about one-fourth as long as eyes; head in dorsal view not thick about one-fifth times as broad as long 711

710' Striae on clypeus reach lower margin of eyes and malar sulcus; temples nearly half as long as eyes; dorsal view of head thick, less than twice as broad as long 712

711(710) Body black to bluish black; breadth of head slightly wider than combined length of pedicel and flagellum in females; occipital carina weak; collar of pronotum weak but sharply marginal except at side; malar space slightly shorter than 0.5 time height of eye; anterior margin of clypeus slightly emarginate medially; mandible with 4 teeth; scape of female antenna 0.8-0.9X eye height, flagella not slender, some subquadrate, 6*th* segment quadrate to slightly transverse; club twice as long as broad; male with slender flagella, scape above level of vertex, club 3 times as long as broad (Fig. 1392); subglobular gaster with petiole as long as nucha; parasite of *Oulema oryzae, Agromyza oryzae, Hydrellia griseola* . . . . . *Trichomalopsis oryzae* Kamijo & Grissell

711' Body green to bluish green; combined length of pedicel and flagellum 0.9-1.0X breadth of head; occipital carina rather strong; collar of pronotum weak, irregularly marginal or not marginal; malar space slightly longer than 0.5 times eye height; lower margin of clypeus weakly emarginate medially; mandible with unequal teeth, left side with 3 and right side with 4; scape of female antenna 0.9 to 1.0 times eye height; flagella rather slender and weakly clavate distally, 1*st* and 2*nd* segment equally long, 6*th* subquadrate to transverse and shorter than the first; club 2.2 times as long as broad; male with antenna inserted higher, toruli nearer to anterior margin of median ocellus than to lower margin of clypeus, combined length of pedicel and flagellum a little longer than head breadth, 6*th* funicle longer than broad (Fig. 1393); hosts same as *T. oryzae* . . . . . *Trichomalopsis shiraki* Crawford

712(710') Lower margin of clypeus cleft medially (Fig. 1394); lower margins of face not projecting below level of lower margins of clypeus; occipital carina strongly curved medially; dorsum of thorax moderately curved . . . . . *Trichomalopsis apanteloctena* (Crawford)

712' Lower margin of clypeus weakly emarginate; lower margins of face curved and projected below level of lower margins of clypeus (Fig. 1395); occipital carina evenly curved medially; thoracic dorsum evenly to weakly curved . . . . . *Trichomalopsis deplanata* Kamijo & Grissell

713(2') Sedentary parasites, attached mainly to the abdomen of host leafhoppers and planthoppers; legless; female twisted-winged fly (**STREPSIPTERA**) 714

713' Mobile insects; legged 716

714(713) Broad-passage opening circular-like, thorax reduced and ring-like behind broad-passage (Fig. 1396); parasites of delphacids and fulgorids . . . . . *Elenchus* spp.

714' Not as above; parasite of cicadellids 715

715(714') Basal collar with 2 dark brown spots at base (Fig. 1397); parasite of *Nephotettix, Recilia* . . . . . *Halictophagus bipunctatus* Yang

715' Basal collar without dark spots but with a pale median band (Fig. 1398); parasite of *Cofana* . . . . . *Halictophagus spectrus* Yang

716(713') Node absent; fontanelle present (**ISOPTERA**) 717

716' Node present; fontanelle absent (**HYMENOPTERA**) 719

717(716) Pronotum flat without anterior lobes; head capsule oval, fontanelle lying at the middle of the anterior margin; antenna 16-segmented; labrum subtriangular with a semihyaline tip; mandible thin, moderately long and slightly sabre-shaped (Fig. 1399) . . . . . *Coptotermes fonnosanus* Shiraki

717' Pronotum saddle-shaped with anterior lobes 718

718(717') Labrum with hyaline tip; head subovate; antenna 16-17 segmented, segment III longer than II or IV; left mandible with subbasal serrations, tip of mandible not strongly curved inwards; pronotum with slightly pointed sides (Fig. 1400); S. Asian species . . . . . *Macrotermes gilvus* Hagen

718' Labrum with a subhyaline tip; head much longer than wide and less ovate; antenna 18-19 segmented; left mandible without subbasal serrations, tips more inwardly curved; pronotum with a transverse mark in anterior one-third, sides more rounded (Fig. 1401); African species . . . . . *Macrotermes bellicosus* Smeathman

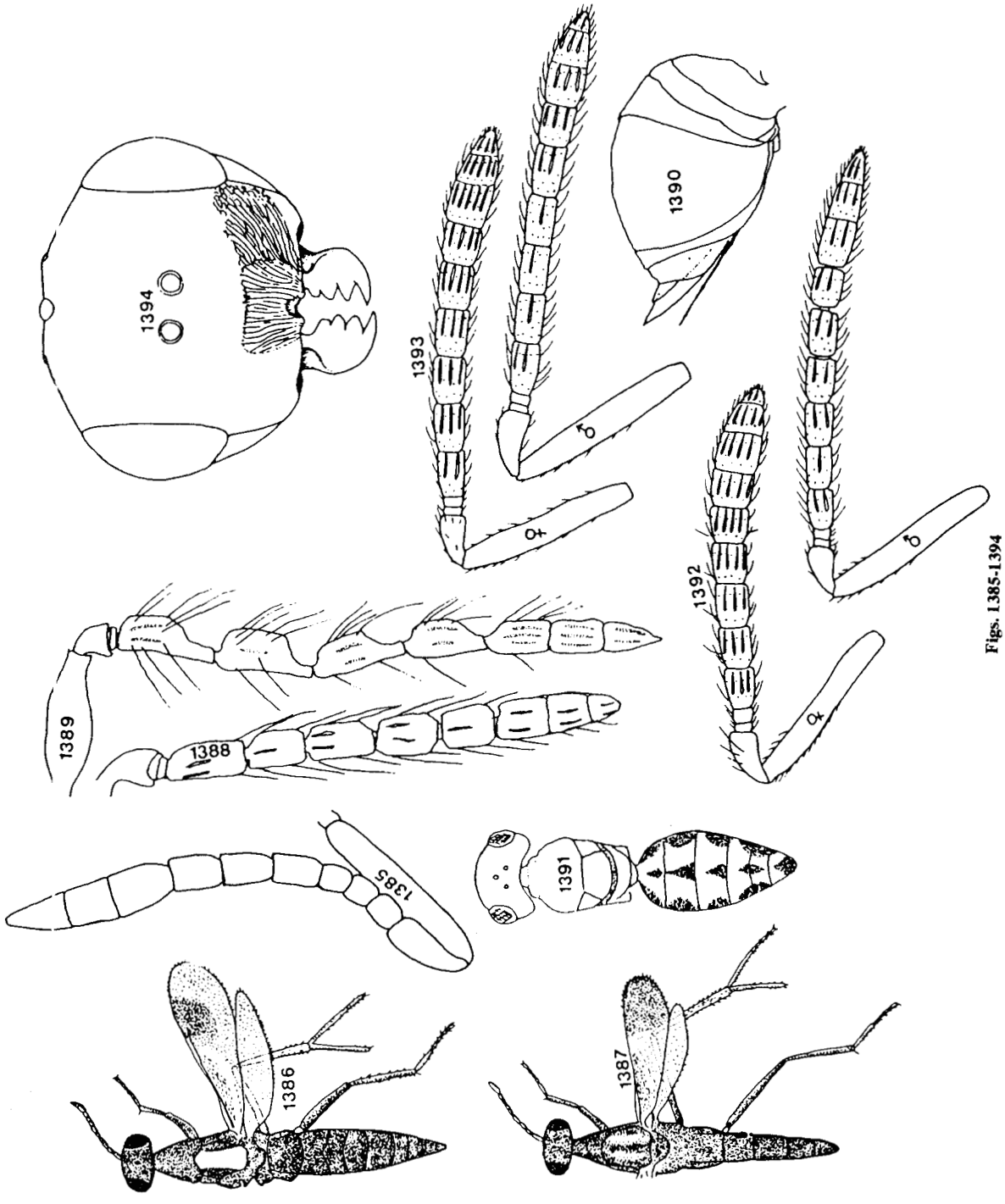
718" Labrum without a hyaline tip; head ovate; antenna 13-segmented, segment II almost twice as long as III; mandible without serrations, tips strongly cross each other but moderately curved inwards; pronotum with elevated anterior lobes, sides hump-like towards lateral (Fig, 1402); African species . . . . . *Microtermes* sp.

719(716') Two nodes (= petiole) present 720

719' One node present 724

720(719) Propodeum with spine 721

720' Propodeum spineless 723



Figs. 1385-1394

721(720) Antenna 11-segmented with and 2-segmented club; palpal formula 2,2; workers strongly polymorphic with small eyes and subquadrate head (Fig. 1403); propodeal spine slightly curved downward towards the posterior (Fig. 1404); reddish brown ants ..... *Pheidologeton* sp.

721' Antenna 12-segmented 722

722(721') Antennal club 4-segmented (Fig. 1405); thoracic dorsum with a deep furrow in the mesoepinotal joint; head subglobular and convex dorsally, vertex in frontal view notched medially; hind leg without pectinate calcaria; propodea, spines small but nearly vertical ..... *Pheidole* sp.

722' Antennal club 3-segmented; thoracic dorsum entire and flat to convex anteriorly; head subrectangular, width more than 0.7 mm, vertex not notched medially as seen in front, enlarged part of first node subquadrate in lateral view, anterior face and dorsum approaching each other through a curve, posterior face longer than anterior, posterodorsal angle higher than anterodorsal; propodeal spine long and acute, upcurved along its length (Fig. 1406) ..... *Tetramorium pacificum* Mayr

723(720') Antenna (Fig. 1407) 12-segmented, club with 3 segments; eyes about 0.06 mm in greatest diameter; head width less than 0.6 mm; body rough and opaque; basal half of first node as high as the second (Fig. 1408) ..... *Monomorium pharaonis* (Linnaeus)

723' Antenna 10-segmented; club with 2 segments, nearly half of flagellum (Fig. 1409); eyes relatively larger than *M. pharaonis* with more than 30 ommatidia; head width not less than 0.5 mm in the smallest form; second petiole almost ovate; propodeal spiracle almost ovate; propodeal spiracle almost at midlength (Fig. 1410) ..... *Solenopsis geminata* (Fabricius)

724(719') Petiole armed with 2 posterolaterally projected horn-like spines similar to that in the propodeum (Figs. 931-933); pronotum with 2 similar spines projected forward; body usually black or abdomen with silvery tinge ..... *Polyrachis* spp.

724' Petiole not as above 725

725(724') Very small ants, less than 2 mm long; antenna 12-segmented, segment XII as long as X + XI; head blackish brown with wide V-shaped frons; antenna and gaster yellowish brown; petiolar node rudimentary (Fig. 1411); scape surpassing occipital corner by more than length of first funicular segment ..... *Tapinoma melanocephalum* (Fabricius)

725' Large ants, usually more than 10 mm long; node very prominent 726

726(725') Head, thorax and petiole including postpetiole strongly striated or grooved; body dull black 727

726' Head, thorax and petiole not striated; if so, striations very fine; mandibles parallel to each other with 3 strong subapical teeth; area between base of antenna and eyes with a deep groove, body glossy 728

727(726) Pronotum with a lateral spine, transversely striated similar to the rest of thoracic dorsum (Fig. 929); head striations widely diverge posteriorly and vertex moderately raised (Fig. 1412); scape hardly beyond back of head; petiole triangular in lateral view, slightly concave in top view and with 3-4 long hairs; postpetiole smooth with long brown-yellow setae and short white hairs; black with reddish brown legs, antennae and mandibles . . . . . *Odontoponera transversa* (F. Smith)

727' Pronotum spineless, striations circular and transversely ovate at middle (Fig. 1413); meso- and metastriations longitudinal and rather long; propodeal spiracle almost at midlength and between striae 8 and 10 from bottom; petiole robust, striated transversely with a moderate concavity between short erect spines (Fig. 1414); striae on top of head above antennal base not expanded and long scape high above the back of head (Fig. 1415); femur and tibia black . . . . . *Diacamma vagans* (F. Smith)

727" Pronotum as in *D. vagans* but striations more transversely ovate (Fig. 1416); top meso- and metastriations more oblique; propodeal spiracles on striae 11 and 13 from top; petiole moderately stout, spines long and V-shaped in between spines (Fig. 1417); striae on top of head expanded at middle; scape as above (Fig. 1418); all legs uniformly reddish brown . . . . . *Diacamma* sp.

728(726') Sting well developed (Fig. 1419); head with a medium longitudinal groove posteriorly; mandibles long and parallel to each other, serrated with 3 strong teeth apically (Fig. 1420); petiole produced into a sharply pointed spine apically (Fig. 1421); head grooved between antennal base and eyes (Fig. 1420) . . . . . *Odontomachus* spp.

728' Sting not developed (Fig. 1422); head without groove posteriorly and between eyes and antennal base; mandibles short but robust, uniformly serrated with teeth of equal sizes (Fig. 1423); petiole thinly narrowed apically, enlarged at middle (Fig. 1424) . . . . . *Camponotus* sp.

729(1') Tarsi 2-clawed with or without claw tufts 730

729' Tarsi 3-clawed, claw tuft absent though spurious claws present 769

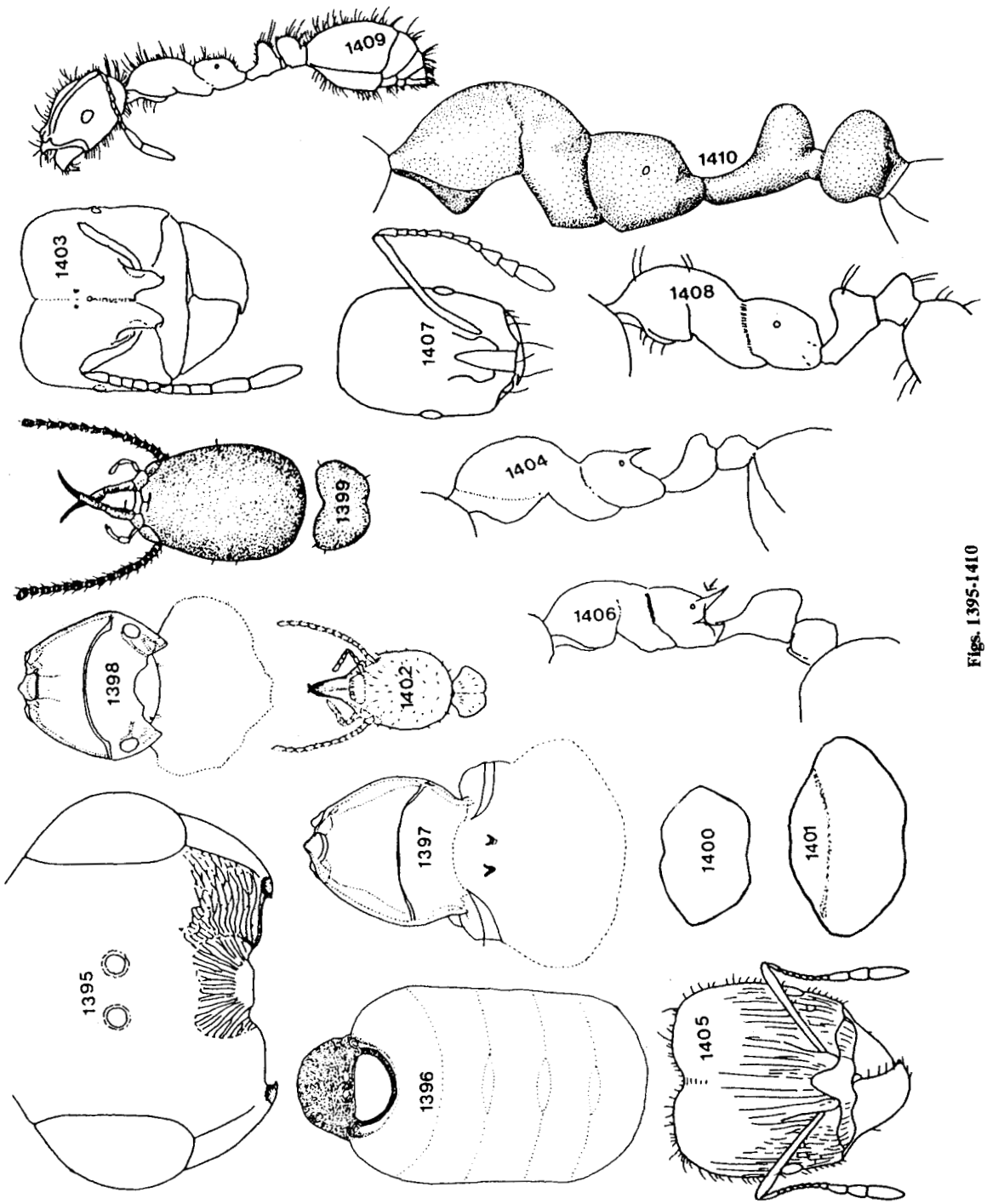
730(729) Eyes arranged in 3 distinct rows, front row with 4 and highly enlarged anterior median, second row with 2 small eyes and a third row with 2 medium sized eyes placed more posteriorly on top of carapace (Fig. 1425); jumping spiders [Salticidae] 731

730' Eyes arranged in 2 rows (Fig. 1426) 739

731(730) Femur and tibia of leg I usually noticeably enlarged; tibia I armed with 3 pairs of ventral stout spines sometimes with leaf-like setae extended up to femur and patella in leg I only 732

731' Femur and tibia of leg I not exaggerated in size 734

732(731) Leg I with leaf-like setae (Fig. 1427) except in metatarsus and tarsus; tibia I 3-4 times wider than metatarsus I, dorsally and ventrally lined with leaf-like setae; in male metatarsus I much longer and lightly colored than tibia I; posterior lateral eyes slightly



Figs. 1395-1410

outside carapacial margin (Fig. 1428); epigynum with a dome-shaped structure at middle and a cavity on both sides (Fig. 1429); palpal organ brown with a shorter and thinner embolius, tibial apophysis acute (Fig. 1430); abdomen a little longer than cephalothorax ..... *Harmochirus bruchiatus* (Thorell)

732' Leg I without leaf-like setae 733

733(732') Posterior lateral eyes (PLE) almost at midlength of frontally flat carapace with a white spot below each eye and a pair of subovate to subtriangular white spots at middle of PLEs (Fig. 1431); median anterior eyes very large, mandibles very short and clypeus relatively high (Fig. 1432); male abdomen with 3 pairs of white spots (Fig. 1433), female pattern irregular; epigynum with a hat-like median structure (Fig. 1434); palpal organ with a bent sharp-ended apophysis (Fig. 1435) ..... *Bianor hotingchiehi* Schenkel

733' Posterior lateral eyes above midlength of carapace; cephalothorax flattened dorsoventrally and short; abdomen ovoid with 2 pairs of apodemes and 3 white transverse median, submedian, and subposterior bands (Fig. 1436), anterior half of abdomen white along margins ..... *Rhene* sp.

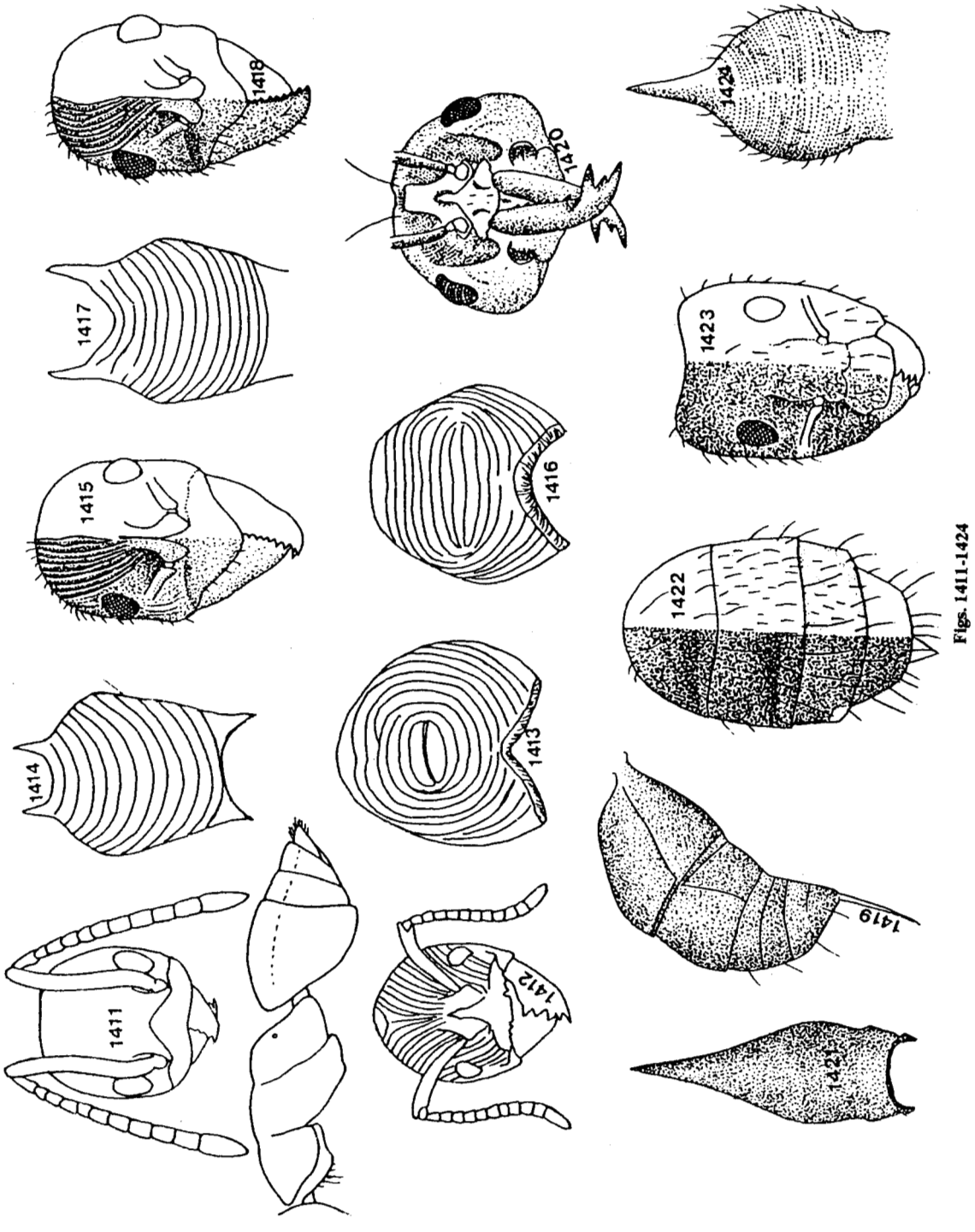
734(731') Sternum narrowed apically, narrower than base of labium; female abdomen with 2 longitudinal bands dorsally; chelicera with 2 promarginal and 1 retromarginal teeth; first pair of legs darker and longer than the rest 735

734' Sternum normally wider than base of labium; cheliceral teeth variable 736

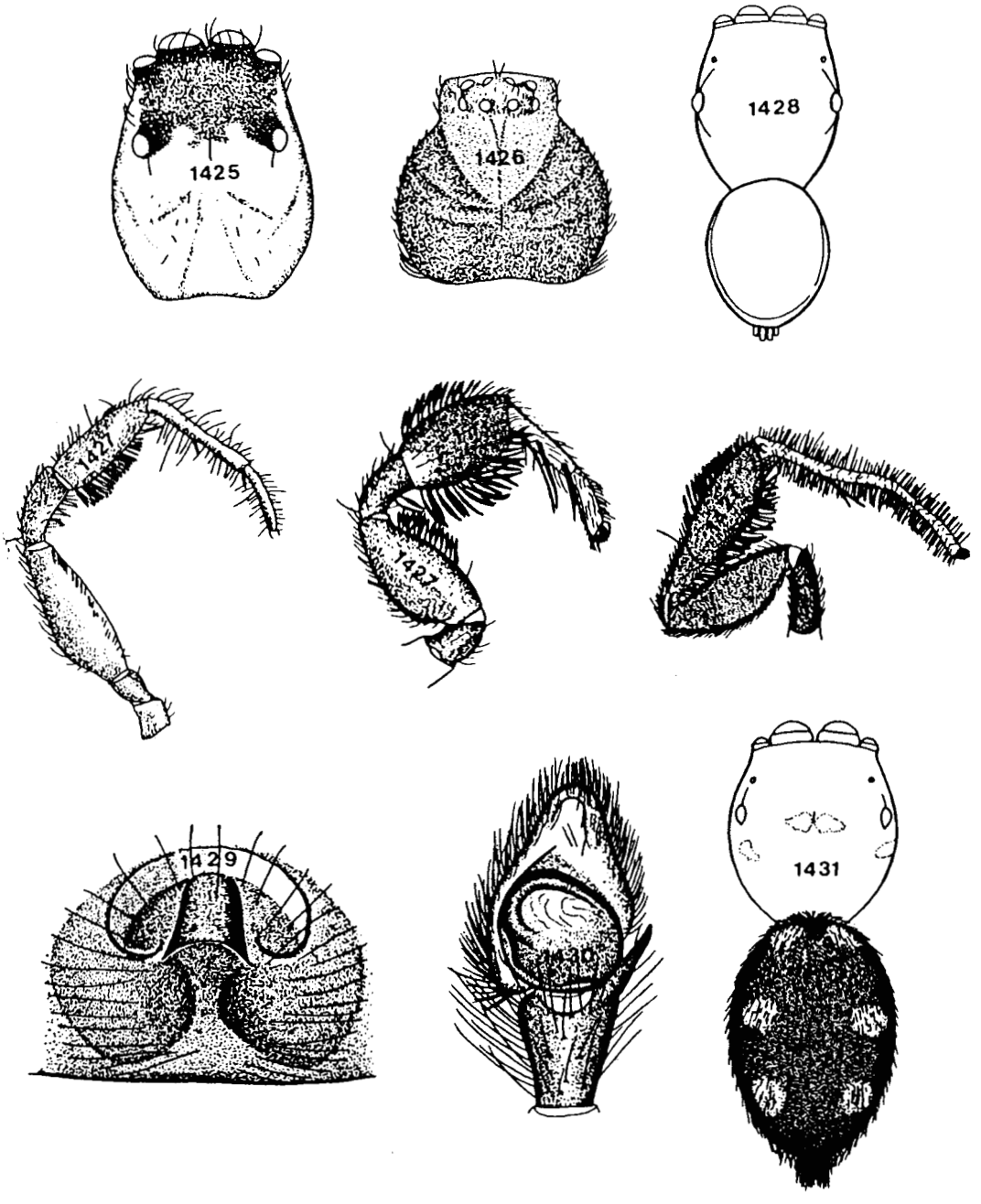
735(734) Eyefield black to blackish brown; male: cephalothorax brown; abdomen light brown, grey laterally with big white-yellow irregular spots and rows of small yellow spots; venter greyish yellow with 3 grey longitudinal streaks; palpal organ orange-brown with a broad tibial apophysis pointed outward (Fig. 1437); female: cephalothorax orange; abdomen with straight longitudinal bands and 2 pairs of rectangular spots posteriorly (Fig. 1438); tibia I with 4 pairs of ventral spines; epigynum with 2 oval depressions divided by a wedge-shaped furrow above epigastric fold and coiled canals above (Fig. 1439) ..... *Maripissa magister* (Karsch)

735' Entire female cephalothorax including eyefield reddish brown with black shades, abdominal longitudinal band undulated in the inside, and tibia I with 3 pairs of ventral spines; epigynum with half-starlike mark above 2 oppositely C-shaped depressions (Fig. 1440); male with lightly colored areas inside the eyefield and behind posterior lateral eyes; abdomen with 3 light colored transverse bands; palpal organ with an acute tibial apophysis, tapering tegulum and apically rounded cymbium (Fig. 1441) ..... *Maripissa elongata* (Karsch)

736(734') Tibia + patella of leg III as long as or longer than tibia + patella of leg IV; first 2 pairs of legs similar; tibia I with 3 pairs of ventral spines; cephalothorax high and convex, sides parallel in the cephalic and rounded in the thoracic; ocular quadrangle occupies about one-third carapace length, narrower in front than behind; retromargin with a single tooth 737



Figs. 1411-1424



Figs. 1425-1431

736' Tibia + patella of leg III shorter than tibia + patella of leg IV 738

737(736) Posterior part of abdomen with 2 or 4 symmetric white-yellow spots (usually 2 large yellow spots in female) (Fig. 1442); female eyefield black; median band broadly yellow and black banded sublaterally, sublateral black bands run up to cephalothorax in male; epigynum large with slit-like copulatory organs, U-shaped anterior part and oval spermatheca (Fig. 1443); palpal organ thick with a slightly hooked tegulum, nearly rectangular bulbus and embolus in its upper part; tibial apophysis short, laterally hooked and reaches one-fourth of cymbium; top of cymbium broadly rounded ventrally and subtruncated laterally (Fig. 1444) . . . . . *Plexippus paykulli* (Savigny & Audouin)

737' Posterior part of abdomen laterally with a mosaic of yeIlow-orange dots on a grey background, median part of entire abdomen with an orange longitudinal band; eyefield light brown to brown, male with dark eye margins pointed towards each other in between posterior lateral eyes (Fig. 1445); epigynum with a dome-shaped bridge between copulatory slit-like organs (Fig. 1446); palpal organ with a rounded tegulum, narrowly rounded top of cymbium both in ventral and lateral view . . . . . *Plexippus setipes* Karsch

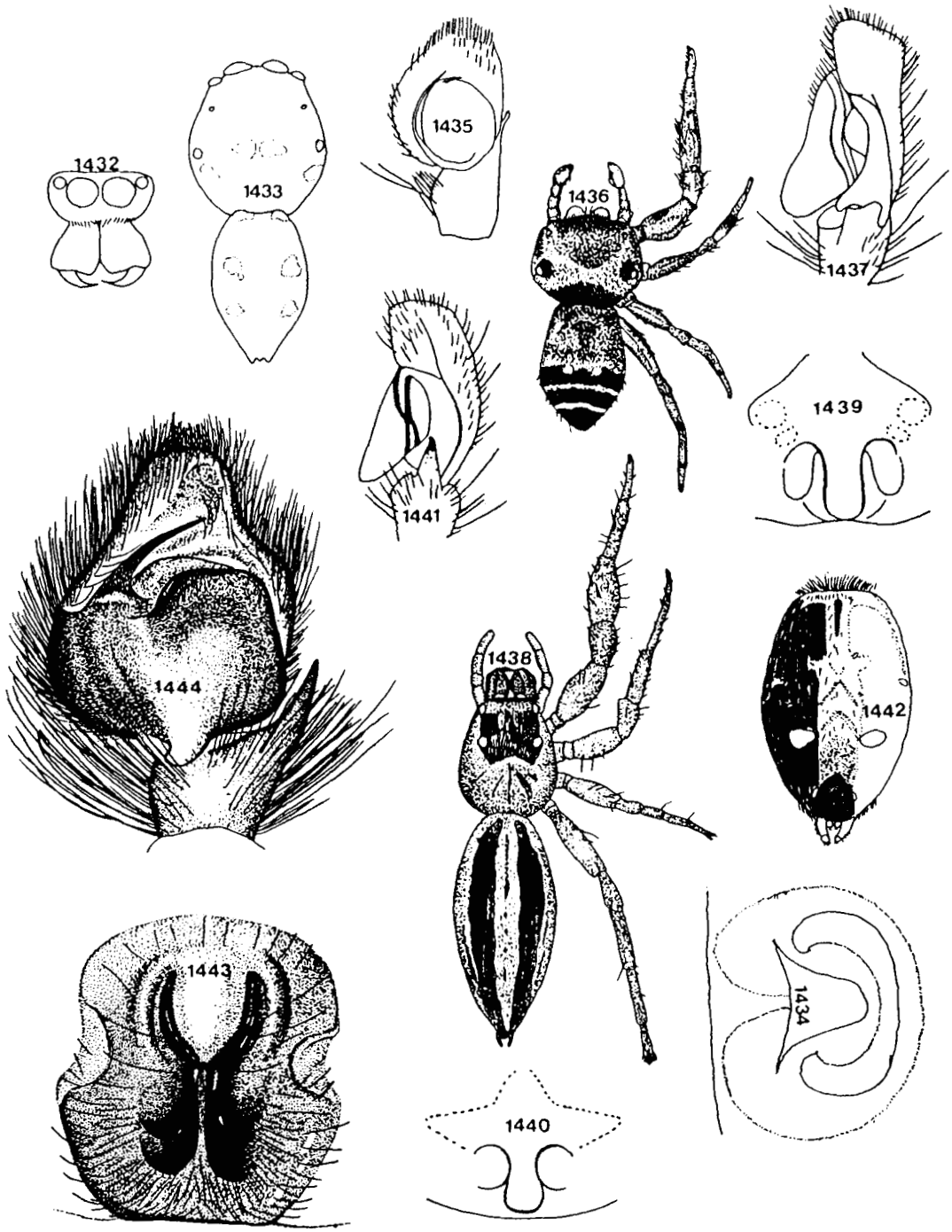
738(736') Retromarginal tooth bifid; eyefield black; cephalothorax with a white band running from behind of left anterior lateral eye to the sides of posterior eye transversing a little below midcephalothorax and ends near right anterior lateral eye; patella + tibia of leg III as long as patella + tibia of leg IV; abdomen greyish to slightly mottled with short and brown hairs in female and black with a wide transverse crescentic band of white across front (Fig. 1447, left) and 2 small white spots towards rear in male (Fig. 1447, right); male without eyebrows in the eye region; epigynum very small with apically converging oblong-shaped structures (Fig. 1448); palpal organ with very small apophysis and embolus, tibia clearly longer than tarsus (Fig. 1449) . . . . . *Hasarius adansoni* (Audouin)

738' Retromargin with a single tooth, cephalothorax without such band running from right to left; anterior lateral eyes passing back of posterior lateral eyes; tibia + patella of leg III shorter than patella + tibia of leg IV; abdomen usually with a light transverse basal band; posterior median eyes twice as far from posterior lateral eyes as from the anterior laterals (Fig. 1450); male with eyebrows in the eye region (Fig. 1451); epigynum moderately large . . . . . *Phidippus* sp.

739(730') Legs I and II usually larger and longer than III and IV, powerful and laterigrade; body crab-like in shape 740

739' All legs of the usual prograde type; body shape not crab-like 755

740(739) Diminutive spinneret (colulus) absent; inner margin of chelicera armed with teeth; apex of metatarsus with a soft trilobate membrane allowing hyperextension of tarsus; posterior eye row recurved with prominent laterals; maxilla not crested; male carapace marked with a large black nearly V-shaped band (Fig. 1452); tibial apophysis short but



Figs. 1432-1444

with 2 teeth (Fig. 1453); female with a yellow-black bordered stripe on the posterior slope of carapace, epigynum with lateral lobes in contact (Fig. 1454); legs very long and spotted black [Sparassidae] . . . . . *Heteropoda venatoria* (Linnaeus)

740' Diminutive spinneret (colulus) present; inner margin of chelicera smooth, the outer alone with teeth; apex of metatarsus sclerotized not allowing hyperextension [Thomisidae] 741

741(740') Legs about equal in length and with true claw tufts; integument with plumose or squamose hairs 742

741' Legs I and II longer than III and IV, claw tuft simple when present; integument with simple hairs 745

742(741) Anterior lateral eyes (ALE) nearer to the anterior median eyes than to the posterior median eyes; anterior eyes smaller and shorter in length than the posterior eyes; posterior eyes more recurved than anterior eyes, medians much farther apart from each other than from the lateral eyes; abdomen with a light broad median band and banded black subdorsally, broadest in apical one-third and moderately rounded towards the tip; legs mottled usually subbasally and subapically in all tibiae (Fig. 1455); epigynum ovoid-shaped with a pair of elongate canals at median (Fig. 1456) . . . . . *Philodromus spinitarsis* Simon

742' Anterior lateral eyes closer to the posterior median eyes than to the anterior median eyes 743

743(742') Posterior eyes not strongly recurved and nearly equidistant from each other; anterior eyes closer to the anterior median than to the posterior eyes; cephalothorax hardly longer than wide; abdomen usually oval with a well marked cardiac area (Fig. 1457) . . . . . *Thanatus* sp.

743' Posterior eyes strongly recurved; abdomen long, cigar-shaped and with a median longitudinal band extended to cephalothorax up to anterior median eyes; posterior part of abdomen with or without paired spots 744

744(743') Posterior part of abdomen without paired black spots (Fig. 1458) . . . . . *Tibellus* sp.

744' Posterior part of abdomen with a pair of black spots; cardiac area with small paired black spots within the band (Fig. 1459); ejaculatory duct of palpal organ in male with a single slightly oblique loop at median, embolus small and acutely pointed (Fig. 1460); epigynum with a pair of small globular rings touching epigastric furrow and separated by a concave posterior piece (Fig. 1461) . . . . . *Tibellus oblongus* (Walckenaer)

745(741') Eyes situated on distinct protuberances 746

745' Eye tubercles indistinct, only slightly protuberant in appearance 749

746(745) Abdomen widened and truncated posteriorly; eyes borne on the tubercles 747

746' Abdomen long and laterally corrugated; eyes borne on a carina 748

747(746) Carapace with a median white T-shaped band and a broad longitudinal deep brown band on each side; abdomen longer than wide and subelliptical; dorsum with 4-5

pointed black sigilla, lateral sides of abdomen with 3-4 deep brown longitudinal thin lines (Fig. 1462); epigynum half moon-like facing each other (Fig. 1463) . . . . . *Thomisus cherapunjeus* Tikader

747' Carapace without such pattern but with a transverse white band along posterior eyes in the female; abdomen of male reddish brown and whitish in female, with 5 rounded dorsal sigilla in both sexes; wider than long and semitruncated posteriorly (Fig. 1464); epigynum inverted J-shape opposite each other (Fig. 1465); palpal organ with a laterally projected tibial apophysis and an upwardly directed one reaching almost half of cymbium (Fig. 1466) . . . . . *Thomisus* nr. *labefactus* Karsch

747" Carapace without white T-band, posterolateral angle of cephalothorax rounded; anterior and posterior portion of abdomen strongly rounded with humps laterally (Fig. 1467); leg I with a median or submedian spot in femur, tibia, and metatarsus; epigynum simple with a globular band above epigastric furrow and transverse ovate slit at middle (Fig. 1468) . . . . . *Thomisus okirawensis* Strand

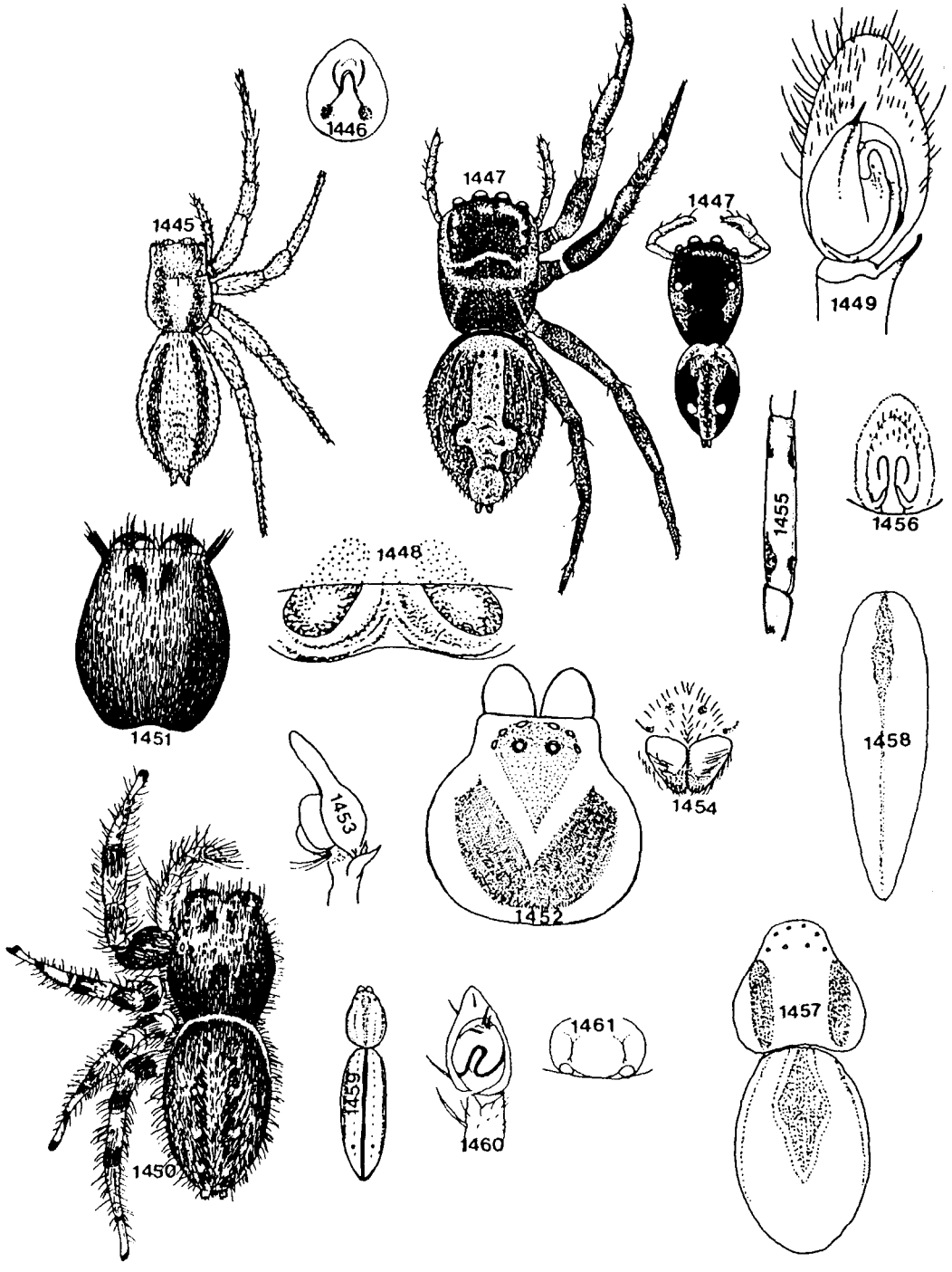
748(746') Carapace with a prominent, thinly white T-shaped band at middle, sides with a parallel brown band of uniform diameter in its entire length; abdomen nearly parallel sided with slightly rounded posterior end, median area with a pair of small longitudinal brown bands and lateral sides with about 4 longitudinal corrugations (Fig. 1469); epigynum with a dome-shaped median structure, basal ends loop inwards close to the epigastric furrow (Fig. 1470) . . . . . *Runcinia albostriata* Boesenberg & Strand

748' Carapacial T-shaped white band and broad lateral dark brown bands both prominent but not reaching posterior margin; abdomen with 3 prominent longitudinal corrugations, venter with oblique dark brown marks (Fig. 1471); epigynum marked with 2 subovate structures bridged together anteriorly by a narrow dome-shaped process (Fig. 1472) . . . . . *Runcinia* sp.

748" Carapace with an indistinct T-band, lateral sides with a posteriorly widened dark brown band; abdomen tapers posteriorly, median area with a long broad pigmented discontinuous line from the base to the tip, lateral sides with conspicuous muscular corrugations and elevated ridges each provided with a row of spines (Fig. 1473); epigynum with a transversely C-shaped structure at middle (Fig. 1474) . . . . . *Runcinia roortwali* Tikader

749(745') Cephalic region as wide as the thoracic region; squarish cephalothorax red, high and clothed with black hairs; anterior and lateral parts deep brown to black, median area also deep brown but not in the male; globular abdomen with a longitudinal, chalk-white anchor-like band at middle and 2 transverse white bands medio-laterally (Fig. 1475) . . . . . *Camaricus formosus* Thorell

749' Cephalic region narrower than the thoracic region 750



Figs. 1445-1461

750(749') Inner half of femur I slightly swollen and narrowed in the basal half, 2-3 spines present near the swollen area; tibia with 5 pairs of ventral spines; posterior one-fourth of abdomen transversely lined with clavate setae 751

750' Femur I normally shaped, posterior one-fourth of abdomen without clavate setae 752

751(750) Abdomen parallel-sided except in the posterior one-fourth, median area with a longitudinal broad dark band; posterolateral corner of cephalothorax with clavate setae (Fig. 1476); tip of tibial apophysis subtruncate (Fig. 1477); chelicera with 4 outer and 3 inner teeth and 4 minute ones in between the 2 rows (Fig. 1478) . . . . . *Regillus* sp. A

751' Abdomen not parallel-sided and median area without a broad dark band; posterolateral corner of cephalothorax without clavate setae (Fig. 1479); tip of tibial apophysis rounded (Fig. 1480); chelicera with 4 teeth each in the outer and inner row (Fig. 1481) . . . . . *Regillus* sp. B

752(750') Tubercles of lateral eyes broadly separated, anterior eyes slightly recurved and posterior row strongly recurved; carapace flat above with 2 subparallel, broad dark bands running from posterior lateral eyes to the basal one-eighth of cephalothorax in female, U-shaped in the male; abdomen with 2 parallel dark brown bands in female (Fig. 1482) and 5-6 transverse posterior bands in male (Fig. 1483) . . . . . *Xysticus* sp.

752' Tubercles of lateral eyes confluent 753

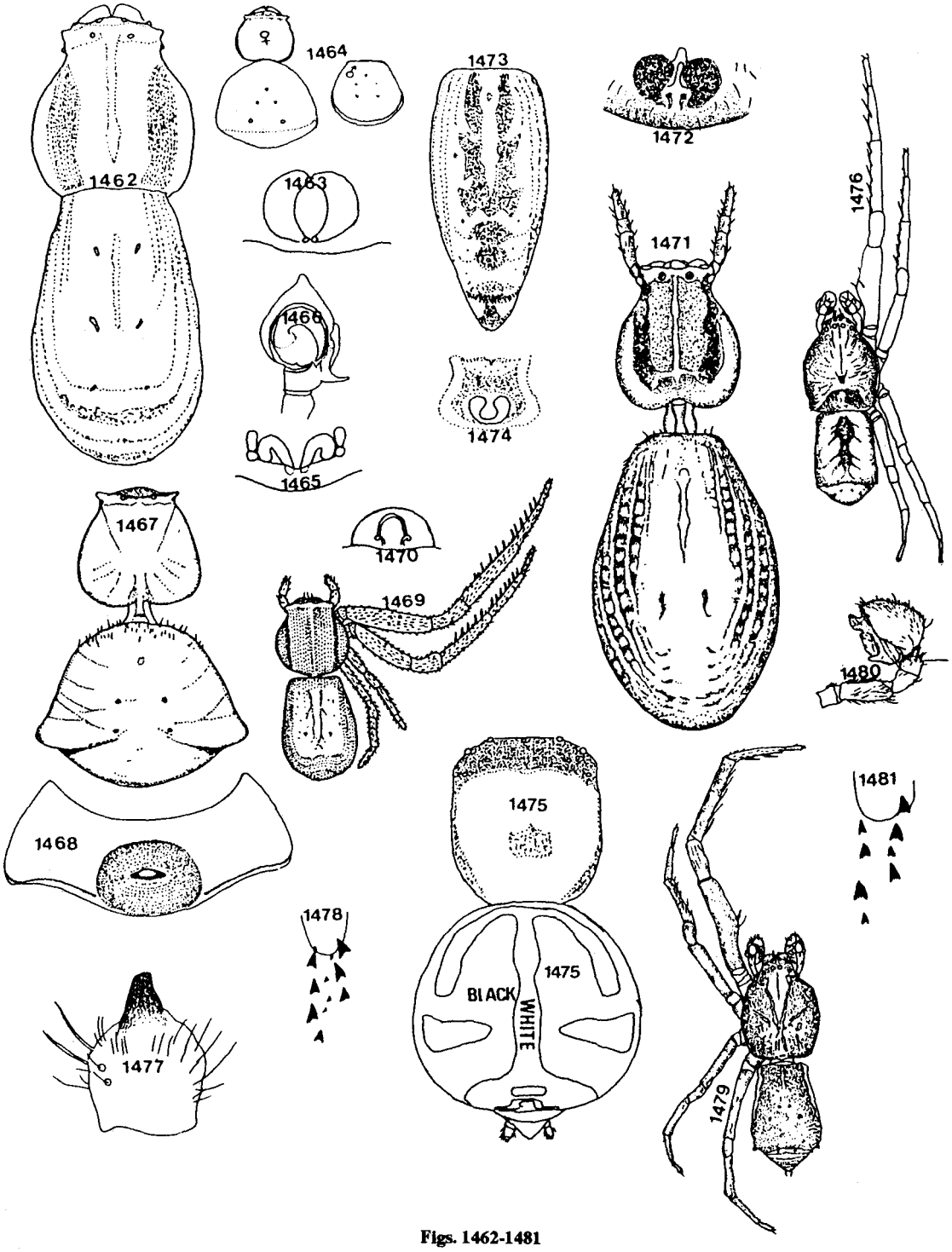
753(752') Anterior eyes similar in size and nearly equidistant; carapace unmarked; abdomen with moderate longitudinal striations laterally and slightly pointed posteriorly (Fig. 1484) . . . . . *Misumena* sp.

753' Anterior lateral eyes larger than the anterior medians 754

754(753') Abdomen with an inverted V-shaped reddish brown band anteriorly and 3-4 thin transverse reddish brown stripes posteriorly, cephalothorax green similar to femur I-IV and almost entire leg III and IV in female (Fig. 1485); epigynum subovate with a transverse C-shaped median mark (Fig. 1486); male cephalothorax reddish brown with a pair of longitudinally broad dark reddish brown bands, abdomen with an ovoid green band at center and a brown spot each opposite its broadest part (Fig. 1487); tibia of palp with a bifurcated retrolateral and inwardly curved ventral apophysis (Fig. 1488) .... *Misumenops tricuspidatus* (Fabricius)

754' Abdomen devoid of an inverted V-shaped band but with 6-8 globular black spots anteriorly and 2 oblique dark bands posteriorly; cephalothorax with dark patches laterally and posteriorly (Fig. 1489) . . . . . *Misumenops* sp.

755(739') Anterior spinnerets cylindrical and separated by a distance about equal to the diameter of one; maxilla with oblique depression; eyes heterogenous, anterior medians dark and normal in position; posterior medians usually oblique [Gnaphosidae] 756



Figs. 1462-1481

755' Anterior spinnerets conical and contiguous; maxilla without oblique or transverse depression; eyes homogeneous [Clubionidae] 758

756(755) Tibia IVwith 2 or more median dorsal spines; eye rows well separated, posterior median eyes nearer each other than to the laterals and oblique; abdomen ovoid (Fig. 1490); sternum posteriorly pointed with labium and maxilla rounded apically (Fig. 1491) . . . . . *Drassodes* sp.

756' Tibia IV with 0-1 median dorsal spine; eyes close together with normal posterior medians and recurved posterior eye row 757

757(756') Abdomen with a white narrow transverse band below the submedian pair of brown spots and about 4 thin concave dark stripes posteriorly (Fig. 1492); ventro-posterior part with a transverse subundulate white stripe above spinnerets (Fig. 1493); epigynum triangular with a pair of elongated, unevenly shaped structures (Fig. 1494) . . . . . *Poecilochroa* sp. A

757' Abdomen with a broad transverse white band dorsosubmedially below the second pair of spots and posteroventrally above spinnerets (Fig. 1495); epigynum with a pair of small ovoid and diverging structures at middle close to epigastric furrow (Fig. 1496) . . . . . *Poecilochroa sp. B*

758(755') Thoracic fovea absent, leg I the longest; posterior spinnerets longer than the anterior 759

758' Thoracic fovea present; leg IV the longest; anterior spinnerets almost as long as the posterior 763

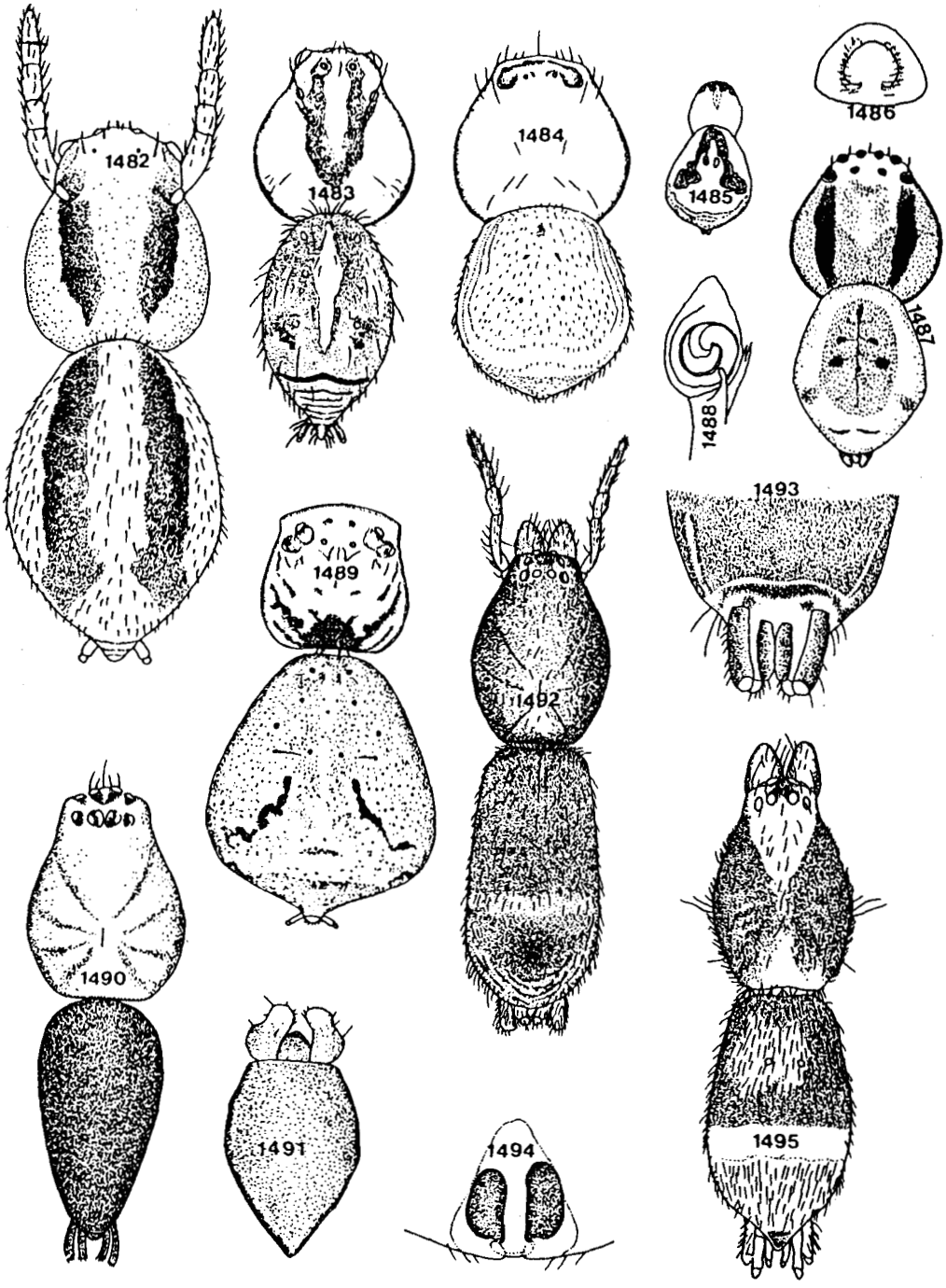
759(758) Abdomen naturally ovoid 760

759' Abdomen elongate-ovate or slightly narrowed in apical one-fourth with sides of cephalic region produced to a small point; cardiac area very distinct 761

760(759) Apices of palp, tarsus and metatarsus blackish (Fig. 1497); epigynum with a knob-like cavity at center emanating from epigastric furrow (Fig. 1498); palpal organ with a slender and apically rounded cymbium, tarsal apophysis long with the inwardly angled-curve part sharply pointed, tibial apophysis single but bifurcated at tip (Fig. 1499); female produces a regularly looped shelter in a rice leaf (Fig. 1500) . . . . . *Chiracanthium japonicum* Boesenberg & Strand

760' Apices of leg segments unmarked (Fig. 1501); epigynum with a pair of moderately robust C-shaped structures facing each other above epigastric furrow, dorsal portion clearly separated (Fig. 1502) . . . . . *Chiracanthium* sp. A

761(759') Cephalic region moderately developed along lateral sides (raised as viewed dorsally); abdomen rounded towards the posterior but with subparallel lateral margins in the basal one-fourth (Fig. 1503); tarsal apophysis sickle-shaped, long and extended beyond diameter of tibia, tibial apophysis single but minutely bifurcated at tip (Fig. 1504); inner



Figs. 1482-1495

margin of chelicera with 5 teeth (6 in some spiders and the most basal), apical one the largest (Fig. 1505) ..... *Chiracanthium* sp. B

761' Cephalic region not elevated laterally, protrusion absent 762

762(761') Posterior spinnerets noticeably long; lateral sides of cephalothorax with some reddish brown patches (Fig. 1506); chelicera without subapical lateral tooth; abdomen elongate ovate; epigynum lip-like with black bands laterally (Fig. 1507); tarsal apophysis short and sharply pointed downwards, tibial apophysis single, reddish dark brown and rounded at tip (Fig. 1508) ..... *Chiracanthium* nr. *unicum* Boesenberg & Strand

762' Posterior spinnerets relatively long; cephalothorax unmarked; abdomen widest a little above midhalf and equally rounded anteriorly and posteriorly (Fig. 1509); chelicera with a subapical lateral tooth (Fig. 1510); tarsal apophysis rather broad and pointed at tip; apex of tibia with a small ventral apophysis and a slightly inwardly curved tip of retrolateral apophysis (Fig. 1511) ..... *Chiracanthium* sp. C

762" Posterior spinnerets moderately exserted; cephalothorax uniformly brownish, darker in the cephalic region and lightly colored in the thoracic part (Fig. 1512); a female spider rests inside a folded rice leaf looped 3 times in a diagonal pattern (see arrow); epigynum with a transverse elongate mark adjacent to the epigastric furrow, and with 4 additional pale marks, 2 globular dorsally and 2 ovoid laterally (Fig. 1513); tarsal apophysis of male sharply pointed inwards but without angled corner in its entire length (Fig. 1514) ..... *Chiracanthium lascivum* Karsch

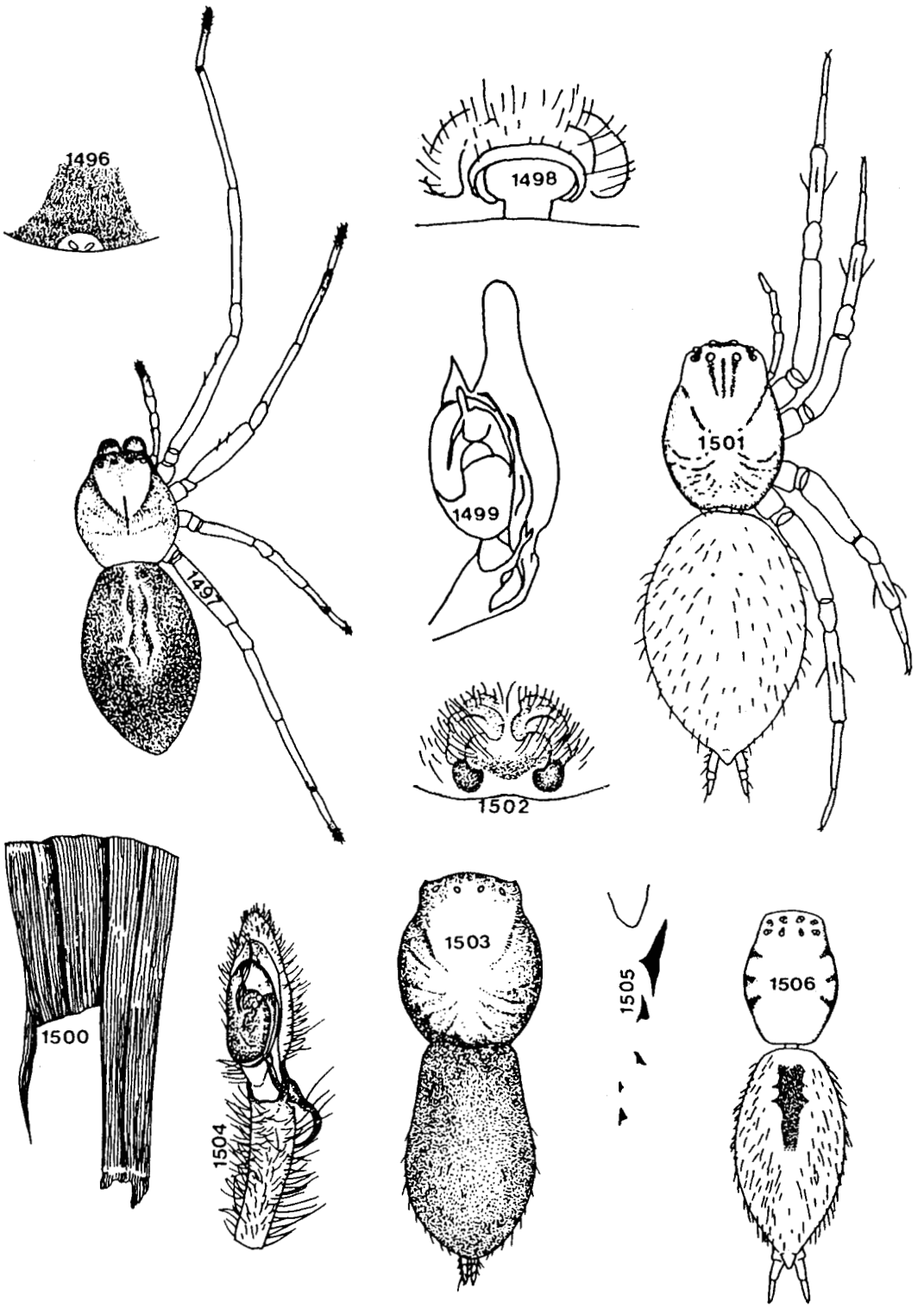
763(758') Abdominal dorsum mottled with greyish to black spots forming a transverse line; legs with greyish to brown bands 764

763' Abdomen and legs unmarked 765

764(763) Carapace with 2 long lateral longitudinal bands and 3 short bands in the cephalic area almost converging along fovea; abdomen with at least 5 concave interrupted bands (Fig. 1515); legs with dark bands near apex of femur, both ends of tibia, and apex of metatarsus (Fig. 1516) ..... *Clubiona* sp. A

764' Carapace without lateral longitudinal bands; abdomen with 7 convex interrupted bands (Fig. 1517); legs without bands; epigynum with 2 semi S-shaped structures facing each other, very broad to subglobular basally towards the epigastric furrow and diverging, normally shaped towards apex and converging, and in contact at middle (Fig. 1518); palpal organ with an outwardly curved embolus (Fig. 1519) ... *Clubiona vigil* Karsch

765(763') Chelicera blackish brown to dark reddish brown with 2 promarginal and 4-5 retromarginal teeth; abdomen of female usually oblong with largely rounded anterior and posterior ends (Fig. 1520); epigynum with a pair of spherical structures anteriorly and paired elongate process posteriorly (Fig. 1521); palpal organ with a sickle-shaped embolus, cymbium laterally rounded at apex; and a bifurcated tibial apophysis (Fig. 1522) ..... *Clubiona japonicola* Boesenberg & Strand



Figs. 1496-1506

765' Chelicera usually brown to light brown; female abdomen usually smaller than above; epigynum and palpal organ differently structured 766

766(765') Abdomen shortly ovoid; E. Asian species 767

746' Abdomen moderately long to very long; S. E. Asian species 768

767(766) Carapace reddish brown; abdomen brown with silky white hairs; femora of legs with 2 dorsal setae (Fig. 1523); epigynum with a pair of circular structures at middle and half-moon like black patches on each side, posterior margin double-notched (Fig. 1524); palpal organ with a short concealed embolus, cymbium slightly pointed at tip and with a depression below it viewed laterally, ventral tibial apophyses much longer than the retrolateral (Fig. 1525) ..... *Clubiona lena* Boesenberg & Strand

767' Carapace light brown; abdomen yellowish brown; femur of legs with 3 dorsal setae (Fig. 1526); epigynum simple, midposterior area closely bilobed with a narrow cleft in between (Fig. 1527); apex of tibia of palpal organ with 2 apophyses nearly converging, ventral apophysis long and bifurcated reaching midhalf of cymbium (Fig. 1528) ..... *Clubiona kurilensis* Boesenberg & Strand

768(766') Lateral side of abdomen with a small tubercle subapically and with some moderately long setae dorsomedially; abdomen 1.4 times longer than cephalothorax (Fig. 1529); chelicera with 6 promarginal and 4 retromarginal teeth (Fig. 1530) ..... *Clubiona* sp. B

768' Abdomen long, more than 1.6 times longer than cephalothorax and without lateral swellings subapically (Fig. 1531); epigynum broadly U-shaped with slightly converging arms well rounded apically, median with a pair of J-like processes opposite each other (Fig. 1532); tibia of palpal organ with a short and broad retrolateral apophysis and 2 long setae at median length (Fig. 1533) ..... *Clubiona* sp. C

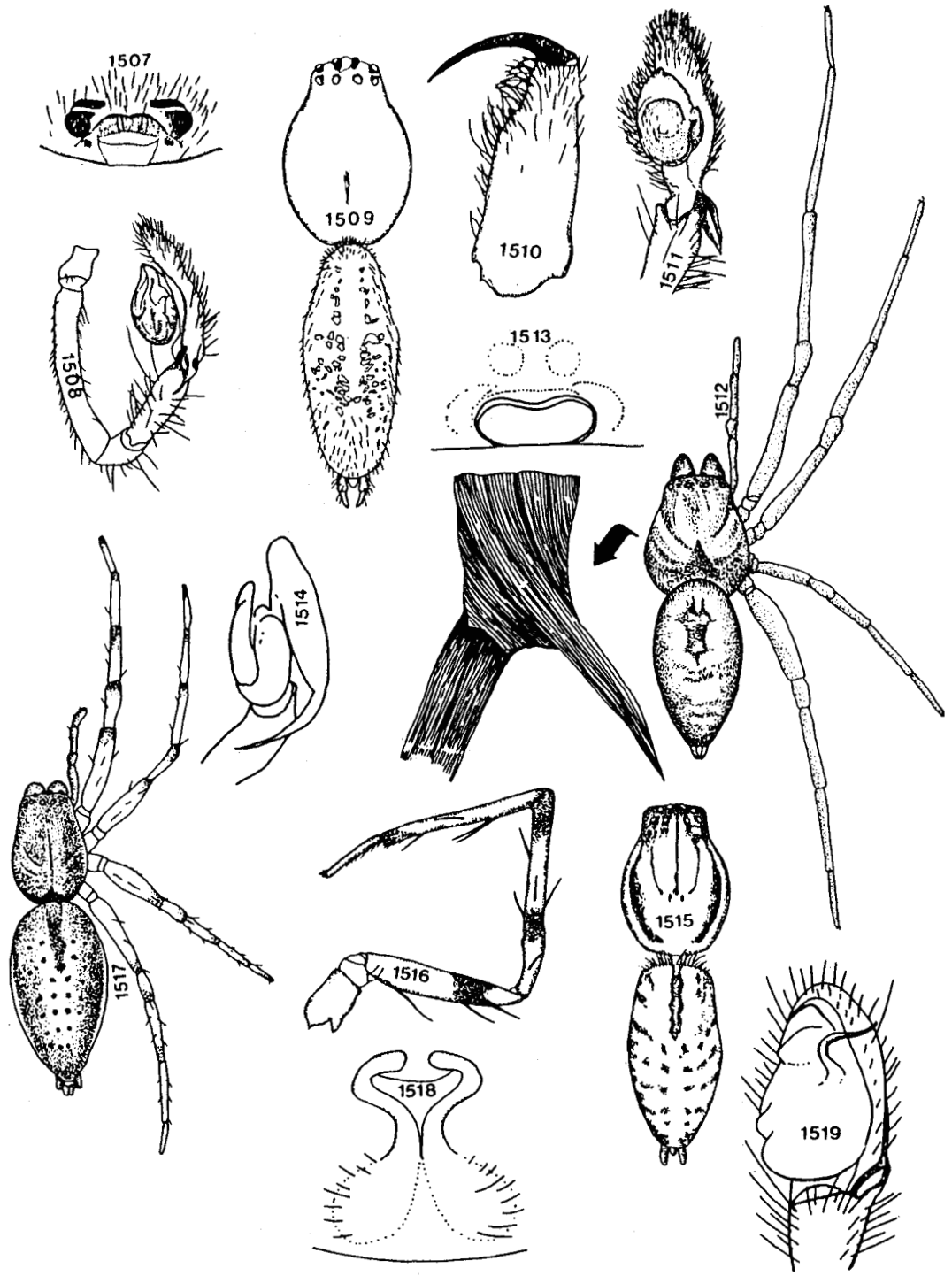
769(729') All legs conspicuously spinose; eye group in a hexagonal pattern, anterior median eyes very small; clypeus usually high 770

769' Legs not conspicuously spinose; eyes never arranged hexagonally 773

770(769) Abdomen with 2 blackish red sublateral (= subdorsal) longitudinal bands similar to the carapace; hexagonal eyes very close to each other (Fig. 1534); epigynum with a dome-shaped median process (Fig. 1535); palpal organ with a long cymbium, apophysis on tibia blunt and hardly protruded outside (Fig. 1536) ... *Oxyopes macilentus* L. Koch

770' Abdomen with oblique sublateral bands; hexagonal eyes not very close to each other 771

771(770') Tibial apophysis of palpal organ very long; cymbium moderately long; embolus curved downward (Fig. 1537); epigynum with a moderately broad median protruding process posteriorly, arms subparallel anteriorly (Fig. 1538) ..... *Oxyopes javanus* Thorell



Figs 1507-1519

771' Tibial apophysis of palpal organ without a long process; epigynum with different structure 772

772(771') Epigynum widely cleft posteromedially with a pair of small cone-like structures anteriorly (Fig. 1539); embolus short and hooked moderately downwards; cymbium slightly short at apex; apex of tibia with 2 small and short apophyses (Fig. 1540) . . . . . *Oxyopes sertatus* L. Koch

772' Epigynum strongly concave with a pair of ball-like structures anteriorly (Fig. 1541); embolar area with 2 slender and a large apically truncate processes; cymbium with a slightly slender and acute apex, base opposite apex of tibia cleft producing 2 tubercles; apex of tibia with a blunt and semi-rounded lateral process (Fig. 1542) . . . . . *Oxyopes Iinealipes* (C. L. Koch)

773(769') Six spinnerets in a transverse row (Fig. 1543) and tracheal spiracles closer to the spinnerets than to the epigastric fold; abdomen with 3 black longitudinal bands interconnected on both ends and 3-4 transverse narrow bands posteriorly (Fig. 1544); anterior median eyes smaller than anterior laterals; posterior eye row strongly procurved (Fig. 1545); chelicerae with 2 promarginal and retromarginal teeth each (Fig. 1546)[Hahniidae] . . . . . *Hahnia* sp.

773' Spinnerets not in a transverse line 774

774(773') Tarsus IV with a comb of serrated setae (Fig. 1547) [Theridiidae] 775

774' Tarsus IV without a serrated comb of setae 782

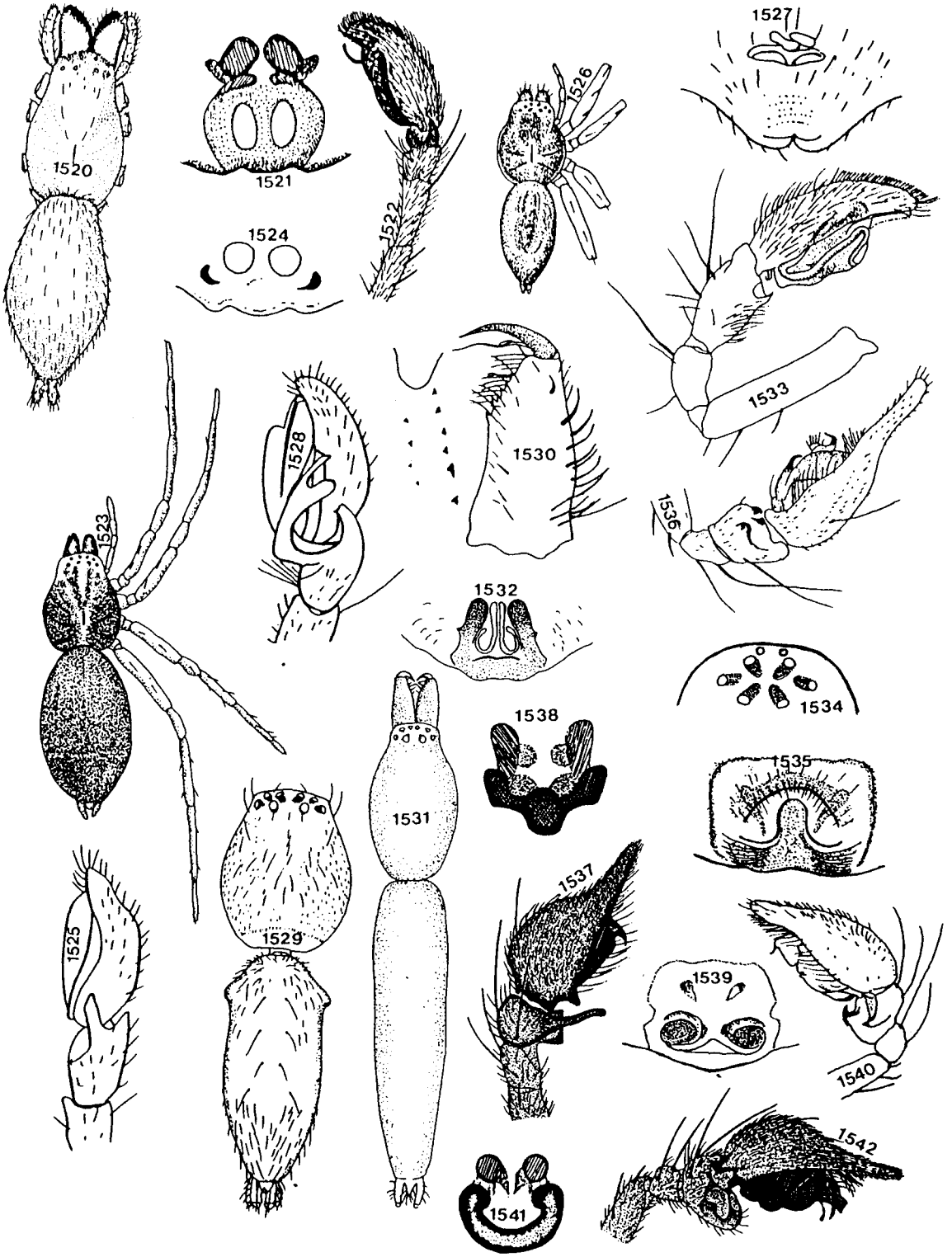
775(774) Cephalothorax with a transverse groove in the middle; abdomen usually prolonged either above (with triangular appearance) or elongated behind the spinnerets; cephalic area of male usually raised 776

775' Cephalothorax without transverse groove; abdomen subglobular or slightly prolonged 780

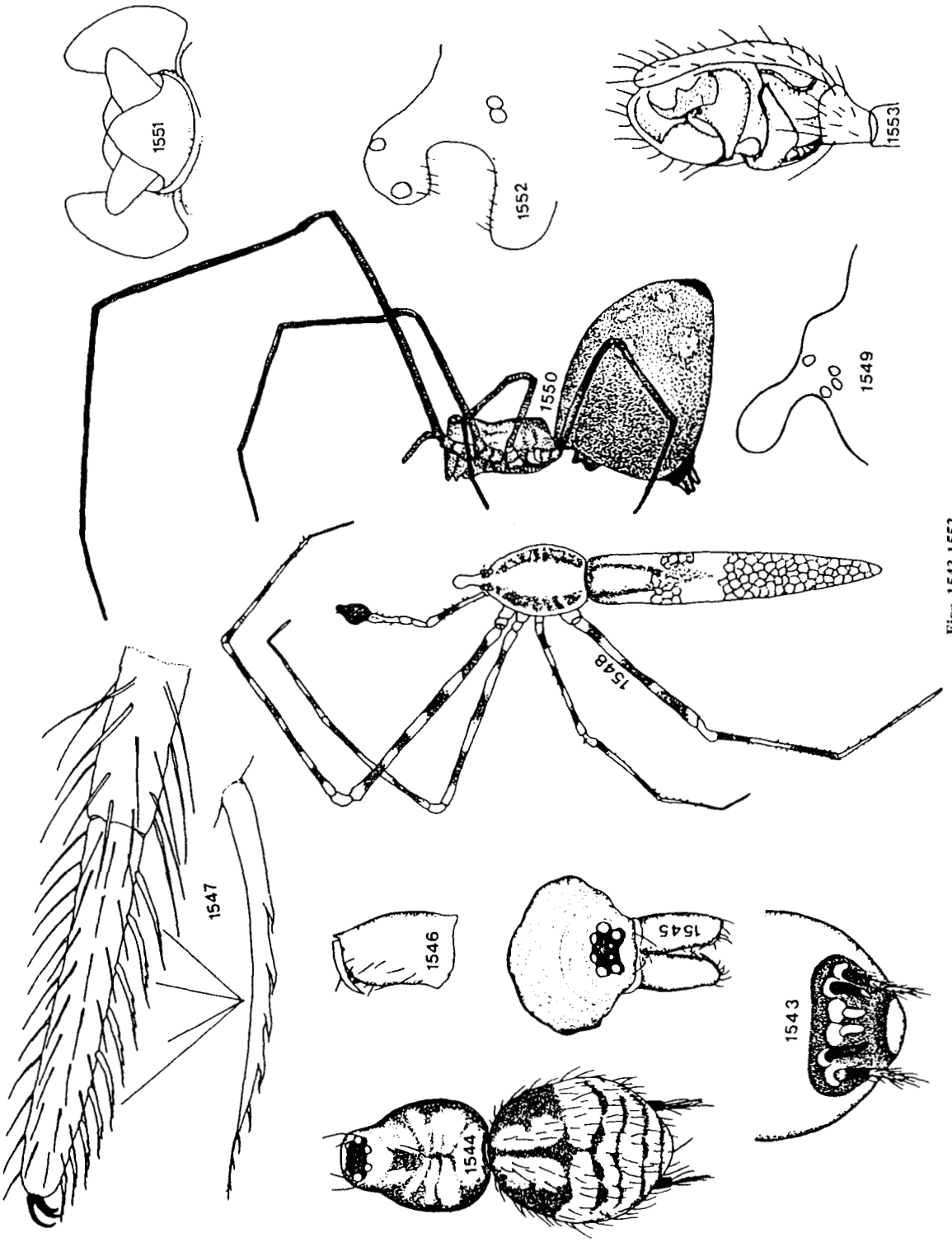
776(775) Abdomen very long and slender, much prolonged behind the spinnerets and tapers posteriorly; carapace with longitudinal brown bands on each side of the elevated foveal area (Fig. 1548); projection in the male head moderately knob-like and without eyes viewed laterally (Fig. 1549); legs long and slender with alternate transparent (colorless) and yellow band (Fig. 1548) . . . . . *Argyrodes saganus* (Doenitz & Strand)

776' Abdomen more or less subtriangular 777

777(776') Abdomen orange-red with a black spot posteroventrally around spinnerets and on top posterodorsally, 4 silvery lateral spots present just below dorsal black spot; margin between 2 black spots almost straight (Fig. 1550); tibia I a little shorter than metatarsus I; median part of epigynum with a pair of diverging horn-like processes directed and overhanging expanded ear-like structures in the lateral sides (Fig. 1551); laterally, male horn on head with 2 eyes, anterior eye slightly bigger than the posterior and deeply



Figs. 1520-1542



Figs. 1543-1553

concave to U-shaped from base of cephalic region (Fig. 1552); parategular apophysis shortly curved and with a middle tooth (Fig. 1553) . . . . . *Argyrodes miniaceus* (Doleschall)

777' Abdomen mostly silvery, subtriangular, and pointed posterodorsally 778

778(777') Venter and basolateral area of abdomen yellowish brown; in lateral view, posterodorsal tip of abdomen in an oblique position from the spinnerets, the latter almost at midhalf from pedicel to posterodorsal end (Fig. 1554); tibia I much longer than metatarsus I; epigynum truncated anteriorly and concaved posteriorly with a bilobed structure at middle (Fig. 1555); laterally, male horn V-shaped from base of cephalic region, with 2 eyes of equal diameter (Fig. 1556); paracymbium narrow medially and slightly swollen apically, median apophysis triangular (Fig. 1557) . . . . . *Argyrodes fissifrons* O.P. -Cambridge

778' Venter and basolateral part of abdomen black, rest uniformly silvery 779

774(778') Abdomen tapers and pointed upward towards the posterior (Fig. 1558); cephalic area of male deeply cleft or V-shaped in lateral view, horn rounded anteriorly with 2 eyes of different diameter, anterior eye larger than the posterior (Fig. 1559); tibia I shorter than metatarsus I; epigynum half circular anteriorly with a subquadrate plate posteriorly containing a pair of globular structures inside (Fig. 1560); palpal organ with a large apophysis anteriorly and transverse tibia (Fig. 1561) . . . . . *Argyrodes bonadea* (Karsch)

779' Abdomen more or less rounded (half ovate) posterodorsally in lateral view; tibia I longer than metatarsus I (Fig. 1562); epigynum with a tongue-like median structure (Fig. 1563) . . . . . *Argyrodes* sp.

780(775') Cephalothorax, legs and abdomen light green; abdomen with 4 pairs of black spots dorsally in the female (Fig. 1564) and 3 pairs in the male (Fig. 1565); epigynum a simple plate with rounded anterior margin and truncate posterior margin, middle with a double hook-like process (Fig. 1566); tibia of palpal organ without a neck basally, tegular apophysis slender and pointed at tip, cymbium rounded on top (Fig. 1567) . . . . . *Theridion octomaculatum* (Boesenberg & Strand)

780' Body and leg coloration yellowish brownish to black or reddish brown; abdomen without paired black spots, usually rounded or with a small hump or protrusion posterodorsally 781

781(780') Carapace with a broad grey-brown longitudinal band trifurcated towards lateral eyes; abdomen subglobular, dorsally blackish brown interrupted medially with silvery marks along cardiac area and laterally with 2 indentions (Fig. 1568); chelicera with an upwardly and laterally projected spine (Fig. 1569); epigynum with a transverse lace-like median structure (Fig. 1570); cymbium bifurcated towards apex, tibia almost 2 times longer than wide (Fig. 1571) . . . . . *Enoplognatha japonica* (Boesenberg & Strand)

781' Carapace without any band; abdomen dorsally ovoid to moderately elongate-ovate, posterodorsally with a protrusion in female and a small hump in male viewed laterally (Fig. 1572); anterior part of male abdomen cleft; epigynum with a pair of subparallel black bands opposite the indention of the posterior margin, median piece Y-shaped (Fig. 1573); cymbium rounded apically, tibia as long as wide apically, embolus long, curved, and with a broad base (Fig. 1574) . . . *Coleosoma blandum* O. P. -Cambridge

782(774') Tarsus IV with very fine hairs (trichobothria) arising at a 90° angle from leg (Fig. 1575); trochanters with or without notch; lip not rebordered 783

782' Tarsus IV without trichobothria; trochanters without notch; lip usually rebordered 809

783(782) Trochanters without notch; tarsus with a single row of trichobothria and usually 3-clawed; terminal segment of posterior spinnerets visible above; longer than basal segment; abdomen with irregularly straight transverse light bands interrupted in cardiac area; carapace with 2 reddish brown bands, broad in the thoracic area and narrowed to a point towards posterior lateral eyes (Fig. 1576); epigynum with a transverse orifice anteriorly divided medially by a longitudinal line (Fig. 1577); tibia of palpal organ with a moderately acute apical apophysis; cymbium swollen subbasally and slender apically (Fig. 1578) . . . . . *Agelena labyrinthica* (Clerck)

783' Trochanters with a notch; tarsus with numerous trichobothria 784

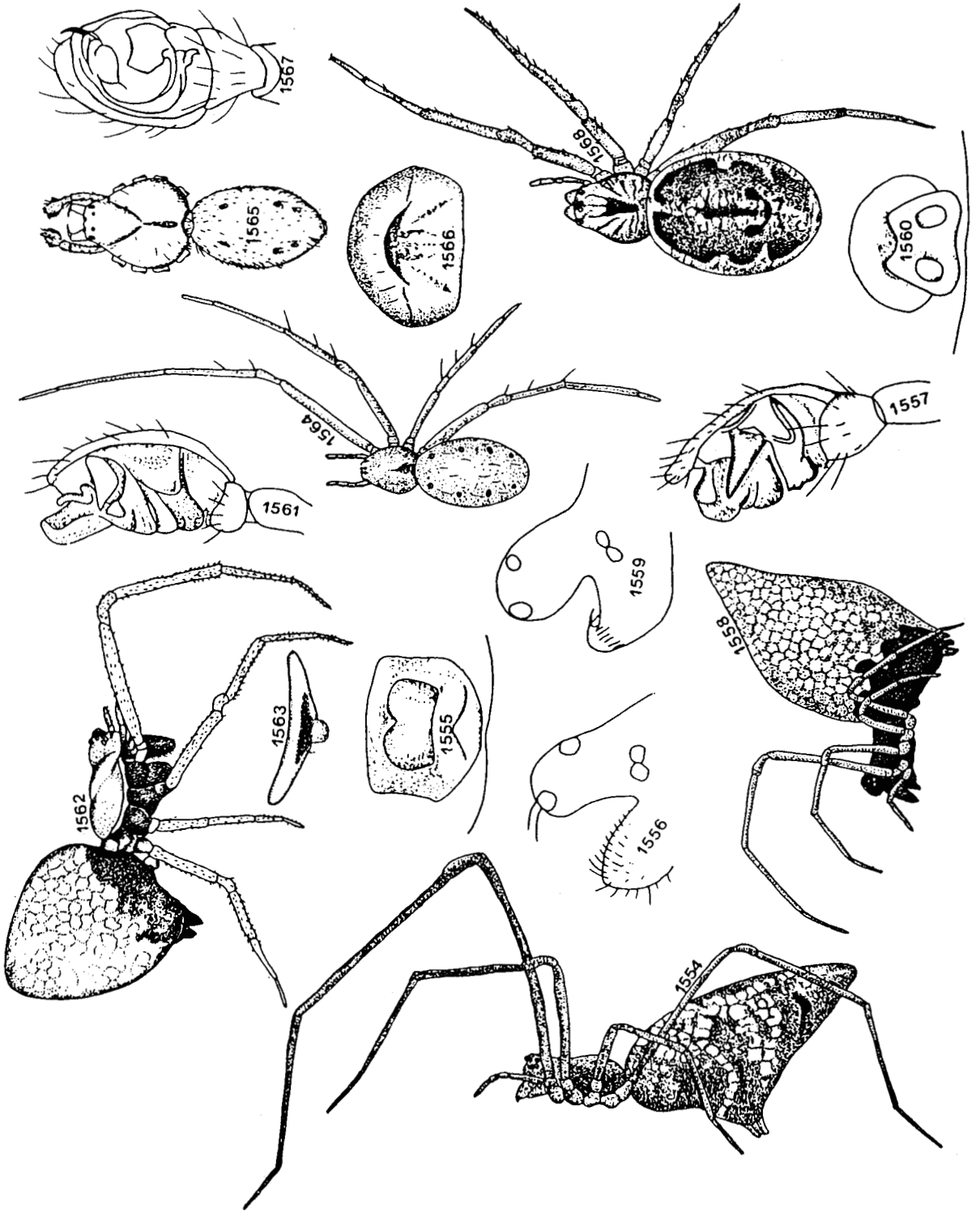
784(783') Median claw of tarsus with 2-3 teeth; lower margin of cheliceral furrow with 3-4 teeth; posterior eye row not forming 2 distinct rows and not strongly recurved; anterior piece of lorum of pedicel with a notch into which the posterior part fits [Pisauridae) . . .785

784' Median claw smooth or with a single tooth; posterior eye row strongly recurved forming 2 rows; anterior piece of lorum rounded behind and fits into a notch of the posterior part [Lycosidae] 787

785(784) Lower margin of cheliceral furrow with 3 teeth; carapace with a relatively broad median longitudinal white band and 2 dark brown to reddish brown longitudinal bands laterally all extended up to the entire length of abdomen (Fig. 1579); sternum yellow media-longitudinally and with 6 ovoid yellow spots along sides (Fig. 1580); epigynum anchor-like with rounded tip of lateral arms and broadened body base (Fig. 1581); palpal organ with a knife-like retrolateral apophysis hairy on the back side (Fig. 1582) . . . . . .*Pisauru lama* Boesenberg & Strand

785' Lower margin of cheliceral furrow with 4 teeth; middorsum of carapace and abdomen with a broad brown band followed by a narrow white band on each side (Fig. 1583) 786

786(785') Epigynum bulb-like, broad below midhalf but almost truncated in the apical margin provided with elongated patches off each side, posterior epigynal margin not cleft medially (Fig. 1584) . . . . . *Dolomedes angustivirgatus* Kishida



Figs. 1554-1568

786' Epigynum tapers to a rounded anterior margin, posterior epigynal margin with 2 clefts producing a small tongue-like process at center (Fig. 1585); apophysis of tibia bluntly truncate in the retrolateral and small but pointed in the ventrolateral, cavity of cymbium rounded apically below embolus (Fig. 1586) ..... *Dolomedes sulfureus* Boesenberg & Strand

787(784') Posterior spinnerets distinctly longer than the anterior, apical segment conical and as long as basal; anterior eye row a little longer than the posterior row; sternum with a median longitudinal black band (Fig. 1587) 788

787' Posterior spinnerets slightly longer than the anterior and apical segment hemispherical and very short; anterior eye shorter than the posterior row; sternum without a median longitudinal black band 789

788(787) Small spiders, total length 9 mm; epigynum bifurcated posteriorly, showing a W-shaped appearance (Fig. 1588); anterior eye row straight; labium longer than wide; distal end of maxilla with distinct scopulae; cephalothorax clothed with line hairs and spine-like hairs in the lateral margins; abdomen pale brown with transverse patches dorsomedially, subtriangular light band opposite tip of anterior median longitudinal brown band (Fig. 1589); palpal organ with a slender apical half of cymbium (Fig. 1590) ..... *Hippasa greenalliae* (Blackwall)

788' Total length less than 9 mm; epigynum with a subtruncate tongue-like structure along the posterior margin (Fig. 1591); anterior eye row slightly procurved; labium wider than long; distal end of maxilla without distinct scopulae; cephalothorax with pubescence, without spine-like hairs in the lateral margins; abdomen strongly chequered, anterior median longitudinally reddish brown followed by pairs of large and less regular lateral grey brown spots (Fig. 1592); palpal organ with a rather short apical part of the cymbium (Fig. 1593) ..... *Hippasa holmerae* Thorell

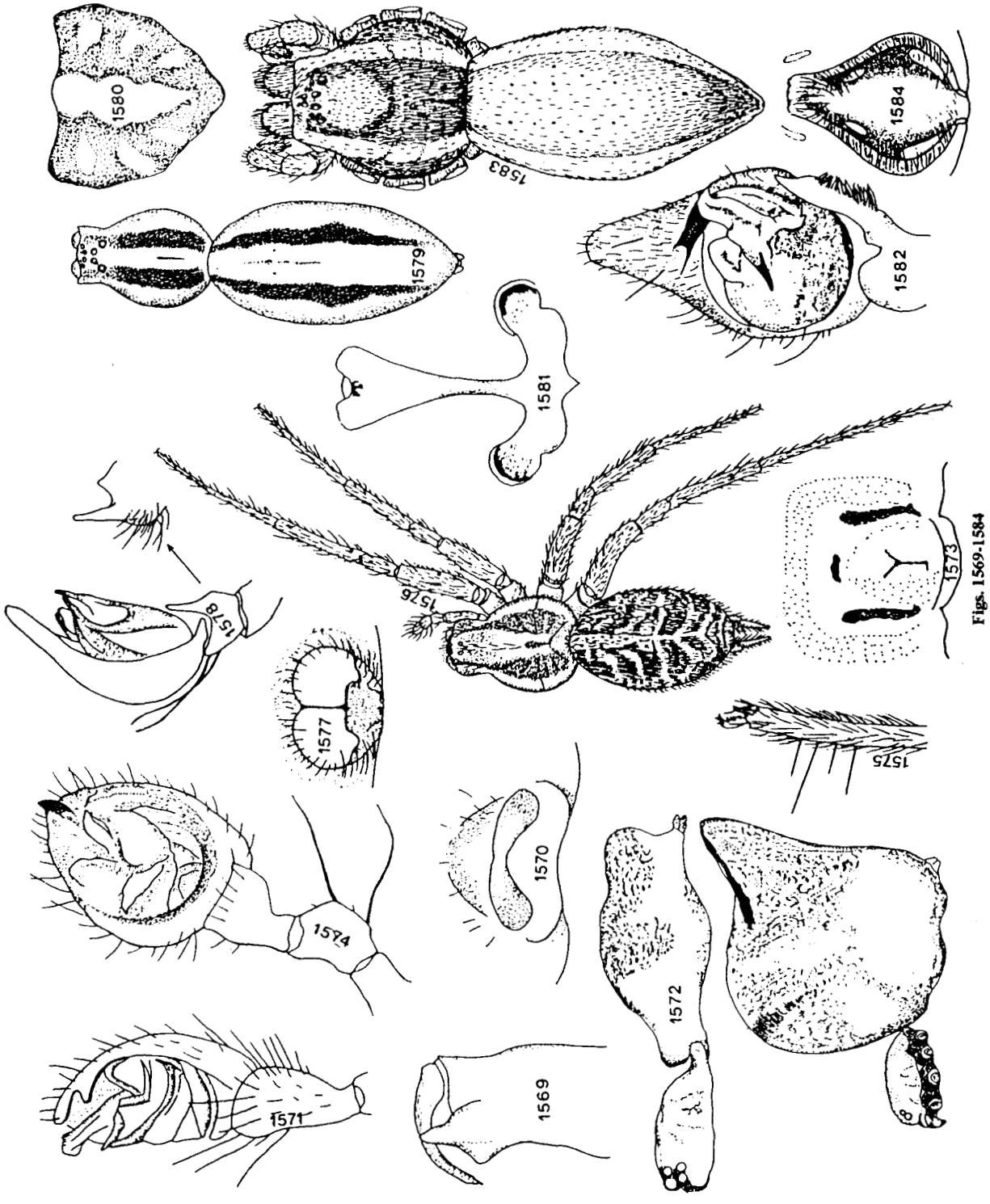
789(787') Metatarsus IV longer than or as long as tibia + patella together; labium wider than long; clypeus vertical viewed laterally; cephalic region not much elevated from thoracic region; superior claw entirely toothed; carapace usually with median band 790

789' Metatarsus IV shorter than tibia + patella combined; clypeus may or may not be slanting viewed frontally 799

790(789) East Asian species of *Pardosa* 791

790' South and Southeast Asian species of *Pardosa* 794

791(790) Anterior part of the median fight band as broad as the distance between the posterior lateral eyes, tapers posteriorly and constricted a little above fovea; head with a truncated area below anterior eye row; chelicera with a thin longitudinal band basally (Fig. 1594); abdomen more lightly colored than carapace with semirectangular to hat-like marks dorsally towards the posterior (Fig. 1595); epigynum cleft posteromedially between 2 lateral openings and bears 2 oblique structures at middle (Fig. 1596); cymbium with 2



Figs. 1569-1584

teeth at apex; median apophysis broad but short and rounded apically ventrally and truncate laterally; terminal apophysis slightly hooked (Fig. 1597) . . . . . *Pardosa laura* (Karsch)

791' Median light band of carapace widens towards posterior lateral eye (PLE) row, as wide as or wider than the distance from PLE-PLE 792

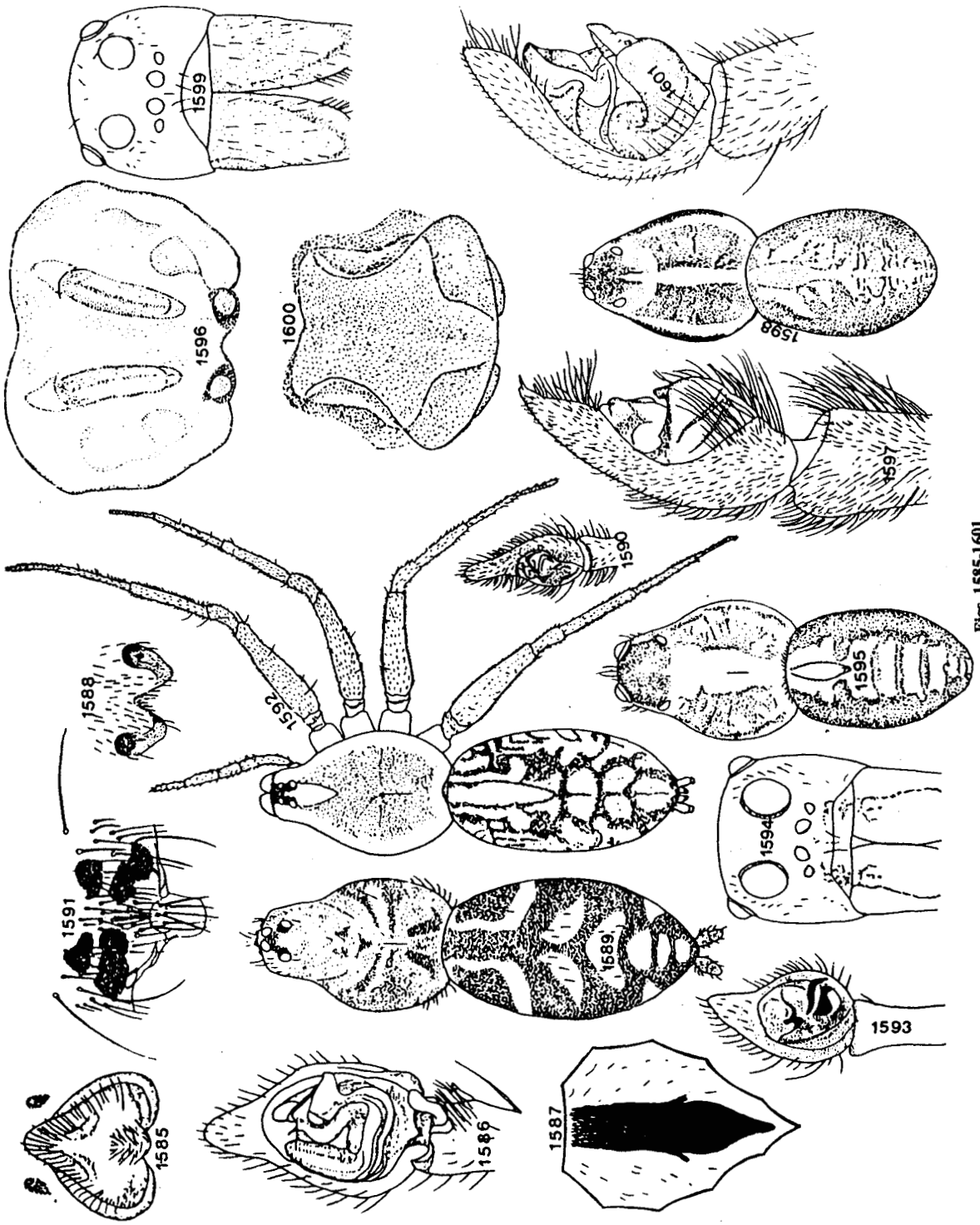
792(791') Median band narrow and slightly trifurcated cephalad, outer arms curved to the lateral sides of each posterior lateral eye and the median almost traversing mid-PLE distance, submargins with narrower bands; abdomen with transverse elongate marks below the tower-like light band in the cardiac area (Fig. 1598); front of head strongly recurved below anterior eye row, each chelicera with a short basolateral longitudinal thin band (Fig. 1599); epigynum with a very broad median piece posteriorly and constricted before anterior margin (Fig. 1600); median apophysis longer than wide, narrowed before a rounded apex, terminal one bifurcate at apex (Fig. 1601) . . . . . *Pardosa palustris* (Linnaeus)

792' Median band not trifid apically behind posterior eye row; abdominal dorsum with light colored rectangular or paired to transverse elongate bands below cardiac area 793

793(792') Dorsum of abdomen with about 3-4 transversely elongated light bands posteriorly and a pair of ovoid light bands on the side of the tapering posterior end of the cardiac area; median light band of the carapace slightly T-shaped, broad below posterior eyes and narrowed posteriorly (Fig. 1602); clypeus high, more than 1 anterior median eye diameter, and concave medially, chelicera without distinct longitudinal bands frontally (Fig. 1603); epigynum with a narrow truncated structure at midposterior margin, widens towards the inside orifice becoming dome-shaped subanteriorly (Fig. 1604); median apophysis sickle-shaped with a rounded tip, tip of cymbium without spine (Fig. 1605) . . . . . *Pardosa astrigera* L. Koch

793' Dorsum of abdomen with 3-4 transversely rectangular light bands opposite posterior end of cardiac area: median light band of carapace not T-shaped (Fig. 1606); clypeus high, almost 2 anterior median eye diameters and recurved, chelicera with 2 parallel longitudinal bands dorsomedially (Fig. 1607); epigynum with a truncated plate slightly beyond posterior epigynal margin and a pair of oblique orifices towards the anterior margin (Fig. 1608); tip of cymbium with 3 teeth, median apophysis broadly rounded apically with a small hook at lower midhalf, terminal apophysis small and lanceolate-like (Fig. 1609) . . . . . *Pardosa isago* Tanaka

794(790') Median light band of carapace prominently forked or Y-shaped anteriorly, sublateral margins with a longitudinal white band; abdomen with 4-5 transverse light bands dorsally (Fig. 1610) in the male and 3 elongate-ovate light bands and a pair of globular light spots dorsally in the female (Fig. 1611); epigynal lateral margin indented inside before posterior end, guide slender and enlarged apically toward posterior epigynal



Figs. 1585-1601

margin (Fig. 1612); tip of cymbium without teeth, terminal apophysis downwardly sickle-shaped, embolus noticeable (Fig. 1613) ..... *Pardosa pseudoannulata* (Boesenberg & Strand)

794' Dorsum of carapace without a Y-shaped or forked anterior median band 795

795(794') Median and submarginal bands indistinct 796

795' Median and submarginal bands distinct 797

796(795) Ocular area covered by posterior eye blackish brown made to an inverted U-shaped light band between posterior lateral eyes; anterior eyes short and straight; sides of cephalic area lightly colored (Fig. 1614); abdomen clothed with fine hairs, dorsum pigmented brown with pale dots; tibia and metatarsus of legs I and II with 4 and 3 pairs of ventral spines; epigynum concave anteriorly with a pair of sclerotized oblique C-shaped cavities at center (Fig. 1615); palpal tibia long about 0.5 times of cymbium; terminal apophysis sharply pointed (Fig. 1616) ..... *Pardosa sutherlandi* (Gravely)

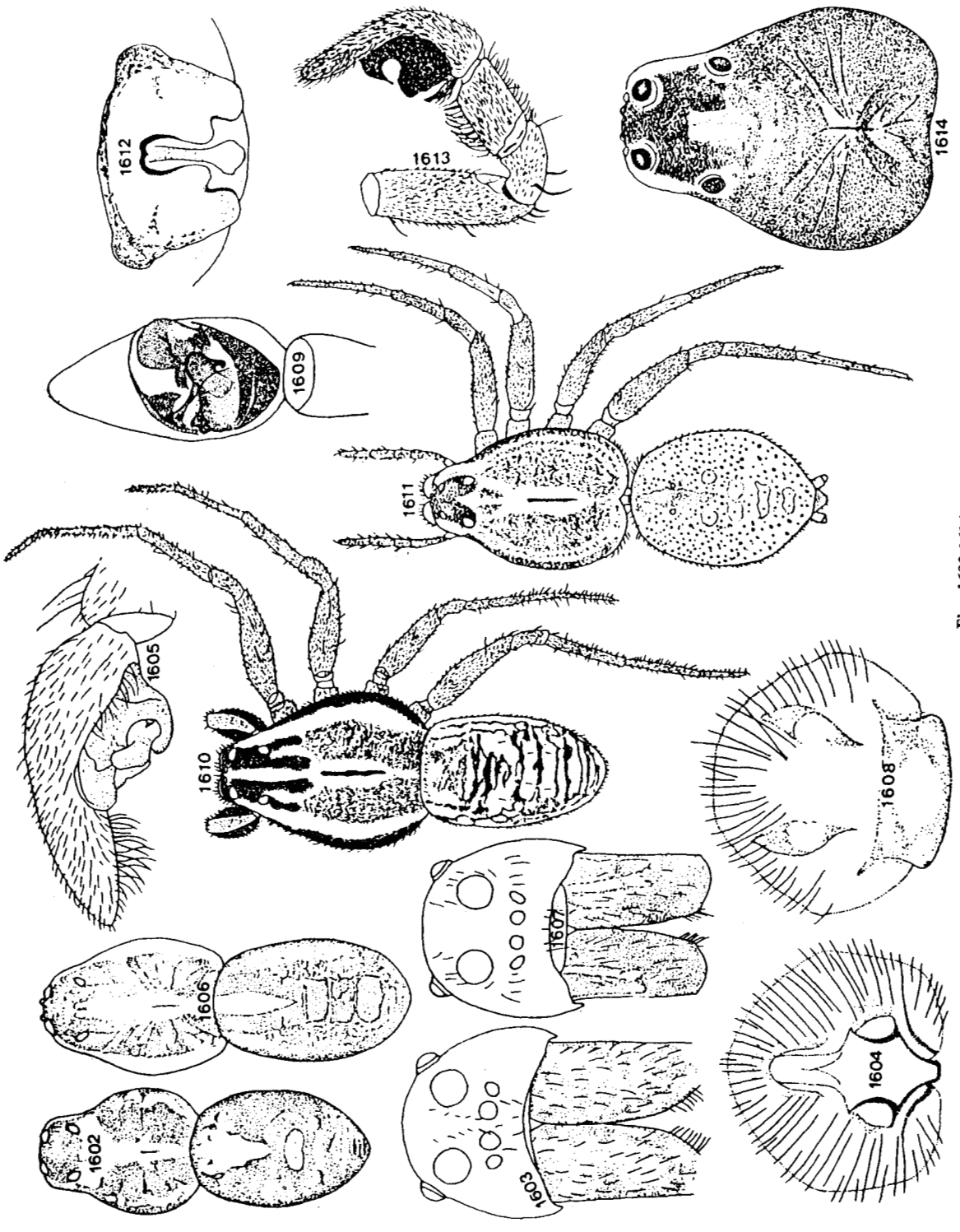
796' Ocular area uniformly dark without an inverted U-shaped mark; sides of cephalic area blackish brown; anterior eyes slightly procurved; abdomen with 3 pairs of subglobular yellow spots and 3-4 transversely irregular light bands (Fig. 1617); epigynum with a rounded to angulate-truncate anterior margin, guide body very narrow only about 0.5 times diameter of guide pocket (Fig. 1618); palp with a white tibia and black tarsus in male (Fig. 1619) ..... *Pardosa birmanica* Simon

797(795') Abdomen clothed with minute light spots all over dorsally; ocular area black and hairy; light median band on carapace tapers posteriorly, constricted above fovea and bifurcated in between posterior lateral eyes (Fig. 1620); submarginal band not very wide; epigynum strongly rounded in the anterior margin, indented posteriorly and bears an expanded tongue-like median plate (Fig. 1621); maxilla with inconspicuous scopulae ..... *Pardosa annandalei* (Gravely)

797' Abdomen with paired lens-like spots; median light band extended inside the ocular area forming an inverted U or partly V-shaped band in the cephalic area; submarginal band prominently wide 798

798(797') Cephalothorax brown; anterior end of light median band of carapace with a pair of small ovate light spots between the posterior lateral eyes (PLE) (Fig. 1622), or apex becoming pointed in between PLE to PME and between posterior median eyes (PME) (Fig. 1623); abdomen dark brown with transverse paired subglobular spots dorsally; apex of the median piece (guide) inverted T-shaped with arms hooked inward-upward (Fig. 1624); maxilla with conspicuous scopulae ..... *Pardosa sumatrana* (Thorell)

798' Cephalothorax yellowish brown, median light band widens above fovea and below posterior lateral eyes, black bases of lateral eye darker than submedian bands (Fig. 1625); abdomen yellowish brown, mid-anterodorsal area with a lens-like marking followed behind by a pale band, sides with 2 longitudinal rows of brownish black bands



Figs. 1602-1614

from base to end; epigynum with a pair of subparallel sclerotized structures anteriorly and a pair of bibulbous structures along posterior epigynal margin (Fig. 1626) . . . . . *Pardosa oakleyi* Gravely

799(789') Carapace without a V-shaped marking above fovea; labium longer than wide . . . 800

799' Carapace with a prominent V-shaped marking above fovea; labium as long as wide to longer than wide 804

800(799) Tibia IV with 2 equally stout dorsal spines (Fig. 1627); anterior eye row straight to slightly procurved, anterior median eyes (AME) never smaller than anterior lateral eyes (ALE) 801

800' Tibia IV with the dorsal proximal spine thinner or more drawn out than the distal one and sometimes reduced to a bristle (Fig. 1628) 802

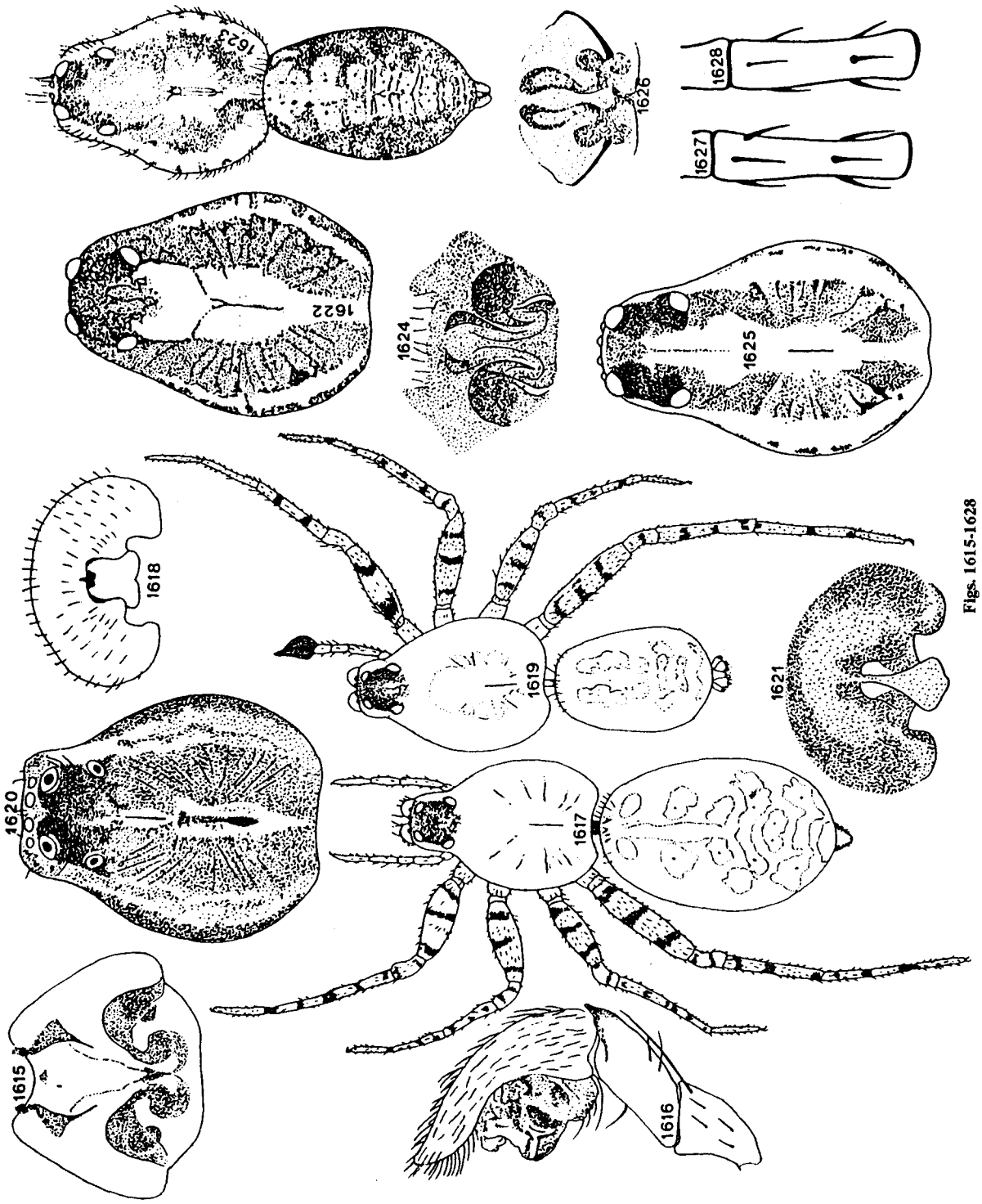
801(800) Median light band of carapace broad extended up to straight anterior median eyes, submedian dark bands similarly broad running from posterior lateral eyes and almost converged at base of carapace; abdomen longer than carapace, provided with reddish brown spots and transverse light brown patches posterodorsally (Fig. 1629); epigynum strongly rounded along anterior margin, posteriorly with 3 indentions, midcleft deeply Y-shaped (Fig. 1630); median apophysis almost rounded at tip, apex of cymbium slightly tapering (Fig. 1631); chelicera of male without dorsal tooth in the fang . . . . . *Lycosa chaperi* Simon

801' Median band of carapace reaching the area in between posterior median eyes (Fig. 1632); anterior eye row slightly recurved; submedian dark band open basally; abdomen shorter than carapace provided with irregular light and dark colored patches; fang of chelicera with a dorsal tooth almost at midlength (Fig. 1633) . . . . . *Lycosa* sp.

802(800') Carapace glabrous without definite longitudinal light band; cephalothorax reddish brown with head region not so distinct; anterior eye row recurved, medians twice as large as the laterals; sternum orange-brown; abdomen black with 3 pairs of brown dots dorsally and light gray ventrally, and shorter than carapace; tarsus I with dorsobasal bristle drawn out thin and fine at the end; legs with transverse bands (Fig. 1634); epigynum broadly subtriangular apically and slightly procurved posteriorly; median with a pair of oppositely faced sclerotized areas (Fig. 1635) . . . . . *Arctosa janetscheki* Buchar

802' Carapace hairy with a median light band; tarsus I without a long and thin dorsobasal bristle 803

803(802') Abdomen with a pair of light yellow longitudinal bands in the anterior half; cephalic area more lightly colored than the thoracic region; eye area without black bands (Fig. 1636); maxilla yellowish towards scopulae and brownish basally (Fig. 1637); epigynum semitriangular apically with a pair of light spots and subparallel trunk of median guide (Fig. 1638) . . . . . *Trochosa* sp. A



Figs. 1615-1628

803' Abdomen with transverse light bands usually with a pair of hairs in each cell; submedian carapacid band prominently dark colored similar to the U-shaped band of posterior eyes (Fig. 1639); maxilla uniformly light colored (Fig. 1640); epigynum with an anchor-like median guide producing 2 distinct clefts in the posterior margin, lateral margins each with an inwardly directed sclerotized hook-like process (Fig. 1641) . . . . . *Trochosa* sp. B

804(799') Anterior median eyes (AME) larger than anterior lateral eyes (ALE) 805

804' AME smaller than or equal to ALE 808

805(804) Anterior eye row as long as posterior median row; carapacial light lateral bands not separated from margins by dark brown bands 806

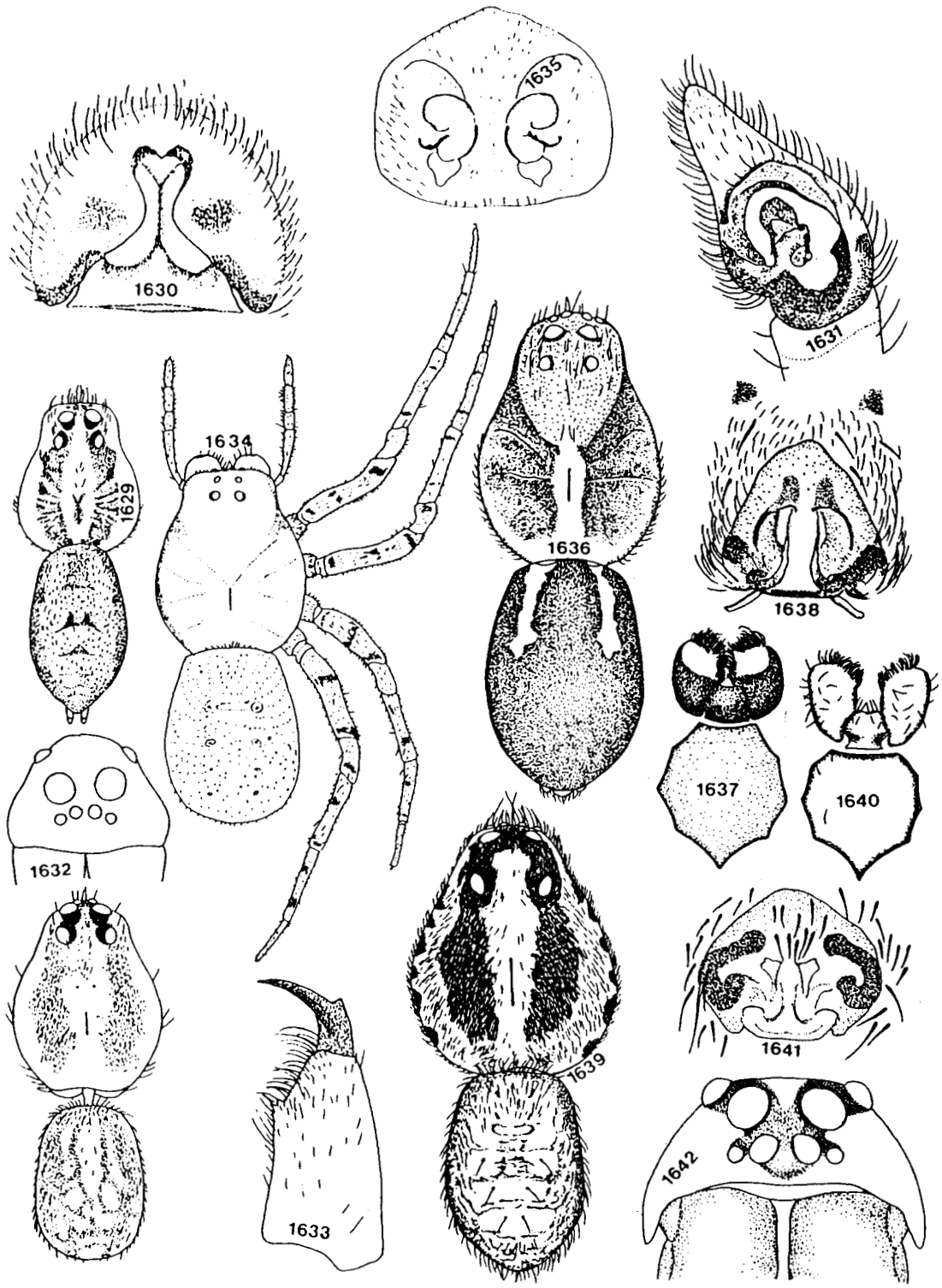
805' Anterior eye row shorter than posterior median row; carapace with a narrow dark brown line along margin; dark brown hands separate light lateral bands from margins in the carapace 807

806(805) Height of clypeus less than 0.5 diameter of AME; AME diameter about twice as large as anterior lateral eyes (Fig. 1642); V-shaped mark of carapace greyish brown; lateral sides of abdomen yellowish brown with blackish grey markings (Fig. 1643); legs grey-brown with indistinct annulations in all femora, metatarsus I with 2 ventral apical spines; epigynum with paired spatulate processes posteriorly and indistinct stalked spermathecae in apical margin (Fig. 1644); median apophysis with a long and slender margin and a small process at apex (Fig. 1645) . . . . . *Pirata subpiraticus* (Boesenberg & Strand)

806' Height of clypeus a little shorter than diameter of AME; AME about 1.5 times as large as ALE; V-shaped mark reddish brown; lateral sides of abdomen reddish brown with white pubescenee (Fig. 1646); legs dark yellowish brown, metatarsus I with 3 ventral apical spines, epigynum with trilobe-like structures at lateral sides, paired spermathecae spatulate and bottle-shaped (Fig. 1647); median apophysis obtuse with a pointed process (Fig. 1648) . . . . . *Pirata piraticus* (Clerck)

807(805') Height of clypeus as wide as AME diameter; AME moderately larger than ALE (Fig. 1649); V-Shaped band blackish brown; abdomen blackish grey with 3 pairs of white spots, a triangular one prominent medially (Fig. 1650); epigynum with a pair of oval processes creating a deep median cleft along posterior margin (Fig. 1651); median apophysis robust with a small dorsal projection (Fig. 1652) . . . . . *Pirata meridionalis* Tanaka

807' Height of clypeus less than half of AME diameter; AME twice as large as ALE (Fig. 1653); V-shaped band brown; abdomen yellowish brown with blackish grey markings, light transverse bands with acute and raised medians prominent dorsally (Fig. 1654); epigynum with paired posterolaterally inverted V-shaped structures (Fig. 1655), spermathecae long and erect (Fig. 1656), slightly diverging apically; robust median



Figs. 1629-1642

apophysis with long apical projection (Fig. 1657), retrolaterally it is wide at the upper part with one projection tapered at end on ventral margin (Fig. 1658) . . . . . *Pirata piratoides* (Boesenberg & Strand)

808(804') Anterior eye row strongly procurved; height of clypeus equal to 1 AME diameter; ME-AME and AME-ALE separation as long as 1 AME diameter (Fig. 1659); carapace with a very narrow dark brown line along margin; abdomen blackish grey dorsally with light transverse bands radiating from median longitudinal area (Fig. 1660); epigynum with a pair of slightly oblique button-like processes provided with 3 pairs of indistinct round structures, anterior epigynal margin strongly rounded and medially cleft along posterior margin (Fig. 1661) . . . . *Pirata procurvus* (Boesenberg & Strand)

808' Anterior eye row weakly procurved; height of clypeus 1.5 times AME diameter; AME closer to each other than to ALE (Fig. 1662); carapace without lines marginally; abdomen blackish grey with broad yellow-brown bands medio-dorsally (Fig. 1663); epigynum with a pair of prominent brown globular structures, median posterior epigynal margin deeply cleft, anterior margin rounded (Fig. 1664); robust median apophysis with a long and slender projection upward (Fig. 1665); retrolaterally sharp at apex . . . . . *Pirata clercki* (Boesenberg & Strand)

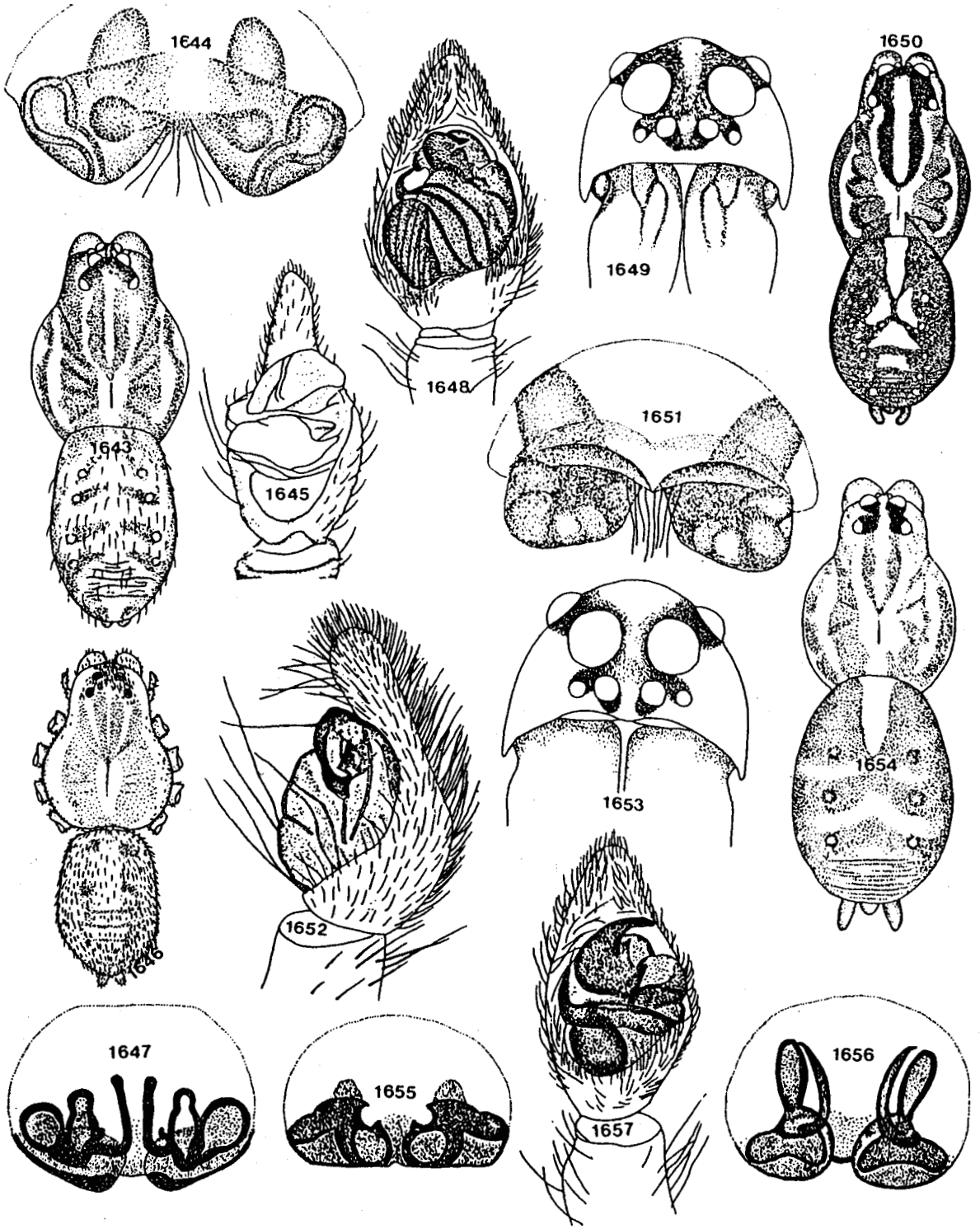
809(782') Chelicera with stridulating ridges (Fig. 1666); paracymbium of male a separate sclerite (Fig. 1667) [Linyphiidae] 810

809' Chelicera without stridulating ridges; paracymbium fused with cymbium (Fig. 1668); not a separate sclerite 814

810(809) Lateral margins of carapace serrated (Fig. 1669), anterior part of chelicera, femur of palpal organ maxilla with teeth; carapace glossy and dark brown or red-brown with darker cervical groove and radial striae; head raised without definite lobe; chelicera armed with a large pointed boss anteriorly and with a row of 6-7 warty teeth antero-laterally (Fig. 1670); sternum black; tibia I-III with 2 dorsal spines and IV with one; position of trichobothrium in metatarus IV 0.42-0.5; metatarsus longer than tarsi, IV without trichobothrium; epigynum prominently lobe-like and armed with a small chitinized brown tooth in the midposterior epigynal margin (Fig. 1671); femur of palpal organ nearly as long as femur II and curved mesally; patella half of femur, distally thickened with a long tapered apophysis ventrally; tibia slender basally with a long ventral projection armed with a small tooth ventrally; paracymbium strongly widened distally (Fig. 1672) . . . . . *Erigone prominens* (Boesenberg & Strand)

810' Lateral margins of carapace not serrated; metatarsus IV with a trichobothrium; superior tarsal claws with a few minute teeth 811

811(810') Position of trichobothrium in metatarsus IV 0.81; chelicera laterally convex, without stridulating organ; cephalic lobe of male distinct with a pit opened within an ocular sulci midway between posterior median eye to lateral (Fig. 1673); female without a cephalic lobe; abdomen with 4 pairs of grey spots in 2 longitudinal rows (Fig. 1674); epigynum



Figs. 1643-1657

with 2 clefts along posterior margin, each leading to an ovate diverging receptacle (Fig. 1675); palpal femur 2 times longer than patella; tibia with 3 sharp apical apophyses; embolic division with a broad triangular scaphium; paracymbium with a small basal part, slender but short median part and a large triangular end-piece (Fig. 1676) . . . . . *Atypena* (= *Callitrichia*) *formosana* (Oi)

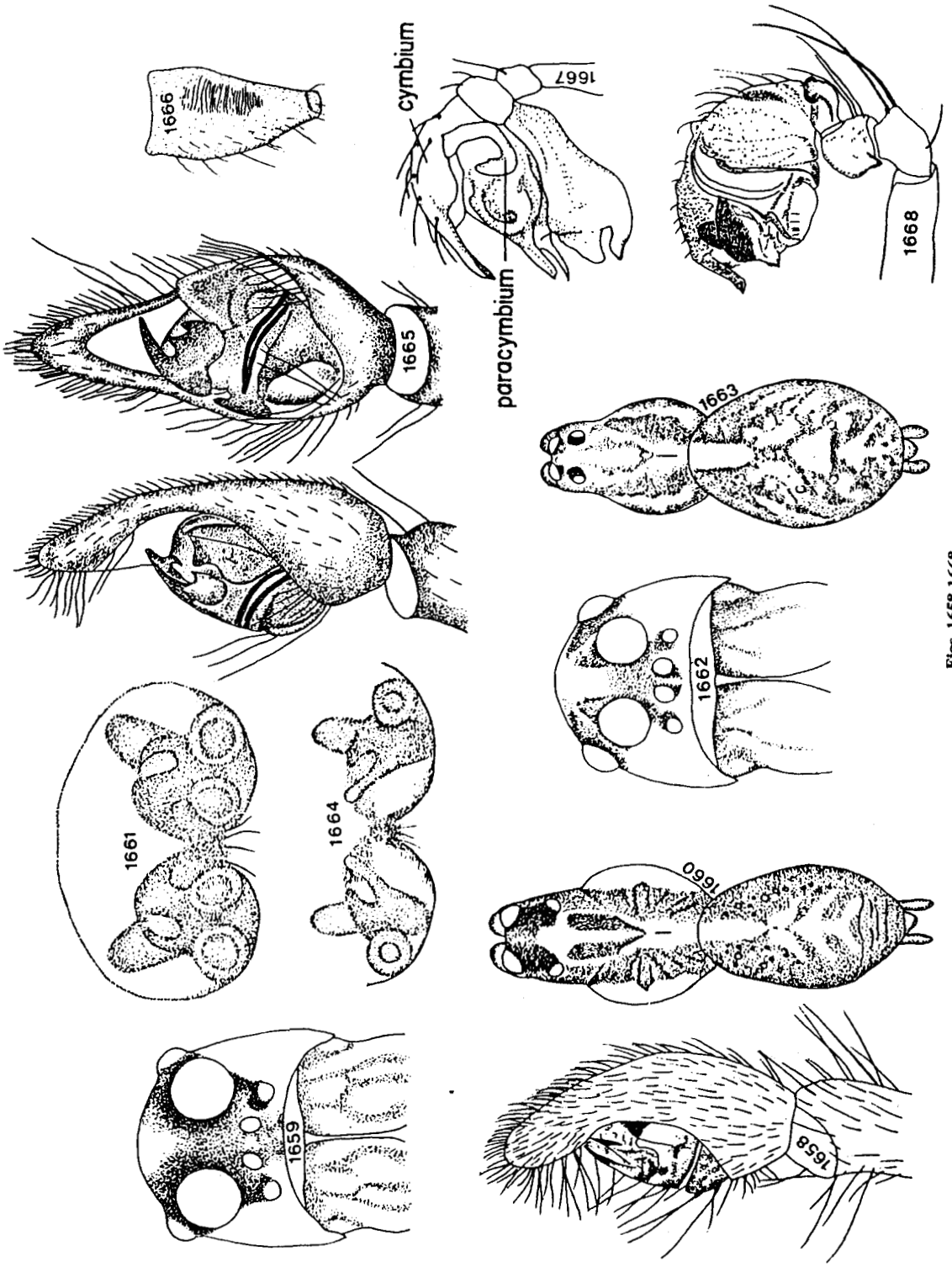
811' Position of trichobothrium in metatarsus IV only 0.42-0.66; head may or may not be elevated in both sexes; stridulating organ usually present; chelicera with warts or antero-lateral granulations 812

812(811') Head not elevated into a lobe in both sexes; eyes rather small, anterior row nearly straight, and posterior row moderately procurved; carapace glossy and nut brown, oval in outline dorsally and evenly rounded on sides; clypeus straight, subvertical and as wide as ocular area; abdomen yellowish dark brown (sometimes black with 4 impressed dots and several faint pale chevrons dorsally (Fig. 1677); position of trichobothrium in metatarsus IV 0.6 epigynum with a large transversely elongate oval opening (Fig. 1678); short patella thickened distally, curved ventrally and with a small ventral tooth; tibia with a broadly truncate lateral tooth (Fig. 1679); genital bulb thin; paracymbium widened into 2 small distal lobes (Fig. 1680) . . . . . *Erigonidium graminicola* (Sundevall)

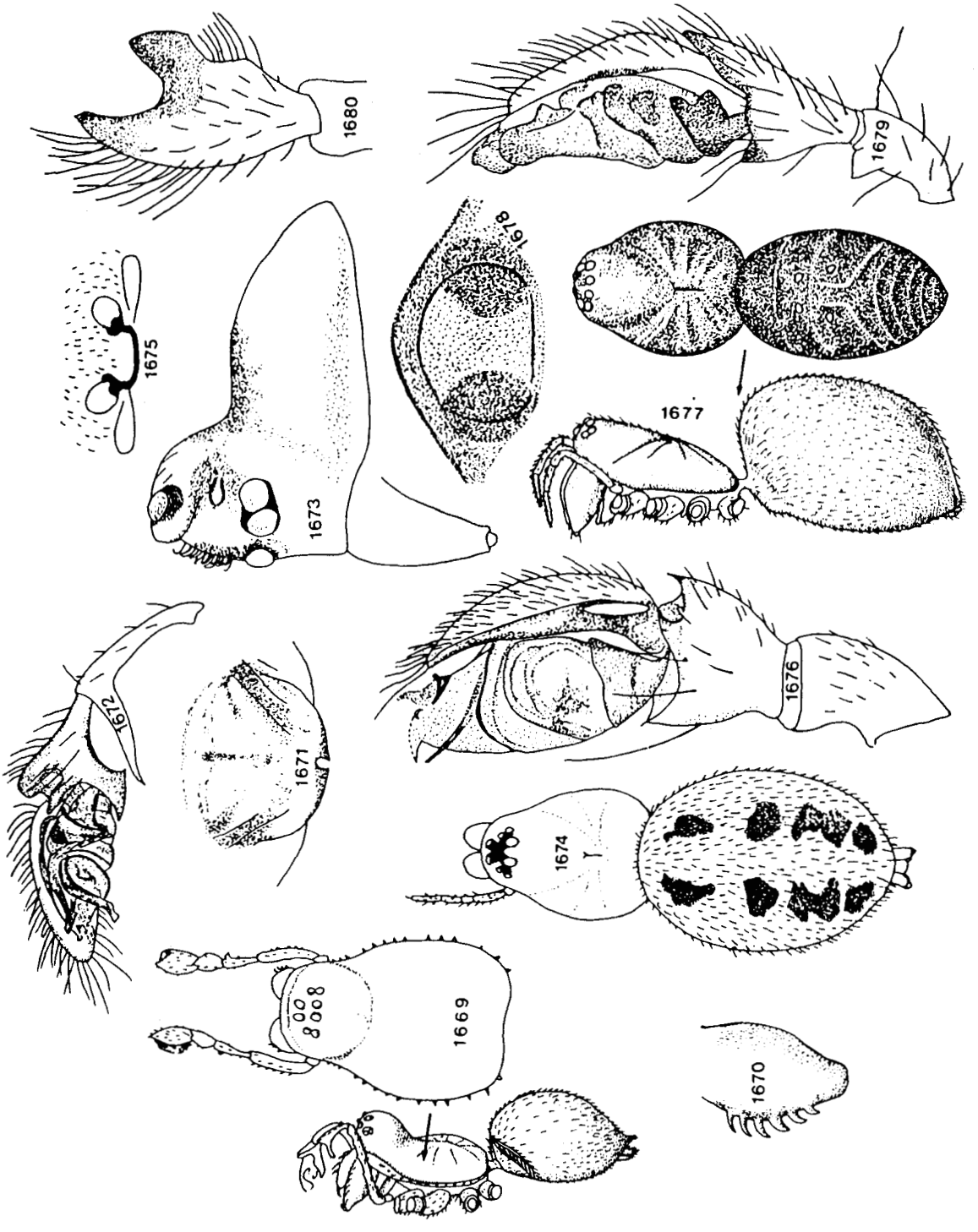
812' Head of male moderately elevated into a lobe; eyes fairly large, sometimes closely grouped; position of trichobothrium in metatarsus IV 0.6-0.66 813

813(812') Abdomen ovoid greyish yellow to black with a pale longitudinal median line dorsally; carapace yellowish brown to dark brown (Fig. 1681); male head elevated behind eyes with a deep transverse suture at midelevation part, female head considerably gibbous above but without transverse suture; chelicera swollen at base with 5 promarginal teeth, armed with a large boss in front and clothed with antero-lateral granulations in male (Fig. 1682); boss absent in the female; position of trichobothrium in metatarsus IV 0.56-0.62; epigynum dark brown with a small orifice divided by a triangular scape (Fig. 1683); tibia as long as patella drawn distally, dorsal margin with a broad apophysis indentated distally; embolus long and coiled at the balbal tip (Fig. 1684) . . . . . *Ummeliata* (= *Oedothorax*) *insecticeps* (Boesenberg & Strand)

813' Abdomen elongate-ovate, dull yellow with longitudinal closed black stripes on each side of the dorsum (Fig. 1685) and on each side of the venter; carapace brown-orange with blackish ocular area and a large hump behind eyes in the male (hump absent in the female); hump broadly rounded in front, moderately deep transverse groove between ocular area and hump (Fig. 1686); chelicera with a large pointed anterior boss curved mesially and warty granulation antero-laterally; position of trichobothrium in metatarsus IV 0.7; epigynum with a large orifice in the lip of scape with clear spermathecae (Fig. 1687); patella twice as long as patella I with a small process on the distal end; tibia funnel-shaped distally, dorsolaterally provided with a black long sickle-like apophysis;



Figs. 1658-1668



Figs. 1669-1680

bulb slender and curved embolus along the membranous semicircular pars pendula (Fig. 1688) ..... *Gnathonarium gibberumn* Oi

814(809') Tiny spiders barely 3 mm long; sternum (Fig. 1689) broadly truncate anterior part with indentations; abdominal pattern without folium; female palp clawless [Theridiosomatidae] 815

814' Small to large spiders usually more than 5 mm long; sternum cordate; abdominal folium prominent; female palp with a claw 816

815(814) Scape prominently exserted beneath entire epigynal posterior margin (Fig. 1690); palpal organ with squarish median apophysis, mesal bristle in the embolic division protruding from beneath the conductor (Fig. 1691); carapace orange-yellow with greyish abdomen; posterior median eye separation at least 1 PME diameter; tibial trichobothria in 2-3 irregular rows, usually moderately long ..... *Wendilgarda* sp.

815' Scape not protruding beneath epigynal posterior margin; palpal organ with the embolic division a short, tubular embolus with apophysis consisting of separated bristle-like parts; median apophysis slightly grooved and gradually tapered apically; carapace dark brown to light tan; eyes nearly of similar sizes, posterior median eye separation 0.5 eye diameter (Fig. 1692) ..... *Theridiosoma* sp.

816(814') Abdomen long and elongate (except in *Dyschiriognatha* with rounded abdomen); chelicera long, usually projected forward and with various teeth arrangements; female genital aperture not sclerotized [Tetragnathidae] 817

816 Abdomen seldom elongated; chelicera short and often vertical; female genital aperture sclerotized or partially sclerotized 831

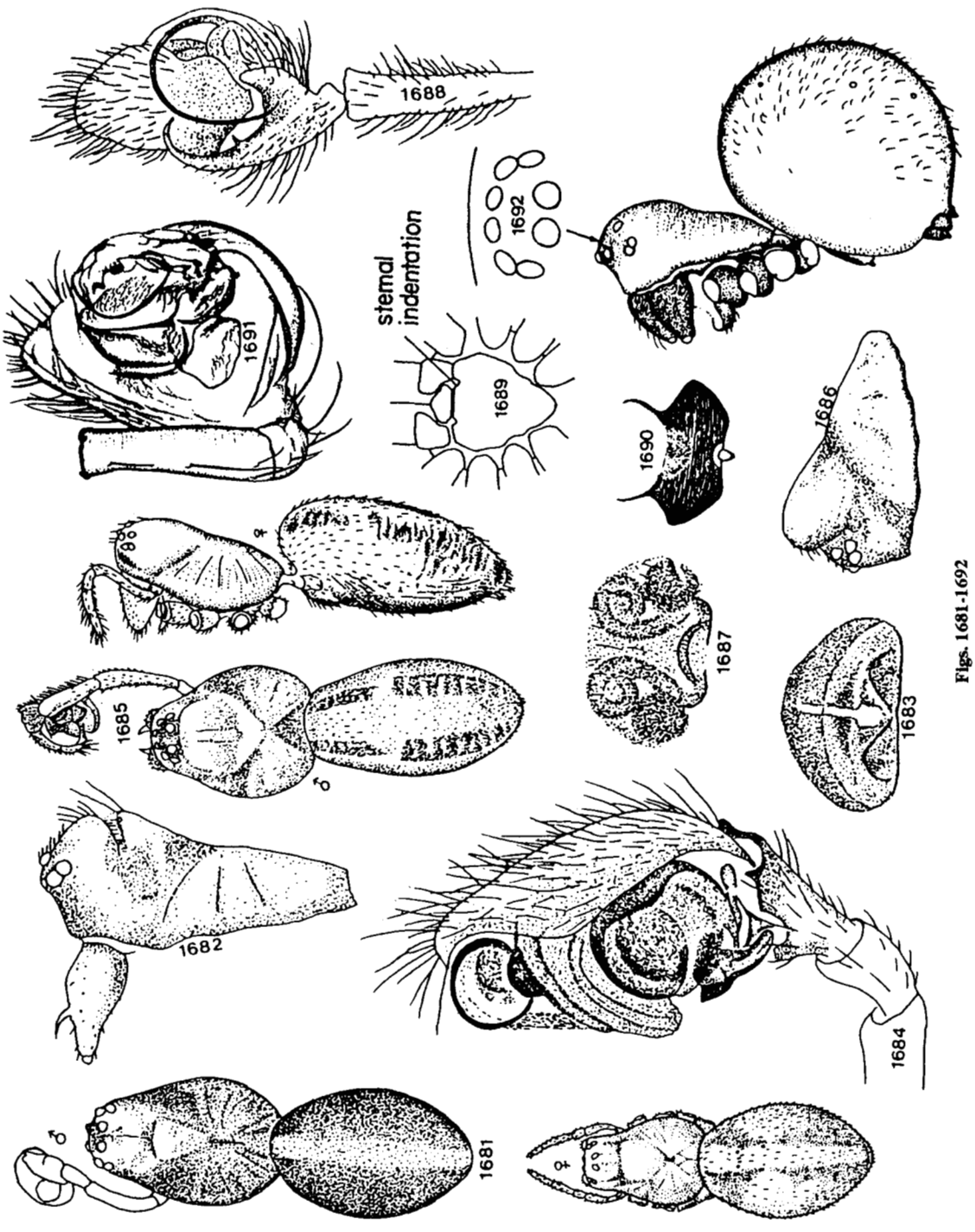
817(816) Abdomen globular or oval with silvery appearance 818

817' Abdomen prominently elongated and less silvery 819

818(817) Abdomen globular with 4 black spherical spots dorsally; palpal organ without long processes above tibia (Fig. 1693); chelicera and carapace red (Fig. 1694) .... *Dyschiriognatha quadrimaculata* Boesenberg & Strand

818' Abdomen globular with longitudinal inwardly hook; dark streaks (sometimes greyish to black) dorsally; chelicera and carapace reddish black (Fig. 1695); palpal organ with 2 long processes above tibia (Fig. 1696) ..... *Dyschiriognatha tenera* (Karsch)

818" Abdomen ovoid with a moderately broad median and 2 thin sublateral longitudinal white bands and a broad reddish to dark brown band between the whitish median and sublateral bands; carapace with 3 longitudinal brown stripes (Fig. 1697); sternum punctured; labium not markedly swollen distally; proximal end of femora I and II with a group of 2-3 trichobothria; paracymbium with a pointed lateral apophysis, rather short not extended beyond bulb, rounded towards apex (Fig. 1698); epigynal fold simple with transverse narrow orifice (Fig. 1699) ..... *Pachygnatha clercki* Sundevall



Figs. 1681-1692

819(817') Spinnerets almost midventrally located; abdomen pointed posteriorly (Fig. 1700); anterior lateral eyes on the margin of carapace (Fig. 1701); guide tooth far from first large tooth in the female (Fig. 1702); apophysis in male bifurcated (Fig. 1703) ..... *Tetragnatha javana* (Thorell)

819' Spinnerets on the abdominal tip 820

820(819') Posterior eye row strongly recurved; posterior lateral eye far from anterior lateral eye 821

820' Posterior eye row gently recurved to straight 824

821(820) Tarsus of palp enlarged; male 822

821' Tarsus of palp normal, female 823

822(821) Fang of chelicera with a subbasal outer excrescence; auxillary fang guide (Ax) bluntly rounded at tip and slightly away from guide tooth (G); upper teeth below guide tooth of equal size and spacing (Fig. 1704); ventrally auxillary fang guide large and close to large guide tooth with a tubercle at middle (Fig. 1705); paracymbium bluntly rounded at tip and conductor hook-like apically; anterior lateral eyes distinctly very small compared to the medians (Fig. 1706) and closer to PLE than to AME ..... *Tetragnatha squamata* Karsch

822' Fang of chelicera with 2 inner cusps (median and subbasal); apophysis (a) short, blunt at tip and slightly curved inward, slanting tooth (SI) on top middle of auxillary fang guide and first large tooth (T) (Fig. 1707); ventrally G closer to T than to Ax, paracymbium slender towards apically rounded tip with a lateral tubercle at midlength (Fig. 1708); distal portion of embolus and conductor truncated laterally after a small cleft (Fig. 1709); ALE smaller than medians, closer to AME than to PLE (Fig. 1710) ..... *Tetragnatha virescens* Okuma

823(821') Chelicera with 7 promarginal and 5 retromarginal teeth; G closer to T than to Ax dorsally (Fig. 1711); genital fold almost parallel-sided and subtruncate apically (Fig. 1712) ..... *Tetragnatha squamata* Karsch

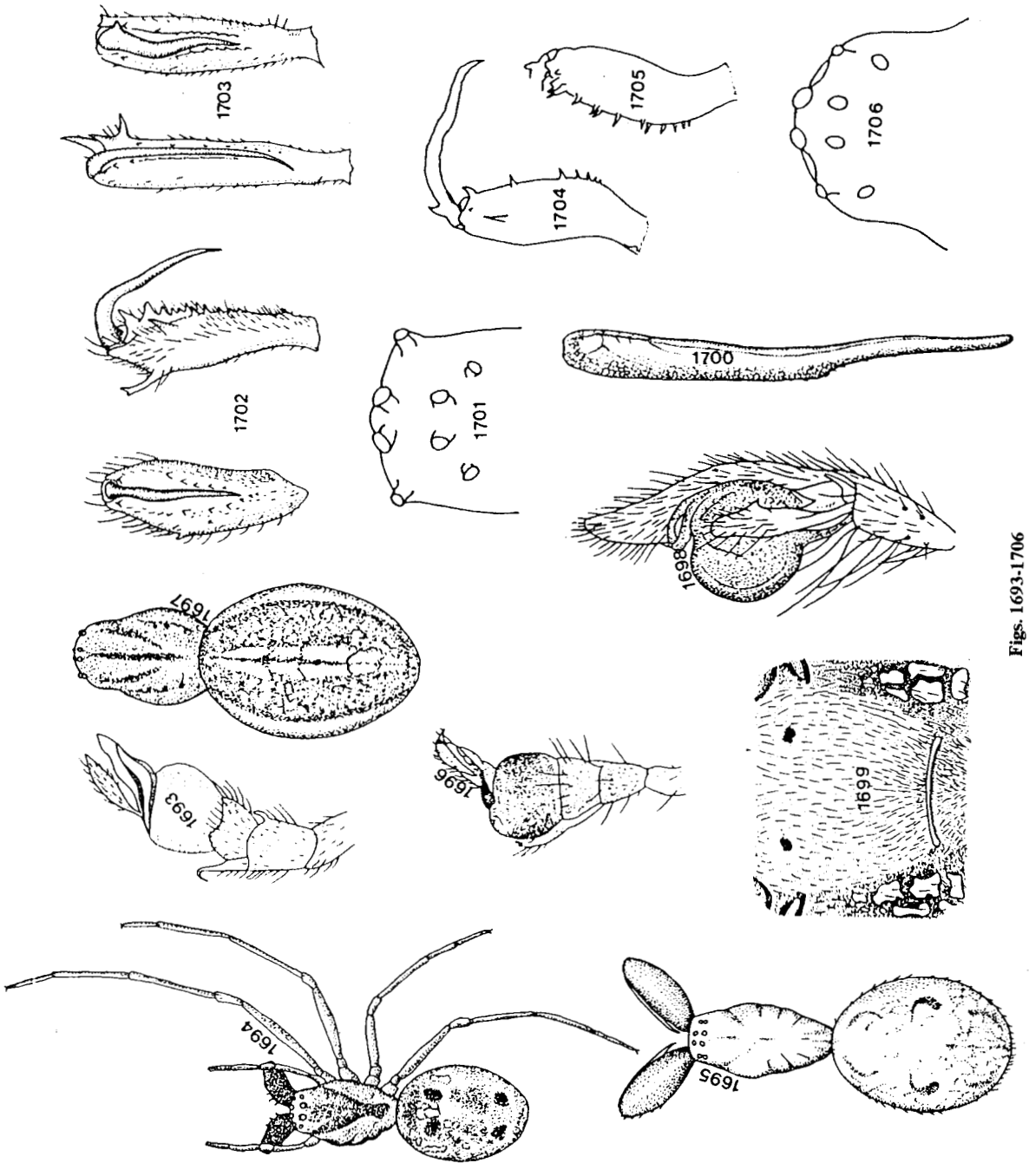
823' Chelicera with 6 promarginal and 5 retromarginal teeth; G almost midway Ax and T dorsally (Fig. 1713); genital fold with lateral indentions before narrowly rounded apex (Fig. 1714) ..... *Tetragnatha virescens* Okuma

824(820') Male 828

824' Female 825

825(824') Chelicera with 3 strong apical teeth, apophysis (a) with a median tubercle; retromargin with about 12 teeth (Fig. 1715); paracymbium with an apical cleft (Fig. 1716); ALE closer to PLE than AME, ocular quad narrower in front than behind (Fig. 1717) ..... *Tetragnatha nitens* (Audouin)

825' Chelicera without 3 strong apical teeth 826



Figs. 1693-1706

826(825') Chelicera with a simple apically pointed apophysis (a), tooth (t) and T absent, promargin with 12 teeth, uppermost one the largest with subswollen base (Fig. 1718); retromargin lined with 15-16 teeth (Fig. 1719); paracymbium narrowly bilobed at apex (Fig. 1720); distal end of embolus and conductor with a wide gap before apex (Fig. 1721); both eye rows of equal length and slightly recurved; ocular quad slightly wider behind (Fig. 1722) . . . . . *Tetragnatha mandibulata* Walckenaer

826' Chelicera with a bifid apophysis 827

827(826') Central ocular quadrangle nearly a square (Fig. 1723); chelicera without an outer subbasal cusp in the fang; slanting tooth (sl) absent; upper guide (G) tooth prominent and about half as long as T; tooth (t) rather minute; G and T space encloses 3 retromarginal teeth; promargin with 8 teeth (Fig. 1724), retromargin with 13 (Fig. 1725); paracymbium slight curved inwards and hooked basally (Fig. 1726); distal end of conductor and embolus pointed and curved . . . . . *Tetragnatha mavillosa* Thorell

827' Central ocular quadrangle not a square (Fig. 1727); chelicera with an outer subbasal cusp in its fang, upper guide tooth absent but slanting tooth present, T very large, t moderately high, and promargin with about 8-10 teeth (Fig. 1728); ventrally chelicera with prominent auxillary fang guide (Ax) and G (Fig. 1729); paracymbium almost parallel-sided in apical half, tip with small and large tubercles (Fig. 1730) . . . . . *Tetragnatha praedonia* L. Koch

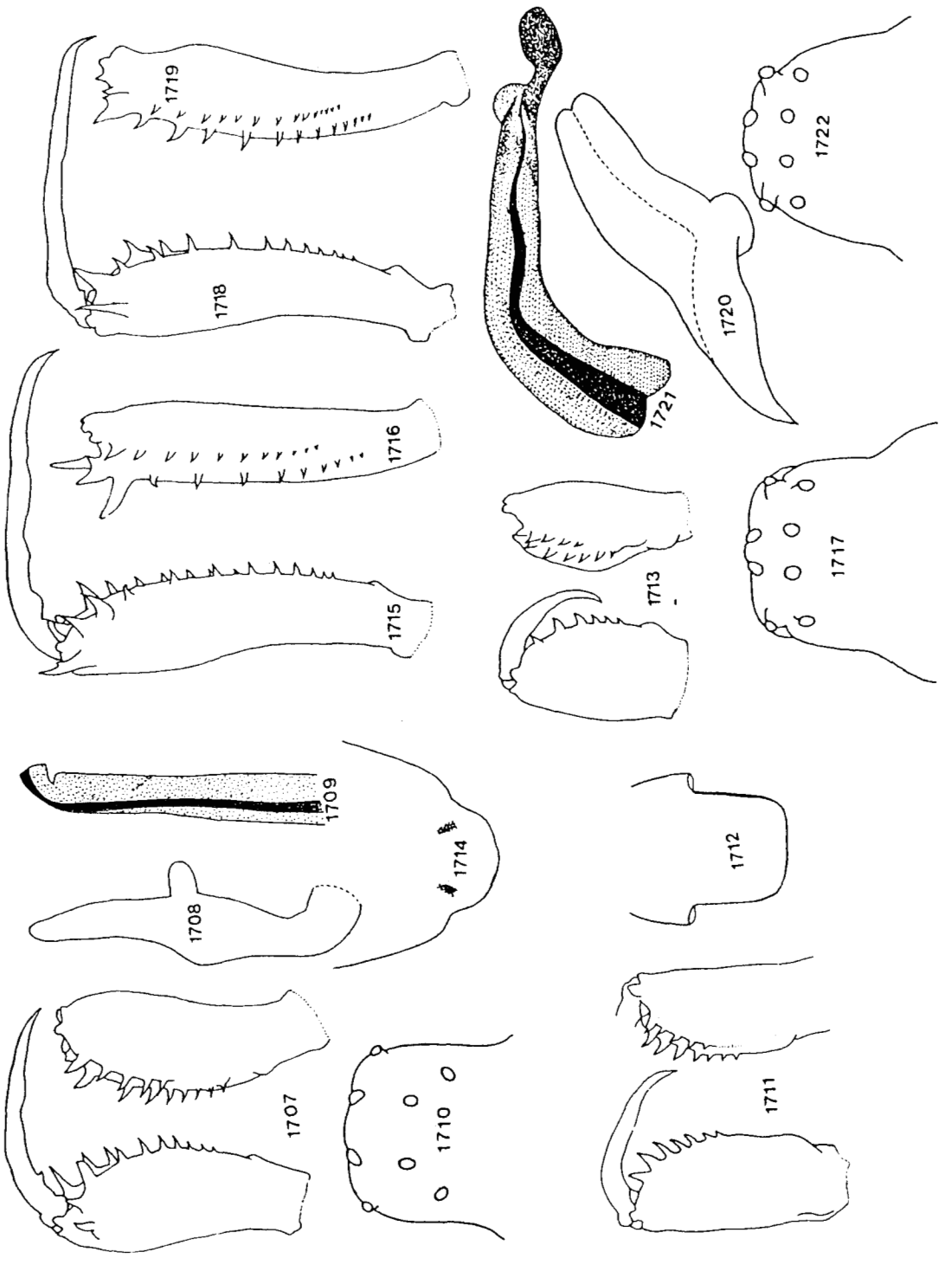
828(824) Fang without an outer cusp; promargin with 8 teeth, uppermost 2 teeth widely spaced enclosing about 4 retromarginal teeth viewed dorsally (Fig. 1731); retromargin with 12-13 teeth (Fig. 1732); genital fold moderately swollen apically with a truncate tip (Fig. 1733); anterior eye row more recurved than the posterior (Fig. 1734) . . . . . *Tetragnatha maxillosa* Thorell

828' Fang with an outer cusp 829

829(828') Lower auxillary fang guide prominently very large, even larger than the guide (G), promargin with 13 teeth (Fig. 1735) and retromargin with 15-16 teeth, fang with an inner cusp in basal one-third (Fig. 1736); genital fold long and penis-like (Fig. 1737) . . . . . *Tetragnatha mandibulata* Walckenaer

829' Lower auxillary fang guide small 830

830(829') Promargin with a tooth guide (G) rather robust compared to the distant T (Fig. 1738); retromargin with 11 with Ax present near G and of equal size, tooth below G with a swollen base (Fig. 1739); genital fold short with a moderately swollen apex (Fig. 1740); anterior eye row (AER) narrower than posterior eye row (PER), AER strongly recurved and PER gently recurved (Fig. 1741) . . . . . *Tetragnatha praedonia* L. Koch



Figs. 1707-1722

830' Promargin with about 9 teeth, guide (G) similar. in size and shape with T (Fig. 1742); retromargin with 12 teeth, fang with a dorsal cusp viewed laterally (Fig. 1743); genital fold moderately short with an apical orifice (Fig. 1744) ..... *Tetragnatha nitens* (Audouin)

831(816') Femur with trichobothria (Fig. 1745); paracymbium (Fig. 1746) usually leaf-like and often divided; abdomen ovoid and occasionally with humps [Metidae] 832

831' Femur without trichobothria; paracymbium often a sclerotized hook (Fig. 1747); abdomen variable often with humeral, dorsal or posterior bumps [Araneidae] 835

832(831) Abdomen yellowish with black spots and elevated anterodorsally becoming subtriangular in lateral view (Fig. 1748); epigynum truncate along posterior epigynal margin, rectangular towards the anterior with a pair of sclerotized circular structures (Fig. 1749); genital bulb subglobular, distal part of embolus and conductor rather bifurcate; paracymbium with a large tooth directed laterally (Fig. 1750); basal half of femur IV without a thick layer of trichobothria ..... *Tylorida striata* (Thorell)

832' Abdomen moderately elongated, usually greenish yellow; basal half of femur IV with a double fringe layer of trichobothria (Fig. 1751) 833

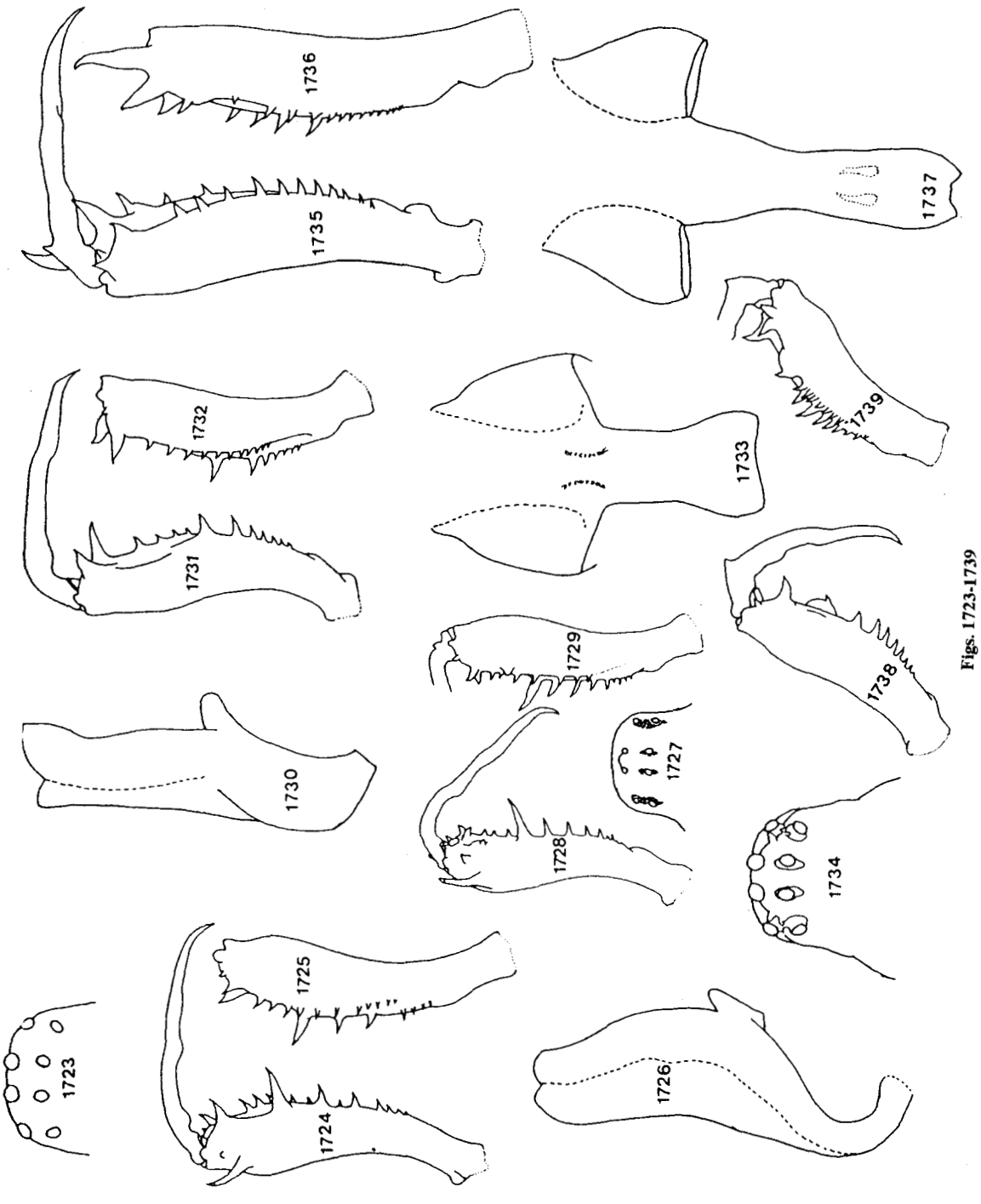
833(832') Abdomen without paired tubercles anterodorsally, uniformly silvery white with longitudinal black bands (Fig. 1752); midanterior part slightly cleft; epigynum with a transverse C-shaped cavity facing the posterior margin, median guide narrow, small notch present below anterolateral corner (Fig. 1753); palpal organ with cymbium and tibia similar in length, tibia and patella each with a long subapical hair (Fig. 1754) ..... *Leucauge celebesiana* (Walckenaer)

833' Abdomen with 1 or more pairs of tubercles anterodorsally 834

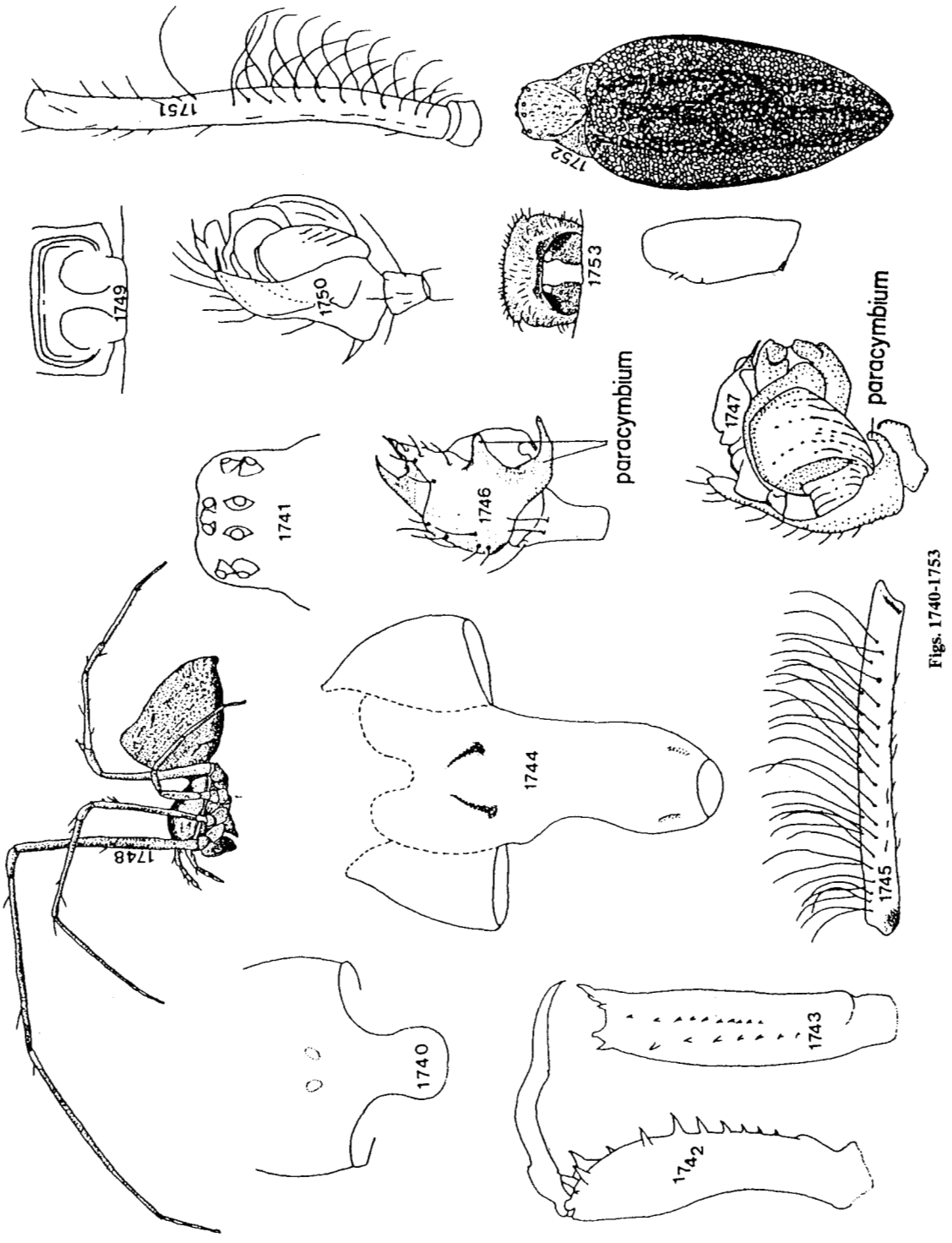
834(833') Caudal tubercle present (Fig. 1755); abdomen with one pair of tubercles, tapers posteriorly and dorsally lined with silvery white and blackish bands (Fig. 1756); epigynum with a medially constricted guide, top of transversely C-shaped cavity with rectangular-like band moderately cleft anteromedially (Fig. 1757) ..... *Leucauge decorata* (Blackwall)

834' Caudal tubercle absent; abdomen with 1 pair of anterodorsal tubercles, each tubercle black on top, entire abdomen yellowish with 3 longitudinal dark bands (Fig. 1758); epigynum rounded anteriorly with a pair of obliquely converging orifices divided by a guide (Fig. 1759); palpal organ with an upwardly curved and apically rounded paracymbium (Fig. 1760) ..... *Leucauge blanda* (L. Koch)

834" Caudal tubercle absent; abdomen with 3 pairs of tubercles in the anterodorsal half (Fig. 1761) strongly overlapping the carapace; silvery white dorsally with a median mark of greyish and blackish patches and a pair of narrow longitudinal black bands laterally (Fig. 1762); epigynum semirectangular with a pair of sclerotized areas divided by a narrow cavity in the middle (Fig. 1763) ..... *Leucauge bengalensis* Gravely



Figs. 1723-1739



Figs. 1740-1753

835(831') Abdomen with lateral and posterior spines; dorsally flattened, hard and provided with conspicuous yellow and black transverse bands or yellowish white lateral bands; spinnerets in an elevated circular area flanged by a ring 836

835' Abdomen without lateral and posterior spines 837

836(835) Six abdominal spines (4 laterals and 2 posterior) very short; abdomen roughly octagonal, dorsum with a pair of large yellowish white patches laterally and dark brown medially (Fig. 1764); carapace with a median conical bulge in the cephalic region; epigynum transversely oblong with a pair of sclerotized black parts in the middle and moderately exserted guide (Fig. 1765) . . . . . *Gasteracantha mammosa* C. L. Koch

836' Lateromedian spine of the abdomen conspicuously large; abdominal dorsum with 3 transverse yellowish white bands, median one connects the large spine; sigilla ovoid with 8 in the anterior dark band and 6 in the posterior dark band (Fig. 1766); epigynum transversely ovate with undulated posterior epigynal margin (Fig. 1767) . . . . . *Gasteracantha* sp.

837(835') Posterior eye row strongly procurved; anterior lateral eyes smaller than posterior laterals 838

837' Posterior eye row nearly straight or procurved; lateral eyes subequal 841

838(837) Abdomen subglobular with a pair of humps anterodorsally; anterior eyes evenly spaced and laterals closer to posterior laterals; posterior eye row strongly procurved (Fig. 1768); carapace spread sidewards frontally (Fig. 1769); epigynum subglobular with the slight V-shaped guide a little below posterior epigynal margin (Fig. 1770) . . .*Gea* sp.

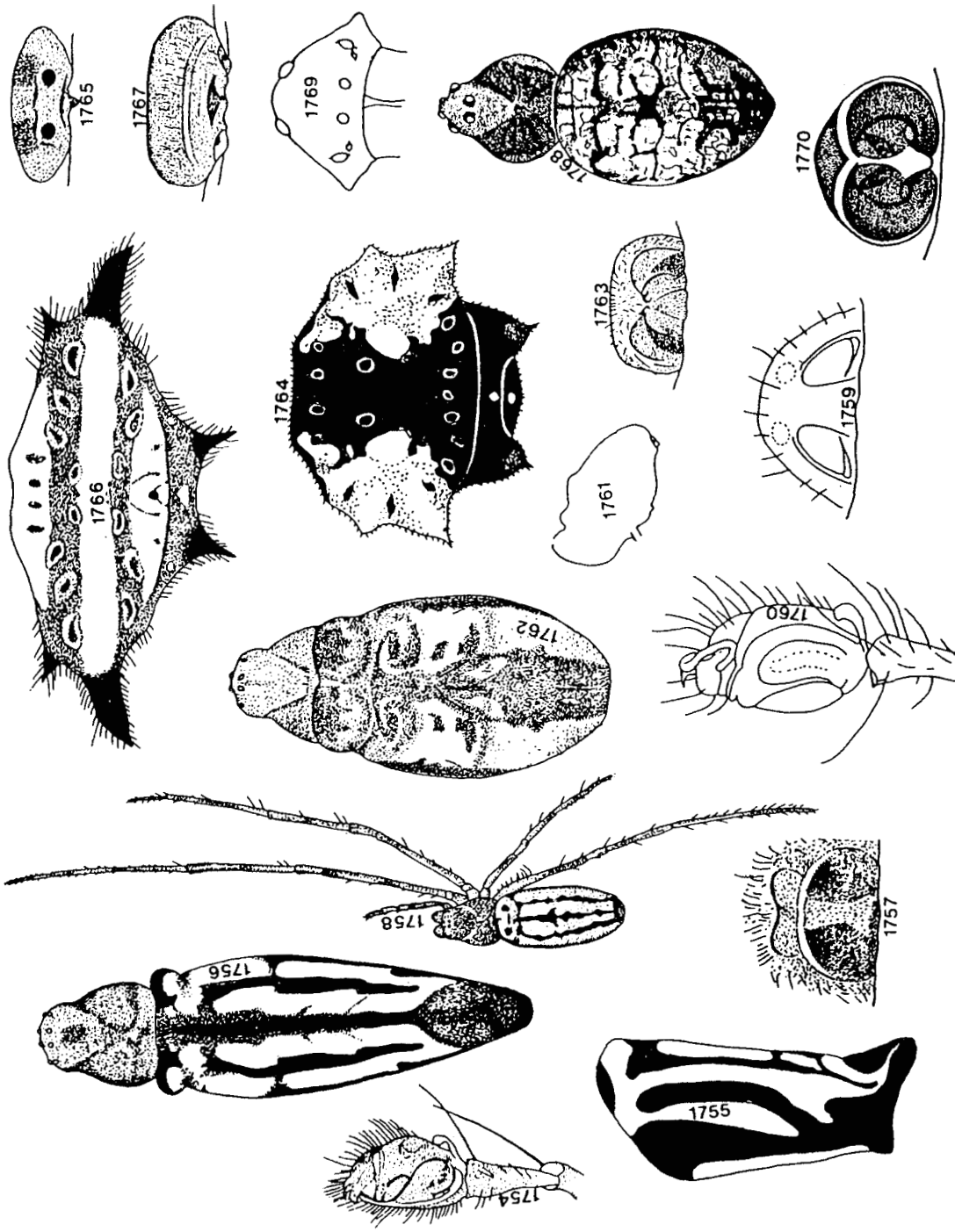
838' Abdomen moderately elongated oval, broadly ovoid, and usually with a blunt anterior part; transverse furrow in the foveal region 839

839(838') Abdomen with alternating transverse yellow and black stripes 840

839' Abdomen with silvery whitish yellow band anteriorly and brown patches of irregular shapes from the median towards the posterior (Fig. 1771); epigynum with a broad scape (Fig. 1772) . . . . . *Argiope catenulata* (Doleschall)

840(839) Abdomen broadly oval, dorsum grey-white with network-like black stripes in the posterior half (Fig. 1773); apical half with 3-4 black almost uninterrupted transverse stripes; epigynum triangular anteriorly, scape moderately cleft apically (Fig. 1774) . . . . . *Argiope aemula* (Walckenaer)

840' Abdomen elongate-ovate, apico-dorsal black band slightly concave at middle, median area with transverse black bands reaching margins and a band each above and below it not extending to the margins (Fig. 1775); apical part of epigynum broadly rounded and button-like, posterior part truncated (Fig. 1776) . . . . . .*Argiope bruennichii* (Scopoli)



Figs. 1754-1770

841(837') Abdomen raised anteriorly and with a pair of shoulder tubercles (Fig. 1777); carapace flat with a prominent thoracic groove and long cephalic region; ocular quad a little longer than wide; lateral eyes equal and slightly separated from each other (Fig. 1778) . . . . . *Cyrtophora* sp.

841' Abdomen not raised anteriorly, with or without shoulder tubercles; carapace not flat, thoracic groove may or may not be distinct 842

842(841') Carapace provided with a U-shaped junction between cephalic and thoracic region; posterior median eyes very close and almost contiguous; abdomen without median and paired tubercles antero-dorsally but with a pair of blunt lateral humps posteriorly and a median caudal one, generally rhombic with broad median silver band and black margins (Fig. 1779); epigynum with a long narrow scape, tip bent (viewed laterally); bilobed laterally above it and moderately broad anteriorly (Fig. 1780) . . . . . *Cyclosa insulana* (Costa)

842' Carapace without U-shaped junction; posterior medians not very close to each other 843

843(842') Abdomen elongated, more than twice longer than wide, a little pointed antero-medially over carapace but without caudal projection (Fig. 1781); epigynum transverse elongate with median constriction anteriorly and a globular mark above it (Fig. 1782) . . . . . *Larinia* sp.

843' Abdomen subovate to ovate, less than twice longer than wide 844

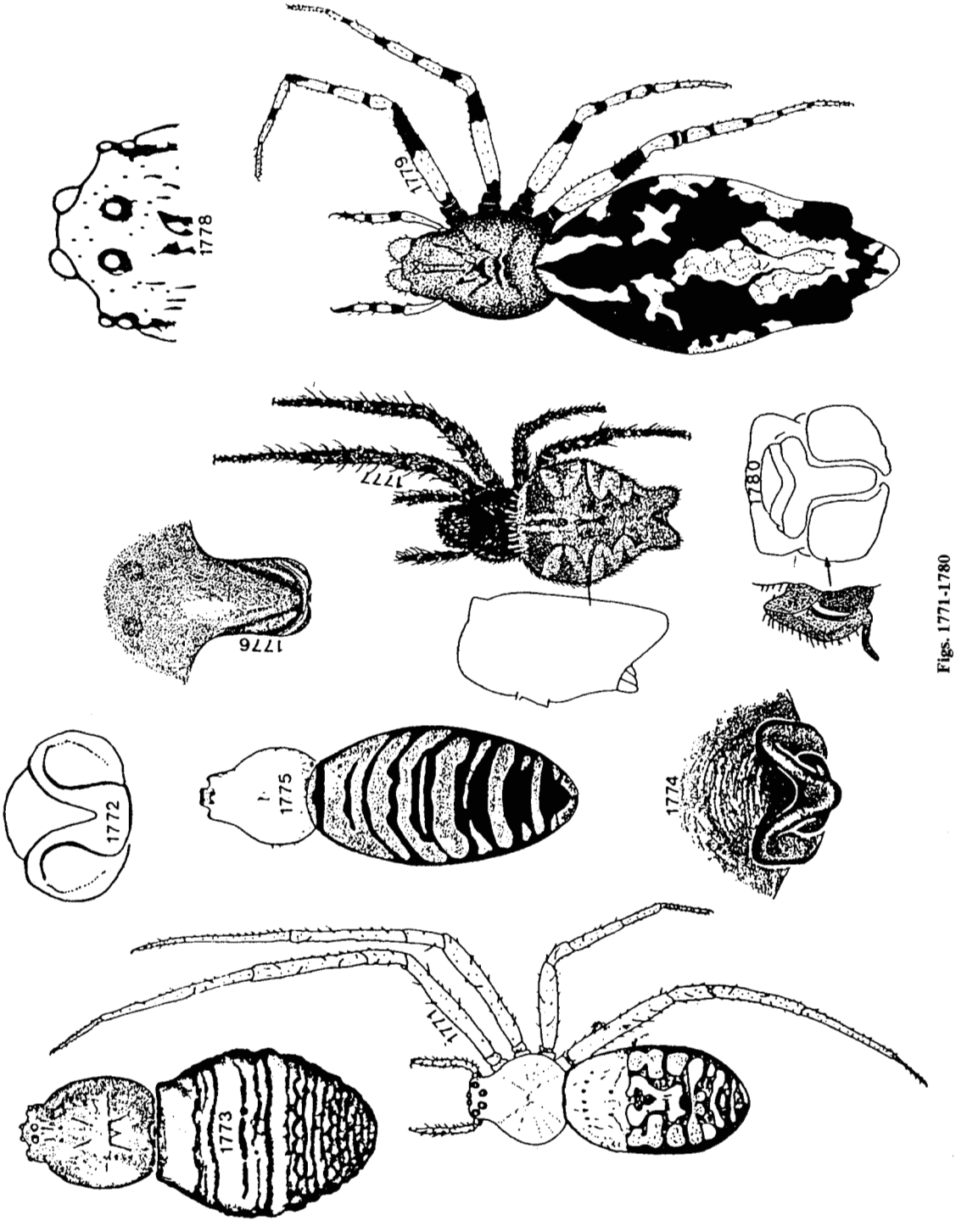
844(843') Carapace with a longitudinal furrow (best seen in front-lateral view); ocular quad forms a trapezium and slightly longer than wide; tibia II of male with macrosetae prolaterally; epigyne simple tongue-like 845

844' Carapace without a longitudinal furrow, usually a transverse furrow present 848

845(844) Yellow-bodied spider including legs with about 5 transverse dark bands not extended to the margins of the abdomen, 3 longitudinal dark stripes in the carapace, and light brown bands on apices of legs (Fig. 1783); epigynum short tongue-like, narrows before sub-truncate apex (Fig. 1784); venter of abdomen with a pair of parallel longitudinal white bands and a transverse one with enlarged tips above spinnerets (Fig. 1785); palpal organ with a deeply bifurcated median process (Fig. 1786) . . . . . *Neoscona doenitzi* (Boesenberg & Strand)

845' Brown with whitish bands to dark reddish brown; legs yellowish brown to reddish brown with or without dark brown bands on apices; abdominal folium a pair of zigzag-like patterns 846

846(845') Carapace with 3 longitudinal dark brown bands becoming fused posteriorly in male (Fig. 1787), open in the female and with series of constrictions in the median band (band sometimes dagger-like) of the abdomen (Fig. 1788); epigynum long and tongue-like, apex rounded and constricted at midhalf before the swollen base (Fig. 1789); venter of



Figs. 1771-1780

abdomen with a pair of C-shaped white bands facing each other and a pair of ovoid white spots above sides of spinnerets (Fig. 1790) . . . . .*Neoscona theisi* (Walckenaer)

846' Carapace without traces of longitudinal dark brown bands 847

847(846') Apices of legs blackish brown similar to the cephalic region, thoracic area reddish; abdominal folium variable ranging from white with a red-brown spot, white mottled brown with a pair of zigzag blackish spots, and brown with white cardiac area and 4 pairs of blackish brown oblique spots (Figs. 1791-93); epigynum long, upcurved before apex and bent apically provided with a canal in the middle (Fig. 1794); median apophysis indented prior to the slightly outcurved structure; tibia rather longer than wide (Fig. 1795) . . . . . *Neoscona scylla* (Karsch)

847' Tibia of legs with pale transverse subapical and submedian dark bands; carapace blackish to yellow-brown (sometimes light medially and darker marginally); abdomen nearly triangular with a tree-like pattern provided with 3 pairs of moderately oblique black spots posteriorly (Fig. 1796); epigynum projected out of body in lateral view (Fig. 1797) and triangularly tongue-like in ventral view (Fig. 1798) . . . . . *Neoscona nautica* (L. Koch)

848(844') Abdominal surface shiny with very few hairs, usually ovoid marked with broad longitudinal dark bands separated by white areas; legs relatively short 849

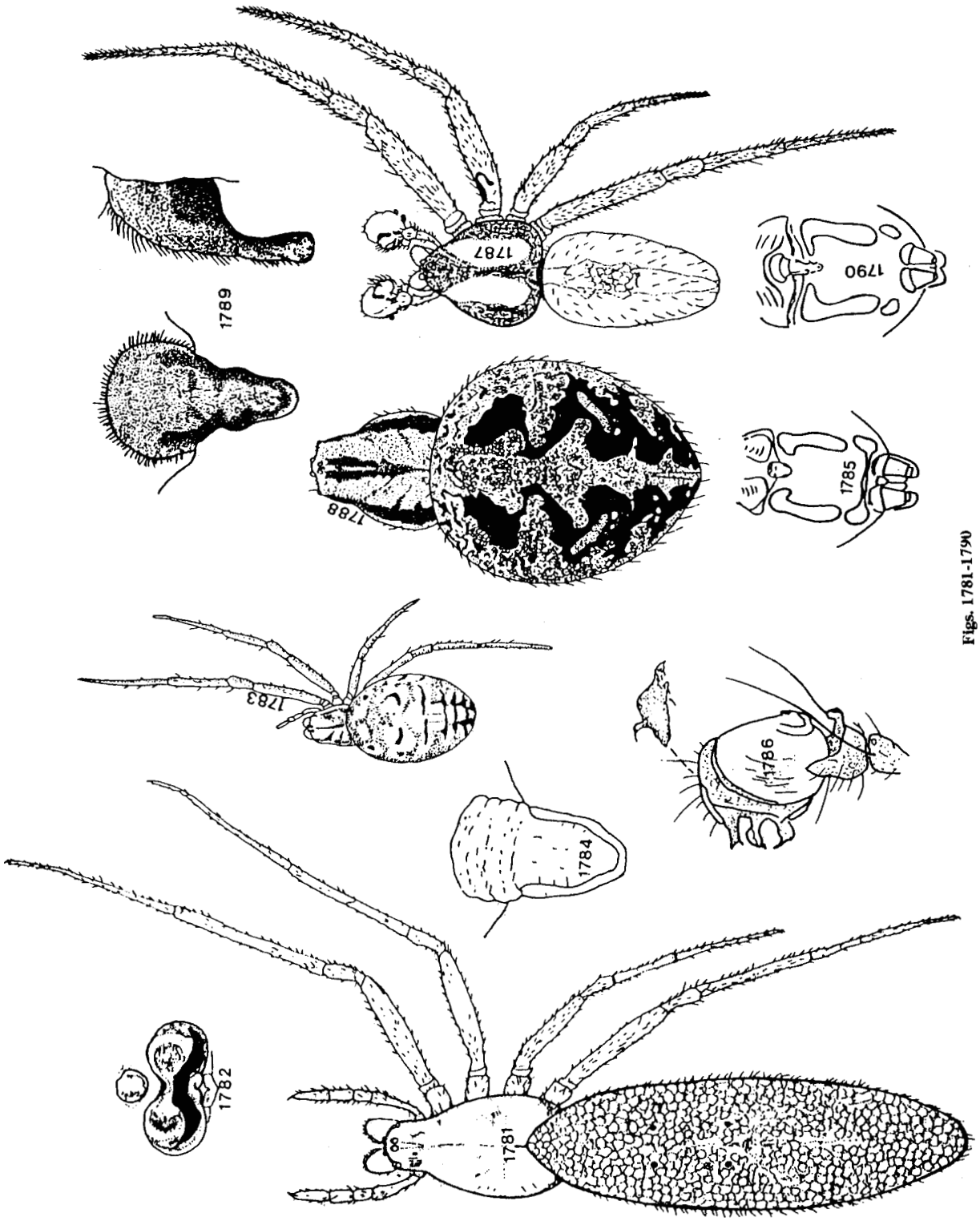
848' Abdominal surface dull but clothed with many hairs, usually subtriangular or partly ovoid with different markings; legs relatively longer 851

849(848) Anterior medians the largest; median ocular quad wider in front than behind; cephalic region usually more dark colored than the thoracic area; abdomen chalk white with a pair of broad longitudinal submedian bands and 4 pairs of light brown globular spots below cardiac area (Fig. 1799); epigynum with noticeable scape and tubercle-like protrusions on each side of scape in the posterior epigynal margins (Fig. 1800); tibia of palpal organ more or less transverse (Fig. 1801) . . . . . *Singa hamata* (Clerck)

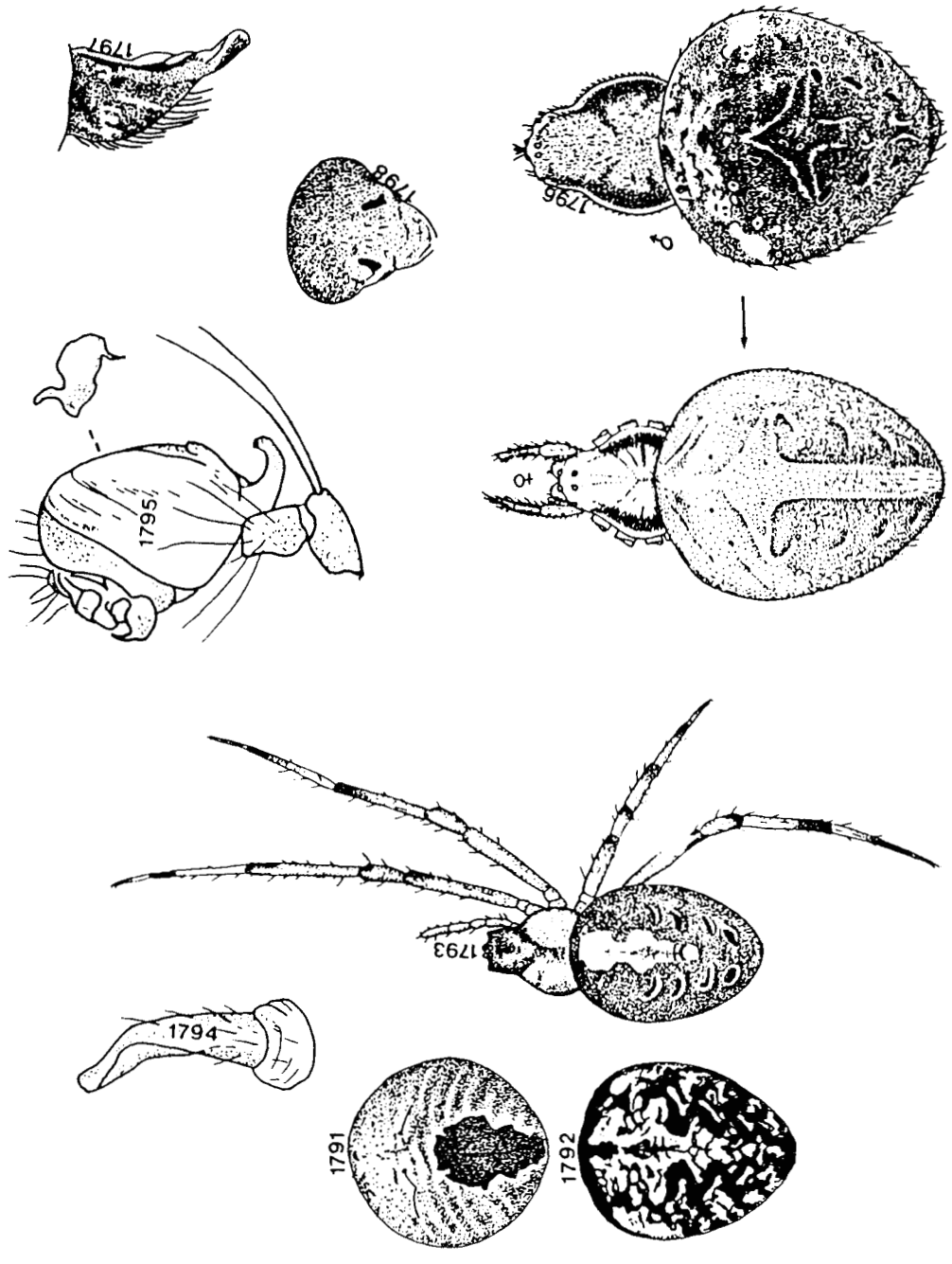
849' Posterior median eyes the largest; abdomen of female usually with 2 broad longitudinal darkbands 850

850(849') Carapace dark brown to black with light lateral margins; femur without median dark bands; abdomen very dark brown to black with cream or light yellow dorsal stripes, dark bands on abdomen with 2 moderate swellings laterally and 1 pair of spots inside the cream band anteriorly (Fig. 1803) or abdomen entirely cream-colored with about 4 light brown spots (Fig. 1802); epigynum transverse ovate with a broad median piece directed towards posterior epigynal margin (Fig. 1804); median apophysis curved and tip of conductor broadly blunt (Fig. 1805) . . . . . *Hypsosinga pygmaea* (Sundevall)

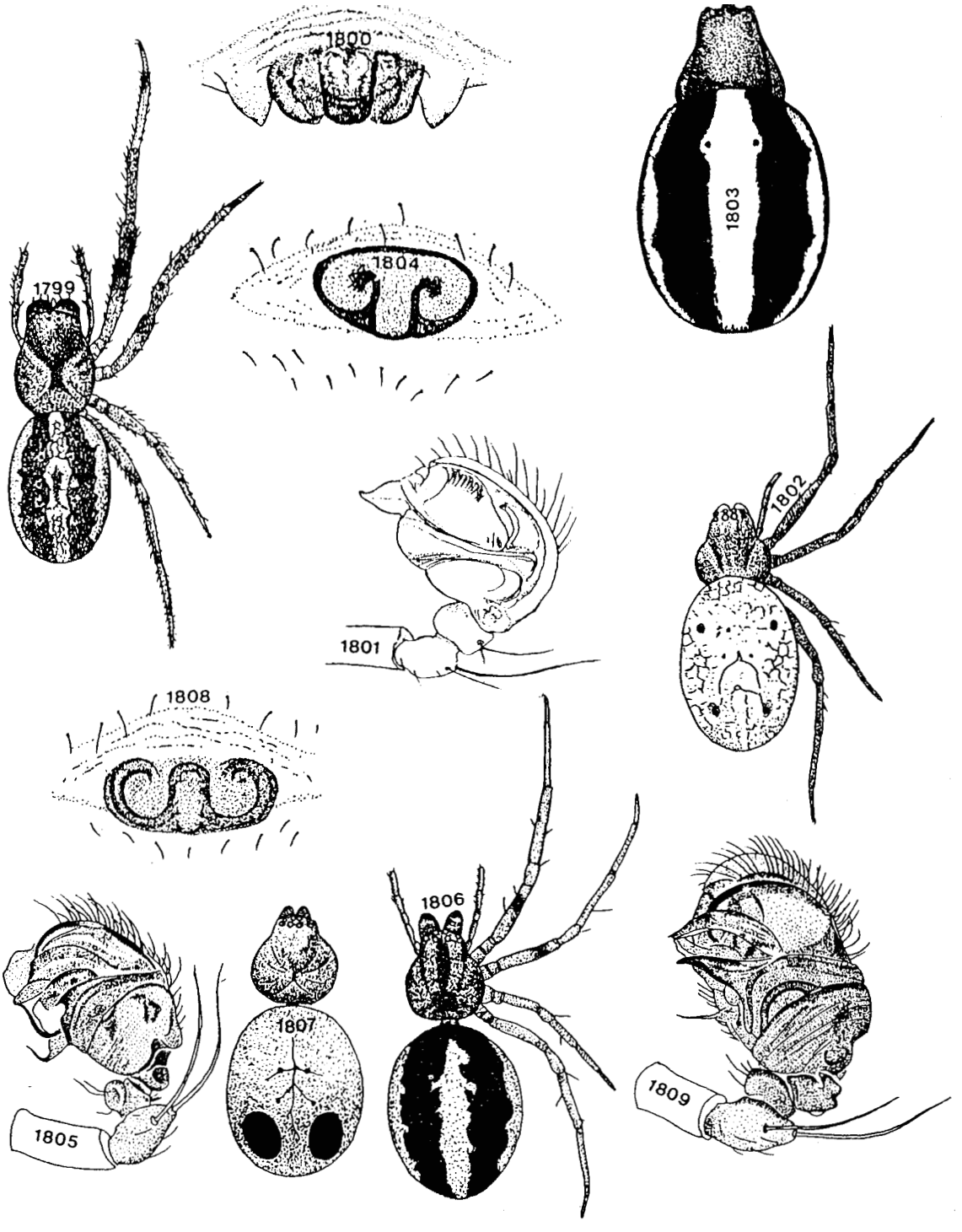
850' Carapace uniform reddish brown without light lateral margins; femur I not darkened; abdomen with broader dark brown bands without lateral swellings, lateral white bands sometimes not contiguous posteriorly (Fig. 1806); abdomen of male orange with a pair



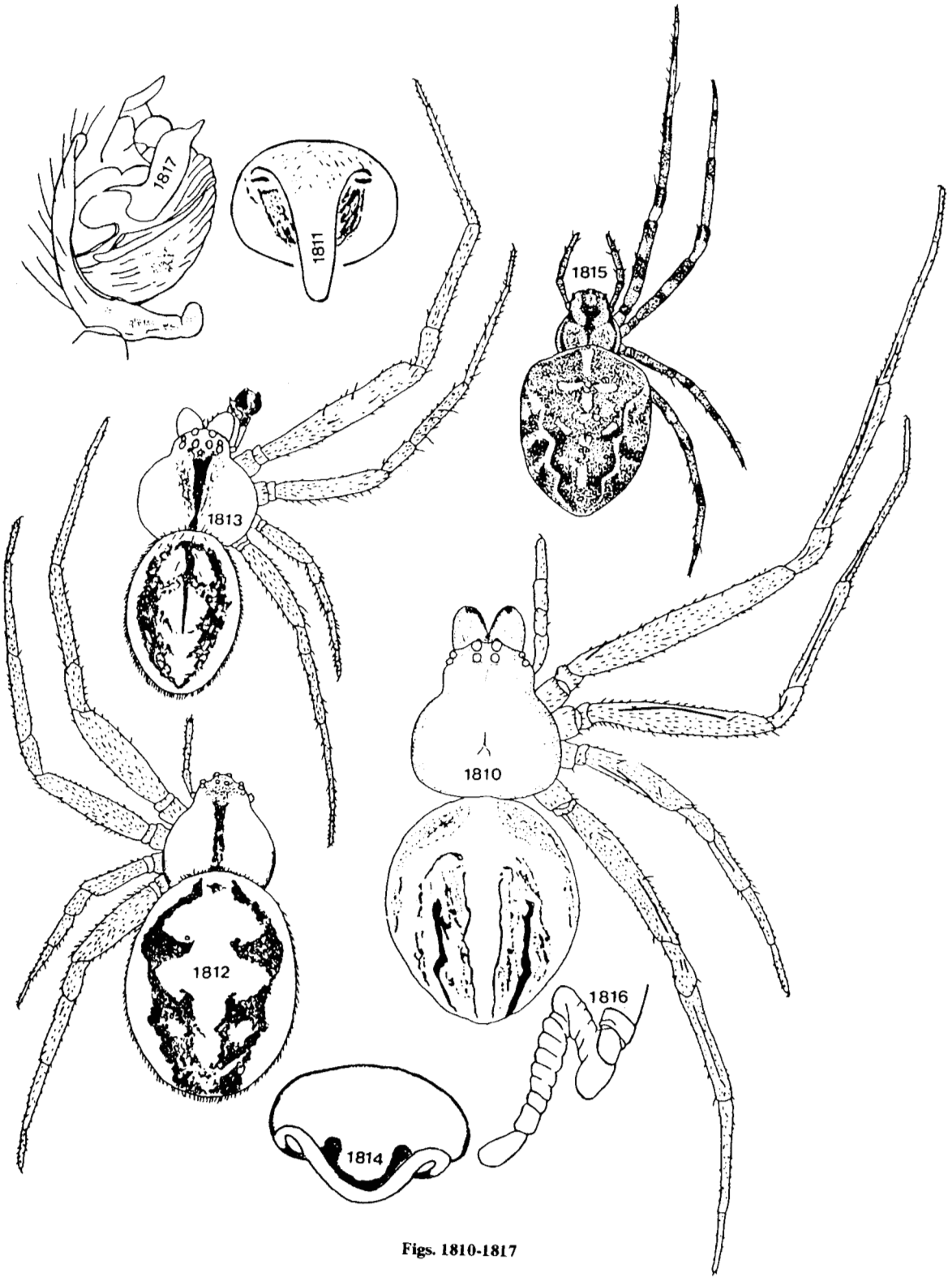
Figs. 1781-1790



Figs. 1791-1798



Figs. 1799-1809



Figs. 1810-1817

of ovoid black spots (Fig. 1807); epigynum transversely E-shaped with median guide directed towards the anterior margin (Fig. 1808); median apophysis acutely pointed and narrow, conductor narrowly blunt at tip (Fig. 1809) . . . . . *Hypsosinga sanguinea* (C. L. Koch)

851(848') Abdomen white with a double V-shaped marking dorsally; carapace yellow-brown (Fig. 1810); epigynum with a moderately long scape extended beyond epigynal margin posteriorly (Fig. 1811) . . . . . *Araneus* sp.

851' Abdomen without a double V-shaped mark, usually with a pair of moderately oblique wavy stripes widening anteriorly 852

852(851') Legs uniformly yellow; abdomen blackish with chalk white median band constricted along lateral margins producing subtriangular marks (Fig. 1812); male with a broad median band toward eyes (Fig. 1813); epigynum simple with a strongly rounded anterior and short but wide tongue-like median plate (Fig. 1814) . . . *Araneus inustus* (L. Koch)

852' Apices of legs dark banded; abdomen with a pair of oblique wavy lines dorsally, tapers posteriorly (Fig. 1815); scape long, with constricted edges and bent in basal one-third viewed laterally (Fig. 1816); median apophysis dolphin-head like at tip (Fig. 1817) . . . . . *Araneus diadematus* Clerck

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II. BIOLOGY AND ECOLOGY

3

Insect Pests of the Rice Plant - Their Biology and Ecology

D. DALE
Department of Entomology
Kerala Agricultural University
Kerala, India

1. INTRODUCTION

THE RICE PLANT IS an ideal host for many insect species. All of the plant parts are vulnerable to insect-feeding from the time of sowing till harvest. There are over 800 insect species damaging rice in one way or another, although the majority of them do very little damage. In tropical Asia only about 20 species are of major importance and of regular occurrence (Grist and Lever 1969). Several species that were earlier considered as minor pests have recently become major pests, whereas the incidence of a few others has considerably declined (Pathak and Dhaliwal 1981). In addition to direct damage (Fig. I), many insects also act as vectors of dreaded diseases of rice.

Rice is primarily a crop of warm and humid environments. About 60% of the world's total rice area is in tropical Asia where insect pest problems are also most severe and numerous. Hence more pests from this region are extensively covered in this chapter. But still, many major, important and representative pests from all the other rice growing regions of the world have been included.

Under each pest synonyms, distribution, host plants, symptoms and extent of damage, life cycle and ecology are given. Mention of a country's name in the distribution only indicates that the pest has been reported from some part of the country and not necessarily that the species is distributed throughout the country. In the case of a few minor pests, little information on their ecology is available for inclusion in this chapter.

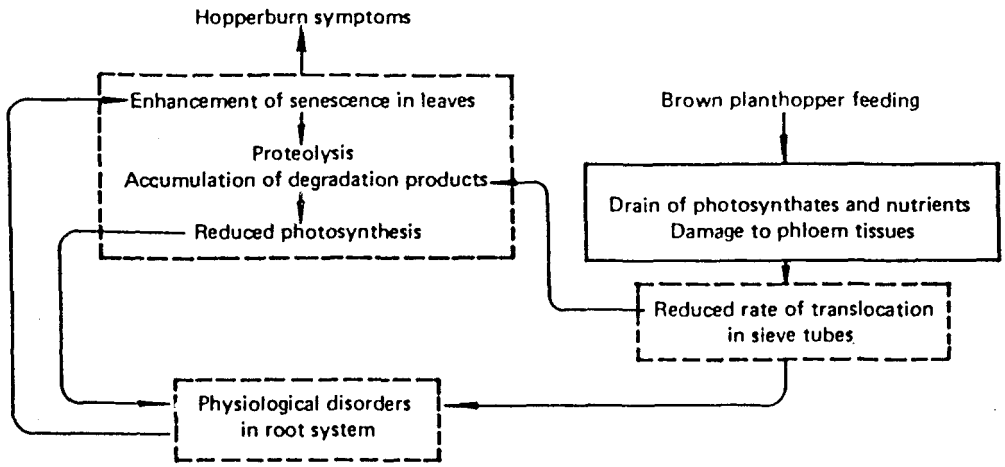


Fig. 1. Possible relationship between *N. lugens* feeding and the development of hopperburn symptoms in rice plants (after Sogawa and Cheng 1979).

2. Root and Stem Feeders

There are many insects which feed on the roots and stem of rice plants. Some, such as white grubs and root aphids, attack exclusively the roots; others (e.g. mealybug, gall midge, rice stem maggot) infest only the stems while there are some pests such as mole crickets which damage both roots and stems.

The infestation of the rice crop by different insect pests is related also to the growth stage of the plants. Seedlings are prone to attack by pests such as the rice seedling flies and the rice seed midges. Insect damage at the early stages of the crop causes the death of the seedlings and leads to an uneven stand.

2.1 Mole Crickets, *Gryllotalpa africana* Palisot de Beauvois (Fig. 2.1), *Gryllotalpa orientalis* Burmeister (Orthoptera: Gryllotalpidae)

Distribution: Africa, tropical Asia, Europe, Japan

Mole crickets are polyphagous insects. They occur in all rice environments but are most prevalent in non-flooded upland rice when the fields are damp. In Japan, much of the damage is noted during spring and autumn when the rice plants are young (Kureha *et al.* 1974). Severe infestations of these pests in nursery beds have been reported from India and Japan.

The nymphs and adults attack stems below ground and close to the roots. Sometimes only one or two tillers are cut and damage is evident only when the tillers begin to dry a few days later. The entire plant dies if the attack is severe. Dried plants can be seen as patches in the rice field. Young and newly-planted seedlings are most commonly attacked in the early part of the season before fields are flooded. Normally damage is greatest near field borders. Unlike field crickets, mole crickets do not take the cut tillers into their burrows (Tripathi and Shri Ram 1968).

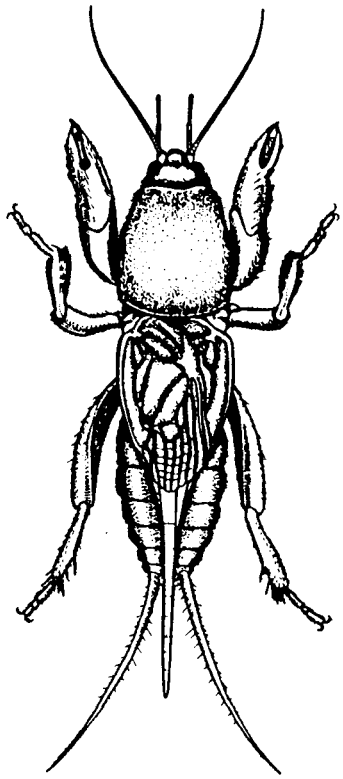


Fig. 2.1

Adult mole crickets are large, light brown in color and 25 to 35 mm long. The forelegs are highly modified for burrowing soil. Adults cannot survive in the rice fields after flooding. They are strong fliers, and are attracted to light traps at night. Female crickets burrow bunds and construct hardened cells in which the eggs are laid. Each cell contains 30 to 50 eggs that hatch in 15-40 days depending on the temperature. Each female may deposit several hundred eggs during its life span of more than 6 months.

Feeding by nymphs causes bare patches in the field. They have only limited capacity for migration and suffer heavy mortality. Cannibalism exists among mole cricket populations. The nymphal period lasts 3 to 4 months.

There is only one generation a year. Adults overwinter in burrows deep in the soil.

2.2 Rice Root Aphids (Homoptera: Aphididae)

The aphid species that infest rice roots and their distribution are given in Table 1. Some of these aphids are also occasionally found on the aerial parts of plants.

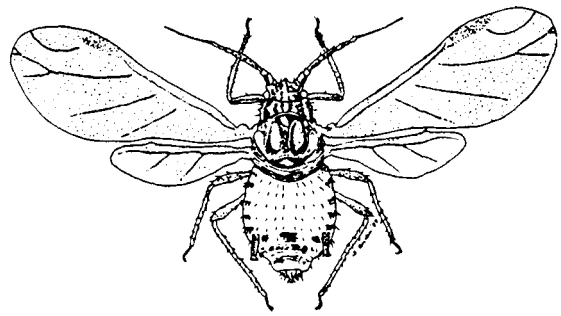


Fig. 2.2

TABLE 1
World distribution of rice root aphids (modified from Yano *et al.,* 1983)

Aphid species	*Host plants*	*Distribution*
Anoecia corni (Fabricius)	Rice	Japan
Anoecia fulviabdominalis (Sasaki)	Rice, barley, wheat, grasses	Japan
Anoecia sp.	Rice	Japan
Chaetogeoica polychaeta Pal & Raychaudhuri	Rice, grasses	India
Forda sp.	Rice	Japan
Geoica lucifuga (Zehntner)	Rice, sugarcane, grasses, *Pistacia*	India, Japan, Malaysia, Philippines, Taiwan
Geoica setulosa (Passerini)	Rice	Italy
Geoica sp.	Rice	Japan
Geoica utricularia setariae (Passerini)	Rice	Italy
Paracletus cimiciformis von Heyden	Rice, barley, grasses	Japan
Prociphilus sp.	Rice, plants belonging to Araceae and Liliaceae	Japan
Rhopalosiphum rufiabdominalis (Sasaki)	*Prunus* sp., rice, grasses	Argentina, Central America, Egypt, Fiji, India, Japan, Malaysia, Morocco, Surinam, Taiwan, Thailand, USA, USSR
Tetraneura akinire (Sasaki)	Rice	Japan
Tetraneura basui Hille Ris Lambers	Rice, grasses	India
Tetraneura nigriabdominalis (Sasaki)	Rice, graminaceous weeds	Cuba, Fiji, India, Indonesia, Japan, Malaysia, New Guinea, Philippines, Sierra Leone, Taiwan, Zambia
Tetruneura radicicola Strand	Rice, grass *Ulmus* sp.	India
Tetraneura sp.	Rice	Japan

Rice seems to suffer very little from root aphids. The damage is mostly due to a few species in isolated areas and that too only at particular seasons of the year. Root aphids occur only in well-drained soils in rainfed environments. Adults and nymphs remove plant sap and cause the leaves to turn yellow and become stunted. But in severe cases, which are very rare, plants wilt and die. In Japan, attacks during the early stage of the crop cause reduction in yield as high as 50% (Tanaka 1961)

Rhopalosiphum rufiabdominalis (Fig. 2.2) is the most important species among the root aphids. It is recorded as associated with ants on the roots of various host plants. The species is mostly a pest of upland rice in Japan and Taiwan and is seldom seen as a threat to irrigated rice anywhere in the world. In Japan, the aphids move to the drained irrigated fields in late summer or autumn and settle on the rice stubbles. Both adults and nymphs congregate on the upper parts of rice roots just above the soil surface when the water is drained from the fields. They sometimes feed on the stem and leaf bases when the aphid population becomes very high and/or the upper portions of the roots are submerged.

Root aphids consist only of the female sex. Adult aphids exhibit wing dimorphism. The apterous female is dark or light green with large red blotches. The nymph-laying period and adult longevity are usually longer for apterous forms than their alate counterparts. The alate form is smaller and mainly reddish brown in color. The winged adults are adapted for migration and they increase in number under stress conditions such as shortage of food and crowding.

The adult aphids reproduce parthenogenetically throughout the year. They start laying nymphs in a day or two after emergence. Fecundity is higher in summer and fall than in winter and early spring. The nymphs molt 4 times before they reach adulthood. The nymphal period is about 7 to 9 days. Winged adults are poor fliers but they often drift long distances by wind or are carried by animals. Although the aphid could complete 53 to 58 generations in a year under laboratory conditions in Taiwan (Hsieh 1970), only 20 generations have been recorded in Japan (Yano *et al.* 1983).

The spring migrants (alate forms) fly from their winter host plants to the rice plants of the first crop. Once this crop is harvested, the aphids move to either summer grasses or rice plants of the second crop. During harvest, the alate forms settle on wheat or rice stubbles where they deposit the overwintering progeny.

Tetraneura nigriabdominalis is a widely distributed species of root aphid. In Japan, it infests only upland rice but not irrigated fields. Many grasses such as *Eleusine indica* (L.) Gaertn., *Pennisetum subangustum* Stapf and Hubb., *Ischaemum rugosum* Salisb. and *Paspalum scrobiculatum* L. serve as alternate hosts in Sierra Leone (Akibo-Betts and Raymundo 1978).

The adult aphids are more or less spherical and brown in color. The body is enveloped in a thin film of white powder. Mature adults measure 3 to 5 mm long. In Japan the infestation starts by April or May every year.

Anoecia fulviabdominalis is a major aphid species attacking the roots of upland rice in Japan. In May, the alate spring migrants move from their primary hosts, *Cornus* spp., to secondary host plants such as barley, wheat and wild grasses. Later, the aphids are carried by wind or ants to upland rice fields.

2.3 Rice Mealybug, *Brevennia rehi* (Lindinger) (Homoptera: Pseudococcidae)

Synonyms: *Ripersia oryzae* Green
Ripersia sacchari Green
Ripersia rehi Lindinger
Heterococcus rehi Lindinger
Tychea rehi (Lindinger)

Distribution: Australia, Bangladesh, Burma, India, Nepal, Papua New Guinea, Puerto Rico, Southern USA

Host plants other than rice: *Apluda mutica* L, *Brachiaria reptans* (L) Gardner & Hubbard, *Chloris barbata* (Sw.), *Cymbopogon caesius* (Nees) Stapf, *Cynodon dactylon* (L.) Pers., *Cyperus rotundus* L., *Dactyloctenium aegyptium* (L.) Willd., *Dichanthium annulatum* (Forssk.) Stapf, *Digitaria sanguinalis* (L.) Scop., *Echinochloa colona* (L.) Link, *Eleusine coracana* (L.) Gaertn., *Eragrostis interrupta* (Lam.) Doell., *Fimbristylis miliacea* (L.) Vahl, *Fimbristylis tenera* Roem. & Schult., *Imperata cylindrica* (L.) Raeuschel, *Isachaemum indicum* (Houtt) Merr., *Iseilema laxum* Hack., *Leptochloa chinensis* (L.) Nees, *Panicum repens* L., *Paspalum scrobiculatum* L., *Saccharum spontaneum* L., *Setaria glauca* (L.) Beauv.,

The rice mealybug is a sporadic pest causing severe losses to rice in the Indian subcontinent. It is prevalent in rainfed rice and is not found in irrigated rice.

Mealybugs occur in colonies attached to the stems and leaf sheaths of rice plants. They suck sap from the plants. White waxy fluff protruding from between the leaf sheath and the stem is the typical indication of the pest's presence. As a result of infestation, plants become stunted and the

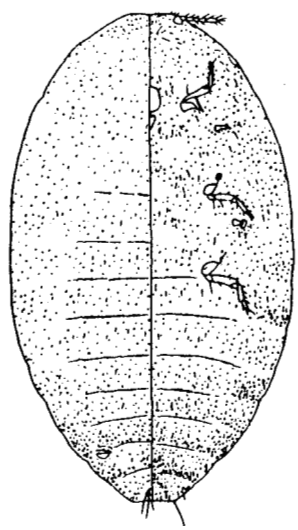


Fig. 2.3

older leaves turn yellow. High incidence inhibits panicle emergence and plants may even dry. Infested fields show isolated patches of stunted plants. Damage is severe during drought conditions when plants can least tolerate the removal of plant sap.

In 1979, when there was a long and severe drought in Bangladesh, a severe outbreak of mealybugs caused yield losses of up to 100% in some fields (Alam and Karim 1981). Heavy losses caused by mealybugs have been reported from several parts of India (Banerjee 1956, Mammen 1976).

The adult females are wingless, oblong and 3-4 mm long. They are bulky and remain stationary on the stems behind leaf sheaths at the base of plants. The body is soft, pinkish, and covered with white waxy threads. Males, pale yellowish, are seldom found in the colonies. They have a single pair of wings and a style-like process at the end of the abdomen but lack mouthparts. They are slender and much smaller than the females. Males migrate freely from plant to plant. Reproduction is parthenogenetically oviparous as well as viviparous (Alam 1965).

The average preoviposition period is 6 days. The female mealybug lays eggs singly, more of less in a chain, inside the waxy threads. A single female can lay 60 to 280 eggs and nymphs in about 5 days, after which it dies. Eggs are yellowish white. The incubation period varies from 3 to 6 hours. Hatching of eggs usually takes place in the morning hours.

Newly-hatched nymphs remain crowded within the waxy threads for 6 to 10 hours before they disperse to various parts of the same plant or to adjacent rice plants. Nymphs are first yellowish white but turn dark yellow after a day. They become fixed between the leaf sheath and stem by driving the proboscis into the stem. The body gets covered with a waxy material in about a day. There are three nymphal instars which take 12 to 18 days to pass and about 12 generations in a year.

Hot, dry weather favors the survival and multiplication of rice mealybugs. But the population drops drastically by the beginning of winter. During winter, the pests survive on weeds and volunteer rice plants. In Nepal, overwintering of mealybugs in both nymphal and adult stages has been observed (Pradhan 1981). When the weather becomes warm, the insects again appear in the rice fields.

Although the reasons for the positive relationship between the high incidence of mealybugs and drought conditions are not precisely known, Fennah and Smith (1954) reported that a low iron content in the soil during drought upsets the normal metabolism of the plant and makes soluble nitrogen more available to 'the mealybug *Neorhizoecus epicopus*. Through simulated drought condition, Wiggins and Williams (1955) showed that amino acid content in the plant increased significantly. Availability of extra amino acid favors rapid growth and multiplication of mealybugs. Fennah (1960) postulated that metabolic upsets in plants caused by water stress accelerates breakdown of protein and that the altered physiological condition of the plant is more nutritionally favorable for sap-sucking insects.

2.4 Black Bugs, *Scotinophara coarclata* (Fabricius), *S. lurida (Burmeister),* and *S. laliuscula* Breddin (Hemiptera: Pentatornidae)

Distribution: *S. coarctata:* Bangladesh, Burma, India, Indonesia, Kampuchea, Malaysia, Pakistan, Philippines (Palawan), Sri Lanka, Thailand, Vietnam (Fig. 2.4A)

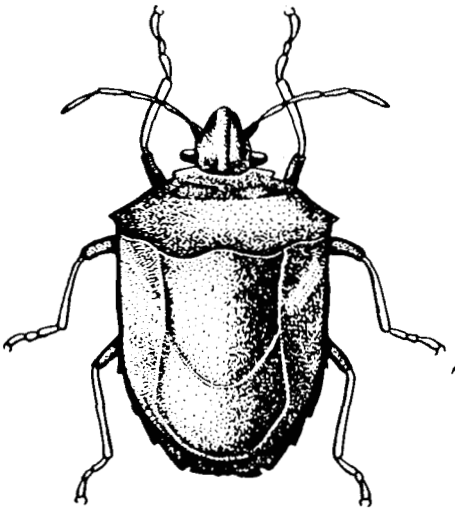


Fig. 2.4A

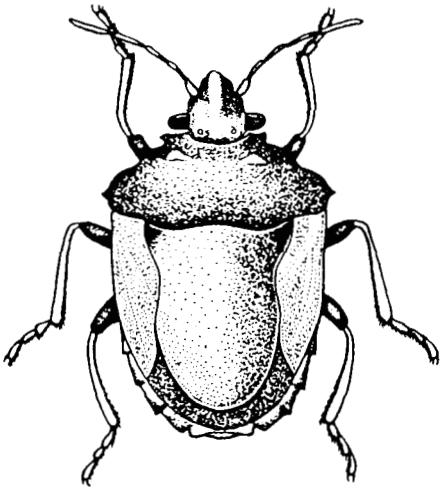


Fig. 2.4B

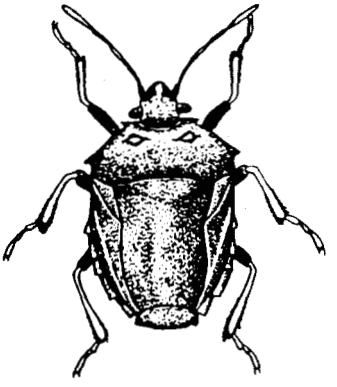


Fig. 2.4C

S. lurida: Bangladesh, China, India, Indonesia, Japan, Kampuchea, Malaysia, Pakistan, Papua-New Guinea, Philippines (Mindanao), Sri Lanka, Thailand, Vietnam (Fig. 2.4B).

S. latiuscula: Indonesia (Sumatra), Philippines (Luzon) (Fig. 2.4C)

Host plants other than rice: *Colocasia esculenta* Schott., *Hibiscus esculentus* L., *Hymenachne pseudointerrupta* C. Muell., *Panicum amplexicaule* Rudge Pl. Guian., *Scirpus grossus* L., *Scleria sumatrensis* Retz., *Vigna unguiculanta* L., and *Zea mays* L.

In recent years, many outbreaks of black bugs have been reported even though the insects were previously considered as minor pests of rice. *Scotinophara coarctata* appeared in South Palawan, Philippines in 1982 and a major infestation followed during the subsequent months. In Indonesia and Malaysia, there were outbreaks in 1978 and 1979 respectively.

Nymphs and adults feed chiefly at the base of stems where they remove plant sap. When the infestation is at the tillering stage, deadhearts occur but continued feeding results in leaves turning chlorotic or reddish brown color, and in reduction in tiller number and stunting. Attack during the booting stage, results in panicles with empty grains similar to the 'deadhearts' caused by stem borers. Direct injury to panicles is also common. Bugs feed on panicles in the milky stage on overcast days and during night. Injured grains are spotted brown. Heavy infestations may lead to the death of plants and the whole field appears 'burned' similar to that of a hopperburned field.

The effect of black bug feeding on yield components of some rice cultivars was studied by Heinrichs *et al.* (1987). They found that yield losses were due to unfilled grains, decrease in tiller

number and less grains per panicle. Percent yield loss at 10 bugs per hill ranged from 14.7% in resistant cultivars to 23.0% in susceptible cultivars.

Adults are brownish black with a few distinct yellowish spots on the thorax which bears spines below the anterior angles. They are 8–9mm long. Tibiae and tarsi are pinkish. They give off an offensive odor typical of stink bugs when disturbed. Adult bugs live for up to 7 months. There is one generation in a year.

Female bugs deposit eggs on the basal parts of rice plants near the water surface. A female lays about 200 eggs during her lifetime and guards them until they hatch. Each egg measures 1 mm long, is greenish when laid and turns pinkish as it matures. The incubation period is 4 to 7 days.

Nymphs are light brown, with a yellowish green abdomen and some black spots. They molt 4 to 5 times and reach the adult stage in 25 to 30 days.

Large numbers of bugs are carried to distant places by strong winds. Adults appear in swarms, and are strongly attracted to light. Ajuk *et al.* (1981) and Latif *et al.* (1982) observed that the flight activity of adults to light traps coincides with the lunar cycle.

The bugs are able to adapt to a wide variety of conditions and are capable of withstanding adverse conditions. They hide in cracks in soil during periods of water stress and during the winter. After overwintering they fly to the rice crop and reproduce over several generations. They again return to their resting sites after the harvest of the rice crop. The black bug aestivates in the adult or late nymphal stage in cracks in bunds, in paddy fields or in adjacent higher grounds to a depth of 30 cm., where it remains torpid. It is gregarious during periods of rice fallow.

Populations are generally less on upland than on irrigated and rainfed wetland rice. The insects prefer continuously cropped irrigated fields to a single-cropped field. Heavy damage by the pest is usually observed after the heading stage of the rice crop especially when irrigation has been stopped during thc maturation period.

In the Philippines, the dry season rice crop is damaged more severely than the wet season crop (Miyamoto *et al.* 1983). The pest is most abundant in poorly-drained rice fields around marshes. Asynchronous double cropping of irrigated rice with high levels of nitrogen seems to favor black bug outbreaks. In Malaysia, the relatively small natural enemy complex of *S. coarctata* and high availability of alternate hosts in the vicinity of rice fields are suggested as possible causes for the frequent black bug outbreaks.

Three species of *Scotinophara* have been reported from the Philippines, but these species are distinctly isolated in their distribution; *S. coarctata* in Palawae *S. lurida* in Mindanao and *S. latiuscula* in Luzon.

2.5 Rice Seed Midges *Cricotopus sylvestris* (F.), *Paralauterborniella subcincta,* and *Paratanytarsus* sp. (Diptera: Chironomidae)

Distribution: Europe, USA

Host plants other than rice: some weeds

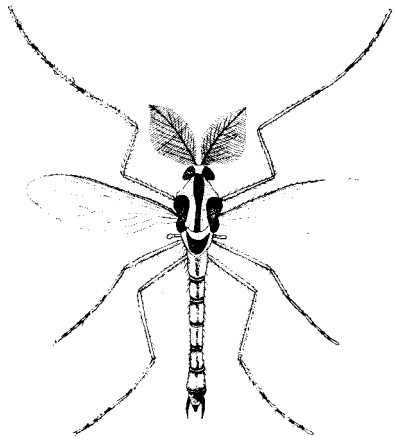


Fig. 2.5

Rice seed midges are common in California rice fields. Serious damage to rice is limited to germinating seeds and very young seedlings. Maggots feed on primary roots and shoots or may hollow out embryos, killing plants. They may also feed on floating leaves, causing small holes that extend completely through the leaves. Once seedlings are fully established, the plants can withstand damage by the larvae. Larval populations increase daily after flooding because of continued egg laying, and delay in planting will expose germinating rice seeds to more midge infestations.

Adult flies resemble small mosquitoes as they swarm over rice fields and levees. Masses of eggs are laid on water in strings held together by a sticky, mucilagenous material that swells in contact with water to form a protective covering over the eggs. Eggs hatch in one or two days.

The larvae use secreted silk and frass to build tubes on the bottom of the rice paddy and on submerged vegetation. The tubes serve as larval retreats and also as webs to entrap algae and diatoms for food. Larvae may also feed on rice seedlings and other plants. Damage to rice is caused mostly by the third and fourth instar larvae. The larvae pass through 4 instars in 7 to 10 days in the spring when the water is warm. Pupation takes place in the silk tubes under water. The pupal period is 2 to 3 days. Three to four generations occur each summer, but only the first two are of economic concern to rice growers in the USA(Anon. 1983)

Numerous other species of Chironomidae have been reported occasionally infesting rice fields in various countries. In Egypt, a *Chironomus* sp. causes damage to rice seedlings grown in saline soils. The Australian *Chironomus tepperi* prefers soils with a high organic content following sod seeding. In the USSR, larvae of a *Chironomus* sp. feed on floating or submerged rice leaves causing a severe reduction in shoot numbers.

2.6 Asian Rice Gall Midge, *Orseolia oryzae* (Wood-Mason) (Diptera: Cecidomyiidae)

Synonym: *Pachydiplosis oryzae* (Wood-Mason)

Distribution: Bangladesh, Bhutan, Burma, China, India, Indonesia, Kampuchea, Laos, New Guinea, Pakistan, Sri Lanka, Thailand, Vietnam.

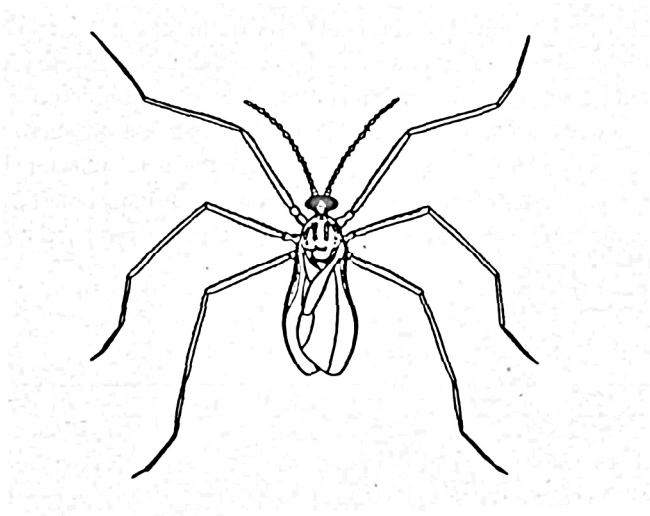


Fig. 26

Host plants other than rice: *Cynodort dacfylott* (L.) Pers., *Echinochloa colorza* (L.) Link, *Heteropogon contomts* (L.) Beauv., *Ischaemunt aristatunt* L., *Leersia hexrrrtdru* Sw., *Oyza barthii* A. Chev., *Panicum miliaceum* L., *Paspalurn scrobiculatum* L., *Sacciolepis interrufa* (Willd.) Stapf

Orseolia oryrae is primarily a pest of lowland irrigated rice but has been rcported in upland and deepwater rice (Venugopala Rao 1975) also. The extent and severity of gall midge infestations has, significantly increased during the last two decades. Favorable weather conditions, cultivation of high-tillering varieties, intensive management practices and low parasitization are conducivc to thc rapid multiplication'of this pest.

The main external symptom of gall midge attack is a 'silver shoot' or 'gall' that resembles an onion leaf. A fully developed gall is a silvery white, hollow tube about 1 cm wide and 10-30 cm long. Larval feeding suppresses leaf primordial differentiation at the growing tip. This, in turn, induces the development of radial ridges from the innermost leaf primordium followed by an elongation of the leaf sheath (Perera and Fernando 1970). Galls appear within a week after the larvae reach the growing point. Attack of rice seedlings leads to profuse tillering and stunting of the plants. A late infestation of the plants at the reproductive shoot apex malforms the leaves and panicles. Israel *et al.* (1959) reported 0.5% loss in yield for every unit percent increase in incidence. But wide varietal differences exist in the effect of infestation on crop losses. In certain varicties, gall formation is not manifested and instead necrosis of the shoot apex results (Picris 1977).

The gall midge attacks rice from the nursery to the end of tillering stage. Young maggots cannot survive in plants past the vegetative stage as there are no actively growing apical buds for them to infest.

The periodicity of infestation and extent of damage caused by the gall midge varies in different countries. In Thailand, the pest has long been reported associated with the rainfed rice of the

North, Northeast and Eastern regions, but in recent years, outbreaks in the irrigated dry season rice of the Central Plains have also occurred (Katanyukul *et al.* 1980a). In India, the gall midge was previously a pest only in the wet season crop but recently it has been observed in the winter crop as well (Kalode and Kasiviswanathan 1976). In Sri Lanka, high infestations of gall midge were observed in the southwest monsoon season (April to July) in the wet zone while in the intermediate and dry zones, they were mostly seen during the northeast monsoon (October-November) (Kudagamage and Nugaliyadde 1981). The extent of insect damage reported by various workers is presented in Table 2.

TABLE 2

Damage by *O. oryzae* in South and Southeast Asia

Country	*Zone*	*Season*	*Damage*	*Reference*
India	Tamil Nadu	Late	30% hills	Natarajan and Chandy 1978
India	Uttar Pradesh	Late	65% hills	Rizvi and Singh 1980
India	Madhya Pradesh	Second crop	45% hills	Kaushik *et al.* 1979
India	Karnataka		50% yield	Subramanian 1935
India	Nizamabad		30% yield	Khan and Murthy 1955
India			15% yield	Israel 1959
India			25% yield	Lever 1970
Thailand			50% yield	Grist 1965
Thailand	Northern	Wet	33% yield	Katanyukul *et al.* 1980b
Thailand	Northeastern	Wet	27% tillers	Katanyukul *et al.* 1980b
Sri Lanka	Dry & Intermediate	Maha	44% tillers	Wickremasinghe 1969
Sri Lanka	Dry & Intermediate	Yala	23% tillers	Wickremasinghe 1969
Sri Lanka	Dry & Intermediate	Maha	100% hills	Wickremasinghe 1969
Sri Lanka	Dry & Intermediate	Yala	18% hills	Wickremasinghe 1969
Sri Lanka	Wet	Yala	80% yield	Wickremasinghe 1969
China		October	60% hills	IRRI 1978

The adult gall midge is similar in appearance to a mosquito. Females have bright red abdomens, Mating takes place soon after emergence and egg-laying starts a few hours later. The female flies mate only once and the unmated ones lay sterile eggs. Adults are nocturnal in habit and are highly attracted to light traps. Eggs are laid either singly or in groups on the underside near the base of rice leaves or sometimes on leaf sheaths. A single female lays 100 to 200 eggs either singly or in groups. The males mostly die in 12 to 18 hours after emergence; females live up to 3 days.

Eggs are long, tubular, and shiny white; sometimes with pink, red or yellow shades. They turn amber before hatching. Eggs require high humidity for development and hatching. The incubation period is around 3 to 4 days.

The newly-hatched maggots are grey-white, fairly stout with a pointed anterior end. They wiggle down the leaf blade in a film of dew and move between the leaf sheath and the stem until they reach the opening point of the apical or side bud at a node. The larva feeds inside the developing bud which is a zone of differentiation for new tillers. A hollow chamber called a 'gall' forms around the larva. As the larva feeds the gall enlarges at the base and elongates having the appearance of an

onion leaf. There are 3 larval instars; total larval period is 15 to 20 days. Generally only one maggot is found in a tiller.

Pupation takes place inside the gall. The male and female pupae can be easily separated by their size and color of the abdomen (Panda and Mohanty 1970). Male pupae are small and brown while the females are larger and pinkish. The color turns darker before adult emergence. The pupa has several rows of abdominal spines that enable it to move up to the tip of the gall before adult emergence. The pupa makes a hole at the gall tip with its spines and the midge emerges through this hole leaving the pupal skin behind. Adult emergence generally takes place at night or early morning. The pupal period varies from 2 to 8 days. The entire life cycle is completed in about 25 to 38 days.

The gall midge remains inactive as a prepupa in wild rice or weeds during the dry season. At the onset of the monsoons, it becomes active and completes one or two generations in grasses before it moves to the rice crop (Reddy 1967). In India pest incidence is high during July and August if there is rainfall during the daytime. This period coincides with the maximum tillering phase in rice. The population then declines rapidly in December, primarily, because of the limited availability of suitable host plants. In some cases, the pest infests rice stubbles left after the first crop.

Wongsiri *et al.* (1971) reported the ecological conditions that usually prevailed in Thailand at the times when gall midge populations were high. The sky was cloudy most of the days and the relative humidity was 75% on an average, the optimum mean temperature for adult emergence and oviposition ranged from 23 to 27°C. Hidaka *et al.* (1974) observed that seasonal fluctuations of gall midge populations were closely related to rainfall. Overcast skies and drizzling rains are favorable for rapid build-up of pest populations.

Israel *et al.* (1961) reported an increase in the pest population with high nitrogen levels. The incidence decreased with high levels of phosphate in combination with nitrogenous fertilizers. The infestation generally increased with higher levels of potash (Israel *et al.* 1963). Prakasa Rao (1972) observed an increased number of absolute tillers and infested tillers per unit area with the application of increased levels of nitrogen. Close spacing of transplanted rice resulted in a greater number of tillers and more leaves per unit area and an increase in relative humidity within the plant canopy which was suggested as the reason for higher gall midge incidence than under wider spacing (Prakasa Rao 1975).

Variable reactions of differential rice varieties to *O. Oryzae* have provided evidence of different biotypes in South and Southeast Asia. The variability of the species is indicated by three biotypes in different regions of India.

2.7 The African Rice Gall Midge, *Orseolia oryzivora* Harris and Gagne (Cecidomyiidae: Diptera)

Distribution: Burkina Faso, Cameroon, Ghana, Guinea, Guinea-Bissau, Ivory Coast, Liberia, Mali, Niger, Nigeria, Senegal, Sierra Leone, Sudan, Togo

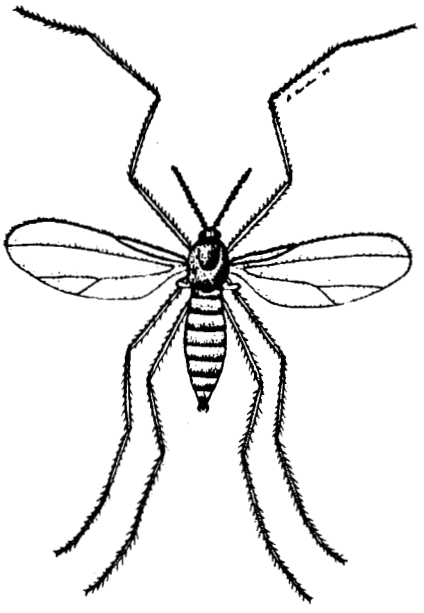


Fig. 2.7

This species had previously been misidentified and considered as *O. oryzae.* It has been recently shown by Harris and Gagne (1982) that the specimens from Asia and Africa are morphologically distinct in the larval, pupal and adult stages.

The distribution of this pest appears to be increasing in the rice growing regions of Africa. Although the gall midge has been reported from several countries, it has not attained the status of a major pest in most of them. In Upper Volta, *O. oryzivora* is one of the most serious and widespread pests of irrigated, rainfed and lowland rice (Bonzi 1980).

The biology of the pest is similar to that of *O. oryzae.* Infestation is most severe when the first rains are early and are followed by a relatively long drought, which delays rice planting. The first generation occurs on grasses and when rice becomes available, it is attacked. The extent of infestation may be related to the availability of host plants, the amount of rain, especially at the beginning of the season, and the cropping pattern at a given locality. Little is known on the pest-host plant relations (Agyen-Sampong 1982).

2.8 Stalk-eyed Borer, *Diopsis macrophthalma* Dalman (Diptera: Diopsidae)

Synonym: *Diopsis thoracica* Westwood

Distribution: Benin, Burkina Faso, Cameroon, Ghana, Ivory Coast, Liberia, Mali, Nigeria, Senegal, Sierra Leone, Swaziland

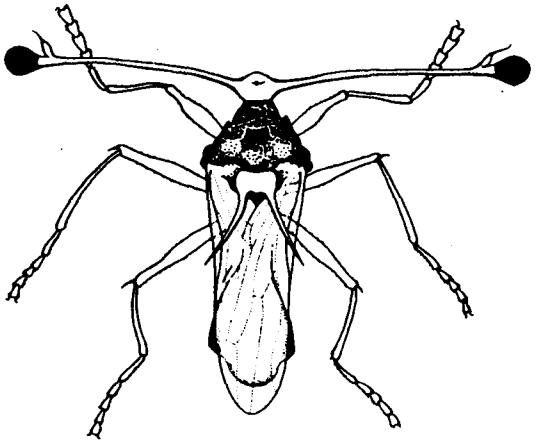


Fig. 2.8

Diopsis macrophthalma is a major pest of rice in many parts of tropical Africa. It causes severe damage in the valley of Benue in North Cameroon, Swaziland and Sierra Leone. In Senegal, it is found only in the south. In Burkina Faso and Mali, it is a sporadic pest in areas with sufficient humidity in the dry season. The pest infests irrigated rice fields in Ivory Coast and Benin, and is less frequent in rainfed areas (Breniere 1976). In Ghana, Abu (1972) noted that it could cause about 9% yield loss. Alghali (1981) reported grain losses from 1.9 to 97% in southern Nigeria.

The stalk-eyed borer is not known to attack crop plants other than cultivated rice. However, it seems probable that the pest has alternate hosts among wild rice and grasses. *Cyperus difformis,* a weed found commonly in rice fields, on which eggs, larvae, pupae or adults are sometimes found, may be a host plant during non-rice cropping seasons (Alghali 1979).

The pest infestation delays booting and leads to a decline in the number of panicles. If the attack comes early, it may cause total crop loss; if it occus later, some varieties compensate for damage by producing new tillers. Studies conducted in Nigeria (Alghali and Osisanya 1982) have shown strong correlation existing between the number of eggs laid in a plant and number of tillers, and the number of eggs and deadhearts.

Adult flies are typical diopsids easily recognized by their characteristic eyes borne on the tip of stalks. Flies are often found in areas with water throughout the year. In the dry season, they occur in swarms in the shade near streams and canals.

Gravid females lay eggs singly on the upper surface of young leaves, normally in the groove of the midrib. Boat-shaped, striated eggs with a characteristic anterior projection are fixed to the leaf with a cement that prevents them from being washed off in heavy rains. Eggs are creamy white when laid but later darken to tan. Each female fly lays about 20 eggs over period of 10 days. Peak oviposition occurs 30-40 days after transplanting and almost terminates by the end of the tillering stage. Alghali and Osisanya (1981) reported that virtually no eggs were laid and no deadhearts developed on 60-day-old plants.

The larva is a yellowish maggot, about 18 mm long and 3 mm wide, easily recognizable by the two long abdominal extensions ending in black hooks pointed forward. The maggot moves down inside the leaf sheath and feeds above the meristem on the central spindle of young leaves causing a deadheart symptom. Every tiller attacked is lost. In its life, a single larva can destroy up to ten neighboring tillers (Feijen 1979). Later generations of larvae feed on the developing flower head. The larval stage lasts for 25 to 33 days.

Pupae are red with brown dorsal bands and clear segmentation. They are flat and almost triangular in section because of the compression inside the stem. During later stages, the imago can be seen developing inside the pupal case. Adults emerge after a 10-12 day pupal stadium. There are two principal generations between June and October, and a third less prominent one in the off-season.

Diopsis apicalis Dalman is a polyphagous species often encountered in rice fields. It is distinguished from *D. macrophthalma* by its small size and an apical smoky spot at the tip of each wing. The larvae feed on healthy plants or on tissue decomposed after a caterpillar attack. They may even eat caterpillars or the maggots of *D. macrophthalma.* However, its useful role as a predator cannot make up for the damage it causes to the rice crop (Breniere 1976).

2.9 Rice Stem Maggot, *Chlorops oryzae Matsumura* (Diptera: Chloropidae)

Distribution: Indonesia, Japan, Korea, Vietnam

Host plants other than rice: *Alopecurus fulvus* J. E. Sm., *Hordeum vulgare* L., *Secale cereale* L., *Triticum aestivum* L.

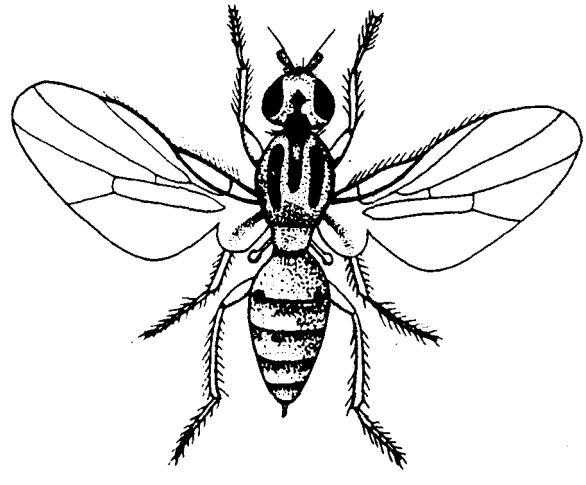


Fig. 2.9

The rice stem maggot is an important pest of rice in Japan and Vietnam where crop losses up to 30% have been reported. In Vietnam, damage is more serious in the colder regions than in the warm areas. Upland rice and early varieties are more prone to infestation than irrigated and late-maturing varieties.

The maggots are located near the growing point of the rice plant and feed on leaf blades. Tillering is reduced and stunting results from early attack. Larvae of later generations feed on developing flowers and this reduces yield considerably. The type of damage differs in north and south Japan. In the north, where there are only two generations, the first brood larvae attack young leaves and growing tips of rice plants. But in the south, where there are three generations, the first brood maggots infest young leaves while the second brood larvae attack only leaf tips (Uyeda *et al.* 1962).

The adult which looks like a small housefly is grey with three black longitudinal stripes on the thorax. Female flies lay 50-100 small white, elongated eggs singly on the leaf blades of rice seedlings in the nursery. The incubation period is 7 days. The adult flies live for a fortnight.

The maggots are white, translucent, and about 1 mm long. The anal segment is bifid. The larvae migrate to the central whorl of the rice plant and start feeding. The larval stage lasts about 6 weeks. Pupation takes place between the leaf sheath and stem and the pupal period is 2 weeks. There are remarkable variations in the growth period of the insect in different regions of Japan (Tamura et al. 1959). The flies of the later generations oviposit on grasses where the emerging larvae overwinter.

2.10 Rice Seedling Flies, *Atherigona exigua* Stein, and *Atherigona oryzae* Malloch (Fig. 2.10) (Diptera: Muscidae)

Distribution: Bangladesh, India, Indonesia, Japan, Malaysia, Pakistan, Papua New Guinea, Philippines, Singapore, Sri Lanka, Thailand

Host plants other than rice: *Cynodon dactylon* (L.) Pers., *Panicum repens* L., *Sorghum bicolor* (L.) Moench., *Zea mays* L.

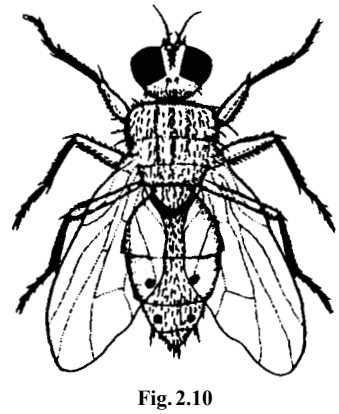


Fig. 2.10

Damage by seedling maggots is highly seasonal in occurrence. It is restricted to upland rice and does not occur in flooded wetlands.

The maggots feed in the central shoot of rice seedlings by tunnelling downward to the base. They move their mouth hooks back and forth in a rasping motion. They produce typical symptoms of twisted deadhearts similar to those caused by lepidopterous stem borers. The attacked plants turn yellow, become stunted and may subsequently die. Maturity of plants which survive is delayed by 7 to 10 days.

The adult is a small fly, about 3 to 3.5 mm long, with a grey thorax, yellow spotted abdomen and yellow legs. The flies have an angular head with deep set antennae. Adults are strong fliers and are active only during the daytime. They are attracted to plants less than a month old for oviposition and a female may lay 100 eggs during its lifetime. Eggs are laid singly on the underside of the leaves 3 to 5 days after mating, usually in the evening hours. Eggs are pure white, elongated and very large (1.5 mm long) in comparison with the adult. Incubation period is 3 days.

The newly-emerged larva is creamy white and moves down the leaf blade on a film of dew in the early morning. The maggots then burrow the leaf sheath towards the base of the stalk. They molt three times in 6 to 10 days and then pupate inside the stem or in the soil within a small yellow puparium. Pupae are barrel-shaped and reddish brown in color and turn to dark brown at the later stages. The pupal period lasts 8 days. Adult emergence can take place any time of the day, but it occurs mostly in the afternoon (Rodriguez 1969). Adult longevity is 10-12 days.

Damaging infestation levels occur several months after the beginning of the rainy season. Peak incidence of the pest in India was reported during the months of July and August (Senapati and Satpathy 1983). The infestation of A. oryzae was most serious on rice after a prolonged period of drought (Fernando and Manickavasagar 1957).

2.11 White Grubs (Coleoptera: Scarabaeidae)

White grubs, the large larvae of scarab beetles, are becoming important pests of upland rice in many parts of the world. As they are mostly polyphagous, various other crop plants are also attacked by these insects.

White grub species are divided into two groups: (1) ‘chafers’ in which adults feed on the foliage of trees and larvae feed on roots of living rice plants, and (2) the ‘black beetles’ in which adults feed on roots and larvae survive on organic matter and do not attack living roots.

The larvae of chafers feed on roots and other subterranean plant portions of rice and many other crop plants. As the grubs grow, they become voracious feeders causing enormous damage to crops. In case of heavy root injury, the whole plant is affected, while partial damage leads to poor growth of host plants. A single white grub is capable of destroying a number of plants. However, in the older crops, plants are not killed outright. In such cases, yellowing followed by withering of the leaves takes place. Clustered distribution is a common feature of white grubs and infestations often tend to occur in the fields year after year (Veeresh 1977).

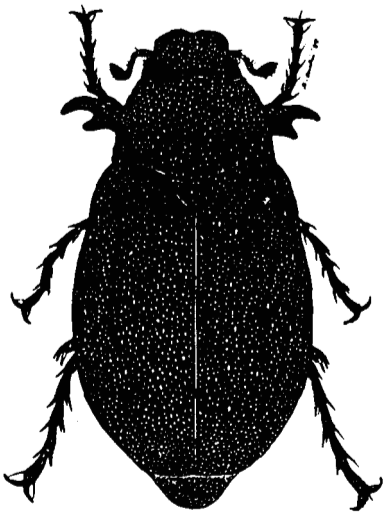


Fig. 2.11

Sporadic occurrence of chafers such as *Anomala dimidiata, Holotrichia seticollis, H. longipennis* and *Popillia cupricollis* has been reported on rice crops from India. Grubs of *P. cupricollis* damage roots of rice seedlings while adult beetles chew the rice grains at the dough stage. Severe outbreaks occurred over large areas in northern India in 1981 and more than 50% of the crop was damaged by white grubs. *Leucopholis irrorata* (Fig. 2.11), another chafer species, caused intensive but highly localized damage to upland rice in southern Luzon, Philippines, in 1974 (IRRI 1976). The distribution of this pest in the Philippines is closely related to sugarcane cultivation (Litsinger *et al.* 1983).

Heteronychus lioderes, a black beetle, is a specific pest on rice in Uttar Pradesh, India (Garg and Shah 1983). *H. plebeins* damages the rice crop in Madagascar in humid soil during the dry season. *H. mosambicus* was recorded as damaging the roots of rice plants in Nyasaland. It occurs only in those fields from which water has receded and the surface remains mostly damp.

Rain at the beginning of the rainy season stimulates the overwintering adults of most species back to activity. But adults of *Leucopholis irrorata* in the Philippines revert to normal activity only a month after rains begin (Litsinger *et al.* 1983). They emerge from the soil leaving behind a small hole on the surface. The beetles then undertake feeding and a mating flight during night and return back to the soil before dawn. They are found in soil up to a depth of 0.3 meter (Rai *et al.,* 1969).

Adult chafer beetles are grey, tan, dark brown or black. The males are considerably smaller than females. The male *Leucopholis irrorata* is 25 mm long and 14 mm broad; the corresponding measurements for the female being 30 mm and 16 mm respectively (Otanes 1924). The beetles feed on leaves and fruits of various trees. Besides being a source of food, these trees serve as mating sites. Beetles, after mating, remain in the trees during the day and at night fly short distances to lay eggs in nearby fields. Hence more egg laying and a higher level of infestation are noticed in fields near trees. Adults are attracted to light traps and catches are the largest during new moon nights.

Eggs are laid in the soil at a depth of 5 to 15 cm. They are creamy white and oval when freshly laid and measure on an average 3 mm long and 1.7 mm broad. The total number of eggs laid per female varies from 50 to 60. Color changes as the development advances and the egg swells up to 4 mm in diameter, one or two days before hatching. Eggs are highly sensitive to dry weather and must be in moist soil to hatch. The egg stage lasts for 1 to 3 weeks.

The newly hatched grub is creamy white in color. The head turns brown and the larva becomes active in a few hours. The first instar larva can feed on the organic matter available in the soil but prefers plant roots. The second and third instar grubs require roots as their food for normal development and pupation. Larvae prefer moist soil. In moist soil, the grubs are seen near the soil surface whereas in dry soil they remain close to a location in the soil where moisture is suitable. The larva can survive for more than 110 days within the earthen cell under low soil moisture levels but cannot survive for more than six days under water-saturated conditions (Veeresh 1977). In nature, continuous rain or a water-logged condition in fallow land for 3 to 4 days forces the grubs to come out of the soil where they are exposed to dehydration and predation by birds, The uneven distribution of white grub larvae within a field is due to their strict moisture requirement.

There are three larval instars. The stadia are 1 to 2 weeks, 3 to 4 weeks and 4 to 8 weeks for first, second and third instars respectively. In the tropics, the grubs feed on the roots of host plants from July to September. The maximum damage is usually done from the middle of August to early September when the grubs are fully grown. Mature larvae descend to a depth of 0.3 to 2.0 m in the soil during the dry season where they prepare an earthen cell and pupate. The pupal cells protect the dark brown pupae from drying out. Adult emergence starts by the last week of September and is completed by the end of November.

The adult beetles remain inactive within their pupal cells till the next April when they begin to leave the soil. There is only one generation of the pest in a year. The life cycle is completed in 11 to 16 weeks in the tropics. In temperate areas 2-year life cycles are common.

The larvae are unable to tolerate low temperatures. The third instar grubs kept at constant temperatures of 4, 10, 15, 20, 25 and 30°C did not survive for more than a month except at 20 and 25°C (Veeresh 1977).

2.12 Grape Colaspis, *Colaspis flavida* (Say) (Coleoptera: Chrysomelidae)

Distribution: Southern USA

Host plants other than rice: *Chenopodium album* L., *Digitaria sanguinalis* (L.) Scop., *Fragaria vesca* L., *Glycine max* (L.) Merr., *Iva Ciliata* Willd., *Lespedeza striata* (Thunb.) Hook & Arn., *Muhlenbergia mexicana* (1.) Trin., *Paspalum laeve* Michx., *Poa compressa* L., *Polygonum lapathifolium* L., *Potentilla bicolor* L., *Pyracantha coccina* Roem., *Rumex crispus* L., *Vitis vinifera* L.

Adults and grubs of *C. flavida* are polyphagous and a number of important cultivated plants are their hosts. The insect first drew the attention of economic entomologists as a pest of grapes, and thence the common name. Rice is the spring host of the overwintering larvae. Damage is mostly

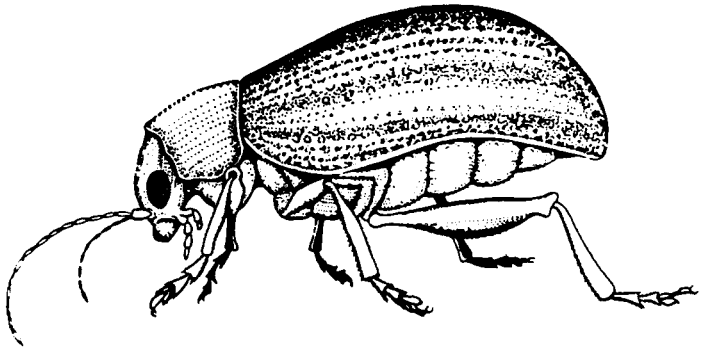


Fig. 2.12

confined to dry-seeded fields. In the spring the overwintering grubs feed on germinating seeds, roots and seedlings reducing the crop stand and reducing tillering.

First brood beetles appear in the field in early June and are abundant up to early July. They mate soon after emergence and may mate several times during their life. The average longevities of the males and females are 7.8 and 13.4 days respectively (Rolston and Rouse 1965). The preoviposition period lasts for 3 to 5 days. Eggs are laid in the soil around the roots of host plants. The incubation period is 6 to 9 days.

Larvae spend up to 7 months in cells pressed slightly into or on the soil. Pupation occurs in the soil and the pupae remain in the soil for 3 to 7 days until adults emerge. Highest larval populations are seen in less compact soils. Beetles are unable to come out from dry, hard soil.

The grape colaspis overwinters as larvae near the boundary of the subsoil and topsoil. The larvae suffer considerable mortality from spring tillage. The surviving larvae move upward and start feeding about the first week of May. Pupation begins in late May and continues until late June. The first brood of adults starts ovipositing from about the beginning of June until mid-August. Some larvae may not pupate until the following spring; others pupate in late July or August and produce a second brood of adults. These adults are responsible for the overwintering larvae that develop in late fall.

CoIaspis occidentalis (L.) from Guyana and *C. prasina* (F.) from Brazil are of relatively minor importance.

2.13 Rice Root Weevil, Echinocnemus oryzae Marshall (Coleoptera: Curculionidae)

Distribution: India

Host plants other than rice: *FimbristyIis tenera* Roem. & Schult. and many wild grasses

The rice root weevil, *E. oryzae,* previously a minor pest of paddy has become an important pest in some river basins in India. Adults feed on leaves of newly transplanted rice, but seldom cause economic damage. Larvae feed on roots during the wet season. Plants attacked during tillering show more damage symptoms than plants damaged after tillering. Yield losses may reach to 10%.

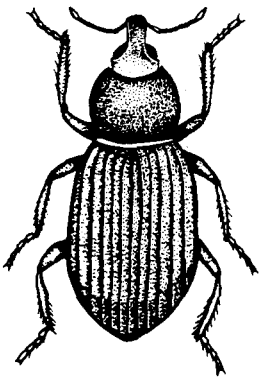


Fig. 2.13

It is probable that the insect is primarily a pest of grasses and that it has only secondarily taken to rice. The distribution of the pest is rather restricted to deltaic regions that have recently been brought under rice farming (Singh and Kalkat 1956). Clay and heavy loam soils favor the incidence. The insect does not seem to occur in sandy soil (Thirumala Rao 1952).

Eggs are laid at the base of plants. Grubs devour the fibrous roots of rice plants and attacked plants become stunted and tillering is reduced. Damage is maximum in the newly transplanted crop during July-August. In severe cases the plants wither and the field has many patches that have to be filled by transplanting fresh seedlings. Once the plant is established, the chances of withering are low.

Adult weevils are black or piceous and densely covered with grey scales. They emerge with the onset of the monsoon towards the end of May. The beetles are usually found on grasses and after pairing, give rise to a new generation of grubs that can be seen among rice roots from July to September.

Larvae are translucent white and about 5 mm long with six pairs of prominent tubercles on the dorsal side of the abdomen. These structures serve a respiratory function by taking in oxygen from the roots. The larvae burrow down into deeper layers of soil to remain in a resting condition and later pupate. There are two generations per year.

2.14 Rice Plant Weevil, *Echinocnemus squameus* Billberg (Coleoptera: Curculionidae)

Synonym: *Echinocnemus bipunctatus* Roelofs

Distribution: China, Indonesia, Japan, Korea, Ryuku Island, Taiwan

Host plants other than rice: *Alisma plantago-aquatica* L., *Callitriche verna* L., *Cyperus rotundus* L., *Echinochloa colona* (L.) Link, *Potamogeton natans* L.

E. squameus is a sporadic minor pest of rice. Adult weevils feed on the leaves of young rice plants at or near the water surface. Feeding damage is evident by a few longitudinal scars that are visible on the leaves when they open. Maximum damage is caused to plants 3 to 4 weeks after transplant-

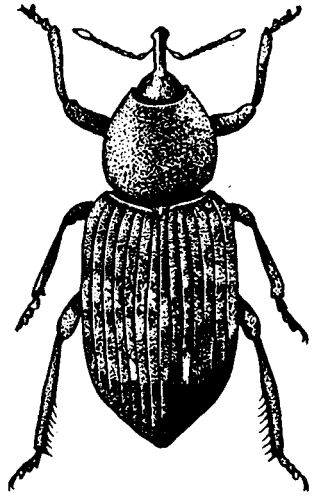


Fig. 2.14

ing. The infected plants are stunted and do not tiller normally. Sometimes irregular and delayed flowering also occurs (Kojima *et al.* 1981). In severe cases, the affected plants break at the site of insect feeding due to wind or submergence. Larval injury on roots is seldom noticed (Kuwayama 1963).

The adult weevils emerge from hibernation and migrate to rice fields by the end of May. In Japan migration to the rice fields coincides with the transplanting time. Plants adjacent to levees are most prone to damage by the beetles. The beetles walk on the surface of water and dive under water or swim. Females dive under water and lay their eggs singly on soil close to the rice plant. Water is indispensable for the development and hatching of eggs (Kuwayama 1963). The incubation period is 6 to 10 days.

The newly hatched grubs burrow into the soil. The spiracles are modified to six paired dorsal hooks on the lateral side of the larvae which under flooded conditions, are thrust into roots to obtain oxygen. Larval feeding occurs on decayed organic matter and rarely on plant roots. The full-grown grubs usually pupate by the end of September, but are unable to pupate under flooded conditions (Oya and Sato 1978). Overwintering sites are low-lying areas and stubbles in rice fields. But adults often hibernate on the roots of grasses on levees. There is one generation annually.

2.15 Paddy Root Weevil, *Hydronomidius molitor* Faust (Coleoptera: Curculionidae)

Distribution: India

This pest is a serious problem to rice cultivation in many parts of Bihar, Gujarat and Haryana states in India. Damage up to 30 to 50% has been reported from Haryana (Kushwaha and Sharma 1980). Even though adult weevils have been observed feeding on rice leaves, the damage caused by them is negligible.

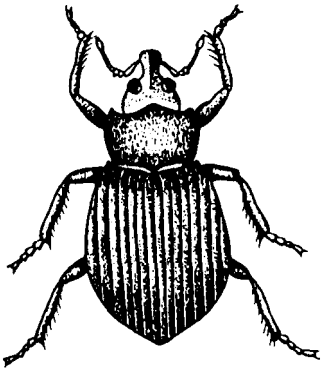


Fig. 2.15

Grubs feed on the roots of young transplanted rice plants. Regenerating roots are also subsequently destroyed by larval feeding. The attacked plants become stunted and tillering is reduced. The leaves turn yellow, develop a rusty appearance and in severe cases, plants are even killed (Kushwaha *et al.* 1983). But once plants are established, larvae cause little damage.

The adults start emerging after the first showers in June. The adult weevil measures 4.5 mm in length and 2.2 mm in width. Freshly emerged weevils are light brown in color, changing to dark brown to black at later stages. Adults are semi-aquatic and are capable of swimming in water. They mate 3 to 4 hours after emergence and females lay their eggs on the soil near the roots of grasses. The eggs hatch in 7 days.

Grubs begin hatching in early July. They are translucent white in color. Grubs crawl down to the root zone and first feed on the root hairs and later on the roots. The maximum larval population is observed in late July which coincides with the main transplanting season. The active feeding stage lasts from August to September, after which the larvae move down into deeper layers of soil where they remain in an inactive resting stage during the winter and summer. Most of the grubs occur at a depth of 25 to 30 cm (Singh and Chaudhary 1968).

There is a short pupal stage of 10 to 15 days before adult emergence in June. There appears to be only one generation of this insect in a year.

2.16 Rice Water Weevil, *Lissorhoptrus oryzophilus* Kuschel (Coleoptera: Curculionidae)

Distribution: Japan, Korea, USA

Host plants other than rice: Many plants belonging to the families Alismataceae, Commelinaceae, Cyperaceae, Gramineae and Juncaceae

The rice water weevil is the most important pest of rice in the USA. A parthenogenetic strain of the pest is believed to have been introduced into Japan from California in 1976. Now *L. oryzophilus* is regarded as one of the most destructive pests of rice in Japan and probably one of the most difficult to control (Okada 1982).

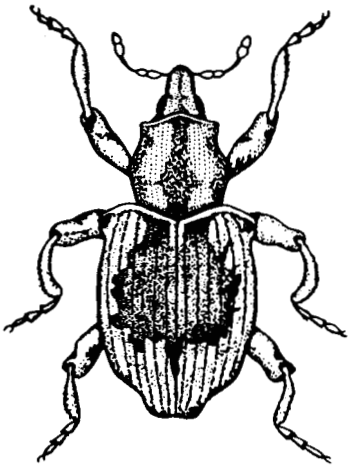


Fig. 2.16

The adult feeds on the leaf epidermis of young rice plants. Adult damage is generally of minor importance and is usually confined to the edge of fields, although Ingram (1927) has reported plant mortality due to it in some late-planted rice fields in the USA. Weevils have also been reported to feed on panicles, consuming floral parts or the endosperm of the developing rice grain. The larvae cut the roots of rice plants. This results in the stunting of plants, delayed maturity and loss in grain yield. Heavy larval infestation may reduce plant vigor and cause lodging of plants prior to harvest. Yield losses up to 75% have been reported (Newsom and Swanson 1962, Grigarick 1963) due to the infestation of the water weevil.

The adult weevil is about 5 mm long, olive-grey to tan, with a dark V-shaped area on the elytra. In the females, this area is more distinct and the abdomen more swollen.

Oviposition begins after the field is flooded. Semi-aquatic adults usually fly into the standing rice crop at night and then move from plant to plant by swimming just below the water surface. The gravid female moves down the stem and lays eggs in or under the basal submerged portion of leaf sheath tissue and, rarely in the roots. Maximum egg-laying occurs one or two weeks after flooding.

The egg is white, elongate and slightly curved. It is about 0.8 mm long. The egg stadium lasts for 4 to 9 days depending on temperature (Raksarart and Tugwell 1975).

Larvae are white, very small and legless. The head is brown, and small in relation to the rest of the body. The first instar grubs mine in the leaf sheath for about a day and then move down the plant to the soil where they start feeding on roots. Larvae possess dorsal hooks that are modified abdominal spiracles. These structures facilitate larval movement in the soil and help in the acquisition of oxygen from the root aerenchyma (Everett 1966). There are four larval instars (Cave and Smith 1983). Larvae attain a maximum length of 8 mm in a period of approximately 21 days.

Pupation takes place in oval mud cells lined with a water-tight material which is attached to the roots. The pupa is white and of the same size as the adult weevil.

In Japan, only one or sometimes two generations are recorded in a year (Tsuzuki *et al.* 1982). But in southern Louisiana, USA under optimal conditions, up to 4 generations occur. Successive generations take place within the same rice field only when there is no crop in the seedling stage in the area.

By the end of August, the weevils move to overwintering sites such as woodland leaf litter, clumps of grass, or rice stubbles. Adult overwintering populations are generally higher in moist places than at dry sites. The weevils come out of overwintering areas and start feeding on grasses from late April to early May. They then fly into rice fields that are transplanted in May. The period of oviposition of the water weevil is mostly governed by the duration of day light in the locality.

The population densities in all stages of the pest are higher in those rice fields with standing water throughout the cropping season than in fields that are only intermittently irrigated (Yasuda *et al.* 1979). Shimohata and Kano (1982) observed that the weevils feed more and produce more eggs on younger rice seedlings.

The critical minimum temperature for adult female survival in Japan was found to be as low as –5 to –10°C (Tsuzuki *et al.* 1979). This demonstrates the ability of the pest to survive in low-temperature regions and to cause damage to rice crops there.

Lissorhoptrus brevirostris, another species of water weevil, has been reported from Cuba (Carbonell and Ravelo 1979). The damage caused by adults is not economically important. But the larvae can destroy up to 83% root tissue and cause 54% yield loss (Carbonell 1982). The pest population is the highest during May to October when the temperature ranges between 20" and 27.5°C and the rainfall is higher than 100 mm. There are two generations in a year with peak populations in June and September.

3. Stem Borers

Rice stem borers are a key group of insect pests, mostly belonging to the two lepidopteran families of Pyralidae and Noctuidae. According to Pathak (1968), pyralid borers are the most common and destructive of all stem borers and usually exhibit a high degree of host plant specificity. The noctuid borers, on the other hand, are polyphagous and only occasionally cause economic losses. A list of common stem borers is provided in Table 3.

in Asia, *Scirpophaga incertuIas* and *Chilo suppressalis* are the major stem borers and are widely distributed from India to Japan. *Maliarpha separatella, Chilo zacconius* and *Sesamia calamistis* are the most common species in Africa. *Diatraea saccharalis* and *Rupela albinella* are the important stem borers of rice in the western hemisphere even though their damage is less severe. In Australia, rice is attacked by a species of *Phragmatiphila* (Hely 1958).

Stem borer larvae start their attack by boring the inner portion of the leaf sheaths. At this early stage, the symptom of damage is the longitudinal yellowish white patches at the feeding sites on the leaf sheath. The subsequent boring of the stem by caterpillars often leads to the severing of the apical plant parts from the base. As a result, the central leaf whorl does not open, turns brown, and

TABLE 3

Common species of rice stem borers (Pathak 1975)

Scientific name	*Common name*	*Distribution*
Ancylolomia chrysographella Koll.	–	Southeast Asia
Chilo agamemnon Blez.	Small purple-lined borer	Africa
Chilo auricilius (Dudgeon)	Gold-fringed rice borer Sugarcane internodal borer	Indian subcontinent, Southeast Asia
Chilo loftini (Dyar)	–	Mexico, USA
Chilo partellus (Swinhoe)	Pink borer Stem borer Sorghum stem borer	Oriental and Ethiopian regions
Chilo phaeosoma (Martin)	–	Ethiopian region
Chilo plejadellus (Zinken)	Rice stalk borer American rice stem borer	Mexico, USA
Chilo polychrysus (Meyrick)	Dark-headed stem borer Rice stalk borer	Indian subcontinent, Southeast Asia
Chilo suppressalis (Wlk.)	Striped stem borer Rice striped borer Pale-headed striped borer Rice stem borer Asiatic rice borer	Asia, Italy, Spain
Chilo zacconius Blezynski	African rice borer	Africa
Diatraea saccharalis (Fabricius)	Sugarcane borer American sugar cane borer Small moth borer	Southern USA, Central and South America
Elasmopalpus lignosellus (Zeller)	Lesser corn stalk borer	Neotropical, Trinidad, Brazil
Maliarpha separatella (Rogonot)	White borer	Africa
Niphadoses gilviberbis (Zeller)	–	Burma
Niphadoses palleucus Common	–	Australia
Phragmatiphila sp.	–	Australia
Proceras indicus (Kapur)	Internodal borer	Indian subcontinent
Rupela albinella (Cramer)	South American white borer	South America
Scirpophaga incertulas (Wlk.)	Yellow stem borer Yellow rice borer Yellow borer	Asia
Scirpophaga innotata (Wlk.)	White rice borer White stem borer	Asia, Australia
Sesamia botanephaga (Tams & Bowden)	–	Ethiopian region
Sesamia calamistis (Hampson)	African pink borer Mauritius pink borer	Africa
Sesamia inferens (Walker)	Pink stem borer Ragi stem borer Purple stem borer Violet stem borer	Asia
Zeadiartaea lineolata (Wlk.)	Neotropical corn borer Maize borer	Venezuela

dries. The lower leaves, however, may still look green and healthy. This condition is known as the "dead heart" symptom and the affected tillers do not bear panicles.

If the detachment of growing plant parts takes place after panicle initiation, the panicles may not emerge. Those that have already emerged may not produce grains. Such panicles are conspicuous in the field by bearing empty grains, being erect and white. They are called "white heads." The plants can compensate for a low percentage of early dead hearts by putting forth additional tillers. But for every percent of white head, 1 to 3% loss in yield may be expected (Pathak 1975).

The bionomics and ecology of a few important stem borer pests are dealt herein.

3.1 Gold-Fringed Rice Borer, *Chilo auricilius* Dudgeon (Lepiodoptera: Pyralidae)

Synonyms: *Chilotraea auricilia* (Dudgeon),
Diatraea auricilia (Dudgeon)
Argyria sticticraspis Hamps.

Distribution: Bangladesh, Bhutan, Burma, China, Hong Kong, India, Indonesia, Malaysia, Nepal, Philippines, Sri Lanka, Taiwan, Thailand, Vietnam

Host plants other than rice: *Saccharum officinarum* L., *Sorghum bicolor* (L.) Moench., many grasses

Chilo auricilius is a serious pest of sugarcane in India, Taiwan and China. It has recently become more abundant on rice plants and is becoming a major pest in Orissa and West Bengal in India and in Bangladesh., Damage caused by this pest was reported to be around 30% loss in grain yield in Orissa (Rao 1964) and 20% in Bangladesh (Alam *et al.* 1964). The following description on the bionomics of the stem borer is mostly based on studies conducted by Rao and Rao (1980) in India.

Moths mate between 8 and 9 p.m. Gravid females lay eggs in masses on foliage, mostly on the undersurface of rice plants. Occasionally a few egg masses are laid on leaf sheaths also. Average oviposition period is 3 days and the maximum number of eggs is laid on the first day of egg-laying. The average number of eggs laid per female was 123 during the entire oviposition period in an average of 9.5 egg masses. Eggs hatch in 5 to 7 days.

Larvae have only four stripes (the dorsal stripe being absent), and their body is proportionately wider than in *C. polychrysus,* and *C. suppressalis* from which the species is separated only by slight differences in the thoracic chaetotaxy. The caterpillar molts six times before becoming a pupa. The larval period is about 30-32 days.

Pupation takes place in the affected stems. The postero-lateral and postero-dorsal spines on the cremaster of the pupa are more prominent than on the other *Chilo* species. The pupal period lasts for 6 days.

Four generations occur in Taiwan and China, and 5 to 7 in India. The insect is active during and just after the monsoon.

3.2 Spotted Stem Borer, *Chilo partellus* (Swinh.) (Lepidoptera: Pyralidae)

Synonym: *Chilo zonellus* (Swinh.)

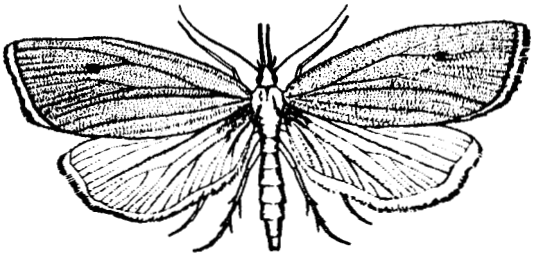


Fig. 3.2

Distribution: Afghanistan, Comoro Islands, India, Kenya, Malawi, Nepal, Pakistan, Sikkim, Sri Lanka, Sudan, Tanzania, Thailand, Uganda

Host plants other than rice: *Eleusine coracana* (L.) Gaertn., *Saccharum officinarum* L., *Sorghum bicolor* (L.) Moench., *Triticum aestivum* L, *Zea mays* L., wild grasses

The insect is primarily a pest of maize and sorghum. But as a rice pest it is particularly important in eastern India. It rarely occurs in lowland irrigated conditions, but in upland rainfed conditions it is often abundant.

Moths are yellowish to yellowish brown with a slender body. Forewings terminate with an acute tip, and are straw-colored with one or two transverse rows of small dark brown dots. Hindwings are white with a marginal fringe. Usually male moths are darker and smaller than the female.

Eggs are laid in two overlapping rows on all parts of the plant. They are oval, flat and whitish. About 300 eggs are laid by a single female. Hatching begins after 3 to 5 days.

Young larvae feed on leaves for about 5-6 days after which they penetrate the midribs of leaves. The larvae are dirty white with setae borne on each segment. There are two dorsal stripes which may merge to form a wide band and lateral stripes. The larvae enter the stem directly or through the growing point. They feed inside the stem until they become fully grown after 18-30 days.

Pupation takes place within the stem and lasts for 6-12 days. Pupae are slender, 10-15 mm long and shining brown. The moths emerge usually just after sunset.

During the winter, older larvae remain dormant in the stems and stubbles. In the tropics, continuous development occurs during the rainy season. In places where there is a distinct dry season, the pest enters a larval diapause after the rainy season. Diapausing larvae pupate after the first showers and the moths emerge a few days later.

3.3 American Rice Stalk Borer, *Chilo plejadellus* Zincken (Lepidoptera: Pyralidae)

Distribution: Mexico, USA (Arkansas, Louisiana, Texas)

Host plants other than rice: *Spartina cynosuroides* (L.) Roth., *Zizania aquatica* L., *Zizaniopsis miliacea* (Michx.) Doell and Aschers

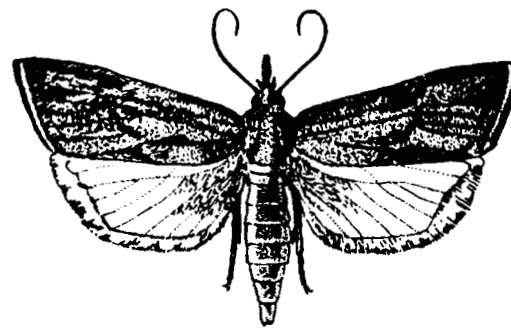


Fig. 3.3

Dr. L. O. Howard first observed this pest on rice near Savannah, Georgia, in 1881 and described it as a new species (Riley 1883). The stalk borer has a restricted distribution and serious infestations are only sporadic.

Moths have pale straw-colored forewings with a sprinkling of minute black dots. The hind wings are white. Moths are lighter in color than *Diatraea saccharalis*. Eggs are deposited in clusters of 50 or more with the individual eggs overlapping. They are oval, flat and nearly white when freshly laid.

The larva is yellowish white and is marked on each side with a brown stripe running the entire length of its body and a fainter brown stripe below it. The larva is about 25 mm long when full grown. The larvae feed on the inner tissues of rice stem causing deadhearts and whiteheads. Newly hatched larvae have also been known to attack at the uppermost node after the panicle has already emerged and partially developed. These panicles may break at the point of injury.

Pupation takes place in the spring, the larvae having spent the winter in the stubble. The pupa is light to dark brown. It is smooth, tapers to a point at the rear and is nearly always found enclosed in a heavy web inside the stem.

3.4 Dark-headed Stem Borer, *Chilo polychrysus* (Meyrick) (Lepidoptera: Pyralidae)

Synonyms: *Chilo polychrysa* (Meyrick)
Chilotraea polychrysa (Meyrick)
Diatraea polychrysa (Meyrick)
Proceras polychrysa (Meyrick)

Distribution: Burma, China, India, Kampuchea, Laos, Malaysia, Philippines, Thailand, Vietnam

Host plants other than rice: *Echinochloa crus-galli* (L.) Beauv., *Hymenachne acutigluma* (Steud.) Gilliland, *Saccharum officinarum* L., *Scirpus grossus* L., *Setaria pallide-fusca* (Schumach.) Stapf and C., E, Hubb., *Zea mays* L.

Chilo polychrysus is a major pest of rice in Malaysia and parts of India. Before 1960, it was the most dominant species in Peninsular Malaysia but since the introduction of double cropping, the yellow

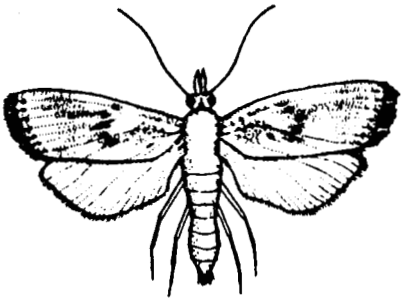


Fig. 3.4

borer is gradually taking its place. In South India, it was first seen attacking the rice crop during the 1955-56 cultivation season and many serious infestations subsequently followed.

The caterpillars attack all stages of the rice crop. The young plants, when attacked, are killed in a short period having no chance of recovery. In the case of mature plants, the infestation results in the formation of deadhearts and whiteheads. A heavy attack of this borer may cause a loss in yield of up to 60%.

The adult moth is light brown with 6-7 tiny black dots and silver sides at the tip of the forewings. The hind wings are yellowish white. It has a body length of 10-13 mm and wing span of 16 to 25 mm. The moths usually live for 2 to 5 days.

The moths are active during the night and oviposition takes place between 7 to 11 p.m. Eggs are laid in batches of 20 to 150 in longitudinal rows along shallow furrows on both surfaces at the basal portions of the leaves. They overlap each other and are scale-like in appearance. A single female moth can lay up to 480 eggs in 3 days. The egg is white when laid but turns black as it nears hatching. The fully-developed embryo eats its way out of the egg shell, usually in the morning hours. The incubation period is 4 to 7 days.

The newly-hatched larvae are greyish white and 1.3 mm long. They are distinguishable from other species by the head and prothoracic shield which are distinctly black. The first instar caterpillar moves down to the leaf base and bores into the outer leaf sheath. Sometimes the larva enters the midrib of a leaf and tunnels down into the leaf sheath. The attacked leaf sheath first appears yellow and then gradually dries up. If the rice plant is thick, stout and succulent, the whole larval and pupal existence are completed within the peripheral leaf sheaths sparing the central culm. On the other hand, if the outer leaf sheaths are thin or dry, the caterpillar bores into the central shoot. One larva is usually found in a single stem. If the host plant is dead as a result of infestation or when it becomes congested with larvae, the larvae migrate to neighbouring plants. In such cases, the points of entry are indicated by plugs of fecal matter.

The last instar larva measures about 21 mm in length. The head is brownish black while the body is creamy white with five distinct brown stripes along the back of the body. The head and body are sparsely clothed with inconspicuous hairs. The full-grown caterpillar, just prior to pupation, makes

an exit hole below which the feeding tunnel is cleared and lined inside with a loose layer of silken frass. There are 6 larval instars, and the larval period ranges from 20 to 41 days.

The newly-formed pupa is dirty white to light straw-colored with the larval body stripes clearly visible. The color subsequently turns deep brown to black. The pupal period lasts for 4 to 6 days.

No dormancy or diapause has been reported. The number of generations in a year varies up to 12 depending on the climate and availability of host plants. Overlapping generations may occur throughout the year. The second and succeeding generations are usually more destructive. In the absence of rice plants, the larvae move on to alternate hosts.

3.5 Rice Striped Borer, *Chilo suppressalis* (Walker) (Lepidoptera: Pyralidae)

Synonyms: *Crambus suppressalis* Wlk.
Chilo simplex (Butl)
Chilo oryzae Fletcher

Distribution: Bangladesh, Bhutan, Burma, China, Hawaii, India, Indonesia, Iran, Italy, Japan, Kampuchea, Korea, Laos, Malaysia, Nepal, Pakistan, Papua New Guinea, Philippines, Spain, Sri Lanka, Taiwan, Thailand, Vietnam

Host plants other than rice: *Echinochloa colona* (L.) Link, *Echinochloa crus-galli* (L.) Beauv., *Phragmites australis* (Cav.) Trin.ex Steud., *Sclerostachya fusca* (Roxb.) A. Camus, *Typha latifolia* L., Wild rices, *Zea mays* L., *Zizania aquatica* L.

The rice striped borer, *Chilo suppressalis* has been considered as one of the most serious pests of rice in temperate and subtropical Asia. However, its importance is gradually declining in many countries. The pest mainly attacks rice in the middle or late stage of plant growth. In addition to causing dead hearts and white heads, larval feeding can also cause reduced plant vigor, fewer tillers, unfilled grains and lodging of plants. High grain yield losses have been reported for this pest; up to 100% grain loss has been reported from Japan (Logothetis 1951), 50% in the Philippines (Otanes and Sison 1947) and 20% in Taiwan (Ou 1959). In Spain, Chilo suppressalis, coupled with *Sesamia* sp., produces an estimated crop loss of about 2% (Grist 1965), but in Malaysia, no serious damage has been reported (Van Vreden and Ahmadzabidi, unpublished).

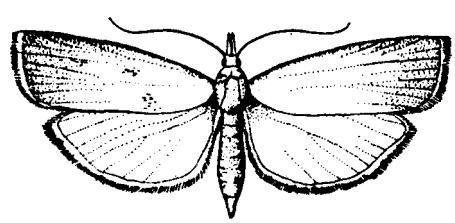


Fig. 3.5

The adult moths are 13 to 16 mm long and with straw to light brown forewings. There are a number of silvery scales and usually five black dots at the tip of the forewing; the hind wing is yellowish white. The females are lighter in color than the males. Moths emerge at about 7 to 8 pm and become active in the early morning. During the day they remain in dense foliage. Moths are capable of flying long distances; sometimes winds carry them to distant places.

Male moths are strongly attracted to virgin females, the attraction being maximum on the evening of their emergence but declining as days pass. Mating usually takes place during the night of emergence, but egg-laying starts only on the next night. The mating frequency is maximum among 2- or 3-days old moths and it then decreases rapidly with age (Kanno and Sato 1978). Through laboratory studies, it has been shown that the threshold light intensity for mating initiation varies with temperature (Kanno 1980). Male and female moths mate as often as 8 and 4 times respectively, in their life times.

A female moth may lay 100 to 550 eggs in batches of 50 to 80, depositing one batch each night over a 3 to 5 day period. Eggs are naked and scale-like, pale to dark yellow, laid in masses formed of overlapping rows. Egg masses are found on the basal half of the leaves or occasionally on the leaf sheaths along the midrib of either the upper or lower surface. The eggs hatch in 3 to 5 days. Maximum hatching takes place in morning between 5 to 6 a.m. Generally, all eggs of a mass hatch together.

The larvae live gregariously during the first three instars (Nozato 1981). If the young larvae are isolated from each other, they suffer high mortality. The newly emerged larvae crawl up the rice plant and then congregate beneath the leaf sheath. All larvae enter the stem through a common hole. Larval feeding generally occurs in the middle of the stem. The fully-grown larva is approximately 26 mm long and 2.5 mm wide. It has a yellowish brown head and has three dorsal and two lateral brownish abdominal stripes. The middle dorsal stripe is lighter in color. The larval stage normally lasts from 20 to 48 days.

Nozato (1982) has shown that larval mortality in the first generation is density-dependent. High mortality among older larvae may be due to the destruction of rice stems through feeding.

Pupation takes place within the stem. The last instar larva makes an exit hole in the internode for the moth to emerge. The pupa is reddish brown in color and is without a silken cocoon.

In temperate regions, the larvae enter into diapause in the winter and development resumes in the spring with warmer temperatures. Temperature, daylength and the stage of growth of rice plants are principal factors inducing diapause. Exposure of larvae to short daylengths (8 to 14 hours) induces diapause while longer days (14.5 to 16 hours) prevents it.

The rice striped borer is well adapted to a temperate climate. All stages of the pest can withstand low temperatures and development proceeds normally in cold habitats of temperate regions. The threshold temperature for egg development is 10 to 12°C. The incubation period decreases with an increase in temperature up to 30°C. At 35°C, the eggs die. The optimum temperature for larval development is between 22 and 33°C even though larvae are able to withstand temperatures as low as −14°C for short periods of time. Under ideal ecological conditions, there are

5 to 6 larval instars while under adverse conditions, as many as 9 instars have been recorded. The rate of pupal development increases with temperature from 15 to 30°C. Beyond 35°C, the pupae suffer high mortality and the emerging moths are mostly deformed.

The pest can have one to five generations per year depending on the availability of host plants and the occurrence of favorable temperature conditions. The longer the period of host plant availability, the more the population is built up through increased generations in a year.

In Japan, distinct ecotypes of *C. suppressalis* have been reported. They are 'Shonai' in the north, 'Saigoku' in the southwest and 'Tosa' from Kochi prefecture. The Shonai ecotype is more tolerant to lower temperature than the Saigoku ecotype. The stem borer population between the areas distinctly occupied by these ecotypes is intermediate in nature.

3.6 African Rice Borer, *Chilo zacconius* Blezynski (Lepidoptera: Pyralidae)

Synonym: *Proceras africana* Auriv.

Distribution: Benin, Burkina Faso, Cameroon, Ivory Coast, Mali, Niger, Nigeria, Senegal

Host plants other than rice: *Echinochloa crus-galli* (L.) Beauv., *Oryza barthii* A. Chev., *Sorghum arundinaceum* (Desv.) Stapf.

Chilo zacconius is a polyphagous pest of rice commonly found in West Africa. Adult moths have pale yellow forewings with irregular black spots. Males are darker than the females. Moths are nocturnal and hide during the day.

Oviposition takes place on the upper or middle leaves. Pale yellow eggs are laid in two or three overlapping longitudinal rows. Eggs are oval, flat and imbricate like fish scales. They hatch after 4 days.

The newly-hatched larva moves around actively on the plant, feeds a little from the leaf and bores into the stem through the leaf sheath. From flowering, the larvae bore into the flower stalk

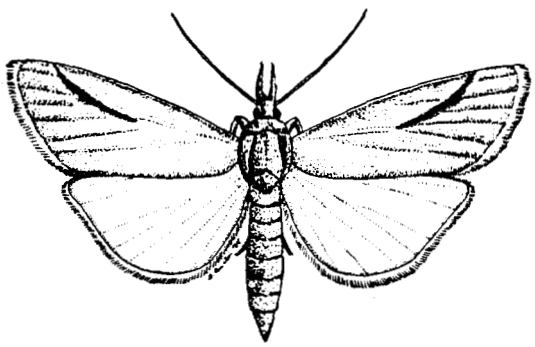


Fig. 3.6

causing whiteheads. Then they descend into the central stem which they perforate at different levels. The larvae can live for several months without food.

The larva has an ivory body with a dark brown head. There are seven longitudinal pink stripes on the body, the ventral ones being incomplete and sometimes indistinct. The larvae pass through 5 instars in a period of 4 weeks before they pupate.

Pupation takes place in the stem or in the leaf sheaths. The chrysalis is dark brown; its abdomen ends in a four pointed crest with another two-pointed crest at the back. The pupal period is 6 to 7 days.

There are 5 to 7 generations per year. The number is mostly governed by the duration of the dry season and the availability of host plants. Generally, two successive generations occur in the same rice field; the first generation larvae attack the stem and the second mostly infest the panicle stalks.

A very similar species, *Chilo diffusilineus* J. de Joannis, has also been reported from the humid equatorial Sudanese areas (Breniere 1976, Bonzi 1982). It differs from *C. zacconius* only in the shape of genitalia in both sexes. The habits and appearance of the larvae are identical. *C. diffusilineus* infests irrigated and rainfed rice plants. The exact distribution of the species is not known.

3.7 Sugarcane Borer, *Diatraea saccharalis* (Fabricius) (Lepidoptera: Pyralidae)

Distribution: Southern USA, Central and South America to Argentina, West Indian Islands

Host plants other than rice: *Brachiaria mutica* (Forssk.) Stapf, *Leptochloa filiformis* (Lam.) Beauv., *Paspalum urvillei* Steud., *Saccharum officinarum* L., *Sorghum halepense* (L.) Pers., *Vetiveria zizanioides* (L.) Nash, *Zea mays* L.

Diatraea saccharalis is the most damaging and the widely distributed stem borer in Latin America. It is more numerous in Texas than the rice stalk borer *Chilo plejadellus* (Bowling 1967).

Adult moths have a wing span of 20 to 26 mm. The forewings are light brown to grey with less continuous lines and a dark discal dot. The moths hide during the daytime under foliage. They are



Fig. 3.7

positively attracted to light. The adult population is maximum when the rice plants are at about 30 days after transplanting.

Oviposition takes place dying night. Eggs are laid on young leaves on both the upper and lower surfaces. They are creamy white when laid but turn yellowish as the incubation period advances. Eggs are deposited in groups of 2 to 100 or more, although the number of eggs usually found in a single cluster is less than 50.

The larva is yellowish white with brown spots. In the winter these spots are absent and the color becomes more deeply yellow. The newly hatched larvae move about and feed on rice leaves for 24 to 48 hours. They then crawl into the space between the leaf sheath and stem to make the entry hole. Sometimes these larvae come out of the initial tunnels and make new attacks on the same plant or search for other plants to infest. Normally 5 to 6 larval instars can be distinguished. The fully-grown larva is 25-35 mm long and makes an exit hole for the adult moth to emerge.

Pupation takes place within the stem. The pupa is light brown and 10-12 mm long. It is naked without being enclosed in a silken web.

The insect spends the winter as a larva in the stubble of host plants. The larvae pupate and moths emerge in spring. The insects breed on alternate host plants until rice plants are big enough to feed upon.

Four and a partial fifth generation appear each year in the cool northern and southern limits of the pest's distribution. In the tropics, as many as 7 generations develop.

3.8 White Borer, *Maliarpha separatella* Ragonot (Pyralidae: Lepidoptera)

Synonyms: *Anerastia pallidicosta* (Hampson)
Enosima vectiferella (Ragonot)
Ampycodes pallidicosta Hampson
Rhinaphe vectiferella Ragonot (Hampson)
R. pallidicosta (Hampson)

Distribution: African countries, Burma and China

Host plants other than rice: *Andropogon tectorum* Schum. & Thonn., *Sorghum bicolor* (L.) Moench.

Among the four stem borers usually found attacking rice in Africa, the white borer *M. separatella* is considered to be the most common. Due to its peculiar habit of remaining at the lower internodes of the rice plant, the larva does not usually produce 'dead hearts' or 'white earheads'. The growing apical portion of the plant is not cut off from the base and hence panicles can be initiated at the last node. The infestation mainly leads to a reduction in plant vigor and tiller number and a high percentage of unfilled grains. The level of *M. separatella* infestation does not correlate with the ultimate damage of the crop. At 75 days after transplanting, 97% hills were infested and 71% tillers were damaged by the larvae. However, the incidence of 'dead heart' was as low as only 1% (Ho *et al.* 1983). Apart from the direct damage, Pollet (1978) has reported a synergistic interaction

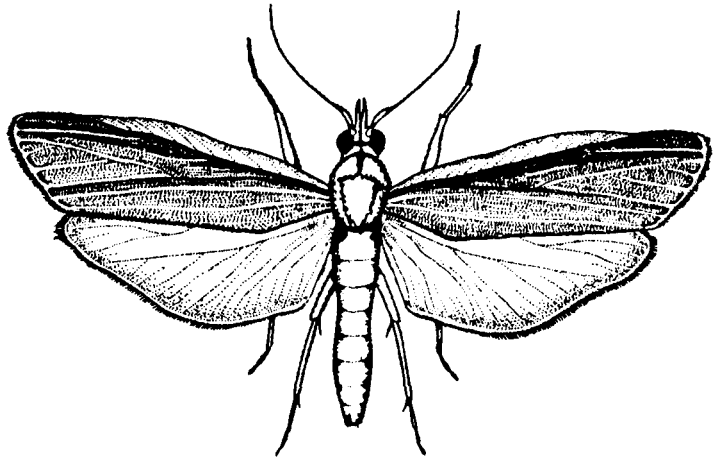


Fig. 3.8

between *M. separatella* and *Pyricularia oryzae,* the organism causing rice blast disease where the fungus preferentially attacks plants already infested with the stem borer.

The adult moth is slender and straw colored with a prominent red-brown line along the anterior margin of the forewing. The hind wings are yellowish white, with a metallic sheen, fringed with long yellow hairs. The body length varies in the two sexes; 11 to 13 cm and 13 to 15 cm in male and female, respectively.

The moths start laying eggs as soon as the rice seedlings are established at about 2-3 weeks after transplanting. The eggs are laid on rice leaves in 3 to 6 parallel rows, each batch containing 30 to 95 eggs. Sometimes eggs are seen deposited within the youngest unopened leaf. The eggs are glued on to the upper surface of the leaves by a sticky secretion which, on drying, completely encloses the eggs. The eggs, white when they are laid, turn yellowish and darken before hatching. The incubation period is 7 to 10 days.

The newly hatched larvae are white with dark brown heads. The caterpillars are very active and disperse immediately after eclosion. They move briskly to the tip of the leaf blade from where they suspend themselves by means of silken threads which they produce. Larvae drift in the wind and attach themselves to the base of a rice plant and they bore into the stem. Dispersal is so efficient that in about 24 hours after hatching, no more than one larva in each stem can be seen. The larvae begin to feed on the inner tissues of the stem once they bore into the first or second internode. They do not migrate from one tiller to another once the larvae have securely lodged themselves within the stems. The larvae are not voracious feeders and throughout the larval stage they confine themselves to one or two internodes. They usually can not survive in plants without internodes. The larva passes through 5 to 7 instars before it pupates. The entire larval period which lasts for 35 to 50 days is spent within a single rice stem.

Before pupation, the larva moves from the feeding site towards the upper part of the stem. An exit hole is cut in the stem before the larvae spin a web channel connecting the inner wall of the stem and the exit hole. The head region is placed upwards at a point 1 to 2 cm below the exit hole.

An important character of *M. separatella* is that it undergoes larval diapause lasting as long as 251 days (Akinsola and Agyen-Sampong 1984). In southern Nigeria, the resting stage starts in July/August and lasts until March of the next year. Rainfall and duration of sunshine play a major role in the initiation of diapause. Induction of diapause usually occurs before the rice plant dies and starts drying. Diapausing larvae are sluggish, milky white and their body is wrinkled while non-diapausing larvae are agile, yellowish white with a rather smooth body.

Among the different stem borers of rice, *M. separatella* is the major species in the upland rice growing areas of Africa. In upland rice, the larvae are located more towards the base of the plant while in flooded and swampy conditions, they tend to be located in the upper portion. In deep water rice it is believed that the initial infestations occur before flooding. The infested tillers are detached from their base (Akinsola 1980). The stem borer attack coupled with water pressure around the base of the plant leads to the detachment of the affected part from the plant. There are usually 3 or 4 generations per year.

3.9 Yellow Stem Borer, *Scirpophaga incertulas (Walker) (Lepidoptera:* Pyralidae)

Synonyms: *Tryporyza incertulus* (Wlk.)
Schoenobius incertulas (Wlk.)

Distribution: Afghanistan, Bangladesh, Bhutan, Burma, China, Hong Kong, India, Indonesia, Japan, Kampuchea, Laos, Malaysia, Nepal, Pakistan, Philippines, Ryuku Islands, Sikkim, Sri Lanka, Taiwan, Thailand, Vietnam

The yellow stem borer *Scirpophaga incertulas* is a serious pest of rice throughout the Orient. It is regarded as monophagous with exclusive host specificity to rice. However, some recent studies (Zaheruddeen and Prakasa Rao 1983a, b) have shown that wild rices *Oryza rufipogon, O. nivara,*

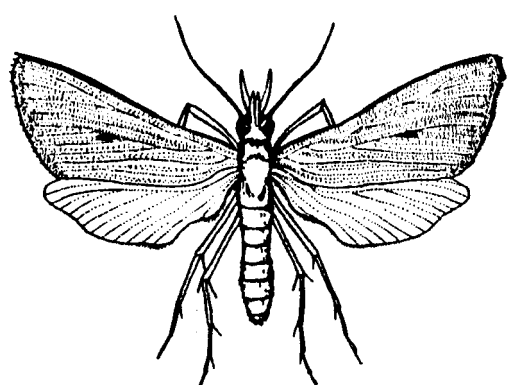


Fig. 3.9

O. latifolia and *O. glaberrima,* and a grass weed *Leptochloa panicoides* can well sustain the borer throughout its development and hence are to be considered as potential alternate host plants of *S. incertulas.*

The yellow stem borer is the dominant and the most destructive stem borer species in India (Walker 1975, Panda *et al.* 1976), Sri Lanka (Fernando 1967), Pakistan (Moiz and Rizvi 1971), Bangladesh (Catling and Alam 1977), Thailand (Yasumatsu 1976) and Malaysia (Chang 1981). However, in Japan, this species is currently limited to the southernmost regions of Kyushu (Kiritani 1981). In Taiwan, it is no longer considered as the most serious pest of rice, probably due to the extensive use of organophosphate insecticides to control the borer (Chu 1971).

The extent of crop losses vary in time and space. *S. incertulas* was reported to cause 1 to 19% yield loss in early-planted and 38 to 80% in late-planted rice crops in India (Khan 1967). A loss of 5 to 10% was reported in the Philippines (Rowan 1923). According to Walker (1975), the stem borer causes 10 to 30% crop loss in Taiwan. In Malaysia, the yield reduction may amount to 10%.

Adult moths often exhibit sexual dimorphism. The female moth is bigger than the male and its forewings are bright yellowish brown with a distinct black spot in the center. The abdomen is wide, the tip being covered with tufts of yellowish hairs. The male moth is pale yellow; the abdomen is slender and the anal end has a thin hairy covering dorsally. Spots on the forewing are not conspicuous.

The moths usually emerge at night between 7 to 9 p.m. They are not active during the daytime, but can be seen resting on stems and leaves. At dusk, especially on still, warm, humid nights, after a rain, the moths mate. Mating generally occurs between 7 to 9 p.m. The female moths lay eggs early at night in small masses covered with hairs and scales derived from the anal tuft. In the tropics, the moths are short-lived and die 2 to 3 days after oviposition. But in Taiwan and Japan, they are reported to live longer (Shiraki 1917); the longevity ranges from 5.3 to 8.8 days in females and 4.5 to 8.6 days in males.

Eggs, numbering 100 to 150, are laid in masses near the tip of leaf blades. They are creamy white, flattened, oval and scale-like and covered with a tuft of tan anal hairs from the female moth. Before hatching in 5 to 8 days, the eggs darken to a purplish tinge.

The first instar larvae are about 1.5 mm long and 0.5 mm wide. The body is pale yellow, the prothoracic shield dark brown and prominent and the head orange. The newly-emerged larvae show a strong tendency to disperse. They move downward and wander about on the plant surface for one or two hours. They can also be seen hanging down by a silken thread to be carried by wind to adjacent rice plants. During this roaming period, many larvae die. The survivors enter between the stem and the leaf sheath and feed on green tissues of the leaf sheath for two to three days. The caterpillars then start boring in the stem, often at the nodal region and feed on the inner tissues of the plant.

Often the larvae leave the first host plant after a week. They move in search of other plants in cylindrical cases made up of rolled leaf tips in which they drift on the irrigation water. After reaching a suitable host plant, the larvae bore in, leaving their cases sticking to the stem at right

angles. In mature rice plants, the caterpillars bore into the stalk at the top region just below the earhead. At this stage, a number of larvae are found in the same stalk (Banerjee and Pramanik 1967).

The full-grown sixth instar larvae are 25 mm long, white or yellowish white, and with a well-divided prothoracic shield. They make a thin silken case over themselves inside the stem soon after the prepupal molt. The larval period usually lasts for 30 days. Before pupation, the larvae make an exit hole through which the adult moth later escapes.

Pupation takes place inside the stem, mostly in the lowest node of the plant or just above the water level. Puttarudriah (1945) found that in seedlings, the larvae pupate in the root region only. Pupae are pale at first and turn darker brown after some time. They are partly exarate, and the tips of their appendages are free (Isaac and Venkatraman 1941). The pupal period is usually 6 to 10 days but may be prolonged in cooler months.

During periods when there is no rice crop and the temperature is not optimal for larval development, mature larvae diapause in rice stubble. These larvae are vulnerable to low temperature and high moisture. Because the larvae cannot survive in the cut straw, they go down into the stubble to diapause. In Japan, where plant stems are cut near the soil level at harvest, the stubble harbors far fewer borers than in Taiwan, where longer stubbles are left when rice is harvested. In Japan, as soon as warm weather begins in April-May, the larvae start pupating (Kawada *et al.* 1934). In single cropping areas of tropical south India, some larvae enter into diapause after harvest in December. These larvae pupate and emerge as moths after the monsoon rains begin in June or July (Perraju and Reddy 1965).

Although eggs show some development at 13°C, they normally develop only at or above 16°C. The optimum temperature is between 24 and 29°C. The humidity requirement for egg development is between 90 and 100%, and hatching is drastically reduced when it falls below 70% (Doke 1936). The threshold minimum temperature for larval development is 16°C. When reared at 12°C, the second and third instar larvae do not molt and they die. The rate of larval development is positively correlated within a temperature range from 17 to 35°C (Lin *et al.* 1959). The threshold for pupal development is 15 to 16°C.

S. incertulas occurs year-round in Sri Lanka, south India and Malaysia where rice is cultivated in succession. The number of generations in a year is governed mostly by the ecological conditions and the availability of rice plants and varies from 2 to 6. In temperate countries like Japan, the pest has only three broods. The third brood moths are generally more numerous than the first and the second (Ishikura and Nakatsuka 1955). The first brood moths appear as early as December-January in subtropical areas such as Hainan Island, China and Taiwan, where six generations occur annually (Kiritani and Iwao 1967). In the cooler areas of China, the fourth brood is usually partial, whereas in warmer areas such as Chunchi, the fourth brood is the largest (Tsai 1936). Three broods are reported to occur during the 6 month growing season in Sri Lanka (Fernando 1967).

Various biotic factors operate in the suppression of yellow stem borer populations at their different stages of growth. Eggs often have a high parasitization rate. In Sri Lanka, as many as 70% of the larvae die mostly because of the activity of parasites and adverse ecological conditions

(Dayawathie 1983). Patel (1970) reported that during dry months the yellow stem borer occurs only as a minor pest in Central India.

The seasonal abundance of *S. incertulas* is highly variable from year to year and region to region. However, some definite trends are discernible. There are two well-defined peaks of pest abundance, (i.e. April-May and September-October) in tropical countries such as India (Banerjee and Mondal 1983), Bangladesh (Lippold 1971) and Pakistan (Ahmad and Afzal 1982).

In tropical rainy climatic zones as in West Bengal, India, high maximum temperatures (average of 39.4°C), low humidity (average 53% in summer months), and low minimum temperature (average 12.7°C in winter months) are associated with low moth populations in these two seasons. In temperate regions such as Kochi in Japan, a prominent population peak occurs in July instead of the one in April-May in the tropics. In subtropical transitional areas, such as Taiwan, many seasonal upsurges of the pest are noted.

High wind, especially above 8 km per hour, interrupts the flight activity of moths. The nocturnal flight activity shows a clear lunar effect, with large catches at or near the new moon and small catches during the full moon, possibly resulting from the effect of relative illumination. The depression in the light-trap catches during the full moon phase showed a proportional inverse relation with the duration and intensity of moonlight (Banerjee and Mondal l983)

The stage of host plant growth and soil fertility are factors that influence oviposition and larval development in the yellow stem borer. Generally, rice plants in the vegetative and early heading stages receive more eyes than those nearing maturity. Plants receiving more nitrogenous fertilizers are preferred for oviposition to those treated with lower rates and provide a better nutritional source for larval growth (Saroja and Raju 1981). However, the application of high amounts of potash reduces the incidence of stem borer, probably by inducing resistance in host plants (John and Thomas 1980, Vaithilingam 1975).

The yellow stem borer is a notorious pest of deep water rice in the main flooding period. In Bangladesh, at harvest, more than 90% of white heads were found to be due to *S. incertulas* (Catling 1980). In Thailand, it comprised more than 95% of the borer population in attacked stems. The average incidence increased with the stage of crop, from early elongation phase to ripening through late elongation and booting-heading stages (Catling 1982). Stem damage and borer activity are apparently very low during the preflood stage from May to mid-July. Stem damage increases gradually during the late preflooding stage and culminates in maximum damage at harvest.

3.10 White Stem Borer, *Scirpophaga innotata* (Walker) (Lepidoptera: Pyralidae)

Synonym: *Tryporyza innotata* (Walker)

Distribution: Australia, India, Indonesia, Laos, Malaysia, Pakistan, Philippines, Taiwan, Vietnam

The white stem borer is a major pest of rice in South and Southeast Asia and Australia. It occurs predominantly in areas where there is only one wet season crop per year and the stubble is left undisturbed during the dry season. The pest is especially important in Indonesia, where it occurs in

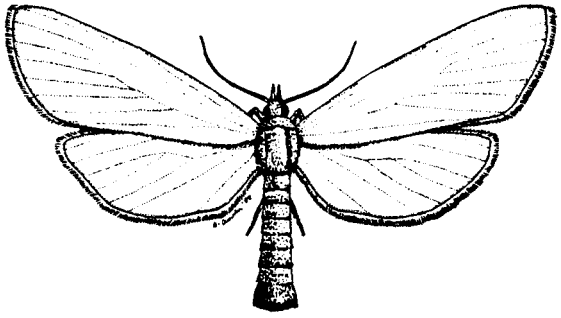


Fig. 3.10

low-lying areas up to 200 m above sea level. It is a dominant species in the upland rice areas of Sarawak. The insect does not occur in regions with high rainfall, as the larvae cannot survive extremely wet situations (Soenardi 1967). Grain yield losses due to the white stem borer of up to 95% have sometimes been recorded in Indonesia. Heavy losses, however, do not occur every year.

The adult white stem borer is similar to the yellow stem borer in appearance. In contrast to the yellow stem borer the female moth of the white stem borer does not have the characteristic black spot on the wing and adults of the two white stem borer sexes are similar in appearance. The white moth with an orange anal tuft is commonly seen in the field especially in the early stages of the crop. The adult female has a wing span of 26-30 mm and the male of 18-24 mm.

Eggs are laid in clusters of 70-260 usually on the underside of young leaves. The egg mass is covered with silky hairs from the anal portion of the female moth and is similar to that of the yellow stem borer. The incubation period is 4-9 days.

The young larva penetrates the leaf sheath and bores down into the stem. It is milky white and grows to a length of 25 mm. The age of host plant has a strong effect on the duration of larval period. It varies from 19 to 31 days.

The full-grown larva pupates within the stem after making an exit hole for the moth to emerge. Pupae are soft-bodied, pale and 12 to 15 mm long. They are more white-colored than those of the yellow stem borer. Pupation is completed in 7-11 days.

Larvae undergo diapause during the dry season. After the crop has been harvested, the caterpillars remain inactive in the lowest internodes of the stubble. Pupation does not take place until the first rains at the beginning of the next season. With the rains, the larvae become active, pupate, and the moths emerge. The threshold rainfall which terminates diapause is about 10 mm (Soenardi 1967).

Adult moths are seen in rice fields only during the wet season. Three to five generations are produced on the rice crop, depending upon the duration of the variety, time of sowing and transplanting. The first 3 generations cause deadhearts in nurseries and in the young crop, while feeding of the two subsequent generations causes whiteheads.

3.11 South American White Borer, *Rupela albinella* (Cram.) (Lepidoptera: Schoenobiidae)

Synonym: *Scirpophaga albinella* (Cram.)

Distribution: Brazil, Colombia, Costa Rica, Ecuador, French Guiana, Guatemala, Guyana, Honduras, Mexico, Nicaragua, Panama, Peru, Surinam, Trinidad, Venezuela

Rupela albinella is not normally a major pest of irrigated rice even though sometimes high populations occur. It can be a serious problem to upland rice, attacking plants at ground level and feeding upward in the stem. The damage is caused by the entry of larvae into the leaf sheath and tunnelling into the nodes. Yellowish stained patches below the axis of leaf sheaths indicate the white borer infestation.

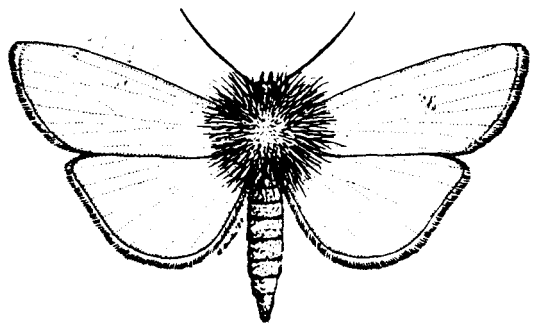


Fig. 3.11

The shining white moths are commonly seen resting on the uppermost leaf tips or flying near rice plants. The anal tuft is white in the male, while in the female moth it is yellow. Male moths live for 4-6 days and females 5-8 days.

Conspicuous yellow clusters of eggs are laid on the leaves. Eggs are oval and yellowish green and are covered with white silken hairs. They are laid in batches of 80 to 120. They hatch in 8-9 days.

Larvae are very agile, cream colored, and are usually dispersed by wind. The head is small and reddish brown. There is a longitudinal dorsal brown stripe on the body. The activity of the caterpillars is mostly restricted to the lower portion of the rice plant. The larvae make characteristic holes in the stem before they pupate. The larval period is 35 to 50 days.

Pupation takes place inside the stem in a white silken cocoon, The pupa is yellowish brown in color. The pupal period is 10 to 13 days. The adult mothcomes out through the hole previously cut by the larva. In Surinam, there are two main periods of moth emergence in a year. Diapause occurs only when the plant has flowered and it is also related to temperature.

3.12 African Pink Borer, *Sesamia calamistis* Hmps. (Lepidoptera: Noctuidae)

Synonym: *Sesamia vuteria*

Distribution: Angola, Burkina Faso, Burundi, Cameroon, Congo, Gambia, Ghana, Ivory Coast, Madagascar, Mauritius, Reunion, Ruanda, Senegal, Sudan, Tanzania

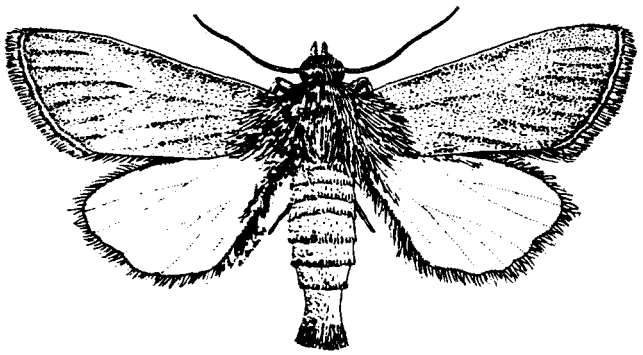


Fig. 3.12

Host plants other than rice: *Chrysopogon aciculatus* (Retz.) Trin., *Coix lachryma-jobi* L., *Hemarthria compressa* (L. f.) R. Br., *Hyparrhenia rufa* (Nees) Stapf, *Paspalum conjugatum* Berg., *Pennisetum pupureum* Schumach., *Pennisetum subangustum* Stapf & Hubb., *Rottboellia exaltata* L. f., *Saccharum officinarum* L., *Setaria splendida* Stapf, *Sorghum bicolor* (L.) Moench, *Sorghum halepense* (L.) Pers., *Tripsacum laxum* Nash, *Triticum aestivum* L., *Vossia cuspidata* (Roxb.) Griff., *Zea mays* L.

Sesamia calamistis is a polyphagous pest and its infestation in the rice crop is highest at the flowering stage. The young caterpillars occupy the stalk at the base of the panicle, which later becomes a whitehead. Older larvae feed lower down in the stalk. The yield loss is directly related to plant damage. In general, irrigated rice suffers less than the rainfed lowland crop. Often upland rice is also severely attacked by this pest (Ho *et al.* 1983).

The adult moth is light beige with brown stripes. The margin of the anterior wings is wide, whitish and partly smoky. The posterior wings are white with a yellowish margin. The moths are nocturnal in habit and are able to travel long distances. Mating usually takes place as early as the first night after emergence and egg-laying begins the same night. Eggs are thrust within the leaf sheath surrounding the upper internodes. They are spherical, flat at the poles, and with numerous longitudinal striations. The egg stage lasts for 7-10 days.

The larvae are smooth, uniformly yellowish pink on their dorsum, with greyish lateral and dorsal stripes. The head capsule and thoracic plate are dark, shiny brown. The caterpillars first feed within the tissues of the leaf sheath, subsequently entering the culm through a horizontal cavity and then moving downward, sometimes through several internodes. They stay within the sheaths or stems. The frass which fills the vertical galleries is partly thrown out through openings in the sheath. The larval period is 4 to 5 weeks.

Pupation takes place within the base of the stem or in the folds of thewithered leaf sheaths. The pupal stage lasts for 10 to 14 days.

In wet climates the life cycle is practically uninterrupted. But drought and cool conditions induce a reduction in the rate of development. Mature larvae become inactive from the start of the dry season until the rains return or the temperature increases. Usually it takes 2 months for the completion of one generation, but towards the end of the crop season, duration of the life cycle may be extended (Breniere 1977).

3.13 Pink Stem Borer, *Sesamia inferens* Walker (Lepidoptera: Noctuidae)

Synonyms: *Leucania inferens*
Nonagria inferens

Distribution: Bangladesh, Bhutan, Brunei, Burma, China, Hong Kong, India, Indonesia, Japan, Kampuchea, Korea., Laos, Malaysia, Nepal, Pakistan, Papua-New Guinea, Philippines, Ryuku Islands, Singapore, Solomon Islands, Sri Lanka, Taiwan, Thailand, Vietnam

Host plants other than rice: *Beckmania crucaefonnis* (L.) Host., *Cymbopogon nardus* (L.) Rendle, *Cyperus japonicus* Houtt., *Echinochloa crus-galli* (L.) Beauv., *Echinochloa frumentacea* Link, *Eleusine coracana* (L.) Gaertn., *Hemarthria compressa* (L. f.) R. Br., *Hordeum vulgare* L., *Panicum maximum* Jacq., *Paspalum scrobiculatum* L., *Paspalum thunbergii* Kunth ex Steud., *Phragmites karka* (Retz.) Trin ex Steud., *Polypogon fugax* Nees, *Saccharum arundinaceum* Retz., *Saccharum officinarum* L., *Saccharum spontaneum* L., *Scirpus maritimus* L., *Sclerostachya fusca* (Roxb.) A. Camus, *Setaria italica* (L.) Beauv., *Sorghum bicolor* (L.) Moench., *Triticum aestivum* L., *Zea mays* (L.)

The pink borer is probably the least destructive pest among the rice stem borers. This may be due to its extreme polyphagy, and outbreaks in rice usually result from a population spill-over from adjacent sugarcane fields or other alternate hosts.

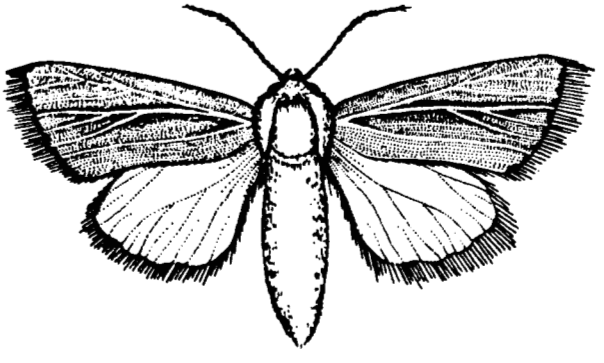


Fig. 3.13

The adult moth is fawn, the forewings being tan with dark brown markings. From a centered point in the forewing, grey-black lines radiate toward the wing tips ending in a thin terminal line of dark spots. There are tufts of hair on the pronotum. The hind wings are white. The wing span is 30 - 35 mm in the female and 20 - 30 mm in the male. The body length is 14 - 17 mm. Male and female moths can be easily distinguished by observing their antennae; they are pectinate in the male but filiform in the female (Pate1 and Rajesh Verma 1980).

Bead-like eggs are laid in rows between the leaf sheath and stem, at 30 to 100 eggs per batch. The female is known to lay over 400 eggs. They are creamy white to dark and are naked. Eggs hatch in about a week.

The larva has an orange-red head capsule and its body is purplish pink dorsally and white ventrally. The head is relatively large compared to the rest of the body. The body is distinctly segmented with no stripes and it tapers towards the abdominal tip. The caterpillars do not tend to congregate but disperse early. They often come out of the stem of one host plant and bore into neighboring rice plants thus destroying several plants. The larva becomes full-grown in 4 - 5 weeks undergoing 5 - 7 molts. At this stage, it is 20 - 26 mm long. As the larvae are highly polyphagous, they can move to adjacent fields or border areas to complete their development even after the rice has been harvested.

Pupation usually takes place inside the larval tunnel within the stem but occasionally occurs outside the stem between the leaf sheath and the stem. The pupa is dark brown with a tinge of purple on the cephalic region. It is 18 mm long and 4 mm wide. The pupal period is about a week.

In the north Indian hilly tracts, low infestation on rice occurs in early July, when larvae cause deadhearts in seedlings. Severe infestations occur in September, with maximum whiteheads of up to 50-60% in the field (Garg and Tandon 1983).

There are up to six generations in a year. The ecology of the pink borer has received little research attention.

4. RICE GRASSHOPPERS

A number of species of grasshoppers are occasionally found in rice fields but rarely cause significant damage other than along the field margins. They chew angular holes in leaves, causing an injury similar to that caused by leaffolders or armyworms. These insects are polyphagous; and besides rice, they feed on maize, sugarcane, millets and many grasses. A list of rice grasshoppers and their general distribution is given in Table 4.

4.1 Large Rice Grasshoppers, *Hieroglyphus banian (Fabricius) (Fig. 4.1)*, and *Hieroglyphus nigrorepletus (I. Biol.) (Orthoptera: Acrididae)*

Synonym: ***Hieroglyphus furcifer*** **(Serv.)**

Distribution: Afganistan, Bhutan, Burma, China, India, Nepal, Pakistan, Sri Lanka, Thailand, Vietnam

TABLE 4

Rice grasshoppers and their distribution

Species	*General distribution*
Acrida turricata K.	India
Acrida exaltata Walker	India
Acrotylus humbertiana S.	India
Aeolopus affinis B.	India
Aeolopus tamulus F.	South and Southeast Asia
Atractomorpha crenulata F.	India, Malaysia
Chrotogonus sp.	India
Colemania sphenarioides Bol.	India
Gastrimargus spp.	Southeast Asia
Heteropternis respondens W.	India, Taiwan
Hieroglyphus banian (F.)	South and Southeast Asia, China
Hieroglyphus daganensis K.	Africa
Hieroglyphus furcifer Sw.	India
Hieroglyphus nigrorepletus (I. Bol.)	South and Southeast Asia, China
Hieroglyphus oryzivorus Carl	India, Pakistan
Oxya chinensis T.	India to north Australia and up through Southeast Asia to Japan
Oxya intricata (Stal)	Africa, South and Southeast Asia
Oxya japonica T.	South and Southeast Asia, Japan
Pyrgomorpha conica 01.	Cyprus, India

Host plants other than rice: *Gossypium hirsutum* L., *Pennisetum typhoides* (Burm. f.) Stapf and C. E. Hubb., *Saccharum officinarum* L., *Sorghum halepense* (L.) Pers., *Setaria italica* (L.) Beauv., *Zea mays* L.

These grasshoppers are specific pests, which occasionally reach economic status, in marshy and humid habitats. Serious outbreaks have been reported from many parts of India (Nair 1978, Singh and Dhamdhere 1982).



Fig. 4.1

The nymphs eat newly germinated rice seedlings and cause them to wither. Adult grasshoppers feed on the leaves and shoots and sometimes cut the earheads. If the emerging inflorescence is attacked, the resulting grains become chaffy (Chatterjee and Debgoswami 1981).

The adult grasshopper is of medium size, the female measuring 34 - 54 mm and the male, 28 - 40 mm in length. It is dull green or yellow-brown. The lower body surface is brownish black. The adults mate after a short pre-copulation period of 1 - 3 days. The longevity of the grasshopper ranges from 1 to 8 months. Adults of *H. nigrorepletus* are more commonly found in the brachypterous form than macropterous form. Egg pods are laid in soil, each pod containing about 35 eggs. The total number of eggs laid per female ranges from 100 to 150. In wet sandy soil, eggs are laid at a depth of 3-5 cm, while in dry sandy soil, they are laid on the soil surface. Oviposition occurs from October to December and the eggs remain in soil till rains begin the following June-July. Individual eggs are yellowish and covered with a gummy substance that hardens into a waterproof coating.

Nymphs hatch out shortly after the rainy season begins. If the rains are poor, the eggs do not hatch and at temperatures above 40°C, there is heavy egg mortality. Young hoppers are brownish yellow and later change to dull green. Nymphs which hatch from egg pods buried in compact soil at a depth of more than 5 cm are unable to come out (Pradhan 1969). Like the adults, nymphs hide from birds during the day and feed on rice foliage at night. The usual number of instars is 5 to 6 for males and 7 for females. There is only one generation a year.

4.2 Rice Grasshopper, *Hieroglyphus daganensis* Krauss (Orthoptera: Acrididae)

Distribution: Chad, Ghana, Nigeria, Sudan

Host plants other than rice: *Andropogon gayanus* Kunth., *Arachis hypogaea* L., *Chrysopogon aciculatus* (Retz.) Trin., *Diectomis fastigiata* (Sw.) Kunth., *Hyparrhenia chrysargyrea* (Stapf) Stapf, *Pennisetum subangustum* Stapf & Hubb., *Rottboellia exaltata* L. f., *Setaria sphacelata* (Schumach.) Stapf & C. E. Hubb., *Sorghum bicolor* (L.) Moench.

The rice grasshopper occurs mainly in swampy grassy areas. In Ghana, it has appeared in large numbers since 1972 and damages many hectares of rice crops. It is estimated that yields are reduced by about 10% in outbreak areas. The following description of the pest is based mainly on the paper by Agyen-Sampong (1975).

Both nymphs and adults feed on leaves but when the population density is high, panicles and the stems are also attacked. The grasshopper population is higher in rice fields than on the grasses during September-October, but the reverse is true during the end of October to early December.

The adult grasshopper is pale greenish yellow or light orange with yellow patches. The head is ochraceous with yellowish brown eyes, pale greenish mandibles and a black band under each of the genae. The male is medium-sized and slender and 3.1 to 4.2 cm long. The female is larger and measures from 4.1 to 6.1 cm in length. Adults are more commonly found in the brachypterous form than in the macropterous form.

Mating and oviposition begin from October to early December. The eggs are laid as pods in the soil and they hatch in the beginning of the rainy season in July of the following year.

The grasshoppers start appearing in rice fields in August and the population reaches its peak during September-October which coincides with booting and panicle initiation stages of the rice plant. At the end of October when the crop begins to mature and leaves start turning yellow, the grasshoppers leave for other grassy host plants.

H. africanus Uvarov is another grasshopper pest found in Africa. It is more robust than *H. daganensis.*

4.3 Small Rice Grasshopper, *Oxya chinensis* (Thunberg) (Orthoptera: Acrididae)

Synonyms: *Oxya chinensis* Walk
Oxya velox (F.)

Distribution: Africa, Burma, China, India, Indonesia, Japan, Korea, Madagascar, Malaysia, Taiwan

Host plants other than rice: *Cyperus rotundus* L., *Saccharum officinarum* L., *Zea mays* L.

This grasshopper is mostly a minor pest of rice. But in Korea up to 20% of the crop may be lost during dry weather in some years.

The nymphs and adults feed on rice leaves, and nurseries suffer the most when attacked. Adults may feed at the bases of maturing earheads causing them to dry up (Ramakrishna Ayyar 1963).

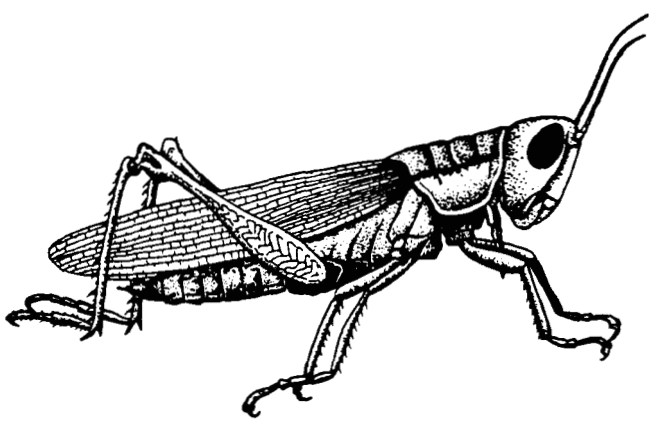


Fig. 4.3

The grasshopper is green or pale brown with a dark stripe running laterally from each eye through the thorax to the base of wings. The male grasshopper measures 20 mm long while the female measures 30 mm.

Eggs are laid in masses of 10 to 30 among rice stems, leaf folds and grass clumps above water level. In dry conditions eggs are deposited just below the soil surface. Eggs are enclosed in a gummy

froth that hardens to form an ootheca. The eggs hatch in 2 - 3 weeks. There are usually 6 larval instars with many females passing through an extra molt. Nymphal development usually takes about 100 days.

In the tropics, pest activity is continuous throughout the year, especially where both early and late varieties are grown. In northern areas, there is only one generation a year and the insect overwinters in the egg stage. In India, the grasshopper is seen in the rice fields all through the year but is more abundant from August to November.

5. LEAFHOPPERS AND PLANTHOPPERS

The rice leaf- and planthoppers have gained great economic significance in recent years as their infestations very often assume epidemic proportions. The leafhoppers (Cicadellidae) attack all the aerial parts of the rice plant. But planthoppers (Delphacidae) confine themselves to the basal portions.

Oman (1949) classified the damage done to rice plants by these insects into four categories: (1) removal of plant sap by direct feeding; (2) injury in the plant tissue and deformation of leaves and stems through defecation and oviposition; (3) transmission of various diseases; and (4) predisposition of plants to diseases such as tungro, rice dwarf, orange leaf, and grassy stunt that are transmitted by leaf- and planthoppers. The biology and ecology and of a few important leafhoppers and planthoppers are herein given.

5.1 White Rice Leafhopper, *Cofana spectra* Distant (Homoptera: Cicadellidae)

Synonyms: *Cicadella spectra*
Tettigella spectra
Tettigoniella spectra

Distribution: Africa, South and Southeast Asian countries such as India, Philippines, Sri Lanka, and Taiwan

Host plants other than rice: *Cyperus rotundus* L., *Echinochloa colona* (L.) Link., *Fimbristylis miliacea* (L.) Vahl., *Saccharum officinarum* L., *Scirpus articulatus* L., *Sorghum bicolor* (L.) Moench., *Zea mays* L.

It is a minor pest of rice rarely occurring at populations causing yield loss and does not transmit any virus disease. Feeding by a large number of nymphs and adults may, however, cause typical sap loss. Leaf tips first dry up and later the leaf turns orange and curls. The pest causes stunting and yellowing of plants, and severe infestations cause plant death (Sam and Chelliah 1984). *C. spectra* occurs in all rice environments but is most common in rainfed wetland rice at the end of the rainy season.

The body of *C. spectra* is yellowish, the forewings grey-white with prominent veins and the head bears four black spots. It is the largest among the species of leafhoppers and planthoppers. The female, including tegmina, measures about 9.5 mm while the male is shorter and around 7.5 mm

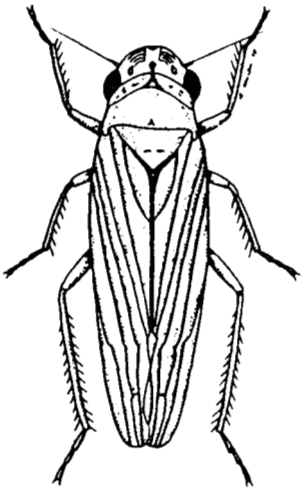


Fig. 5.1

long. The adult longevity recorded in India for males and females is 7 and 10 days respectively (Sam and Chelliah 1984).

Adults rest on the lower surface of the leaves or on tillers at the base of the plant. They are highly attracted to lights at night. During oviposition, the female makes a cut parallel to the long axis of the leaf sheath with its saw-like ovipositor. Eggs are laid in rows of 10 to 15 across the slit at the base of the plant above the paddy water. The number of eggs laid per female averages about 50. They hatch in 5 to 12 days.

Adults appear in transplanted rice fields in July-August and multiply and reach a peak population during September-October. Then the population gradually declines through the cold months of November and December. Many overwinter as eggs, though a few adults can also be seen at this time. The overwintering eggs hatch in December-January, develop in grass hosts and the resulting adults appear in January-February. Another population peak is reached during March. Then the population again declines gradually.

5.2 Green Leafhoppers, *Nephotettix* spp. (Homoptera: Cicadellidae)

Green leafhoppers are important insect pests of rice throughout Asia. They cause either direct damage to the rice crop by sucking the sap and injecting toxic chemicals or indirectly by transmitting virus diseases such as dwarf, transitory yellowing, tungro, yellow dwarf and yellow-orange leaf.

The genus *Nephotettix* is widely distributed all over Asia and Africa. The important Oriental species are *N. nigropictus, N. virescens, N. cincticeps, N. malayanus* and *N. parvus.* Their distribution and the virus diseases they transmit, are given in Table 5. The genus in Africa and Madagascar has been found to be represented by two species – *N. modulatus* and *N. afer* (Ghauri 1968).

TABLE5

Distribution of green leafhopper vectors of rice virus diseases

Leafhopper	*Distribution*	*Virus disease Transmitted*
N. nigropictus	Australia, Bangladesh, Bhutan, Burma, China, Hong Kong, India, Indonesia, Japan, Kampuchea, Korea, Laos, Malaysia, Nepal, Pakistan, Papua-New Guinea, Philippines, Sri Lanka, Taiwan, Thailand	Dwarf, transitory yellowing, tungro, yellow dwarf, orange leaf
N. virescens	Bangladesh, Burma, Hong Kong, India, Indonesia, Laos, Malaysia, Pakistan, Philippines, Taiwan	Tungro, leaf yellowing, transitory yellowing, yellow dwarf, orange leaf
N. cincticeps	China, Japan, Korea, Taiwan	Transitory yellowing, yellow dwarf, dwarf
N. malayanus	Burma, China, India, Malaysia, Philippines, Sri Lanka, Taiwan	Waika, tungro
N. parvus	India, Malaysia, Sri Lanka	Tungro, yellow dwarf

Feeding by green leafhoppers is confined mostly to the leaf and leafsheath of rice. Mild infestations may reduce the vigor of the plants and the number of productive tillers. Heavy infestations cause withering and complete drying of the crop.

Among the diseases transmitted by *Nephotettix* spp., tungro is the most destructive. The infection occurs primarily in the early stages of crop growth. It is the only known non-persistent or transitory rice virus (Ling and Tiongco 1979). When the epidemic is severe, 100% yield loss can occur (Heinrichs 1979). Heavy epidemics of tungro occurred in Indonesia, Thailand, Malaysia, Bangladesh and India during the last two decades. In the Philippines, the disease has been a serious threat ever since it first appeared as an epidemic in 1957.

Nephotettix spp. were known only as minor pests in Bangladesh until 1955 (Alam and Islam 1959). But since then, 50 to 80% damage has been reported from different regions of the country. The emergence of green leafhoppers into a major pest has been commonly attributed to the introduction of high yielding rice cultivars and the accompanying high nitrogen applications (Karim and Pathak 1979).

The optimum temperature for the development of green leafhoppers ranges between 25 and 30°C. Insects exposed to higher temperatures lay less eggs, some of which may not hatch. The high incidence of *Nephotettix* spp. is attributed to favorable temperature, low rainfall and good sunshine. A positive correlation has been obtained in Japan between the hopper population and the amount of sunlight while a negative correlation exists between the population build-up and relative humidity.

Acoustic behavior of green leafhoppers during courting has been well established as a function of communication between the two sexes. Ichikawa (1976) first reported the vibration signals emitted from the abdomen of male and female *N. cincticeps* prior to mating. He could also show that male sounds are the essential stimuli for the female to receive an appropriate mating partner. Later Inoue (1982) demonstrated that these calling sounds in *Nephotettix* spp. are species-specific

and may act as one of the mechanisms of reproductive isolation among the different species of green leafhoppers.

There are five closely related species of the genus *Nephotettix* in Asia. The distribution of some of these species is symmetric in the tropics and subtropics. Further, some are not isolated seasonally and have a common host plant: *N. virescens* and *N. nigropictus* on rice in the tropics, *N. virescens, N. nigropictus* and *N. malayanus* on the weed *Leersia hexandra* in the tropics and the subtropics.

The genus *Nephotettix* is represented in Africa and Madagascar by two species *N. modulatus* and *N. afer* (Ghauri 1968). Both are largely symmetric and widely distributed throughout Africa. Information regarding their bionomics and their possible role as vectors of rice virus diseases is Scanty.

5.2.1 *Nephotettix nigropictus (Stål)*

Synonym: *Nephotettix apicalis* Ishihara et Kawase

Host plants other than rice: *Echinochloa colona* (L.) Link, *Echinochloa crus-galli* (L.) Beauv., *Eleusine indica* (L.) Gaertn., *Ischaemum indicum* (Houtt.) Merr., *Leersia hexandra* Sw., *Paspalum scrobiculatum* L., *Saccharum officinarum* L., wild rices, *Zea mays* L.

The adult is green, the male possessing a median black wedge-shaped mark on the forewings. In the female, this area is brown in color. Both nymphs and adults are very active in summer, especially on hot sunny days. With the onset of cold weather, they become somewhat sluggish.

The premating period ranges between 2 to 5 days after the final molt. Females start laying eggs 1 to 3 days after mating and prefer to oviposit in the basal portions of leaf sheaths of young rice seedlings. The eggs are laid in batches of 10 to 15 into the epidermis and cortex and sometimes in the air cavities of the leaf sheath with the saw-like ovipositor. They are arranged in a single row, along the length of the leaf sheath. Most eggs are laid during the afternoon hours (Dhawan and

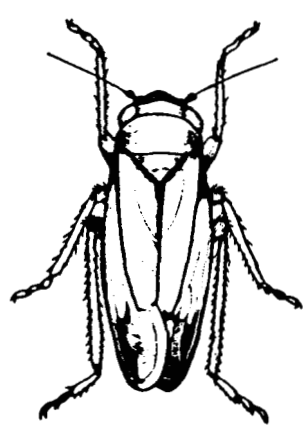


Fig. 5.21

Sajjan 1976). The ovipositional sites can be seen as slightly bulged portions and are lighter green in color. The number of eggs laid starts declining with age after the second week of mating. In India, the average adult longevities for males and females are 56 to 62.3 days respectively during the months of June to October. But the period extends during the winter months (Misra 1980).

Eggs are somewhat crescent-shaped, pale yellow and measure 1 × 0.3 mm. Reddish eye spots are visible just before hatching. The incubation period varies from 8 to 14 days depending on the temperature.

Nymphs are creamy white at first and later turn green. The color darkens as the nymphs pass through five successive molts. The nymphal period is 2 to 3 weeks in summer and longer in winter. Nasu (1967) observed a longer nymphal period in the case of females than in males. Nymphal survival was found higher on the weed *Leersia* sp. than on rice cultivars (Razzaque 1984).

Seasonal occurrence is based on studies conducted in India (Misra 1980). The leafhoppers start appearing in the rice fields in August. They multiply and reach a peak population during October-November. Then the population declines drastically due mainly to the fall in temperature. Surviving adults live on grasses found near irrigation canals and levees. The ratoon and self-sown rice also harbor the pest. During December-January, the hoppers migrate to rice nurseries and then in February-March to the transplanted crop. A rise in population takes place during this time even though the number is comparatively smaller than that in October-November. Again the hoppers move on to grasses during summer for feeding and egg-laying. The adults emerging from these grasses migrate to the rice fields during late July or early August.

5.2.2 *Nephotettix virescens* (Distant)

Synonyms: *Nephotettix bipunctatus* Distant
Nephotettix impicticeps Ishihara et Kawase

Host plants other than rice: *Cynodon dactylon* (L.) Pers., *Echinochloa crus-galli* (L.) Beauv., *Eleusine indica* (L.) Gaertn., *Leersia hexandra* Sw., *Panicum ramosum* L., *Saccharum officinarum* L., wild rices, *Zea mays* L.

The newly-emerged adult is yellowish in color. It gradually turns yellowish green and then green in about 3 hours after emergence. Most of the adults emerge early in the morning. The adult green leafhopper is about 4 mm long. It has a pointed vertex and a green head. Males have green forewings with a small dark brown or black band in the middle while in females there is no such band.

The premating period ranges from 1 to 2 days. Eggs are laid in small slits made in the soft parts of the leaf sheath. The number of eggs in a batch seldom exceeds 30 and the total eggs laid during the life cycle is around 350. Unmated females lay sterile eggs randomly on the leaf sheaths, while mated females lay fertile eggs which are inserted in the leaf sheath in an arranged manner. Newly-laid eggs are barely visible and are oblong, bent and pale yellow. The incubation period varies from 6 to 12 days.

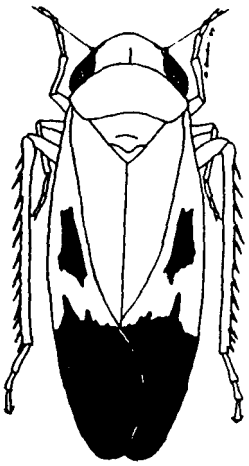


Fig.5.2.2

Young nymphs are creamy white with black longitudinal stripes on the sides of the body. They turn yellow or yellow-green in about an hour after molting. First instar nymphs are more numerous on the lower surface of older leaf blades, but from the second instar onwards, they distribute themselves rather evenly on all leaves. Nymphs and adults suck sap from leaf sheaths and blades.

The rate of nymphal development is faster at higher temperatures. Cheng and Pathak (1971) reported that the average larval duration was only 14.1 days at 35°C while it was 37.3 days at 20°C. The male nymphal period is usually shorter than that of females. Rice plants at the tillering and panicle initiation stages are most favorable for the rapid build-up of pest populations. The nymphal stage is greatly prolonged during winter. The insect can withstand long periods of starvation (Basu *et a1* ., 1976).

Ho and Chen (1968) observed 8 generations of the pest in Taiwan whereas in India, occurrence of up to 11 generations has been recorded. Throughout India, the population of *N. virescens* is higher than that of *N. nigropictus* (Mathur and Chaturvedi 1981).

Leafhoppers move from one rice crop to another and during the intervening periods they feed and breed on grasses found in the rice ecosystem. There are two population peaks in a year — one in March during the first crop season (February to May/June) and another in October-November during the second crop (June to December).

It Vietnam, it was reported that during a year when there is little rain with low temperature and high humidity, there will be a heavy incidence of green leafhopper (Quyen 1963). Similar conditions lead to sudden *N. virescens* outbreaks in India (Ghosh *et al.,* 1960).

5.2.3 *Nephotettix cincticeps* (Uhler)

Host plants other than rice: *Alopecurus aequalis* Sobol., Avena *fatua* L., *Echinochloa crus-galli* (L.) Beauv., *Leersia japonica* Honda, *Leersia oryzoides* (L.) Sw. var *japonica,*

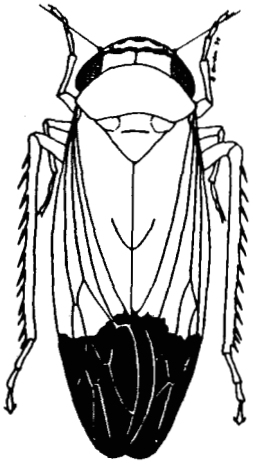


Fig. 5.2.3

Phalaris arundirtacea L., *Phleum paniculatum* Huds., *Phragmites australis* (Cav.) Trin. ex Steud., *Poa annua* L.

Nephotettix cincticeps is the only species related to the incidence of the yellow dwarf disease in Japan. Yield loses as high as 75% have been reported due to this disease.

Life history and habits are similar to those given for *N. nigropictus*. But there are differences in the seasonal occurrence caused primarily due to the ecological differences in the pest habitats. The following description is based on the study of Hirao and Inoue (1978) conducted in Japan.

N. cincticeps passes the winter as a half-grown, mostly fourth instar, diapausing nymph. During the off-season of rice cultivation, a winter grass, water-foxtail *Alopecurus aequalis* serves as the main host plant. This grass is widely seen in fallow fields after rice harvest. Adults migrate from the wild host vegetation to paddy fields in early summer immediately after transplanting. Afterwards, the hoppers spend three generations in paddy fields. The adult emergence of the last generation is interrupted by the nymphal diapause induced by short day length of autumn. There are four generations of the pest in most regions of Japan. But there may be a fifth or even a partial sixth generation in the warmer southern parts of Kyushu.

A positive relationship exists in Japan between low populations of *N. cincticeps* and heavy snowfall although this factor is not the only one in checking pest outbreaks (Otake 1966).

5.2.4 *Nephotettix malayanus* Ishihara et Kawase

This is one of the two Malayan species of the genus *Nephotettix* reported by Ishihara and Kawase in 1968. It formed 3.9% of the hopper specimens collected from North Krian District, Perak of the Malay Peninsula during 1960-62. *N. malayanus* is less of a threat to rice cultivation than the other green leafhoppers because a weed, *Leerisia hexandra* is the most preferred host plant.

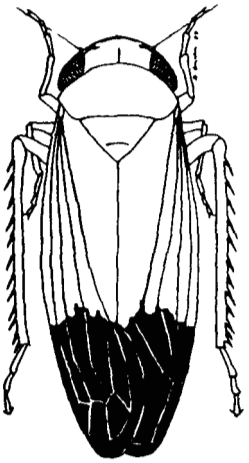


Fig5.2.4

N. malayanus adults are mostly greenish although the head is tinted with yellow. It is smaller in size than the closely allied species *N. cincticeps.* Body lengths, including tegmina, of the male and female are 3.8-4.6 mm and 4.3-5.0 mm respectively. Adults usually emerge in the morning.

Eggs, which are deposited in leaf sheaths, hatch in 7 to 10 days. The newly hatched nymphs remain on the leaf sheath for about an hour and then disperse to the leaf blades. There are five nymphal instars. The nymphal period varies from 13 to 19 days.

The effect of temperature on the development of *N. malayanus* on *L. hexandra* was studied by Kim (1985). He found that the developmental period was longest at the lowest temperature. At 25°C, the incubation period of the eggs was 10.2 days while at 33°C, it decreased to 7.1 days. Similarly, the life span of the adult hoppers was longest (23.3 days) at 25°C while it was only 17.3 days at 33°C.

N. malayanus is the vector of two virus diseases of rice - waika and tungro. Both adults and nymphs of *N. malayanus* transmit rice waika virus and transmission efficiency is higher than in *N. cincticeps.* But in the case of tungro, transmission efficiency is generally lower with *N. malayanus* than with *N. virescens* (Kim 1985).

5.2.5 *Nephotettix parvus* Ishihara et Kawase

This species was also established by lshihara and Kawase (1968) from their insect collections from the Malay Peninsula. It formed 1.7% of specimens belonging to the genus *Nephotettix.*

N. parvus is the smallest among the green leafhoppers. Females closely resemble those of *N. nigropictus* but the crown is more prolonged anteriorly and the body is comparatively shorter and narrower.

5.2.6 *Nephotettix modulatus* Melichar

Distribution: Angola, Congo, Egypt, Ethiopia, Israel, Ghana, Ivory Coast, Kenya, Madagascar, Malawi, Morocco, Nigeria, Senegal, Sudan, Tanzania, Tunisia, Uganda, Zambia

The usual color pattern is almost like that of *N. nigropictus* with which *N. modulatus* is very often confused. It is lighter in color than *N. afer.* Specimens of *N. modulatus* are slightly larger than those of *N. afer* and differ in that the anterior margin of vertex is conically produced, ovipositor is longer, and dorsal setae of male pygofers are longer.

5.2.7 *Nephotettix afer* Ghauri

Distribution: Angola, Congo, Ethiopia, Kenya, Madagascar, Nigeria, Rhodesia, South Africa, Sudan, Tanzania, Uganda, Zambia

The color pattern of *N. afer* is similar to that of *N. nigropictus,* even more so than *N. modulatus.* Three transverse black bands, marginal and submarginal on the vertex, are well developed in most specimens.

5.3 Zigzag Leafhopper, *Recilia dorsalis* (Motschulsky) (Hornoptera: Cicadellidae)

Synonyms: *Inazuma dorsalis*
Dellocephalus dorsalis

Distribution: Australia, Bangladesh, Bhutan, Burma, China, India, Indonesia, Japan, Kampuchea, Korea, Laos, Malaysia, Pakistan, Philippines, Sri Lanka, Taiwan, Thailand, Vietnam

Host plants other than rice: *Cynodon dactylon* (L.) Pers., *Cyperus rotundus* L., *Echinachloa colona* (L.) Link., *Hordeum vulgare* L., *Leersia hexandra* Sw., *Saccharum officinarum* L., *Triticum aestivum* L.

R. dorsalis is one of the vectors of rice dwarf, orange-leaf and tungro viruses in many parts of Asia. Only the female is viruliferous. Both nymphs and adults suck sap from the leaves and leaf sheaths. Leaf tips dry and leaf margins become orange. Later the entire leaf becomes orange and leaf

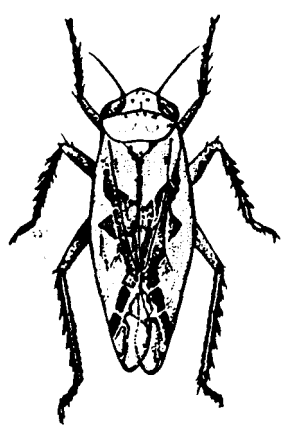


Fig. 5.3

margins curl. Damage appears first on older leaves. Young seedlings wilt and die when *R. dorsalis* is abundant. However, it usually occurs in low population densities and seldom causes significant damage to the rice crop by removal of plant sap. It occurs in all rice environments but transmits virus diseases only to wetland rice. Adults are highly mobile and enter rice fields in the early growth stages.

The forewings of the adult insect are white with light brown bands taking the shape of a 'W' and giving the wing a zig-zagged pattern. Body length is 3.5-4.0 mm.

The premating period, after the final molt, ranges from 2 to 4 days. Egg are laid in rows within the leaf sheaths. The average number of eggs laid per female is 98 (Misra 1980) and eggs hatch in 7 - 9 days. The ovipositional sites can be located with difficulty as small brownish spots; sometimes micropylar ends of eggs protrude from the leaf surface. The adult hoppers live for 10-14 days.

There are five nymphal stages lasting for 16 days. The nymphs are yellowish brown in color varying from 1.0 to 3.0 mm in body length. They are found both on leaves in the upper parts of the rice plant and on tillers near the base.

In India, the adults make their first appearance during the rainy season, June-July, in the rice nurseries and newly-planted fields. Their number gradually increases to reach a peak during August-September. The population then gradually declines in October-November. At that time some adults are still found on plants on the leaves of paddy fields. These overwintering adults again appear in December-January in the seedbed of the first crop. In the newly-transplanted crop, they multiply rapidly and reach a peak during February-March. Then the population starts declining.

R. dorsalis in southern Japan has four generations in a year and hibernates in the egg stage.

5.4 Smaller Brown Planthopper, *Laodelphax striatellus* (Fallen) (Hornoptera: Delphacidae)

Synonyms: *Delphacodes striatellus*
Laodelphax striatella

Distribution: China, Europe, Japan, Korea, Philippines, Siberia, Taiwan

Host plants other than rice: Wheat, barley, maize, oats, sugarcane, millets and various grasses

Laodelphar striatellus is important as a vector of rice-stripe and black-streaked dwarf virus in China and Japan (Anon. 1976). Once it has acquired the virus it remains a vector throughout its life. Although the nymphs and adults suck plant sap, feeding damage rarely causes yield losses. It is abundant in temperate subtropical regions.

Adults have two wing forms, brachypterous and macropterous. The adult males are usually 3.5 mm long, while the females are smaller, about 2.0 mm long. Sometimes the insects have red eyes.

The female lays 60-260 white eggs in masses in the leaf midrib or leaf sheath near the base of the plant. The eggs hatch in 5-15 days.

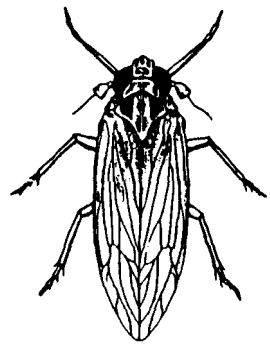


Fig. 5.4

The nymphs are light to dark brown and are usually smaller than those of other species at corresponding instars. There are five larval instars. At a temperature of 25°C, the nymphal period is about two weeks.

The hoppers congregate on the lower portions of the plant just above the water level in irrigated fields, and in the interior of the clustered bases of the tillers, strongly suggesting that the insects prefer humid conditions. Close planting and weedy rice fields favor the incidence of the pest.

There are six to seven generations in a year. In Japan, this species hibernates as last instar nymphs in winter wheat. The emerging adults then move into the transplanted rice in late May and early June. Usually 5% of these hoppers carry stripe virus. By July-August, they infest the second rice crop.

The smaller brown planthopper harbors yeast-like symbiotes in the fat body, which are transmitted to the next generation through eggs (Noda 1977). High temperature (35°C) destroys the symbiotes and leads to a poor growth of the host insects (Noda and Saito 1979).

5.5 Brown Planthopper, *Nilaparvata lugens* (Stål) (Homoptera: Delphacidae)

Synonyms: *Nilaparvata oryzae* Esaki et Hashimota
Hikona formosana Matsumura
Nilaparvata sordescens Kuwayama

Distribution: Australia, Bangladesh, Bhutan, Burma, China, Fiji, India, Indonesia, Japan, Kampuchea, Korea, Laos, Malaysia, Nepal, Pakistan, Papua New Guinea, Philippines, Solomon Islands, Sri Lanka, Taiwan, Thailand, Vietnam

Host plants other than rice: *Leersia hexandra* Sw.

The brown planthopper became a threat to rice production throughout South and Southeast Asia in the early 1970s. Outbreaks have coincided with the large-scale release and cultivation of high yielding varieties. The brown planthopper damages the plant through the removal of plant sap and as a vector of rice viruses. The honey dew excreted by the nymphs and adults at the base of the

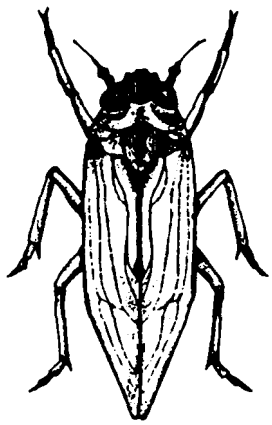


Fig. 5.5

plants is covered with sooty mold. Even the introduction of rice cultivars with genetic resistance to the brown planthopper has not provided a panacea because of the selection for biotypes that arc capable of surviving on these cultivars (Pathak and Khush 1979).

The insect prefers rainfed and irrigated wetland fields to upland rice, and direct-sown fields to transplanted fields. It is known only to feed on rice and the weed *Leersia Hexandra* (Heinrichs and Medrano 1984). It infests the rice crop at all stages of plant growth. As a result of feeding by both nymphs and adults at the base of the tillers, plants turn yellow and dry up rapidly. At early infestation, round yellow patches appear which soon turn brownish due to the drying up of the plants. This condition is called 'hopperburn.' The patches of infestation then may spread out and cover the entire field. Crop loss is usually considerable and complete destruction of the crop occurs in severe cases. *N. lugens* is a vector of the virus diseases - grassy stunt, ragged stunt, and wilted stunt (Hibino 1979, Chen and Chiu 1981).

Adult emergence takes place at the basal part of the host plant. It begins at dawn and continues for 4-5 hours. The adult planthoppers are ochraceous brown dorsally and brown ventrally. The tegmina are subhyaline with a dull yellowish tint. The female measures about 5 mm and the male 4.5 mm in length. Adult longevity differs considerably between laboratory and field conditions (migrants), maximum values being 36.6 and 9.0 days respectively.

The brown planthopper is dimorphic, with fully-winged 'macropterous' and truncate-winged 'brachypterous' forms. The macropters are potentially migrants and are responsible for colonizing new fields. At the time of colonization, the macropterous forms dominate in a rice field both under temperate (Kisimoto 1956,1965; Kusakabe 1979) and tropical conditions (Dyck *et al.,* 1979). After settling down on rice plants, they produce the next generation in which most of the female insects develop as brachypters and males as macropters. There are many factors which have been suggested to be responsible for wing morphism in the brown planthopper. Crowding during the larval stage and reduction in the quality and quantity of insect food induce macroptery (Kisimoto 1965). Short daylength and low temperature also favor the production of macropterous forms (Johno 1963,

Kisimoto 1965). Saxena *et al.,* (1981) have shown a signifcant increase in macropterous forms among progenies reared on senescent and hopperburned rice plants.

Sexual communication between the adults of the brown planthopper operates primarily by means of acoustic signals transmitted through the substrate (Ichikawa and Ishii 1974, Ichikawa *et al.,* 1975). These signals resemble most of the smaller Auchenorrhyncha (Claridge 1983). Courtship behavior may be initiated by either sex. Both virgin females and mature males start emitting signals within a few minutes of settling on a host plant. The female call consists of simple intermittent pulses produced by a visible vibration of the abdomen. On receiving the signal, the male walks rapidly towards the female. If the female stops signalling, the male stops walking and starts sending its own signals until they are reciprocated by the female. The male call has a more complicated structure (Claridge *et al.,* 1985). In consists of repeated sections which themselves consist typically of three phases: (a) a series of 3 to 10 complex pulses, (b) a series of regularly and rapidly repeated pulses, and (c) further complex groups of pulses. Thus an alternation of male and female calls eventually leads the male to make contact with the receptive female and mating may take place. Claridge *et al.,* (1984) studied populations of *N. lugens* from different geographically defined areas and found some to differ significantly in the pulse repetition frequencies of male calls. The biggest differences were found between populations from Australia and those from the Solomon Islands.

Adults usually mate on the day of emergence and the female starts laying eggs from the day following mating. Brachypterous females lay 300 to 350 eggs, while macropters lay less eggs. The eggs are thrust in a straight line generally along the mid-region of the leaf sheath, though sometimes eggs are laid on the leaf midribs. Eggs are covered with a dome-shaped egg plug secreted by the female. Only the tips of eggs protrude from the plant surface. The egg-laying sites appear as brownish streaks. The number of eggs laid at a site has been reported to vary in different countries – 2 to 3 in Japan, 4 to 10 in the Philippines, and 2 to 12 in India. Red eye spots appear at one end of the egg before hatching. Eggs hatch in about 6 to 9 days.

The newly hatched nymph is cottony white and turns purple brown within an hour. Feeding on the plant sap, it undergoes five instars to become an adult. The nymphal period varies widely depending on the food conditions, density during development, and other environmental factors. In the tropics, it takes about 10 to 18 days from hatching until the first instar nymph reaches adulthood.

Temperature is a critical factor in the life activities of the insect. The threshold temperatures of embryonic and post-embryonic development of the brown planthopper are 10.8 and 9.8°C respectively (Suenaga 1963). The hatchability and survival rate are the highest around 25°C. Eggs are very sensitive to desiccation and soon shrivel when the host plant starts wilting (Kisimoto 1977). The temperature conditions in the nymphal stage affect the longevity and oviposition of adult hoppers (Mochida 1964). The population growth of *N. lugens* is maximum at a temperature range of 28 to 30°C in the daytime and slightly lower at night. In warm and humid climates the planthoppers remain active throughout the year and their population fluctuates according to the availability of host plants, activity of natural enemies and other environmental factors prevailing in the locality.

There are many reports (Miyake and Fujiwara 1962, Okamura 1963, Sugimoto 1967) on the incidence of diapause in the egg stage of *N. lugens*. Low temperature coupled with short photoperiod and rice plants at the ripening stage were factors reported to induce females to deposit diapausing eggs. However, it is questionable to consider this as actual diapause because none of these reports defined diapausing eggs either morphologically or physiologically.

N. lugens is a long-range migrant. The brown planthoppers make wind-assisted migratory flights each year to colonize the summer rice growing areas of China. By capture of marked hoppers the insects are found to migrate 200 to 300 km in mainland China (Tu 1979). The hoppers are carried to Korea and Japan by prevailing winds from permanent breeding grounds in southern China. Influxes of the brown planthopper occur from late June to mid-July every year coinciding with the arrival of low pressure fronts from the south. In the tropics, migrations also occur. Saxena and Justo (1984) collected hopper adults in two successive inter-island voyages indicating that migrant planthoppers are reaching the Philippine Archipelago from certain rice-growing areas lying to the southwest of the Philippines in the Indian Ocean. The inflowing warm and humid air currents facilitate this migration. Observations indicate that the brown planthoppers take off at dusk and that some are capable of continuously flying up to 26h if the temperature is more than 17°C (Rosenberg and Magor 1983). Others may fly for shorter durations giving the transient population a chance of dispersal and colonization on rice plants on the way.

Several biotypes of *N. lugens* are known to occur throughout tropical Asia. They are distinguishable by their differential virulence, honeydew production and ability to survive on various rice varieties. The susceptibility of IR26, the first brown planthopper-resistant variety released by IRRI, in India signalled the evolution of biotypes among hopper populations.

The seasonal prevalence of the pest is mostly dependent on the availability of host plants. In the warm and humid tropics, planthoppers remain active throughout the year. In India, in most regions, the peak population is observed during the late rainy season from October to November. Another peak appears during the dry season from April to May in the regions where double cropping is widely practiced. In Japan and Korea, macropterous adults immigrate into rice fields from late June to early July every year. Afterwards, the pest spends several generations on rice and moves or dies at the end of cropping season.

N. lugens can have several generations during one cropping season on irrigated rice in the Asian tropics depending on the length of the crop. It has 5 generations on one rice crop in southern Japan (Mochida 1964), 5-6 in the central China (Lei and Wang 1958) and 4 to 6 in Indonesia (Mochida *et al.,* 1977). There are usually three generations on the modern high yielding intermediate duration varieties in the tropics (Heinrichs *et al.,* 1986).

N. lugens is a phloem-feeding insect. Removal of translocating nutrients from the plant sap reduces the net photosynthate available to the plant for sustenance and storage. The biological effects which collectively lead to plant damage have been detailed by Sogawa and Cheng (1977) and Chen and Cheng (1979). The effects and their interactions are schematically presented in Fig. 1(see Page 364).

Many factors have been attributed to the rapid development of brown planthopper populations. Laboratory studies of Sogawa (1971) have shown that the hoppers prefer and feed more on plants receiving high nitrogen rates. This leads to faster insect development and higher fecundity. These findings were confirmed in the work of Heinrichs and Medrano (1985) where results clearly showed that insect weight, feeding rate and population growth increased with the application of N fertilizer. Observations from the Philippines (IRRI 1979), Indonesia (Mochida *et al.* 1979) and Taiwan (Cheng 1977) all concur that intensification of rice production through continuous irrigation favors outbreaks. Insecticides have been suggested as the major factor involved in brown planthopper outbreaks due to the poor control and reproductive stimulation of the hopper at sublethal rates and destruction of natural enemies (Heinrichs and Mochida 1984).

5.6 Whitebacked Planthopper, *Sogatella furcifera* (Horvath) (Homoptera: Delphacide)

Synonyms: *Delphax furcifera*
Delphacodes furcifera
Sogata furcifera
Sogata distincta
Sogata pallescens
Megamelus furcifera
Chloriona furcifera

Related species infesting rice:
Sogatella kolophon
Sogatella nigeriensis
Sogatella vibix

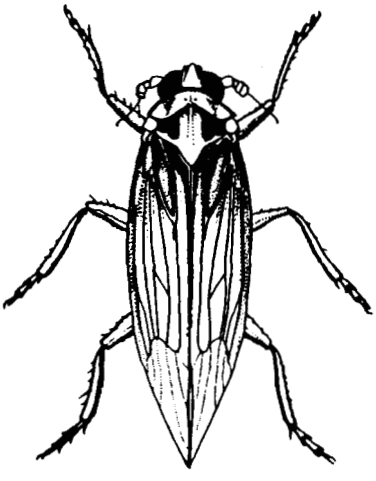


Fig. 5.6

Distribution: Afghanistan, Australia, Bangladesh, Bhutan, Burma, China, India, Indonesia, Japan, Kampuchea, Korea, Laos, Malaysia, Mongolia, Nepal, Pakistan, Papua New Guinea, Philippines, Sri Lanka, Taiwan, Thailand, Vietnam

Host plants other than rice: Millets, maize and many grasses

Sogatella furcifera has a long history as an insect pest of rice. It was first reported from Japan in 1899 and from India in 1903 (Chaudhary *et al.,* 1968). The whitebacked planthopper has emerged as a major pest of rice in many Asian countries where it has destroyed sizeable proportions of the crop in certain years. The whitebacked planthopper occurs in both upland and wetland rice environments.

Long-winged adults enter the field at about 30 days after sowing and usually complete fewer generations on a crop than does the brown planthopper. The whitebacked planthopper prefers a young crop and often produces long-winged migratory forms before the plants flower. Both adults and nymphs suck sap primarily at the base of the rice plants which leads to yellowing of the lower leaves, reduced vigor and stunting of plants. Because seedlings are attacked in the nursery, infestation is often carried through eggs into the transplanted crop. Severely attacked seedlings do not grow; are stunted, wilt and eventually die. If the infestation is at the panicle initiation stage, the number of grains and the panicle length decrease. But when attacked later, during the maturation period, grains do not fill fully and ripening is delayed. When the hoppers are present in large numbers late in the crop growth stage they are seen infesting the flag leaves and panicles. Gravid females cause additional damage by making oviposition punctures in leaf sheaths. Feeding points and wounds caused by egg-laying may later become potential sites for the invasion of bacteria and fungi. Moreover, the honeydew produced by the hoppers serves as a medium for mold growth. The pest has not been proven to be a vector of any rice virus disease.

The rice plants affected by the whitebacked planthopper appear uniformly in large areas throughout the field rather than as localized hopperburned patches as in the damage by the brown planthopper. This may be due to the difference in the distribution patterns of the two planthopper species.

Under favorable conditions, the insect produces several generations and inflicts heavy damage on the rice crop. Serious outbreaks of the pest in the tropics have been reported in Bangladesh, India, Indonesia, Malaysia, Nepal, Pakistan, and Vietnam (Mochida *et al.,* 1982). In Japan, the grain loss caused by this pest has reached up to 90% in some fields (Suenaga 1971). A study on the percentage loss of paddy caused by the artificial infestation of the whitebacked planthopper was conducted by Khatri *et al.* (1983). The percentages of grain loss varied from 11 to 39 when 15 insects per hill were released at varying stages of plant growth.

The adult hopper is 3.5 - 4.0 mmn long. Forewings are almost uniformly subhyaline with dark veins. There is a prominent white band between the junctures of the wings. The body is creamy white with the mesonotum and abdomen black dorsally and the legs, ochraceous brown. There is a conspicuous black dot at the middle of the posterior margin of each forewing which meets when the forewings come together. Macropterous males and females and brachypterous females are com-

monly found in the rice crop whereas brachypterous males are very rare. The planthoppers, especially adults, prefer to stay at the upper portion of rice stems. Adults are positively phototropic and hence are attracted to light traps.

The preoviposition period ranges between 3 to 8 days. Eggs are laid in longitudinal rows within the leaf midribs. On an average, a female hopper laid 164 eggs in tests in India (Vaidya and Kalode 1981). But in Japan, Suenaga (1963) noted that the total number of eggs laid per female ranged between 300 and 350. Eggs are similar in size and shape to those of the brown planthopper but have a longer, more pointed, egg plug. The eggs hatch in about 6 days. Nymphs are white to a strongly mottled dark grey or black and white in color. They reach adulthood in 12 to 17 days passing through five instars.

In Japan (Miyake and Fujiwara 1961) the macropterous males and females immigrate into rice fields during late June and early July. At this time, the hoppers show distinct ovipositional preference for rice plants. During summer, the number of brachypterous adults increases. The pest population declines in the rice fields in late August. Then there is a shift in ovipositional preference from rice to grass. During October-November, the adults emerging on grasses start laying diapaused eggs which hatch by the middle of April. Nymphs prefer weeds for feeding. The adult hoppers which develop from these nymphs infest the rice fields in June-July and the cycle repeats.

The ecological conditions and factors reported to be conducive for a population explosion of the whitebacked planthopper differ in various regions. In Vietnam, daylength, temperature and humidity play important roles in planthopper epidemics. According to Tao and Ngoan (1970), macropterous and brachypterous adults are usually abundant during the wet season when day and night temperatures do not vary much and the humidity remains around 85%. A prolonged monsoon with intermittent rain and application of heavy doses of nitrogenous fertilizers were suggested as the cause for an epidemic in Pakistan in 1978 (Majid *et al.,* 1979).

S. furcifera is known to migrate across mainland China (Wang *et al.,* 1982) and from China to Japan and Korea (Mochida *et al.,* 1982). Saxena and Justo (1984) collected airborne hoppers in traps set aboard inter-island vessels sailing in the Philippine archipelago.

The importance of the whitebacked planthopper as a rice pest has tremendously increased during the last decade both in upland and lowland areas, particularly where varieties resistant to brown planthoppers are grown. It may be that the ecological niche vacated by *N. lugens* is gradually being occupied by *S. furcifera* (Khan and Saxena 1985).

5.7 Rice Delphacid, *Tagosodes orizicolus* (Muir) (Homoptera: Delphacidae)

Distribution: Argentina, Brazil, Caribbean Islands, Central America, Colombia, Mexico, southern United States, Surinam

Host plants other than rice: Grass weeds such as *Echinochloa crus-galli* (L.) Beauv.

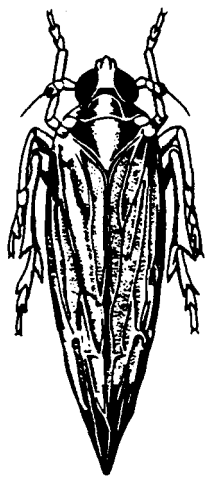


Fig. 5.7

The rice delphacid causes severe damage to the rice crop as the principal vector of hoja blanca or white leaf disease. It is also often present in sufficient populations to destroy entire rice fields through feeding damage. Adults and nymphs suck sap from rice leaves, stems, and also from developing panicles during the flowering stage. The insects excrete honeydew which forms the substrate for sooty mold on leaves and stems. The pest feeds on both rice and weeds even though it prefers rice. These insects are rather sedentary in habit but are distributed by heavy winds and flowing water.

Adults are 3 to 4 mm long, brownish red with a light median stripe dorsally. The body darkens towards the abdomen. Males are smaller and darker than the females. Nymphs have two black stripes running the entire length of the body. Adults are of two forms — macropterous and brachypterous. The wings are yellowish, the veins yellow except for some in the apical area and the white costal veins that form the dorsal stripe when the wings are folded over the body.

The females lay 300 to 500 eggs in batches of 7 in the midribs of rice leaves. About 95% of the eggs are laid on the upper side of the leaves. Eggs are 0.1 mm long, cylindrical, and slightly curved. They are white when laid but darken subsequently.

The pest is prevalent in Brazil throughout the year with three population peaks in April-May, September and December-January (Ferreira and Silveira Neto 1979). Studies conducted in Cuba (Sousa *et al.,* 1977) have shown that the development and multiplication of *T. orizicolus* are greater on young than on mature rice plants.

This delphacid can diapause in the egg stage, but nymphs usually hatch in 4 to 8 days. The population increases as the rice crop matures.

6. LEAF-FEEDING THRIPS

6.1 Rice Thrips, *Stenchaetothrips biformis* (Bagnall) Thysanoptera: Thripidae)

Synonyms: *Bagnallia biformis* Bagnall
Thrips oryzae Williams
Chloethrips oryzae (Williams)
Thrips holorphnus Karny
Thrips dobrogensis Knechtel
Baliothrips biformis (Bagnall)

Distribution: Afghanistan, Bangladesh, Bhutan, Burma, China, Europe, India, Indonesia, Japan, Kampuchea, Korea, Laos, Malaysia, Nepal, Papua-New Guinea, Philippines, South America, Sri Lanka, Taiwan, Thailand, Vietnam

Host plants other than rice: *Agropyron kamojo* Ohwi, *Alopecurus aequalis* Sobol., *Arundinella hirta* Tanaka, *Cyperus iria* L., *Cyperus rotundus* L., *Digitaria ciliaris* (Retz.) Koel., *Echinochloa colona* (L.) Link, *Echinochloa crus-galli* (L.) Beauv., *Eragrostis ferruginea* Beauv., *Festuca parvigluma* Steud., *Imperata cylindrica* (L.) Raeuschel. *Leersia japonica* Honda, *Panicum repens* L., *Paspalum scrobiculatum* L., *Pertnisetum japonicum* Trinius, *Phragmites australis* (Cav.) Trin. ex Steud., *Zea mays* L., *Zoysia japonica* Steud.

Stenchaetothrips biformis is a sporadic pest of rice infesting mostly young plants. It can damage large areas of paddy fields within a few days because it builds up high populations due to a comparatively short life cycle. The pest infests both upland and wetland rice crops. In years of a delayed monsoon or low rainfall during June-July, severe outbreaks of rice thrips have often been reported from India (Mammen and Nair 1977, Nath and Sen 1978, Velusamy and Chelliah 1980, Gubbaiah 1984), Bangladesh (Husain 1982) and China (Zu-yin *et al.,* 1978).

Larvae and adults have rasping mouthparts that lacerate the green tissue of leaves. They have only one mandible that is used to puncture leaf tissue. The maxillae and mouth cone, which form a

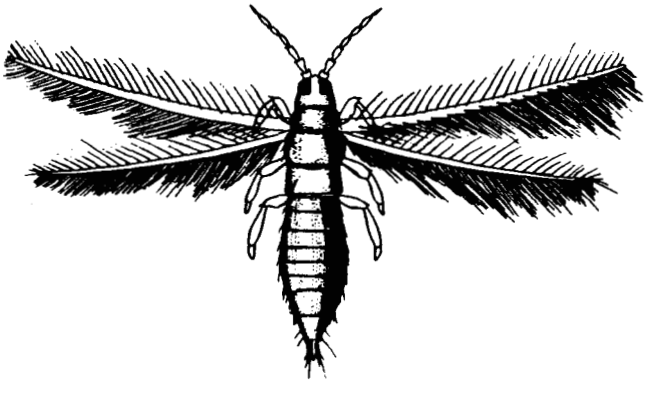


Fig. 6.1

tube, are used to suck leaf sap. Young plants, usually of 1 to 2 weeks after transplanting, are the most affected. Damage becomes evident as fine yellowish lines or silvery streaks on the leaves which later curl from the margin towards the midrib. The lower leaves are often killed. In severe infestations, the plants become stunted and wither. But the plants that survive early infestation usually recover and are able to bear normal grains.

Adult thrips are minute elongate insects, about 1 mm long, dark brown and with pronounced seven-jointed antennae. They can be either winged or apterous. Wings when present, are long, narrow, and fringed with fine hairs and lie along the insects' backs when they are at rest. At the base of the forewing is a light spot. The males, which are smaller and more slender than the females, are seldom observed. Reproduction is believed to be parthenogenetic. Adults are day-flying insects and are not attracted to light. Despite their small size and fragile appearance, thrips can travel long distances. They migrate during the day and seek out newly planted rice fields or other grassy hosts. But they prefer to confine themselves to rolled leaves most of the time (Nugaliyadde and Heinrichs 1984). Adult thrips live for about 20 days.

Eggs are reniform and are inserted singly in tissues of the youngest leaves on the side facing the stem. They are hyaline when laid but turn pale yellow as they mature. A female lays about 25 eggs in its lifetime. Eggs hatch after 3 days.

The newly hatched larvae are almost transparent but they turn yellowish white after the first molt. The legs, head and antennae are darker. After a brief resting period, the larvae start feeding actively on leaves and on the basal parts of leaf sheath. If young rice plants are not available, the thrips may even feed on rice flowers. The larvae remain on the same plant in which they hatched. There are 3 larval instars which last for a total of 6 to 8 days.

The prepupae are usually seen in groups. Pupation takes place inside rolled leaves. At this stage, the appendages are clearly visible and the wings reach up to the fourth abdominal segment. Prepupal and pupal stages together last for 3-4 days.

Thrips are normally abundant during the dry season when there is little or no rainfall. Therefore, plants that are transplanted preceeding the rains become the main target of thrips attack. Prolonged rainy periods and heavy rains reduce the pest population (Zu-yin *et al.,* 1978). The outbreak of thrips in Bangladesh in 1982 was attributed to a long winter followed by a Summer drought (Husain 1982).

In China, the thrips have 10 generations a year. The threshold temperature for temperate regions is 11.5 ± 12°C; the optimum temperature for development ranges from 15 to 25°C. Adults of the overwintering generation emerge in the middle of April and lay eggs on weeds. During the early half of May, adults of the second generation invade the fields and infest rice plants. Maximum crop damage, however, is caused by the second and fourth generations from the middle of May to the middle of July. The peak population is attained in the middle of June.

Seasonal abundance in tropical countries is slightly different probably due to the change in seasons and planting times. In northern India, the thrips appear on rice plants the first week of August. The population reaches its peak by the third week and declines thereafter. The crop that

is planted in early July has less infestation compared to that planted in late July or early August. Older plants, particularly those at 30 days after transplanting, have very low populations (Senapati and Satpathy 1982).

Nugaliyadde and Heinrichs (1984) studied the effects of plant age, adult density and temperature on fecundity and population growth of the rice thrips. Plant age did not influence female longevity. However, male longevity was significantly less on the two-leaf-stage plants than on the six-leaf-stage plants. Daily mean fecundity was significantly higher on rice seedlings at the third, fourth, and fifth-leaf stages than on seedlings at the first, second, cr sixth-leaf stages. Females on plants with low population density levels produced significantly more progeny. The total progeny produced per female over 14 days of the early reproductive period was not affected by the temperatures tested in the study (23, 26, 29 and 32°C).

7. LEAF-FEEDING LEPIDOPTERA

7.1 Rice Leaffolder, *Cnaphalocrocis medinalis* (Guenee) (Lepidoptera: Pyralidae)

Synonym: *Cnaphalocrocis jolinalis* Led.

Distribution: Afghanistan, Australia, Bangladesh, Bhutan, Brunei, Burma, China, India, Indonesia, Japan, Kampuchea, Korea, Laos, Madagascar, Malaysia, Nepal, Pakistan, Papua-New Guinea, Philippines, Sri Lanka, Taiwan, Thailand, Vietnam

Host plants other than rice: *Brachiaria mutica* (Forssk.) Stapf, *Echinochloa colona* (L.) Link, *Eleusine coracana* (L.) Gaertn., *Isachne dispar* Trin., *Leersia hexandra* Sw., *Pennisetum pedicellatum* Trin., *Saccharum officinarum* L., *Sorghum bicolor* (L.) Moench., *Triticum aestivum* L., *Zea mays* L.

The rice leaffolder, *Cnaphalocrocis medinalis,* earlier considered as a minor and sporadic pest of rice in many Asian countries, appears to have become increasingly important with the spread of high-yielding rice varieties and accompanying changes in cultural practices. Misuse of insecticides

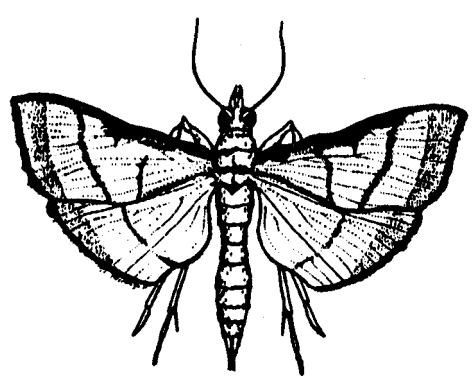


Fig. 7.1

and excessive use of nitrogenous fertilizers have been cited as the cause for high leaffolder populations (Dhaliwal *et al.,* 1979). Outbreaks have been reported from India (Yadava *et al.,* 1972, Chatterjee 1979), southern Japan (Hirao 1981) and Vietnam (Bautista *et al.,* 1984)

Infestation usually occurs during late growth stages of the rice crop. The larvae fold the leaves and scrape the green tissues of the leaves from within and cause scorching and leaf drying. Each larva is capable of destroying several leaves by its feeding. Under heavy infestation, each rice plant may have several rolled leaves, which severely restricts its photosynthetic activity. When plants are attacked in the bootleaf stage, grains are partially filled. A close correlation between the intensity of leaffolder attack and loss in grain yield very often exists (Upadhyay *et al.,* 1975). Bautista *et al.,* (1984) have clearly shown that yield loss due to rice leaffolder is positively related to the percentage of damaged leaves. In their studies, yield was significantly decreased at 17.5% damaged leaves resulting in 16.5% yield loss, and a 21.3% yield loss occurred with 26.6% damaged leaves. Sellamal Murugesan and Chelliah (1983) reported that a 10% increase in flag leaf damage by the leaffolder reduces grain yield by 0.13 g per tiller and the number of fully-filled grains by 4.5%. However, rice plants sometimes compensate for flag leaf damage by increasing the photosynthesis rate of the leaf adjacent to the flag leaf (Derui 1984). Leaf feeding also predisposes the plants to fungal and bacterial infections.

Moths are nocturnal and in the day time, they are usually seen resting on the under surface of leaves and on stems. During the early morning hours, moths are often active but their activity diminishes as the sun increases in severity. The attraction of moths to light is rather poor.

Adult moths are yellow-brown in color, small, and are 10 to 12 mm long with a wing expanse of 13 to 15 mm. The wings take the shape of an equal sided triangle when at rest. The forewings have three dark oblique lines of varying lengths. The hind wings have a broad anal area. The tibiae are tufted with black hairs which are prominent in the male but not in the female. The tip of the abdomen is blunt in the male but pointed in the female (Lingappa 1972). The female attracts its mate with a pheromone and generally mates between dusk and midnight. Adults hide on the host plants during the day to escape predation by buds and only take short flights when disturbed. Adult longevity is about a week.

Egg-laying starts one or two days after mating. Flat, oval and whitish yellow eggs are laid singly or in rows, parallel to a midrib on both surfaces of young leaves and rarely on stems. The eggs are laid in batches of 10 to 12, the biggest batches being laid on the fourth to seventh nights after the emergence of moths. Each female moth may lay about 300 eggs during its lifetime. The incubation period varies from 3 to 6 days.

The newly hatched larva is white translucent with a light-brown head. The body, however, turns green once the larva starts feeding. After hatching, it crawls to the base of the youngest unopened leaf and begins to feed. The second instar migrates to an older leaf and folds the leaf together. Some of the newly hatched larvae suspend themselves by silken threads from the leaf tip and disperse to other plants by wind (Velusamy and Subramaniam 1974). Mostly, only one larva is found in a leaf fold (Yadava *et al.,* 1972). Leaf tubes are generally made by folding a single leaf but cases are also observed where two or three leaves are used for making one fold. There are generally

five larval instars in tropical countries. The frequency of larval molting is affected more by the growth stage of the rice plant than by the temperature in temperate regions (Wada 1979).

Details regarding the mode of construction of leaf folds by larvae have been reported by Ramasubbaiah *et al.* (1980) and Fraenkel and Fallil (l981). The larva selects a point on a leaf about 15 cm from the tip and lines the surface for about 6 cm with a salivary secretion as a flooring for the leaf fold. Then the larva swings its head in quick succession between two opposite leaf margins, affixing a silk thread at each touch-down. The tiny threads from about 100 such movements fuse together to a firm band which on drying contracts. Ten to 25 such bands are produced on a leaf at distance of a few millimeters. The entire process requires about 45 minutes, the larva resting several times during the period. The nature of the folds depends on the age of the crop (Rajamma and Das 1969). In rice seedlings and young plants, 3 to 4 leaves of adjacent plants are webbed together longitudinally to make a tubular fold. In the more mature plants, folds are made out of single leaves that are folded either longitudinally and rarely transversely. Only fully grown larvae make a transverse leaf roll. In the earhead stage, the larvae make a shelter by webbing together the bootleaf and the earhead.

The full grown larva is about 16 mm long and 1.7 mm wide across the thorax. It is yellowish green in color with a dark brown head and prothoracic shield. Mature larvae jump or wiggle rapidly when touched. The larval period lasts for 15 to 25 days.

Pupation takes place inside the leaf roll in loosely woven strands of silk. The newly formed pupa is slender and greenish brown and turns brown later. The moth emerges after 6 to 8 days.

Overwintering has been confirmed only in Okinawa, Japan (Miyahara 1981). As the insect does not hibernate, low temperature in winter affects overwintering survival. Both eggs and larvae cannot survive winter in Japan (Sato and Kishino 1978). Very little is known about the cold-hardiness of the leaffolder.

The leaffolder moths have been recorded in tropical countries throughout the year, although they are most abundant during the wet season. In countries such as Japan, with a cold winter, moths are first seen in the paddy field in mid-June (Wada *et al.* 1980). Then their population gradually increases until late August after which the larval density decreases and very few eggs are seen on rice leaves. At the end of the season, the generations overlap each other as indicated by the various instars seen in a field at the same time.

C. medinalis moths migrate long distances. In 1977, many moths were captured on a vessel in thc East China Sea far from land (Kisimoto 1978). During migration, most of the female moths remain unmated and once they settle on rice plants, they immediately mate and start laying eggs (Miyahara 1980). The insect is believed to take the same migration route from China to Japan and Korca as *Sogatella* and *Nilaparvata* do (Miyahara 1981).

High humidity and optimum temperatures are conducive ecological factors for the rapid multiplication of the leaffolder (Pathak 1975). The threshold temperatures of development for egg, larva and pupa are 12.5, 12.2 and 142°C respectively (Wada and Kobayashi 1980). The larval period is significantly extended when the larvae are reared on leaves of rice plants at the ripening stage.

There are many other factors that play a role in the development and population increase of the rice leaffolder. It has been shown by Hanifa *et al.* (1974) that silica in host plants plays an important role in the feeding activity of leaffolder larvae. Arrangement of silica chains in the leaf varies in resistant and susceptible cultivars. Closer silica chains, high epidermal silica deposition, heavy deposition of silica in the intercostal area, and single or double rows of silica in resistant varieties provide a sufficient mechanical barrier to the feeding by caterpillars.

There are varying reports on the effect of nitrogenous fertilizers on rice leaffolder incidence. Many workers (Regupathy and Subramanian 1972, Michael Raj and Morachan 1973, Subbaia and Morachan 1974, Chandramohan and Jayaraj 1977, Upadhyay *et al.* 1981) have shown that the incidence of leaffolder is positively correlated to the level of nitrogenous fertilizers. A combined application of high doses of N, P and K has been shown to alter the mineral metabolism of rice plants in favor of leaffolder development and multiplication (Regupathy and Subramanian 1972). But when K was applied alone, leaffolder infestation was significantly reduced (Subramanian and Balasubramanian 1976).

It is interesting to note that the damage is more severe in shady areas particularly near the levees (Velusamy and Subramaniam 1974). Close crop growth consequent to heavy manuring is also conducive for leaffolder activity.

Adult feeding influences the fecundity and subsequent population build-up of the pest. The female moths require an exogenous source of sugar for the production of eggs. The increase in fecundity under laboratory conditions resulting from the utilization of hopper-excreted honeydew indicates that adult moths can use honeydew as a source of sugar in rice fields (Waldbauer *et al.* 1980)

7.2 Rice Leaffolder, *Marasmia exigua* (Butler) (Lepidoptera: Pyralidae)

Synonym: *Susumia exigua* (Butler)

Distribution: Australia, Bangladesh, Brunei, Fiji, Guam, India, Japan, Korea, Malaysia, Solomon Islands

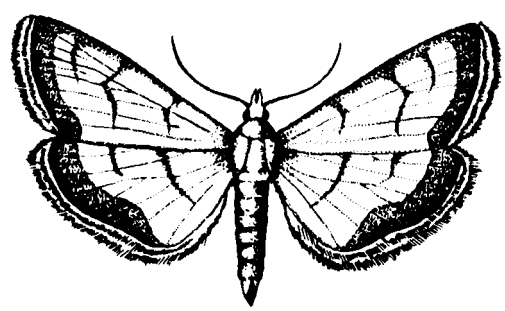


Fig. 7.2A

Three *Marasmia* species, *M. exigua, M. patnalis* (Bradley) and *M. ruralis* (Walker), attack rice. They are distinguished by wing markings. *M. exigua* (Fig. 7.2A) is the most common pyralid pest of rice in Fiji. The habits and the biology of the insect are very similar to those of *Cnaphalocrocis medinalis.* The adult moth has three long, dark bands on the forewings while *C. medinalis* has two long and one short band. Earlier the species was misidentified as *Marasmia venilalis* (Walker).

The adult moth is about 7 mm long with a wing span of 13 mm. Its forewings have light yellow and brown markings. The gravid female moths prefer to lay eggs on the green parts of tall rice plants. Eggs are laid overlapping one another, in a row parallel to the midrib of the leaf. The eggs in a cluster average 3 but may be as high as 11. They are flat and translucent. The incubation period is about 5 days.

The newly-hatched larvae tend to be gregarious for some time and then start feeding on the leaves. The second instars draw the leaf margins together and stitch them with contractile silk. Both ends of the leaf roll are left open. The larva feeds on the green tissue leaving conspicuous white scars on the leaf blade. There are six larval instars and development takes approximately 4 weeks. The larva differs from that of *C. medinalis* in that the apex of the pronotum is convex while it is straight in *C. medinalis.*

Pupation takes place within the leaf roll. The pupa is not enclosed in a cocoon but is surrounded with silken frass and fecal plugs, Pupae are 8 mm long and 1.7 mm wide. The pupal period is about 9 days (Hinckley 1963). The insect is most abundant in Fiji during April and May.

Marasmia patnalis (Fig. 7.2B), a closely related species, has recently been reported as a pest of rice in Southeast Asia (Bradley 1981). The species is shade-loving and is considered as a major pest of rice in Sri Lanka. Forewings are pale yellow with a greyish marginal band. Hind wings are also pale yellow but whitish basally. The male moth is readily distinguished by the presence of a prominent patch of dark brown and shining adroconical scales at the middle of the forewing costa.

The life cycle of *M. patnalis* was studied in the Philippines by Joshi *et al.* (1985). Eggs are laid singly or in groups of 2 to 9 on the upper side of the leaves but sometimes eggs are also seen on leaf

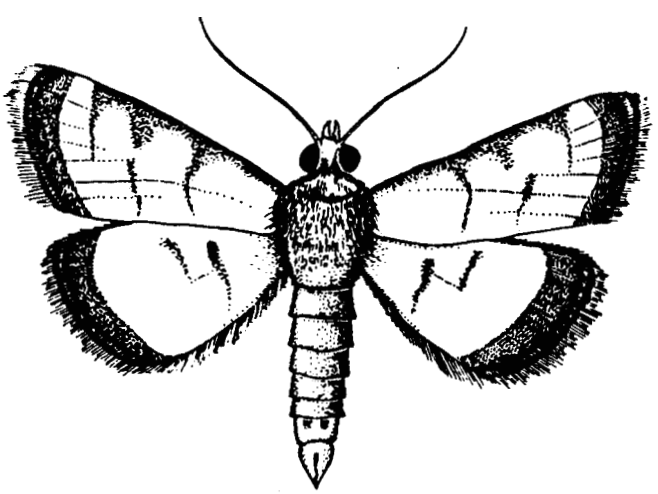


Fig. 7.2B

sheath. The incubation period is 4 days. First instar larvae scrape the leaf surface. The second instar larvae fold leaves and start feeding from within. The larval period is about 23 days.

The pupal period is 9 days and takes place within a silken cocoon, most commonly between leaves that have been stitched together. Adult emergence takes place at night.

7.3 Rice Caseworm, *Nymphula depunctalis* (Guenee) (Lepidoptera: Pyralidae)

Synonym. *Nymphula stagnalis* (Zeller)

Distribution: Argentina, Bangladesh, Bhutan, Brazil, Burma, China, Gambia, Ghana, India, Indonesia, Kampuchea, Laos, Madagascar, Malaysia, Malawi, Mauritius, Mozambique, Nepal, Nigeria, Papua-New Guinea, Philippines, Sri Lanka, Taiwan, Uruguay, Venezuela, Vietnam, Zaire

Host plants other than rice: *Brachiaria murica* (Forssk.) Stapf, *Brachiaria ramosa* (L.) Stapf, *Cynodon dactylon* (L.) Pers., *Cyperus iria* L., *Cyperus rotundus* L., *Cyrtococcum patens* (L.) A. Camus, *Echinochloa colona* (L.) Link, *Isachne dispar* Trin., *Leersia hexandra* Sw., *Panicum repens* L., *Paspalum conjugatum* Berg.

Nymphula depunctalis is an important pest of irrigated and rainfed wetland rice in the Orient. Even though rice is its preferred host plant, the insect infests various other grasses as well. The pest occurs regularly in low populations, but sporadic increases in population result in intense defoliation of plants. An extensive outbreak occurred in Kerala, south India in 1968 (Joseph 1969). The infestation is more severe on dwarf, compact, heavy-tillering, high-yielding varieties (Kittur and Chauhan 1974).

Damage is caused by larvae cutting off the leaf tips for making the characteristic leaf cases and by the removal of the green tissue. Defoliation occurs in rice plants before the maximum tillering stage. Plants that have recently been transplanted are preferred but the larvae may infest the nursery. It does not occur after maximum tillering. Larvae scrape the leaf tissues, leaving only the papery upper epidermis. Generally, several larvae attack the same rice plant and cut off most of the

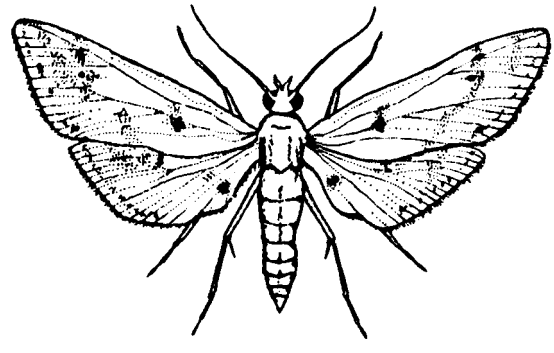


Fig. 7.3

leaf tips for constructing larval cases and scrape the remaining leaves. Caseworm damage can be distinguished from that of other pests by the ladder-like appearance of the removed leaf tissue, resulting from the back and forth motion of the head during feeding. Also, the pattern of damage is not uniform because the larvae in the cases are carried to one side of the paddy by winds or water currents. Attacked plants often become stunted.

Many workers have studied the bionomics of the rice caseworm in India (Srivastava *et al.* 1970, Kittur and Chauhan 1974, Viraktamath *et al.* 1974, Pillai and Nair 1979) and in the Philippines (Sison 1938).

Moths are nocturnal in habit and are attracted to light. They are delicate, white with fuscous markings and black specks on wings. Female moths are larger than the males. Mating mostly takes place during the night; egg laying occurs the next night. Usually all the eggs are laid during a single night. Each female lays about 60 eggs and may die 2 - 3 days after oviposition. The male moths live for 4-5 days.

The freshly laid eggs are light yellow, smooth and spherical. They are laid in batches of about 20 on the underside of leaves floating on the water. The eggs turn dark yellow as they mature. The incubation period lasts for 4 days.

Larvae are transparent green in color with light brownish orange heads. The first instar larva starts feeding on the green tissues by scraping the leaf surface. It then moves to the leaf tip and cuts a slit on the margin at a point 2 - 3 cm below the tip and makes a fold. Then the larva makes another cut about 1 cm below the first and rolls the margin with silk to form a tubular case. The inside of the case is lined with silk to hold a thin film of water which is essential for both respiration and preventing desiccation of the larva. A new case is constructed after every larval molt. The case that is carried along by the caterpillar whenever it moves helps the larva to float on the water surface. During the daytime, larvae hide in cases while at night they crawl up rice plants and feed with their head and legs protruding from the case. Feeding is reduced under dry conditions and the presence of water droplets on the leaves is helpful for larval feeding. Larvae are 20 mm long when fully grown, and are semi-aquatic in habit with lateral, slender, filamentous gills.. The larval stage lasts for 15 - 30 days.

Pupation takes place inside the larval case with both ends closed and attached to the rice stem just above the water level. The case has an inner silk lining with a slit-like opening at the anterior end. The fresh pupa is milky white which gradually changes to light yellow. The adult moth emerges in 4 - 7 days.

In south India, moth populations reach two peaks, one during November-December and another in May-June. These peaks coincide with periods of high rainfall and high humidity. Variations in temperature do not appear to be correlated with pest populations (Pillai and Nair 1979). In northern India, the infestation is more severe in the months of August - November (Srivastava *et al.* 1970). The insect occurs in overlapping generations and does not hibernate.

N. nympheata, commonly called China mark moth, is a related species of *N. depunctalis* distributed mainly in Italy and Hungary. Five generations occur per year in Italy, the first being the

most important as it attacks very young plants. A smaller rice caseworm, *N. vittalis* Bremir has been reported from Japan, Korea, Manchuria, and USSR. The larvae fold leaves of the plant and feed from within.

7.4 Green Horned Caterpillar, *Melanitis leda ismene* Cramer (Lepidoptera: Satyridae)

Distribution: Bangladesh, Bhutan, Burma, China, India, Japan, Kampuchea, Laos, Malaysia, Nepal, Pakistan, Philippines, Thailand, Vietnam, West Africa

Host plants other than rice: *Imperata cylindrica* (L.) Raeuschel, *Panicum maximum* Jacq., *Saccharum officinarum* L., *Sorghum verticilliflorum* (Steud.) Stapf

Melanitis leda ismene is a minor pest of rice. The pest occurs in all rice environments but is more prevalent in rainfed areas. Deep water rice in Bangladesh is also often infested by this insect (Alam 1974).

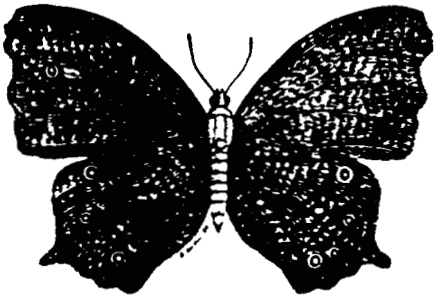


Fig. 7.5

The adult is a large, dark brown butterfly measuring about 7.5 cm across expanded wings and with a body 2.2 cm long. It flies at dusk making darting movements among the rice plants. There are large, round spots on the upper surface of the forewings. The underside is ochreous brown with dark transverse stripes and target-like spots; hind wings have six prominent spots on their ventral side. The wings are folded above the body when the insect is at rest.

Pearl-like eggs are laid singly or in rows on rice leaves and are 1 mm in diameter. Each female lays 50-100 eggs in a lifetime of about 2 weeks. They hatch in about 4 days. The caterpillars feed on the margins and tips of leaves and remove leaf tissue and veins. Damage in similar to that of grasshoppers and armyworms. The yellow-green larva blends into the rice foliage, and is difficult to see, in spite of its large size. The body is covered with small, yellow hairs. The head is flat and quadrangular with a pair of brown horns; at the posterior extremity of the body are two slender processes. Pupation takes place on the rice leaf. The pupa is dark green, smooth, and hangs by its anal extremity from the leaf. The pupal period lasts for 10 days. In Bangladesh, the pest is observed to reach its peak population during October (Alam 1974).

7.5 Rice Skipper, *Parnara guttata* (Bremer et Grey) (Lepidoptera: Hesperiidae)

Distribution: Bangladesh, China, India, Indonesia, Japan, Kampuchea, Korea, Laos, Malaysia, Pakistan, Philippines, Taiwan, Thailand, Vietnam

Host plants other than rice: *Carex olivacea* Boott., *Phragmites communis* Trin.

Parnara gutatta (Bremer and Gray) and *Pelopidas mathias* (F.) are the most common rice field species of the day-flying skippers.



Fig. 7.5

The rice skipper, *P. gutatta,* is one of the major pests of rice in China (Chiang 1977). Outbreaks of the pest also often occur in the paddy fields of central and western Japan. *P. guttata* is the most dominant species among the rice skippers in Japan and China (Masuzawa *et al.* 1983). It occurs in all rice environments but is mostly a pest of irrigated rice.

The caterpillars feed on leaves from the margins inwards and then parallel to the midrib which is often left uneaten. In addition, the larvae tie, with silken threads, the two edges of the same leaf or two adjacent leaves together to form a tube in which they live. Damage is severe in young transplanted rice seedlings and the attack may continue till the plants mature. In severe cases, the plants do not recover. Grain quality is adversely affected by the pest.

Adult butterflies are olive brown and 10 to 15 mm long with a wing span of 20-44 mm .There are 5-9 small whitish specks on the forewings and similar spots, 2 to 4 in number, on the hindwings. The butterflies are swift fliers being active only during the day.

The white spherical eggs are glued singly on leaf blades by the female moths. The eggs hatch in 3-4 days. Larvae rest at the base of the plants during the day and feed on leaf blades at night. The full grown caterpillar is pale green, and has a dark head with a W-shaped black mark on the rear. The mature larvae often move from one rice plant to adjacent plants. There are 5 larval instars in Taiwan, but the fifth instar larvae molt once more in Japan (Ishii 1980). The larval period is about a month. Pupation takes place inside the leaf tubes. The light brown or light green pupa rests in a pad of silk and has a pointed end which is attached to the folded leaf. Adults emerge after 8 to 10 days.

Adult polymorphism is exhibited by the skipper butterflies. Hasegawa (1975) has reported that the species has two seasonal forms; the yellowish brown 'summer form' and the dark brown 'autumn form'. Conditions of temperature and photoperiod prevailing during the larval stage mostly determine the morphological characters of the adult butterfly. A long photoperiod induces pale wing coloration and small size of adults. But low temperature induces larger size, stronger melanization and more conspicuous spots on the wings (Ishii and Hidaka 1979). The ecological factors such as photoperiod and temperature may also affect the physiology of the migrating butterflies. Females reared under 14-hour photoperiod, which corresponds to the migratory adults growing in early autumn, have higher flight capacity, lower fecundity and a longer pre-ovipositional period than those under a 16-hour photoperiod which corresponds to the non-migratory adults in summer (Ono and Nakasuji 1980).

Parnara guttata is well known as a migrant butterfly in central and western Japan. Second generation butterflies fly en masse to the warmer southwest in early autumn for hibernation. Eggs of the third generation are laid on grasses and the larvae develop on those grasses in autumn (Nakasuji *et al.* 1981). Average migration distance is less than 100 km (Nakasuji and Ishii 1983). However, some of the migrants fly more than 500 km over the Pacific Ocean (Asahina and Turuoka 1969) and may thus reach the southwest islands of Japan or even Taiwan.

7.6 Rice Skipper, *Pelopidas mathias* (F.) (Lepidoptera: Hesperiidae)

Distribution: Bangladesh, China, India, Indonesia, Japan, Kampuchea, Korea, Laos, Malaysia, Pakistan, Philippines, Taiwan, Thailand, Vietnam

Host plants other than rice: *Cynodon dactylon* (L.) Pers., *Eleusine coracana* (L.) Gaertn., *Imperata cylindrica* (L.) Raeuschel, *Livistona chinensis* R. Br., *Miscanthus sinensis* Aderss., *Paspalum scrobiculatum* L., *Sorghum halepense* (L.) Pers., *Zea mays* L.

Pelopidas mathias is a minor pest of rice with an extensive distribution in the rice growing regions of the world. It occurs in all rice environments but in Japan and Taiwan upland rice is the most affected.

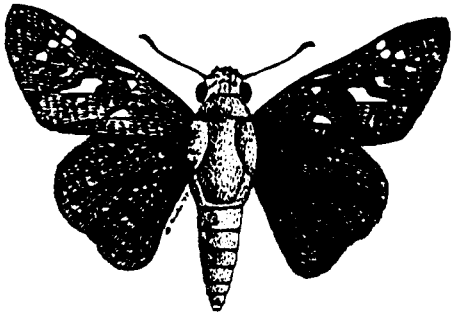


Fig. 7.6

Damage is caused by the larvae that defoliate the rice plants similar to that of *P. guttata.* The newly hatched larvae feed on tender leaves. Then they roll up and stitch together two or more leaves that are eaten from the margin inwards. Generally, only one larva is found in a fold (Teotia and Siya Nand 1966).

The adult butterfly differs from *P. guttata* in usually having only 2 spots in the discal cell of the wing and 2 groups of 3 white specks, one anterior and one marginal from the first group. The hind wings are olive brown, usually without spots. Mating generally takes place during morning hours. Eggs, averaging 90, are laid singly on the upper surface of leaves.

Eggs are smooth and creamy white in color. They are hemispherical in shape with a flat base. The incubation period ranges from 3 to 6 days.

Larvae are pale green with a vertical red streak on either side of the head. There are five larval instars. The full-grown caterpillar measures 30 mm in length and 3.5 mm across the middle of the body. The larval stage lasts for 13 to 26 days.

Pupation takes place in a silken web spun inside the leaf fold. The pupa is at first green in color with stripes clearly visible on the back, but changes to dark brown later. It is cylindrical and gradually tapering towards the hind end. The cremaster is transversely flattened and bears on its posterior margin a number of small spines. The pupal skin is thin and almost transparent. The adult butterfly emerges in 7 to 12 days after pupation.

In India, the insect passes through four overlapping generations. The adults of the first generation appear in the fields about the third week of August and those of the second generation, the second week of September. The butterflies of the third and fourth generations appear towards the third week of October and last week of November, respectively.

P. mathias is most active from August to November and with the advent of winter a high percentage of the larvae hibernate thereafter. The overwintering pupae remain inside the cocoons in folded leaves. The butterflies emerge from them in the spring when the weather becomes warmer.

7.7 Rice Ear-cutting Caterpillar, *Mythimna separata* (Walker) (Lepidoptera: Noctuidae)

Synonyms: *Leucania separata* (Walker)
Pseudaletia separata (Walker)

Distribution: Afghanistan, Australia, Bangladesh, Bhutan, Burma, China, India, Indonesia, Japan, Kampuchea, Korea, Laos, Malaysia, Nepal, New Zealand, Pakistan, Papua-New Guinea, Philippines, Sri Lanka, Taiwan, Thailand, Vietnam

Host plants other than rice: *Avena sativa* L., *Brachiaria mutica* (Forssk.) Stapf, *Brachiaria setigera* (Retz.) C. E. Hubb., *Cynodon dactylon* (L.) Pers., *Cyperus rotundus* L., *Echinochloa colona* (L.) Link, *Eleusine coracana* (L.) Gaertn., *Hordeum vulgare* L., *Nicotiana tabacum* L., *Panicum antidotale* Retz., *Pennisetum purpureum* Schumach.,

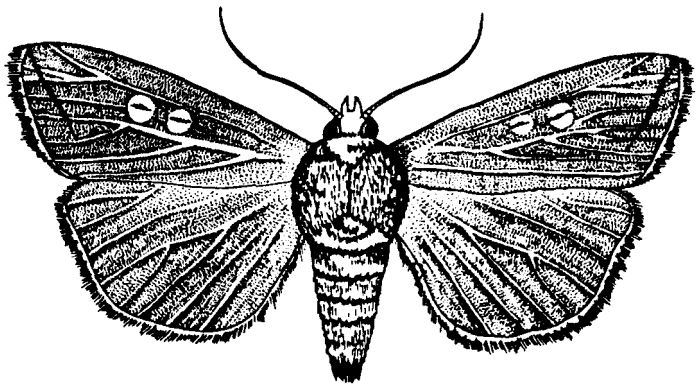


Fig. 7.7

Saccharum ofjicinarum L., *Setaria italica* (L.) Beauv., Sorghum *bicolor* (L.) Moench., *Triticum aestivum* L., *Zea mays* L.

Mythimna separata, a minor pest of rice until recently, has become a serious pest in several parts of Bangladesh, China and India. Severe outbreaks of this insect have been reported by many workers (Alam and Nurullah 1977, Chaudhary and Singh 1980, Barwal l983). The attacks may be sporadic but if heavy, the entire crop may be lost. The pest occurs in all rice environments but is most abundant in upland and rainfed wetland environments.

The early instar caterpillars first feed on dried leaf tissues and later move on to green leaves for feeding. They also eat the lemma and palea of the developing grains as well as the anthers of flowers (Papel *et al.* 1981). Mature larvae, from 4th to 6th instars, become gregarious and feed voraciously on young leaves at night. The sixth and final instar larvae cut off rice panicles from the peduncle, causing the most serious losses to the rice crop. In cases of severe infestation, the damage may go up to 60% or even more. Katiyar and Patel (1969) reported grain losses up to 1,640 kg/ha in Madhya Pradesh, India. Besides the direct loss, many farmers, anticipating the pest incidence, are tempted to harvest the crop prematurely. This produces large quantities of chaffy grains which may reduce the market price of the product. Moreover, a large number of grains and panicles are seen lying in the fields as the result of feeding damage. Experiments with third instar caterpillars indicated that for each increase of 1% leaf area consumed, there is a reduction of 0.058 cm in panicle length, 0.88 grain/panicle and 0.072 g yield/hill at the booting stage of the crop (Alam *et al.,* 1980). But these values are liable to change with the instar of larva and rice cultivar used for the study. Khamparia *et al.* (1981), working with a different variety and fifth instar caterpillars, reported that there was a yield reduction of 0.41 g/hill with an increase of every one percent of foliage loss by the larvae.

The adult is a stout, pale red brown moth which measures 20 mm long with a wing expanse of 40 mm. The forewings have two pale round spots, and the hind wings are dark on top and white underneath. The moths feed on nectar from flowers and honeydew excreted by mealy bugs and

other Homoptera. The female moths start egg laying in three days. Eggs are laid in batches of about 100 between the leaf sheaths and stems of rice plants or grasses. Males live for only 3 days while the female moths live longer.

Eggs are spherical, green-white when fresh, gradually turning pale yellow and finally black. The egg period varies from 5 to 7 days. Newly-hatched caterpillars are dull white, but later turn green. The head is orange or brown. Four longitudinal light grey to black stripes run along the body. The larvae are nocturnal in habit and during the day they hide in loose soil, under trash, in stubbles, in leaf sheaths and in whorls. During the night, they become active and resume their feeding activity. The entire larval stage lasts for about 28 days. The larvae pupate in the soil. Sometimes naked pupae are also observed among the tillers. The pupal period is 8-11 days.

Plants with dense foliage coupled with heavy tillering are most commonly attacked by the pest (Pate1 1979). Heavy application of nitrogenous fertilizers produces more succulent and green plants in which the armyworm population is found to be higher (Koyama 1966). Survival rate and fresh weight of larvae are both high on these plants. It is interesting to note that plants of the aromatic rice variety 'Basmati' are seldom attacked by the pest.

Many conditions have been reported ideal for outbreaks of this pest in different countries. In India, heavy late rains after a long drought often result in widespread oviposition and larval development. In Bangladesh also, major outbreaks are always associated with a long drought followed by wet weather (Alam and Nurullah 1977).

In China, the moths migrate to the north from southern China in the spring and fly back in the autumn. The overwintering boundary is considered between 32 and 34°N latitude (Li Kuang-po and Chen Rui-lo 1983). There are four important migrations annually. The first (March-April) and the second (May-June) are from low latitude and low elevation to high elevations; the third and fourth, vice versa.

Rice may not be the ideal plant for *M. separata.* On an overall basis of development, reproduction, survival and growth, *Sorghum* was found to be the most suitable host plant, followed by *Pennisetum* (Alam and Khatri 1980). Larvae develop faster on maize than on rice (Tripathi *et al.* 1982).

In India, adult moths start coming to rice fields by early May. The population of the first generation caterpillars is small and the damage is not conspicuous. The second generation larvae are active from middle to late June. The damage of the third generation caterpillars is mostly restricted to millets (Purohit *et al.* 1971). The rice ear-cutting caterpillar has 3-4 generations a year.

7.8 Common Armyworm, *Pseudaletia unipuncta* (Haworth) (Lepidoptera: Noctuidae)

Synonyms: *Cirphis unipuncta* (Haworth)
Pseudaletia unipuncta (Haworth)

Distribution: Southern Canada, USA, Central and some South American countries, Southern Europe, West Africa



Fig. 7.8

Host plants other than rice: Wheat, oats, barley, corn, forage grasses

Mythimna unipuncta is a cosmopolitan pest of grasses. Rice is not an ideal host for the armyworm. However, it occurs sporadically in epidemic numbers on rice in California (Lange and Grigarick 1970).

The armyworm infestations occur relatively late in the growing season, 3 to 4 weeks before heading. During the early instars, larvae skeletonize tender, young leaves or the inside of leaf sheaths. Later, the larvae remove irregular portions of the entire leaf starting from the edge, but leaving the midvein intact (Rice *et al.* 1982a). Feeding damage is generally found on the distal portion of rice leaves. Rice *et al.* (1982b) have shown that defoliation averaging 25 to 30% by armyworm larvae resulted in yield reductions up to 50%.

The adult moths are light red to pale brownish and have a hairy body with black spots and patches. They have a wing span of about 35 to 45 mm. There is a distinctive white spot in the middle of each forewing. Moths are nocturnal in habit, positively phototropic and remain inactive during daytime. Mating and oviposition usually take place after sunset. Generally, the males die shortly after mating. The female moths lay eggs for about 5 days.

The eggs are laid in several rows, each mass consisting of 90 - 230 eggs. They are round, pale yellow and 0.6 - 0.7 mm in diameter. The incubation period is 7-9 days.

Larvae are nocturnal and hide under leaves and debris during the day. Freshly hatched larvae are dull white with a brownish black head. There are 6 larval instars. Of the total amount of leaf area consumed, more than 90% is eaten by the fifth and sixth instar caterpillars (Rice *et al.* 1982a). The full grown larva is usually dark or greeenish grey in color and has a color yellow stripes just below a line of a prominent black spiracles. The larval duration is on is 24-28 days

Pupation takes place in individual earthen cells in the soil. The pupae are light amber at the beginning and turn dark brown just before adult emergence. The average pupal period lasts for 16 days. There are five generaations of the pest in a year; usually only one generation is spent on rice.

7.9 Rice Green Semiloopers, *Naranga aenescens* Moore, and *Naranga diffusa* Walker (Lepidoptera: Noctuidae)

Distribution: China, India, Indonesia, Japan, Korea, Malaysia, Philippines, Taiwan, Vietnam *(N. aenescens);* India, Indonesia, Malaysia *(N. diffusa)*

Host plants other than rice: *Cyperus diffusa* L., *Echinochloa colona* (L.) Link, *Leersia hexandra* Sw., *Leptochloa chinensis* (L.) Nees, *Paspalum conjugatum* Berg., *Sorghum bicolor* (L.) Moench.

Naranga aenescens (Fig. 7.9) is an important pest of rice in eastern Asia (Ando *et al.* 1980). But *N. diffusa* is only a minor pest. The caterpillars feed on the leaves causing defoliation which often results in a great loss in rice yields. *N. aenescens* is only found in wetland environments and is abundant in the rainy season.

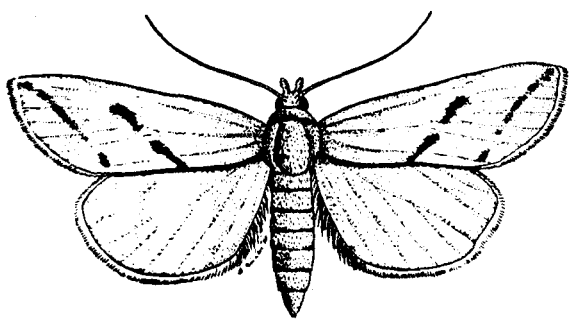


Fig. 7.9

The adult is a small moth with a wing expanse of 17 mm. The forewings of the female are golden yellow each with two transverse brown bands; hind wings are dark brown. The male moth is dark purple-red. The moths which emerge from overwintering pupae late in spring mate in the daytime. Adults hide in rice fields or grassy areas at the base of the plants during the day and become active at night. They are highly attracted to lights.

Each female lays 50-100 eggs during its lifetime of 3 to 5 days. Spherical eggs are laid on leaves in groups of up to 15 each. They are yellow when newly laid and later develop purple markings.

The larva is a semilooper, light green with white stripes. The larvae prefer actively growing plants, from the seedbed through the tillering stage. Young larvae scrape the tissue from the leaf blades and older larvae eat large areas at the edge of leaves to form notches. Young plants can often recover but yield loss occurs when *N. aenescens* occurs in combination with other non-defoliating pests. The population density during the larval stage of *N. aenescens* is known to be one of the factors responsible for inducing larval diapause (Kishino and Sato 1975). The larva forms a pupal chamber by folding a rice leaf over and securing it with silk. The pupa is light brown and smooth

bodied. Development from egg to adult takes 18 to 21 days in the Philippines (Pantua and Litsinger 1984). There is often a short pupal diapause for the last generation.

Cloudy days accompanied by low temperature favor pest outbreaks. There are 4-5 generations in a year except in northern Japan where there are only 3 - 4.

7.10 Green Hairy Caterpillars, *Rivula atimeta* (Swinhoe), and *Rivula basalis* Hamps, (Lepidoptera: Noctuidae)

Distribution: Philippines (*R. atimeta*); India (*R. basalis*)

The hairy caterpillars defoliate rice at the vegetative stage. In addition to rice, *R. atimeta* (Fig. 7.10) feed on grassy weeds. Damage is similar to that of the green semilooper. Damaged plants often recover when defoliation is not severe but high populations can kill seedlings, especially when they occur in combination with other insect pests. The description of the pest is based on the paper by Sunio *et al.* (1983).

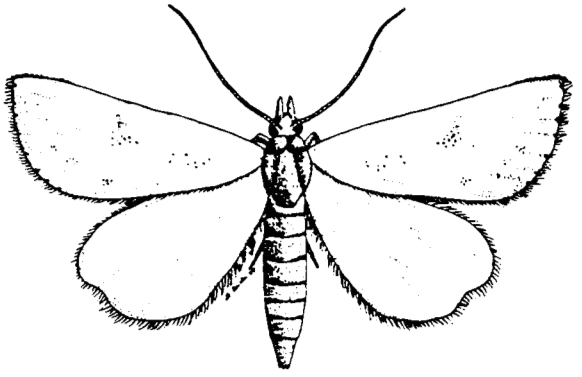


Fig. 7.10

Adult moths of both sexes are white-grey or light brown and are active at night. During the day, they hide under vegetation with their heads pointed down.

Spherical, pale green eggs are laid singly in rows on both sides of a leaf. The number of eggs laid per female moth averages 130. The incubation period is 3 - 5 days. Adult longevity of male and female moths is 4 and 5 days respectively.

The larva has long thread-like hairs on its green body and the average larval period is 13.5 days. When ready to pupate, larvae spin a cocoon of silk on a leaf blade. The pupal period is 5 days.

7.11 Fall Armyworm, *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae)

Synonym: *Laphygma figiperdu* (J. E. Smith)

Distribution: Central and South America, Guyana, Mexico, USA, West Indies

Host plants other than rice: Grasses, cereals, legumes, cotton, cabbage, tobacco

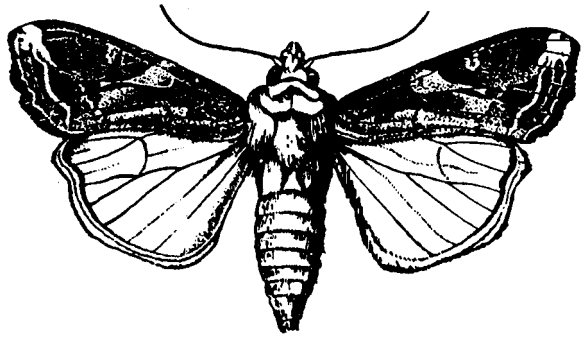


Fig. 7.11

The attack of *Spodoptera frugiperda* is perhaps the most spectacular because of its sudden appearance in the rice fields and the quick devastation of the crop. The insect is popularly called 'fall armyworm' as it appears in the northern parts of USA in late summer or fall. It is a polyphagous pest attacking many grasses and crop plants.

Newly-emerged caterpillars scrape leaf tips of young rice plants; as a result, the leaf tips appear burnt. The older larvae defoliate the crop. Infestations appear as isolated, circular patches in the rice field and seldom affect the whole field. All plants, except those eaten completely, normally recover and produce grains. Generally, the pest appears on young rice plants and does not remain in the same field for long. They march gregariously seeking fresh fields.

Adult moths are ash-grey in color with forewings having irregular white and pale grey markings. The hind wings have a pinkish white luster bordered by a light brown band. The moths are 2 cm long with a wing expanse of 4 cm. They are nocturnal, strongly attracted to light, and live for 2 - 3 weeks. The female moth flies into rice fields at night and deposits clusters of eggs on young rice plants. There are 50 to 300 eggs per egg mass which is covered with hairs and scales from the moth's body. Eggs are round, about 0.5 mm in diameter, dull white in color and with a ridged surface.

Freshly-emerged larvae are white with a shiny black head. They later turn green to black with a white stripe down each side below which there is a yellow band. The caterpillars may crawl inside the leaf sheaths or move from one plant to another suspended by a silken thread. They become full-grown in 2 - 3 weeks.

Pupation occurs in the soil between leaves that are spun together. Most larvae that develop on flooded rice never pupate (Bowling 1967). The pupa is yellowish brown and darkens as it ages. The pupal period is 10 - 14 days.

In Guyana, the pest is more serious in spring (October to February) than on the autumn crop (May to August) especially when the young crop passes through a dry period (Rai 1969). Poor rainfall both in frequency and intensity during the spring crop is responsible for greater incidence of *S. frugiperda* on this crop than on the autumn crop. Heavy rain kills this pest.

Hibernation in the extreme south of the United States occurs as full-grown larvae. In successive generations the moths move northwards. As many as 6 generations are reported from the southern States (Pathak 1975).

7.12 Common Cutworm, *Spodoptera litura* (Fabricius) (Lepidoptera: Noctuidae)

Synonym: *Prodenia litura* (Fabricius)

Distribution: Australia, Bangladesh, Bhutan, Burma, China, India, Indonesia, Japan, Kampuchea, Korea, Laos, Malaysia, Nepal, Pakistan, Papua-New Guinea, Philippines, Sri Lanka, Taiwan, Thailand, Vietnam

Host plants other than rice: Cabbage, castor, corn, jute, millets, sweet potato, tobacco and a wide variety of other plants.

Spodoptera litura is a highly polyphagous pest infesting rice only sporadically. The young caterpillars feed on leaf surfaces from the edge towards the midrib. As they grow, they become voracious. Young rice plants are often cut at ground level while older plants are only defoliated. The pest is generally a problem on upland rice because it needs dry soil for pupation. Lowland fields also occasionally suffer damage when the larvae move from one field to another grazing over the young rice plants.

The adult moth has dark purplish brown forewings with numerous spots and light colored lines. The hind wings are whitish, narrowly banded along the outer margin. Moths are nocturnal in habit and hide during the day at the base of rice plants and grassy weeds. Adults are strong flyers and can migrate hundreds of kilometers. Female moths start oviposition 2 - 3 days after emergence.

Eggs are laid on leaves in clusters of 200 to 300 and they are covered with buff colored hairs. The eggs are white, round and have a ridged surface. They hatch in 3-4 days.

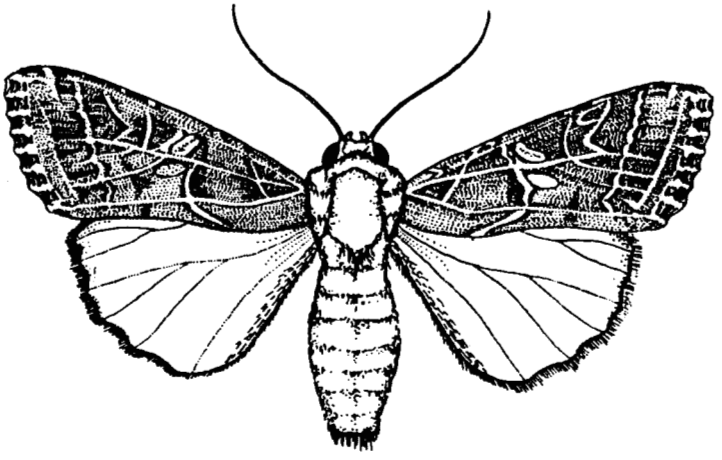


Fig. 7.12

Newly-hatched caterpillars are small, and blackish green with a distinct black band on the first abdominal segment. They feed gregariously for 3-5 days before they disperse. Larvae pass through 5 instars before they pupate. Mature larvae are stout, smooth, dull greyish in color, with a bright yellow stripe down the back and along each side of the body. There are black crescent spots next to the stripes. The head is black to dull brown with a yellow V-shaped marking. The larval period is 20 - 26 days.

In upland conditions, pupation takes place in soil in individual earthen cells. In wetland fields, larvae pupate in the rice plants or in grassy areas along field borders. The pupa in reddish brown in color and the moth emerges in 6-7 days.

7.13 Rice Swarming Caterpillar, *Spodoptera mauritia* (Boisd.) (Lepidoptera: Noctuidae)

Distribution: Australia, Bangladesh, Bhutan, Burma, China, Fiji, Hawaii, India, Indonesia, Japan, Kampuchea, Korea, Laos, Madagascar, Malaysia, Nepal, Pakistan, Papua-New Guinea, Philippines, Sri Lanka, Taiwan, Tanzania, Thailand, Uganda, Vietnam

Host plants other than rice: *Agropyron* sp., *Axonopus compressus* (Sw.) Beauv., *Brachiaria mutica* (Forssk.) Stapf, *Fimbristylis acuminata* Vahl., *Isachne globosa* (Thunb.) O. Kuntze, *Ischaemum indicum* (Houtt.) Merr, *Panicum repens* L., *Paspalum conjugatum* Berg., *Saccharum* sp., *Zea mays* L.

The rice swarming caterpillar is a sporadic pest occasionally causing up to 20% loss in rice yield. It is also polyphagous and infests various graminaceous plants. Severe outbreaks of this pest have been reported from Sarawak (Rothschild 1969) and India (Sathiyanandam *et al.* 1984). It occurs in all rice environments but is least abundant in irrigated fields.

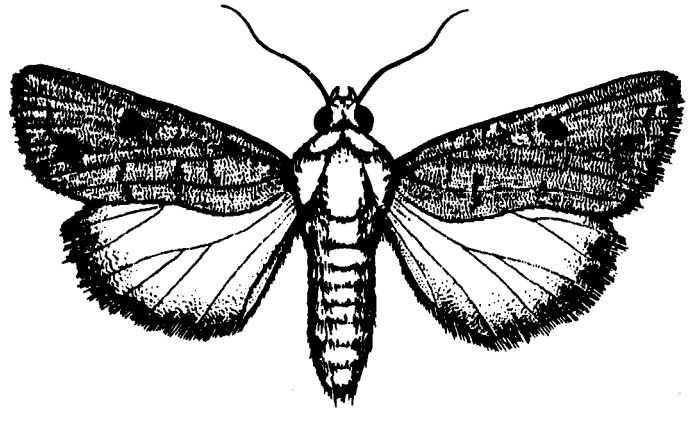


Fig. 7.13

The caterpillar damages rice by feeding on the leaves at night. The damage by early instar larvae is negligible and escapes notice. But the older caterpillars are voracious and can devastate a whole field within a short time. They feed mainly on young rice plants in the nurseries or shortly after planting. When a field has been stripped bare, they migrate in large numbers into adjoining fields to continue feeding. Their migration is facilitated by the absence of standing water in the fields. The plants are reduced to mere stumps which may die or even if they recover, do not bear earheads uniformly. Nurseries situated near ill-drained marshy areas are attacked earlier than those near dry ground. The infestation starts at the onset of the monsoon. Seedlings 4 to 20 days old in wetbed nurseries as well as plants from direct seeded rice in poorly-drained fields suffer the most serious attacks. Rice plants older than 6 to 7 weeks are usually not attacked.

The adult moth is stout with a body length of about 1.6 cm and wing expanse of 3.5 - 4.0 cm. Forewings of the female moth are greyish brown with wavy lines and a dark spot subcentrally. Wings of the male moth are more greyish. The hindwings are brownish white with thin black margins. Moths are nocturnal in habit and hide in crevices in the soils or under vegetation during the daytime.

Female moths generally mate on the night following emergence. Egg laying commences on the third night and continues for a week. Peak oviposition is on the first night of egg-laying. Eggs are laid on the underside of grass leaves and are covered with a thin layer of brownish grey felt. Oviposition rarely occurs on rice plants and the first instar larvae usually migrate from grassy vegetation to the rice field. But in the later stages of infestation, eggs may be laid on rice leaves. A single female moth may lay 5 to 6 oblong egg masses each containing 150 to 200 spherical eggs. The egg is cream colored when laid and acquires a brown tinge as development proceeds. The incubation period ranges from 3 to 9 days.

Young larvae are light green with yellowish white lateral and dorsal stripes, later becoming greyish brown, with a crescent shaped black spot on the side of each segment. The lateral stripes have a reddish upper margin. The larvae are darker brown when populations are high.

First instar larvae prefer succulent young foliage for feeding. The weight of frass produced by the last instar caterpillar is almost five times of that of the previous instar. This feeding pattern explains the cause of sudden devastating damage by late instar armyworms in the field (Rothschild 1969).

The number of larval instars of *S. mauritia* has been reported from different countries; 4 in the Philippines (Otanes and Sison 1952), 5-6 in India (Ananthanarayanan and Ramakrishna Ayyar 1937, Nair 1978), 7 in Sarawak (Rothschild 1969) and occasionally 8 in Hawaii (Tanada and Beardsley 1958). The larval period is 15-24 days.

Pupation is in soil, within an earthen chamber. The pupa is dark brown in color and measures 16.5 mm long and 5 mm wide. The pupal stage lasts 7-14 days.

The adult moths are strong fliers and migrate long distances for oviposition. But there is little evidence of migration in Sarawak (Rothschild 1969). It is suggested that the 1967-outbreak was due

to ecological factors. A prolonged period of dry weather followed by heavy rainfall led to the abundant growth of young grasses which favored survival and development.

The pest infestation is governed by various climatic conditions. In south India, *S. mauritia* is more prevalent in the 'punja' crop during October - December. Oviposition ceases by the end of February when the weather becomes hot and dry. In Taiwan, 7 - 8 generations occur per year.

8. LEAF-FEEDING DIPTERA

8.1 Rice Leaf Miner, *Hydrella griseola* (Fallen) (Diptera: Ephydridae)

Distribution: China, Egypt, France, Germany, Italy, Japan, Korea, Malaysia, North Africa, USA

Host plants other than rice: *Agropyron* sp, *Agrostis tenuis* Sibth., *Alisma plantago-aquatica* L., *Allium cepa* L., *Avena sativa* L., *Bellis perennis* L., *Bromus inennis* Leyss., *Cynodon dactylon* (L.) Pers., *Cyperus rotundus* L., *Dactylis glomerata* L., *Digitaria sanguinalis* (L.) Scop., *Echinochloa colona* (L.) Link, *Festuca parvigluma* Steud., *Hordeum vulgare* L., *Hydrocharis morsus-ranae* L., *Lamium album* L., *Lemna minor* L., *Lolium perenne* L., *Lychnis dioica* L., *Muhlenbergia mexicana* (L.) Trin., *Panicum repens* L., *Paspalum scrobiculatum* L., *Phalaris arundinacea* L., *Phleum paniculatum* Huds., *Phragmites australis* (Cav.) Trin. ex Steud., *Poa compressa* L., *Polygonum lapathifolium* L., *Polypogon fugax* Nees, *Sagittaria latifolia* Willd., *Scirpus grossus* L., *Secale cereale* L., *Setaria glauca* (L.) Beauv., *Stellaria media* (L.) Cyr., *Siratiotes aloides* L., *Trifolium pratense* L., *Triticum aestivum* L., *Typha latifolia* L., *Veronica officinalis* L., *Zea mays* L., *Zizania aquatica* L.

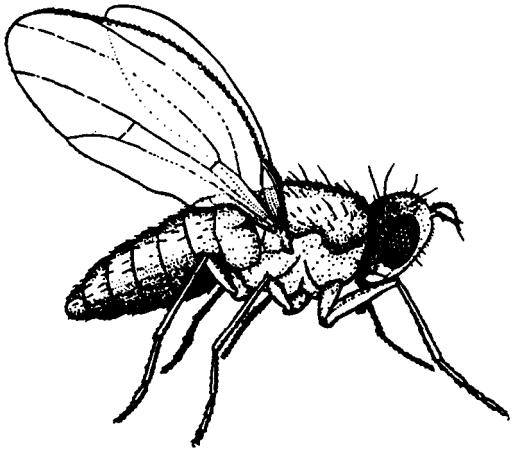


Fig. 8.1

The rice leaf miner is an early-season pest of rice in California and in Japan. Direct seeded rice is more at risk than transplanted rice. The pest also attacks other crops such as barley, oats, timothy and wheat.

The larvae mine the leaves and rarely leaf sheaths, and feed on the mesophyll tissues. The early mines are usually linear which later widen and coalesce to form big white blotches. The leaves then shrivel and lie on the surface of the water. Damage is more severe if the attack occurs at the seedling stage. Deep water and cool temperatures during the early part of the growing season reduce plant vigor (Kuwayama 1956, Grigarick 1963). These conditions cause the leaves to lie on the water surface which results in increased oviposition and subsequent mining by the larvae. But if the weather becomes warm and conditions become favorable for the growth of leaves in an upright position, the infestation may be drastically reduced due to egg and larval mortality (Grigarick 1959). Manandhar and Grigarick (1983) have shown that feeding effects on younger leaves are more pronounced than on older leaves. The maggots are mobile and move on to new leaves after old ones are completely mined.

The newly emerged adult is light grey, and looks like a small housefly. It walks briskly and stops repeatedly to stroke and brush various parts of the body with its front and hind legs. Adults are positively phototropic and are attracted to bright reflecting surfaces. Mating occurs 3 days after emergence. Flies of both sexes are polygamous. Copulation is observed most often on the water surface and floating leaves (Grigarick 1959). Adults are mobile and oviposit throughout the rice field. They live for 3-4 months.

Leaves lying on or very close to the water surface are the preferred sites for oviposition. A single fly may lay about 50-100 eggs singly on the upper surface of leaves. The average incubation period is 5 days.

The newly hatched maggots are transparent to light cream in color. They feed using their well-developed mouth hooks. Under conditions of limited food supply, crowding or submergence of the infested leaves, the larvae may leave their first mines and migrate to newer leaves. The maggots pass through 3 larval instars in a period of 7-10 days and pupate in larval mines.

The puparium is ovoid, tapering, and light to golden brown in color. It measures about 3.5 mm long and 1.0 m wide. The pupae can easily be seen inside the transparent mines. Puparia are also occasionally found on soil.

Kuwayama *et al.* (1955) reported the critical low temperature for the egg stage at 10°C, larval stage at 6°C and pupal stage at 8°C. These temperatures are within 1.6 to 3.2°F of the threshold temperatures recorded in California by Grigarick (1959). Total developmental time in California, from hatched egg to adult varies from 13 days at 32°C to 94 days at 10°C. Larvae may be killed by extremely high temperatures (44-46°C), especially when they mine upright leaves exposed to the sun (Anon. 1983).

In Japan, high populations of adult flies are observed in the paddy fields from the middle of June up to the end of July. But in the weedy fields, the adults begin to appear earlier (i.e. from April

onwards). The peak of fly population in Japan is reached in the months of May and July (Murai 1967). In California, the fly population is at its highest during March and April (Grigarick 1959).

H. griseola is a multivoltine species. All stages of the life cycle can generally be found after the first generation of the year. It is possible to have 10 generations in a year under California conditions.

8.2 Whorl Maggot, *Hydrellia philippina* Ferino (Diptera : Ephydridae)

Distribution: Bangladesh, India, Indonesia, Laos, Philippines, Taiwan, Thailand

Host plants other than rice: *Cynodon dactylon* (L.) Pers., *Echinochloa colona* (L.) Link, *Echinochloa crus-galli* (L.) Beauv., *Eleusine indica* (L.) Gaertn., *Fimbristylis miliacea* (L.) Vahl., *Paspalum scrobiculatum* L.

The insect was first reported as a pest of rice in Thailand (Patanakamjorn 1964). Ferino, then in 1968 studied the taxonomy and bionomics of the whorl maggot in the Philippines. At the International Rice Research Institute, the occurrence of the pest has been recorded throughout the year. There are reports from many rice growing countries in Asia that *H. philippina* is becoming a serious pest. This species is a pest of rice seedlings only under irrigated or rainfed conditions. Rice plants grown with continuous standing water the first 3 or 4 weeks after transplanting have more insect damage than plants in fields where the soil is water-saturated, but without standing water. The gravid flies prefer flooded fields for oviposition (Viajante and Heinrichs 1985a). Ferino (1968) reported an estimated yield loss of 1.4 tons per hectare due to the damage of this pest in the Philippines. In south India, Thomas *et al.* (1971) reported that the whorl maggot could cause 20 to 30% yield loss on the first crop during April to September. But the infestation was less in the second crop. However, Nurullah (1979) reported that whorl maggot leads to no adverse effect on tiller production and it even increases the number of productive tillers to compensate for possible grain

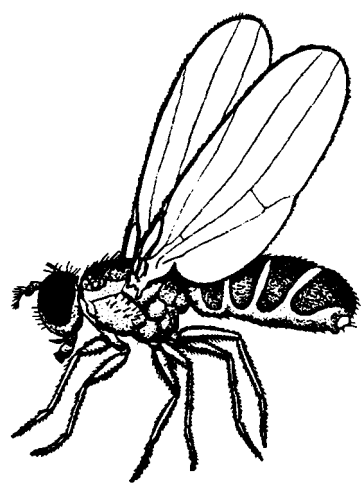


Fig. 8.2

losses. Viajante and Heinrichs (1986) conducted six yield loss experiments and found that the whorl maggot did not adversely affect yield of IR36 but did delay maturity. The experiments were conducted by comparing yields of artificially infested and non-infested caged plots. The conflicting reports regarding yield losses are likely due to different experimental conditions. When yield losses are reported, insecticides that cause plant growth stimulation are sometimes used as an insecticidal check to eliminate whorl maggots for comparison with infested plots. Also, cages are not used and infested plots are a combination of the whorl maggot and several other pests at low levels and the combined effect may be sufficient to cause yield loss. Another possible reason for reported yield losses in some studies may be the inability of plants to fully recover from whorl maggot damage when simultaneously stressed by soil mineral deficiencies or toxicities. Further studies should be conducted to determine the importance of whorl maggot damage.

The maggots feed on unopened leaves, nibbling the inner margins. Conspicuous linear feeding lesions are visible when the central leaf opens. Damaged leaves become distorted and may break off in the wind (Ferino 1968). Infested plants are stunted. However, the pest can cause damage to the boot leaf and developing panicles (Sain *et al.* 1983) which can lead to only partial filling of the grains (Varadharajan *et al.* 1977). Small punctures appear in the middle of the flag leaf and its margins get discolored (Basu 1979). The chlorotic effect coupled with disrupted sugar metabolism and poor nutrient uptake are probably the reasons for the manifested effects on infested plants (Ramamurthy *et al.* 1977).

The peak time of adult emergence is from 7 to 10 a.m. Adults are dull grey flies. Females are about 1.8 to 2.3 mm long but the males are slightly smaller. The flies have a definite preference for high moisture conditions and are not found in upland rice fields. They are often found on floating foliage in calm water and prostrate vegetation near slow-flowing drainage and irrigation canals (Karim 1969). The flies move by a combination of walking and hopping in a zigzag pattern. Adults are saprophagous on dead aquatic insects. Mating occurs mostly during morning and evening hours from the second day after emergence. Adults locate rice fields by reflected sunlight from the water surface. Once the canopy closes they can no longer find the rice crop, thus direct-seeded fields or seedbeds are not highly attractive to the adults.

The white elongate, cigar-shaped eggs are laid singly on either surface of the leaves. Females lay about 100 eggs during the lifetime of 3-7 days. Flies prefer the basal portions of the leaf to the upper half. The maggots emerge after 2-6 days. The larvae move down the leaf into the whorl on a film of dew and feed within developing leaf whorls. The larva is transparent to very light cream during the first instar but later becomes yellow. Larvae mostly remain outside the leaves, and feed on the mesophyll tissues of the foliage. When the leaves emerge from the whorl, damage can be seen as pinholes in the leaves and white and yellowish lesions at the leaf edges. Severely damaged leaves break in the wind. The larva undergoes 3 instars; the larval period ranges from 8 to 17 days. Pupation takes place between the leaf sheaths where the pupa is loosely attached to the stem. The puparium is light to dark brown, ovoid and subcylindrical in shape. The pupal period is 5-9 days.

The fly population in the Philippines is at its lowest during the first six months of the year which also coincides with times of high temperature and low rainfall. The fly population begins increasing

in July and continues to increase up to November after which it declines. But in India, the autumn rice (April to mid-July) is reported to be most affected by whorl maggots, with a peak infestation in the first week of June (Sasidharan *et al.* 1979).

The optimum temperature for normal development is between 29 and 33°C, at which the life cycle is about 19 days (Karim 1969). Adult flies have a special preference for high moisture areas. Under natural conditions, environments such as ponds, streams, lakes and irrigated rice fields provide a favorable ecological niche for the breeding of the flies.

Close planting decreases oviposition and subsequent damage by the whorl maggots (Viajante and Heinrichs, 1985b). Similarly, an azolla cover on the surface of rice fields reduces the egg population and consequently leaf damage by the larvae.

Hydrellia philippina is a multivoltine species with overlapping generations under field conditions. Temperature, humidity and availability of host plants influence the number of generations. It is believed that the whorl maggot has 13-15 generations in a year.

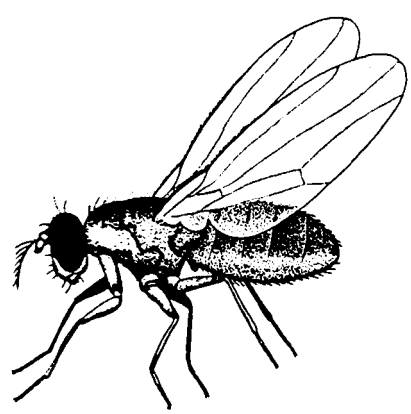
8.3 Paddy Stem Maggot, *Hydrellia sasakii* Yausa et Isitani (Diptera: Ephydridae)

Distribution: Japan

Host plants other than rice: *Leersia japonica* Honda, *Leersia oryzoides* (L.) Sw. var *japonica* Hack., *Leptochloa chinensis* (L.) Nees

The pest is particularly important on the late-planted rice crop in Japan. It is most damaging to young rice plants at one month after transplanting. The insect closely resembles *Chlorops oryzae* in its biology.

Newly hatched maggots feed on the unopened tender leaves which are marked with small spots and stripes due to the insect attack. The older larvae enter the central whorl to feed on the inner



margin of unopened leaves causing large marginal spots on the leaves. Larvae occasionally infect the panicles in the booting stage and damage the developing grains. A heavy attack may stunt the crop and reduce yield. Heavy tillering varieties or plants transplanted with several seedlings per hill are less damaged by the pest. The percentage yield reduction is 0.3 of the percentage of leaves having large spots on the marginal part of the foliage.

The fly is blackish grey tinged with bronze. The halteres are vividly yellow and their bases are orange in color. The females are usually larger and with a more swollen abdomen than the males. The flies are often seen resting on the leaf tips of rice plants. Rice planted with wide spacing is preferred for oviposition.

Eggs are laid singly on both sides of the leaf and hatch in about 2 days. The larvae are milky yellow and 4.0-4.5 mm long. The larval stage lasts for 2-3 weeks. Pupation occurs between the leaf sheath and stem. Fresh pupae are light brown and gradually turn to dark brown as they mature. The average pupation period during summer is 5-8 days but it is about 17 days during spring.

During winter the insect hibernates as larvae on graminaceous weed plants. The maggots are fairly tolerant to fluctuations in temperature of from 18 to 39°C (Okamoto and Koshihara 1962).

The insect has 5 overlapping generations in a year. The population is high during July to early September. This period corresponds to the third and fourth generations of the pest.

9. Leaf-Feeding Coleoptera

9.1 Rice Hispa, *Dicladispa armigera* (Oliver) (Coleoptera: Chrysomelidae)

Synonyms: *Hispa armigera* Oliver
Hispa aenescens

Distribution: Bangladesh, Bhutan, Burma, China, India, Indonesia, Kampuchea, Laos, Malaysia, Nepal, Pakistan, Papua-New Guinea, Sri Lanka, Thailand, Vietnam

Host plants other than rice: *Cynodon dactylon* (L.) Pers., *Echinochloa colona* (L.) Link, *Echinochloa crus-galli* (L.) Beauv., *Panicum repens,* L., *Paspalum paspalodes* (Michx.) Scribn., *Vetiveria zizanioides* (L.) Nash, *Zizania aquatica* L.

The pest causes heavy crop losses in many Asian countries particularly in Bangladesh. It is most common in wetland environments. Sporadic outbreaks have been reported from many parts of India (Budhraja *et al.* 1980, Das 1980, Chand and Tomar 1984). Infestations of hispa have increased in recent years. Introduction of high yielding varieties to more areas and improved agronomic practices seem to be partly responsible for the increased infestation (Dhaliwal *et al.* 1980). The extent of damage in Bangladesh reaches 65% (Alam 1967).

Both grubs and adult beetles feed on rice plants. Grubs mine the leaves by feeding on the mesophyll between the veins and tunnelling the tissue in the direction of the main axis of the leaf advancing towards the leaf sheath (Acharya 1967). Adults remove chlorophyll first between the

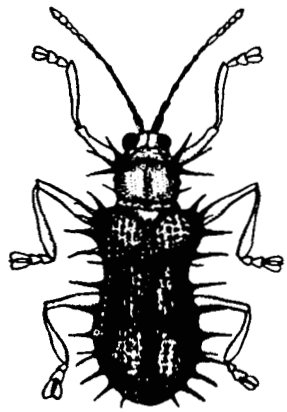


Fig. 9.1

veins of the lamina giving the appearance of white parallel streaks on the leaves. Later due to feeding on the veins, white irregular blotches appear on the leaves. In severe cases, leaves are brown and the field presents a dried up appearance. Even replanting may not be of much avail as the pests persist in the field and infest the freshly planted rice seedlings.

Adult beetles emerge in early morning and rest on the lower parts of the plant during day time. They are small, shiny black beetles about 5.5 mm long, with spines on their wing covers. The feeding activity of beetles is maximum during morning hours. They begin feeding mostly from the apical parts of leaves and proceed downward. The adult beetles prefer to feed on tender leaf tissues mostly from the dorsal side of the leaf. A single adult beetle consumes about 25 mm^2 of leaf area per day (Budhraja *et al.* 1979). Females live for 20 days while the males' longevity is only a fortnight. The beetles mate 3-4 days after emergence. Eggs are laid singly within the epidermal layers of the ventral surface of rice leaves. A single female lays on an average about 55 eggs. The minute eggs are usually found towards the leaf tips. The incubation period ranges from 4 to 5 days.

The newly hatched larvae are pale yellow, dorso-ventrally flattened and about 2.4 mm long. They start mining from the leaf tip towards the base of the leaf blade. Larval movement inside the leaf is easily seen when it is placed against light. A single grub was found to consume, on an average 123.4 mm^2 of rice leaf area in its lifetime (Budhraja *et al.* 1979). The larval stage lasts for 7-12 days.

The pupae are flat, brown and exarate. The pupal stage is completed within the leaf mines and takes 4-5 days. The adult beetles cut their way out of the rice leaf and become external feeders.

The number of generations of the pest seems to depend on the nature and number of crops grown. In regions such as Bangladesh where three rice crops are grown in a year, 6 generations of hispa occur. The sequence is: one generation during February in the winter rice (boro), one during April-May in graminaceous weeds, one on upland rainfed rice (aus), and three others in the monsoon crop (aman) from July to November in succession (Sen and Chakravorty 1970).

Adult beetles appear in rice fields in February and the population gradually increases until June-July when the larvae as well as adults cause heavy damage to young rice plants. The population declines after August. Adult beetles in small numbers can still be collected from rice fields up to September-October (Pathak 1975).

Many factors have been reported to influence the incidence of hispa in rice fields. Prakasa Rao *et al.* (1971) reported that top dressing with high levels of nitrogen during periods of pest abundance resulted in greater susceptibility of the rice crop to the pest. Dhaliwal *et al.* (1980) found hispa incidence to increase with an increase in nitrogen levels from 0 to 100 kg/ha. However, at 150 kg, the infestation considerably decreased.

Adult beetles prefer to feed and oviposit on rice crops in the vegetative stage (i.e. plants from 25 to 60 days old). After this phase, the leaves become silicified and less succulent perhaps offering mechanical resistance to feeding (Prakasa Rao *et al.* 1971). Data of studies conducted by Basu and Banerjee (1957) showed that plants just after transplanting were more prone to damage than those of other stages.

Date of plating influences the ultimate damage caused by hispa. It was shown by Prakasa Rao *et al.* (1971) that though the July plantings suffered considerable infestation by the two early broods, they soon recovered and reached a stage of least susceptibility for the two succeeding broods. But plantings in August suffered severe damage with less chance of recovery.

Weather conditions prevailing in regions of infestation in south India indicate that high humidity after rains and intermittent bright sunshine seem to favor hispa development. In north eastern India, rainfall was reported to have a negative effect on the activity of hispa (Ghosh *et al.* 1960). Heavy rainfall in July followed by unusually low rain in August and September was characteristic of epidemic years.

Dicladispa gestroi is a pest of rice in the coastal regions of Malagasy Republic. It is as important as stem borers in this area. The nature of damage is similar to that of *D. armigera.*

Another species, *Dicladispa vindicyanea,* occurs in Burundi, Kenya and Zaire. The insect is suspected to be a vector of yellow mottle virus in Kenya. The adult beetle is metallic blue-green, about 5 mm long with five lateral spines on each side of the thorax. The female lays eggs on the underside of young leaves and covers them with excreta. The grubs mine the leaves making transparent patches and adults eat leaf tips. There are 3-6 generations in a year; the life cycle takes 24-40 days to complete.

9.2 African Rice Hispa, *Trichispa sericea* (Guerin) (Coleoptera: Chrysomelidae)

Distribution: Angola, Burundi, Cameroon, Ethiopia, Ivory Coast, Kenya, Madagascar, Mali, Rwanda, Senegal, South Africa, Sudan, Swaziland, Tanzania, Togo, Uganda, Zaire

Host plants other than rice: *Chloris virgata* Sw., *Echinochloa holubii* (Stapf) Stapf, *Eragrostis aethiopica* Chiov., *Eragrostis heteromera* Stapf, *Digitaria zeyheri* (Nees Hend., *Diplachne* fusca (L.) Beauv. ex Stapf

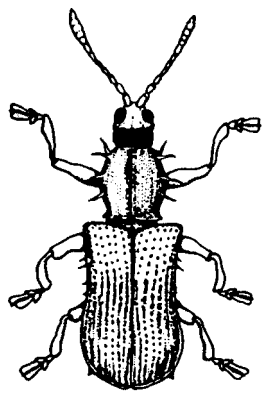


Fig. 9.2

Trichispa sericea is only recorded from Africa. It is an important pest in rice nurseries and only sporadically serious on transplanted rice. It is reported to transmit rice yellow mottle virus in Kenya.

Both adults and grubs feed on leaf tissues of young rice. The first attack is highly localized but spreads rapidly. Attacked plants have irregular pale brown patches and narrow white streaks on the leaves; the pale brown patches are the larval mines, and the whitish streaks are the feeding scars by the adult beetles. Severe attacks kill the plant.

The adult is a dark grey beetle covered with spines. It is about 3-4 mm long. Adult females live for about a fortnight and may lay more than 100 eggs during this period.

White, boat-shaped eggs (1 mm long) are laid singly in slits in the leaf made by the adult beetle, the wound being covered by a spot of excreta. Hatching takes place after 3-4 days.

The grub is slender and yellowish which when fully grown is about 6 mm long. The larvae mine inside the leaf, the damaged portions being visible externally as a pale brown blotch. The larval period lasts about 10 days.

Pupation takes place within those portions of the leaf lamina that are not submerged. The pupal period generally lasts about 6 days. Emerging adults migrate to alternate host plants.

9.3 Rice Blue Beetle, *Leptispa pygmaea* Baly (Coleoptera: Chrysomelidae)

Distribution: India

Host plants other than rice: *Arundinella metzii* Hochst., *Ischaemum travancorense* Stapf, *Paspalum scrobiculatum* L., *Pennisetum purpureotyphoides* (Schum.), *Saccharum offjicinarum* L., *Verivena zizanioides* (L.) Nash

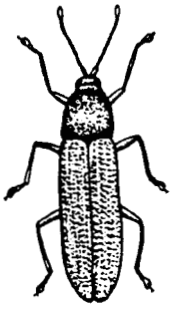


Fig. 9.3

Leptispa pygmaea, a minor pest of rice, assumed serious proportions in poorly drained rice fields of central India in 1978. The pest appeared in an epidemic form for the first time during the second crop (July to November) in Maharashtra.

The adult is a small bluish elongated beetle measuring about 5 mm in length and 1.5 mm in width. Both adults and grubs feed on the surface tissues of rice leaves. Damage by the adult is similar to that of the hispa but the feeding lesions are narrower and more regular in shape. The attacked leaves become wafer thin, and dry up. This pest usually appears along with rice hispa aggravating the damage done by it to the rice crop.

The pest survives the off-season (November-February in the adult stage on grasses, volunteer rice plants, ratoon rice or on sugarcane. The activity of the pest is at its lowest during this period. No egg laying has been observed on the alternate hosts during the pest's inactive stage (Khanvikar *et al.* 1983).

9.4 Rice Leaf Beetle, *Oulema oryzae* (Kuwayama) (Coleoptera: Chrysomelidae)

Synonyms: *Lema oryzae* Kuwayama
Lema suvorovi Jacobson

Distribution: China, Japan, Korea, Ryuku Islands, eastern Siberia, Taiwan

Host plants other than rice: *Dactylis glomerata* L., *Glyceria tonglensis* C. B. Clarke, *Leersia oryzoides* (L.) Sw., *Phragmites australis* (Cav.) Trin. ex Steud., *Zizania latifolia* (Griseb.) Turez. ex Stapf

Oulema oryzae occurs in upland and wetland environments and is one of the serious pests of rice in northern Japan, Korea and China leading to crop losses of up to 30%. The percentage of yield reduction in Japan is computed as 0.25 of the percentage of injured leaves. In Taiwan, it infests the first crop in the mountain regions.

Both adults and larvae feed on the leaf surface causing a scorched appearance of the foliage. Larvae skeletonize leaf blades in a linear fashion. In short duration rice varieties, plants often do not recover from *O. oryzae* damage. Retardation of plant growth and decrease in the number of leaves

and tillers have been observed (Kojima and Emura 1979). Ripening of grains in infested plants is considerably delayed leading to reduction in both quality and quantity of grain yield. In cases of severe infestation, the plants die and the fields present an appearance of having been burned by fire. In Japan, damage varies from 5% to 10% when slight and 20% to 30% when severe. The tolerable injury level is set at 20% injured leaves in late June (Koyama 1978).

Adult beetles are metallic blue with the head and antennae black and the thorax yellowish brown. The females deposit cylindrical eggs in masses on the upper surface of leaves. The oviposition period lasts 15 days and incubation varies from 5 to **11** days. The life of the adult extends for one year or more.

The brown larvae are globular in shape and rather heavily sclerotized and with dark brown nodules on a yellow base. They cover their body with dark greenish excreta and appear as mud on leaves. The larval period is 13-19 days. The full-grown larva pupates within an ellipsoidal whitish cocoon mostly on the rice leaves, though in upland fields, pupation sometimes takes place on or under the ground.

There is one generation per year and overwintering occurs in the adult stage. In Japan, the increase in the number of leaf beetles often coincides with the transplanting of rice seedlings. The beetles leave their hibernating sites by late May, mate and start laying eggs by early June. Oviposition continues until nearly the end of July. Then the adults bury themselves in the debris of mountain bush and under the roots of grasses.

O. oryzae is highly adaptable to low temperatures. In the north temperate regions of Japan, female beetles stop depositing eggs early and adult longevity is shortened if the atmospheric temperature rises early in summer. On the other hand, when cooler days continue to prevail in summer, the hibernating adults survive for a longer time in the field and oviposition continues longer (Kuwayama 1966).

10. Leaf-, Stem-, and Panicle-Feeding Aphids

Many aphid species (Homoptera: Aphididae) infest the aerial parts of rice even though rice is not the primary host plant for most of them. A list of aphids reported on rice with their geographical distribution is provided in Table 6.

The rusty plum aphid *Hysteroneura setariae* feeds on the leaves and unripened grains of rice. Moderately infested grains show brown necrotic spots. A heavy infestation turns all spikelets brown and chaffy. Severe attacks by this aphid have been reported recently from countries such as Sierra Leone (Akibo-Betts and Raymundo 1978), India (Garg and Sethi 1978) and Nigeria (Akinlosotu 1980).

The wingless adults of *H. setariae* are 3-4 mm long and are rusty to dark brown in color. Nymphs are pink. The average nymphal period is 10 days. In Africa, the aphid appears in large numbers with the May rains and remains active on the rice crop till December. But heavy rains greatly reduce its population during August-October. In India, this aphid is found on rice throughout the season.

TABLE 6

Distribution of aphid species feeding on the leaf. stem, and panicles of rice (Yano *et al.* 1983)

Aphid species	*Host plants*	*Distribution*
Aphis craccivora Koch	Rice, many plants	Many countries
Aphis gossypii Glover	Rice, many plants	Completely cosmopolitan, absent only from the colder parts of Asia and Canada
Brachysiphoniella montana (van der Goot)	Rice	India
Diuraphis noocia (Mordivilko ex Kurdjumov)	Rice, grasses	North Africa
Hysteroneura setariae (Thomas)	Rice	India, Philippines, Thailand, West Africa
Melanaphis sacchari (Zehntner)	Rice, sugarcane, sorghum, maize, wheat, grasses	Japan, Philippines
Metopolophium dirhodum	Rice, grasses	Central Asia
Myzus persicae (Sulzer)	Rice, many crop plants, weeds	Virtually cosmopolitan
Rhopalosiphum maidis (Fitch)	Rice, many crop plants, some weeds	Throughout the tropics, subtropics and the warmer temperate regions
R. nymphaeae (L.)	Rice, *Monochoria vaginalis, Saginaria, Trifolia, Prunus* spp.	Bangladesh, Fiji, North America, Philippines, Spain, Taiwan
R. padi (L.)	Rice, many plants belonging to Gramineae and Cyperaceae	Africa, America, Asia, Australia, Europe
Rhopalosiphum sp.	Rice	Japan
Schizaphis graminum (Rondani)	Rice, wheat, barley, oats, Italian millet	Africa, Asia, South America, USA
Sipha glyceriae (Kaltenbach)	Rice, grasses	Italy
Sitobion akebiae (Shinji)	Rice, wheat, wild weeds	Japan, Korea
S. avenue (F.)	Rice, grasses	Europe, North America, Taiwan
S. fragariae (Walker)	Rice	Spain
S. graminis (Takahashi)	Rice, grasses	Oriental and Ethiopian regions
S. miscanthi (Takahashi)	Rice, graminaceous plants	Australia, China, New Zealand, Philippines, South Pacific regions, Taiwan.

Rhopalosiphum padi is variously known as the bird cherry oat aphid and the apple grain aphid. It is a vector of the virus disease 'giallume' (yellow disease or rice yellows) of rice in Italy. The primary host of this aphid species in Italy is the fruit tree *Prunus padus*. When *P. padus* is not available, the aphid overwinters on secondary hosts such as rice and various grasses.

11. RICE STINK BUGS

The characteristic foul odor produced by scent glands on the abdomen of these insects has led them to be commonly called 'stink bugs'. About 60 stink bug species have been reported to infest rice fields and at least half of them are considered pests causing yield loss or pecky rice.

'Pecky rice' is referred to as the condition of the grain after being sucked by stink bugs and partially or wholly stained by bacteria or fungi. If a sample of rice contains some pecky grains, the whole lot is considered contaminated and the market price is decreased in some countries. An

emphasis on rice has shifted from yield to quality. In Japan, the inspection for rice grain quality has become stricter and the pecky rice problem has assumed increasing importance. The major bugs causing pecky rice in Japan are listed in Table 7.

TABLE 7

Bugs that cause pecky rice in Japan (Kisimoto 1983)

Family	*Species*
Alydidae	*Leptocorisa chinensis* (Dallas)
Coreidae	*Cletus punctiger* Dallas
Lygaeidae	*Nysius plebejus* Distant *Togo hemipterus* Scott
Miridae	*Stenodema sibiricum* Bergroth *Trigonotylus coelestialium* Kirkaldy
Pentatomidae	*Dolycoris baccanum* L. *Eysarcoris lewisi* Distant *E. parvus* Uhler *E. ventralis* Westwood *Lagynotomus elongatus* Dallas *Nezara antennata* Scott *N. viridula* (L.) *Scotinophara lurida* Burmeister
Ropalidae	*Aeschynteles maculatus* Fieber

Stink bugs of the genera *Leptocorisa, Nezara,* and *Oebalus* are separately dealt with.

11.1 *Leptocorisa* spp. (Hemiptera: Alydidae)

Host plants other than rice: More than 65 plant species (Srivastava and Saxena 1967)

The rice bugs are major pests of rice wherever the crop is grown. The most important species in the tropical and subtropical rice regions belong to the genus *Leptocorisa.* Another genus, *Stenocoris* which was earlier a subgenus under *Leptocorisa,* also contains a few species which are very often recorded from rice fields. Many species share a common distribution but very often their relative abundance differs. For example, in the Philippines, *L. oratorius* is more abundant than *L. acuta* (Fig.ll.1).

Rice bugs are found in all rice environments, but are more prevalent in rainfed wetland or upland rice. Factors that favor high bug populations are adjacent woodlands, extensive weedy areas near rice fields and staggered rice planting (Reissig *et al.* 1985).

The intensity and type of damage caused by rice bugs depends on the stage of the rice crop, population density of the pest and ecological conditions. Both nymphs and adults are destructive to the crop, even though the damage by nymphs is more severe (Pathak 1975). Nymphs prefer grains at the milky stage for feeding. They feed by the insertion of the proboscis at points where the glumes meet. During the process, the bug secretes a proteinaceous stylet sheath to form a feeding canal for its sucking mouthparts (Gyawali 1981). Removal of stored assimilates from the developing grains may result in either unfilled or partially filled grains with damage symptoms. Uichanco

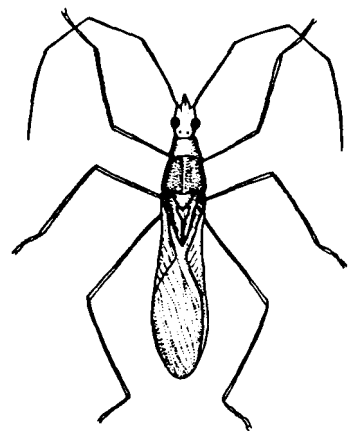


Fig. 11.1

(1921) considered that the bugs inhibited kernel development either through mechanical injury at feeding or injection of some toxin in addition to the removal of milky sap. Panicles in heavily infested fields remain erect.

The quality of grains is also reduced by the insect attack. Pecky rice in Japan and the United States is down graded and priced low. The smell of the infested grains lowers market value. Damaged grains even after cooking retain the buggy smell. Sometimes even the straw has an off-flavor which is unattractive to cattle.

In India, on an average, 5-10% of the grains are damaged due to infestations of the rice bug. In years of severe attacks, damage reaches 40-60% (Kalode 1982). In the case of early paddy, maturing in September, the loss is usually greater than in the late maturing varieties. *Leptocorisa* spp. cause significant damage in Thailand every year. In the Malay Peninsula, the yield loss in certain areas exceeds 25%.

The adult bug is long and slender, about 16-19 mm long. Rice bugs are diurnal but are most active during early morning and evening. During the hotter parts of the day, the bugs are seen taking shelter under the leaves of rice plants or weeds near rice fields. Rice bugs fly short distances when disturbed. The females are stronger fliers than the males. The males are capable of mating shortly after emergence but the females start only one or two weeks after becoming adults. Mating generally takes place in the morning hours and rarely at night. Oviposition starts 3-4 days after mating. The female lays 250-300 eggs in two or three straight rows along the midrib on the upper surface of the leaf blade. Eggs are laid during the night. They are disc-shaped, the convex lower surface being attached to the leaf by means of a white gummy substance. Eggs are dorsally flat and elliptical, with the surface slightly granulate and shining. The incubation period is about a week. Females feeding on rice lay more eggs than those feeding on grasses.

Rice bugs become active when monsoon rains start. They complete 1-2 generations on grassy weeds before migrating to rice fields. A small number of adults usually appear in the rice fields as soon as the plants start flowering. When about 80% of the grains have ripened, the adults migrate to fields having rice plants of less maturity. Akbar (1958) noted that before flowering, the bugs feed on the seedlings by sucking sap from leaves and tender shoots.

Rice bugs are often seen on flowering wild grasses near canals. In Papua-New Guinea, numbers of *Leptocorisa* were observed (Sands 1977) to increase enormously when weeds in the adjacent paddies were left unmanaged. The bugs are attracted to the rice crop when the plants start flowering. Kainoh *et al.* (1980) have shown that adult bugs of *L. chinensis* can detect the odor of rice plants when they are close to the rice field. But their aggregation on the panicles seems to be due to the arresting effect of the flowers. The adults have been observed to live for up to 4 months.

The freshly hatched nymphs are green but turn brownish as they grow. They congregate around the empty egg cases for some time before they disperse for feeding. Nymphs feed voraciously and gregariously until the fourth instar. Feeding on the flowering heads continues throughout the day especially in the early morning and at dusk when the sunlight is not intense. The nymphs pass through 5 instars in a period of 25-30 days to become adults. The final molting takes place at night. Nymphs stop feeding about 5 hours prior to selecting a place to molt on the leaves or flowers of the host plant. The nymph then remains motionless in an extended position for about 2 hours before ecdysis. The actual process of molting takes only 2 minutes.

The bug reacts favourably to high humidity and frequent drizzles prevailing from April to June, the active season of the bugs in India (Singh and Chandra 1967). Srivastava and Saxena (1967) reported that it was the light intermittent rain which favoured the build-up of bug populations while heavy rains had an adverse effect on the pest. In the Philippines, rice bug activity was at its peak during the rainy period in November-December, and dry season crops which attained the milky stage in March-May were less severely attacked (Uichanco 1921).

In Papua-New Guinea, rice bug abundance depends on the availability of suitable host plants rather than on seasonal weather fluctuations, except for periods when adult aestivation occurs (Sands 1977).

In India, the bugs start laying eggs by the last week of June when the monsoon generally breaks. In early July, many nymphs and adults are seen on rice nurseries and on grasses around fields planted to rice or millet during the previous season. Maximum population of the pest occurs during September. The population declines from the end of October and in December, only a few adult bugs are seen on grasses growing in shady areas. Four overlapping generations have been recorded in a year. In the Philippines, population build-up is greatest in September-October after which the adult bugs undergo aestivation or diapause in the grasses (Pathak 1968).

In Japan, *L. chinensis* hibernates on ferns and weeds under humid and shady conditions (Ito 1978). In India, teeming populations of *L. acuta* have been found to hibernate on trees during the relatively colder and drier months of December to March (Banerjee and Chatterjee 1965).

11.2 *Nezara viridula* (L.) (Hemiptera: Pentatomidae)

Distribution: All the rice growing regions of the world

Host plants other than rice: Many, especially legumes, cotton, tomato.

Nezara viridula, the southern green stink bug, is a polyphagous pest. It occasionally causes serious losses to rice. Nymphs and adults suck sap from stems and developing grains. At harvest, grains may be shrivelled or speckled. An adult *N. viridula* can produce on an average 1.5 pecky rice grains per day (Kisimoto 1983).

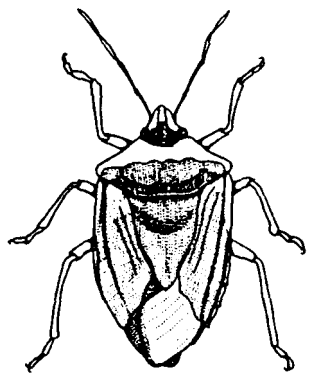


Fig. 11.2

The pest has assumed great economic significance in Japan since 1956 when the introduction of early-transplanting resulted in the flowering of the rice crop at the same time as the emergence of first generation adults. Moreover, at this time of the year, host plants other than rice are relatively scarce. In Indonesia, *N. viridula* is considered as an important pest of rice. But in Malaysia, although localized damage may be serious and spread over several hectares of rice fields, the overall crop loss is less than 1% (Van Vreden and Ahmadzabidi 1985).

The adult bug is 12-18 mm long and green in color except for the membrane of the forewings which is hyaline. Four distinct color morphs have been identified. Females start mating one week after emergence and the preoviposition period varies from 2 to 3 weeks. The bugs are attracted to light and heading rice. They are active fliers and are distributed rather randomly in the paddy field.

Egg are laid in parallel rows on the lower surface of leaves in masses of 70-130. Each female usually lays 2-8 egg masses. Eggs are yellow but turn red just before hatching.

The newly-hatched nymphs congregate for some time around the empty egg shells before they disperse for feeding. After the fourth instar, nymphs feed solitarily. The nymphs undergo 5 molts in 35-45 days to become adults. The nymphal population is usually heterogenous in color patterns.

Rice fields surrounded by wild vegetation seem to be especially vulnerable to pest infestation. Mass migrations of the bug from vegetable fields to the rice crop have also been observed. Adults of *N. viridula* can fly over a distance of 1 km even with a hill in their flight path (Kiritani and Hokyo 1970).

In southern Japan, the insect has three overlapping generations with a partial fourth. In years that are warm in March-June, the hibernating bugs become active earlier and complete the fourth generation. Adults hibernate in shaded dry places. After hibernation the emerging adults feed on grasses, orchards, and other spring and summer crops before they migrate to rice.

Among the external conditions influencing mortality of the green stink bug in the overwintering season, weather conditions are the most important. In severe winters, mortality as high as 97.5% has been reported in Japan (Kiritani and Hobo 1970). Intrinsic factors such as sex, body size and color type of the adult influence the bug mortality in the overwintering period.

11.3 *Oebalus* spp. (Hemiptera: Pentatomidae)

Distribution: *O. pugnax* (F.): Cuba, Dominican Republic, USA
O. ornata (Sailer): Brazil, Dominican Republic, Haiti, Puerto Rico
O. poecila (Dallas): South American rice growing regions

Host plants other than rice: *Avena sativa* L., *Cyperus iria* L., *Digitaria sanguinalis* (L). Scop., *Echinochloa crus-galli* (L.) Beauv., *Hordeum vulgare* L., *Panicum dichotomiforum* Michx., *Paspalum urvillei* Steud., *Secale cereale* L., *Sorghum bicolor* (L.) Moench., *Triticum aestivum* L., *Zea mays* L.

Several species of *Oebalus* cause damage to rice kernels in the Americas. Among them *O. pugnax* is the most important and the one that has been studied in detail. The bionomics of other species are similar to those of *O. pugnax* (Fig. 11.3).

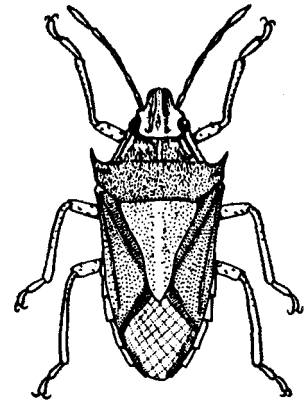


Fig. 11.3

O. pugnax is commonly found in North America, east of the Rocky Mountains, and as far north as Minnesota and New York (Sailer 1944). The insect is a pest of rice in the southern rice producing areas.

Nymphs and adults suck rice grains at the milky stage. Florets fed upon during the early endosperm formation are often wholly or largely drained of their content, which may result in either empty or severely atrophied grains. Feeding is accompanied by subsequent formation of an area of chalky discoloration surrounding the feeding site. This injury is evident on the mature hulled kernel also. 'Pecky' grains are structurally weak at the region of insect injury and often break during milling. This results in a reduction in market value. Pecky rice which escapes breakage during milling is of inferior quality as a finished product owing to its discoloration.

Economic losses due to stink bugs vary. *O. ornata* causes crop losses as high as 50% in the Dominican Republic. Early estimates in the USA put the loss caused by *O. pugnax* from a negligible amount to 25% (Ingram 1927). Consistent and severe losses in rice yields were reported for infestation levels of 7-8 bugs per 1,000 panicles (Swanson and Newsom 1962).

The adult bug is a straw colored pentatomid, approximately 1.2 cm long, with prominent lateral pronotal spines. The antenna is pale red, with the first segment lighter in color than the others. The legs are yellow with scattered black punctures. The hind wings are iridescent and frequently appear green. The bugs give off a strong, disagreeable odor when disturbed.

The premating period for both males and females averages 2.4 days (Nilakhe 1976). The barrel shaped eggs are laid in masses numbering 10-47. They are arranged in two rows on stems, leaves or panicles. Eggs are bright green when laid but turn red before they hatch. The incubation period is 4-8 days. Females reared on barnyard grass and vasey grass laid significantly fewer eggs than those reared on rice (Nilakhe 1976).

The newly hatched nymphs congregate on and around the empty egg shells for about a day before they disperse to feed. When they hatch, they nymphs have a black thorax, head, legs and antennae and two black spots on the red abdomen. But this coloration fades away with successive nymphal molts. There are five nymphal instars and the nymphal period lasts from 16 to 20 days.

Bugs start hibernating during the first week of October. Wood trash and bunch grass are the major hibernation sites (Odglen and Warren 1962). The insects start emerging out of hibernation by the first week of April and complete their emergence by the last week. Males are the first to come, about 10 clays before the females. Adult bugs are seen voraciously feeding on the flowers of wild grasses. They reproduce on favourable host plants in or adjacent to rice fields or pasture lands until rice begins to flower. Factors responsible for initiating movement of the adults from grasses to rice are not fully understood. Douglas (1939) reported that the stink bugs forsake the grasses as the rice panicles emerge. He also noted that when an early field of rice is harvested, the bug population in the adjoining rice fields increases. Bowling (1967) suggested that the movement to rice is initiated when other hosts become unfavourable as food.

Oebalus ornata is a serious pest of rice in the Dominican Republic. The bugs are very active on the panicles during morning hours, but migrate to the base of plants when the sun becomes hotter. On cloudy or light rainy days, the nymphs and adults remain and feed on the panicles all day. The

insect is active in the Dominican Republic throughout the year and has seven generations. The population is usually at its peak during July, which coincides with the flowering of the first rice crop and is comparatively lower in February when the second crop flowers. In May, the population is at its lowest.

12. PANICLE THRIPS

12.1 *Haplothrips ganglbaueri* Schmutz (Thysanoptera: Phlaeothripidae)

Synonym: *Haplothrips aculeatus* Karny

Distribution: India, Malaysia, Pakistan, Sri Lanka

Host plants other than rice: *Ageratum conyzoides* L., *Asytasia gangetica* (L.) Aners., *Blumia wightiana* DC, *Bothriochloa pertusa* (L.) A. Camms, *Celosia argentia* L., *Chloris barbata* Sw., *Cyperus rotundus* L., *Echinochloa crus-galli* (L.) Beauv., *Eragrostis nigra* Nees ex Steud., *Hydrolea zeylanica* Vahl., *Imperata cylindrica* (L.) Raeuschel, *Ischaemum indicum* (Houtt.) Merr., *Leucas aspera* Sprng., *Paspalum scrobiculatum* L., *Pennisetum typhoides* (Burm. f.), *Polytrias amaura* (Buse) O. Kuntze, *Solanum torvum* Sw., *Sorghum bicolor* (L.) Moench., *Triticum vulgare* Vill.

Cereal thrips *Haplothrips ganglbaueri,* is a polyphagous species infesting the inflorescence of various cereal crops such as rice, wheat, sorghum and millets. The pest also abounds in several weeds common in and around rice fields. A positive correlation often exists between the thrips populations in the weeds and in the rice plants (Ananthakrishnan and Thangavelu 1976). The population build-up of the insect is very high and outbreaks have been reported from many parts of India (Chaudhary and Ramzan 1971, Abraham *et al.* 1972).

Due to the laceration and feeding by larvae and adults of *H. ganglbaueri,* the rice inflorescence is variously affected. The damage on the lemma and palea causes development of irregularly oval and diffused brownish patches (Abraham *et al.* 1972). Vidyasagar and Kulshreshtha (1983) reported three distinct types of damage: (1) light brown spots with a perforation at the proximal part of the unopened spikelets, (2) sterile spikelets that retain their green color throughout their development and (3) oozing of milk over the grain without any external feeding marks. The affected panicles are erect due to the dropping of damaged grains. Continuous feeding causes chaffy grains.

The adult thrips are dark brown with a dominant reddish tinge. The average lengths of males and females are 1.3 and 1.6 mm respectively. The preoviposition period lasts for 2-3 days. Eggs are laid on the outer surface of the lemma and palea mostly in clusters of 4,8 and 12 (Ananthakrishnan and Thangavelu 1976). Eggs hatch in 2-4 days. There are two larval instars which together last for 8-11 days. There is a short prepupal stage of 1 day which then passes to the pupal stadium. The pupal period is 3-4 days. Female thrips live for 12-15 days while males live for only 3-5 days.

Incidence in South India is serious during the first fortnight of December. During this period, the weather is humid with occasional drizzles and the sky is often overcast for most of the day.

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4

Rice Pests and Agricultural Environments

MICHAEL E. LOEVINSOHN
International Development Research Centre
Ottawa, Canada

1. INTRODUCTION

THIS CHAPTER FOCUSES ON the ways in which the fundamental forces affecting pest species, that determine the presence and abundance of pests in a particular area and that govern their assemblage into communities, are shaped by the manner in which rice is grown. These forces, generally considered as "natural" (the impact of weather and micro-climate, the limitations imposed by host plant availability and quality and the action of natural enemies), are profoundly influenced by decisions at various levels, from the farmer's to the policy-maker's. Changes, for example, in the time of planting, in irrigation practices, and in the spatial or temporal intensity of rice cultivation relax or tighten the constraints on pest species by modifying the fundamental forces. All too often, the effects are unintended and poorly understood by scientists and farmers. Effective pest management demands, however, that we learn to predict the consequences of human action and that we use this knowledge to better plan interventions.

Two themes dominate this chapter. The first is that the response of pests to alteration of their environment is dynamic. Evidence of adaptation by pests can be found today in patterns of genetic differentiation between populations. Evolutionary responses have been best studied with respect to control measures, particularly the widespread use of insecticides and host plant resistance, but they are evident as well in the face of changes in the timing, intensity and synchrony of cultivation. Though there is little direct evidence of the process, it is quite possible that over the 10,000-odd years that rice has been cultivated, human modification of natural forces has led to the emergence of new pest species. The dynamic nature of pest response is also visible at the community level: environmental change that acts to the detriment of one species may offer new opportunities to another, leading to changes in species composition.

The second theme that will be developed is that the key processes at work are scale-dependent. The practice of rice entomology has been pre-occupied with the dynamics of individual species, for the most part at the smallest of spatial and temporal scales. As one's attention turns to forces acting on populations and communities at scales greater than the dimensions of a field and longer than a season, one is struck by the paucity of data and the abundance of speculation. The presence, absence or relative importance of a species in an area has generally been treated as a given. This orientation is perhaps understandable given the often pressing needs of control. But there has been little basis on which to predict the impact of widespread agricultural change or to explain differences in the pest situation between rice environments. In the course of this chapter we point to new methods and approaches that may provide a basis for a more forward-looking environmental management, holding out the promise of avoiding rather than merely coping with pest problems.

2. THE ASSEMBLAGE OF PEST FAUNAE: MODIFICATION OF THE PHYSICAL ENVIRONMENT

2.1 CLIMATE AND RANGE

Rice is grown on every continent, save Antarctica. It can be found from near 50ºN in China (IRRI 1978) to 35ºS in Australia (Moomaw and Vergara 1965), and from sea level to over 2600 m in Nepal (Shahi and Heu 1979). The majority of rice production, however, is located within the tropics and subtropics. Of the world total, some 90% is within Asia, 4% in Latin America and less than 2% in sub-Saharan Africa (Palacpac 1982). Though few Asian countries are able to bring much new land under rice cultivation, considerable scope for expansion remains in both Africa and Latin America.

Climatic factors vary widely across the range of rice cultivation. Temperature, humidity and wind affect the rates of increase of pest populations directly, by limiting longevity, fecundity and dispersal, and indirectly, through their effects on host plant vigor and natural enemy action. Pests also make use of physical cues correlated with the availability of host plants, such as photoperiod and humidity, to break the inactive states of quiescence and diapause. The literature on climatic effects on rice pests has been reviewed recently by Mochida *et al.* (1986).

As man extended rice cultivation beyond its center of origin in Southeast Asia and southern China, it was often to areas of greater climatic extremes. Individual insects able to make use of a more widely available host were at a selective advantage within their populations. Where this ability was due to a genetically determined tolerance or behavioral plasticity, natural selection resulted in genetic differentiation. Though direct evidence of the process is impossible to obtain at this point, perhaps centuries after the fact, the results of the process should be visible in differing tolerances of populations inhabiting areas of contrasting climate.

Therc has been little research on this topic, particularly within the tropics. Many might consider it of only academic interest that, say, yellow stem borers in the hot and arid Punjab show greater resistance to high temperatures than those from Japan. But a similar process has occurred on repeated occasions on a more local level and with more immediate consequences. I refer to the

response of pests to the new opportunities that have arisen across much of tropical Asia in the past few decades with the shift from single to double rice cropping made possible by irrigation. In many locations, there are marked differences between wet and dry seasons in temperature, relative humidity and wind speed and direction.

2.2 ADAPTATION TO THE DRY SEASON

Few if any pests have been totally unable to colonize the dry season crop. Reliable contemporary records are frustratingly rare, but in most cases the available evidence suggests that the lag between the widespread adoption of dry season cropping and the appearance of damaging infestations has been either nil or very brief.

The rice gall midge provides an interesting case study. Hidaka and his co-workers (Hidaka *et al.,* 1974) studied the seasonal dynamics of this pest in an area of northern Thailand where a single crop of rice is grown each year from March to November. They found that after cultivated rice had passed the vegetative stage and could no longer support infestation, females oviposited on nearby grass hosts, particularly wild rice and, to a lesser extent, *Paspalum distichum.* Larvae were observed there throughout the dry season, however, few large and readily visible galls could be found before the wet season rice crop was established. Low relative humidity, the authors suggested, arrested the insect's development. Experimental evidence supported this conclusion: not one of 50 newly hatched larvae placed on dry rice plants achieved penetration, while all of the larvae on plants sprayed with water managed to do so *(ibid.,* pages 54-62). More striking yet was their observation that, in a 400 m^2 field planted on-station during the dry season, not one gall was found in nearly 3,000 hills, and only 2 larvae upon dissection of the stems. The authors recommended planting a dry season crop to avoid damage by the gall midge *(ibid.,* pages 74-75).

These findings, however, might be looked at in a different light. As the authors noted, farmers in that part of northern Thailand planted only during the wet season in the late 1960s and early 1970s. In such an environment, individual gall midges able to make use of a dry season crop, due to their tolerance of drier conditions, responsiveness to different phenological cues and/or altered dispersal behavior, had no particular selective advantage. Indeed, most likely the contrary. The situation would be radically changed were rice to be grown in the dry season on a regular basis and over an appreciable area. Insects capable of colonizing the dry season would have an enormous edge in fitness, especially initially, before natural enemies had themselves adapted to the new conditions. How long a dry season crop need be cultivated and over how wide an area before natural selection can be expected to produce a population fully able to exploit the new resource depends on such factors as the numbers, likely very low, of "adapted" individuals in thc original population. the rate of mutation of the necessary traits and the rate of immigration from populations where they already exist. These factors would determine the durability of dry season cropping as a means of escaping the gall midge.

There is evidence from several sources that the dry season in fact constitutes a fairly minor evolutionary barrier to the gall midge. Four years after their studies in northern Thailand, Hidaka and a different set of co-workers (Hidaka *et al.,* 1978) reported on a serious infestation of gall midge

in the dry season in the Central Plain. There, farmers had planted the crop over nearly 500 ha and were at the time in their second year of double cropping. The authors attributed the outbreak to the susceptibility of the variety that had been used and, in particular, to the supposedly moister micro-climate resulting from direct seeding and closer plant spacing. Yet serious dry season infestations are now a common occurrence in areas of the Central Plain where double cropping is regularly practiced (Hidaka and Yaklai 1980), as appears to be the case elsewhere in Asia (Soeharjdan *et al.* 1973, Kalode 1974, Bhaskara Rat, 1981, Chand 1981). In the light of these developments there is good reason to question the wisdom of Hidaka *et als'* (1974) earlier recommendation.

The purpose here has certainly not been to latch onto someone's unfortunate turn of phrase, secure in the wisdom of hindsight. This particular case illustrates as clearly as any could a principle to which I will have occasion to refer again: the fundamental processes of population genetics and population dynamics operate at characteristic scales. What one confidently documents at the scale of the experimental plot of 100 m^2 over a season or two is likely a poor guide to what will transpire when the practice is implemented on hundreds or thousands of hectares and over a period of years.

2.3 ADAPTATION TO ALTERED TIMING OF CULTIVATION

In other situations, advancing or delaying the time of cultivation within a season has rendered unreliable physical cues that pests had depended on to end quiescence or diapause. Such changes have in some instances been introduced specifically as a control measure; elsewhere other considerations have been determinant. Whatever the reason, the altered timing has presented pests with an evolutionary challenge that has been met with variable success.

Two relatively well documented cases involving stem borer species may indicate the range of responses. Research conducted in Java prior to independence (van der Goot 1925) showed that the length of the larval diapause of white stem borer *(Scirpophaga innotata)* in rice stubble and the timing of adult emergence was correlated with the date of the first rains of the wet season. The relationship was sufficiently close that safe dates for transplanting, after which minimal infestation might be expected, could be calculated once the first rain had fallen. From 1929 to 1941, planting over an area of several thousand hectares was forbidden by regulation prior to the announced date. The willingness of the colonial administrators to enforce the regulations strictly and the apparent lack of variation in the white stem borer population with respect to diapause-breaking or emergence cues combined to render the control measure remarkably effective over the 12 year period (van der Goot 1948). Similar results have been obtained in northern Australia and Queensland (Halfpapp 1982).

In Japan after the Second World War, the development of cold-tolerant rice varieties allowed farmers to plant earlier in the year. Although early planting had been suggested as a means of avoiding damage due to the striped stem borer, it appears primarily to have been agronomic concerns, particularly the possibility of increased double cropping that motivated most farmers to adopt the new varieties. Kiritani and Iwao (1967) provide evidence that, as the area on which rice was planted early increased, striped stem borer itself emerged earlier. Experimental evidence

confirmed that genetic differentiation was responsible for the phenomenon: insects taken from areas where early rice was widely grown required fewer degree-days in spring to achieve emergence from their over-wintering sites.

Aside from these two cases, there are few well-documented studies of the long-term effectiveness of changed planting dates practiced over a wide area. The literature, however, is replete with studies that have charted the seasonal pattern of pest abundance as determined by infestation in experimental plots planted at different times. From this information, many authors have derived recommendations regarding safe planting dates, either earlier or later than the prevailing practice (This literature is reviewed in Chapter 6 in the context of cultural control). Here, as in the case of adaptation to the dry season, scale-dependence is expected where evolutionary processes are involved.

In many instances, a pest species can continue to exploit a rice crop that has been shifted in planting date only by means of physiological or behavioral adaptations of a genetic nature. If the area planted on the new schedule is small relative to the typical dispersal distance of the insect, the selection pressure on the population will be low. That is to say, individuals ("phenotypes", in genetic terms) able to infest the new planting will not be better represented than other forms in succeeding generations, as their offspring will disperse into areas following a different schedule where they will be at a disadvantage. As the area planted on the new date increases, so does the advantage of those phenotypes in terms of Darwinian fitness. The longer the practice continues, the greater the chances that an adapted phenotype will emerge, through mutatation, recombination or immigration, if it does not already exist within the population.

An important constraint to such adaptation may be the complex nature of the diapause phenomenon in the species where it occurs. It is only phenotypes responsive to different cues or with different responses to the original ones that will be able to exploit a rice crop shifted in time. It appears to have been such a failure to adjust its diapause that prevented the white stem borer from overcoming the delayed planting that was enforced in Java for 12 years. Yet pests of other crops are often known in both diapause and diapause-free forms. Interestingly, the white stern borer in a double cropped area in south Cotobato in the southern Philippines appears to have been able to discard the diapause nature (J.A. Litsinger, personal communication).

The ability to exploit rice appearing at any time of year is characteristic of the major pests of intensive tropical rice cultivation. In much of the tropics, neither temperature nor humidity prove to be absolute constraints on pest activity. Lack of diapause and responsiveness to cues not linked to a particular time of year appear to be the correlates in the insect of photoperiod-insensitivity in the plant. Many authors however appear to assume that a particular seasonal pattern of abundance represents a dependable species characteristic, rather than reflecting adjustment to the local availability of the rice host (Fig. 1). In tropical areas, a recommendation to shift planting backwards or forwards in order to escape pests that do not possess a diapause is likely to be of benefit to the first people adopting it, but much more disappointing to the majority of farmers should they follow suite.

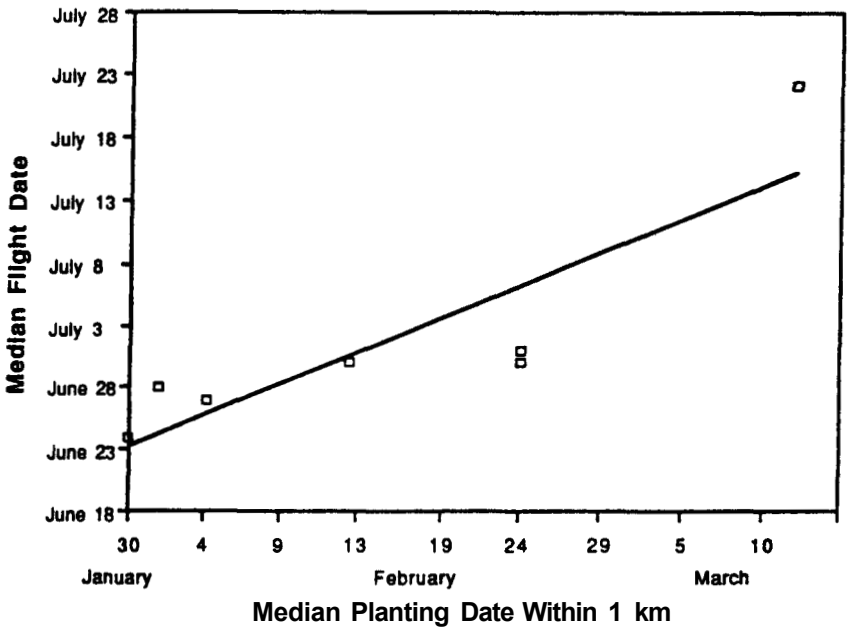


Fig. 1. Yellow stem borer activity in relation to delay in planting. Due to damage to the main canal that limited irrigation flows, planting along Lateral C of District III, Upper Pampanga River Integrated Irrigation System, Philippines, was unusually drawn out during the 1981 dry season. At each of 7 sites along a 13 km stretch of the canal, two kerosene light traps were installed. Median flight dates are the day by which 50% of the seasonal total in those traps had been caught. Median planting dates were similarly calculated for a circle of radius 1 km centered on the traps, making use of records of the National Irrigation Administration. The equation for the regression is : $Y = 159 + 0.520\ X$ ($r = 0.86$, $P < .02$). where X and Y are measured in days from January 1. Loevinsohn (unpubl.).

3. THE ASSEMBLAGE OF PEST FAUNAE: THE INFLUENCE OF THE CROPPING SYSTEM

We have been concerned to this point with the effect of the physical environment on the occurrence of insect pests at one location, particularly as cultivation is extended into the dry season or shifted in time. We consider now spatial patterns of species occurrence in relation to the form of rice culture that is practiced and the distribution of rice in the landscape.

3.1 CULTURAL TYPES

Three principal cultural types may be recognized, distinguished by the degree of flooding (De Datta 1981). In upland cultivation, flooding is no more than transient, in lowland culture standing water is present more or less continuously but does not exceed 1 m, while in deepwater areas flooding regularly exceeds this depth at some point in the crop's growth. As Table 1 indicates, irrigated or rainfed lowland rice is dominant in tropical Asia, while a significant fraction of the rice area in Africa and Latin America is devoted to upland culture.

TABLE 1

Harvested rice area (percentage) in four cultural types by region, 1985. Adapted from IRRI (1989)[a]

Region	Irrigated	Rainfed lowland	upland	Deepwater	Total (× 1000 *ha*)
South Asia	32	40	13	15	60,270
Southeast Asia	38	40	11	12	31,150
East Asia	92	6	2	0	34,890
Africa	22	28	46	3	4,510
Latin America	32	6	62	0	7,180

[a]Areas of mangrove swamp cultivation in Africa are included in the rainfed lowland total.

Environmental conditions are often sufficiently different as to effectively restrict Certain pests to one or another of these cultural types. White grubs (Scarabaeidae), for example, widely distributed pests that attack the roots of rice in upland cultivation, cannot survive in the saturated soils of lowland or deepwater culture. For other species, the differences between cultural types may be reflected in varying rates of population increase and hence in abundance and pest status. This is the case for example with the brown planthopper: a major pest of lowland cultivation, it is of generally minor importance in deepwater rice (Catling *et al.* 1987a). Recent descriptions of cultural types as habitats for insect pests and of the fauna encountered are provided by Litsinger *et al.* (1987) for upland cultivation and by Catling *et al.* (1987b) for deepwater rice.

However, the form of rice culture practiced in an area is only one determinant of the composition of its pest community and of the abundance of individual species. The spatial scale over which rice is cultivated and the proximity of alternative host plants, as well as the seasonal pattern of cultivation within the area will affect the success of different life-history strategies, that is, the characteristic ways in which pest species exploit crucial resources. Certain trends can be recognized in the data available.

3.2 SPECIALIZATION AND THE GEOGRAPHY OF CROPPING SYSTEMS

One of the dimensions along which insect lie-histories can be classified is the degree of specialization in the use of host plants. To the extent that specialization is associated with greater efficiency in the exploitation of the plant resource (Roughgarden 1972) monophagous and oligophagous pests are expected to be relatively more abundant where their host plant is concentrated than polyphagous insects of otherwise similar biology *(ie.* within the same ecological guild). In other agricultural contexts, specialist herbivores are indeed found to be more abundant in fields where monoculture rather than mixed cropping (polyculture) is practiced (Risch *et al.,* 1983, Altieri and Letourneau 1984). Rice being seldom intercropped with other plants (except in certain cases of upland cultivation), our primary concern is with "resource concentration" at a larger scale, beyond the field. Yet similar trends are observed at this level as well. A number of studies have examined the distributions in different environments of stem boring insects that are either monophagous on rice or that can also infest other grasses and crop plants. In Kenya, Ho and Kibuka (1983) found that in upland areas, where rice was often grown in proximity to other cereals, the principal stem borers were *Chilo partellus* and *Sesamia calamistis* which also attack sorghum and maize. In the lowlands

where large tracts of irrigated rice are found, the monophagous *Maliarpha separatella* was dominant. A similar pattern is apparent in Madagascar (pers. observation, M. Loevinsohn).

Surveying the composition of the stem boring guild in the Philippines, Cendaña and Calora (1967) found the polyphagous *Chilo suppressalis* dominant on rice farms in Laguna province, while some 100 km away in Central Luzon, the monophagous *Scirpophaga incertulas* was almost exclusively present. The authors proposed climatic factors in explanation, but though Laguna is somewhat moister and has a less extreme range of temperatures, the difference is far less than either species has successfully accommodated elsewhere in its geographic range. A more significant difference may be the fact that in Laguna, rice cultivation is concentrated in a narrow strip surrounding Laguna de Bay, and upland crops, such as maize (an alternative host of *C. suppressalis)* are planted nearby on higher land. In contrast, over much of the broad Central Luzon plain, rice is the only crop grown.

This hypothesis gains credence when one examines trends in species composition at one location over time. In Laguna, major changes have occurred in farming systems since the late 1960s, changes that are often collectively referred to as the Green Revolution. One element in this process has been an increase in the extent of dry season cropping: in the irrigation systems surrounding the IRRI farm at Los Baños, the proportion of farm area double-cropped rose from 39% in 1969 to 99% two years later (Loevinsohn 1984). Three fluorescent light traps have been in operation at IRRI continuously since 1965 and provide a record of insect abundance in the vicinity. As Table 2 indicates, mean annual catches of both *S. incertulas* and *C. suppressalis* have increased, though the former to a significantly greater extent than the latter (176% vs 65%).

TABLE2

Contrasting effects ofagricultural change on specialist and generalist pests[a]

	Mean annual catch		*Ratio*
Years	*Scirpophaga incertulas*	*Chilo suppresalis*	*Scirpophagal/Chilo*
1965-70	4370	670	6.49
1971-79	12042	1107	10.9

[a] Mean annual catches and their ratio for two stem borer species, one monophagus on rice *(S. incertulas),* the other *(C. suppressalis)* polyphagous, in periods of lesser (1965-70) and greater (1971-79) incidence of double cropping. The change in the ratio of the species is significant ($c^2 = 688$, $P < .001$). Annual totals are for 3 light traps on the farm of the International Rice Research Institute at Los Baños in Laguna Province, Philippines.

A similar trend is observed in N. Krian, Malaysia, where agricultural change appears to have included the same key elements as in Laguna (Loevinsohn 1984, Loevinsohn *et al.,* 1988). In particular, the completion of a major irrigation project made dry season cropping possible for most farmers for the first time. Light traps were used to monitor the occurrence of several pests, including *S. incertulas* and the dark-headed stem borer *Chilo polychrysus,* which, like *C. suppressalis,* attacks cereals other than rice. *S. incertulas* increased in abundance relative to its polyphagous guild mate coincidentally with the spread of double cropping. Explanations for why the *Chilo* species increased in the one case and declined in the other must be sought in the distribution of alternative hosts and in the detailed biology of the two insects. We will return to the light trap records of Laguna

and N. Krian in a later section when we consider more closely the population dynamics of rice specialist pests under agricultural change.

3.3 SPECIALISTS *vs* GENERALISTS: DISTRIBUTION AND IMPORTANCE

Although comparative studies appear to have concerned themselves most often with stem borers, the dominance of specialist life-histories in areas of intensive rice cultivation can be observed for the pest fauna as a whole. This pattern is likely to become increasingly generalized as further investment in irrigation enlarges the area under intensive cultivation. Two related trends are worthy of particular note.

Firstly, the specialist pests appear also to have been the most successful in following rice as its cultivation spread to new areas and thus today are the most widely distributed. This trend is most apparent within Asia, a point to which I return below. Monophagous and oligophagous pests such as brown planthopper, green leafhopper, yellow stem borer, gall midge and caseworm are common across tropical Asia and several of these are common in the semi-tropical and sub-temperate regions, while, with a few notable exceptions, generalists tend to have a more restricted distribution. The similarity of lowland rice culture across the continent and the moderating effect on microclimate of irrigation likely facilitate the spread of specialist pests.

Secondly, specialists appear to be in general the most damaging to the crop. Having coevolved with rice as cultural practices developed, these insects are efficient at locating and tracking their host, overcoming its chemical and physical defenses and surviving the fallow between crops. Large populations, in prolonged contact with their host, would be expected to extract substantial amounts of photosynthate from the plant, and from the yield at harvest. Disease organisms that cause significant mortality to their host in a natural population may, over time, evolve reduced virulence, for their own persistence is dependent on the survival of at least some hosts (Lenski 1988). In agricultural systems similar selective pressures are unlikely to be acting on specialist pests as farmers replant the crop each season.

3.4 FALLOW SURVIVAL STRATEGIES

Specialization is certain to prove a more complex phenomenon than the simple categorization above suggests. While a species as a whole may be found to have a broad host range, individual populations may display considerably greater discrimination (Cates 1981). As well, polyphagy may have a seasonal character: a species effectively restricted to a preferred host at one time of the year is obliged to shift when it is no longer available. A second important dimension therefore along which pest life histories can be assessed is their strategy for surviving the fallow period between rice crops. Four principal types may be identified:

(1) "Promiscuous" pests are those that abandon rice, and often the semi-aquatic paddy environment, after the harvest. These are generally species that show no marked preference for rice or adaptation to efficiently exploiting it and are polyphagous at an individual level. Examples are the armyworm *Spodoptera* spp., the oriental locust *Locusta*

migratoria and, in Africa, the African pink borer *Sesamia calamistis* and the stalk-eyed borer *Diopsis apicalis.*

(2) "Companion" pests on the other hand prefer rice and are adapted to aquatic conditions. Following the harvest they move to aquatic weeds and grasses, on which their rate of increase is found *(e.g.* for the caseworm) (IRRI 1981) to be less than on rice and indeed often negative. Other Asian examples of this strategy are the rice green semilooper *Naranga aenescens* and the green leafhopper *Nephotettix virescens.*

(3) "Stick-it-out" strategists are oligophagous or monophagous and generally remain with the rice plant through the fallow. Some form of quiescence or diapause is usually found. The most striking examples are among the specialized stem borers: yellow stem borer and white stem borer in Asia and *Maliarpha separatella* in Africa.

(4) "Vagabond" species are also rice specialists but escape the fallow by dispersing to areas following different cropping schedules. The best known example is the monophagous brown planthopper.

3.4.1 Pest Strategies and the Availability of Rice

Each of these strategies has different habitat requirements and is affected differently by increases in the extent and timing of rice cultivation (Fig. 2). A promiscuous life history may be the only viable one when rice is introduced to an area and when it is a minor element in a diverse floral landscape. Such habitats, and pest faunae dominated by promiscuous species, can be found in the more isolated rice growing regions, including many parts of Africa. For example, rice was introduced to Rwanda some 25 years ago and is today cultivated in widely separated valleys, nowhere more than 600 ha in extent. The only pest commonly encountered is a *Diopsis* sp., clearly polyphagous for it is already abundant several days after transplanting in valleys where rice has never before been grown (M. Loevinsohn, pers. obs.).

Where rice is cultivated more extensively, and over a longer period of time, a companion strategist that can more efficiently exploit the crop will be able to build up large populations and hence selective pressures will emerge for specialization. As has been observed for other crops and plants, this may involve adaptation by a polyphagous species or the recruitment to rice of a specialist on related grasses or possibly on plants in a different family (Turnipseed and Kogan 1976, Strong *et al.,* 1984). Polyphagous pests that do not adapt to rice and the paddy environment may suffer from the extension of rice culture, particularly if they depend on alternate hosts that are displaced.

With the increased area under cultivation, a stick-it-out strategist may be able to maintain a viable population. A strictly monophagous pest that exploits an annual crop like rice requires a minimum degree of asynchrony in cultivation between fields if it is to persist and such variation in the timing of farm operations is typically found to increase with area (Loevinsohn 1984). To see more clearly the importance of asynchrony, consider an insect such as the yellow stem borer. It passes the fallow period as a quiescent late instar larva in the base of rice stubble (Bannerjee and Pramanik 1967), and must pupate and emerge before its host is destroyed by the plowing, harrowing

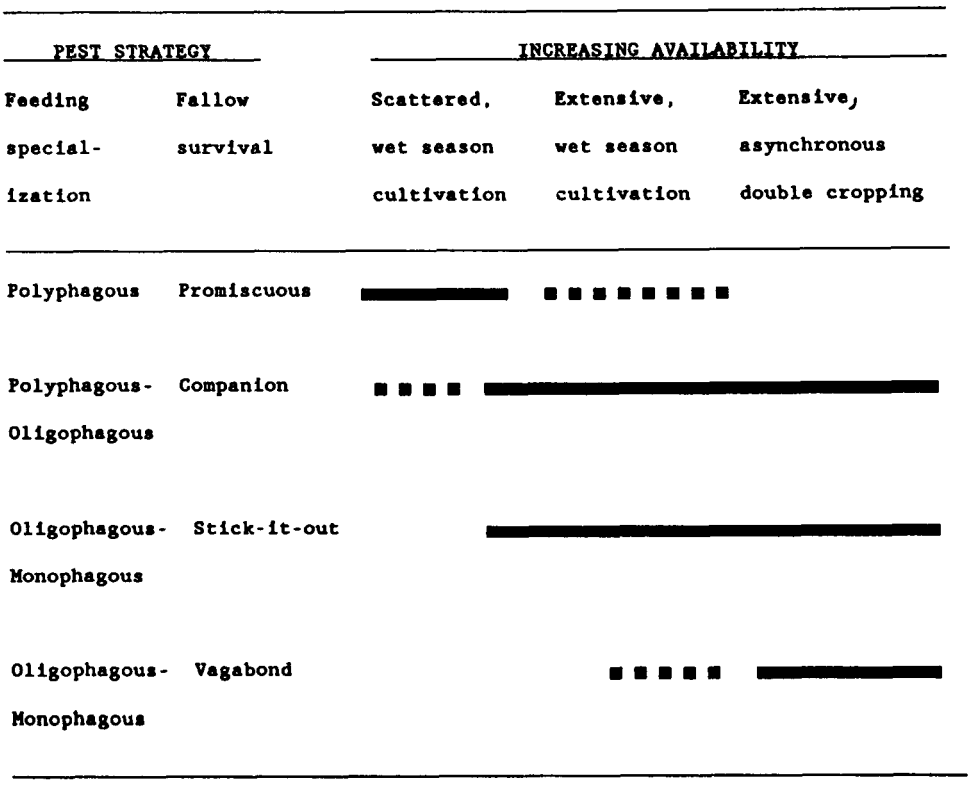


Fig. 2. The relationship between pest life history strategy and the availability of rice. Fallow survival strategies are defined in the text. Solid lines suggest optimum environments for a given strategy, broken lines more marginal conditions.

and puddling of the field. Even if it puts off emergence to the last moment, the adult cannot possibly oviposit in the field in which it developed or others planted at the same time: it lives only a few days, while land preparation may take several weeks and the new crop cannot support an infestation until perhaps 20 days after transplanting. Successful oviposition thus depends on the adult locating a field sufficiently delayed or advanced in the cultivation sequence within its flight range.

The requirement for asynchrony is even greater in the case of a vagabond strategist such as the brown planthopper: without diapause or quiescence, it depends on a succession of rice plants at a stage suitable for infestation. Where a single wet season crop is grown each year, dispersal on the scale of 10s or 100s of kilometers may be needed to find its hosts. Numbers reaching a point are typically found to decline exponentially with distance and thus the proportion surviving to infest another crop may be very low. In a northern semi-temperate area such as Japan, where "environmental resistance" (including in particular natural enemy action) is relatively weak, the low density of brown planthopper immigrants that appears responsible for reestablishing the population each

year is able to multiply to economically significant levels (Kuno and Hokyo, 1970). In tropical areas, the more effective and consistently density-dependent response of natural enemies to the brown planthopper appears sufficient to contain population increase where only one crop a year is grown. Twenty five years ago, the brown planthopper was considered of no more than occasional importance — at a 1964 symposium on the "Major Insect Pests of the Rice Plant" (IRRI 1967) it was paid only cursory attention — and today its abundance in areas of single cropping appears often to be related to the distance from more intensive cultivation (Perfect and Cook 1987).

The most recent stage of habitat evolution in Asia has been that associated with the Green Revolution. Although, as will be discussed below in greater detail, the process has been complex, common features have been the marked expansion in double cropping and increased asynchrony in the timing of cultivation that has often followed in its wake. In intensive rice cultivation, promiscuous pests find it difficult to locate non-aquatic host plants and appear seldom to be of economic importance. Companion and stick-it-out strategists, on the other hand, are favored by the reduced fallow and the shorter time they must remain on less preferred alternative hosts or in quiescence or diapause. We have already seen evidence of a shift in the relative importance of promiscuous and stick-it-out pests in the case of stem borers. But it is vagabond species that appear to have been the most favored by the increased availability of rice. The rise of the brown planthopper and other Homoptera to the status of major pests is among the most important and widespread environmental impact of the Green Revolution.

3.4.2 Agricultural Development and Species Establishment

It is certainly a crude simplification to reduce the diversity of pest life histories to only four types. Similarly, the evolution of rice agroecosystems has not everywhere followed the same path toward greater host availability. Changes in the various components of host availability (areal extent and time within and between seasons) are likely to have quite different effects on pest populations and communities (see further below). Yet even in its present form, we believe the approach is of value in emphasizing that the dominant species in a pest community are far from a random selection of those present in the regional pool. Species have particular requirements, dictated by their life histories, for rice; whether these can be met depends on the pest being able to locate suitable stages of its host within a distance it can disperse. This perspective implies that it is a combination of the area over which rice is cultivated, the number of crops grown per year (cropping intensity), the asynchrony with which they are established and the isolation from other rice growing regions that determine the success of a given species and of the life history strategy it embodies.

We explore below some ways in which these habitat parameters may be combined in quantitative form and employed to explain variation in the abundance of pests. Qualitatively however, the framework permits some broad predictions about the evolution of the pest fauna as rice cultivation develops. Returning to the example of Rwanda, we find that the production of rice rose almost 5-fold between 1970 and 1985, faster than any other food crop (Government of Rwanda 1987). The area cultivated, in many valleys now irrigated, is expanding rapidly and double cropping is becoming the norm. On the basis of what has been said above, one might expect that companion and

stick-it-out strategists could now maintain viable populations in some areas. Similarly, cultivation in certain coastal areas of Madagascar is now sufficiently extensive and asynchronous that a vagabond pest might be able to establish itself.

It is impossible to predict, in either case, whether the pest will be a long distance migrant or whether it will emerge from the indigenous fauna as a result of an expansion or shift in host range. The probability of invasion might be thought higher in the case of Rwanda: *Maliarpha separatella,* the stick-it-out stem borer, is found in neighboring Uganda and Tanzania, whereas Madagascar is isolated by several thousand kilometers from Asian sources of vagabonds. However, factors other than distance affect the likelihood of such long-range dispersal, notably wind direction and speed. Human agency, "assisted transport" by plane or surface means, has also played a role in past invasions and may have been responsible for the introduction of the rice water weevil *Lissorhoptrus oryzophilus* Kuschel, of American origin, to Japan. But such a chance event, represented perhaps by the arrival of a single gravid female, is a necessary but not sufficient condition for successful establishment: cultivation must have evolved to a stage where rice is sufficiently available to support the pest's life history.

4. Pest Population Dynamics and the Cultural Environment

4.1 THE IMPACT OF AGRICULTURAL CHANGE

The shifts we have been considering in the composition of the pest fauna as agriculture evolves can be followed as well in the rising and falling fortunes of populations of particular species. It is in periods of rapid agricultural change that one might expect the effects of the cultural environment on pest populations to be most clearly highlighted. In practice, however, such change is rarely a simple process: many aspects of the environment typically vary together and their separate effects may be difficult to unravel.

The Green Revolution that transformed rice cultivation across much of tropical Asia in the 1960s and 1970s is a case in point. The revolution entailed widespread adoption of modern varieties, greater use of chemical inputs and expansion of irrigation that brought in its wake increased cropping intensity and asynchrony of planting. Each of these elements has been at some point implicated in the marked increases in the abundance of specialist pests that typically followed. The division of opinions and resulting confusion is nowhere better illustrated than in the proceedings of the 1977 symposium that sought an explanation for the widespread outbreaks of the brown planthopper (IRRI 1979). The focus of research on individual factors has made it difficult to put their relative contribution into perspective or to support a comprehensive understanding of rice pest dynamics to guide management.

A recent attempt to come to grips with this challenge (Loevinsohn and Litsinger, in press) draws on series of light trap catches spanning the period of agricultural change. At the IRRI farm in Laguna, Philippines, annual totals for three of the principal pest species increased markedly

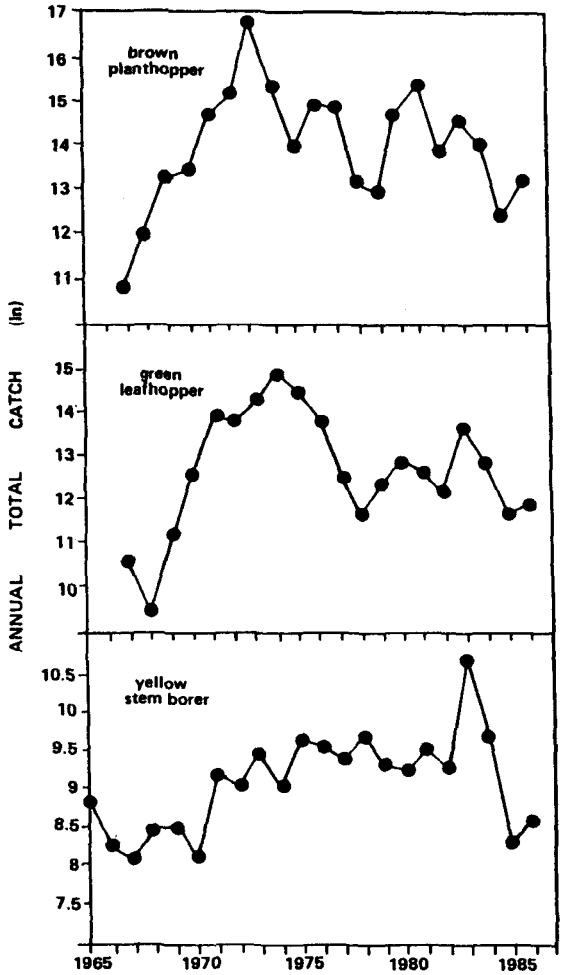


Fig. 3. Population of three rice specialist pests over a period of agricultural change. Annual total catches are for three fluorescent light traps on the IRRI farm at Los Banos, Laguna, Philippines.

beginning in the late 1960s (Fig. 3). Similar changes at about the same time occurred for yellow stem borer and the green leafhopper in North Krian, Malaysia.

In all 5 cases, the rise and fall of catches between months reflect the local pattern of cultivation, making it possible to identify seasonal minima, n_y, maxima, N_y, and totals and to examine the forces regulating pest populations. Two statistics may also be defined the within-season rate of change,

$$Rw_y = \ln N_y - \ln n_y \quad (1)$$

and the (negative) between-season rate of change,

$$RB_{xy} = \ln n_x - \ln N_y \quad (2)$$

where season x precedes y. The changes that have occurred in the agricultural environment can be divided into those that affect R_W, such as increased use of agrochemicals, and those that affect R_B, notably increased dry season cultivation with irrigation. Asynchrony of cultivation between fields, often exacerbated by irrigation, acts on both rates, extending the time available to mobile insects for increase and reducing the length of the fallow they need endure.

4.1.1 Population Change Within and Between Seasons

One means of assessing the relative importance of factors acting within and between season is to plot log maximum numbers during a season against log minimum numbers at the beginning of that season. As is illustrated for the brown planthopper in Figure 4, significant positive correlations were obtained in 4 of the 5 cases in the wet season, with the coefficient of determination (the proportion of variation in maximum numbers accounted for by variation in minimum numbers) in the range of 47% to 78%. The residual variation reflects the contribution of changes in factors acting within the season, in addition to measurement error and imprecise model formulation. In certain cases, it is possible to implicate particular developments in these deviations: for example, the first and third largest positive residuals from the regression for brown planthopper occurred in 1973 and 1976 when varieties incorporating the *Bph* 1 and *bph* 2 genes respectively succumbed to evolved virulence

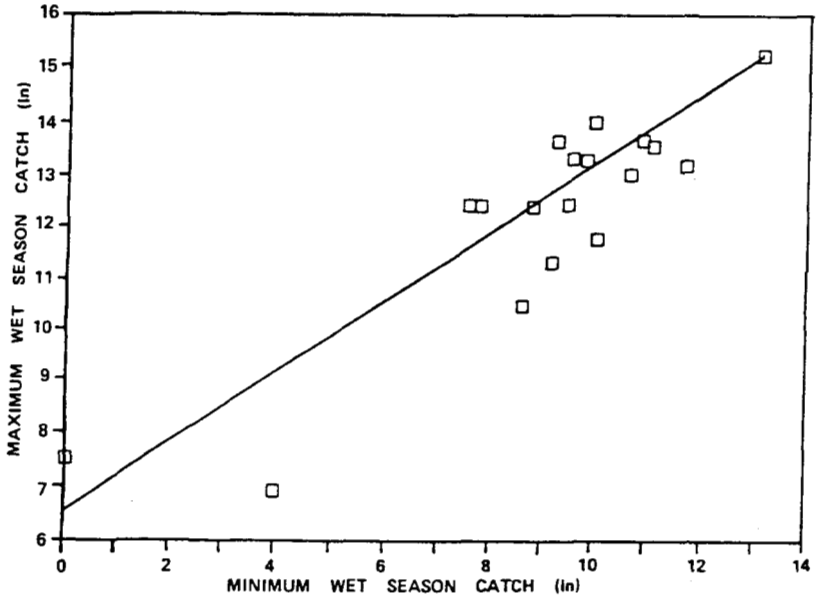


Fig. 4. Dependence of pest population on initial numbers. Maximum 4-weekly catches of brown planthopper during the wet season in relation to minimum catches at the beginning of the season; IRRI farm Laguna. 1967-1986. The best fitting equation using Bartlett's technique (Sokal and Rohlf 1981), which provides unbiased estimates of regression parameters when both variables are measured with error is: $\ln Y = 6.90 + 0.594 \ln X$ ($P < .01$).

in the insect (Loevinsohn *et al.,* 1988). Continuous records of within-season factors that would make it possible to put such an analysis on a firmer footing are unfortunately not available. Nevertheless, the results suggest that factors acting within a season are no more and are often less important in determining maximum numbers that season than are those that affect initial levels.

What then determines these initial levels? Two variables prove to be significant: maximum numbers during the preceding season (4 of 5 cases) and the number of months between the seasons (again, 4 of 5 cases). In multiple regressions, the two variables together account for from 4.6% to 95% of the variation in log minimum numbers in the wet season.

The size of the preceding season's population is determined both by within-season factors and, when it is a dry season, by the proportion of the farm area on which double cropping is practiced. However, only the between-season factors are implicated in the inverse correlation between the wet season minimum and time between seasons. The data are inadequate to calculate an index of asynchrony, but the effect of cropping intensity can be clearly seen. In N. Krian, there were, on an average, 6.0 months between seasons for yellow stem borer in the years when double-cropping was practiced on less than 10% of farms in the surrounding irrigation system, compared to 2.9 months thereafter ($t = 2.53$, $P < 0.05$). The overall impact of cropping intensity on the numbers surviving

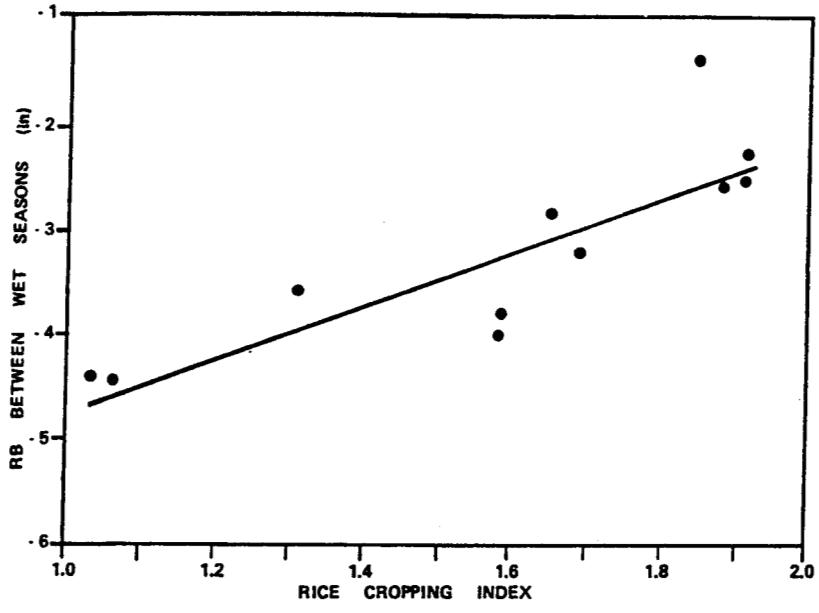


Fig. 5. Effect of cropping intensity on population dynamics between seasons: yellow stem borer in N. Krian, Malaysia, 1965-75. The rate of population change between successive wet seasons was calculated as the difference between the in minimum 4-weekly catch in the light traps at the beginning of one wet season and the In maximum catch the wet season previous. The rice cropping index, the mean number of crops per year on land devoted to rice cultivation, is calculated for the adjacent Krian/Sungeri Manik irrigation scheme. From data in Lim and Heong (1977). The least squares regression is: $Y = -7.25 + 2.53\ X$; $t = 4.71$, $P < .005$.

to infest a crop is illustrated in Figure 5: R_{Bww} , the rate of change between successive wet seasons, increased with the spread of dry season cropping. Significant relationships of this type are found in 3 of the 5 cases.

4.1.2 Population Regulation and Cropping Intensity

A double logarithmic regression as in Figure 4 provides important information about the extent of density-dependence in the population's rate of change. A slope that, as in this case, lies between 0 and 1, implies that the within-season rate of change is imperfectly density-dependent, that is, it declines as the seasonal minimum rises, but to an extent insufficient to compensate for the variation in these initial levels. The same is found to be true for the 3 other populations for which significant regressions were obtained. The pervasive and effective control exerted on rice pests in the tropics by their natural enemies, described in Chapter 7, is likely responsible in large measure for this density-dependence.

In contrast, the rate of change between seasons is found in each case to be independent of density, that is, minimum numbers at the beginning of a wet season are a more or less constant proportion of the preceding maximum when the time between the seasons is held constant. This finding should not be surprising, as survival through the fallow of a stick-it-out pest like yellow stem borer or a vagabond like brown planthopper appear in large measure to be a function of physical factors (desiccation and flooding in the first case, distance and meteorological conditions in the second) that do not respond to density.

This pattern of imperfect density-dependence within seasons and density-independence between is found once again when one examines the determinants of pest abundance in the dry season. These findings can be combined in a model of population dynamics over the whole year, one prediction of which is that increases in the area planted to rice in the dry season will lead to larger populations not just in that season but in the wet season as well. This was indeed found to be the case when pest abundance was measured in areas of the Philippines differing in cropping intensity (Fig. 6). Crop losses appear to parallel pest numbers: the proportion of the wet season harvest lost to insects averaged 13% in the sites where a single rice crop was planted each year, compared to 33% where double cropping was practiced (Loevinsohn *et al.,* 1988).

The above results suggest an underlying similarity in the annual dynamics of rice specialist pests and point to limitation of cropping intensity as a fundamental element in their management. Further reduction in the length of the fallow as a consequence of triple cropping would be expected to result in yet higher seasonal populations and reports do indicate that infestations are more damaging in such situations than under double cropping (Li 1982). Similarly, retrenching from two crops per year to one would be expected to result in lower densities of specialist pests and introducing an upland crop before or after rice would augment the effect by breaking the life cycles of species like yellow stem borer.

In general, all other conditions being equal, a given rice hectarage should result in the lowest abundance of specialist pests when production is spread over the widest area possible: from the perspective of crop production, the goal should be to "extensify" rather than intensify cultivation.

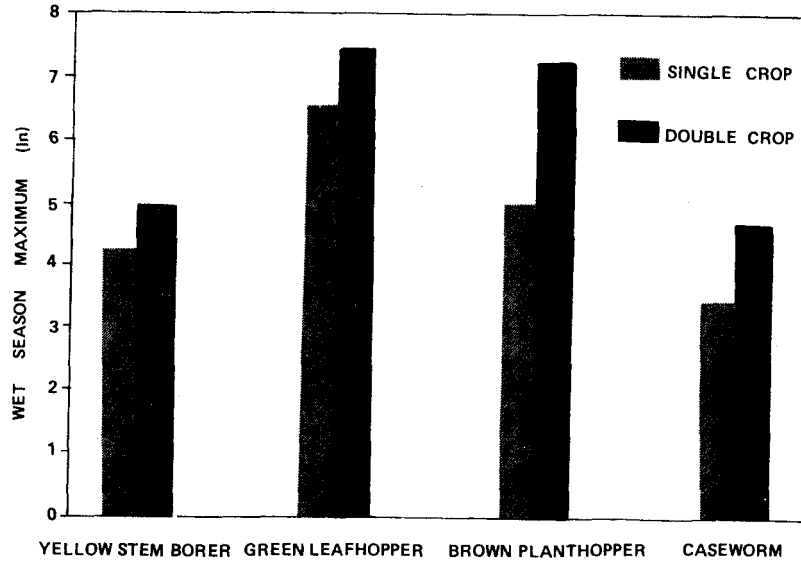


Fig. 6. The response of specialist pest populations to cropping intensity. Mean wet season maxima in kerosene light traps installed at sites of IRRI's Cropping Systems Program in the Philippines. A single rice crop per year was grown in Cagayan and Pangasinan provinces under rainfed wetland conditions (n = 5 sites, 1979-80); two crops were grown under irrigated conditions in Nueva Ecija province (n = 6, 1981). The means differ significantly ($P \leq .05$), save in the case of the green leafhopper.

In the major Asian rice-growing areas, the scope for drawing on these insights is constrained by a host of social, economic and agronomic factors and the overall effects of any such change must be carefully considered. The prospects may be brighter in upland or rainfed areas with a history of diversified production and in those parts of Africa and Latin America where rice is expanding but is not yet a dominant crop.

4.2 ASYNCHRONY AND ABUNDANCE

But what of the effect of asynchrony of cultivation on rice pest populations? For modern varieties whose flowering is largely insensitive to photoperiod and, in the lowland tropics, to temperature, variation in the time of planting results in equivalent variation in maturity. As noted earlier, the consequent asynchrony of plant host availability both extends the period of increase for pests able to disperse between fields and shortens the fallow they must endure. The evidence available (Loevinsohn 1984; Loevinsohn and Litsinger, in press) bears on the former within-season effect.

Considering the dispersive (adult) phase of a species, increased populations in one season are expected where the range of planting dates exceeds a generation length and where this variation is

encountered over a distance that adults can readily move. Beyond the threshold, the population response to asynchrony will be related to the species' intrinsic powers of increase and to the extent of density-dependent constraints.

These hypotheses were tested in a 20,000 ha irrigated area in Nueva Ecija province, Philippines, of almost uniform double cropping, planted to modern varieties of similar growth duration. Significant relationships between seasonal abundance in light traps and asynchrony, as measured by the standard deviation of planting dates within a given radius of the traps, were obtained for 8 of the 9 species considered. This is illustrated for brown planthopper (Fig. 7), whose numbers varied 28-fold among the sites, none of which were separated by more than 13 km. Results for the other species are presented in Table 3. Density-dependence in the response to asynchrony is apparent for 5 of the 8 species, and the effect of variation in the time to maturity of varieties in the vicinity in a further 2 cases. The one pest whose numbers appeared unrelated to asynchrony, in either of the two seasons considered, was *Cnaphalacrocis medinalis* (Guenée), a pyralid leaffolder.

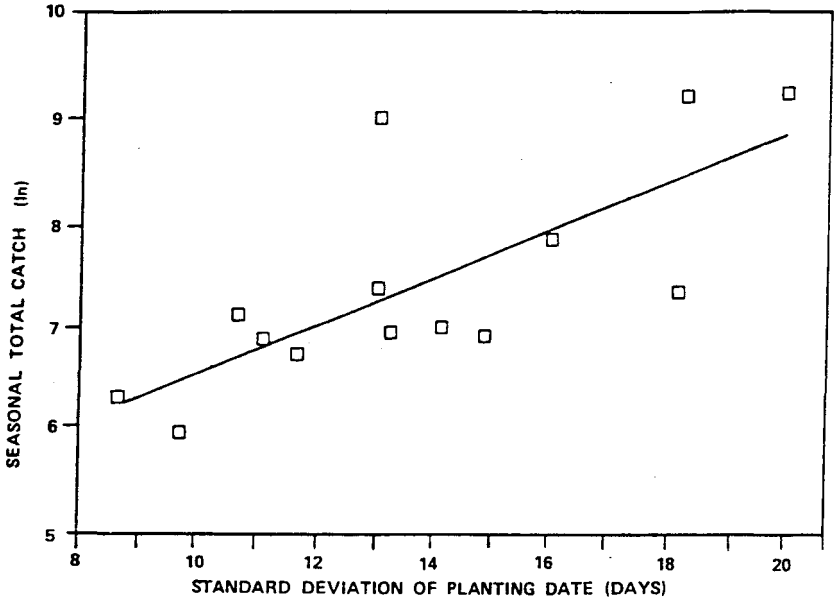


Fig. 7. Seasonal abundance of the brown planthopper in relation to the asynchrony of planting within 2 km. Nueva Ecija. Philippines; wet season 1981. At each site, 2 simple kerosene light traps were established in rice fields and lit nightly by farmer cooperators. Standard deviations of planting date around each of the sites were calculated within radii of 0.2 - 2.0 km, using maps and data furnished by the irrigation administration. For the brown planthopper, the correlation between In abundance and asynchrony was maximized when the latter was calculated within 2 km. In Y = 4.31 + .223 X (t = 3.13, n = 14 sites, P < .01).

TABLE 3

The response of rice pests to asynchrony and the ecological characteristics conditioning that response over 14 sites, wet season, 1981

Species	*Best fit ting model*[a]	*Response to arynchrony*[b] *(rate/day)*	*Maxiumum increase*[c] *(rate/mo.)*	*Best fitting radius*[d] *(km)*	*Median dispersal distance*[e]
N. nigropictus (green leafhopper)	2	1.17*	2.37	1.4	na
N. virescens (green leafhopper)	3	0.79*	2.10	0.6	na
N. malayanus (green leafhopper)	1	0.32***	1.86	2.0	na
N. depunctalis (caseworm)	2	0.87**	1.92	0.4	na
N. aenescens (green semilooper)	3	0.64*	2.22	0.4	0.3
P. fluctuosalis	2	0.51*	1.78	0.4	0.6
N. lugens (brown planthopper)	1	0.22**	1.46	2.0	2.5
S. incertuas (yellow stem borer)	1	0.08*	1.13	0.4	0.6

[a] Determined by maximum R (correlated for df) in regressions of In season total on different independent variables: 1 - standard deviation of planting date (SD); 2 - SD and SD; 3 - SQ, SD and mean maturity of varieties planted.
[b] Coefficient of SD in best fitting model. * P < .05; ** P < .01; *** P <. 001 by one-tailed test.
[c] Exponential rate calculated from mean greatest proportional change between consecutive monthly light trap totals.
[d] Radius within which SD calculated in best fitting model.
[e] Calculated from catches over several weeks in paired light traps placed upwind of isolated sources of naturally dispersing insects: a 2 ha field planted out of season (species 5, 6,8; n = 16 traps) and an extensive area of wild and volunteer rice cultivated for the first time in several years (species 7; n = 32 traps). These experiments took place during a fallow period (January-February 1982) when there were no other significant areas of rice in the vicinity. Median dispersal distances were computed from the integration and rotation of the best-fitting equations through 360 degrees, assuming, in other words, that movement was similar in all directions. na - not assessed.

The details of the relationship between asynchrony and abundance agree with expectation in three regards:

(1) The species' rate of response to asynchrony were significantly related to a measure of their maximum realized rates of increase ($r = 0.87$, $P < .01$). Both parameters were lowest in the case of yellow stem borer, whose generation length, 40-50 days, is substantially greater than those of the other pests.

(2) The radius within which asynchrony is calculated that provides the best fit to seasonal abundance differs among the species and appears to reflect relative validity. This radius was consistent between seasons ($r = 0.94$, $n = 5$, $P < .02$) and was significantly correlated ($r = 0.98$, $P < .02$) with the median dispersal distance of four species, estimated independently.

(3) There was evidence of the expected threshold in population response to asynchrony. In a dry season in which planting date variation was unusually low and at some sites insufficient for any of the species to complete an additional generation, the relationship between asynchrony and seasonal abundance was initially flat and then curved upward for 4 of the 5 species considered. These results suggest that an ecologically significant degree of synchronization is attainable in some areas under existing conditions without special effort.

The results of this and the previous section demonstrate that changes in the duration of rice cropping, reflected in reduced time between and increased time within seasons, affect rice specialist pests in a broadly similar fashion. This suggests that efforts aimed at restricting the availability of rice will have multiple benefits, a decided advantage in comparison with many control measures, cultural, biological, or genetic, that are species-specific in their effect.

Dispersal range, generation length and rate of increase provide the spatial and temporal criteria with which to predict the impact on pest populations of variation in the time of planting. In intensive rice growing areas, problems in delivering water to or draining it from fields appear often to be key in determining the magnitude and distribution of asynchrony. In Nueva Ecija, it was found that most farmers in the normal course of affairs attempt to compensate for delays imposed by the centrally-managed irrigation system by hastening farming operations under their own control, such as land preparation and transplanting (Loevinsohn 1984). There, as elsewhere, farmers' efforts to limit asynchrony can be supported by appropriate irrigation scheduling and correction of system faults. The above results provide a basis for setting realistic targets: there is no justification in terms of pest suppression for attempting to complete planting within much less than a pest's generation length over an area much larger than its dispersal range. Imposition of such standards could harm both farmers and agricultural laborers by, for example, driving up tractor hire rates and encouraging the shift from transplanting to direct seeding.

While there have been scattered attempts at synchronizing cultivation, the contrary, purposeful staggering of planting within a farmer's holding, has also been promoted. The advantages are that seasonal peaks in input demand and slumps in harvest price are avoided, while the risks of catastrophic loss are minimized, for example, due to typhoons. One such approach, known as the "rice garden" (Morooka *et al.,* 1979), involves the division of a farm into plots, one of which typically is planted and another harvested each week. In this way, up to four harvests a year are obtained and asynchrony is maximized. Adoption of the rice garden has been limited as few farmers have access to or can afford the continuous irrigation that it demands. Concern has also been raised about the potential for pest build-up, to which the above results lend considerable support.

Pantua (1979) however, found no consistent difference in infestations between a 2 ha rice garden and an adjacent double cropped field. While a number of points can be made about the manner in which the comparison was made, the most important one to consider is the question of scale. The dispersal estimates reported above indicate that the majority of insects landing in a 2 ha

field would have originated from outside it and thus density would be affected by factors of host plant abundance over a much wider area. The experience of an isolated, early- adopting farmer would be very different from one who takes up the practice well after his neighbors. (Recall that similar advantages accrue to early adopters of altered planting dates and double cropping.) Where the rice garden has been implemented over a wider area, as on some corporate farms on the island of Mindanao, Philippines, serious losses have been reported due to brown planthopper, and green leafhopper and the viruses they vector.

4.3 ADAPTING TO THE AVAILABILITY OF RICE

The characteristics that determine species' responses to factors of rice availability such as asynchrony and cropping intensity, generation length, fertility, survival and dispersal range, are not constants but vary among individuals. Efforts to manage the environment so as to limit the population that can develop, whether by synchronizing cultivation or by restricting the intensity of cropping, can be expected to create counteracting selection pressures favoring individuals less affected by these measures. As variation in the above characteristics is likely to have at least some heritable component, evolution would with time give rise to populations with at least partial resistance to such cultural controls.

Evidence for processes of this sort can be found in populations inhabiting neighboring areas differing naturally in synchrony or cropping intensity (Loevinsohn 1984). In Mapalad, Nueva Ecija, Philippines, at the base of the Sierra Madre Mountains, a single crop of rainfed rice is grown in a relatively synchronous fashion. The area lies about 10 km from the irrigated Central Luzon Plain where double cropping predominates (it was here that the study on pest abundance in relation to asynchrony was conducted). In the vicinity of Zaragoza, in the center of the plain, planting is highly asynchronous due to irrigation and drainage faults.

Egg masses were collected from yellow stem borer moths at both locations and the newly hatched larvae reared on caged plants at Zaragoza under conditions of constant density. The duration of the larval and pupal stages, survival over this period and maximum fecundity of these offspring are presented in Figure 8 and Table 4. Significant differences in all three parameters are found insects from Mapalad emerged sooner, were more fecund but had poorer survival than those from Zaragoza. Calculations suggest that under conditions of relative synchrony, where the length of a season is most reduced, a papulation with the Mapalad characteristics would have the greater rate of increase and attain a larger size by harvest. The Zaragoza parameters, on the other hand, would prove advantageous where the season is more drawn out and where the pressure exerted by natural enemies is high. Predators, parasites and pathogens are expected to be more abundant in asynchronous, double cropped environments, like Zaragoza, where, as we have already seen, their insect hosts are more readily available. The differentiation that is observed between the two sites in bionomic parameters of the yellow stem borer thus appears to be in the direction that natural selection would be expected to work.

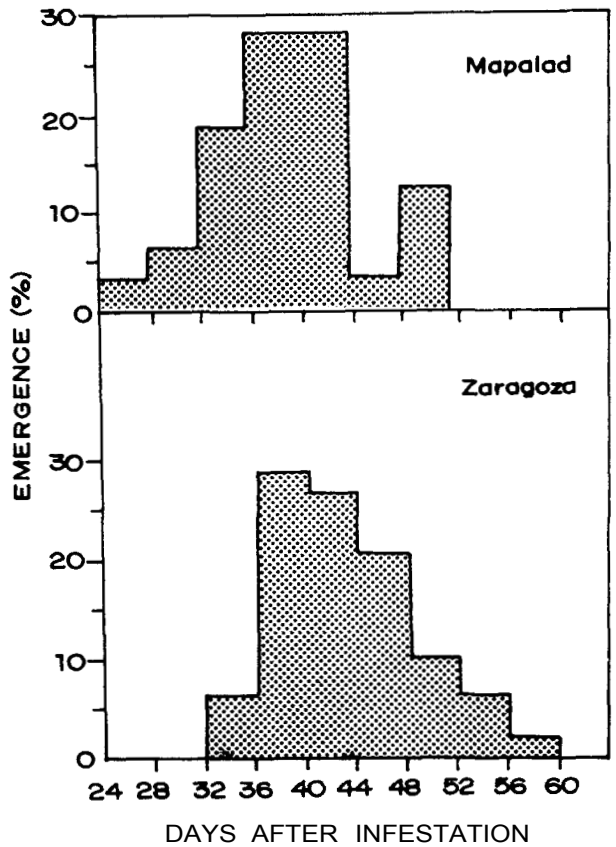


Fig. 8. Differentiation of generation length at sites of contrasting availability of rice. Time to adult emergence of newly hatched yellow stem borer on caged rice plants. A synchronously planted single rice crop is grown at Mapalad (n = 32); Zaragoza (n = 49) is an area of asynchronous double cropping. See also Table 4.

TABLE 4

Adaptation of yellow stem borer to the availability of rice[a]

Site	*Time to emergence (days)*	*Total oocytes in ovary (number)*	*Survival rate* (%)
Single crop, synchronous (Mapalad)	38.5[a]	269[a]	11.3[a]
Double crop, asynchronous (Zaragoza)	42.5[b]	234[b]	18.6[b]

[a] Life history parameters were determined by infesting newly hatched larvae on caged rice plants (IR36) at the beginning of the 1981 wet season. Means in a column followed by different letter differ at $P < .05$.

Our confidence in this interpretation is increased by the results of a second experiment, similar to the first, but that involved stem borers collected from three sites. Here, insects originating from

Mapalad and Zaragoza were compared to those from Ibabaw bana, lying within the area of double cropping but benefiting from relatively problem-free irrigation and experiencing asynchrony comparable to Mapalad's. Conditions of rice availability there are thus intermediate between those of the original sites. As Table 5 indicates, parameters of the Ibabaw bana population are also intermediate. The shorter mean times to emergence of both Mapalad and Ibabaw bana are an effective adaptation to a short rice season (determined by asynchrony). Survival rates are similar at the two sites that are double cropped, though if these do in fact reflect adaptations to natural enemy pressure, a somewhat lower value might have been expected at Ibabaw bana where asynchrony is less than at Zaragoza. Unfortunately, due to equipment failure, it was not possible to measure fecundity in this experiment and to ascertain whether Ibabaw bana's relatively short generation length and high survival are purchased at the expense of reduced egg production.

TABLE 5

Adaptation of yellow stem borer to the availability of rice[a]

Site	*Time to emergence* (*days*)	*Survival rate* (%)
Single crop, synchronous (Mapalad)	44.4[a]	11.8[a]
Double crop, synchronous (Ibabaw bana)	45.1[a]	17.6[b]
Double crop, asynchronous (Zaragoza)	49.1[b]	17.2[b]

[a] The experiment was similar to that reported in Table 4 but employed the variety IR42 and was carried out toward the end of the 1982 wet season. Means in a column followed by different letter differ at $P < .05$.

The conditions of cropping intensity and asynchrony that distinguish the three sites date from the introduction of widespread irrigation in the mid-1970's. Thus, within a period of 6 years (at the time of the study), significant genetic differentiation had already taken place in those parameters and in those directions which would tend to counteract the change. Yet this evolution has not been sufficient to eliminate the differences in abundance due to rice availability: catches of yellow stem borer in light traps were 3.2 times greater at Zaragoza than at Ibabaw bana in the 1981 wet season. Whether further evolutionary change is possible that would reduce this difference or whether a "design limit" has been reached can only be determined by follow-up studies in these same areas. Answers to such questions are key to an assessment of the long term durability of cultural control measures based on restricting the availability of rice to its pests.

5. CONCLUSIONS

In considering the environments that rice pests inhabit, we have focused on a limited number of characteristics, in essence, those that determine the spatio-temporal availability of the rice host. The variability of these factors over space and their change over time is mirrored in a hierarchy of responses at the level of pest populations, in their dynamics and genetics, and in the rising and declining dominance of species. The processes at work operate at characteristic scales, often greater than those considered in most entomological experiments. Taking the measure of effects

acting over kilometers and over seasons will in many cases require rethinking and refining accepted methods. It is vital that we accustom ourselves to thinking in terms of such processes, including pest evolution, that too often appear to take us by surprise. For the most part, variation and change in agricultural systems has tended to act on pests and diseases; return flows, in the form of design and management options based on an understanding of the effects, have been very weak. It is in developing these options and elaborating a preventive pest management, that we encounter one of our greatest challenges.

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III. CONTROL TACTICS AND STRATEGIES

5

Host Plant Resistance

E. A. HEINRICHS
Department of Entomology
Louisiana State University Agricultural Center
Baton Rouge, Louisiana

1. INTRODUCTION

RICE IS THE WORLD'S MOST important food crop as based on cultivated area. Rice serves as a major source of calories for 40% of the world's population (De Datta 1981). Most of the rice is produced in tropical Asia where the human population is high and where *per capita* income and rice yields are low. Among the numerous abiotic and biotic stresses that affect rice yields, insect pests and the plant pathogens that they vector, are major factors. Estimates in Asia by Cramer (1967) and Pathak and Dhaliwal (1981) indicate that insects are responsible for more than 30% yield losses. A 10% increase or decrease in food grain production on a global scale can make the difference between a glut and acute scarcity (Swaminathan 1983). Because of the high yield losses national rice research programs throughout the world are in various phases of developing and implementing management strategies to minimize the losses caused by insects. Management strategies consist of various mixes of chemical control with insecticides, cultural controls, biological agents (parasites, predators and diseases) and planting of cultivars that have genetic resistance to insects. Resistant cultivars are sought as the major tactic in an integrated approach to rice insect control. The incorporation of insect resistance into modern cultivars is a major objective of most rice breeding programs in Asia (Hargrove and Cabanilla 1985) (Fig. 1) for several reasons (Heinrichs *et al.,* 1985a):

- Income per hectare in rice production is relatively low and money spent for controls such as insecticide significantly lowers profits. Resistance in rice cultivars is essentially free to the farmer.
- Insecticide prices are increasing faster than the rice price in most countries.

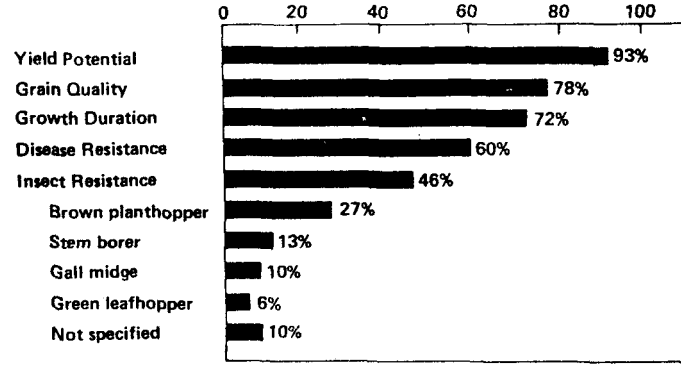


Fig. 1. Rice breeding objectives in ten Asian countries in 1984 (modified from Hargrove and Cabanilla 1985).

- Land holdings of most rice farmers are small. Maintaining insecticide application equipment is not economical on many small farms.
- Prophylactic or calendar based applications of insecticides are often wasted because farmers do not know how to apply insecticides according to economic thresholds.
- Insecticides cause accidental poisoning incidents.
- Insecticides may pollute the environment killing fish, and livestock.
- Varietal resistance is generally compatible with other control tactics: chemical control, cultural control, and biological control.

Because of its unique advantages host plant resistance is often utilized as a key tactic in the integrated control of rice insect pests. Insect resistant rice cultivars are of special value under the conditions existing in most developing countries and as such have become a component of rice breeding programs. Teams of entomologists working with plant breeders and other problem area scientists throughout the rice growing regions of the world have been, for the most part, successful in developing rice production systems with an increased level of resistance/tolerance to abiotic and biotic stresses. This is of extreme necessity as stresses are severe constraints to scientists' attempts to increase the profitability of agricultural production (Heinrichs 1988a). The progress achieved in the identification of insect resistant rice germplasm and its use in the breeding of high yielding cultivars with resistance to multiple stresses has been an integral part of the success of the green revolution and has increased the profitability of rice production and minimized safety risks to farmers, and contributed to a more healthful environment.

In the last three decades there has been a dramatic shift away from the planting of traditional rice cultivars and the use of traditional cultural methods for insect control to the growing of modern, high-yielding rice cultivars with an emphasis on insecticides and plant resistance. As a result, yields

have in many cases increased but yield stability, with the unilateral use of insecticides, or resistant cultivars, has not been achieved (Heinrichs and Mochida 1984, Heinrichs 1988b). Because of the short life of control programs based on one control tactic, there has been a significant interest among rice scientists in the development and implementation of programs that integrate a multiple tactic approach to rice insect control (see Chapters 10, 11, 12 and 13).

2. Role of Host Plant Resistance in Rice IPM

Professor Chiu Shin-Foon of the South China College of Agriculture in a meeting of rice scientists in Guangzhou in 1980 reported that "the breeding of resistant varieties has been the missing link' in the integrated pest control in China for some time but resistance breeding has recently been initiated" (Chiu Shin-Foon 1980). The development of insect resistant cultivars has proceeded at a rapid pace in China and throughout the world and the planting of insect resistant cultivars is being integrated with well established cultural, chemical and biological control methods.

Resistant cultivars alter the physiology and behavior of rice insects which in turn affects the insects' susceptibility to chemical and biological controls. The adverse effect on the physiology of the insect is evident in the work of Padgham (1983) where he reported a decrease in the survival and migration potential of brown planthoppers *Nilaparvata lugens* (Stål) on resistant cultivar IR36 as compared to those on susceptible IR20. Because of the decreased level of lipid synthesis when feeding on IR36 only 27% of the insects had a flight capacity of greater than 10h whereas 74% of those reared on IR20 had a comparable flight potential (Fig. 2).

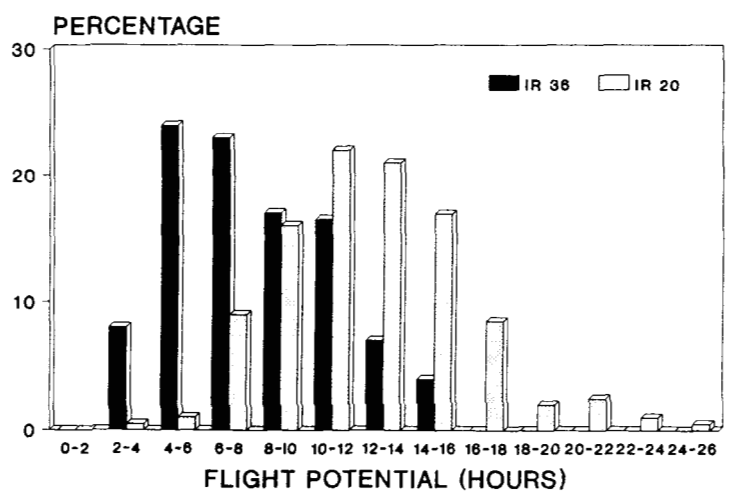


Fig. 2. Distribution of potential flight durations of the brown planthopper *Nilaparvata lugens* developing on mature plants of susceptible IR20 or resistant IR36 rice cultivars (after Padgham 1983).

2.1 HOST PLANT RESISTANCE AND CULTURAL CONTROL

Agronomic practices that are used in rice production systems to evade insect populations are the synchronous planting of fields in a given area and the planting of early maturity cultivars (Heinrichs 1988c). Synchronous planting of rice within an area related to the effective dispersal of the brown planthopper and yellow stem borer *Scirpophaga incertulas* (Walker) decreases the pest load on the crop (Loevinsohn *et al.,* 1988). In Indonesia, brown planthopper populations in areas synchronously planted were one fourth that of areas where planting was staggered (Oka 1979). The combined effect of resistant cultivars and synchronous planting significantly decreases pest populations.

Early maturing rice cultivars evade the later generations of multiple generation pests. They become unsuitable for feeding before the brown planthopper reaches the damaging third generation (Heinrichs *et al.,* 1986a). Early maturity complements host plant resistance and other cultural, chemical and biological controls.

2.2 HOST PLANT RESISTANCE AND BIOLOGICAL CONTROL

Resistant cultivars have an indirect adverse effect on natural enemies because of lower prey density. They have also been shown to adversely affect the development of parasites and predators by decreasing the suitability of the prey (insect pest) as a food source (Orr and Boethel 1986). However, resistant cultivars and biological controls are generally considered to be compatible. Resistant cultivars have a major impact on conserving natural enemies by decreasing the insecticide load.

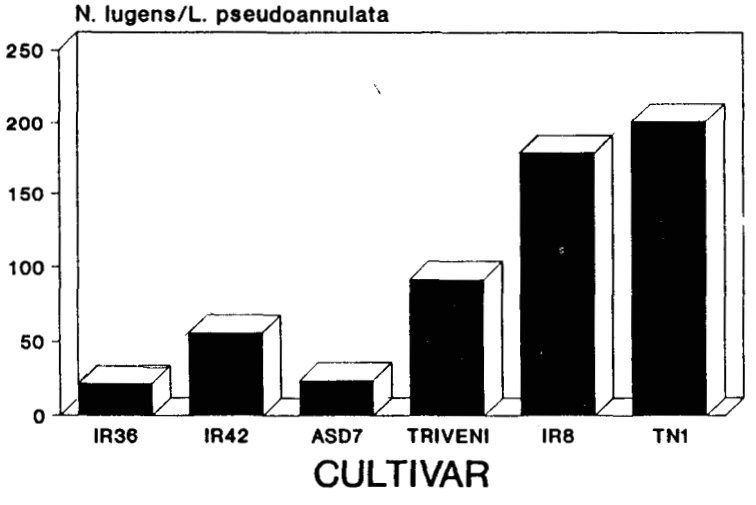


Fig. 3. Brown planthopper *(Nilaparvata lugens)* /spider *(Lycosa pseudoannulata)* ratios at 40 days after transplanting of rice cultivars with varying levels of *N. lugens* resistance. IR36, IR42, and ASD7 are resistant, Triveni is moderately resistant, and IR8 and TNl are susceptible (modified from Kartohardjono and Heinrichs 1984).

The activity of certain natural enemies is enhanced when preying on insects that are feeding on resistant cultivars. Resistance increases the predation rate of the spider *Lycosa pseudoannulata* (Boesenberg et Strand) on the brown planthopper (Kartohardjono and Heinrichs 1984). Apparently, the restlessness and subsequent movement of the brown planthopper on the resistant cultivar causes it to be detected by the spider. Brown planthopper: spider ratios in the field are most favorable for biological control activity on resistant cultivars (Fig. 3). Also, the combined effect of predation by a mirid bug *Cyrtorhinus lividipennis* Reuter and cultivar resistance significantly reduces brown planthopper populations more than either the predators or cultivar resistance alone (Kartohardjono and Heinrichs 1984).

The combination of varietal resistance and predation by *C. lividipennis* has a cumulative effect on green leafhopper *Nephotettix virescens* (Distant) control (Myint *et al.,* 1986). *N. virescens* mortality when feeding on the resistant cultivar IR29 was 66% but increased to 92% with the addition of *C. lividipennis.* On susceptible TN 1, *N. virescens* mortality was only 41% with *C. lividipennis* predation.

2.3 HOST PLANT RESISTANCE AND CHEMICAL CONTROL

Insecticides provide more effective control when insects are feeding on resistant plants. Whitebacked planthoppers *Sogatella furcifera* (Horvath) and brown planthoppers feeding on resistant or

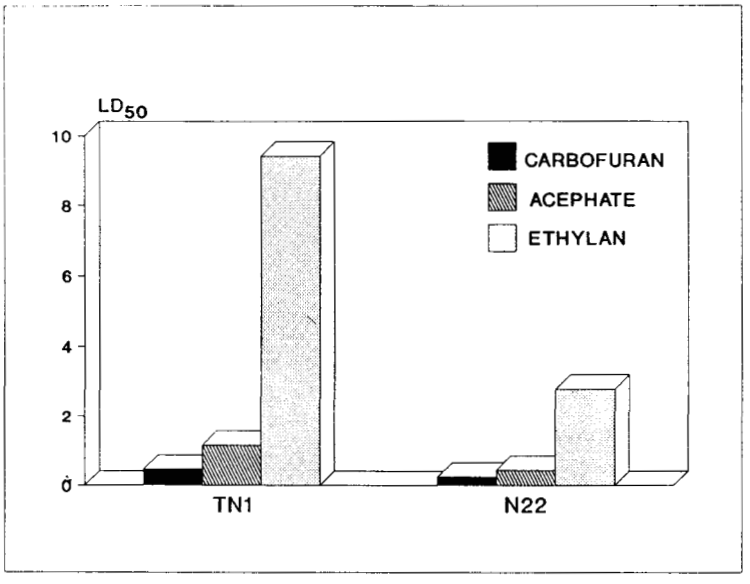


Fig. 4. LD_{50} of insecticide applied topically to the whitebacked planthopper *Sogatella furcifera* reared on susceptible TN 1 and moderately resistant N22 rice cultivars (modified from Heinrichs *et al.,* 1984).

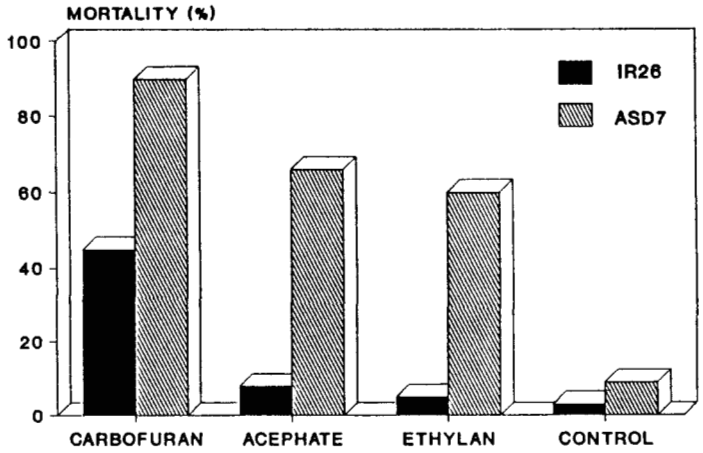


Fig. 5. Contact toxicity of insecticides applied with a Potter's spray power against the brown planthopper *Nilaparvata lugens* biotype 2 when reared on susceptible (IR26) and moderately resistant (ASD7) rice cultivars (modified from Heinrichs *et al.,* 1984).

moderately resistant rice cultivars are killed with lower insecticide rates than those feeding on susceptible cultivars (Heinrichs *et al.,* 1984). LD_{50} rates of insecticides applied topically to the whitebacked planthopper were two to three times as high on susceptible TN 1 than moderately resistant N22 (Fig. 4). Biotype 2 brown planthoppers reared on moderately resistant ASD7 had mortality rates 2-12 times that of brown planthoppers reared on susceptible IR26 when sprayed with various insecticides (Fig. 5). Thus insecticide rates required for adequate planthopper control are lower on a moderately resistant cultivar than that on a susceptible cultivar.

Host plant resistance and insecticides have a cumulative effect in the control of the green leafhopper and the tungro virus that it vectors (Heinrichs *et al.,* 1986b). Green leafhopper resistant cultivars have a low incidence of tungro and susceptible cultivars have a high incidence regardless as to the number of insecticide applications (Fig. 6). However a cultivar such as IR36 that has moderate resistance to the vector shows a response to insecticides in that treated field plots have a decreased tungro infection percentage and untreated plots have a high incidence of tungro infected plants.

Host plant resistance can mitigate the degree of brown planthopper resurgence when rice fields are treated with resurgence-inducing insecticides. Brown planthopper populations on resistant plants treated with a resurgence-inducing insecticide were only 10 per hill whereas there were 1,100 hoppers per hill on treated susceptible cultivars (Aquino and Heinrichs 1979). In fields where the leaffolder or other insects regularly reach the economic injury level and require insecticide treatment, brown planthopper resurgence can be minimized by planting a brown planthopper resistant cultivar.

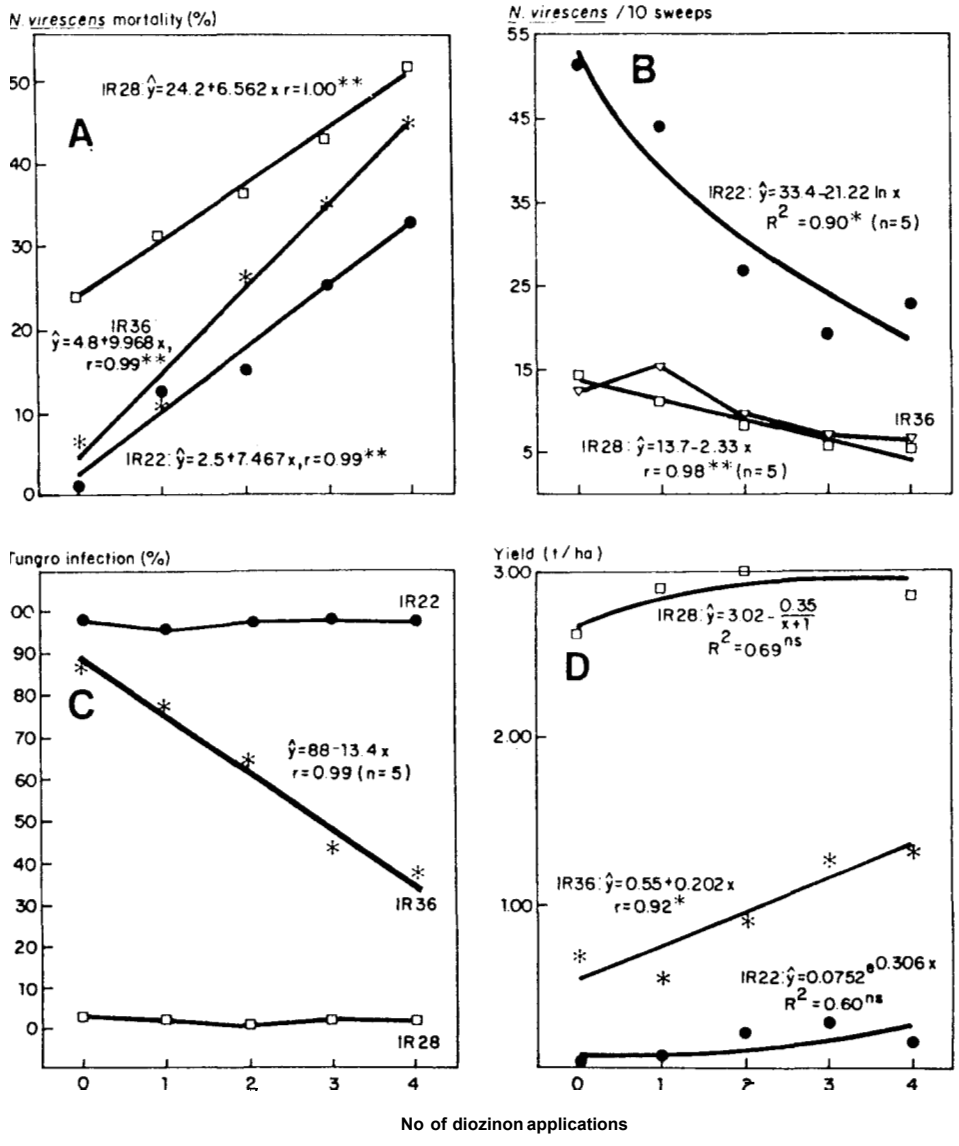


Fig. 6. Green leafhopper *Nephotettix virescens* mortality (A), and field populations (B), rice tungro virus infection (C), and rice grain yields (D) as affected by number of diazinon applications at 1.5 kg (AI)/ha on *N. virescens* susceptible rice cultivar IR22, moderately resistant IR36, and resistant IR28 (modified from Heinrichs *et al.,* 1986b).

Decreasing the amount of insecticide applied to rice through the planting of insect resistant cultivars conserves natural enemy populations, preserves the quality of the environment, slows the

rate of selection for insecticide resistant insect strains and increases the profitability of rice production. The integration of host plant resistance with insecticides, cultural controls and biological control agents in a crop production system is more effective, environmentally safer, economically more profitable, and more stable than complete reliance on insecticides to control insects on susceptible cultivars.

2.4 INSECT RESISTANT CULTIVARS AND CONTROL OF NON-INSECT PESTS

There are a myriad of interactions among the various pests (insects, diseases, nematodes, rodents, and weeds) that attack rice plants. The various pests, abiotic environmental factors, and the rice plant are interdependent and linked. Thus the control of a target pest may cause population increases, or decreases, or may not affect another pest (Reissig *et al.,* 1986).

Weeds and plant diseases may be adversely affected by the planting of insect resistant cultivars. Insects that feed on susceptible seedlings and plants in the vegetative stage slow plant growth and reduce the plant foliage area. This causes the closing of the plant canopy to be delayed and reduces the competition for light and nutrients which in turn allows greater weed growth. Insect feeding predisposes rice plants to attack of bacterial and fungal pathogens that invade the insect-damaged plant tissue. Some insect species, especially the leaf- and planthoppers, are rice virus vectors. Decrease in the feeding activity on non-preferred rice cultivars decreases the incidence of virus infection.

3. Collection, Evaluation, and Utilization of Insect Resistant Germplasm

3.1 PRESERVING RICE GERMPLASM

Since antiquity rice has been cultivated under a multitude of diverse growing conditions in respect to elevation, climate, and soil types. The ecogenetic differentiation of rice occurred primarily through natural and human selection in these different environments, following hybridization, segregation or mutation (Swaminathan 1984). Germplasm in *Oryza* is derived from three sources: (1) wild species, natural hybrids between cultivated varieties and their wild relatives and primitive cultivars, (2) commercial, obsolete, and special purpose cultivars, and (3) cultivars arising from human intervention, whether unwittingly, or intentional.

It has been estimated that the number of rice cultivars in collection may reach 120,000. Starting in the 1930s every major rice-producing country in Asia began collecting germplasm from indigenous rices (Chang 1984). The size of national collections varies from several hundred cultivars in Nepal to about 40,000 in China (Table 1). India has about 35,000 cultivars and the U.S. more than 18,000. Although the commercial cultivars are well represented in these collections few wild rices have been collected and few primitive cultivars and breeding lines have been maintained. Because of a lack of refrigeration facilities many of the tropically stored collections have been eroded.

TABLE 1

Estimates of rice germplasm holdings in major centers and their storage conditions (From Chang 1985)

Country/Center	*Number of samples in national center*			
	Total	*Indigenous*	*Duplicate samples in IRGC*[1]	*Storage condition*[2]
Bangladesh	–	5,285	5,285	MT
Burma	–	2,080	1,724	MT
China (mainland)	40,000[3]	33,000	3,767	ST, MT, LT
China (Taiwan)	6,520[3]	1,662	1,185	MT
India	35,000[4]	33,000	14,585	ST
Indonesia	7,500	–	7,840	MT
Japan	42,455[5]	16,200	978	MT, LT
Kampuchea	–	–	906	–
Korea (S.)	4,227	1,027	1,023	LT
Laos	–	–	1,431	–
Liberia	409	–	1,159	MT
Malaysia	4,550	3,130	2,395	MT
Malagasy	2,000	2,000	218	ST
Nepal	780	–	1,247	ST
Pakistan	1,224	1,404	936	MT
Philippines	–	1,187	3,954	ST
Sri Lanka	2,145	2,745	2,069	MT
Thailand	6,000	–	2,906	MT, LT
U.S.	18,065[6]	92	4,511	MT, LT
U.S.S.R.	3,514	–	372	LT, MT
Vietnam	–	–	1,634	–
IITA	7,633	n/a	1,024	MT
IRAT	3,842	n/a	1,577	MT

[1] IRGC = International Rice Germplasm Center (IRRI)
[2] ST = Short term, MT = medium term, LT = long term
[3] Including many duplicates; collections scattered over more than 10 institutions.
[4] Including many duplicates; collections scattered over 70 institutions; 15,000 accessions at CRRI; 3,464 accessions deposited at IRRI.
[5] Including many duplicates; collections scattered over the national center (NIAR), more than 30 national and lesser experiment stations, 12 universities, and the Institute of Genetics; 18,000 accessions at NIAR.
[6] Including deposits by IRRI; more than 5,000 accessions are held at BARC, Beltsville under MT storage as a working collection.

The International Rice Research Institute (IRRI) established a germplasm center in 1961. It is a conglomerate of all of the national collections. According to its Director, Dr. T. T. Chang (pers. communication), at the end of 1989 the IRRI International Rice Germplasm Center held 78,420 accessions of *O. sativa,* 2,408 strains of *O. glaberrima,* 2,214 wild species and species-hybrids, and 206 genetic testers and mutants. This collection makes IRRI the world's largest repository for a single crop. To provide extra security for the IRRI collection the institute deposits a duplicate set of seed in the U.S. National Seed Storage Laboratory, Fort Collins. Colorado, USA. In cooperation

with the International Board for Plant Genetics Resources, IRRI is collecting and conserving the remaining 30,000-40,000 cultivars and when this task is completed, rice may be the first major food crop to be preserved in as complete a collection of naturally occurring genetic variability as can be achieved (Swaminathan 1984).

3.2 EVALUATION OF RICE GERMPLASM FOR INSECT RESISTANCE

Collection of germplasm is a prerequisite for any crop improvement program. Because of the abundance and diversity of rice germplasm the collections provide a rich source of insect resistant material. The importance of interdisciplinary cooperation in a typical insect resistance breeding program is illustrated in Figure 7. The role of the entomologist is to (1) develop screening methods, (2) identify donor parents with insect resistance for use in the breeding program, (3) evaluate the level of resistance in breeding lines produced, (4) identify the mechanisms involved in resistance, and (5) collaborate with the breeder in identifying the genes imparting insect resistance.

Breeding for insect resistance has only been a focus of rice development programs since the early 1960s. The discovery of high levels of resistance to leafhoppers and planthoppers in traditional cultivars sparked a widespread interest in the development of high yielding, insect resistant rice cultivars. As a result, screening methods for more than 30 rice insect species have been developed (Table 2) (Heinrichs *et al.,* 1985a).

TABLE 2

Status of screening and breeding for varietal resistance to rice insect pests (modified from Heinrichs *et al.,* 1985a)

Insect		*Status*				
Common name	*Scientific name*	*Screening methods developed*	*Resistance sources identified*	*Resistant breeding lines available*	*Resistant varieties released*	*Genes for resistance identified*
Brown planthop-Per	*Nilaparvata lugens*	†	†	†	†	†
Whitebacked planthopper	*Sogatella furicifera*	†	†	†	†	†
Smaller brown planthopper	*Laodelphax striatellus*	†	†	†	†	–
Rice delphacid	*Tapsodes orizicolus*	†	†	†	†	–
Green leafhopper	*Nephotettix virescens*	†	†	†	†	†
Zigzag leafhopper	*Recilia dorsalis*	†	†	†	†	†
White leafhopper	*Cofana spectra*	†	†	–	–	–
Blue leafhopper	*Empoascanara maculifrons*	†	†	–	–	–
Rice striped borer	*Chilo suppressalis*	†	†	†	†	–
Yellow stem borer	*Scirpophaga incertulas*	†	†	†	†	–

(*Contd.*)

Insect		Status				
Common name	*Scientific name*	*Screening methods developed*	*Resistance sources identified*	*Resistant breeding lines available*	*Resistant varieties released*	*Genes for resistance identified*
Sugarcane borer	*Diatraea saccharalis*	†	†	†	–	–
African striped stem borer	*Chilozacconius*	†	†	–	–	–
African white stem borer	*Maliarpha separatella*	†	†	–	–	–
Lesser cornstalk borer	*Elasmopalpus lignosellus*	†	†	–	–	–
African pink borer	*Sesamia calamistis*	†	†	–	–	–
S.A. white borer	*Rupelaalbinella*	†	†	–	–	–
Stalk-eyedfly	*Diopsis macrophthalma*	†	†	†	–	–
Rice stem maggot	*Atherigonaoryzae*	†	†	–	–	–
Whorl maggot	*Hydrellia philippina*	†	†	†	†	–
Gall midge	*Orseolia oryzae*	†	†	†	†	†
Rice seedling fly	*Atherigonaexigua*	†	†	–	–	–
Armyworm	*Mythimna separata*	†	–	–	–	–
Thrips	*Stenchaetothrips biformis*	†	†	†	†	–
Rice bug	*Leptocorisa oratorius*	†	†	–	–	–
Black bug	*Scotinophara latiuscula*	†	†	†	†	–
Caseworm	*Nymphula depunctalis*	†	†	–	–	–
Leaffolder	*Cnaphalocrocis medinalis*	†	†	†	–	–
Rice water weevil	*Lissorhoptrus oryzophilus*	†	†	†	–	–
Hispa	*Dicladispa armigera*	†	†	–	–	–
Bloodworm	*Chironomus tepperi*	†	†	–	–	–
Rice weevil	*Sitophilusoryzae*	†	†	–	–	–
Maize weevil	*Sitophiluszeamais*	†	†	–	–	–
Lesser grain borer	*Rhyzopenha dominica*	†	†	–	–	–
Angoumois grain moth	*Sitotroga cerealella*	†	†	–	–	–

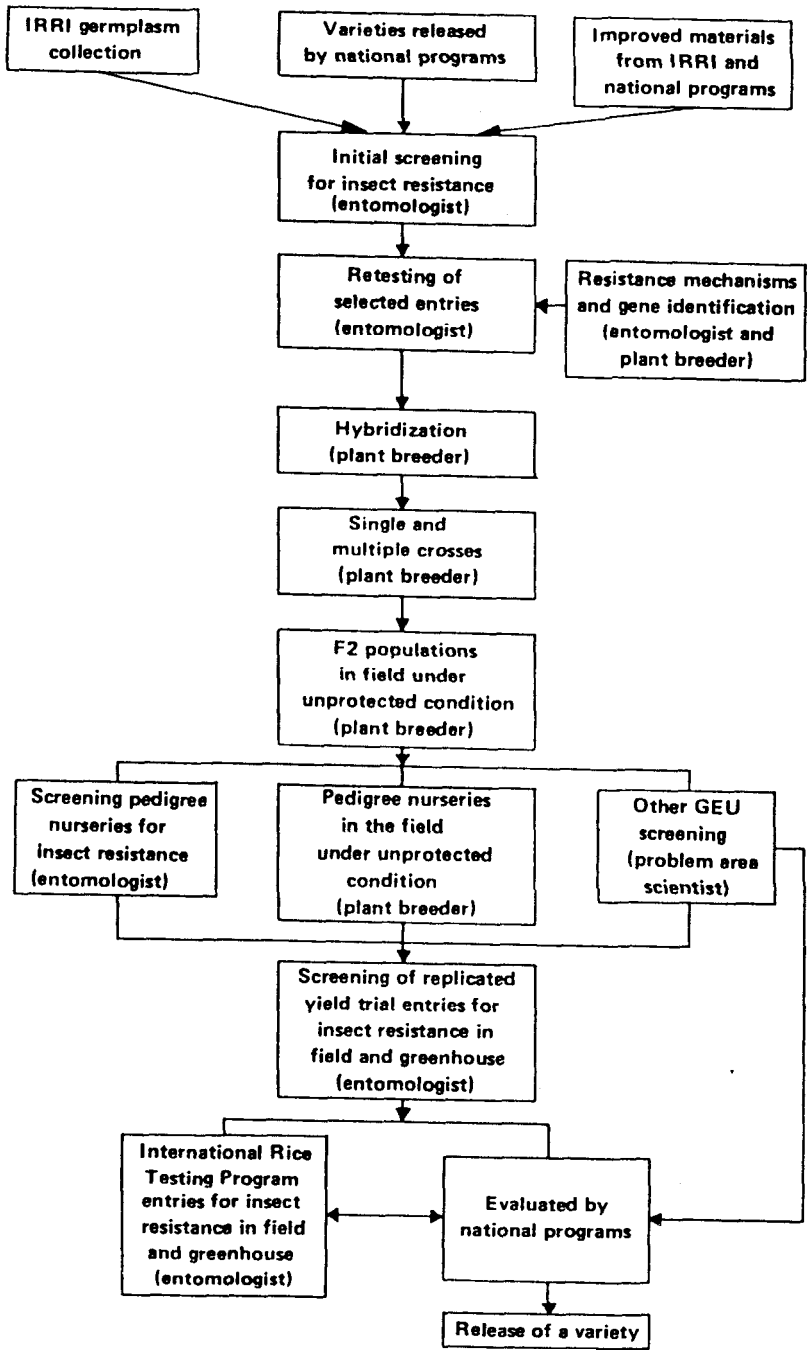


Fig. 7. Steps in the breeding for insect resistant rice cultivars at IRRI (after Heinrichs *et al.*, 1985a).

Screening for rice insect resistance is being conducted throughout the world. Major emphasis has been on the leafhoppers in Asia and stalk-eyed fly in Africa, rice delphacid in South America, and rice water weevil in the U.S.A. Minor emphasis has been given to the rice storage insects. Screening methods employed for the various rice insects throughout the world are described in detail and sources of resistance identified are listed in Heinrichs *et al.* (1985a).

3.3 BREEDING INSECT RESISTANT RICE CULTIVARS

Successful rice breeding programs consist of an interdisciplinary approach where scientists from several key disciplines work together as a team. This is because the degree to which a new cultivar is a success depends on a number of factors involving many disciplines. Thus, entomologists, plant pathologists, physiologists, agronomists, cereal chemists, soil scientists and biotechnologists must work closely with the plant breeders. Such rice breeding programs have resulted in the development of insect-resistant cultivars with high yield potential that are being utilized as a major tactic of integrated pest management in rice production systems in many countries.

3.3.1 Green Leafhoppers, *Nephotettix spp.*

Nephotettix virescens (Distant) occurs in South and Southeast Asia, southern Japan and Taiwan. It is of major importance because it is an efficient vector of rice tungro virus. Because of the lack of virus resistance in rice, insect resistance has been employed as a means of controlling tungro virus. All of the IR cultivars except IR22 have moderate to high levels of resistance to *N. virescens* and all have varying levels of resistance to *N. nigropictus* and *N. malayanus* (Heinrichs *et al.,* 1985b). Many countries are growing rice cultivars with resistance to the *Nephotettix* species. Genetic analysis has identified eight genes *(Glh* 1, *Glh* 2, *Glh* 3, *glh* 4, *Glh* 5, *Glh* 6, *Glh* 7, *Glh* 8) that impart resistance to *N. virescens* (Athwal *et al.,* 1971, Siwi and Khush 1977, Karim and Pathak 1982, Ghani and Khush 1988). Many of these genes provide cross resistance to *N. nigropictus* and *N. malayanus.*

3.3.2 Zigzag Leafhopper, *Recilia dorsalis*

The zigzag leafhopper is a minor pest but occasionally reaches populations of sufficient magnitude to directly damage the rice crop through the removal of plant sap. Breeding for resistance to this insect has been limited. IR56 among the IR cultivars is resistant to this insect (Heinrichs *et al.,* 1985b). Three genes have been identified for zigzag leafhopper resistance: *Zlh* 1, *Zlh* 2, and *Zlh* 3 (Angeles *et al.,* 1986).

333 Brown Planthopper, *Nilaparvata lugens*

Because of the importance that the brown planthopper has assumed as a pest in the last three decades, all of the major rice producing countries in South and Southeast Asia have breeding programs to control this pest. Distinct differences in levels of resistance to the brown planthopper under greenhouse conditions were first observed at IRRI in 1963 (Pathak *et al.,* 1969). More than 50,000 accessions have been screened for resistance to this pest at IRRI and more than 400 resistant accessions have been identified (Rapusas and Heinrichs 1987a). Biotype development has compli-

cated breeding for resistance to the brown planthopper. Sources resistant in one region may be susceptible in another (Heinrichs 1988b). The latest IR cultivars are resistant to the three biotypes in the Philippines (Heinrichs *et al.,* 1985b)

Seven genes have been identified that impart resistance to the brown planthopper; *Bph* 1, *bph* 2, *Bph* 3, *bph* 4, *bph* 5, *Bph* 6 and *bph* 7 (Athwal *et al.* 1971, Lakshminarayana and Khush 1977, Khush *et al.* 1985, Kabir and Khush 1988). IR26, the first IRRI cultivar with brown planthopper resistance resulted from a cross made in 1969, of IR24 and TKM6, the latter having the *Bph* 1 gene for resistance. IR26 has multiple resistance to several major diseases, and insects, good grain quality, and high yield potential (Khush 1977). Breeding programs for brown planthopper resistance have been established in most of the Asian countries and numerous cultivars have been released since that of IR26 in 1973. Brown planthopper resistance has been incorporated into the hybrid cultivars being grown in China. IR36, the most widely grown rice cultivar has brown planthopper resistance from the recessive gene, *bph* 2 (Khush 1977).

3.3.4 Whitebacked Planthopper, *Sogatella furcifera*

The whitebacked planthopper is an important pest in the tropics and subtropics in Asia. Removal of plant sap by the insect causes 'hopperburn', a drying of the plant. Of about 50,000 accessions screened at IRRI, more than 400 have resistance to the whitebacked planthopper (Romena *et al.,* 1986). Genetic analyses of selected accessions have resulted in the identification of five genes for resistance; *Wbph* 1, *Wbph* 2, *Wbph* 3, *Wbph* 4, and *Wbph* 5 (Sidhu *et al.,* 1979, Angeles *et al.,* 1981, Hernandez and Khush 1981, Wu and Khush 1985). Breeding for resistance is being conducted at IRRI and has resulted in the release of moderately resistant cultivars IR48, IR52, IR60, and IR62 (Heinrichs *et al.,* 1985b).

3.3.5 Rice Delphacid, *Tagosodes orizicolus*

The rice delphacid is a serious pest of rice in South and Central America, and in the Caribbean. In addition to causing direct damage, by feeding, it vectors the hoja blanca virus, the most serious rice disease in the Western Hemisphere (Khush 1977). In 1967 scientists at the Centro International de Agricultural Tropical (CIAT) in Colombia observed that plants in field plots of the Asian cultivar,IR8, were resistant to *T. orizicolus.* Further evaluation of 5,000 cultivars under greenhouse testing at CIAT identified 100 from Asia, where the insect does not occur, as resistant (Jennings and Pineda 1970). The cultivars CICA 4 and CICA 6 released jointly by CIAT and the Institute Colombiano Agropecuaria (ICA) were resistant to *T. orizicolus.* Resistance to *T. orizicolus* is due to tolerance and no major genes have been identified. Resistant cultivars are playing a major role in the control of *T. orizicolus* and hoja blanca.

3.3.6 Smaller Brown Planthopper, *Laodelphax striatellus*

The smaller brown planthopper occurs in Japan, Korea and China and is a vector of rice stripe, a serious rice disease in East Asia, and a vector of black-streaked dwarf virus. Commercial cultivars with resistance to this pest have been released. ASD7 has been reported as highly resistant in Korea,

Murunaga 137 and Pannetti are resistant in Taiwan and Tadukan is resistant under field conditions in Japan (Khush 1977).

3.3.7 Rice Striped Stem Borer, *Chilo suppressalis*

Of about 20 rice stem borer species, the rice striped borer and the yellow stem borer *Scirpophaga incertulas* occur most commonly in Asia and cause serious yield losses (Chaudhary *et al.,* 1984). The rice striped borer is the most widely studied rice stem borer species and occurs in East Asia, Southeast Asia, South Asia, Egypt and Japan. It occurs in both the tropics and subtropics while the yellow stem borer is primarily a tropical species.

Extensive screening for resistance to the striped borer under natural field infestations has been conducted in India, Japan, and at IRRI (Khush 1984). High levels of resistance have not been found and resistance is of a polygenic nature. Breeding for resistance at IRRI started in 1965, using as a donor TKM6, the best source of resistance at the time. In 1968, a breeding line IR532E576 was identified as resistant and it was released as IR20 in 1969 (Chaudhary *et al.,* 1984). Since then, several striped stem borer resistant cultivars with better agronomic qualities than IR20 have been released by IRRI (Heinrichs *et al.,* 1985b). Of the IR cultivars, IR36 has the highest level of resistance. Cultivars such as Ratna have been developed in India from TKM6 crosses.

3.3.8 Yellow Stem Borer, *Scirpophaga incertulas*

The yellow stem borer has become the dominant rice borer species in several regions. The breeding program for yellow stem borer resistance began in India in 1964 when TKM6, CB1 and CB2 were used as donors and crosses have been made with high yielding semi-dwarf cultivars and local improved lines (Roy *et al.,* 1969, 1971). None of the lines developed had combined high levels of resistance to the borer and high yields.

Evaluation of the germplasm collection for resistance to the yellow stem borer at IRRI started in 1962 (Rapusas and Heinrichs 1987a). About 17,000 accessions have been screened. Screening is conducted in a screenhouse and in field plots where stem borer populations are high ('hot spots') (Heinrichs 1980, Heinrichs *et al.,* 1985a). Only about 40 *O. sativa* accessions (0.1 % of the accessions tested) and 80 wild rice accessions (18% of the accessions tested) have been identified as having good levels of resistance to the yellow stem borer (Rapusas and Heinrichs 1987a). Several *O. sativa* accessions from India such as CO 7, CO 15, CO 18, CO 21, Ratna, TKM6 and WC 1263 were reported as resistant (Chaudhary *et al.,* 1984). A breeding line, IR 1820-52-2, was found to have a higher level of resistance than previously identified donors. Wild rice species with resistance included *O. eichingeri, O. punctata, and O. latifolia* from Africa, *O. minuta* from the Philippines, and *O. officinalis* from India.

Breeding for yellow stem borer resistance at IRRI began in 1972. IR20 was the first moderately resistant cultivar released. IR36 and IR40 were released as moderately resistant cultivars in 1976. Later releases having moderate resistance were IR50 and IR54 (Heinrichs *et al.,* 1985b). Because of a lack of high levels of resistance in commercial cultivars, a male-sterile facilitated recurrent selection approach was utilized to breed for resistance (Chaudhary *et al.,* 1981). Genetic male-

sterile IR36 as a female parent was crossed with 26 donor parents including CO 18, CO 21, IR 1820-52-2, TKM6, and WC 1263. Twenty lines with a high level of resistance were selected and these are being used as sources of resistance in the breeding program.

3.3.9 Gall Midge, *Orseolia oryzae*

The Asian gall midge, *Orseolia oryzae* Wood-Mason is a serious pest in India, Indonesia, Sri Lanka and Thailand. The larval stage damages the plant by causing the leaf sheath to produce a gall called a 'silver shoot' that prevents panicle production. An early observation on differences in cultivar reactions to the gall midge was reported by Nguyên (1922) in Vietnam and Hegdekatti (1927) in India. Rice improvement programs in Bangladesh, India, Indonesia, Sri Lanka, and Thailand screen for resistance to the gall midge and about 200 resistant cultivars have been identified (Heinrichs and Pathak 1981).

Most of the resistant cultivars identified in screening programs are from India and a few originate in Thailand. Field screening of the 3,600 cultivars of the National Collection of Rice at the Central Rice Research Institute (CRRI) in India began in 1948. The Indian cultivars Ptb 18 and Ptb 21, and the Thai cultivar Leuang 152 were selected. Later screening at Warangal, India, resulted in the selection of Eswarakora, HR42 and HR63, and the Thai cultivar Siam 29. Between 1968 and 1970 the All India Coordinated Rice Improvement Project (AICRIP) coordinated the screening of accessions from India and IRRI. Two cultivars from the Jeypore Botanical Survey and 44 Assam Rice Collection (ARC) cultivars were selected. Of the 3,804 accessions from IRRI, Ptb 10, AC 1423, DNJ45, and DV 12, originally from India, were resistant. Cultivars identified as resistant in India have been evaluated in several national programs through the coordination of the IRRI International Rice Testing Program. The development of means of mass rearing the gall midge has accelerated the screening program.

Studies on the inheritance of resistance in Indian cultivars indicated dominant genes *GM*-1 in Usha, Samredhi, and BdG-1, and *GM*-2 in Surekha and IET 6286 (Chaudhary *et al.,* 1985). Breeding for resistance is being conducted in India, Indonesia, Philippines (IRRI), Sri Lanka, and Thailand (Heinrichs and Pathak 1981). Breeding was first conducted in India and the Indian program is the most active. In the 1960s, crosses between Ptb 18 and Ptb 21 as resistant donors, and GEB24, then the most popular local cultivar, produced several CR55 and CR56 selections with resistance to the gall midge (Khush 1984). With the advent of the short-statured, high yielding cultivars such as IR8, hybridization programs at CRRI and AICRIP used CR55, CR56, Eswarakora, Ptb 18, Ptb21, and Siam 29 as donor parents. Selections from these crosses resulted in the release of the gall midge resistant cultivars Shakti in Orissa State, Vikram in Karnataka, and Surekha in Andhra Pradesh. Many of the gall midge resistant cultivars have multiple resistance to insects and diseases. The Warangal selections, WC 1252, WC 1253, WC 1257 and WC 1263 are resistant to the gall midge, thrips, stem borers and leafhoppers (Shastry *et al.,* 1972). Utilizing Warangal cultivars as gall midge resistant donors, RD4 and RD9 were released in Thailand. BG400-1 and BG276-5 from the Batalagoda program have been released in Sri Lanka (Heinrichs and Pathak 1981).

At IRRI, crosses between multiple-resistant, improved-plant type breeding lines and Ptb 18, Cr 94-13 (Ptb 18 x Ptb21), Eswarakora and Ob677 have been made. Commercial gall midge resistant cultivars with multiple resistance to insects and diseases include IR36 released in 1976 and the subsequent IR cultivars IR38, IR40, and IR42 (Khush 1984). Utilization of resistant cultivars in combination with other control tactics in pest management programs is providing effective and economic gall midge control.

4. MECHANISMS OF RESISTANCE

Breeding for resistance to rice insects has resulted in the release of commercial cultivars that have successfully been integrated into crop management systems and have had a significant economic impact on rice production. Plant resistance has been successful in spite of the fact that knowledge of the nature of resistance in rice is limited. However, a more in-depth understanding of the factors that cause resistance is needed as the information can be used to develop more efficient screening programs and it provides guidance for the breeding program.

Resistance in plants is the result of a series of interactions between plants and insects that influences the degree of establishment of insects on plants (Saxena 1986). Insect responses are influenced by physical factors that interfere with insect vision, locomotion, feeding, mating, and oviposition and chemical factors that alter the behavior or physiology of the insect.

Information on the physical and chemical factors that impart resistance to rice insects is limited. Research has concentrated primarily on the green leafhoppers, brown planthopper, rice striped stem borer, and the yellow stem borer.

4.1 GREEN LEAFHOPPERS

Kawabe (1985) studied thc mechanisms involved in the resistance of Japanese cultivars to *Nephotettix cincticeps*. Mechanisms consisted of the three components of resistance; antibiosis, antixenosis, (nonpreference) and tolerance (Fig. 8). Electronic monitoring of feeding behavior indicated that the insect withdraws its stylets from the phloem sap soon after obtaining a taste. He suggested that the phloem contained a biological or physiological mechanism such as a phytoalexin or possibly a mechanical barrier that inhibits phloem sap ingestion.

Heinrichs and Rapusas (1990) used an electronic monitor and a video camera to study the feeding behavior of *N. virescens* on resistant and susceptible rice cultivars. When on susceptible TN 1 most of the feeding time was spent ingesting phloem sap. On resistant cultivars xylem ingestion was the main feeding activity although the stylets were able to reach the phloem. On moderately resistant IR36 a small amount of phloem ingestion was observed but most of the time was spent feeding on the xylem. Similar to Kawabe's study, there appeared to be some unidentified mechanism in the phloem seive elements that prevents *N. virescens* from ingesting phloem sap. The shift from phloem to xylem feeding on resistant cultivars is not understood. Auclair *et a1*. (1982) speculated that the presence of a feeding deterrent adjacent to or within the phloem seive elements or the formation of callose or slime plugs in the phloem prevents feeding. Cheng and Pathak (1972)

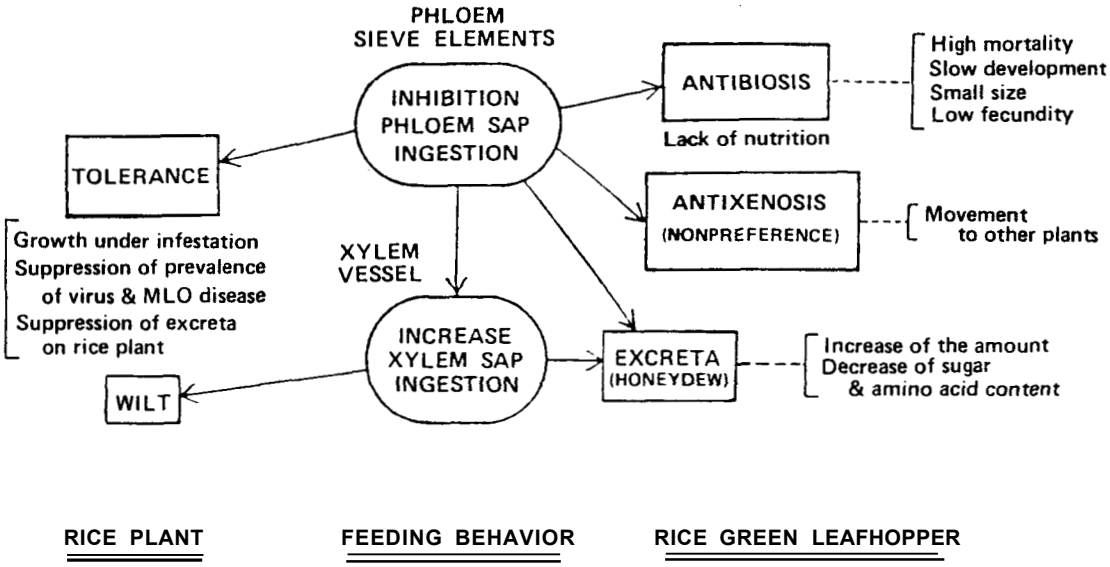


Fig. 8. Mechanism of resistance to the rice green leafhopper *Nephotettix cincticeps* (after Kawabe 1985).

stated that resistance to *N. virescens* is not due to mechanical factors that interfere with feeding but that resistant plants lacked phagostimulants, possessed feeding deterrents or toxic materials or lacked nutrients.

Application of the steam distillate extract of a resistant rice cultivar to susceptible plants disrupted the normal feeding behavior of *N. virescens.* Reduced phloem feeding on extract-treated plants was associated with a significant increase in probing frequency and an increase in the duration of salivation and xylem drinking (Khan and Saxena 1985). Because phloem feeding is considered necessary for *N. virescens* to transmit tungro virus (Heinrichs and Rapusas 1984a) *N. virescens* resistant plants have low levels of tungro infection.

Plant age has a distinct effect on the levels of *N. virescens* resistance in rice (Rapusas and Heinrichs 1982a, 1987b). Plants of the moderately resistant cultivar IR36 at 10 days after sowing (DAS) were most preferred as compared to older plants. *N. virescens* survival, growth index and adult weight were higher on 20 DAS plants than on plants at 40, 60, or 80 DAS. Phloem feeding was highest on young plants and tungro virus transmission was related to extent of phloem feeding (Fig. 9).

4.2 BROWN PLANTHOPPER

Resistance of rice cultivars to the brown planthopper has not been attributed to morphological or anatomical characteristics of plants. Reduced feeding on resistant plants, however, has been attributed to either a lack of phagostimulants or to the presence of antifeedants (Saxena 1986).

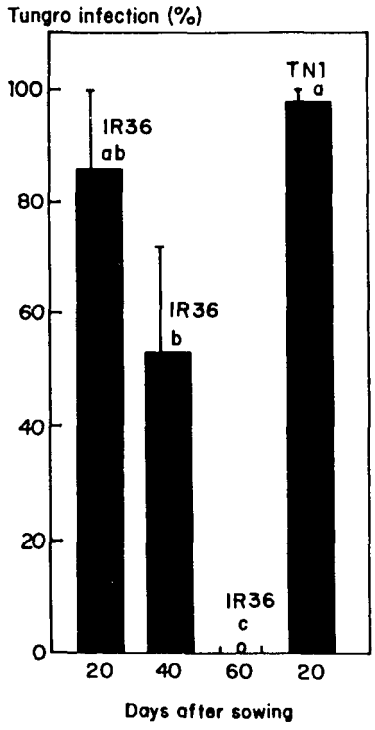


Fig. 9. Percentage of moderately resistant rice cultivar IR36 plants infected with tungro virus when two viruliferous green leafhoppers *Nephotettix virescens* were released per plant of four plant ages and susceptible TN 1 infected at 20 days after sowing. Columns with the same letter are not signifiantly different ($P<0.05$; Duncan's multiple range test). Bars indicate ± 1 Sd (after Rapusas and Heinrichs 1987b).

Brown planthopper resistance in the cultivar Mudgo was considered to be due to a low concentration of amino acids, especially the sucking stimulant, asparagine (Sogawa and Pathak 1970). Later, Yoshihara *et al.* (1979, 1980) reported that soluble silicic acid and oxalic acid in resistant rice plants served as sucking inhibitors. Using a brown planthopper resistant, Japanese breeding line, Shigematsu *et al.* (1982) identified b sitosterol and other sterols in the phloem sap. They reported that b sitosterol is a strong brown planthopper sucking inhibitor and Kaneda (1982) reported that low asparagine content intensifies the inhibitory effect of b sitosterol.

Volatile chemicals extracted as steam distillates, have been shown to affect the behavior and biology of the brown planthopper (Saxena and Okech 1985). The insect preferred susceptible plants sprayed with its own extract over the same cultivar sprayed with the extract of a resistant cultivar. Feeding activity was greater when feeding on a sucrose solution mixed with the extract of a susceptible cultivar than that on a sucrose solution mixed with extracts of resistant cultivars. The

identity of the allelochemics was not determined but it is believed that the steam distillation method employed extracts of essential oils, terpenoids, aldehydes, fatty acids, esters, waxes, etc.

Cook *et al.* (1987) suggested that the surface of the rice plant plays a role in food plant selection by the brown planthopper. Surface waxes have been shown to affect brown planthopper behavior (Woodhead and Padjham 1988). Reduced settling and probing of the plant surface after exploration, and movement off of the stem on to the leaves results from chemical cues in the wax. Sensory structures on the labial tip of the brown planthopper receive chemical stimuli during the exploration of the plant surface that occurs before probing and this affects host choice. Chemical cues received by the brown planthopper from the plant surface originate from the alkanes or carbonyl compounds of the epicuticular wax and vary among cultivars. Analysis indicates that the chemical differences between waxes are due to a higher ratio of long to short carbon chain components in resistant cultivars. The enhanced surface activity and brown planthopper dispersal from IR46 as reported by Woodhead and Padjham (1988) may account for the field resistance of this cultivar as reported by Heinrichs (1986). This resistance mechanism is believed to be associated with minor genes which could be exploited in breeding for polygenic resistance to the brown planthopper.

4.3 STEM BORERS

Various plant morphological, anatomical, biochemical, and physiological factors have been suggested as imparting resistance to the rice striped borer and the yellow stem borer (Chaudhary *et al.,* 1984). Although, some of the reported factors are correlative with resistance, they may not actually be resistance mechanisms.

Several plant morphological factors have been reported. Plant height, stem diameter and length and width of the flag leaf were positively correlated with number of eggs laid by stem borer moths (Patanakamjorn and Pathak 1967). In addition, resistant cultivars possessed tight leaf sheaths that totally covered the internodes whereas susceptible cultivars had loose leaf sheaths that partially covered the internodes. Tight leaf sheaths were believed to prevent newly hatched larvae from feeding on the inner part of the leaf sheath before boring into the stem. A positive correlation between stem size and borer infestation was reported (Jodon and Ingram 1948). Tall plants with wide and long leaves and a large number of tillers appeared most susceptible (Israel 1967). Awnless cultivars were more susceptible than those with awns (Shiraki 1917).

Anatomical studies of stem borer resistant cultivars indicated that the stems had four to five layers of sclerenchymatous tissue that apparently offer resistance to larvae boring inside the stem (Van and Guan 1959). Also, cultivars with a narrow stem lumen were less susceptible to borers.

Non-preference of stem borers for oviposition is considered to be at least partially of a biochemical nature. A stem borer attractant, oryzanone (p-methylacetophenone) attracts ovipositing moths and larvae by its odor (Munakata *et al.,* 1959). Non-preference of the rice striped borer for TKM6 is due to the presence of allomones which inhibit oviposition and adversely affect egg hatching, larval survival, and larval development (IRRI 1978). The chemical has been identified as a pentadecanal in a collaborative effort between IRRI and the former Tropical Development Research Institute, London.

Silica content has been associated with resistance to rice stem borers. High amounts of silica in rice plants adversely affected larval survival and reduced 'dead heart' formation (Pathak *et al.,* 1971). Mandibles of larvae feeding on the cultivar Yabani Montakhab, with a high silica content, were worn down, whereas those feeding on Sapan Kwai, with a low silica content, were normal. Larvae with damaged mandibles have a low feeding efficiency and suffer high mortality.

Studies on the chemical bases of resistance to stem borers and to other rice pests, have received relatively little attention and much is left to be discovered. A better understanding of the mechanisms of resistance would allow a more directed program for the breeding of rice insect resistance and may lead to the development of rice cultivars with more stable resistance to insect pests.

5. Variable Resistance to Insects in Rice Cultivars

Insect populations have a wide range of genetic variability that maximizes their fitness in the presence of genetic diversity of host plants. The widespread planting of one rice cultivar that has been commonplace since the release of the 'green revolution' cultivars has significantly decreased the genetic diversity of rice plants. As a result, certain rice insects have developed virulence and this causes severe damage to cultivars that previously were resistant. Such apparently new forms of pests have been termed 'biotypes' (Claridge and den Hollander 1983). The term 'biotype' refers to a population of insects that is capable of damaging plant cultivars that are resistant to other populations of the same species. It is distinguished from other populations of the same species by parasite ability (Heinrichs 1988b). Biotype selection enables an insect species to keep pace with the changes in the defenses of its host plant that occur through natural selection and plant breeding programs (Saxena and Barrion 1987). Biotypes of the rice leaf miner *Agromyza oryzae* (Munakata), gall midge *Orseolia oryzae* (Wood-Mason), rice stem maggot *Chlorops oryzae* (Mats.), green leafhopper *N. virescens,* and the brown planthopper *N. lugens* have been reported on rice (Saxena and Barrion 1987). Green leafhopper, brown planthopper, and gall midge biotypes have been a major constraint to the breeding of resistant rice cultivars and have been extensively studied.

5.1 GREEN LEAFHOPPER

Allopatric populations of *N. virescens* with variable levels of virulence to differential cultivars were reported by Karim and Pathak in 1979 when comparing reactions of seedlings to a Philippine *N. virescens* population maintained in culture at IRRI, and a Bangladesh population maintained at the Bangladesh Rice Research Institute. Cultivars with the *Glh* 1, *Glh* 2, *Glh* 3 or *Glh 5* gene were resistant at IRRI but susceptible at BRRI. Results of an international collaborative study conducted a few years later indicated that Pankhari 203 *(G1h* 1 gene) was susceptible in Bangladesh, India and Malaysia but was resistant in the Philippines, Thailand, and Vietnam (Heinrichs *et al.,* 1986c).

Although *N. virescens* resistant cultivars with the *Glh* 3 gene were sequentially grown in the Philippines for 20 years, evidence of an increase in virulence was not discovered until 1982 (Rapusas and Heinrichs 1982b). IR36 was released in the Philippines in 1976 and subsequently became the

most widely grown cultivar. Results of a survey in the Philippines in 1979 indicated no evidence of an increase of *N. virescens* virulence on the cultivar. However, in a survey conducted in 1984 *N. virescens* populations of Luzon Island had levels of virulence significantly greater than those of the greenhouse colony that had not been exposed to selection pressure (Rapusas and Heinrichs 1986).

Laboratory selection for virulence of *N. virescens* on resistant cultivars indicates an increase in survival, decrease in the nymphal duration and a shift from xylem feeding to increased feeding on the nutrient-rich phloem (Heinrichs and Rapusas 1984a). Increased phloem feeding results in increased rates of tungro virus transmission (Heinrichs and Rapusas 1984b).

5.2 BROWN PLANTHOPPER

Variability in the levels of brown planthopper virulence on resistant cultivars has been a very severe problem in South and Southeast Asia. IR26 with the *Bph* 1 gene was the first *N. lugens* resistant cultivar released by IRRI in 1974. Although it was resistant in the Philippines it was susceptible to the Indian *N. lugens* population indicating variable levels of virulence in allopatric populations. Within the Philippines, *N. lugens* outbreaks were observed in IR26 after 2-3 years of commercial cultivation (approximately 6 crops). Laboratory studies showed that high levels of virulence of *N. lugens* populations to resistant cultivars could be selected in 7 to 10 generations (Pathak and Heinrichs 1982). *N. lugens* resistant cultivars released subsequently to IR26 have also succumbed to biotype selection within a few years after release (Heinrichs 1988b).

Confirmation of the extreme variability of virulence patterns in the field was evident in the result of the studies of Claridge *et al.* (1982). When six Sri Lankan *N. lugens* populations collected from a wild rice species, traditional cultivars, and modern improved cultivars were tested for virulence, they were shown to be most closely adapted to the cultivar, from which they were collected, despite the fact that all populations were collected within a 200 km area. Grouping of brown planthopper biotypes as based on the response of differential cultivars has indicated the presence of several different biotypes in South and Southeast Asia (Heinrichs 1988b). Virulence has been shown to be inherited as a polygenic or quantitative trait (den Hollander and Pathak 1981).

5.3 GALL MIDGE

The first evidence of differential reactions of rice cultivars to gall midge populations was reported in comparing reactions in Nizamabad, South India with those of the same cultivars exposed to a gall midge population at Cuttack, India, 1,200 km to the northeast (Israel and Vedamoorthy 1953). Further studies at 11 sites in India confirmed the existence of gall midge populations with varying levels of virulence on specific cultivars.

International collaborative studies among rice scientists in China, India, Indonesia, Sri Lanka and Thailand have resulted in the classification of gall midge biotypes in South and Southeast Asia (IRRI 1981). Testing of six cultivar groups against the various gall midge populations resulted in the identification of eight different reactions. The populations were designated as the China, Indonesia, Thailand, India-Raipur, India-Andhra Pradesh, India-Orissa, India-Bihar, and Sri Lanka biotype. In spite of the presence of allopatric biotype populations increased virulence of gall midge popula-

tions through selection on commercially released, gall midge resistant cultivars, has not been documented as it has for the brown planthopper.

6. Rice Breeding and Gene Deployment Strategies

The successful management of rice insect populations requires an integrated apprach in which insect resistant cultivars are combined with other control tactics and other crop production practices. In spite of the development of virulent biotypes on previously resistant rice cultivars, plant resistance to insects will remain a key tactic in rice insect management programs. To increase the value of plant resistance several strategies have been developed to increase the stability of insect resistant cultivars.

There is a great deal of genetic diversity in the world collection of rice. Because of a concerted effort to collect and maintain the worlds rices at IRRI and in national program gene banks, this diversity is available for use in rice breeding programs. Because of the tremendous amount of diversity, several strategies are available to cope with the problems caused by biotype selection.

6.1 SEQUENTIAL RELEASE

Sequential release refers to a gene deployment strategy where a cultivar with a single major resistance (R) gene replaces a cultivar with an R gene that has been overcome by the selection for a virulent biotype. Replacement of IR26, a *Bph* 1 gene cultivar, with IR36, a *bph* 2 gene cultivar, is such an example. This strategy requires a continuous search for new R genes. Genetic analysis of the world collection of rices has been limited to a few insects and a limited number of cultivars and there is much scope for identifying additional R genes, especially for leafhopper and planthopper resistance. A prerequisite to the success of this strategy is an active and productive breeding program to keep ahead of the biotype selection process.

6.2 GENE PYRAMIDING

Incorporation of two or more major R genes into the same cultivar using the pedigree method of breeding is a strategy that is believed to be a means of increasing the stability of insect resistant cultivars. Although the success of this strategy has not yet been proven in rice, crosses have been made to combine two major genes for grown planthopper resistance and future studies will indicate the value of this strategy in slowing the development of biotype selection and increasing the commercial life of brown planthopper resistant cultivars.

6.3 HORIZONTAL RESISTANCE

Horizontal resistance is a type of resistance that is expressed equally against all biotypes. Because it is generally considered to be of a polygenic nature (several minor genes), which is difficult for an insect species to overcome, it is durable. In contrast to antibiosis, tolerance is of a polygenic nature and is durable because it exerts no selection pressure on the insect population. Tolerant plants

possess the ability to grow and reproduce and to repair injury in spite of supporting a population approximately equal to that damaging a susceptible host (Painter 1951).

Greenhouse and field methods have been developed to evaluate rice cultivars for tolerance to the brown planthopper (Heinrichs *et al.,* 1985a, Panda and Heinrichs 1983). Field evaluation of moderately resistant cultivars identified cultivar Utri Rajapan from India as having a high level of tolerance. Genetic analyses indicated that the field resistance (level of resistance increases with plant age) in Utri Rajapan and Triveni is governed by the same R gene (Velusamy *et al.,* 1987). Triveni, also an Indian cultivar, possesses both antibiosis and tolerance.

6.4 MULTILINES

This strategy involves the incorporation of different R genes into isolines and planting the lines together in the same field as a mixture. Although a feasibility study was conducted under field conditions at IRRI the lack of isogenic lines and the difficulty for farmers to maintain seed mixtures has dampened the enthusiasm for this approach.

6.5 GENE ROTATION AND GEOGRAPHICAL DEPLOYMENT

Gene rotation, also referred to as temporal deployment, is a strategy where cultivars with different R genes are used in different cropping seasons. In geographical deployment different R genes are used in adjacent cropping areas.

Gene rotation is used in certain regions in Indonesia where the green leafhopper-vectored tungro virus has been a severe threat to production. A set of cultivars with certain genes for green leafhopper resistance is planted in the dry season and another set of cultivars with a different gene is planted in the wet season

A type of geographical deployment is utilized in selected villages of northern Vietnam. Fields within a village are planted to several different cultivars having different maturities and grain types and possessing different R genes for brown planthopper resistance. This is a type of diversity that insures against several abiotic and biotic stresses and minimizes the need for labor at harvest time because the harvest season is spread over a long period.

6.6 BIOTECHNOLOGY

Recent advances in biotechnology provide the possibility of solving some of the constraints that have limited the practical use of genetic resistance to insects in pest management programs. Biotechnology involves several techniques that provide new possibilities of manipulating germplasm.

6.6.1 Wide Hybridization

Wild rice species are a rich source of R genes for use in breeding programs for insect resistance. This is of extreme importance in breeding for resistance to those insects for which R genes have not been found in *Oryza sativa* and in cases where biotype selection may overcome all of the *O. sativa* R

genes. In this context, wide hybridization is a plant breeding tool for the incorporation of alien genetic variation from wild species of *Oryza* into commercially useful cultivars.

Most of the wild rice accessions in the IRRI germplasm collection have been screened for resistance to planthoppers, leafhoppers, stem borers, leaffolder *Cnaphalocrocis medinalis,* whorl maggot *Hydrellia philippina* and the caseworm *Nymphula depunctalis* (Heinrichs *et al.,* l985a. W_U. Jung-Tsung *et al.,* 1986, Romena and Heinrichs 1989). Wild rices are a rich source of insect resistant germplasm and may provide new genes which can be used in the various gene deployment strategies (Table 3). The embryo rescue technique has been utilized in the crossing of *O. sativa* and wild rice species in breeding for brown planthopper resistance (Khush and Jena 1986).

TABLE 3

Agronomically important characteristics identified among the wild *Oryza* species (from Toenniessen and Herdt 1989)

Species	*2n*	*Genome*	*Characteristics*
O. nivara	24	AA	Grassy stunt virus resistance
O. rufipogon	24	AA	Source of cytoplasmic male sterility, tolerance to stagnant flooding
O. glaberrima	24	AA	GLH resistance, early vegetative vigor
O. barthii	24	AA	Bacterial blight resistance
O. longistaminata	24	AA	Floral characteristics for outcrossing
O. punctata	24,48	BB,BBCC	BPH, WBPH, GLH resistance
O. officinalis	24	CC	BPH, WBPH, GLH resistance
O. eichingeri	24	CC	BPH, WBPH, GLH resistance
O. minuta	48	BBCC	BPH, WBPH, GLH, blast, and bacterial blight resistance
O. australiensis	24	EE	BPH resistance, drought tolerance
O. brachyantha	24	FF	Whorl maggot and stern borer resistance
O. ridleyi	48	—	Whorl maggot resistance

Wild rice species are serving as useful donors in wide hybridization projects for rice improvement. The IRRI breeding program has utilized the wild rice species. *O. brachyanthta* in crosses with *0. sativa* in the development of brown planthopper, whitebacked planthopper and stem borer resistance. Some progeny are resistant to all known biotypes of the brown planthopper as well as resistant to the whitebacked planthopper.

6.6.2 Molecular Genetics

The Rockefeller Foundation International Program on Rice Biotechnology was established in 1984 and has significantly enhanced the scientific input into the development of molecular biology techniques for rice (Toenniessen and Herdt 1989). The program consists of a coordinated effort among research institutions in the developed world that are at the forefront of plant molecular and cellular biology and the International Rice Research Institute.

Based on a set of criteria a list of priority traits, for use in the Rockefeller Foundation Rice Biotechnology Program, was established. Insect pests include the yellow stem borer, gall midge, brown planthopper, leaffolder, storage pests, striped stem borer, and whitebacked planthopper (Table 4).

TABLE 4

Rank order of priority traits for the Rockefeller Foundation's Rice Biotechnology Program (from Toenniessen and Herdt 1989)

Resistance to tungro virus
Resistance to yellow stem borer
Resistance to gall midge
Cytoplasmic male sterility
Drought tolerance
Resistance to brown planthopper
Submergence tolerance
Greater lodging resistance
Seedling vigor
Resistance to ragged stunt virus
Tolerance to drought at anthesis
Tolerance to waterlogging
Resistance to leaffolder
Resistance to sheath blight
Cold tolerance at seedling stage
Apomixis
Tolerance to coastal saline/acid sulfate conditions
Resistance to bird damage
Resistance to storage pests
Resistance to bacterial blight
Resistance to blast
Resistance to striped stem borer
Resistance to whitebacked planthopper

The Rockefeller Program includes the (1) development of genetic maps and markers, (2) protoplast techniques, (3) genetic transformations, and (4) cloning and characterizing rice genes. The genetic transformation of rice through the introduction of alien or modified genes is a principal goal of the program. Genetic engineering should make it possible to incorporate any gene from any source into rice. This will make it possible to further utilize the insect resistant wild rice accessions and other much more distant relatives of rice. It has been demonstrated that transgenic plants other than rice express toxin genes from the insect pathogen, *Bacillus thuringiensis* and are resistant to insect feeding. If this can be done in rice there are hundreds of B. t. strains that can be utilized in the development of transgenic plants that express resistance to the various lepidopteran species such as the leaffolder, stem borers, and caseworm.

Because of the high yields of modern rice cultivars, the amount of rice in storage has increased. Storage insects cause severe losses and there is a need to develop cultivars with resistance to insects attacking grain in storage.

Genetic engineering provides the potential of providing a novel means of rice storage insect control. Current projects supported by the Rockefeller Foundation are seeking to isolate genes from wheat which code for inhibitors of digestive enzymes of the rice weevil *Sitophilus oryzae,* a

major pest of stored rice. The goal is to isolate wheat genes that provide a good source of genetic resistance to weevils and transfer them to rice which lacks resistance to weevils (Toenniessen and Herdt 1989).

7. CONCLUSIONS

Rice is an outstanding example of the successful utilization of host plant resistance as a tactic in the integrated management of insects. The large number of cultivars in the world collection of rice is a wealth of genetic diversity. Much of the world collection has been evaluated for insect resistance and many cultivars have been used as donors in breeding programs throughout the world. These breeding programs have successfully provided rice farmers with insect resistant commercial cultivars that are playing a significant role in the management of rice insects.

In spite of the significant progress in the breeding and commercial exploitation of insect resistant rice cultivars, much remains to be done. There are still numerous insects for which suitable levels of resistance have not been found in *O. sativa.* Molecular genetics holds promise as a means of transferring insect resistance from wild rice species and other species into *O. sativa.* In certain cases insect resistant commercial rice cultivars have succumbed to biotype selection. Innovative conventional plant breeding techniques and molecular genetics may provide means of developing commercial cultivars with stability to variable insect populations.

It must again be stressed that no one control tactic is a panacea for rice insect control. Host plant resistance integrated with cultural, biological and chemical control tactics has been shown to be an effective strategy for rice insect control and must be pursued by rice entomologists working in concert with scientists in other disciplines.

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6

Cultural, Mechanical, and Physical Control of Rice Insects

JAMES A. LITSINGER
Department of Entomology
Intentational Rice Research Institute
Los Baños, Philippines

1. INTRODUCTION

Cultural methods to control insects involve crop husbandry practices that have a dual purpose of crop production and insect pest suppression. Farmers have developed these practices through observation and trial and error. The insect control component of these practices, handed down through generations, is often forgotten by present day farmers. Thus there are two types of cultural control practices, primary and secondary. Primary cultural control practices are those done specifically to control insects such as draining a field when the brown planthopper is abundant, planting a trap crop for stem borers, or transplanting older seedlings to minimize whorl maggot damage. Secondary practices are those that are specifically done for crop husbandry such as land preparation, weeding, and fertilization but also happen to minimize insect buildup. Farmers often adopt cultural practices that embody several beneficial effects. Plowing prepares the soil for planting but also turns under stubble harboring stem borers. Weeding grasses removes host plants of the rice bug. Splitting application reduces fertilizer losses as well as minimizing brown planthopper buildup.

Mechanical and physical control practices use principles of physics — mass, energy, and force. Mechanical methods involve motion and force such as trapping or crushing insects by hand, tool, or machine. The energy to produce the force can be chemical or gravitational. Man and machines chemically convert food and fuel into mechanical energy. Gravity often augments this energy. Physical methods involve mass such as an obstruction (covering a seedbed), electromagnetic energy

such as heat (spreading straw in the sun to kill resident stem borer larvae), or light (light traps) to arrest nocturnal flying insects.

Cultural, mechanical, and physical methods of insect control are often complementary. Tillage by plow and harrow is a cultural control practice, but insects die from mechanical crushing and physical exposure to heat. Flooding is a cultural practice to control weeds and minimize drought but the timing and depth can be manipulated to physically drown insects such as armyworms attacking a seedbed. Dense plantings provide physical obstructions to flying insects. Older seedlings are physically harder for stem borer larvae to tunnel into. Burning straw is normally done as a cultural practice to remove a waste product because straw does not biodegrade quickly, but insects are physically killed by the heat.

Magical and superstitious practices are, in the broad sense, forms of cultural control that employ the anthropological definition of culture as patterns of behavior handed between generations. Rice culture has a rich source of folklore regarding indigenous practices. Unfortunately few of these methods have been objectively evaluated as to efficacy. Most practices that offer potential fall in the categories of chemical, cultural, mechanical, and physical control.

TABLE1

Cultural, Mechanical, and Physical Insect Control Practices for Rice

Cultural	*Mechanical*	*Physical*
Field geometry	Handpicking from plants	Light trap
Mixed cropping	Tools to capture or remove insects	Shaving bunds to drown or expose insects
Planting method	Dislodging insects by beating foliage or passing a rope	Plastering bunds to trap insects in their tunnels
Age of seedlings	Digging out insects	Barriers (trenches or nursery boxes)
Pruning	Roguing	Burning stubble or straw
Plant density	Pounding or rolling the soil to crush insects	Spreading straw in the sun
Crop background		
Water management		
Fertilizer		
Crop rotation		
Crop area		
Number of rice crops		
Plant maturity		
Planting time		
Synchronous planting		
Trap crop		
Tillage		
Weeding		
Harvest method		
Use of straw as fodder, mulch, fuel or mushroom culture		
Ratooning		
Grazing		

Mechanical, physical, and cultural rice insect control methods are listed in Table 1. I have divided the discussion of mechanical and physical control methods in this chapter into two categories – (1) those that require mainly labor and (2) those that require mainly capital. Cultural control methods are divided into single field and community-wide methods.

2. Labor Intensive Mechanical and Physical Methods

Manual methods of controlling rice insects are among the oldest and most labor intensive. These methods decline in usage as labor costs rise and less expensive alternative methods become available. Socialist countries that can organize large gangs of cheap labor have a greater tendency to practice them. Manual methods of insect control are perhaps underutilized as they are no more tedious than manual weed control practices (Maxwell-Lefroy 1906). Manual methods of insect control are most attractive for high value crops where labor is cheap, insect pests are aggregated, and the collected insects can be used as food or have an economic value (Isely 1951). Collected insect egg masses can be held in containers to allow parasites to escape, increasing this method's utility.

2.1 HAND PICKING

The most direct manual method is removal of insects by hand. Fast moving or camouflaged insects are too difficult to collect. Slow moving and aggregated large armyworm, cutworm, and butterfly larvae can be handpicked from foliage (Maxwell-Lefroy 1906, Hutson 1920, Kuwana 1930, Liu 1935). Rice bug nymphs fall when disturbed and can be tapped into hand held buckets filled with kerosene and water (Austin 1922). Grasshopper adults are sluggish at night and can be picked directly from foliage and either eaten or destroyed by burning, crushing, burial, or placing in oil or kerosene (Jones and Mackie 1913). Immobile caseworm larvae are skimmed from the water surface after the foliage is beaten (Ghosh 1924a, Otanes 1947). Dispersing stem borer larvae cling to floating leaves that can be removed (Kondo 1917). But insects floating in water are more efficiently removed by nets than by hand.

Eggs are immobile and are thus attractive stages for handpicking. Species which lay eggs in masses are preferred. Rice bug (Otanes 1937), stink bug (Wallace 1957), and black bug (Corbett and Yusope 1924) eggs can be removed by hand and placed in special containers to allow parasites to escape. In Japan, China, and India, stem borer and armyworm egg masses as well as moths were traditionally removed by hand from seedbeds (Ramakrishna Ayyar 1933). Moths are difficult to capture by hand but are relatively easy to capture by net. Skill is required to locate *Chilo* and *Sesamia* egg masses because they are deposited behind leaf sheaths. Best results occur with *Scirpophaga, Mythimna* and *Spodoptera* which lay egg masses openly on foliage.

Seedbeds laid out in 1 m wide beds between alleyways facilitate inspection by children (Dammerman 1929). Egg masses are removed every 5 days and placed in special containers to allow parasitic wasps to escape while trapping the emerging larvae in a kerosene moat (Kiritani 1979). The necessity of removing egg masses from seedbeds is questionable. Seedlings have narrow solid

stems that cannot be successfully tunnelled by first instar stem borer larvae which then succumb to natural enemies and desiccation. The stem walls of seedlings are also densely packed with silica making larval penetration difficult. Consequently, removing stem borer egg masses from the seedbed is considered to be of doubtful value because damaged plants usually compensate from early stage damage (Jepson 1954). Those that believe removing egg masses is highly useful cite up to 40% yield loss if not done (Ghose *et al.,* 1960). Such studies probably refer to situations where older more susceptible seedlings undergoing elongation were transplanted.

Removal of stem borer egg masses from the field is more efficiently done if timed as based on light trap collections (10 days after a peak moth flight) or timed to coincide with a susceptible crop growth stage. Light trap peak catches in tropical environments, however, have proved to be poor indicators of stem borer field populations. Better prediction is possible in temperate areas. In northern China, egg collections are timed for three generations of yellow stem borer and two generations of striped stem borer (Asa and Fey 1924). Timing of stem borer egg mass removal should coincide with susceptible growth stages – (1) stem elongation in the vegetative stage (to prevent deadhearts) and (2) panicle exsertion (to prevent whiteheads) (Koyama and Tsuchiyama 1964, Tian 1981). Hand removal of egg masses 1 week before panicle exsertion reduced whiteheads by 45% and increased yield by 18% in China (Shiraki 1917) and reduced whiteheads by 50% in Japan (Jepson 1954). It takes approximately 4 days for one skilled person to remove yellow stem borer egg masses from 1 ha (Grist and Lever 1969).

With the onset of monsoon rains, scarab beetles in dryland rice areas fly to host trees to mate. Their larvae, called white grubs, feed on rice roots. White grub beetles can be shaken from trees and collected by children (Otanes 1947, Raodeo and Deshpande 1987). Community efforts are successful because the beetles, with one or two year life cycles, aggregate to preferred host trees and are abundant only over a period of several months each year. Collecting adults prevents egg laying. But some report that the beetles in the trees have already laid their eggs thus nullifying the effect (Kalshoven 1981). Adults can also be boiled and deep fat fried as food.

Swarming locusts can be herded into pits. The technique is to form a human gauntlet made by two rows of workers holding banana leaf or galvanized iron sheet barriers (Jones and Mackie 1913). Others drive the nymphs slowly without alarming them, otherwise they scatter. Rather than digging pits, the nymphs can be driven into portable bag traps (Pratt and South 1913).

Tools have been helpful in removing insects by hand. In Japan striped stem borer larvae, emerging in mass in the spring from stored straw, were raked up and destroyed (Japan 1953). In the field, large combs were designed to run through rice foliage to remove caterpillars (Kuwana 1930).

Sweeping rice plants with nets, bags, or baskets – some coated with sticky materials (jackfruit, latex, castor oil, grease) – have been used to remove rice bugs (Barnes and South 1925), black bugs (Corbett and Yusope 1924), stink bugs (Wallace 1957), leafhoppers (Abalos 1939), planthoppers (Miller and Pagden 1930), armyworm larvae (Nanta 1933), caseworm larvae (Shroff 1920), leaf beetles and hispa (Ghosh 1924b, Kuwayama and Onozaki 1936), grasshoppers (Main 1912) and leaf worms (Korea 1973). Early morning is the best time to net hispa and *Oulema* larvae that are transfering to new leaves (Taiwan 1936). One person can net 2 liters of hispa per day. Armyworms

are best netted at night or, if the field is flooded, swept into baskets (Ramakrishna Ayyar 1933). Large canvas bags (2 x 1 m) on bamboo frames or sectioned oil drums coated on the inside with grease are dragged through rice foliage by two men to capture insects. Walking into the wind keeps canvas bags open and blows the insects inside. Wind inflation of the bag also minimizes crop damage. Some farmers object, however, to passing a net through a crop at the ripening stage, but allow it in grassy borders (Corbett 1930). Triangular aquatic nets are used to collect armyworms, caseworms, and migrating stem borer larvae in cases (Banerjee 1954). Often the water level is raised ahead of time so the insects can be driven to the top portions of the plants for easy removal. Ropes are dragged across the plants or the plants are beaten to dislodge the insects (Ballard 1922). Sometimes ropes are coated with grease to snare rice bugs and other insects (Hutson 1930). A man can rotate a rope across the foliage by tying one end to a stake and walking in a circle holding the other end taut.

Digging up mole cricket (Novelli 1914) and grasshopper (Pratt 1915) eggs from the soil is most efficient in breeding grounds (Gonzales 1932). Plowing is preferred to digging with a shovel or hoe. Mole crickets, their egg pods (Korea 1973) and white grubs (Otanes 1947) are collected by hand from fields during plowing. Mole cricket tunnels are destroyed by shovel (Korea 1973) and adults eaten (Nanta 1935). Logs are dug out of slash-and-burn dryland fields to remove termites (Dammerman 1929), but others (Raymundo 1986) state that logs are beneficial and act to divert termites from the crop.

Techniques have been developed to attract insect pests for more efficient manual destruction. The methods have been most commonly used in seedbeds or small fields. Rafts made of bamboo or banana leaves attract armyworm larvae after the crop is submerged (Otanes 1947). Weeds can be heaped to attract armyworm larvae (Nanta 1935), mole crickets (Kureha *et al.,* 1974), or field crickets (A.T. Barrion, IRRI, personal communication). These insects should be regularly destroyed otherwise they will build up to severely damage the crop. *Echinocnemus* root weevil adults are attracted to erect sticks placed around the seedbed or to sweet potato sections (Kuwayama 1963). Bundles of straw dipped in a mixture of sugar, wine, and vinegar attracts *Echinocnemus* adults. Male white grub beetles are attracted to crushed chillis (Dammerman 1929). Rice bugs are attracted to putrefied meat (Dresner 1958) or decaying aquatic plants (van der Goot 1949) bagged and suspended from poles around a field. Such mixtures are laced with insecticide.

2.2 ROGUING

Roguing is removal of pest infested plants or plant parts by hand or with hand tools. The damage has been done but the effort is exerted to prevent the pest population from increasing. Stem borers (Maxwell-Lefroy 1907, Okazaki 1938), mealy bug (Cherian *et al.,* 1935), root aphids (Tanaka 1961), gall midge (Nguyen 19221, and leaffolders (Korea 1973) have been claimed to be controlled by roguing. Removing deadhearts and whiteheads was first popularized on sugarcane (Jepson 1954). For rice stem borer control roguing should be done thoroughly over a large area and over a number of years (DuPort 1919). However, pulling deadhearts or whiteheads often fails to extract all the stem borer larvae (Ramakrishna Ayyar and Anantanarayanan 1937). Others practice cutting off deadhearts with a knife (Kondo 1917).

A small hand tool was developed in Japan to remove whiteheads but a farmer could only kill 40-80 larvae per day as only half to two-thirds of those whiteheads contained larvae. A further step, said to be only efficient on young rice plants, is to uproot the whole plant upon seeing deadhearts (Usman 1954). Such a practice is counterproductive as plants are destroyed. Roguing silver shoots for gall midge control is advocated but some feel this hinders the plants' compensatory ability (Barnes 1956).

2.3 BUND SHAVING

Mowing and shaving rice bunds is a common rodent and weed control practice that secondarily affects a number of insect pests that spend at least a part of their life in the soil. Armyworms pupate (McKay 1917), grasshoppers oviposit (Ramakrishna Ayyar 1933) and mole crickets tunnel (Kureha *et al.,* 1974) in rice bunds. Soil trimmed from the bunds can be thrown into the flood water to drown eggs and pupae. The sides of bunds can be plastered with fresh mud to trap mole crickets (Hutson 1920).

2.4 CRUSHING, BEATING, AND DRAGGING

Locust breeding grounds can be pounded with malls to crush eggs (Jones and Mackie 1913). Plowing is an easier method. Rice bugs are driven from a crop by frequent beating with sticks (Maxwell-Lefroy 1906). Farmers can beat the foliage during the day but rice bugs are also active at night. A rope soaked in kerosene and held by two men can be brushed across the foliage to kill thrips, hispa, and mealybug (Banerjee 1954, Ghose *et al.,* 1960) by contact. The degree of control, however, is minimal.

2.5 BARRIERS

Aggregated nonflying armyworm larvae, ants, and chinch bug and locust nymphs can be prevented from invading a field or a seedbed by constructing a moat, trench, or petroleum barrier along the field perimeter. Trenches with back-sloping front walls have a greater effect (Hutson 1920). A water moat can be made more impervious with a kerosene film. Barriers work only if the direction of pest movement can be predicted and if the movement occurs over a short period (Isely 1951).

3. Capital Intensive Mechanical and Physical Methods

Using mesh or cloth to protect the seedbed or rice crop is a relatively new technology whereas the use of kerosene light traps for insect control is a traditional practice. The former is used because other modern methods failed and the latter was developed before the era of highly effective petroleum-based insecticides.

3.1 BARRIERS

In temperate areas, nursery boxes are used to incubate seedlings for machine transplanting during early spring and this practice prevents early infestation of insect vectors (Kiritani 1983) and root

weevils (Kuwayama 1963). In warmer climates, covering seedbeds with mesh cloth prevents virus transmission by leafhoppers. But covered seedbeds developed high stem maggot infestations (Okamoto 1957). Farmers in Japan have gone to the extreme of erecting vinyl sheeting wall barriers to prevent *Nephotettix* from entering fields (Hashizume 1964).

3.2 ROLLERS

Animal drawn rollers can be used to crush armyworms and locusts in fallow areas before they invade rice fields (Hutson 1920, Jones and Mackie 1913). Rollers are used to kill overwintering stem borers in stubble (Wouters *et al.,* 1961) and work best if combined with flooding (Douglas and Ingram 1942). In Australia, crushing the stubble with tractor drawn rollers killed 88% of *Scirpophaga innotata* compared to 58% mortality from burning (Halfpapp 1979).

3.3 OIL FILM ON PADDY WATER

A traditional method to control many insect pests is to pour 30-40 liters of kerosene per ha onto a flooded field (Korea 1973). A kerosene soaked rag can also be placed at the water inlet (Ghosh 1924a). Kerosene works best against more mobile insect pests — leaf beetles (Frappa 1938), black bugs (de Alwis 1941), leafhoppers (Japan 1913), planthoppers (Suenaga 1966), seed bugs (Maxwell-Lefroy 1908), root weevils (Kuwayama 1963), armyworm larvae (MacKenna 1918), caseworm larvae (McSwiney 1919), caterpillars (Chu 1936), and grasshoppers (Korea 1973).

In a young crop, two men can drag a rope across the foliage bending it into the kerosene film on the water (Misra 1920). Older rice plants are beaten with bamboo poles or branches or brushed with a rope soaked in kerosene to dislodge insects into the oil. More insects are killed if the operation is done early in the morning when insects are lethargic and after raising the water level as high as possible (Sakai 1934). This technology dates from the 1600s in Japan where whale oil was used before kerosene became available (Korea 1973). A kerosene film is made more toxic if mixed with pyrethrum (Iso 1954). Fields were drained after 6 hours to prevent phytotoxicity. Oil films on the paddy water are highly toxic to many predators and may have caused resurgence of brown planthopper (Kenmore *et al.,* 1984).

3.4 LIGHT TRAPS

Impressed with the many insect pests attracted to light, farmers long ago used fire and established grids of light traps as a communitywide control measure. Bonfires were lit to attract rice bugs (Hutson 1930) and moths (Ramakrishna Ayyar and Anantanarayanan 1937) which then died in the flames. Light traps are said to control stem borers (Yusope 1920), armyworms (Jhaveri 1920), leafhoppers (Fletcher 1913), seed bugs (Sen and Chaudhuri 1959) mole crickets (Otanes 1947), leaffolders (Nanta 1935), gall midges (Murthy 1957), planthoppers (Ghose *et al.,* 1960), root weevils (Newel1 1913), caseworms (Ghose *et al.,* 1960) and caterpillars (Korea 1973). Greater numbers of leafhoppers, planthoppers, and black bugs are collected during a full moon whereas more moths are attracted during a new moon. At peak adoption of this method in the 1930s, over one million traps were set out 1-1.5 m above the crop canopy in China (1 trap per 2.3 ha) (USA 1977) and in Japan

(20 traps per ha) (Kaburagi 1938). A trial in India placed 7 petromax powered light traps per 200 ha and claimed 33% yield increase from gall midge control (Khan and Murthy 1955). As further proof of the value of light traps, pest outbreaks have been reported to occur in India after power blackouts because many insects are normally killed at street lights (Israel and Seshagiri Rao 1954).

Electric powered traps attract high insect numbers but are expensive to operate. Inexpensive low voltage electric traps were developed in China to lower costs (Wittwer 1987). To further minimize expenses, light traps can be set out using seedbeds as trap crops or during critical periods such as right after transplanting for stem borers (Ballard 1923, Puttarudriah 1945) and gall midge (Murthy 1957) and at booting for stem borers (Ramakrishna Ayyar and Anantanarayanan 1937). Also costs can be reduced by operating the traps only during the first few hours after sunset (Kaburaki and Kamito 1929).

Greater catches of leafhoppers are claimed if a person walks through the field at night carrying a lantern held over a basin with soapy water while a second person beats the rice foliage with a stick (Abalos 1939). Better results are achieved if done early in the crop season before most leafhoppers have oviposited.

The use of light traps to control insects has been criticized as farmers in Japan and China noted the same number of deadhearts or whiteheads with or without light traps (Shiraki 1917). Dissatisfaction with light traps also came because of their high cost (Li 1982), theft (Ballard 1923), erratic attraction (Pang 1932), and killing of beneficials (Kondo 1917). Not all pest species are attracted and trapped. The sex ratio of collected insects often favors males (Squire 1933). Many attracted females also had laid most of their eggs (Stewart 1934).

The recent revelation that captures from pheromone traps occur at different times than those in light traps points out that light traps attract insects which are dispersing and thus are not reproductively active. A high mortality normally is associated with dispersing insects so the efficiency of the trap is less than if it attracted virgin females.

Cultural control methods employing crop husbandry practices which require little additional labor or capital may be divided into two spatial dimensions: (1) single field or (2) communitywide. Some practices are effective on either scale.

4. Single Field Cultural Methods

4.1 FIELD GEOMETRY

Larger and more square fields have a lower perimeter to area ratio and therefore suffer relatively less damage from water weevils (Grigarick 1984) or grasshoppers (Main 1912) that accumulate along field borders. Small isolated fields concentrate highly mobile rice seed bugs which seek out flowering stage rice crops (Lim 1970a).

4.2 MIXED CROPPING

One of the first decisions in crop husbandry is selecting the type of crop to be grown. Dryland rice has greater opportunities than puddled rice for crop diversification. Few studies have been con-

ducted to show how insect abundance is affected by intercropping. Dryland rice intercropped with cotton or pigeon pea in one study (Satpathy *et al.,* 1977) resulted in low green leafhopper and whitebacked planthopper numbers. Mixing dryland rice cultivars of various maturities and harvesting individual panicles at maturity reduces storage time and consequently storage pest problems (Raymundo 1986). Wetland rice intercropped with sweet flag, an insect repellant plant, did not affect gall midge (CRRI 1964). In Java the labor intensive sorjan system of alternating ditches and raised beds is practiced. Wetland rice is transplanted in the ditches, and vegetables, field crops, and/or fruit trees are cultivated on the beds. The nonrice crop may offer protection to adjacent intercropped rice. But two studies comparing the incidence of gall midge, yellow stem borer, and leaffolder in sorjan with that in nearby sole cropped ricefields showed no consistent differences in pest abundance (Ruhendi *et al.,* 1976, Rochman *et al.,* 1977).

4.3 PLANTING METHOD

Rice can be planted either by direct sowing into dry or moist soil with dry seeds, onto puddled soil with pregerminated seeds, or by transplanting seedlings in fields with or without flood water. Direct seeding onto dry or nonflooded soil is disadvantageous to aquatic pests. On the other hand, transplanting into flooded fields prevents the establishment of dryland adapted pests. Planting rows oriented north-south lessens intraplant shading and consequently is said to reduce brown planthopper incidence (Oka 1979).

Most of the effects of planting method on pest numbers are the result of differences in planting time, plant density, or water level which occur as a result of changing planting methods. Transplanted rice is often reported to have higher stem borer numbers than a direct seeded crop (Jinnendradasa 1954, Koyama *et al.,* 1968, Israel 1969) which can be attributed to later planting, lower plant density, and a proportionally longer flooding period than a direct seeded crop.

Direct seeded rice often grows less vigorously without standing water during the vegetative stage making it less attractive to yellow stem borers. Stems of direct seeded rice grow more hard and narrow, and therefore cause higher mortality to first instar stem borers (Shiraki 1917). Transplanted crops mature later in the season allowing stem borers to build up on earlier plantings.

A seedbed offers certain advantages for crop protection. The longer seedlings remain in the seedbed the less time vegetative stage pests such as whorl maggot (IRRI 1980) and gall midge (CRRI 1964) have to damage the transplanted crop. Because of their smaller area, seedbeds can be more readily protected from insect vectors than a transplanted field so delayed transplanting is a management tactic to control vector-transmitted diseases. This is particularly important because delayed infection of a crop reduces disease severity (Kiritani 1983). Seedlings can be cultured on plastic or concrete away from fields and thus isolated from insect vectors. In a cold climate, seedlings can be grown in protected nursery boxes and planted earlier than a direct seeded crop. Machine transplanted plants from seedbeds grown under cover had low incidence of dwarf virus vectored by the green leafhopper in Japan (Kiritani 1983). Whorl maggot is not attracted to a densely planted seedbed (Bandong and Litsinger 1986). Alternating flooding and draining of seedbeds, which is practiced to enable seedlings to be easily pulled, is detrimental to both dryland

and aquatic adapted pests. Control of pests is less expensive in a seedbed than a field (Lippold 1972).

A transplanted crop has a shortened field maturation and with the exception of whorl maggot is less damaged by vegetative stage pests. Bundled seedlings, prepared for transplanting, can be held for two days to drive out stem borer larvae (Ramakrishna Ayyar and Anantanarayanan 1937) or can be dipped in hot water to kill hispa (Bouriquet 1937).

4.4 AGE OF SEEDLINGS

Irrigated rice farmers have the choice to plant either young or old seedlings, but yields of modern cultivars decline dramatically when older seedlings are transplanted. Rainfed farmers plant traditional cultivars that are little affected by seedling age. The rainfed farmer has selected such cultivars because he must quickly transplant when rains arrive. Increasing seedling density per hill is necessary to compensate for lack of tillering in older seedlings. The effects of seedling age on stem borer abundance are however inconsistent (CRRI 1983).

4.5 PRUNING

Clipping the tops of bundled seedlings is primarily a practice to prevent lodging (of old seedlings) and stimulate tillering of traditional cultivars but secondarily removes stem borer (Khan 1967) and hispa eggs (Reddy 1968). The practice is not commonly done with modern semidwarf cultivars that are 2-4 weeks old when transplanted and will actively tiller.

Removing the top third of standing crop foliage before flowering has been a practice with traditional tall cultivars to obtain fodder for cattle during the wet season when fallow lands are few (Otanes 1947). This practice removes stem borer egg masses (Catling and Alam 1977), hispa (Agarwala 1955), thrips (Usman 1954), leaffolders (Otanes 1947) and caterpillars (Alam and Alam 1977). Pruning may stimulate higher yields even on a healthy crop (Tripathi *et al.,* 1973) but should not be carried out if the crop is under stress (Jepson 1954). This practice, on the other hand, stimulates tillering making the plants more susceptible to gall midge (CRRI 1975). Cutting rice foliage also makes wounds for entry of bacterial leaf blight (Chu 1971).

4.6 PLANT DENSITY

Dense planting increases populations of planthoppers (IRRI 1977), leafhoppers (Shukla and Anjaneyulu 1981a), leaffolders (Kushwaha and Sharma 198l), gall midge (Pillai *et al.,* 1979), black bug (Dammerman 1929), and caseworm (Venugopal Rao *et al.,* 1982). But whorl maggot (CRRI 1978), root aphids (Tanaka 1961), root weevils (Rolston and Rouse 1964), and leaf beetles (Dhaliwal and Jaswant Singh 1979) are less abundant. Reports on stem borers are mixed; some say stem borers are more abundant (Israel 1969), while others less (Kiritani and Iwao 1967). High seeding rates generally guarantee high yield and offer greater tolerance from those pests that remove seeds or kill seedlings (Pimentel and Goodman 1978). Effects of plant density on insect pest abundance can however be more varied and complex. Dense plantings change crop growth, development, and the microclimate which in turn affect pests and their natural enemies (Teetes

1981). Sparse plantings encourage weeds, and indirectly affect insect abundance. Gall midge numbers rise proportionally with the density of growing points (tillers), therefore greater incidence of galls occurs in dense plantings (Vungsilabutr *et al.,* 1972).

The complexity of the effects is further elaborated with stem borers. More moths hide during the day in dense plantings, presumably because they prefer a high humidity (CRRI 1961). However, at night they oviposit more in sparse plantings, but egg parasites will reach more egg masses in a less dense crop. Both stem borers and parasites can easily penetrate the canopy in less dense plantings (van der Goot 1925). Yellow stem borer moths are also more attracted to water which is more detectable in sparse stands. Tillers elongate more and are softer in dense plantings — thus are more susceptible to penetration by the first instar larvae ensuring higher survival and more deadhearts. High tiller densities result in more infested tillers per area but a lower percentage (CRRI 1970). Results, therefore, should be expressed as the number of infested tillers or deadhearts per area as well as percentage. If there is competition among stem borer larvae for tillers, more tillers guarantee more larvae will survive (Yamazaki and Hatai 1960). However if greater fitness occurs with wider diameter tillers then more larvae will survive in sparse plantings.

Brown planthopper numbers dramatically increase in a dense planting (Hino *et al.,* 1970). The reason given by most researchers is that high relative humidity favors survival (Pillai *et al.,* 1979). However, phytotron studies show that brown planthopper mortality increases at humidities over 60% perhaps because of increased pathogen infection (IRRI 1976). Two other explanations are (1) dense plantings provide more plant surface area and less competition for oviposition or feeding sites (Kenmore *et al.,* 1984) and (2) denser canopies impede egg parasitic wasps (Shepard and Arida 1986).

Whorl maggots lay progressively fewer eggs per area as plant density increases (Bandong and Litsinger 1986). Females may be first attracted to open water and secondarily to rice plants. If the water surface in the field is covered with a dense crop, whorl maggots overfly the field.

4.7 CROP BACKGROUND

Low whorl maggot incidence when azolla water fern covers the water surface during the early vegetative stage, supports the water attraction theory (Viajante and Heinrichs 1985). Reports that azolla augments green leafhoppers and tungro virus are unfounded (IRRI 1983a). The orange leaves of tungro-infested plants contrast more against a green azolla background than open water, and therefore stand out more. Plastic mulch to conserve moisture in dryland rice in Japan resulted in an outbreak of striped stem borer (Ichihara and Matsuo 1970). Perhaps soil dwelling stem borer predators were impaired.

4.8 WATER MANAGEMENT

Aquatic pests — whorl maggot (Feron and Audemard 1956), root-feeding midges (Abul-Nasr *et al.,* 1970), water weevils (Isley and Schwardt 1934), yellow stem borer (Fang 1977), and caseworm (Sison 1938) — are suppressed when fields are drained for 1 or 2 days. Caseworm larvae respire via gills and midge larvae through their body wall. Larvae of water weevils respire through pointed

dorsal protuberances jabbed into the air spaces of roots. The air spaces collapse when the plant is not in standing water (B.S. Vergara, IRRI, personal communication). Draining the field is a common practice to control planthoppers (Das and Thomas 1977) and armyworms (Anantanarayanan and Ramakrishna Ayyar 1937). Drainage as an insect control method was believed to have been discovered because the water in an infested field smelled bad and farmers were primarily concerned with eliminating the bad odor. Draining the field is reported to harden plant tissue making the crop more resistant to insect feeding. Calcium is readily taken up when the field is drained which may be an explanation for this observation (H.U. Neue, IRRI, personal communication).

Dryland adapted pests (which pass at least one stage in the soil) are highly vulnerable to flooding. These pests include armyworms (Ingram 1927), grasshoppers (Katsumata and Nishikawa 1935), thrips (Commun 1937), ants (Dammerman 1929), white grubs (Berthet 1918), mole crickets (Gonzales 1976), root aphids (Grist and Lever 1969), termites (Grist and Lever 1969), root weevils (Tirumala Rao 1952), and seedling maggots (Dammerman 1929). Armyworms attacking a wetland seedbed can be flooded with little effort if water is available. Flooding a dryland environment, however, is normally not considered a rational alternative (Tjoa 1952).

Many wetland pests may be termed semiaquatic, and are controlled by alternate flooding and draining. Semiaquatic insects include black bugs (Fernando 1961), planthoppers (Hinckley 1963), gall midge (Yen *et al.,* 1941), hispa (Bouriquet 1949), and most stem borers (Jepson 1954). Draining minimizes these pests if carried out for 5-7 days but reflooding is necessary to control weeds and prevent crop desiccation. Frequency of the action is important because alternative flooding and draining causes high losses of nitrogen. The degree of control against these pests is enhanced by other management factors acting at the same time.

Increasing the water level drives insects up plants to concentrate their numbers for more effective chemical, biological or mechanical control (Ramakrishna Ayyar 1933). Sowing rice underwater gives initial protection from hispa (Bouriquet 1949) but would inhibit tillering on modern cultivars.

4.9 FERTILIZER

Stem borers (Subramanian *et al.,* 1977), leaffolders (Jaswant Singh and Shahi 1984), planthoppers (Uthamasamy *et al.,* 1983), leafhoppers (Oya and Suzuki 1971), gall midge (Chelliah and Subramanian 1972), armyworm (Koyama 1966), root weevils (Bowling 1963)and leaf beetles (Prakasa Rao *et al.,* 1971) tend to do more damage and increase in number with fertilization, particularly nitrogen. Nitrogen increases the nutrition of both plants and pests. Nitrogen augments plant growth rates leading to softer tissues and quicker penetration by first instar stem borer larvae. This allows more larvae to escape natural enemies (Nadarajan and Janandhanan Pillai 1985). Nitrogen promotes tillering and the increased tiller density affects insects as described earlier. Fertilization promotes even development of a crop in contrast to natural grasslands with varied tillering patterns and consequently low insect incidence (van Emden 1966). Fertilization synchronizes pest development and survival.

The effects of well fertilized plants on insects are greater insect survival, increased tolerance to stresses (pesticides, cold), large body size (greater fecundity), increased feeding rate (more damage), and faster growth (more generations per crop) (van Emden 1966, Sogawa 1970, Tandon 1973, Pimentel and Goodman 1978). Some insect pests, such as thrips (Ghose *et al.,* 1960), and whorl maggot (IRRI 1980) become less abundant if nitrogen is applied.

Nitrogen accelerates plant physiological processes and the production of greater amounts of volatile chemicals attracting more pests which locate their host by odor (Chandramohan and Jayaraj 1977). Nitrogen also reportedly causes, oryzanone, a stem borer attractant to exude from the leaves (Seko and Kato 1950). Organic fertilizer also attracts seedling maggots (Dammerman 1929) and white grubs.

The beneficial effect of nitrogen on plant yield outweighs the pest controlling effect of entirely omitting its use (Oka 1983). Bigger plants from nitrogen application, allow greater tolerance of insect damage (Otanes 1947). But splitting the application, first with a basal soil incorporation for slow release, and using judicious amounts help meet the dual goals of high yields and low pest incidence (Israel and Prakasa Rao 1968).

Phosphorous tends to increase abundance of stem borers but to a lesser degree than nitrogen (Hirano and Ishii 1961, Ferreira 1983). Phosphorous is important in root development therefore allowing the crop to tolerate root weevils (Tirumala Rao 1952).

Potassium however suppresses many pests (whorl maggot, green leafhopper, yellow stem borer, brown planthopper, thrips, leaffolder) by lowering levels of plant sugars and amino acids as well as leading to greater production of allelochemics, thicker cell walls, and greater silica uptake (Baskaran 1985).

Silica, provided by addition of slag, plowing under straw, or from river irrigation water, hardens stems making the crop resistant to stem borer larval feeding (Sasamoto 1957). Zinc is reported to minimize *Elasmopalpus* damage in dryland rice (Ferriera 1983) and bone meal is said to control gall midge (Reddy 1967).

5. Communitywide Cultural Methods

5.1 CROP ROTATION

Breaking the rice cycle with other crops as a method of insect control works best against species with limited host ranges, limited dispersal powers, and long life cycles (Isely 1951). Crop rotation is advocated to control gall midge (Krishnamurthy Rao and Krishnamurthy 1960), stem borers (Sauer 1939, Tian 1981), white grubs (Kalshoven 1981), termites (Ferreira 1983), grape colaspis (Rolston and Rouse 1965), planthoppers (MacQuillan 1974), seed bugs (Uichanco 1921), and armyworm (Am and Nurullah 1977). Crop rotation should be carried out in synchronized plantings over a wide area (Khan 1967). The degree of control increases each year until pest numbers stabilize. The most serious rice pests in Asia are monophagous. But the majority of pests are oligophagous

preferring graminaceous plants. Choosing crops outside the grass family therefore affects the greatest number of pest species. Polyphagous armyworms which build up on rice, can attack a following crop such as berseem fodder (Majid *et al.,* 1978). Maize, wheat, and barley (common crops in rotation with rice) encourage mole cricket (Novelli 1914), smaller brown planthopper (Hokyo *et al.,* 1976), and *Diatraea, Chilo,* and *Sesamia* stem borers (Ingram 1927, Koyama 1964, Lippold 1972).

However two rice pests in the Americas – colaspis and *Elasmopalpus* – have legume hosts. In North America colaspis builds up on lespedeza and soybean planted the previous year (Bowling 1967). Minimal irrigation of lespedeza is recommended to lower colaspis populations (Rolston and Rouse 1965). They further state that planting species of lespedeza resistant to colaspis prevents buildup on rice, and delaying planting of rice and plowing under resulting weeds reduce the impact of colaspis.

Clover rotated with rice is claimed to lower stem borer numbers in untilled stubble (Khan 1967). Otherwise tillage during land preparation of any rotated crop is the significant mortality factor affecting stem borer larvae, not the rotated crop species (Zhan 1977).

5.2 CROP AREA

Most insect pests undergo a period of aerial dispersal in their life cycle but have limited ability in locating a rice crop. The larger the area grown to rice, the greater is the probability that dispersing insects will descend on a rice crop (Loevinsohn 1984). Most pests cannot actively search out a crop and die if they do not land on a suitable host. Increasing the crop area has been said to favor stem borers (USA 1977) and brown planthopper (Kalode 1983). Continuously cropped rice gardens of less than several ha escape insect pest buildup (Pantua and Litsinger 1981) but corporate ventures of the scale of several hundred ha – C.P. Brewer, Solomon Islands (MacQuillan 1974, Ho and Taro 1985) and Philippine Packing, Mindanao – succumb to increasing pest pressure within 5-10 years.

But as the rice area decreased in Japan, green leafhopper and yellow dwarf increased as grassy fallows favored their overwinter survival (Nakasuji 1974). Polyphagous mobile pests however are least affected by crop area (Squire 1933).

5.3 NUMBER OF RICE CROPS PER YEAR

A dry season fallow typical of rice growing areas in the tropics lowers the carrying capacity of rainfed environments (Loevinsohn 1984). Root weevils (Tirumala Rao 1952) and *Scirpophaga innotata* (van der Goot 1948) are highly adapted tropical rainfed species surviving the dry season in the soil or stubble but are eliminated during tillage of a dry season irrigated crop.

Dry season cropping of photoperiod-insensitive cultivars with irrigation extends the temporal availability of rice. Continuous cropping throughout the year allows exponential insect population growth (Loevinsohn 1984). The following pests are reported to be encouraged by sequential rice cropping – whorl maggot (Kalshoven 1981), leaffolders (Tu *et al.,* 1985), black bug (Krishna Ayyar 1929), leafhoppers (Chowdhury and Mukhopadhyay 1973), planthoppers (Oka 1979), thrips (Tu *et*

al., 1985), and stem borers (Khan and Murthy 1955). Pest species that are particularly favored are those that develop on all crop growth stages and are monophagous — *Nilaparvata lugens* (Kalode 1983), *Nephotettix virescens* (Anjaneyulu *et al.,* 1982), *Scirpophaga incertulas* (Tian 1981), and *Maliarpha separatella* (Appert 1967). Gall midge, now also believed to be monophagous (Gagne 1985), is increasing in abundance in dry season irrigated crops (Japan 1984).

On the other hand, continuous rice also sustains natural enemies and behaves as a perennial crop (Balasubramanian and Ooi 1977). Increasing the number of rice crops per year is reported to lower stem borer populations (Tsou 1947). Stem borers have longer generation times than most rice pests and much of their life is spent as relatively immobile larvae. Many are removed and killed during frequent harvests. One report from China claims lower pest incidence in triple than double cropped rice due to the shorter field duration in triple crops (Wong and Kiang 1934). However insect vectors and virus diseases normally build up to unmanageable levels if more than two rice crops are grown.

5.4 PLANT MATURITY

Traditional, photoperiod-sensitive cultivars can only be grown during long day lengths of the wet season. High yielding, photoperiod-insensitive cultivars shorten the maturation time of rices and with irrigation allow yearround cultivation in the tropics (Balasubramanian and Ooi 1977). Early maturing cultivars shorten Geld time, limiting the number of pest generations on each crop. Insect numbers increase exponentially with each generation, therefore shortening crop maturation by only two weeks can have a profound effect (Loevinsohn 1984).

Early maturing cultivars have a reduced vegetative stage. Therefore the negative effect of early harvest has greatest impact on stem borers (Dinther 1971, Agyen-Sampong 1982), armyworms (Alam and Nurullah 1977), gall midge (Patel *et al.,* 1957), leaffolders (Lippold 1972), white grubs (Chowdhuri 1966), leafhoppers (Misra 1920) and planthoppers (Kiritani 1979) which colonize the vegetative stage and can develop over succeeding growth stages. Use of early maturing cultivars as an escape mechanism is particularly effective if planted after a rice-free period induced by winter or a dry season. The effect can be made even more pronounced by early planting and methods that hasten maturity such as dense planting and reduced fertilizer (Isely 1951).

A shortened vegetative stage, however, limits the capability of the crop to compensate from pest damage. Highest yield losses from insects have been recorded in the earliest maturing rice cultivars (Litsinger *et al.,* 1987). As a rule, early maturing cultivars are low yielding (Ghose *et al.,* 1960), but provide greater flexibility for crop managers to shift planting times to avoid seasonal pest incidence. But in the tropics higher yields are attained by growing more crops per year, thus early maturity is often desired. Delayed transplanting at the beginning of the monsoon season using early maturing cultivars causes a suicidal flight of stem borers while still allowing for a timely harvest.

Having a contiguous area planted to a mosaic of different fields of early, medium, and long maturing cultivars, breeds insect pest problems through staggered plantings (Tian 1981). In Taiwan, mixing early (4 month) and late (7 month) maturing cultivars in the same field resulted in high yellow stem borer numbers in the late crop (Shiraki 1917). If an area is dominated by a single-crop

planted to photoperiod-sensitive cultivars higher damage often occurs from stem borers than a double crop using early maturing cultivars (Torii 1971).

5.5 PLANTING TIME

The effects of shifting the planting time of the rice crop are more highly site specific than perhaps any other cultural control method. Generalizations are difficult as a shift of planting time of 1 week is sufficient to significantly increase or decrease insect numbers (Jepson 1954). Both early or late plantings may miss peak abundance of the damaging pest stage. Early plantings minimize gall midge (Prakasa Rao 1975), thrips (China 1976), grasshoppers (Mochizuki 1957), leaf beetles (Breniere 1966), stem borers (Khan 1967), root weevils (Isely and Schwardt 1934), leafhoppers (Shukla and Anjaneyulu 1981b), planthoppers (O'Connor 1952), seed bugs (Srivastava and Saxena 1967), whorl maggot (Mochizuki 1957) and caterpillars (Okamoto and Abe 1960).

Late plantings likewise minimize many of the same pests—gall midge (Mallik and Behera 1965), thrips (Yau-i 1980), leaf beetles (Frappa 1938, Hirao 1978), stem borers (Tsutsui *et al.,* 1957, Sauer 1939), root weevils (da Silva Martins 1976), leafhoppers (Kiritani 1981), planthoppers (Okamoto *et al.,* 1967), seed bugs (Kiritani *et al.,* 1961), leaf miner and black bug (Mochizuki 1957), and caterpillars (Ishikura 1961).

Pests for which only early plantings resulted in low populations were midges (Grigarick 1984), seedling maggots (van der Laan 1951), leaffolders (Okamoto and Abe 1960), whorl maggots (Okamoto and Kashihara 1954) and armyworms (Hutson 1920). Pests for which only late plantings were recorded as offering control were white grubs (Chowdhuri 1966), root aphids (Tanaka 1961), leafminers (Ito *et al.,* 1970), and grasshoppers (Mochizuki 1957).

The basis for planting time shifts is in the cyclical occurrence of insect stages, as not all stages injure the rice plant. Shifting the planting date will disadvantage the pest when the prevalent insect stage is vulnerable to air or water temperature extremes, heavy rainfall, a nonpreferred crop growth stage, or the abundance of natural enemies (Teetes 1981). Although there are exceptions, often early plantings of a first or single crop escape pest colonization (Pimentel and Goodman 1978) while late plantings of a first crop are benefited by high levels of natural enemies and delayed plantings of a second crop by suicidal flights. Planting time interactions are greatest if carried out over large areas and against monophagous pests that attack one growth stage or are highly seasonal in appearance (Isely 1951). Shifting planting time has little effect in an asynchronous area (Logothetis 1951). A disadvantage is that shifting a planting date may reduce the number of crops that can be grown annually (van der Goot 1948).

An effective use of planting time is to strategically time an areawide rice planting after a dry season. The most classical example was practiced in Java in the 1920s and 1930s where planting after the prolonged dry fallow period was delayed to control *Scirpophaga innotata* (van der Goot 1948). *S. innotata* underwent a predictable aestivation period that was broken by the first monsoon rains. Delayed planting until after the moths emerged and died — termed a suicidal stubble flight — suppressed the stem borer for the entire crop season.

On the other hand, timely planting with the onset of monsoon rains allows the crop to mature past the early growth stage before pests can colonize the crop. Rain breaks the dry season dormancy of the gall midge and planting early allows the crop to escape the vulnerable tillering period. Low gall midge damage also occurs if the crop is planted later than normal because by that time its parasites have become abundant. With photoperiod sensitive cultivars, late planting have a reduced tillering period and less gall midge damage (Hidaka *et al.,* 1974).

In temperate regions, *S. incertulas* emerge from field stubble sooner and more synchronously than *C. suppressalis* which emerges from straw stored under various conditions and thus at various temperatures. Two effects of shifting planting time were identified — (1) the timing of emergence of overwintered moths in relation to the crop growth stage and (2) the stage of development of the second generation larvae at harvest. Greatest reduction in stem borers occurred if both effects acted negatively on the same crop. The shift in the 1950s to earlier planting in southern Japan to avoid typhoons was studied intensively with regard to changes in pest abundance (Ishikura 1964). The rice crop is particularly vulnerable to stem borers during tiller elongation and panicle exsertion (van der Goot 1925, Tian 1981). Timing the crop so that eggs are laid either before or after these stages substantially reduces damage (Suenaga 1966). Early planting minimized both stem borer species that emerged to oviposit on a crop before or after tiller elongation. Heavy mortality also occurred if harvest was timed when stem borer larvae were too small to enter diapause (Ono *et al.,* 1972).

Early planting in Japan increased green leafhopper and the rice dwarf disease they transmit. They overwinter as mature nymphs in grassy fallow areas, and the crop is transplanted from covered seedbeds before the nymphs molt. Colonizing adults then attack a favored rice crop instead of a fallow.

The green leafhopper is highly seasonal in South Sulawesi, Indonesia, thus the tungro virus disease it vectors is controlled in an irrigated double crop area carrying out strict planting schedules (Manwan *et al.,* 1985).

When only a portion of the farmers plant early and others delay, this creates staggered planting and increased pest buildup (Oka 1979). Communitywide coordination therefore is necessary.

Shifting planting time also means growing the crop under different weather conditions and often planting early in a rainfed area increases risk from drought or typhoons. An early planted rainfed crop may take advantage of the flush of mineralized nitrogen which could either mean greater tolerance to pest damage or make the crop more susceptible to stem borers. Although the crop is more susceptible to stem borers few may find the crop.

5.6 SYNCHRONOUS PLANTING/FLOWERING

Staggered planting ensures greater survival of rice pests yearround by extending the temporal availability of rice as a host in a farm community (Ramakrishna Ayyar 1933, Loevinsohn 1984). Asynchrony of harvest in the community lessens the risk of crop failures due to typhoons or other

calamities. In Japan the introduction of early planting caused staggered planting and green leafhoppers increased five fold (Kiritani *et al.,* 1970).

Synchronous planting allows a planned non-rice break to occur during the year to interrupt pest cycles. Planting of contiguous crops should occur within a time span less than the generation time of rice pests and over a spatial scale larger than the effective dispersal range, normally in the order of 1 km. Therefore a minimal area of 1 km^2 (314 ha) should be considered. Often synchronous planting on an area-wide basis is enforced bylaw (Logothetis 1951, Khan and Murthy 1955, Manwan *et al.,* 1985). Synchronous planting is advocated for management of planthoppers (Oka and Bahagiawati 1984), leafhoppers (Basu *et al.,* 1976), stem borers (Chen *et al.,* 1968), gall midge (Li 1982), leaf beetles (Iso 1954), caseworm and caterpillars (IRRI 1983) and mites (Ho and Lo 1979), and root weevils (Tucker 1912). Monophagous pests are most affected by synchronous planting. Also planting cultivars of differing maturities to ensure synchronous flowering reduces panicle feeding pests (Uichanco 1921, Kiritani 1971).

On the other hand, asynchrony maximizes populations of natural enemies (Lim 1970b). However synchrony is a more reliable control measure than natural enemies especially in preventing virus disease transmission by insects.

5.7 TRAP CROP

The trap crop technique relies on the attraction of insect pests to plantings other than the main rice crop (Isely 1951). Timing is important in utilizing a trap crop (Jepson 1954) as the pests should not be allowed to reproduce. A trap crop should not sacrifice field area.

The Chinese have used the trap crop technique to control stem borers by planting many small fields comprising 0.7 to 5.0% of the rice area ahead of the main crop and increasing their attraction by using susceptible cultivars, high amounts of nitrogen, and lights (Cheo *et al.,* 1964, S-mei 1976, Zhan 1977). Stem borers are controlled by manually removing egg masses from the trap crop plants or with insecticide (van Dinther 1971). Trap crops were also used in Java to attract the highly synchronized emergence of *Scirpophaga innotata* moths (Li 1961).

It is important to plant a trap crop over an area large enough to attract the resident pests. Trap crops in India occupying too small an area (200 m^2) did not show promise (Khan 1967).

Another successful method used in Japan was to delay spring land preparation of the weedy fallow until after emerging green leafhopper and small brown planthopper adults laid eggs (Kono *et al.,* 1972). This method requires perfect timing. Leaving small patches of weeds to attract seed bugs also has been used (Corbett 1930). The patches are frequently sprayed with insecticide while fields are thoroughly weeded.

A final technique, only tested experimentally, is to plant 2-3 border rows of a field ahead of the main crop to a highly susceptible cultivar to attract stem borers (Ghosh and Choudhury 1969), brown planthoppers (Saxena and Justo 1984), or green leafhoppers (Saxena and Justo 1987). The border areas are then sprayed. The problems with earlier plantings are that more extended water

delivery is required, the pest-free fallow period is reduced, and synchronous planting is less effective (Isely 1951).

5.8 FLOODING STUBBLE

In areas with sufficient water, harvested fields can be submerged to drown stem borers (Harukawa 1920), armyworms (Hutson 1920), and grasshoppers (Katsumata and Nishikawa 1935) that would persist to attack a following crop. This method is particularly effective if carried out community wide.

Flooding the field after harvest has been used mainly for stem borer control. Yellow stem borer is highly adapted to submerged conditions and is a serious pest of deepwater rice. The larva survives only because of the triple membrane it builds to seal itself within the tiller (Shiraki 1917). It is inadvisable to flood right after harvest unless the operation is combined with tillage to lacerate the stubble allowing quicker entry of water (Tian 1981).

Hours and days rather than minutes are required to drown insects. Striped stem borer larvae died within 1 hour in 45°C water but 28 hours were necessary at 30°C. The warmer the water, the greater is the mortality (Harukawa 1920). However in many areas the stem borer larvae are in a state of diapause and respire at very low levels. Reports from China state that flooding for at least 1 month is required to cause significant mortality of insects in dormancy (Li 1982). Very few locations would have such quantities of water to manage pests. However if the flooding is done in the spring after the larvae have terminated vernal diapause but before moth emergence, high levels of mortality occur. Timing of the operation is obviously critical and the field should be underwater for 1 week (van der Goot 1925).

Flooding the stubble before the monsoon rains is a way of initiating a suicidal *Scripophaga innotata* flight. Again timing is critical because the larvae must pass 3.5 months in aestival diapause before they become responsive. Flooding too early will have no effect. Flooding must be done only several weeks before the main monsoon rains are expected and diapause is broken (Li 1972).

5.9 TILLAGE

Turning the soil over crushes insects, buries them, destroys their nests, and exposes them to desiccation and predators. A moldboard plow gives best results particularly if combined with harrowing to break up root masses (Khan 1967). Tillage can be performed most frequently in dryland fields during land preparation or interrow weed cultivation of rice or crops preceding or following rice. Soil insects prefer moderately moist soil. If the soil is wet, more insects will be within the plow zone (Tjoa 1952). Dry season cultivation in the drylands is therefore of little benefit for insect control as the insects have tunnelled deep into the soil. Soil-dwelling pests of dryland rice—whitegrubs (Maxwell-Lefroy 1906), mole crickets (Novelli 1914), termites and ants (Dammerman 1929), root bugs (Headlee and McColloch 1913), and ants – become reduced in number with each tillage operation. Dryland communities extensively cropped to annuals and where tillage is practiced throughout the year have fewer soil insect pest problems than communities with large areas of perennial grasses which remain a source of reinfestation.

Tillage of wetland fields is more limited and can be done only when the soil is moist, which generally means after soaking during land preparation or after harvest (Chatterjee *et al.,* 1979). Tillage after rice harvest directly kills stem borers (Jepson 1954), armyworm pupae (Jhaveri 1920), grasshopper eggs (Jones and Mackie 1913), black bugs (Shepard *et al.,* 1988), and root weevils (Kuwayama 1963). Tillage to destroy crop residues is of greater importance if more than one crop is grown annually.

Tillage soon after harvest prevents unwanted crop regrowth (volunteer ratoon) which perpetuates gall midge (Reddy 1967), leafhoppers (Hokyo 1975), and planthoppers (Sakanoshita and Koide 1971), and virus diseases that may be transferred to neighboring seedbeds or younger fields (Anjaneyulu 1975). Stubble plowdown kills the ratoon to stop pest cycles, particularly monophagous pests, if carried out communitywide. Stubble plowdown should be combined with synchronous planting for best results (Fernando 1967). Greatest benefit occurs in areas where more than one rice crop per year is planted. In single cropping, high mortality normally occurs during the long fallow with the exception of pests that undergo dormancy (*e.g.* stem borers and gall midge). Turning over the stubble mat breaks the hibernacula of stem borer larvae allowing moisture and pathogens to enter (Khan 1967). Undamaged stubble, even though plowed under, allows high stem borer survival. The stubbles need to be broken open for greatest mortality (Khan 1967). Also, lower stem borer survival is related to how long stubble is buried rather than depth of coverage (Shiraki 1917).

It is preferable agronomically to plow stubble under after harvest to increase soil organic matter and recycle nutrients (Cleare 1927). But allowing the ratoon and weeds to grow is often done to provide grazing for livestock during the off season. This practice allows insect pests to carryover between crops. Tillage during land preparation can control dormant stem borer larvae before they emerge as adults, but timing of these operations on a community wide basis is highly critical. If for some reason tillage is delayed, pest problems worsen.

5.10 WEEDING

Most rice pests can develop on the common ricefield weeds, mostly grasses, that occur in fallow fields, border areas, or in association with rice. Weed hosts act as a bridge between rice crops or preferred stages of rice crops to sustain pest populations (Jepson 1954). Weedy rice fields often have higher populations of some rice insects. Weeding is advocated for control of leaffolders (Kalshoven 1981), leafhoppers (Abalos 1939), planthoppers (Oka 1979), seed bugs (Akbar 1958), gall midge (Israel *et al.,* 1970), caterpillars (Japan 1913) leaf beetles (Prakasa Rao *et al.,* 1971), stem borers (Catling and Alam 1977), black bug (Corbett and Yusope 1924), mealybug (Ramakrishna Ayyar 1939), armyworms (Hutson 1920), caseworm (Shroff 1920), root aphids (Otanes 1947), root bugs (Isely and Horsfall 1931), root weevils (Ishly 1975), colaspis (Rolston and Rouse 1965), leafminer (Kuwayama 1950) and seedling maggot (Grist and Lever 1969). Dense vegetation is a preferred habitat for leaffolder and stem borer moths. Weeds also interfere with insecticide coverage. Hispa (Prakasa Rao and Israel 1970), seed bugs (Dammerman 1929) and water weevils (Tucker 1912) build up on grassy weeds early in the season and later transfer to rice. Weeds

therefore can act as a diversion but the effect is reversed once the weeds are controlled or senesce. Armyworms prefer grassy weeds and transfer to rice after weeding operations (Grigarick 1984). Early weeding therefore is important to kill the armyworms before they become large enough to migrate. The gall midge does not occur in regions lacking wild rice alternate hosts.

Areawide weed control is a requirement for successful insect control as most pests are highly mobile and can fly to distant fields. Good weed control also allows the rice crop to tolerate more pest damage (Rolston and Rouse 1965).

5.11 HARVEST METHOD

The cutting height of the crop at harvest influences the control of stem borers. Panicle harvesting, a traditional practice, allows 98% of the stem borer population to carryover to the next rice crop (FAO 1979). Stem borer larvae descend to the base of the plants to pupate or to pass an unfavorable season in larval diapause. How far they descend depends on the pest species and flood water depth. Lowering the cutting height results in proportionally more larvae in the straw (Shiraki 1917). The greatest degree of control occurs when the stubble is cut below 15 cm (Lippold 1972). The yellow stem borer was claimed to be controlled in Taiwan when the stubble was cut at ground level (Jepson 1954). However, if the larvae were in diapause, ground level cutting only removed 14%(Islam 1976). Harvesting before larvae descend below the cutting height is a practice to capture more larvae in the straw (Li 1961).

5.12 STRAW AND STUBBLE DESTRUCTION

Management of postharvest crop residue is mainly directed at stem borers. Even though there is normally a high natural mortality after harvest, small differences in numbers that carry-over from one crop season to the next, can, through exponential increase, become significant. Burning straw and stubble in the field is a common practice and is claimed to control stem borers (Commun 1934), armyworms (Alam and Nurullah 1977), planthoppers (Oka 1979), and leaffolders (Korea 1973). Piled straw burns thoroughly but standing stubble does not. Spreading the straw to allow the sun's heat to kill stem borers is just as effective as burning (Khan 1967) and allows natural enemies to seek shelter to survive (Lim 1970) as well as conserve nutrients which would be lost in the smoke (Cleare 1927). Attempts to increase the burn of stubble by flame throwers (Israel and Prakasa Rao 1968) or collecting more straw from neighboring fields (Khan 1967) are impractical. Weedy and direct seeded fields produce better burns.

Often straw is stacked to be used as fodder, mulch, fuel, or in mushroom culture. Using straw as fertilizer in greenhouses in Japan is claimed to help control striped stem borer (Kiritani 1979). Stacked straw can be mixed with stems of maize or sorghum. Striped stem borer but not yellow borer larvae will transfer to these plants that act as a trap crop (Shiraki 1917). Stacking straw in the open overwinter confers greater mortality of stem borers particularly those exposed in the outer layers. As the straw is used, larvae in the newly exposed layers will be killed by the cold. In Japan, striped stem borer moths emerge two weeks earlier in the spring from straw stacked in the open compared to straw under a shelter (Ozaki 1940). Earlyemergence becomes a suicide flight as the seedbeds are

either covered or not yet sown. Another method is to cover the stacked straw with a cloth in the spring to prevent moth emergence (Pang 1932).

Striped stem borers remain in the stubble at or below the ground level. A labor intensive practice was to pull out the stubble by hand or by hand tool, roots and 211 (Shiraki 1917). A special hand tool was developed in Japan to recut the stubble below ground level after harvest (Shiraki 1917). Stubble was also raked to kill stem borers (Khan 1967). Over 90% of striped stem borers were controlled by these intensive methods. Stubble destruction before winter also reduced the number of tillage operations needed in the spring.

5.13 RATOONING

A ratoon extends crop availability for additional pest generations. The higher the main crop is cut, the sooner the ratoon appears, as the new tillers emerge from axillary buds. Reproductive stage pests are favored in a ratoon. Stem borers survive in the stubble. Leaffolders thrive in a ratoon crop, perhaps because of the large or physiologically older leaves (Chen and Wang 1978). Gall midge is favored by tillering but normally parasite numbers are also high and temper the infestation (Rao and Murthy 1961). Planthoppers and leafhoppers would be expected to multiply, but as their predators and parasites are also spared, build up is normally curtailed. Seed bugs can increase as they are long lived and can survive between the ripening stages of the main crop and ratoon.

The most serious pest problem is insect-vectored virus diseases—yellow dwarf and tungro—which can be contracted late in the main crop without visible symptoms but later appear in a ratoon (Prakasa Rao and John 1974). Vegetative pests — whorl maggot, caseworm, defoliators *(Naranga, Rivula)* — are disadvantaged (dela Cruz and Litsinger 1988) because the vegetative stage is of minimal duration in a ratoon.

5.14 GRAZING

Grazing livestock in a recently harvested rice field causes stem borer larvae lingering in the stubble to be trampled. The beneficial effect is on the subsequent crop and is proportional to the stocking rate and size of animal. Studies in the USA (Douglas and Ingram 1942) and Australia (Li 1972) claim 57-75% control. But many cattle died from an unknown cause when grazed on rice during an outbreak of fall armyworm (Brown and Mohamed 1972). Grazing also helps to remove weeds (Hutson 1930).

6. SYNOPSIS

A wide range of mechanical, physical, and cultural methods are potential practices, and their use will depend on existing alternatives and local conditions. A synopsis of the most practical methods is presented.

Handpicking and netting are labor intensive but can be useful in certain situations. Because they are food items, white grub adults, locusts, and mole crickets may be rewarding for the poorer

farmers. It may be appropriate to net caterpillars, armyworms, and caseworms when abundant in seedbeds or small dryland fields. Complete control is not necessary in these situations as the seedlings can normally recover from moderate infestations. Stem borer egg masses pose little threat to a seedbed but it may be attractive to remove them by hand from the field before stem elongation, particularly eggs of those species that oviposit openly. Egg masses are most easily seen on young plants. Egg parasites should be spared by allowing them to escape. Collecting egg masses just before panicle exsertion is probably futile as they are difficult to see in fully grown plants.

Roguing is not practical as the damage is already done. Shaving rice bunds would not be done solely to control insect pests but is a normal practice of most farmers for rodent and weed control. It would be an exceptional case where constructing a moat or kerosene barrier to protect a seedbed from invading armyworms would be practical. Nursery boxes are used in temperate regions primarily to start an early crop, and insect control is secondary. Rollers and other heavy equipment are generally unavailable and thus of improbable use of small scale farmers.

Kerosene or oil applied to flooded fields is expensive, phytotoxic, harmful to aquatic natural enemies, and requires additional effort to dislodge pests from foliage. The treatment would have to be repeated before any significant population reduction would occur. Light traps are expensive and capture only a small proportion of a pest population.

Changing field geometry and intercropping are done for reasons other than controlling insects and are usually not a viable pest control option. Changes from transplanting to direct seeding are done because of labor costs, not to alleviate insect damage. But in a tungro infested area, farmers may wish to establish dapog seedbeds away from infested fields.

In irrigated areas low yields are expected if transplanting of modern varieties is delayed beyond one month. Irrigated farmers therefore have little incentive to transplant older seedlings. Rainfed farmers, however, plant low tillering traditional cultivars that can be transplanted from 2 to 3 months old seedbeds without yield loss. Rainfed farmers transplant when the rains occur and cannot risk delaying transplanting to achieve better insect control. Pruning seedlings is a practice for traditional varieties but is usually done to prevent lodging and promote tillering. There is some scope to support the practice of clipping foliage from rice plants attacked by thrips, hispa, or leaffolders and to use the foliage as animal forage. Yield may be stimulated if pruning occurs before tillering. Moderate plant densities appear to be a practical target for best agronomic yield and lowest insect pest numbers in general.

Draining a field to control aquatic insect pests has merit if water is less expensive than other control measures. Irrigation costs are often high making this option unattractive. Fields should be reflooded within a few days, for weed control, if drained before canopy closure.

Excessive use of fertilizer invites insect and disease problems. Therefore optimal levels of fertilizer with split applications are warranted.

It is impractical to consider regulating crop area. Ecologically, flooded rice is cultivated in contiguous lowlying areas in which dryland crops would become waterlogged in the rainy season. The effect of limiting the area planted on insect control is minimal except at low crop densities.

The most profound cultural control practice is to isolate the rice crop in time. This is accomplished by growing no more than two rice crops annually. Early (100-130 days) cultivars should be grown. Cultivars less than 100 days seed-to-seed are too sensitive to stress. Crop maturity greater than 140 days encourages stem borers and brown planthopper. If possible, the crops should be planted at times of least pest abundance and the rice-free period should occur during the driest part of the year so that stubble will not regrow, thereby killing insect pests and virus diseases. The stubble should be plowed under during the rice-free period to control stem borers. The best effect is to plow under the rice stubble before planting a non-rice third crop, and again before the wet season, followed by prolonged flooding. Flooding should last one week during land soaking to ensure greatest stem borer control at the start of the season. Each of the two rice crops should be planted synchronously (within three weeks) over an area of more than 300 hectares. In temperate regions small trap crop seedbeds may be planted at the beginning of the rainy season and then plowed under.

Management of the cutting height and straw is directed towards stem borer control. If rice is double cropped with early maturing cultivars and the stubble is plowed under between crops, then cutting height and straw management are not important considerations. However if the rice crop is long maturing then management of crop residues becomes important. The stubble should be cut lower than 15 cm and the straw spread and dried in the sun. If the stem borer undergoes dormancy in the off season then wet season plowing and flooding are advisable. Populations of insect pests are not static and can adapt to stresses from pesticides (insecticide resistance), resistant cultivars (biotypes), parasites (encapsulation), and predators (change behavior to avoid capture). Rice insect pests have also adapted to changes in cultural practices.

Local biotypes of striped stem borer exist in various regions in Japan. These biotypes emerge at different times in the spring in response to prevailing planting schedules rather than spring temperatures per se. Moths began to appear earlier in areas that switched to early planting (Fukaya 1951). When Japanese farmers changed to early maturing cultivars, striped stem borers emerged from hibernation earlier (Ishikura 1956). Longer maturing biotypes of striped stem borer developed on early maturing late season rices in order to time their development so that the larvae were in a pre-diapause stage right before harvest, thus ensuring the greatest off season survival. Ill-adapted biotypes emerge near harvest to constitute a suicidal third generation that perishes overwinter. In addition, when stubble heights were lowered, natural selection favored stem borer larvae that descended below the prevailing cutting height (DuPort 1925).

However, cultural control practices that are preventative rather than corrective form a first line of defense. Combining a rice-free period with crop rotation of botanically unrelated crops, for example, poses a difficult obstacle for rice insect pests to overcome. However, mechanical, physical and cultural methods will not by themselves prevent economic damaging levels from being reached. These practices along with resistant cultivars and judicious use of chemicals to conserve natural enemies form the foundation of insect pest management in rice.

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7

Predators and Parasitoids of Rice Insect Pests

P. A. C. OOI,
CAB International Institute Of Biological Control
(CIBC) Malaysian Station, Batu Tiga
Selangor, Malaysia

B. M. SHEPARD
Department of Entomology
International Rice Research Institute
Los Baños, Philippines

1. APPRAISAL AND DIRECTION

LONG HISTORIES OF RICE CULTIVATION in many parts of the world have allowed stable relationships to evolve between rice insect pests and their natural enemies. Natural biological pest control managed insect pests long before the advent of synthetic insecticides. That action of indigenous predators, parasitoids and insect pathogens forms the cornerstone of modern Integrated Pest Management (IPM) programs in rice.

When modern improved rice varieties were introduced in the mid-l960s, chemical insecticides were embraced as part of the package of technologies of the green revolution. With increased adoption of new high yielding varieties, use of insecticides also increased. Planting resistant varieties and using chemical insecticides were the primary insect control tactics.

The destruction of predators and parasitoids that followed insecticide misuse resulted in resurgence of several rice pests including the brown planthopper (BPH), *Nilaparvata lugens* (Stal) (Homoptera: Delphacidae) (Heinrichs and Mochida 1984, Kenmore, *et al.,* 1984), green leafhopper (GLH), *Nephotettix* spp. (Kobayashi l96l), and rice stem borers (Lim *et al.,* 1980). Chronic outbreaks of the brown planthopper in Indonesia in the mid 1980s were attributed to excesive use of insecticides in rice fields. The result was the Presidential decree in 1986 banning use in the rice

environment of more than 57 insecticides (England 1987). The story of mismanagement of natural enemies, particularly predators and parasitoids, has repeated itself many times before in other crops, for example cotton in Peru (Boza Barducci 1972), cocoa in Sabah (Conway 1971), and oil palm in Peninsular Malaysia (Wood 1964). Pest outbreaks were reduced following a conscious effort to conserve the natural enemies in all these cases.

Classical and inundative biological control approaches tried so far have met with dismal failures, and there is little potential for this approach in rice. Here we emphasize maximizing the impact of indigenous natural enemies as an essential part of IPM programs. We believe biological control of rice insect pests in tropical south and southeast Asia lies in the identification and conservation of their natural enemies.

Because much of the scattered literature related to the biological control of rice insect pests is anecdotal, with few quantitative or definitive studies, we make no attempt to include an exhaustive literature search. Our objective is to focus on biological control issues and concepts drawn from selected literature and our own experiences. This chapter covers arthropod predators and parasitoids in rice in tropical south and southeast Asia and is oriented toward plant protection specialists, particularly those working in rice. The important insect pathogens are covered in chapter 8 and the taxonomy of predators and parasitoids is included in chapter 2.

2. CASE STUDIES

In the past, biological control of rice insect pests emphasized the importation of parasitoids and/or mass rearing of egg parasitoids for release at regular intervals. Little attention was paid to the use of predators. Two groups of insect pests were involved, stem borers and defoliators. The examples of attempts at biological control of rice insect pests listed in Table 1 were selected to show the limited successes of introduction, augmentation, and inundation of natural enemies in controlling pests.

2.1 EXOTIC PARASITOIDS FOR EXOTIC PESTS

In two cases, introduction of exotic parasitoids resulted in successful biological control (Table 1). The first was the biological control of *Chilo suppressalis* (Walker) (Lepidoptera: Pyralidae) (referred to as *C. simplex)* in Hawaii. *C. suppressalis* had been accidentally introduced into Hawaii, probably in rice straw used for packing. Three parasitoids were introduced in 1929, an egg parasitoid, *Trichogramma japonicum* Ashmead (Hymenoptera: Trichogrammatidae), from Japan and two larval parasitoids, *Eriborus sinicus* (Holmgren) (Hymenoptera: Eulophidae) and *Bracon chinensis* Szepligeti (Hymenoptera: Braconidae), from China. All three parasitoids helped reduce the infestation of this stem borer (Sweezey 1931).

In the second case, reported by Hinckley (1963), the leaffolder, *Marasmia (Susumia) exigua* (Butler) (Lepidoptera: Pyralidae), had arrived in Fiji sometime before 1944. A larval parasitoid, *Trathala flavoorbitalis* (Cameron) (Hymenoptera: Ichneumonidae) was introduced from Hawaii. Apparently, the introduction reduced leaffolder population density.

TABLE 1

Some examples of past attempts at classical, augmentative and inundative biological control of rice insects pests

Pest group/species	*Parasitoid species*	*Origin*	*Introduced into*	*Year*	*Stage attacked*	*Status**
Stem borers						
Chilo suppressalis	*T. japonicum*	Japan	Hawaii	1929	egg	S
	E. chinensis	China	Hawaii	1929	larva	S
	E. sinicus	China	Hawaii	1929	larva	S
Chio polychrysus	*P. claripalpis*	Trinidad	Malaysia	1951	larva	F
Scirpophaga incertulas	*T. japonicum*	Japan	Philippines	1934	egg	E
	S. *inferens*	India	Philippines	1966	larva	E
Chilo suppressalis	*Trichogramma* sp.	Philippines	Japan	1929	egg	F
Chilo polychrysus	T. *japonicum*	indigenous	Malaysia	1931	egg	F
Defoliator						
Susumia exigua	*T. flavooribitalis*	Hawaii	Fiji	1928	larva	S

* Status of biological control:
S - successful biological control
F - failed to provide control
E - established but no control exerted

However, not all attempts at classical biological control of rice pests have sucessful conclusions. The sucesses mentioned here were dependent on the types of pests involved. Both were exotic pests, suitable candidates for classical biological control.

2.2 EXOTIC PARASITOIDS FOR INDIGENOUS PESTS

Several attempts have been made to introduce exotic parasitoids to control indigenous rice insect pests in south and southeast Asia (Table 1). One case involved the introduction of *Paratheresia claripalpis* (ven der Wulp) (Diptera: Tachinidae) to control *Chilo polychrysus* (Meyrick) (Lepidoptera: Pyralidae) in Malaysia. *P. claripalpis* is a parasitoid of sugarcane stem borers in the new world. The rice environment and the rice stem borer it was meant to control were very different in Malaysia. The tachinid apparently failed to adapt and, after the release of 8,187 adults, none were recovered.

A more recent introduction of parasitoids from a different host to control a rice insect pest also failed. B. M. Shepard introduced two egg parasitoids to control the Malayan black bug, *Scotinophara coarctata* (F.) (Hemiptera: Pentatomidae) on the island of Palawan in the Philippines. The parasitoids, *Psix lacunatus* Johnson and Masner (Hymenoptera: Scelionidae) and *Telenomus cyrus* (Nixon) (Hymenoptera: Scelionidae), were collected from the eggs of an economically unimportant pentatomid, *Scotinophara latiuscula* Breddin (Hemiptera: Pentatomidae) on the island of Luzon. A total of 12,840 *P. lacunatus* and 19,330 of *T. cyrus* were released in 1985-1987; to date, none have been recovered.

While a few introductions of parasitoids from a different species of pest related to the target insect have been successful, examples are not common and none are known in rice. The best known case is the biological control of the coconut moth in Fiji (Tothill *et al.,* 1930). In this case a larval tachinid parasitoid, *Bessa remota* Aldrich (Diptera: Tachinidae) which parasitised *Zeuxippa catoxantha* Hampson (Lepidoptera: Zygaenidae) in Malaysia was introduced to control *Levuana iridescens* Bethune-Baker (Lepidoptera: Zygaenidae) in Fiji. Both *L. iridescens* and 2. *catoxantha* caused similar damage to coconuts and it is likely that the parasitoid had little difficulty adapting to a similar environment.

Kamran and Raros (1971) reported the introduction of *Sturmiopsis inferens* Townsend (Diptera: Tachinidae) from India in an attempt to control rice stem borers in the Philippines. Although the parasitoid was established, it is not an important mortality factor. This is another example of the failures experienced with the classical biological control approach of indigenous rice insect pests in tropical south and southeast Asia.

In 1929, Shibuya and Yamashita (1936) imported an egg parasitoid from the Philippines into Japan and experimented on its mass rearing and release for the control of *C. suppressalis* (known as *C. simplex).* This introduction was carried out despite an existing indigenous egg parasitoid, *Trichogramma japonicum* Ashmead (Hymenoptera: Trichogrammatidae). The introduced parasitoid could be differentiated from the black native one by its yellowish body color. The researchers found that the imported egg parasitoid did not perform as well as the indigenous one, and concluded that there was no possibility of success in using the imported species. This example suggests that the introduction of additional species when there are already effective indigenous parasitoids is inappropriate.

The above cases suggest that there is no justification for importations of parasitoids. Most rice insect pests in tropical south and southeast Asia already are under biological control by indigenous predators and parasitoids. A more viable approach may be to determine the most important natural enemies and investigate their possible use against rice pests in other continents.

2.3 INUNDATIVE RELEASES

The case study for this approach is taken from an attempt in the early 1930s to rear *T. japonicum* for the control of *C. polychrysus* in Malaysia. Having recognized that egg parasitoids are important mortality factors, Miller and Pagden (1930) recommended that large numbers of *T. japonicum* (referred to as *T. nanum)* be reared and released. Up to 1,300,000 parasitoids were released per acre. However, Corbett and Pagden (1933) concluded that *T. japonicum* was not effective, even when released in large numbers. Pagden (1932) suggested that two other egg parasitoids, *Tetrastichus schoenobii* Ferriere (Hymenoptera: Eulophidae) and *Telenomus rowani* (Gahan) (Hymenoptera: Scelionidae) were more effective.

The failure of inundative releases and subsequent realization of the importance of existing biological control of the rice stem borer suggests that this approach is not appropriate for indigenous rice insect pests in the humid tropics. This conclusion concurs with that of Nickel (1964).

2.4 CASUAL INTRODUCTIONS

An examination of introductions of natural enemies into the Philippines indicates that many of them were introduced without adequate evaluation. Baltazar (1964) reported on the introduction of *T. japonicum* from Japan in 1934. Nickel (1964) pointed out that the parasitoid was already an indigenous species in the Philippines. This species is also indigenous in Thailand (Yasumatsu *et al.,* 1982) and Malaysia (van Vreden and Abdul Latif 1986).

Casual introductions result in wasted effort and may create problems which seriously retard advancement in the field of biological control. For example, the casual introduction of house crows to control insect pests on coffee in Malaysia (Carey 1903) led to the establishment of a nuisance. Several other examples of the adverse consequences of this careless, non-scientific approach can be found. These incidents have haunted attempts at biological control of insect pests in Malaysia, and probably other developing countries.

While studies of the ecology of both pests and natural enemies are recommended, unnecessary prolongation of such studies may seriously hamper IPM efforts. The procedure recommended by Nickel (1964) is a useful guide. It involves an extensive survey of natural enemies of the pests followed by detailed ecological studies. Studies of rice insect pests and their natural enemies should be a continuous part of a research program, both to identify important natural enemies and to promote practices that enhance their conservation.

From the evidence so far, biological control in the classical sense is suitable only for exotic rice pests. Attempts to enrich parasitoid species and inundative releases mostly have met with failures. Casual introductions of beneficials in the past, probably stimulated by sucessful classical biological control in the United States, have resulted in more failures, and may have discouraged plant protection scientists from pursuing other approaches to biological control, such as conservation. Most rice insect pests in tropical south and southeast Asia are indigenous and have their own indigenous natural enemies.

3. Role of Predators and Parasitoids

Although species diversity and total numbers of predators and parasitoids in tropical rice are impressive, generalizations about the precise role and relative importance of individual species are difficult. Clearly, abundance shifts seasonally and geographically, but in general only relatively few species have been shown to impact heavily on target insect pests. This is primarily due to the fact that little definitive work has been done and techniques that allow researchers to dissect these communities of parasitoids and predators and determine their individual roles are not available. Their collective role can be clearly demonstrated by observing outbreaks of insect pests after a broad spectrum insecticide has removed the natural enemy community. A comprehensive review of techniques for evaluating arthropod natural enemies has been published by Luck *et al.,* (1988), although relatively few of the techniques have been used in rice. Examples of specific techniques for evaluating predators and parasitoids are discussed by Shepard and Ooi (in Prep.).

We have selected three groups of pests to illustrate the role of predators and parasitoids; stem borers, leaffolders, and leaf- and planthoppers. They were selected because their natural enemies have been more extensively studied than those of other rice insect pests.

3.1 RICE STEM BORERS

3.1.1 Stem Borer Parasitoids

Before chemical insecticides were introduced, natural enemies played an important role in maintaining stem borer populations at low levels (Yasumatsu 1967a). The major focus of early work on natural enemies was on parasitoids. Nickel (1964) reported over 100 species of stem borer parasitoids. Of the 99 species of natural enemies reported by Yasumatsu (1967b) most were parasitoids. Other authors have identified many stem borer parasitoid species (Kamran and Raros 1969, Rothschild 1970, Yasumatsu and Torii 1968). In general, egg parasitoids are considered the most important; only three groups, namely, *Telenomus* spp., *Tetrastichus* spp. and *Trichogramma* spp. dominate the complex (Catling *et al.,* 1983, Delfinado 1959, Nickel 1964, Rothschild 1970, Shepard and Arida 1986).

In a study in the Philippines in both direct seeded and transplanted rice, parasitism of yellow stem borer, *Sciropophaga incertulas* (Walker) (Lepidoptera: Pyralidae), eggs was found to reach more than 60% then declined with crop age (Shepard and Arida 1986). In Bangladesh, Catling (1979) found an average of 75.5% of egg masses and 49.7% of eggs were parasitized. *T. schoenobii* was the most important parasitoid. Catling *et al.,* (1983) reported a similar situation for deepwater rice in Bangladesh, where 61-89% of yellow stem borer egg masses were parasitized. The two most important parasitoids were *T. rowani,* which was able to parasitize 64% of the eggs in parasitized egg masses, and *T. schoenobii,* which destroyed 98% of the eggs. Subba Rao *et al.,* (1983) reported 77% egg parasitism by *Tetrastichus* spp., *Telenomus* spp. and *Trichogramma* spp. in India. On the IRRI farm in the Philippines, egg parasitism by *T. schoenobii, T. rowani,* and *T. japonicum* averaged 84, 42 and 24 per cent, respectively (Kim *et al.,* 1986).

Several reports have suggested that *T. schoenobii* is the most important yellow stem borer egg parasitoid (Rothschild 1971, Ooi 1974, Than Htun 1976, Catling *et al.,* 1983, Shepard and Arida 1986) because it attacks several eggs during its development, a behavior not unlike that of a predator.

Although the complex of larval and pupal parasitoids is large, they are not as abundant as egg parasitoids (Table 2). Subba Rao *et al.,* (1983) reported that the action of larval/pupal parasitoids and microbial action caused as high as 58% mortality in the Warangal region of India. In our experience, larval and/or pupal parasitism has not approached this level. More detailed records can be found in Nickel (1964), Rothschild (1971), Yasumatsu (1967b), and Yasumatsu and Torii (1968).

TABLE 2

Some common parasitoids of stem borers

Borer species	*Stage attacked*		
	Egg	*Larva*	*Pupa*
S. incertulas	*Tetrastichus schoenobii* Ferriere***	*Temelucha philippinensis* (Ashmead)*	*Tetrastichus ayyari* Rohwer*
	Telenomus rowani (Gahan)**	*Stenobracon nicevillei* (Bingham)*	
	Trichogramma japonicum Ashmead. *	*Bracon chinensis* Szepligeti*	
C. polychrysus	*T. japonicum* * *	*Cotesia flavipes* Cameron* *	
		Tropobracon schoenobii (Viereck).	
C. suppressalis	*Telenomus dignus* (Gahan)*	*C. flavipes* *	*Xanthopimpla stemmator* (Thunberg)**
		*B. chinensis**	

* common; ** important; ***very important

3.1.2 Stem Borer Predators

The importance of predators in natural control of stem borers has received little attention. Pantua and Litsinger (1984) reported up to 65% of the eggs of yellow stem borer were consumed by *Conocephalus longipennis* (de Haan) (Orthoptera: Tettigoniidae). Predation on eggs of the yellow stem borer averaged about 30% during an entire season at the IRRI farm (Shepard and Arida 1986). The single most important predator was the grasshopper, *C. longipennis.* Although *C. longipennis* has been reported to damage rice panicles (Rothschild 1971, Barrion and Litsinger 1987, van Vreden and Abdul Latif 1986), its predatory role is more significant. Rubia *et al.,* (1990) showed that *C. longipennis* could consume over eight yellow stem borer egg masses in three days. The grasshopper population increased late in the season, when yellow stem borer is usually a more serious problem.

Other predatory orthopterans such as *Metioche vittaticollis* (Stal) (Orthoptera: Gryllidae) that feed readily on eggs of the striped stem borer, *C. suppressalis,* would not feed on yellow stem borer egg masses (Rubia and Shepard 1987). Manti (unpublished information) found that *Cyrtorhinus lividipennis* Reuter (Hemiptera: Miridae) had a similar habit, feeding on egg masses of striped stem borer but not that of yellow stem borer. Than Htun (1976) reported that the wolf spider, *Lycosa pseudoannulata* (Boesenberg and Strand) (Araneae: Lycosidae), confined in a small arena in the laboratory killed up to 90% of 130 borer larvae in one day. This wolf spider is also capable of attacking stem borer moths (Figure 1).

An anthocorid, *Euspudaeus* sp. was the only known important predator of the striped stem borer in Japan (Oho 1954-55). This predator alledgedly attacked 90% of *C. suppressalis* adults in rice straw.



Fig. 1. *Lycosa* sp. feeding on the moth of a rice stem borer.

A sizeable but seldom recognized predator community attacks first instar stem borers before they enter the stem. Pena (1987) found very little correlation between egg mass density and resulting damage by stem borer that could not be explained entirely by the action of egg parasitoids or predators. Small predators such as *Micraspis* spp. and other lady beetles, carabids such as *Ophionea,* ants, etc., attack and consume first stage stem borer larvae before these larvae enter the stems. In laboratory trials, we have observed that the water bugs, *Microvelia douglasi atrolineata* Bergroth (Hemiptera: Veliidae), *Mesovelia vittigera* (Horvath) (Hemiptera: Veliidae) and *Limnogonus fossarum* (F.) (Hemiptera; Gerridae) feed voraciously on early stage stem borer larvae (unpublished information). Larter (1955) observed *Paederus fuscipes* Curtis (Coleoptera: Staphylinidae) attacking newly hatched stem borer larvae in the field.

3.13 Stem Borer Management Strategy

There is ample evidence that if stem borer attack occurs during the vegetative stage the rice plant is able to compensate for damage by producing new tillers (IRRI 1987). More than 40% of the tillers can be removed during the early vegetative stage with no significant effect on yield. This

factor is important in developing management strategy, because a buildup of stem borer predators and parasitoids can be allowed early in the season without fear of yield loss. Insecticide use at this time is usually not considered as a viable tactic. Later in the season, when the crop cannot compensate as easily for damage, dense communities of arthropod natural enemies will be present.

In our judgement, losses by stem borers have been grossly exaggerated. Catling *et al.,* (1978) reported that crop losses due to stem borers in Bangladesh were lower than most estimates for rice in India. There is evidence to show that the high yielding modern varieties are not as severely damaged by stem borers as older traditional varieties (Balasubramanian and Ooi 1977). This is likely due to the action of natural enemies and the re-tillering capacity of modern varieties which have thinner stems that are less suitable for stem borer development. Khoo and Lee (1978) suggested that the shorter crop development time of modern varieties may also reduce the incidence of stem borers.

3.2 LEAFFOLDERS

3.2.1 Parasitoids of Leaffolders

The major parasitoids of leaffolder eggs in the Philippines are *Copidosomopsis nacoleiae* (Eady) (actually an egg-larval parasitoid)(Hymenoptera: Encyrtidae) and *Trichogramma* spp. The larval and pupal parasitoid complex is richer. Rao *et al.,* (1969) listed 32 species of larval and eight species of pupal parasitoids. Parasitism averaged about 40% on the IRRI farm and in nearby farmer's fields in Laguna, Philippines (Arida and Shepard 1990). From a total of 4,904 leaffolder larvae collected, 15 species of parasitoids belonging to nine families were found. The seasonal incidence of leaffolder larval parasitism is shown in Figure 2. Some of the most common parasitoid species encountered in the Philippines are listed in Table 3.

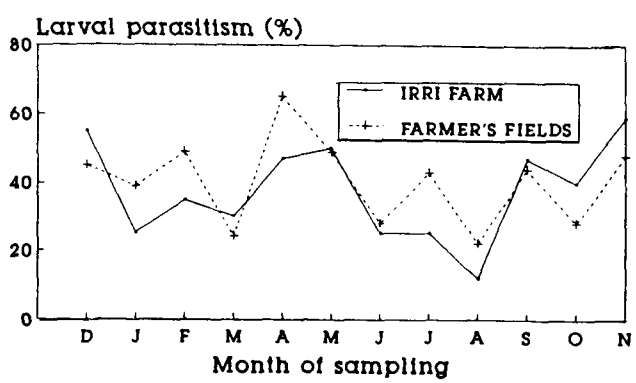


Fig. 2. Seasonal incidence of leaffolder larval parasitism on the IRRI farm and in nearby farmer's fields. 1985.

TABLE3

Some common parasitoids of leaffolders *(Cnaphalocrocis medinalis* and *Marasmia patnalis)*

Egg parasitoids	*Larval parasitoids*	*Larval parasitoids*
Copidosomopsis nacoleiae (Eady)**	*Goniozus nr. triangulifer* Kieffer*	*Xanthopimpla flavolineata* Cameron*
Trichogramma japonicum Ashmead**	*Cotesia angustibasis* (Gahan)*	*Tetralichus ayyari* Rohwer*
	Cardiochiles philippinensis Ashmead*	
	Macrocentrus philippinensis Ashmead*	
	Trichomma cnaphalocrosis Uchida*	
	Temelucha philippinensis (Ashmead)*	

*common; **important

32.2 Predators of Leaffolders

Kamal (l981) reported 70% leaffolder mortality by predators. The predator complex that feeds on eggs and larvae of leaffolders is nearly the same as for stem borers. A notable exception is the cricket, *M. vittaticollis,* which feeds voraciously on leaffolder eggs but will not attack eggs of yellow stem borer (Rubia and Shepard 1990). Leaffolder egg predation averaged about 50% in both direct seeded and transplanted rice (Arida and Shepard 1990). These levels were detected by placing plants with leaffolder eggs in the field and recording the missing eggs two days later.

C. lividipennis also attacks leaffolder eggs. Because the egg chorion is left intact, predation by this mirid is easily overlooked and underestimated. Although both lady beetles feed on eggs of

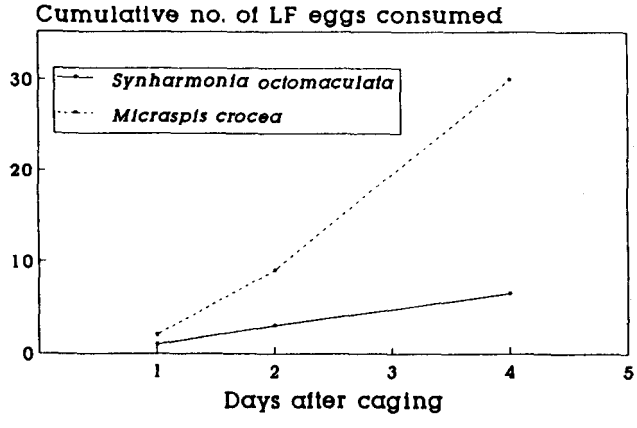


Fig. 3. Laboratory study to evaluate consumption of leaffolder (LF) eggs by two rice field coccinellids, *Synharmonia octomaculata* (F.) and *Micraspis crocea* Mulsant.

leaffolders, in laboratory experiments *Micraspis crocea* Mulsant (Coleoptera: Coccinellidae) consumed more eggs than another common rice field coccinellid, *Synharmonia octomaculata* (F.) (Coleoptera: Coccinellidae) (Figure 3). Predation on newly hatched larvae is more difficult to assess, but mortality caused by the same complex of predators that attack young stem borer larvae must be high. An *Ophionea* sp. is shown eating a leaffolder larva in Figure 4. After a leaffolder rolls the leaf, the pest is partially protected from predators. Parasitoids then play a more significant role in suppressing populations.



Fig. 4. *Ophionea* sp. feeding on a leaffolder larva.

3.3 LEAF- AND PLANTHOPPERS

Greathead (1983) reviewed natural enemies of leaf- and planthoppers, and Subba Rao *et al.,* (1983) catalogued the important parasitoid species. Table 4 presents a list of the major predator and parasitoid species. A substantial amount of attention has been given to parasitoids of leaf- and planthoppers (Otake, 1977; Chandra 1980a, b; Bentur *et al.,* 1981; Chang 1980; Subbao Rao *et al.,* 1983; Chua and Dyck 1982; Pena and Shepard 1986). However, our experiences and those of

Kenmore *et al.,* (1984) have led us to believe that, in general, predators impact hopper populations more strongly than do parasitoids. In at least one instance, failure to assess predation led to conclusions that a decline in hopper population could not be due to natural enemies (Otake 1978).

TABLE 4

Some common predators and parasitoids of brown planthopper and green leafhopper

Hopper species	*Predator/Parasitoid species*	*Stage of host attacked*
	Predators	+
N. lugens	*Cyrtorhinus lividipennis* Reuter***	Egg/Nymph
	Lycosa pseudoannulata (Boesenberg and Strand)***	Nymph/Adult
	Microvelia douglasi atrolineata Bergroth**	Nymph/Adult
	Synharmonia octomaculata (F.)**	Nymph/Adult
	Paederus fuscipes Curtis**	Nymph/Adult
Nephotettix spp.	*L. pseudoannulata****	Nymph/Adult
	*C. lividipennis'**	Egg/Nymph
	Tetragnatha spp.*	Adult
	Oxyopes spp.*	Nymph/Adult
	Parasitoids	+
N. lugens	*Oligosita yasumatsui* Viggiani et Subba Rao*	Egg
	Anagrus spp.*	Egg
	Pseudogonatopus spp.*	Nymph/Adult
Nephotettix spp.	*Gonatocerus* spp.*	Egg
	*O. yasumatsui**	Egg
	Haplogonatopus apicalis Perkins*	Nymph/Adult
	Tomosvaryella spp.**	Nymph/Adult
	Pipunculus spp.**	Nymph/Adult

* common; ** important; *** very important

3.3.1 Parasitoids

Seasonal abundance and incidence of parasitism in nymphs and adults of brown planthopper, *N. lugens,* whitebacked planthopper, *Sogatella furcifera* (Horvath) (Homoptera: Delphacidae) and green leafhopper, *Nephorettix* spp. were monitored in Laguna Province, Philippines (Pena and Shepard 1986). The major parasitoids of *N. lugens* were dryinids *(Pseudogonatopus* spp., *Haplogonatopus* spp. and *Echthorodelphax fairchildi* Perkins) (Hymenoptera: Dryinidae) and strepsipterans *(Elenchus yasumatsui* Kefune and Hirashima) (Hymenoptera: Strepsiptera). At 12 locations parasitism averaged below 10%. Host densities were normally low throughout the study.

Chandra (1980b) reported that parasitism rates by dryinids reached 40% when host densities were high during the wet season (July-October) in the Philippines. Normally, parasitism levels were similar to those reported by Pena and Shepard (1986).

Similarly rates of parasitism of the *S. furcifera* by dryinids and strepsipterans were low (Pena and Shepard 1986; Chandra, 1980a, b). Parasitism of *S. furcifera* by strepsipterans reached somewhat higher levels (26%), but this group did not impact strongly on *N. lugens* or *Nephotettix* spp. lncidence of parasitism by pipunculids on *Nephotettix virescens* (Distant) (Homoptera: Cicadellidae) and *Nephotettix nigropictus* (Stal) (Homoptera: Cicadellidae) was higher than for any of the parasitoid species (Pena and Shepard 1986) and pipunculids may be an important source of irreplaceable mortality in green leafhoppers. During the 1984 dry season (January-April), parasitism reached more than 50% on *N. nigropictus.*

33.2 Predators

The most abundant predator of hoppers is the mirid, *C. lividipennis.* When offered eggs of brown planthopper, whitebacked planthopper and green leafhopper, *C. lividipennis* exhibited a preference for brown planthopper eggs (Figure 5). We have found that increasing the ratio of brown planthopper to *C. lividipennis* in cage experiments resulted in a population increase of the hopper (Manti and Shepard, unpubl.) (Figure 6). Based on the results of laboratory studies and field observations of a strong numerical response of the mirid to brown planthopper populations, we disagree with Kenmore (1980) that *C. lividipennis* is an opportunistic predator that exploits outbreaks of hoppers only after other control factors have failed. Clearly, *C. lividipennis* must rate as one of the most important predators of hoppers in the rice ecosystem. Observations by Stapley (1975, 1976) in the Solomon Islands support this conclusion Although primarily an egg predator, *C. lividipennis* also feeds on young hopper nymphs.

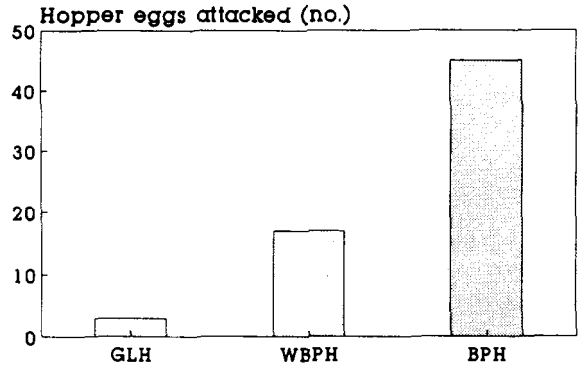


Fig. 5. Feeding preference by *Cyrtorhinus lividipennis* Reuter on eggs of green leafhopper (GLH). whitebacked planthopper (WBPH) and brown planthopper (BPH).

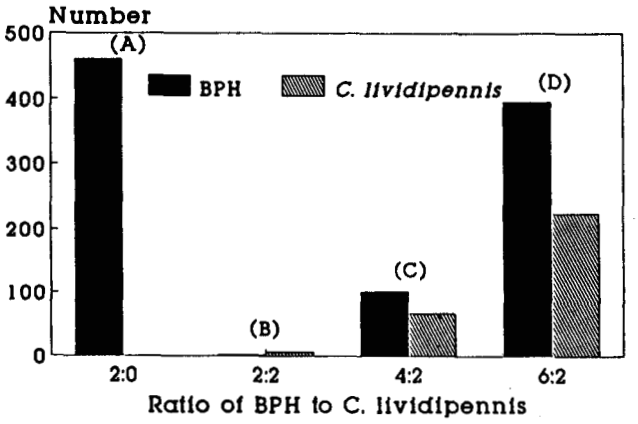


Fig. 6. Results of an experiment to determine the effect of different ratios of the brown planthopper to *Cyrtorhinus lividipennis* Reuter. The resulting populations at the end of 60 days are shown for each treatment. (A) 2 pair BPH O pair *C. lividipennis;* (B) 1 pair BPH: 1 pair *C. lividipennis;* (C) 2 pair BPH 1 pair *C. lividipennis;* (D) 3 pairs BPH: 1 pair *C. lividipennis.*

The wolf spider, *L. pseudoannulata* is also recognized as a major regulator of brown planthopper populations, and probably is its most important predator. Kenmore *et al.,* (1984) reported a strong correlation between *L. pseudoannulata* density and peak populations of brown planthopper. Studies using arenas in the laboratory reveal that a single wolf spider can easily consume between 7 to 45 hoppers per day (IRRI 1975,1985).

In addition, Nakasuji and Dyck (1984) suggested that *M. d. atrolineata* is an important brown planthopper mortality factor. In one of their field studies, 67% of the Yrown planthopper adults fell



Fig. 7. *Micraspis crocea* Mulsant feeding on a brown planthopper.

from the rice plant. If this phenomenon is common, the hoppers would be subjected to high levels of predation by water bugs. Other surface dwelling bugs such as *Mesovelia* sp. and *L. fossarum* feed on both whitebacked planthoppers and brown planthoppers or almost any small, soft-bodied insect that falls into the paddy water. The complex of predators that attack the whitebacked planthopper and green leafhopper, *Nephotettix* spp., is similar to that of brown planthopper. The most important are various species of spiders which occupy the different strata of the rice canopy. Tetragnathids and oxyopids, which inhabit mostly the upper canopy, attack *Nephotettix* spp. Beetles, such as *Micraspis* sp. (Figure 7), *Ophionea nigrofasciata* (Schmidt-Goebel) (Coleoptera: Carabidae) and *P. fuscipes* also feed on green leafhoppers, but probably do not cause major mortality.

4. Maximizing the impact of Predators and Parasitoids

Natural enemies are always present in the rice field, working to keep pests in check. However, little effort has been spent to maximize their impact. We recommend the following procedures to realize the full benefit of the action of predators and parasitoids.

4.1 SURVEYS

Maintaining an inventory of natural enemies is the first step towards recognizing their existence. Many countries already possess some information about indigenous predators and parasitoids. An example on parasitoids of rice pests was reported by Pagden (1934). This subsequently developed into a larger volume compiled by Ahmad and Ho (1980).

Such an inventory must be constantly revised and updated in order to correct incomplete or sometimes inaccurate records. Often, predatory insects are mistaken for pests. For example, the cricket *Anaxipha longipennis* (Serville) (Orthoptera: Gryllidae), is predatory but many members of the family are plant feeders (Canapi *et al.,* 1988). Few rice extension workers would recognize it as a beneficial species.

When an inventory of beneficial species is not available, a system for collecting this information should be initiated immediately. Reference to entomological literature would be the first step to determine available information from within a country, region or climatically similar areas, This should be complemented with extensive field collections. Rice field arthropods can be collected using a variety of techniques, including sweep nets, suction machines or collecting live arthropods individually with vials.

Individual collection is important for identifying suspected predators or rearing parasitoids to the adult stage. Suspected predators should be tested in laboratory cages or arenas by offering them different hosts. Samples of live insect pests can be reared in individual containers to provide accurate records of parasitism. When insects are reared together, records may be inaccurate. Arthropods should be catalogued and the asistance of well known insect identification services consulted to identify them. Many of the rice insects can be identified by the Entomology Department of the International Rice Research Institute. However, for many predators and parasitoids,

the assistance of established taxonomic services would be most helpful *(e.g.* the CAB International Institute of Entomology).

When possible, outbreaks should be investigated to determine their causes. Often, outbreaks of rice insect pests in tropical Asia result from adverse farm practices, such as unnecessary and intensive insecticide use. These records are important in providing directions for research into IPM implementation.

4.2 SAMPLING AND SURVEILLANCE

After gathering information on the composition of beneficial species, the seasonal and relative abundance of rice pests and their natural enemies should be determined. Sampling for the abundance of rice pests alone can result in a change in agricultural practices that adversely affect natural biological control.

For example, rice stem borers were considered the most important pests of rice in Malaysia since 1887. When two attempts at biological control failed, emphasis was placed on using insecticides for control (Wyatt 1956, 1957; Koyama 1964; Kimura 1965). Those studies resulted in the recommendation by the Department of Agriculture to treat rice plants prophylactically for stem borer control. Lim (1972) recognized the integration of chemical and biological control and recommended the use of granular insecticides instead of liquid formulations. However, surveys by Ooi (1974,1976) showed low incidence of rice stem borers in the Muda Scheme and the Tanjung Karang Irrigation Scheme. This low incidence was subsequently confirmed by Khoo and Lee (1978) and Zam and Ooi (1978). With percent bored tillers being generally less than 5% nationwide, there was no justification for preventive applications of insecticides for rice stem borer control.

Similar trends were observed in Bangladesh, where a crop loss assessment study by Catling *et al.* (1978) confirmed that the stem borer is under natural control. Evidence that egg parasitism and predation are important mortality factors is given in Catling (1979), Catling *et al.,* (1983), Hikim (1988), Khoo and Lee (1978), and Shepard and Arida (1986).

These examples show the importance of field surveys which, when properly conducted, can provide strong circumstantial evidence of the impact of natural enemies. At the same time, the overall importance of the target pest can be assessed.

Surveys of predator populations are useful in establishing their relative importance. A study of the abundance of the brown planthopper and its predator, *C. lividipennis* shows a strong correlation between the populations of pest and predator in the rice field (Figure 8). While the figure does not show direct causal effect of the action of the predator on the pest population, it indicates a strong numerical response between predator and prey numbers in the field even at low pest densities.

Not all predators in the rice field respond to prey populations like *C. lividipennis.* Indeed, Figure 9 shows that, there is little relationship between the spider predator *(Lycosa* sp.) and prey numbers. However, this important predator of brown planthopper removes large numbers of this pest in the field and serves as the first line of defence against a pest buildup.

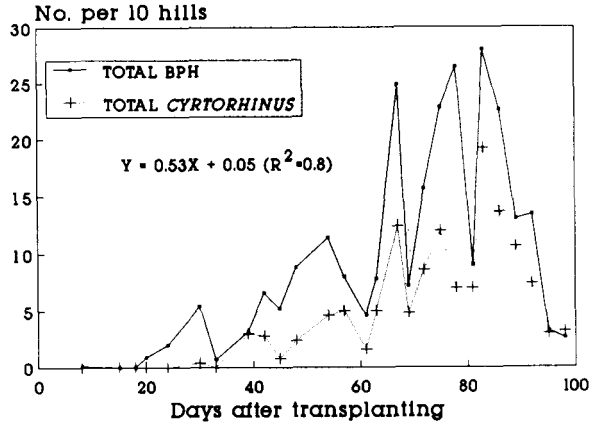


Fig. 8. Population trends of the brown planthopper (BPH) and *Cyrtorhinus lividipennis* in an insecticide free field in Sungai Burong, Malaysia (Season 2,1983). Data were collected using sticky boards. There is a significant correlation between *Cyrtorhinus* and BPH populations.

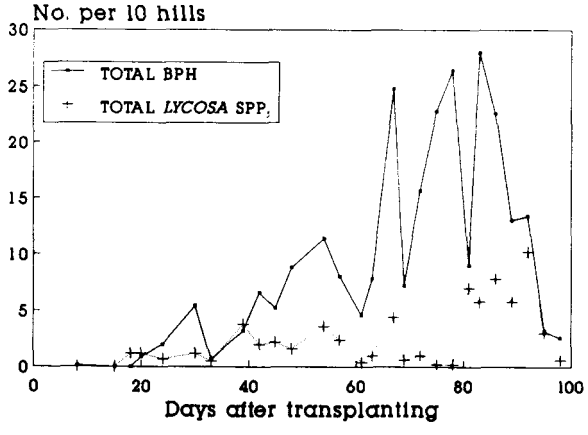


Fig. 9. Population trends of the brown planthopper (BPH) and *Lycosa* spp. in an insecticide free field in Sungai Burong, Malaysia (Season 2, 1983). Data were collected using a sticky board. While there is no correlation between populations of the spider and BPH, the spider's presence in the field throughout the season will limit the populations of the hoppers and other insect pests.

Field studies of both pests and predators may lead to the development of practical pest surveillance and forecasting techniques. A system developed in Malaysia has been described by Ooi (1982a). This surveillance system requires that the field scout counts and records planthoppers, number of damaged tillers and leaves and predators. Although many predators of the brown

planthopper have been recorded (Otake 1977, Chiu 1979, Kenmore *et al.,* 1984), only those considered to be important in the regulation of the brown planthopper in Malaysia (Lim et al., 1978) are counted. These predators are *C. lividipennis, Lycosa* spp. and other spiders, *P. fuscipes, Cusnoides interstitialis* (Schmidt-Goebel) (Coleoptera: Carabidae) and *S. octomaculata.* After an examination of the data collected by the surveillance system, Ooi (1982b) concluded that the brown planthopper population is checked by predators as long as the ratio of brown planthopper to the combined predators does not exceed 50 : 1. Even if the population of the brown planthopper passes the economic threshold level, the recommendation for chemical intervention takes into consideration the prey:predator ratio.

Incorporting predators into decision making has helped maximize the impact of predators in the rice field. Farmers are encouraged to use insecticides only when the ratio is in favor of the pest. Such an approach has been adopted by some rice farmers in Malaysia. Absolute counts are not necessary. Relative numbers of predators to pest numbers indicate quickly whether natural control is working.

Another way to maximize the action of predators is provided by Shepard *et al.,* (1986) who recommended the use of a sequential sampling program for hopper pests. This program is particularly useful in saving the time needed to reach a decision about whether or not to make an insecticide application. Further refinement of the model was made by incorporating predators (Shepard *et al.,* 1988). In the model, numbers of hoppers are adjusted according to numbers of predators. For each predator counted, five hoppers are subtracted from the total number of large nymphs and adult hoppers. The adjusted number of hoppers is then used in deciding whether or not to treat a field. This improved sequential program is useful in preventing unnecessary insecticide treatment.

4.3 RESEARCH

Successful IPM programs in the tropics have developed from observations that natural enemies play an important role and their conservation through reduced insecticide usage results in cost effective pest management (Conway 1971, Wood 1964). Way (1973) described this empirical approach in recognizing the importance of existing natural enemies as an important prerequisite to successful pest management. However, qualitative observations must lead to quantification of the action of natural enemies to ensure that it continues to be an important paradigm in tropical rice IPM programs. Some research carried out to quantify the impact of predators. and parasitoids has been reviewed here to provide some directions on how such studies can benefit IPM programs.

In the past, the study of parasitoids of rice pests was emphasized more than that of general predators. In the case of rice stem borers, such emphasis was justifiable, because egg parasitoids are very important in checking the borer population. However, general predators are also important. For example, Pantua and Litsinger (1984) reported that in a study to determine levels of parasitism of the yellow stem borer, the experiment was disrupted by extensive egg predation attributed to *C. longipennis.* Rothschild (1970), Sands (1977) and Manley (1985) reported that *C. longipennis* is an important predator of rice insect pests. However, Grist and Lever (1969) and van Vreden and Abdul Latif (1986) reported that *C. longipennis* also damages rice plants. Research is needed to determine the role of this longhorned grasshopper as a predator and as a pest.

Besides the study of the biology of predators in the laboratory and the types of prey they feed on, research into prey preference and consumption rates are important to indicate their relative importance. General predators have been found to exhibit preferential feeding. This has been shown with *M. virraticollis* (Sec 3.1.2), rice field lady beetles (Figure 3) and *C. lividipennis* (Figure 5). Rate of feeding is another important aspect of predation that can be evaluated in the laboratory.

Lim (1970) pointed out the possible importance of weeds along field levees that serve as alternate hosts for stem borers. These weeds can sustain a reservoir of natural enemies during the crop and from one crop to the next. Thus, manipulation of weed communities may offer possibilities for increasing populations of stem borer parasitoids and predators. Studies by Rubia and Shepard (1987) showed that *M. vittaticollis* oviposit in four species of weed in addition to rice plants. In a free choice experiment, it was found that the different weeds were as attractive as rice plants for oviposition.

One method for laboratory evaluation of predators and parasitoids is to study the functional response of the natural enemies to different population densities of prey. Nakasuji and Dyck (1984) confirmed that *M. d. atrolineata* is one of the more important natural enemies of brown planthopper on the basis of a study of its functional response and the high populations of the veliid in rice fields.

Field experiments are a necessary extension of the laboratory studies. A comparison of sprayed and unsprayed fields indicates the population trends of both pests and natural enemes. Ooi (1986) showed that mirid predator and spider populations are adversely affected, resulting in an increase in the brown planthopper population. In an adjacent field, where only one early spray was applied, the brown planthopper was kept in check by the same predators (Figure 10). Kenmore *et al.* (1984) demonstrated that pest outbreaks can be cawed by insecticide sprays that kill predators.

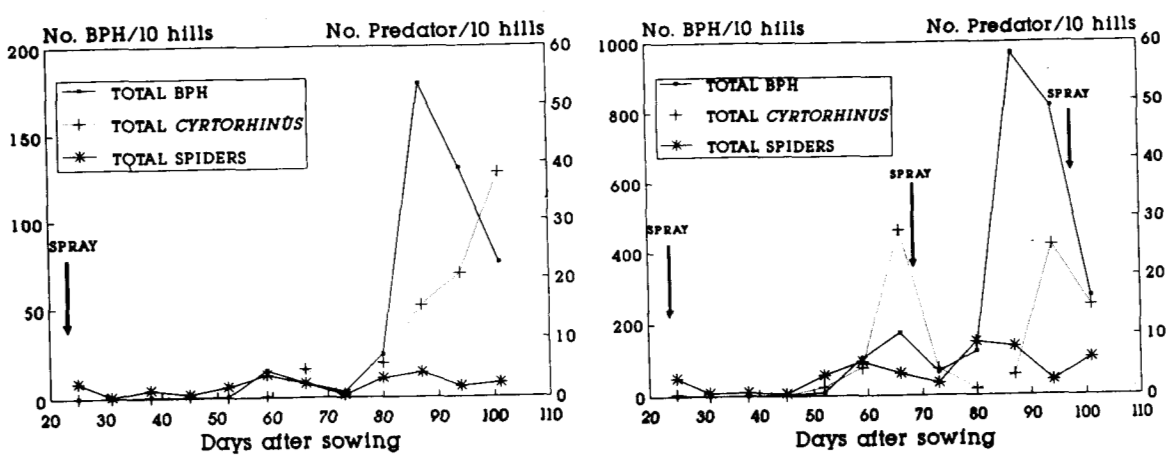


Fig. 10. Comparison of two adjacent fields in Sekinchan, Malaysia to show the difference of a field that received a single spray early in the season (left), with a field that received at least three sprays (right). Insecticide sprays killed predators and allowed the brown planthopper (BPH) to develop a high population.

Using cages to exclude predators is another effective method to demonstrate the importance of predators in regulating pest populations (Kenmore *et al.,* 1984). The results of an exclusion cage study in Tanjung karang, Malaysia is shown in (Figure 11). One gravid female per hill was introduced into a field cage enclosing 9 hills. In one cage, predators were excluded while in the second, the sides of the cage were opened 24 hours after introduction. The resulting large population of brown planthopper in the absence of predators mimics an outbreak situation. In contrast the population in the cage with the predator shows the importance of predators in keeping brown planthopper populations down.

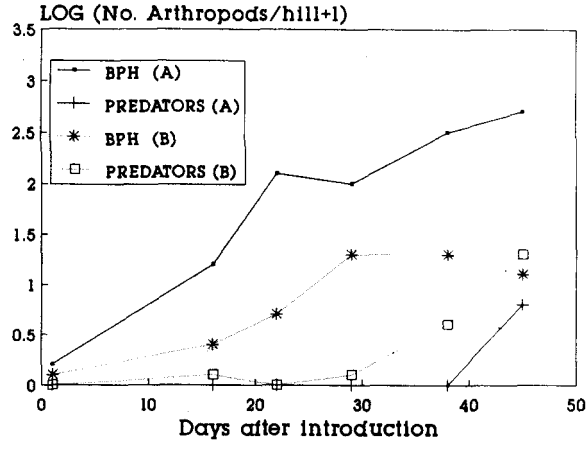


Fig. 11. Exclusion cage study conducted at Tanjung Karang, Malaysia. (A) One gravid female brown planthopper (BPH)/hill was allowed to develop within a cage free of predators. After 45 days, the population increased to513 BPH/hill. (B) A similar experiment but the sides of the cage were opened 24 hours after introduction of the gravid females. After 45 days, the population was 10 BPH/hill. BPH= adults + numphs; Predators= *C. lividipennis* + spider.

To demonstrate the action of predators and parasitoids on the eggs of rice pests, van den Berg *et al.,* (1988) exposed eggs of *Rivula atimeta* (Swinhoe) (Lepidoptera: Noctuidae), *Naranga aenescens* Moore (Lepidoptera: Noctuidae) and *Hydrellia philippina* (Ferino) (Diptera: Ephydridae) on rice seedlings in the field. Egg predation in all three insect pest species increased as the crop matured (Figure 12). Their study shows that predators should be conserved because of their importance in controlling these early season pests.

We have discussed ways that entomological research in rice can contribute to maximizing the impact of predators and parasitoids. The examples were selected to illustrate the possible outcome of such studies. Transferring this knowledge from research to the farmers through extension programs is the next important step. It is our firm belief that, as we unravel the complexities of natural biological control in rice fields, the beneficiary will be the rice farmers. These farmers have lived with the predators and parasitoids for many years and it is appropriate that they learn about them and work to conserve them.

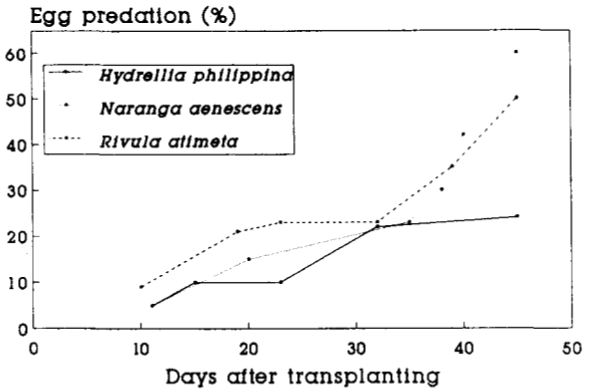


Fig. 12. Per cent predation on *Hydrellia philippina, Naranga aenescens* and *Rivula atimeta* in a farmer's field, Victoria, Laguna, Philippines, 1987. (after van den Berg *et al,* 1988)

4.4 DEMONSTRATION

After going through the procedure of surveying for natural enemies, estimating their impact through sampling and surveillance and confirming this through research, the next step is to demonstrate the importance of natural enemies to the rice farmers. While we recognize that farmers are the eventual recipient of the information about natural enemies, we also appreciate that support from policy makers, agricultural administrators and technicians is essential.

A first step toward explaining the possibilities of natural control is the publication of appropriate materials. A field guide developed by Shepard *et al.* (1987) illustrates that the natural enemies of rice pests are actually friends of the rice farmers. Another useful publication is the book by van Vreden and Abdul Latif (1986) about rice pests and their natural enemies. The next step is to train the agricultural technicians how to demonstrate the action of predators and parasitoids to farmers. A manual to do this has been prepared by Ooi, Shepard and Kenmore (in preparation).

This manual suggests that the extension worker and farmers work together in the rice fields. The first step is to visit rice fields with farmers to show them the important "friendly insects", particularly predators. As parasitoids are generally small, the manual suggests using predators to bring home the message. Predators, such as *L. pseudoannulata* are collected, starved for a day or so and fed pests in the presence of rice farmers. This step is supplemented by field cage experiments where predators are excluded and farmers are shown what would happen in the absence of predators.

More sophisticated procedures, such as insecticide disruption of natural biological control are described to demonstrate that insecticides can be a disadvantage if used indiscriminately. Placing known numbers of prey insects in the field and returning later to determine predation and parasitism is also a useful techinque. If agricultural technicians foIlow the procedures outlined, both the technicians and farmers should feel as secure about natural biological control as they now do about using chemical insecticides.

5. Sustaining the Natural Enemy Core of IPM

Integrated Pest Management (IPM) has its origin in the integration of biological and chemical conrol (Stern *et al.,* 1959). Central to this is the concept that natural biological control is the core of IPM. Hence, good pest management should start with a knowledge about the natural enemies of the pest and their role in controlling pest numbers, and how other control measures can be integrated with this core.

For rice, it is impossible to develop an IPM program without understanding the role of predators and parasitoids. These "friends of the rice farmer" (Shepard *et al.,* 1987) were associated with rice pests long before rice was cultivated in its present form. From our review of these natural enemies, we conclude that predators and parasitoids in the rice fields of tropical south and southeast Asia are essential for maintaining insect pest populations at low levels.

However, methods of rice cultivation are undergoing great biotic and abiotic changes. Some of these changes may adversely affect the indigenous biological control communities. IPM practitioners should recognize that changes in rice cultivation are inevitable. They should involve themselves with these changes to ensure that, although other crop production practices may change, predators and parasitoids are not adversely affected. We suggest some steps to sustain the action of natural enemies.

Ongoing research activities enable integration of natural enemy research into other areas of activities such as breeding for pest resistance. Studies by Kartohardjono and Heinrichs (1984) and Joshi (1988) have indicated that action of natural enemies combined with resistant rice varieties resulted in lower pest populations, thereby slowing down the development of adaptations to these varieties. Joshi (1988) showed that when insecticides were sprayed onto fields of resistant and susceptible rice varieties, hopper population resurgence was less in the resistant than in the susceptible variety (Figure 13). Clearly, resistance in the rice variety was masking the impact of

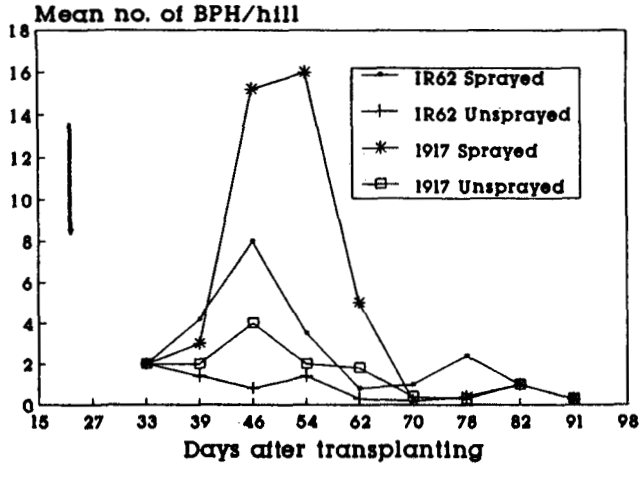


Fig. 13 Mean numb of macropterous brown planthopper (BPH) adults sampled by D-Vac in the wet season, 1986, Koronadal, Mindanao, Philippines to demonstrate the effects of insecticide spray on the BPH population in resistant (IR62) and susceptible (IR 1917) rice varieties (Joshi 1988).

natural enemies. The importance of this interaction between natural enemies and resistant varieties is slowly being recognized.

Another related aspect is the potential for developing new plant types which possess morphological characters that affect the efficacy of some natural enemies. Changes in plant morphology (*e.g.* leaf pubescence) have been reported to have negative effects on some parasitoids in tobacco (Rabb and Bradley 1968, Elsey and Chaplin 1978) and in soybean (Turner 1983). Similarly, there could be changes in plant chemistry that could affect natural enemies.

Mechanical drilling and broadcasting of seed and mechanical transplanting are replacing traditional transplanting in some areas. The implications of these changes on the efficacy of predators and parasitoids should be determined. In the study of parasitism and predation of stem borer eggs, Shepard and Arida (1986) suggested that the higher incidence of egg parasitism in transplanted rice was due to a more open canopy.

A cultural practice that may affect the efficacy of predators and parasitoids involves planting synchrony. The decline in incidence of rice stem borer in Malaysia following double cropping was attributed to the survival of natural enemies provided for by the asynchrony that developed (Balasubramanian and Ooi 1977). However, Loevinsohn (1984) suggested that asynchrony is responsible for increased incidence of rice pests. Oka (1979) reported synchronous planting was critical to the management of the brown planthopper. We believe that there is insufficient evidence to prove that either synchrony or asynchrony are important factors affecting the efficacy or natural enemies. More studies are required in this field.

The importance of weeds on rice field levees as reservoirs of natural enemies should be further investigated (Sec 4.3). The possibility of using or manipulating alternate plant hosts or even alternate arthropod hosts of important natural enemies to provide effective biological control early in the season is another area for future research. Such an approach may overcome the problem of late stem borer egg parasitism reported by Catling (1979) and Catling *et al.,* (1983). Surely, we are only on the threshold of understanding the impact of natural enemies in a dynamic rice ecosystem.

Further understanding of natural enemies may occur through modelling. This approach should include a description of the 'problematique' in terms of its biological, technical, social and economic dimensions (Norton and Heong 1988). Such a holistic approach to problem solving will encourage development of a pest control concept such as 'inaction' levels (Sterling 1984) which will feature strongly in rice integrated pest management with a core founded on natural biological control.

6. SUMMARY

A review of past attempts at biological control of rice insect pests provides evidence that importation of exotic parasitoids is effective when the pests we also exotic. Failures were recorded with inundative releases and importation of exotic parasitoids against indigenous insect pests. casual introduction of natural enemies is an antithesis to good biological control. Rice insect pests in the tropical south and Southeast Asia have a long and close association with their natural enemies.

Predators and parasitoids of these pests are most important in keeping them under biological control.

Conserving the natural enemies is the strategy recommended. In the past, emphasis has been on the qualitative studies of parasitoids of rice pests. Recent quantitative studies have confirmed the importance of predators and parasitoids of rice stem borers, leaf- and planthoppers and leaffolders. In recognition of their importance, a procedure is recommended to maximize the impact of these beneficial arthropods. The steps are (1) surveys for identification, (2) sampling and surveillance, (3) research to assess predator and parasitoid impact, and (4) demonstration.

Natural biological control as the center of integrated pest management is the paradigm maintained in this review. Hence studies of the action of predators and parasitoids should be part of an ongoing research program. To ensure sustained efforts in maintaining this core of IPM, it is advised that research into natural enemies should take cognizance of changing plant types and a dynamic rice ecosystem.

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8

Pathogens of Rice Insects[1]

MICHIEL C. ROMBACH[2] AND D. W. ROBERTS
Insect Pathology Resource Center
Boyce Thompson Institute for Plant Research at Cornell University
Ithaca, NY

REMEDIOS M. AGUDA
Department of Entomology
International Rice Research Institute
Los Baños, Philippines

1. INTRODUCTION

SEVERAL INSECT GROUPS OCCASIONALLY cause damage to rice in Asia. These include the stem borers, leaffolders, stink bugs, and a few plant- and leafhopper species. However, in undisturbed rice fields most pests are effectively suppressed by indigenous populations of natural enemies such as predators, parasites and entomopathogens. Conservation of these natural enemies is the key to stable rice pest control in southeast Asia. Most pest problems occur when agricultural practices such as excessive pesticide use destroy these populations of natural enemies. The disruptive influence of broad spectrum chemical insecticides on natural enemies is well documented (Kenmore *et al.,* 1984). Several selective chemical insecticides are available, but these chemicals are often

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2. Insect Pathology Resource Center, Boyce Thompson Institute for Plant Research at Cornell, Tower Road, Ithaca, New York 14853, U.S.A. Seconded to Department of Entomology, International Rice Research Institute, Los Baños, Laguna, Philippines. *Postal address:* IRRI, P.O. Box 933, Manila, Philippines.

too expensive for use by the small scale rice farmers in the developing Asian countries where rice is mostly a subsistence crop and profit margins are small.

Insect pathogens may offer an alternative to selective chemical insecticides. Microbial insecticides are already widely used in agricultural systems (Burges 1981, Fuxa and Tanada 1987), and knowledge of the biology and ecology of the diseases has greatly increased in recent years (Samson *et al.,* 1986). Microbial control agents are more easily manipulated for field use than are predators and parasites and their mass production is comparatively easy. Many entomopathogens, notably the insect bacteria and fungi, can be produced in industrial type fermentors in inexpensive liquid media. The products are formulated, packaged and can be stored for several months. These features make production of some of the insect microbials at the community level a viable approach. Insect pathogens are safe to humans and other non-target species so they can be used harmoniously with other control tactics. Application of these materials can usually be made with conventional spraying equipment.

New biotechnology techniques can be used to induce changes in insect microbes that increase their efficacy (Kirschbaum 1985). This biotechnological approach can be carried out on a wide range of insect pathogens, with bacterial and viral pathogens being prime candidates for genetic manipulation.

The incorporation of the genetic material from the insect pathogens into the plant may also offer promise (Meeusen and Warren 1989, Vaeck *et al.,* 1986). For example, incorporation of *Bacillus thuringiensis* Berliner genes into plants induces production of the Bt endotoxins by the plant cells. The toxins affect foliage feeding caterpillars as well as stem borer larvae. This may become an effective and economical way to reduce the necessity for chemical insecticides.

The literature is replete with anecdotal accounts of infections of rice insects by entomopathogens and, more rarely, reports on epizootics of viruses and fungi. However, few studies report on the manipulation of insect pathogens for rice pest control.

There is no doubt that naturally occurring microbial agents are important in the regulation of rice insect populations. However, the environmental conditions triggering natural epizootics are ill defined. In rice the natural outbreaks of entomopathogens are positively correlated to pest density. Usually this density is above the damage threshold and naturally occurring pathogens do not prevent crop damage. Manipulation (*i.e.* mass production and application) of some of the microbials should be attempted to suppress pest populations below threshold levels.

This chapter reviews some of the most pertinent literature on pathogens of rice insects. More references are provided in Rombach *et al.,* (1987c). Identification and practical application of several groups of rice insect pathogens are discussed. Mycological terminology used in this chapter is defined in Table 1.

TABLE 1

Explanation of mycological terms used

Basipetal chain, chain of conidia with the youngest conidium at its base *(e.g.,* as in *Metarhizium, Paecilomyces,* and *Nomuraea).*

Blatospore, a spore (conidium) which is differentiated from a hypha by budding.

Byssoid, cotton-like, made up of delicate threads.

Cerebriform, brain-like or convoluted.

Conidium, asexsual and nonmotile spore of a deuteromycetous fungus.

Conidiogenesis, process of conidium formation.

Conidiogenous cell, fertile cell from which or inside which the conidia are produced.

Conidiophora, simple or branched hypha with conidiogenous cells which produce the conidia.

Epizootic, epidemic of insect disease.

Fungi Imperfecti, anamorphs of higher (sexually reproducing) fungi in the classes Blastomycetes (yeasts), Hyphomycetes (molds), and Coelomycetes (pycnidial fungi).

Hypha fungus filament.

Hyphal ***body,*** short hyphal fragment.

Hyphomycetes, class of Fungi Imperfecti, molds. Mycelia can be sterile or bear conidia on separate hyphae which can be agregated *(e.g.* in a synnema), but not in distinct conidiomata.

Marcescens process, production process for filamentous fungi in which mycelium mass is produced by submerged fermentation, filtrated, dried, milled, and formulated. The mycelium particles are applied in the field and sporulate on the plants.

Mycelium, mass of hyphae.

Mycoparasite, fungus parasitic on another fungus (as in *Calcarisporium ovalisporum).*

Phialide, a conidiogenous cell which produces basipetal chains of conidia from one or more open ends.

Polyphialide, phialide with more than 1 neck.

Rachis, the zig-zag extension on the conidiogenous cell (as in *Beauveria bassiana)* resulting from sympodial conidiogenous cell development.

Ramificated, branched.

Resting spore, a spore which germinates after a resting period, an "overwintering" spore *(e.g.* large thick walled spores in the Entomophthorales).

Stroma, compact mass of hyphae.

Sympodial proliferation, a mechanism of conidium production in which each new conidium is formed just behind the previous conidium, resulting in elongation of the cell *(e.g.,* as in *Beauveria bassiana).*

Synnema, aggregation of erect hyphae, conidiophores, and conidiogenous cells. This structure can be sturdy *(e.g.,* as in *Hirsutella citriformis)* or loose *(e.g.,* as in *H. strigosa).*

Verticillate, having parts in rings (verticils), whorled.

Zygospore, large, thick walled spore produced by conjugation of hyphae (as in the body cavity of insects infected by entomophthoralean fungi).

2. ENTOMOGENOUS FUNGI

Various entomogenous fungi have been collected from rice arthropods including planthoppers and leafhoppers (Homoptera), caterpillars (Lepidoptera), stink bugs (Hemiptera), and spiders (Arachnida). Some of these fungi can cause devastating epizootics, but other fungi *(ie.* most spider

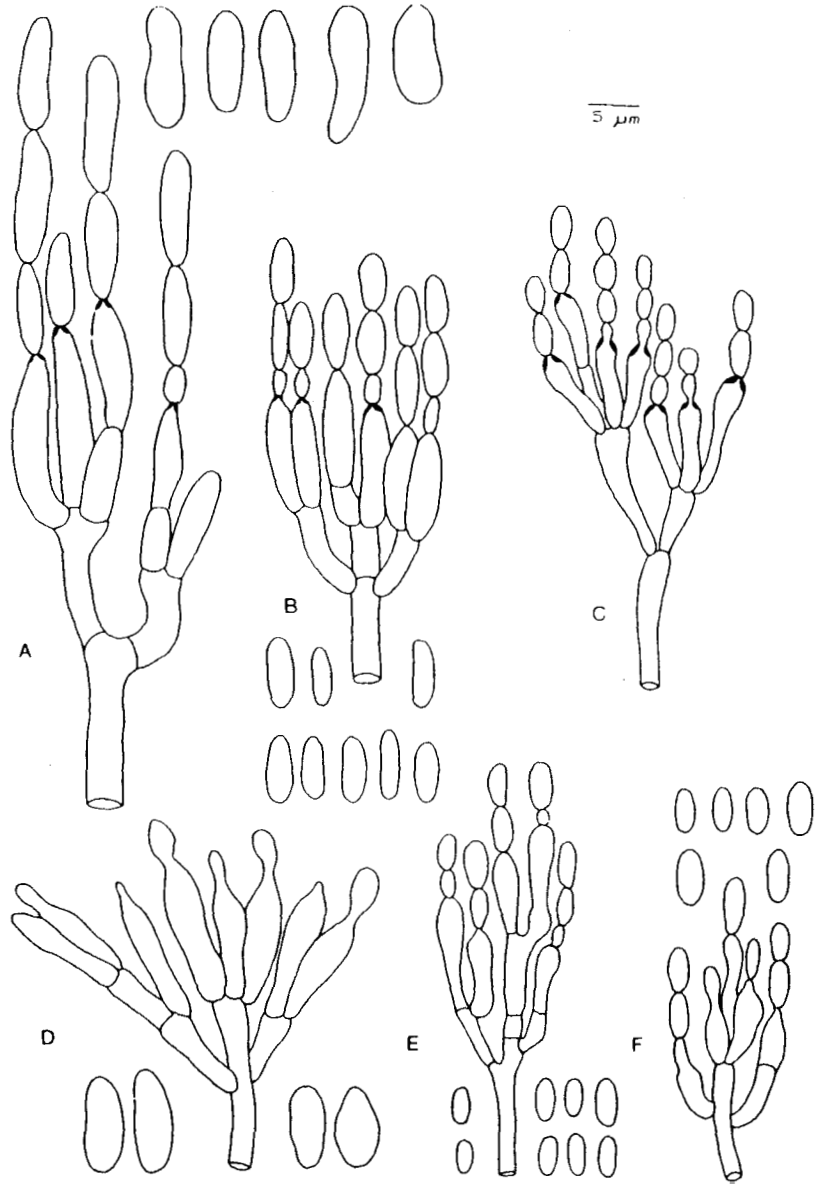


Fig. 1. *Metarhizium:* **A.** ***M.*** *anisopliae* var. *majus* Johnston, from coconut beetles; **B.** ***M.*** *anisopliae* (Metsch.) Sorokin var. *anisopliae,* from the brown planthopper *Nilaparvata lugens* (Stal); **C.** ***M.*** *album* Petch from the rice white leafhopper, *Cofana spectra* (Distant); **D.** ***M.*** *flavoviride* var. *flavoviride* Gams & Roszypal, from soil; **E.** ***M.*** *flavoviride* var. *minus* Rombach, Humber & Roberts, from the brown planthopper; and F in culture.

pathogens) are mostly collected on individual spiders, and epizootics have not been observed. The reason for the different epizootic potential of the fungi is not known, and offers an interesting area for ecological research.

Virtually all fungi of agricultural insect pests are Hyphomycetes or Entomophthorales (Roberts and Humber 1981), although entomogenous fungi occur in nearly all fungal orders. Collections of rice insects infected with the fungi and the isolation, mass production, and application of the fungi

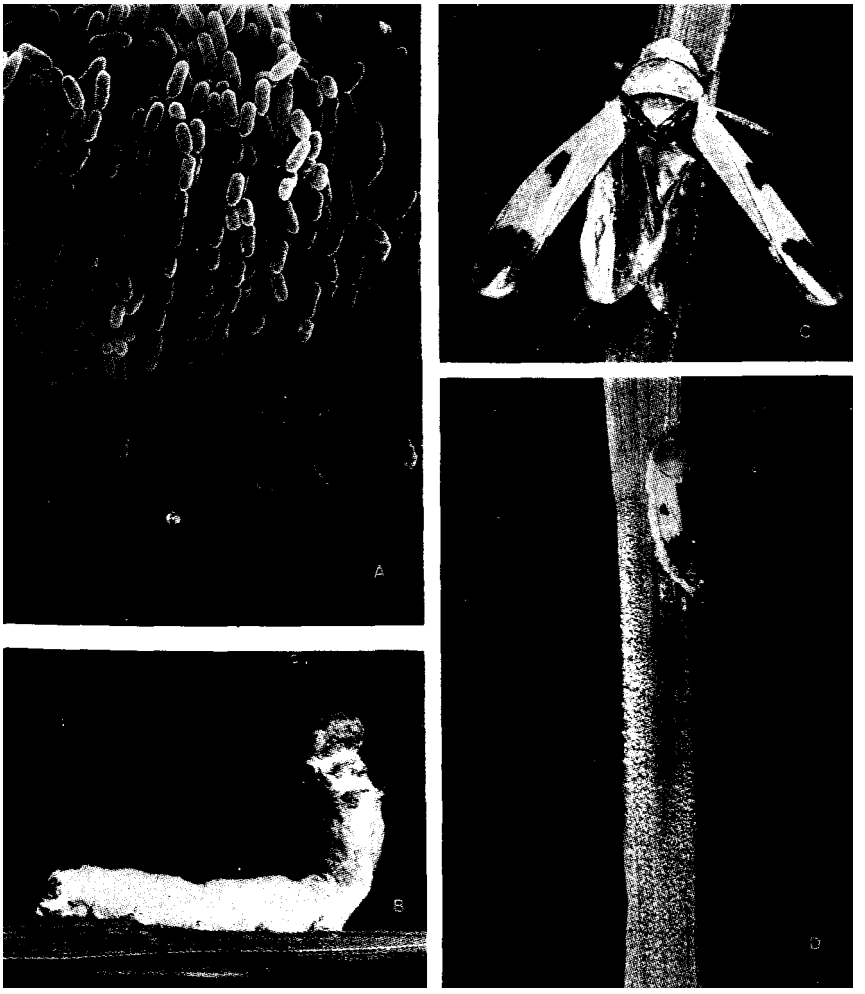


Fig. 2. **A.** *Metarhizium anisopliae* (Metsch.) Sorokin, palisade layer of phialides and conidia; **B.** *Nomuraea releyi* (Farlow) Samson infecting a rice looper; **C.** *Erynia delphacis* (Hori) Humber on the green leafhopper *Nephotettix virescens* Distant; **D.** *Conidiobolus coronatus* (Cost.) Batko on the green leafhopper, *Nephotettix virescens* (Distant). Note the halo of conidia on the lower part of the rice leaf.

will be discussed. A practical guide on handling fungi is given by Aguda and Rombach (1986) and a review on application and mass production by Hall and Papierok (1982). Fungal pathogens will be discussed by host group.

2.1 ENTOMOGENOUS HYPHOMYCETES

2.1.1 Hyphomycetes on Planthoppers and Leafhoppers

Few species of entomogenous Hyphomycetes are found in agricultural crops as compared to natural tropical habitats (Evans 1974, 1982). Fungi most commonly collected in agricultural crops include species of *Metarhizium, Beauveria, Hirsutella, Nomuraea,* and *Paecilomyces* (Samson 1981). Most of the pathogens infecting planthoppers and leafhoppers belong to these fungus genera (Soper 1985).

The planthoppers *Nilaparvata lugens* (Stal), leafhoppers *Nephotettix virescens* (Distant), and *Recilia dorsalis* (Motschulsky), rice stink bug, *Leptocorisa oratorius* (F.), and black bugs *(Scotinophara* spp.) feed by inserting their mouthparts into the plant. These insects are free of pathogens which require oral uptake, such as insect protozoans, viruses, and bacteria.

Common pathogens of rice planthoppers and leafhoppers are *Metarhizium anisopliae* (Metsch.) Sorok., *M. flavoviride* Gams & Rozsypal var. *minus* Rombach, Humber & Roberts, *Metarhizium album* Petch, *Beauveria bassiana* (Bals.) Vuill., and *Hirsutella citrifomis* Speare. Saprophytic species of *Penicillium,Aspergillus* and *Fusarium* were also reported from these insects. However, these fungi mostly invade dying or dead insects, and are of no significance in biological control.

Metarhizium Species.- M. anisopliae, the "green muscardine fungus", is a common insect pathogen. Veen (1968) compiled a list of more than 200 insects infected with *M. anisopliae.* Ferron (1978, 1981) discussed the ecology and practical use of *M. anisopliae.* The fungus is used in Brazil for control of cercopid spittlebugs such as *Mahanarva postica* (Wlk.) on a large scale.

Tulloch (1976) reports on *M. anisopliae* var. *anisopliae* Tulloch (Figs. 1B, 2A, 3A, D) and *M. anisopliae* var. *majus* Johnston (Fig. 1A). These varieties differ in morphology and host range. Brady (1979d) provides detailed descriptions of these varieties.

M. anisopliae var. *anisopliae* commonly infects planthoppers and leafhoppers, rice black bugs *(Scotinophara* sp.) (Fig. 3D), and various other rice insects. It can decimate cultures of rice plant- and leaf-hoppers (Aguda *et al.,* 1984a, Medrano *et al.,* 1984a). It has powdery masses of dark green to yellow-green columns of conidia which arise from white mycelium. Cylindrical phialides, 6-13 × 2-4 μm are located on stout conidiophores. The conidia are cylindrical to broadly ellipsoid with rounded ends, 4.5-8.5 × 2.5-4,um, and are produced in long dry parallel chains. The fungus looks the same in pure culture as on the insect.

M. flavoviride was collected from curculionid larvae and was isolated from soil (Gams and Rozsypal 1973) (Fig. 1D). Recently *M.flavoviride* var. *minus* was described from planthoppers and leafhoppers on rice in the Philippines and Solomon Islands (Rombach *et al.,* 1987b) (Figs. 1E, 4A). It produces greyish green conidial masses. Phialides, 9-15 × 3-4 μm, are club shaped and placed on

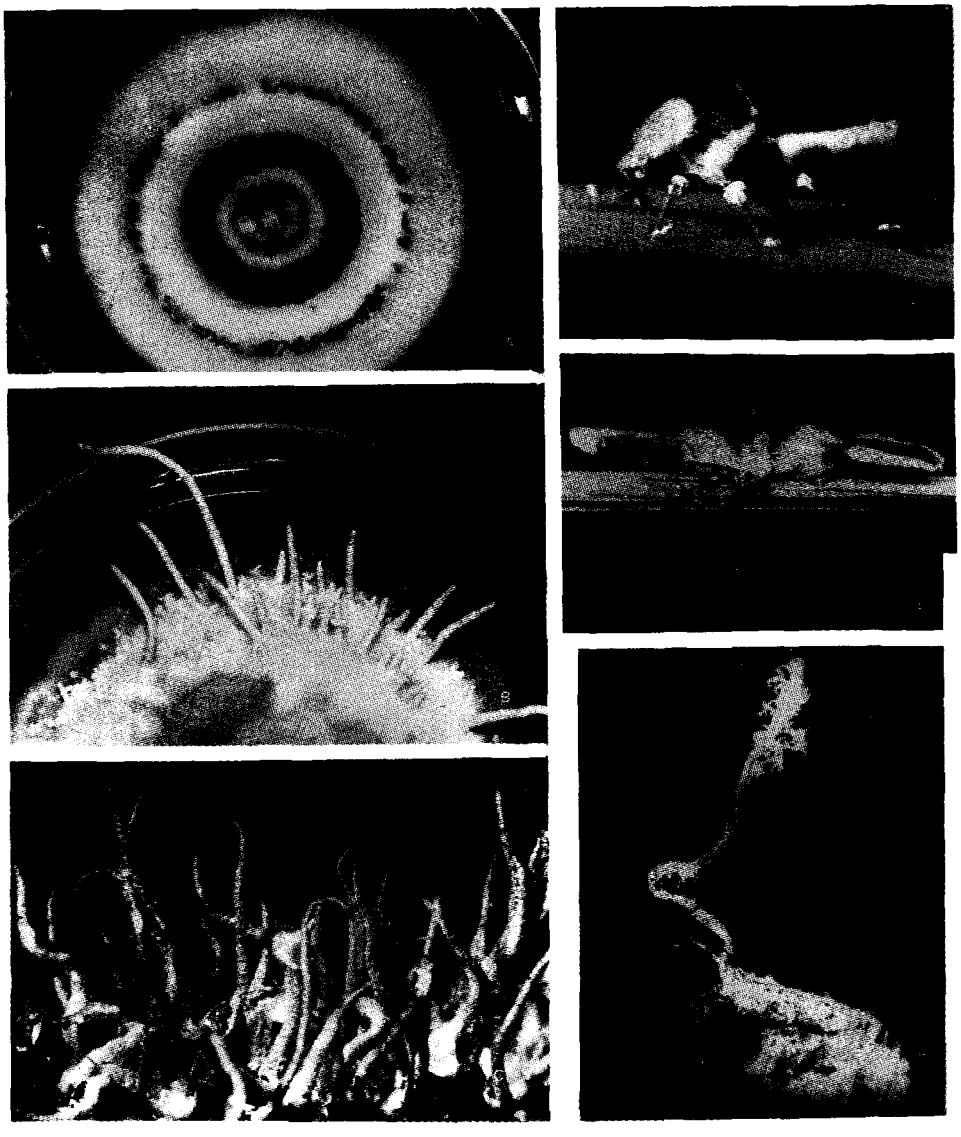


Fig 3. **A.** *Metarhizium anisopliae* (Metsch) Sorokin in culture. Note difference between the mycelium growth (white) and sporulation (dark green); **B.** *Paecilomyces farinosus* (Holm ex S. F. Gray) Brown and Smith, synnemata formation in culture; **C.** *Hirsutella cidiformis* Speare, synnemata formation in culture; **D.** *Metarhizium anisopliae* (Metsch.) Sorokin infecting the Malayan black bug, *Scotinophara coactata* (F.) **E.** *Beauveria bassiana* (Bals.) Vuill. on the rice bug, *Leptocorisa oratorius* (E); **F.** *Paecilomyces tenuipes* (Peck) on a lepidopteran pupa. Note the synnemata lifting fertile area above the soil surface.

conidiophores on a white mycelium mat. Conidia, 4.5-7.5 × 2-3μm, are ellipsoid. Synnemata are produced in culture.

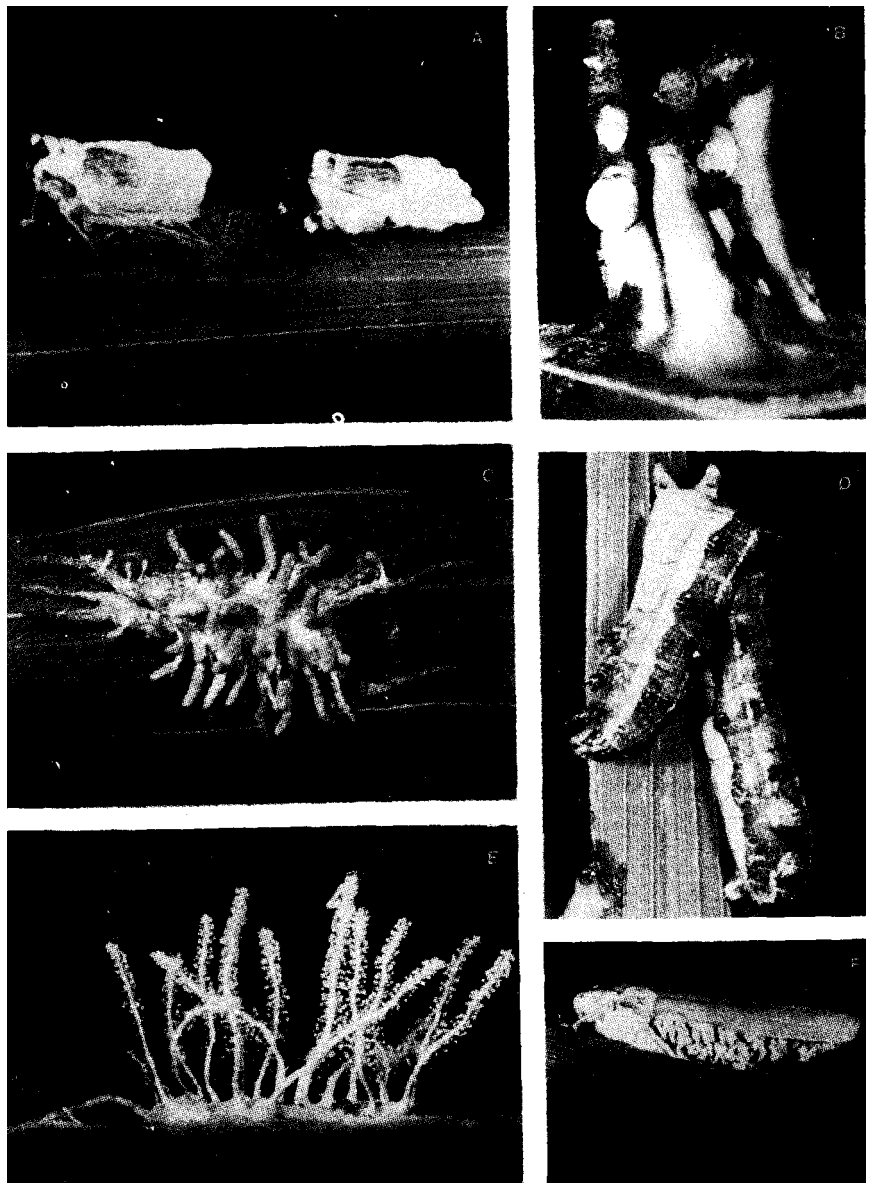


Fig. 4. **A.** *Metarhizium flavoviride* var. *minus* Rombach, Humber & Roberts infecting the brown planthopper, *Nilaparvata lugens* (Stal); **B.** *M. flavoviride* var. minus in culture; **C.** *Gibellula leiopus* (Vuill.) Mains on a spider; **D.** *Mythimna separata* (Walker) infected by a nuclear polyhedrosis virus (NPV); **E.** *Gibellula pulchra* (Sacc.) Cavara on a spider; **F.** *Metarhizium* album Petch on *Cofana spectra* (Distant).

M. album infects the cicadellid *Cofana spectra* (Distant) (Petch 1931) (Figs. 1C, 4F) and the green leafhopper in the Philippines and in Indonesia. It differs from *M. anisopliae* in its white color,

cerebriform structure of the stroma, and in size of the conidia. *M. brunneum* (Petch 1935) was found on a cicadellid insect in the Philippines. However, recent collections on the green leafhopper and *C. spectra* show that *M. album* and *M. brunneum* are conspecific (Rombach *et al.,* 1987a) and that *M. album* is the correct name for this species. It produces bulging masses of hyphal bodies covered by a layer of white mycelium. Up to 80 µm long conidiophores have verticillate ramifications near the top (Fig. 1). Each branch bears 2-5 cylindrical to club shaped phialides, 10-12.5 × 2-3.5 µm. Conidia, 4-6 × 1.5-2.5 µm, are broadly to narrow ellipsoidal and whitish brown. Cylindrical conidia of 8-11 µm length are found in culture.

The Russian scientist Eli Metschnikoff (1845-1916) pioneered mass production and field application of *M. anisopliae. Metarhizium* species can be easily isolated and grown in culture (Fig. 3A). On Sabouraud dextrose agar (SDA) mycelium grows abundantly but conidiation is sparse. On less nutritive media such as Emerson's YpSs (YpSs), oatmeal agar (OA), and malt extract agar (MEA) mycelium growth is flat and conidiation abundant. YpSs and MEA are the standard media for *Metarhizium* cultivation.

Solid media are commonly used for *Metarhizium* mass production (Soper and Ward 1981). Plastic bags or flasks with rice or bran are inoculated, and the conidia harvested after a few weeks. This is the common mass production procedure in Brazil and China (Ferron 1981) where the fungus is used to control spittlebugs in pasture land and sugarcane leafhoppers. Marques *et al.,* (1981) provides detailed information on small production plants and production procedures.

M. anisopliae also grows in liquid culture where mycelium pellets as well as hyphal bodies (blastospores) are produced. This material can be processed with the marcescent process. This method is develped for production of Entomophthora-like fungi (McCabe and Soper 1985), but it can also be used for Hyphomycetes (Rombach *et al.,* 1986c) (Fig. 5). The fermentor slurry is filtrated and the mycelium dried and milled. The particles can be stored for several months at low temperatures. When applied in the field the particles adhere to the plant where they produce conidia after a few days. These conidia infect the insects, Rombach *et al.,* (1986a) demonstrated the effect of *M. anisopliae* marcescent particles in brown planthopper control. The method has not yet been tested on a large scale.

The ecology of *Metarhizium* on rice insects is not well known. *M. flavoviride* var. *minus* is restricted to planthoppers and leafhoppers, while *M. anisopliae* var. *anisopliae* has a wide host range. Ferron *et al.,* (1972) show that different *M. anisopliae* strains infect different hosts. Therefore, infectivity tests with different strains have to be carried out before large scale field experiments are started.

Metarhizium spp. produce dry conidia which are easily dislodged by air movements. Wind is therefore important for dispersion. *M. flavoviride* and *M. anisopliae* are commonly isolated from soil (Domsch and Gams 1970, Domsch *et al.,* 1980) where conidia can survive. Soil is probably the source of inoculate for natural epizootics.

Few experiments have been conducted using *M. anisopliae* for control of rice insects. However, it has been shown that epizootics of *M. anisopliae* and *M. flavoviride* can be initiated in brown

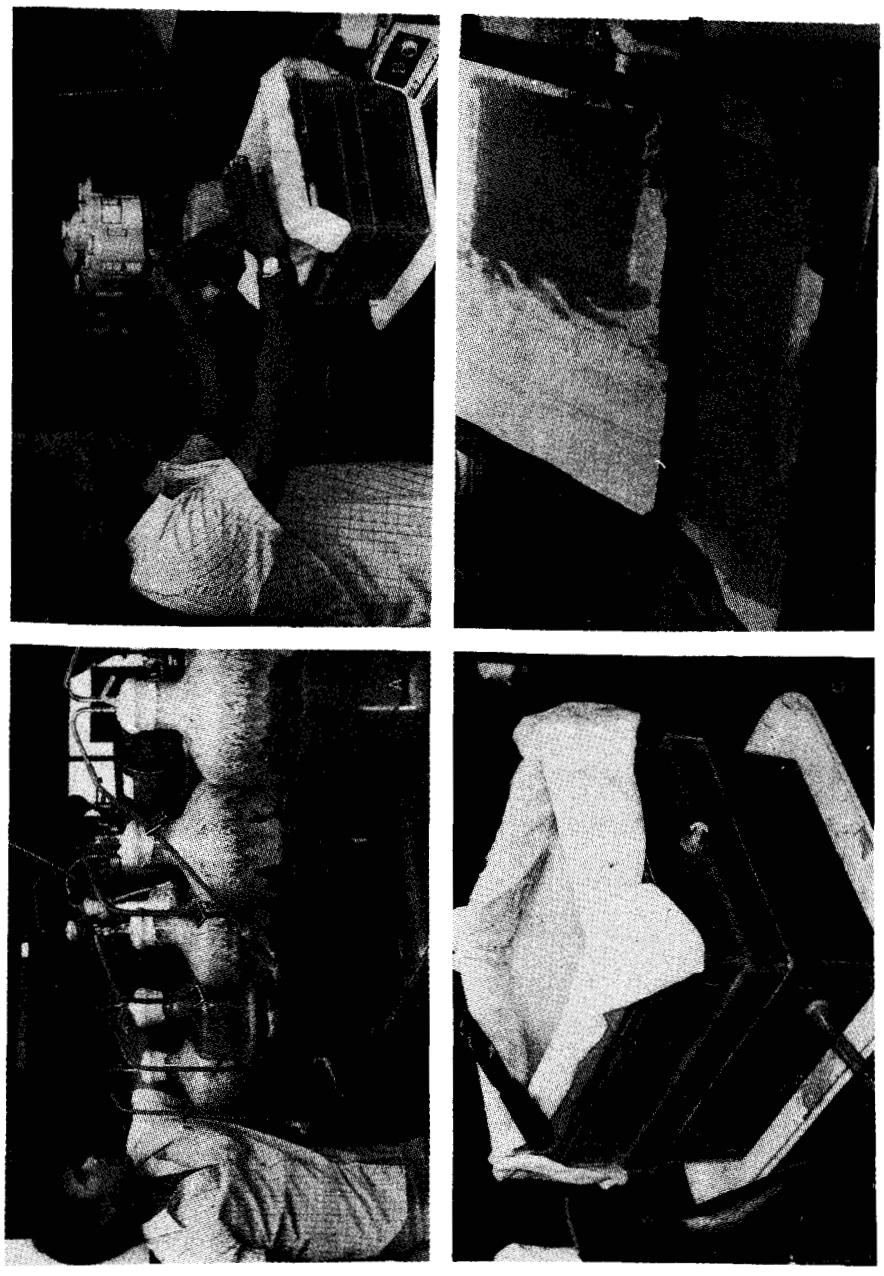


Fig. 5. Marcescent process: **A.** Growth of *B. bassiana* mycelium in 15 liter airlift fermentors; **B.** Harvesting of mycelium on cotton cloth in a vacuum filter unit; **C.** The moist mycelium cake after filtration; **D.** Drying of mycelium cake on racks. Handsprayer (right, corner) contains maltose solution for protection of mycelium.

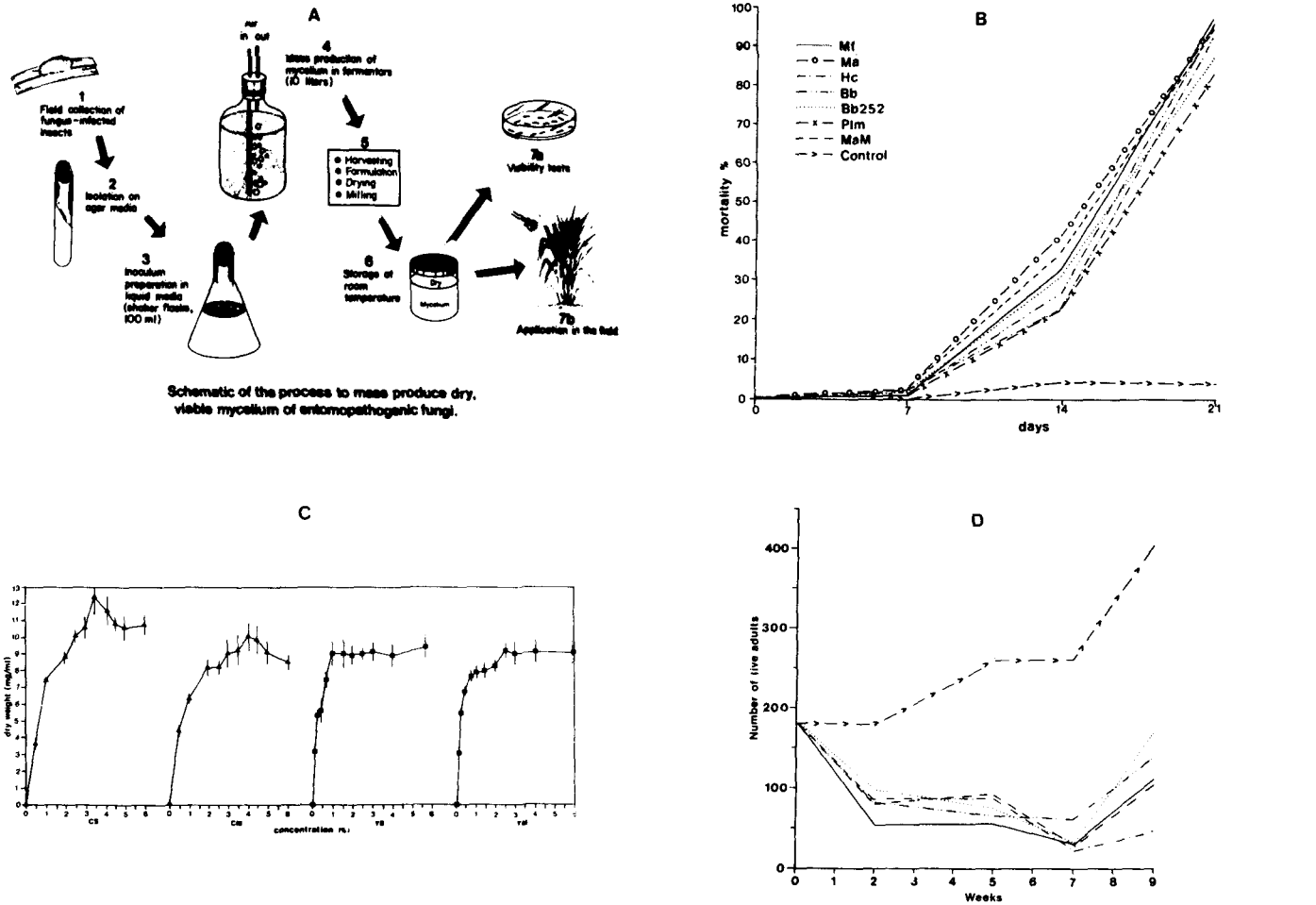


Fig. 6. **A.** Schematic representation of the production and application of dry mycelium of entomogenous Hyphomycetes; **B.** Infection of the brown planthopper in the field by different entomogenous fungi at 7, 14, and 21 days after application, Mf = *Metarhizium flavoviride* var. *minus* Rombach, Humber & Roberts, conidia; Ma = *M. anisopliae* (Metsch.) Sorokin, conidia; Hc = *Hirsutella citrifomis* Speare, conidia; Bb and Bb 252 = *Beauveria bassiana* (Bals.) Vuill., conidia; Plm = *Paecilomyces lilacinus* (Thom) Samson, mycelium; MaM = *M. anisopliae,* mycelium; Control - untreated; **C.***B. bassiana* mycelium production in different liquid media (CS = saccharose-yeast extract medium at different concentrations, CM = maltose-yeast extract medium at different concentrations, YS = yeast extract medium (1%) with increasing concentrations of saccharose, and YM = yeast extract medium (1%) with increasing concentrations of maltose); **D.** Suppression of the Malayan black bug in the field by different entomogenus fungi, — *M. anisopliae* (Metsch.) Sorokin, conidia; .... = *Beauveria bassiana* (Bals.) Vuill., conidia; -..- = *Paecilomyces lilacinus* (Thom) Samson, mycelium; -.- = *P. lilacinus,* conidia; —= *M. anisopliae, mycelium;* ® ® = untreated control.

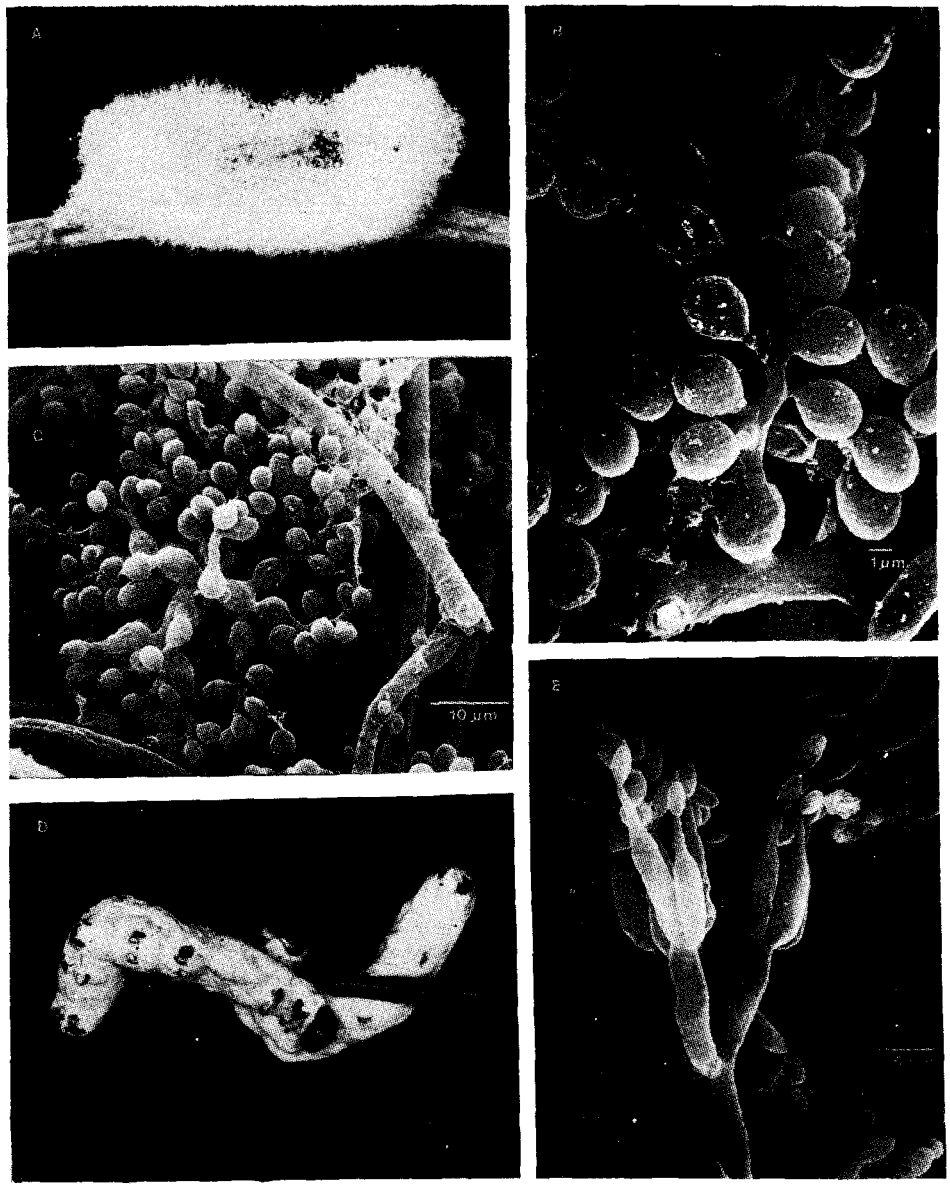


Fig. 7. **A.** *Beauveria bassiana* (Bals.) Vuill. on the brown planthopper; **B-C.** *Beauveria bassiana,* sympodial conidiogenous cell and cluster of conidiogenous cells; **D.** *Nomuraea rileyi* (Farlow) Samson infecting the green semilooper, *Naranga aenescens* Moore; **E.** *Paecilomyces farinosus* (Holm ex S.F. Gray) Brown & Smith, whorl of phialides and conidia.

planthopper populations by a single conidia application (Rombach *et al.,* 1986b) and by applications with dry mycelium (Aguda *et al.,* 1987) (Fig. 6B). Mortality levels exceeded 80% at 3 weeks after

spraying. Albornoz and Parada (1984) tested *M. anisopliae* against *Sogatodes oryzicola* (Muir). One application of 10^9 conidia/ml caused 100% morality after 12 days. A lower dosage of 10^7 conidia/ml resulted in a 50% mortality.

Beauveria Species. - *Beauveria bassiana,* or 'white muscardine fungus', is being used for agricultural pest control worldwide (Ferron 1978,1981). Brady (1979c) provides a description, illustration, and discussion on *B. bassiana.* In the USSR the fungus is applied against the Colorado potato beetle, *Leptinotarsa decemlineata* (Say), the potato ladybug, *Epilachna* sp., and several forest pests (Yevlakhova 1979). In China, *B. bassiana* is used against the European corn borer, *Ostrinia nubilalis* (Huebner), and forest pests (Franz and Krieg 1980). *B. bassiana* commonly infects rice planthoppers and leafhoppers. It is found on the leafhoppers *Nephotettix nigropictus* (Stal) and *Nephotettix virescens* (Distant) (Nayak and Srivastava 1979b), and on the brown planthopper (Rao 1975, Srivastava and Nayak 1978c, Rabindra 1973) in India. Chu and Hirashima (1981) report the fungus from rice leafhoppers in Taiwan. We collected and isolated *B. bassiana* from all species of rice leafhoppers and planthoppers in the Philippines. *B. bassiana* collections on rice insects are also reported as 'white muscardine' fungus, *Spicaria densa* (Link ex Pers.) Vuill., and *B. densa* (Link per Pers.) Picard.

Beauveria brongniartii (Sacc.) Petch is occasionally reported from rice insects as *B. tenella* (Sacc.) McLeod. It differs from *B. bassiana* in its ellipsoid conidia and absence of dense clusters of conidiogenous cells. *B. brongniartii* is, in general, restricted to melolonthid beetle larvae and adults. We collected the species on white grubs *(Holotrichia* sp.), serious soil pests in tropical upland rice. Collections of *B. brongniartii* from other rice pests are probably misidentifications of *B. bassiana.* Hoog (1972) provides detailed descriptions, illustrations, and lists of synonyms of *Beauveria* spp.

B. bassiana forms white powdery conidial masses that cover the insect (Fig. 7A). Host cadavers stick to a rice leaf or float on the water. Conidia, 2.5-3.5µm, are globose to broadly ellipsoid and are produced on sympodial conidiogenous cells that are present in dense clusters on hyphae arising from the mycelium mat (Fig. 7B,C). Conidiogenous cells have a globose to flask-shaped base, 2-3 × 2-4µm, with a dented zig-zag shaped rachis up to 20 µm long (Fig. 8B). In culture conidiogenous cells with an elongated base can occur.

B. bassiana is easily isolated on common mycological media. Malt extract (4%) agar (MEA) or SDA are good for growth and sporulation. It grows well in liquid media, in which it produces hyphal bodies ('blastospores') and mycelial pellets. The species can be produced by the marcescent process, and over 10^9 conidia per mg dry mycelium can be produced (Rombach *et al.,* 1988) (Fig. 5). On solid and in liquid media red or yellow oosporeins are excreted (E1 Basyouni *et al.,* 1968).The species can be mass produced on cheap solid media such as bran, boiled rice and soybeans with processes similar to those used to produce *M. anisopliae.* In China *B. bassiana* is mass produced at the community level; the starter cultures are grown in small flasks, but the actual mass is produced in trays or even in open pits in the ground. Media are wheat bran, corn stalk powder, and compost humus (Chiang and Huffaker 1976). Some *B. bassiana* strains have a strong antibiotic activity and can grow in non-sterilized liquid media (Yevlakhova 1979). A high-yielding production method

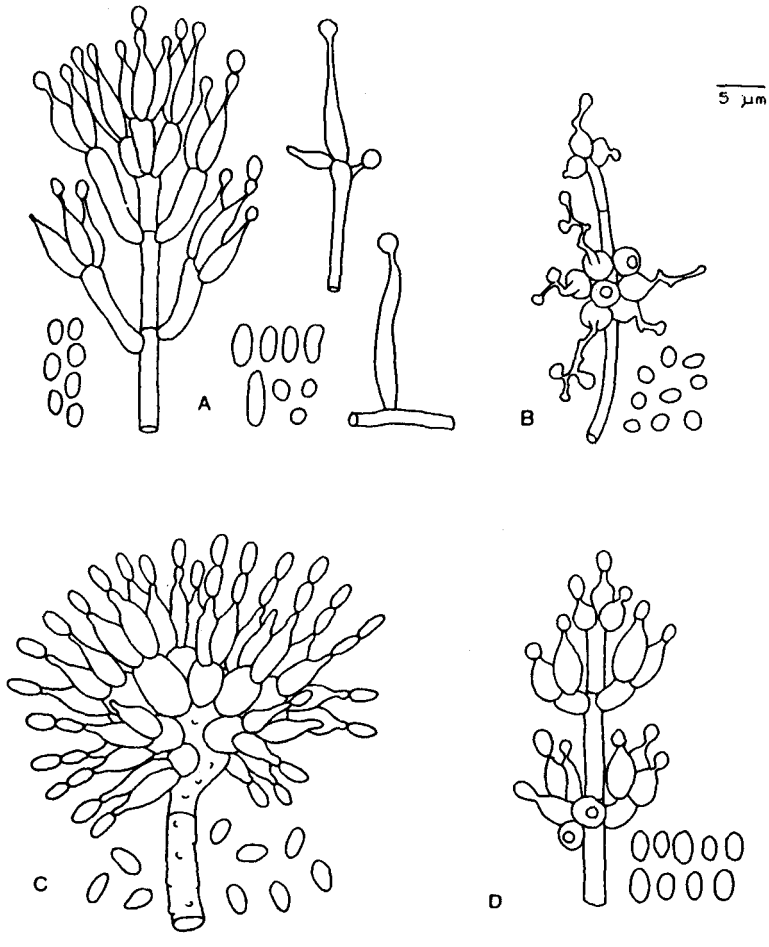


Fig. 8. **A.** *Paecilomyces lilacinus* (Thom) Samson, (left) from the Malayan black bug *Scotinophara coarctata* (F.), and (right) in liquid culture; **B.** *Beauveria bassina* (Bals.) Vuill., the white muscardine fungus, from plant and leafhoppers; **C.** *Gibellula pulchra* (Sacc.) Cavara, from a spider in the Philippines; **D.** *Nomuraea rileyi* (Farlow) Samson, a fungal pathogen of the hairy caterpillar, *Rivula atimeta* (Swinhoe), in the Philippines.

using stationary liquid cultures was described by Samsinakova *et al.,* (1981). *B. bassiania* is a suitable candidate for production and application where only low technology is available. Ferron (1981) provides a review of ecology and field application of *B. bassiana.*

B. bassiana isolates were tested for their virulence against the green leafhopper *N. virescens,* the whitebacked planthopper *Sogatella furcifera* Horvath, and brown planthopper on rice. Differences in pathogenicity of the different strains were present (Aguda *et al.,* 1984b). Rombach *et al.,* (1986b) field tested *B. bassiana* for brown planthopper control in the field. One conidial spray caused high mortality levels after 3 weeks (Fig. 6B). Aguda *et al.,* (1987) applied dry *E. bassiana* mycelium for hopper control on rice in Korea (Fig. 9A, B). Long term control and significant reduction in

hopperburned rice plants was achieved. Also, virulence of *B. bassiana* isolates was compared with other insect fungi (R.M. Aguda and D. J. Im, unpubl.,1986). Insects were dipped in suspensions of conidia and suspensions of formulated, dry mycelium of *B. bassiana.* No differences in virulence between the fungi were detected, and mortality levels only slowly increased with increasing dosage of the fungi (Fig. 10).

Hirsutella Species.-Various Hirsutella species have been collected from planthoppers and leafhoppers (Soper 1985). Only *H. citriformis* Speare and *H. strigosa* Petch have been found on rice hoppers (Rombach and Roberts 1989). *H. strigosa* is commonly found on the brown planthopper and green leafhopper in the insectary and field at the International Rice Research Institute, Los Banos, Laguna, Philippines (Fig. 11D, E). The fungus covers the host in a light brownish mycelium that forms byssoid strands on the rice leaves. Phialides, 15-35 × 4.5-6µm, with a cylindrical base and a stout neck, 12-25 × 1-2µm, are scattered over the mycelium strands. Base and neck are warted. Polyphialides are present (Fig. 12). Conidia, 9.5-12.5 × 3.5-6µm, are cymbiform with rounded ends or ellipsoid, and are produced mostly with 1

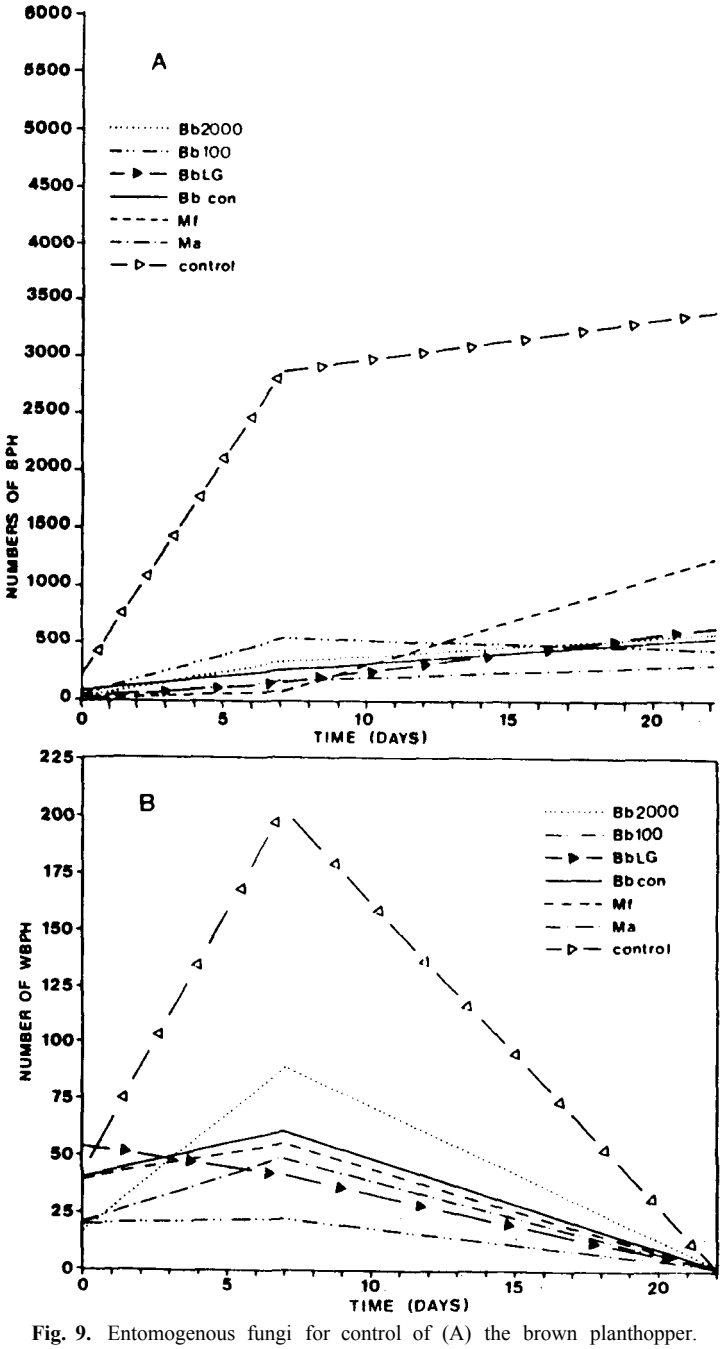


Fig. 9. Entomogenous fungi for control of (A) the brown planthopper. *Nilaparvata lugens* (Stal), and (B) the whitebacked planthopper, *Sogatella furcifera* (Horvath) in South Korea. (Bb2000 = 2000 g formulated dry *B. bassiana* mycelium/ha; Bb100 = 100 g formulated mycelium; BbLG = mycelium formulated the water absorption; Bbcon = *B. bassiana* conidia, $5x10^{12}$/ha;, Mf = *Metarhizium flavoviride* var. minus, conidia at $5 x10^{12}$/ha; Ma = *M. anisopliae* conidia at $5x10^{12}$/ha;, control = untreated control).

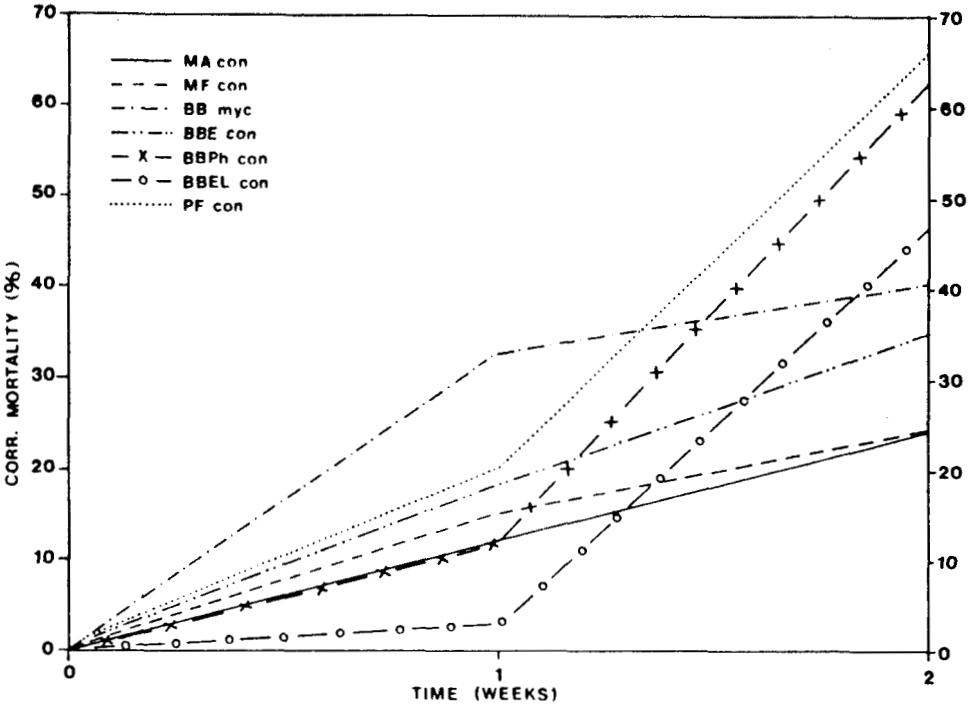


Fig. 10. Bioassay of fungi against brown planthopper, *Nilaparvata lugens* (Stal) from South Korea. Insects were dipped in suspensions of either 5×10^7 conidia/ml, or in suspensions of 10 g formulated mycelium/liter. MA = *Metarhizium anisopliae;* MF = *Metarhizium flavoviride* var. *minus;* BBE, BBPh, and BBel = *Beauveria bassiana,* different strains; PF = *Paecilomyces farinosus;* BBmyc = *B. bassiana* mycelium.

or 2 in a mucus drop. In pure culture synnemata are produced (Fig. 11D), and the phialides and conidia are markedly smaller.

H. citriformis (Speare 1920) is widely distributed on rice planthoppers and leafhoppers and can be found on the brown planthopper in most of the rice growing areas of Asia (Fig. 13 A-D). Brady (1979b) provides a description and discussion on *H. citriformis.* Gabriel (1968) illustrated the species for the Philippines. During periods of high insect density the fungus is often the major mortality factor; epizootics killing total populations are common and dozens of infected specimens are clustered on a single stem of rice. *H. citriformis* has long, filamentous brownish grey to brownish pink synnemata. The insect is covered in mycelia which also grow for short distances on the plant surface, attaching the host to the substratum. Synnemata are 1-10 mm long, depending on the stage of infection; they bear short and stumpy branches. Phialides, up to 45µm long, have a globose to ellipsoid base, and long and slender needle-like necks. Conidia, 5-8.5 × 2-3µm, are cymbiform with rounded ends, or ellipsoid, and enveloped in mucus (Fig. 12A). Synnemata are also produced in culture.

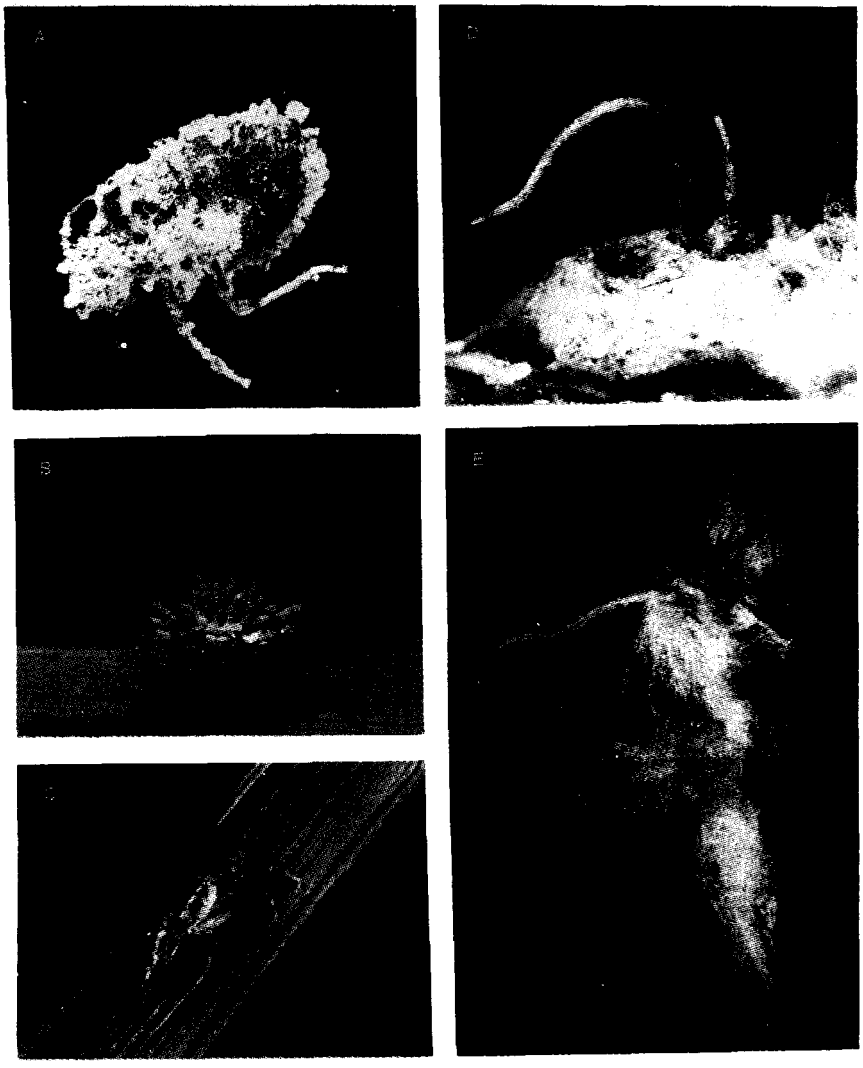


Fig. 11. A. *Paecilomyces lilacinus* (Thorn) Samson infecting the black bug *Scotinophara coarctata* (F.); **B.** *Gibellula leiopus* (Vuill.) Mains on a spider; **C.** *Hirsutella jonesii* (Speare) on the predator *Cyrtorhinus lividipennis* Reuter; **D.** *Hirsutella strigosa* Petch, synnemata in culture; **E.** *Hirsutella strigosa* Petch infecting the green leafhopper, *Nephotettix virescens* (Distant).

H. citriformis can be grown on media. SDA is best for isolation and growth. The species is isolated by touching the synnemata with a sterile, preferably glass, needle to transfer conidia to the agar. It can also be isolated by transfer of internal mycelia, or hyphal bodies, to the culture plate. *H. citriformis* grows slow on solid media and colonies reach a diameter of 1-5 mm after 1-2 weeks of incubation at room temperature. The competitive ability of *H. citriformis* in culture is low, and

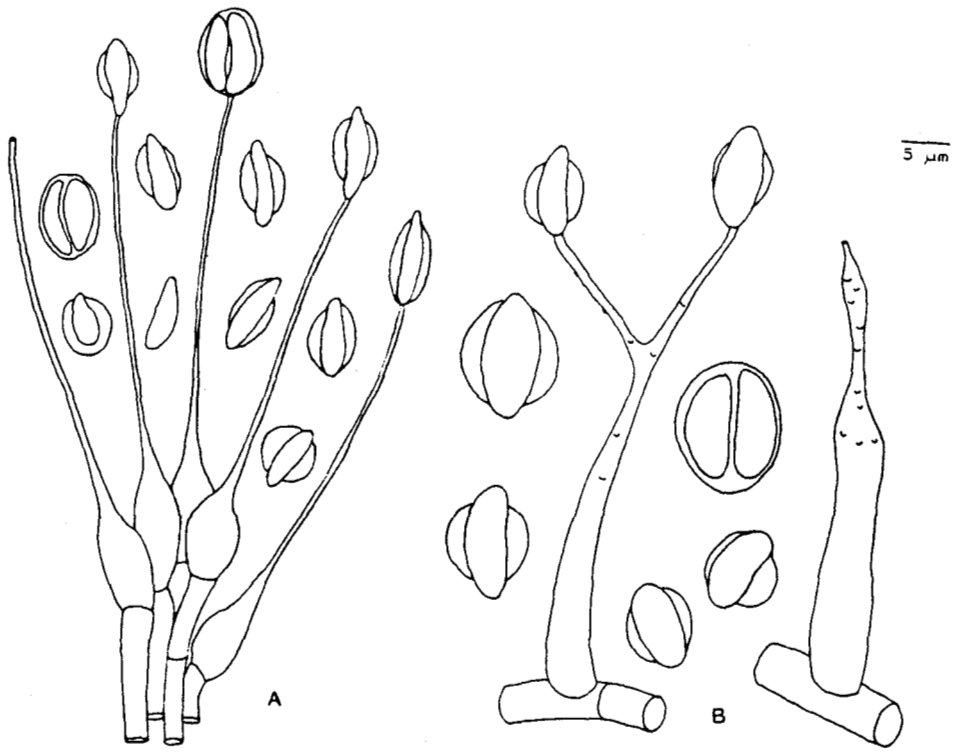


Fig. 12. A. *Hirsutella citriformis* Speare, fungal pathogen of the brown planthopper. Note the conidia in mucus; **B.** *Hirsutella strigosa* Petch, fungal pathogen of the green leafhopper *Nephotettix virescens* (Distant).

cultures are easily overgrown by bacteria, yeasts, and other fungi. Cultures are white, velvety and wrinkled. After 4-8 weeks synnemata are produced in the center of the colonies (Fig. 3C). Light does not affect production of synnemata. Phialides and conidia are present on the synnemata and on the velvety mycelium. A medium sized colony of 5 cm diameter produces about 10^6-10^7 conidia. This is few compared to the conidia production of the muscardine fungi. Therefore, production of conidia on solid media is only possible for laboratory studies and small field trials. For mass production other methods with submerged fermentation have to be developed. *H. citriformis* can be propagated in liquid yeast extract/molasses media; in this broth over 10 g dry weight of mycelium per liter can be harvested from well aerated fermentors (Rombach *et al.,* 1989b). In culture *H. citriformis* produces a highly viscous metabolite similar in nature to the polysaccharides produced by *H. gigantea* Petch (Loughheed and MacLeod 1958).The rate of excretion of the metabolites differs among strains. Epizootics of *H. citriformis* were induced in populations of the brown planthopper where single applications with a suspension of mycelium and conidia resulted in mortality levels exceeding 80% at 3 weeks post treatment (Rombach *et al.,* 1986b).

The mycoparasite *C. ovalisporum* Petch was collected on *H. citriformis* on the brown planthopper in the Solomon Islands (Rombach and Roberts 1987) (Fig. 13 E,F). *C. calcarisporium* is present

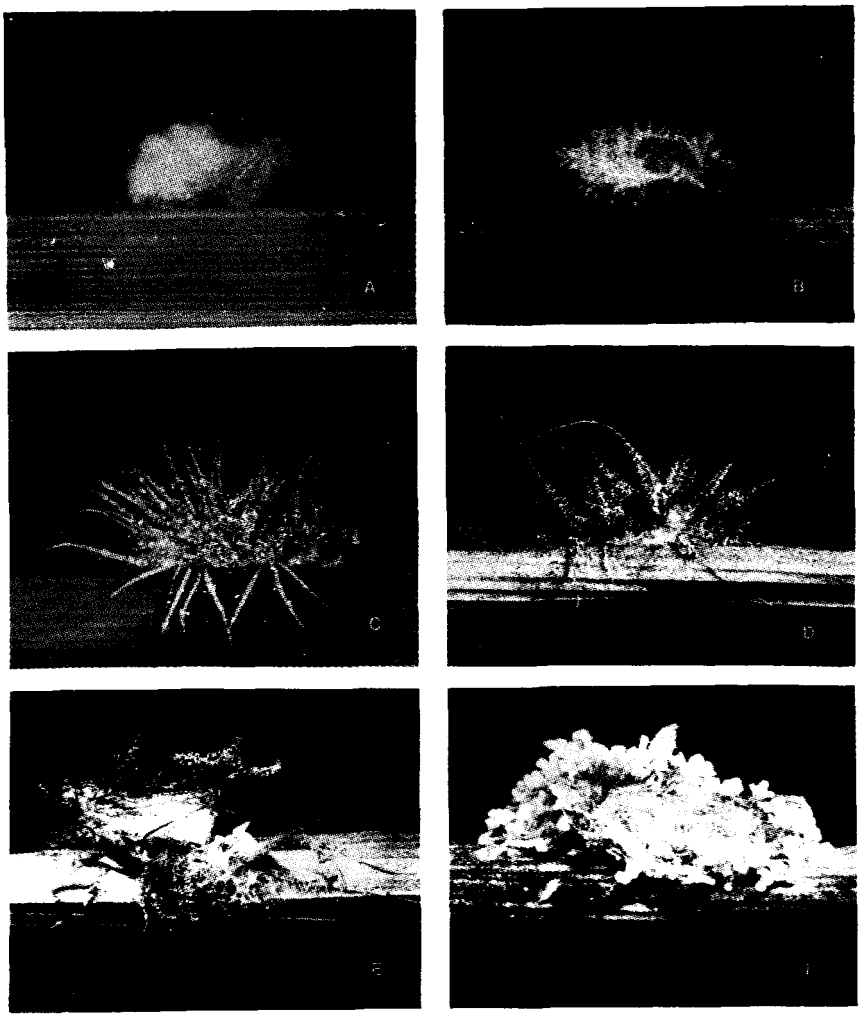


Fig. 13. A-D. *Hirsutella citriformis* Speare, at different stages of development on the brown planthopper; **E-F.** *Hirsutella citriformis* infected with the mycoparasite *Calcarisporium ovalisporum* Petch., early stage of infection (E), and final stage of infection with the insect fungus completely overgrown with the parasitic fungus (F).

as a diffuse, purely white mycelium and loosely bound, short and stumpy synnemata on brown planthoppers infected with *H. citriformis. C. ovalisporum* grows in culture, but does not sporulate on media lacking (heat-killed) mycelium of the host fungus. On virtually all *H. citriformis* infected brown planthopper specimens collected on the Guadalcanal Plains (Solomon Islands) the

mycoparasite was also found. *C. ovalisporum* probably has an effect on *H. citriformis* epizootics in brown planthopper populations.

2.1.2 Other Hyphomycetes

Morimoto (1957) and Aoki (1941) reported *Paecilomyces farinosus* (Holm ex S. F. Gray) Brown & Smith (Fig. 3B) from rice planthoppers and leafhoppers in Japan. Kuruvilla and Jacob (1980b) reported on its pathogenicity to several insect pests. *P. farinosus* is a common insect pathogen which occurs in soil (Samson 1974). Müller-Kögler (1965) reviewed the literature on biological control with *P. farinosus.*

Paecilomyces fumosoroseus (Wize) Brown & Smith has a wide host range including Lepidoptera and Diptera. The species was isolated from brown planthoppers collected in a field at the International Rice Research Institute, Philippines. Samson (1974) provided detailed descriptions of *Paecilomyces* spp. These fungi are suitable candidates for biological control studies on rice.

Fusarium species have been reported infecting rice insects, including Lepidoptera and Homoptera (Hongke 1983, Kuruvilla and Jacob 1979). Hongke reported 51-80% mortality of brown planthopper populations in bioassay tests. Kuruvilla and Jacob (1979, 1980a) describe field cage tests with *F. oxysporum* Schlecht. These tests resulted in total infection of brown planthopper populations, even at a dose of 1-6 $\times$ 10^6 conidia/ml sprayed on rice plants. Nayak and Srivastava (1978a) reported *F. oxysporum* infecting the rice greenhorned caterpillar *Melanitis leda ismene* Cramer. Sinha and Prasad (1975) mention the occurrence of *F. aleyrodis* on larvae of the stem borer *Chilo partellus* (Swinhoe).

Caution should be exercised in experimentation with Fusarium species. Only a very few *Fusarium* species are considered insect pathogens *sensu stricto.* Other *Fusarium* species are not insect pathogenic or only weakly so, and they include plant pathogens, food contaminants, and mycotoxin producers. These are factors that limit the use of *Fusarium* species in biological control. Extensive research on mass production and field application of *Fusarium* species is discouraged, especially because virulent, and obligate fungi such as *Beauveria* and *Metarhizium* species that are safe to humans are available.

2.13 Hyphomycetes on Stink Bugs and Weevils

Few pathogens have been found infecting rice black bugs, *Scotinophara* spp. (Pentatomidae: Hemiptera) and the stink bug *Leptocorisa oratorius* (F.) (Alydidae: Hemiptera). These bugs feed by sucking, and are free of diseases that infect through oral uptake.

Katsumata (1930) reported on *M. anisopliae* on *Scotinophara lurida* Burm. in Japan. Morimoto (1957) reported on *M. anisopliae* and *P. lilacinus* and their use in biological control of *S. lurida* in Japan. *P. lilacinus* was also collected from *Scotinophara coarctata* (F.) in Malaysia (Fig. 11A); *M. anisopliae* (Fig. 3D) and *B. bassiana* were isolated from this host in Palawan, Philippines. In the Philippines, *B. bassiana* is common in populations of *L. oratorius* (M. C. Rombach and R. M. Aguda,

unpubl.), (Fig. 3E). Meneses Carbonell *et al.,* (1980) report on the successful control of the rice water weevil, *Lissorhoptrus brevirostris* (Curculionidae) with *M. anisopliae* in Cuba.

Paecilomyces lilacinus.- *P. lilacinus* (Thom) Samson occurs on insects, nematodes, and in soil. *Spicaria rubido-purpurea* Aoki (1941) is synonymous with *P. lilacinus;* it was reported on *S. lurida* on rice in Japan (Morimoto 1957). *P. lilacinus* has promise for biological control of nematodes (Candanedo *et al.,* 1984), in addition to its possible value in biological control of insects. On *Scotinophara* short synnemata (up to 1 mm long) are produced on the joints. The mycelium is white, turning whitish purple at sporulation. Conidiophores have verticillate short branches with whorls of 2-4 phialides (Fig. 8A). The phialides, 7-9 × 2-2.5 µm, are flask shaped with a swollen basal part and a short neck of 1-1.5 µm long. The conidia, 2-2.5 × 1.2-2µm, are broadly ellipsoidal and in short chains.

The fungus is easily isolated on PDA, SDA, MA (4%), and YpSs agar. Isolation can be difficult, because infected insects are often collected from wet paddy mud and are heavily contaminated. With such specimens internal mycelium or hyphal bodies are used for isolation. *P. lilacinus* also produces conidia in liquid culture (Fig. 8A); the phialides are elongated and the conidia vary in shape and size.

A review by Morimoto (1957) summarizes his earlier work (1952-1954) on the microbial control of *S. lurida* by *P. lilacinus* and *M. anisopliae.* These fungi infect *S. lurida* but are relatively safe for the silkworm. Rice plants with field populations of *S. lurida* were sprayed and dusted with *P. lilacinus* and *M. anisopliae.* Sprays were more effective than dusts. Also, black bug mortality was higher in *M. anisopliae* plots than in *P. lilacinus* plots where mortality levels of 60-100% for up to 46 days were observed after application with *M. anisopliae* conidial dust. In one region with low insect numbers the populations were completely eliminated at 14 days after application. The fungus spread to untreated adjacent fields and caused high infection levels of up to 100%.

Morimoto (1957) distributed silkworm pupae infected with *M. anisopliae* in rice hills. These cadavers generate a natural and constant inoculant to infect immigrating black bugs. This effect of a more or less continuous conidia supply is also achieved by field application of mycelium particles from the marcescent process (Rombach *et al.,* 1986c). These particles adhere to the rice plants, and produce conidia for at least one week in the hot tropics, and for several weeks in cooler temperate regions such as Korea (Aguda *et al.,* 1987).

Rombach *et al.,* (1986c) reported results of experiments on the microbial control of the black bug *S. coarctata,* in the Philippines in which *B. bassiana, M. anisopliae,* and *P. lilacinus* were tested (Fig. 6D). In these experiments single conidia and dry mycelium applications significantly reduced black bug populations for over a 2-month period.

It should be noted that handling *P. lilacinus* poses possible safety problems. This species has also caused keratitis in human patients, but only in those that were under post operative treatment with cortico-steroids and antibiotics (Kozarsky *et al.,* 1984, Morgan *et al.,* 1984). These "mycoses" are saprophytic invasions of decomposing organic matter. Active invasion of healthy mammal tissues by *P. lilacinus* has not been reported. Although, handling of *P. lilacinus* in the Course of

biological control programs is most probably safe, overexposure of eyes and the pulmonary system should definitely be avoided, and simple safety precautions such as the use of dust masks and safety glasses should be taken.

2.1.4 Hyphomycetes on Lepidoptera

Lepidopteran larvae on rice are infected by entomogenous fungi, but epizootics are rare. Only a few fungi are of interest for the biological control of rice Lepidoptera.

Nomuraea rileyi (Farlow) Samson is often collected on rice lepidopteran larvae (Kish *et al.,* 1974). This fungus is well studied because it causes epizootics in populations of noctuid caterpillar pests on cabbage, clover, soybean, velvetbeans and other crops (Ignoffo 1981, Allen *et al.,* 1971, Sprenkel and Brooks 1973), and at present there is interest in its commercial production. On these crops early instar larvae are more susceptible to the fungus than later stages. Ignoffo *et al.,* (1976a, b) concluded that it is most practical to apply the fungus as a prophylactic agent before damaging populations occur. In recent years *N. rileyi* was collected and isolated from rice pests such as armyworms and cutworms, *Mythimna* spp, and *Spodoptera* spp. respectively, the hairy caterpillar, *Rivula atimeta* (Swinhoe, Fig. 8D), and the green semilooper, *Mocis frugalis* (F.) (Fig. 28) and *Naranga aenescens* Moore (Fig. 7D). *N. rileyi* was also collected on larvae of the leaffolders *Cnaphalocrocis medinalis* Guenee and *Marasmia* sp.

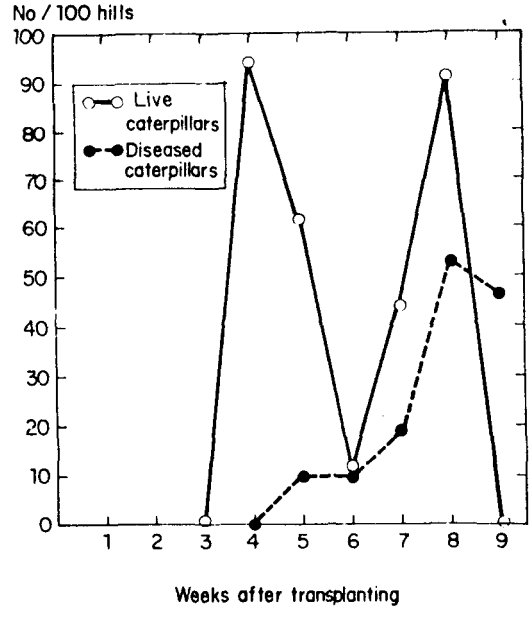


Fig. 14. *Nomuraea releyi* (Farlow) Samson, suppression of hairy caterpillar, *Rivula atimeta* (Swinhoe.), in the Philippines. This natural epidemic of the fungus effectively suppresses the second, most damaging, population of the hairy caterpillar.

N. rileyi produces a compact, pale green to gray-green layer of conidiophores on a white basal felt of mycelium on the insects. Conidiophores have branches in close whorls near septa with 2-5 phialides on each branch (Fig. 8D). Phialides, 4.7-6.5 × 2.3-3.0µm, have a cylindrical or swollen base and the neck is absent or greatly reduced. Conidia, 3.5-4.5 × 2-3µm, are broadly ellipsoid and in dry chains.

The fungus is easily isolated on agar media, but growth is slow; it sporulates well on YpSs and OA. Information for the mass production of the fungus is limited (Ignoffo 1981).

To date no biological control experiments with the fungus have been carried out on rice in the field. However, some information on its natural occurrence is available. A natural and dramatic outbreak of the fungus prevented damage by an increasing population of a *Spodoptera* sp. (F. Medrano, per. comm., 1985) on rice in the Philippines. Also, *N. rileyi* often suppresses outbreaks of the second generation of the green hairy caterpillar, *R. atimeta,* in South Cotabato, Philippines (Fig. 14). Bioassay tests with *N. rileyi* and *B. bassiana* against larvae of *Cnaphalocrocis medinalis* Guenee show an ED_{50} of 3.5 x 10^5 conidia/ml (Aguda and Rombach 1987), when the larvae are dipped in the suspension and incubated on rice leaves. In these tests *B. bassiana* was more effective in infecting this insect than *N. rileyi.* However, differences in susceptibility of insects and virulence of *Nomuraea* strains exist (Boucias *et al.,* 1982, Puttler *et al.,* 1976).

P. fumosoroseus has been reported attacking various lepidopteran and dipteran hosts. It was reported from the European corn borer *Ostrinia nubilalis* (Huebner) in China (Sheng *et al.,* 1965, In Samson 1974) and France (Maniania and Fargues 1984). *P. fumosoroseus* was also isolated from the striped stern borer *Chilo suppressalis* (Walker) (Maniania and Fargues 1984). Studies of the virulence of the isolate for *Spodopfera* spp. indicated that some insect strains were highly susceptible. Riba *et al.,* (1983) reported that eggs of *O. nubilalis* were highly susceptible to the fungus. This is an interesting observation because the egg and neonate larvae of stem borers are the most vulnerable stages; older larvae hide inside the rice stem.

P. farinosus is a cosmopolitan insect pathogen (Samson 1974) (Fig. 7E, 3B). Biological control experiments with the fungus are listed by Steinhaus (1949) and Müller-Kögler (1965). *P. farinosus* was reported from the striped stem borer *C. suppressalis* in Japan (Nickel 1964). *P. fumosoroseus* and *P. farinosus* are easily mass produced and applied in the field. They should be further evaluated for rice stem borer control.

Paecilomyces tenuipes (Peck) Samson (Fig. 3F) is rarely collected on lepidopteran pupae. The species has been isolated on artificial media, but its value for biological control of lepidoptera is not known.

B. bassiana is a pathogen of European corn borer, *O. nubilalis* eggs (Lynch and Lewis 1978), larvae (Steinhaus 1949), and adults (Smith and York 1960). York (1958) and Riba (1984) reported high mortalkty in field populations of *O. nubilalis* after *B. bassiana* applications. In China, microbial control of this borer by *B. bassiana* is practiced over large areas (Hussey and Tinsley 1981). *B. bassiana* infects rice stem borers (Rao 1975, Yadava *et al.,* 1979, Math *et al.,* 1966, Srivastava and Mathur 1970), and the rice skipper, *Pamara mathias* F. (Nayak *et al.,* 1978a). The closely related

fungus *B. brongniarti* was also tested for rice skipper infection (Nayak *et al.,* 1978a). Experiments on biological control of rice stem borers and other rice Lepidoptera with *B. bassiana* have been restricted to laboratory bioassay tests (Nayak *et al.,* 1978b, Nayak and Srivastava 1979b, Yadava *et al.,* 1979). N'Doye (1976) observed reduced oviposition rates and viability of *C. suppressalis* eggs in survivors of a mycosis. Laboratory bioassay tests show that leaffolder *Marasmia* sp. larvae can easily be infected with *B. bassiana* (M. C. Rombach and R. M. Aguda, unpubl.).

B. bassiana is relatively simple to mass produce on solid media as well as with the marcescent process (Fig. 5). It is safe for humans and beneficial organisms. Therefore, this pathogen is a prime candidate for experimentation of microbial control of rice stem borers and leaffolders.

2.2 ENTOMOPHTHORALES

Entomophthoralean fungi (Zygomycetes) commonly cause epizootics in insect populations (Wilding 198l), and several of these fungi have potential for commercial development. In this group the conidia are forcibly discharged by turgid cells and are launched over distances of several centimeters. This results in an aureole or halo of conidia on the plant substratum surrounding dead hosts (Fig. 2D). The forced discharge of the conidia can be exploited when culturing Entomophthorales. Dead hosts are placed on the inside of a petri dish lid and the agar surface placed above the cadaver, and conidia will be dispersed on to the agar. The most adequate medium for isolation of entomophthoraleans is coagulated egg-yolk medium/SDA combination (Stevens 1974). A mycostatic agent, Mycostatin®, and antibiotics such as a penicillin — streptomycin combination or Gentomycin® can be added to inhibit contaminant growth.

Entomophthoralean fungi grow vegetatively as short and irregular hyphal segments or hyphal bodies. The life cycle includes thick walled resting spores and zygospores which are produced in the body cavity of the host; these structures are produced after conjugation of adjacent hyphal cells. These resistant spores survive periods of adverse environmental conditions.

Entomophthoralean taxonomy became increasingly complicated after the basic studies of Roland Thaxter (1888) a century ago. Humber (1981) reviewed the most recent taxonomic criteria and taxonomic keys are provided by King and Humber (1981) and Waterhouse and Brady (1982).

At present there are about 150 species of entomophthoralean insect fungi. Of these six occur on planthoppers and leafhoppers worldwide, with three species on rice planthoppers and leafhoppers.

2.2.1 Entomophthorales on Planthoppers and Leafhoppers

Erynia (Entomophthora) delphacis (Hori) is an obligate pathogen of planthoppers, leafhoppers and spittlebugs (Latg *et al.,* 1980). It is found on rice hoppers in Asia (Fig. 2C). *E. delphacis* conidia, 15-33µm long, are elliptical to ovoid with a papillate base. The conidiophores are branched and sometimes simple. Resting spores and rhizoids are not produced.

E. delphacis closely resembles the aphid pathogen *Erynia neoaphidis* Remaudiere & Hennebert. *Entomophthora aphidis* Hoffman is the older synonym of *Erynia neoaphidis; E. delphacis*

was reported several times as *E. aphidis* on rice (e.g. Hinckley 1963). *E. delphacis* can be isolated and cultured on egg-yolk medium and SDA. Growth is optimum at a temperature of 25°C and a pH of 6.3-6.7 (Shimazu 1976). Optimum temperature for germination is 25°C, and a relative humidity exceeding 93%, but preferably free water, is necessary for germination (Shimazu 1977).

E. delphacis has not yet been applied to control field populations of rice hoppers. But, this pathogen is a suitable candidate for biological control. It can be isolated in pure culture and mass produced by the marcescent process (R. S. Soper, pers. comm. 1986).

Erynia radicans (Brefeld) Humber, Ben-Ze'ev & Kenneth is often incorrectly referred to as *Entomophthora sphaerosperma* Fres. or *Zoophthora rudicans* (Brefeld) Batko. Turian (1957) proposed to institute *E. rudicans cicadelliphaga* for the fungus attacking leafhoppers. The fungus is collected worldwide on plant and leafhoppers. It was collected on the brown planthopper in southeast China (Shimazu 1979), and Samal *et al.* (1978) reported *E. radicans* as *E. fumosa;* the latter fungus is synonymous with *Neozygites fumosa* (Speare) Remaudiere & Keller. Ben-Ze'ev & Kenneth (1981) provided a detailed description of *E. radicans.*

In *E. radicans* rhizoids attach the insect to the plant. Conidiophores form a compact layer on the host. Primary conidia, 16-24 × 5.5-8 µm, and secondary conidia, 13.5-18 × 6-9 µm, are ellipsoidal; capilliconidia, 19-24 × 4.5-8 µm, are almond shaped. The fungus can produce globose resting spores, 22-29 µm, inside the cadaver.

E. radicans causes devasting epizootics in populations of *Empoasca kraemeri* Ross & Moore on cowpea in Brazil (Daoust *et al.,* 1983) and brown planthopper in Asia (Shimazu 1979). The fungus can be readily cultured on artificial media and mass production through the marcescent process is feasible. Application against rice hoppers should be tested.

Conidiobolus coronatus (Cost.) Batko is common on rice planthoppers and leafhoppers (Fig. 2D). King (1976a,b; 1977) provided information on the taxonomy and biology of *C. coronatus.* Primary conidia, 14-39 × 17-49µm, are spherical to pyriform with rounded apex, and multinucleate. Microconidia, 7.5-2.5µm, are globose and attached to the outside of the original conidium. Villose conidia are present on the host and in pure culture.

In certain *C. coronatus* strains the conidia can actively transverse the sclerites and the membranes of insects (Yendol and Paschke 1965), and these strains are insect pathogens *sensu stricto.* However, other strains are a saprophytic, grow in soil, or cause human and equine entomophthoromycosis (King 1979).

The brown planthopper was controlled by one application of *C. coronatus* conidia (R. M. Aguda, pers. comm. 1984). Padua and Gabriel (1975) developed a coconut-milk medium for its mass-production. We consider this fungus hazardous for biological control experimentation because of the possibilities of mammalian infection. Its mass production and field application is discouraged.

Zoophthora radicans (Brefeld) Batko was collected from the leaffolders. *Marasmia* sp. and *Cnaphalocrocis medinalis* Guenee (M. C. Rombach and R. A. Humber, unpubl. 1988 (Fig. 15). The

fungus causes extensive epizootics in greenhouse leaffolder populations, but is rarely collected in the field.

22.2 Entomopthorales on Grasshoppers

Entomophaga grylli (Fres.) Batko occurs in field populations of grasshoppers worldwide and epizootics can significantly reduce populations (Pickford and Riegert 1964, McDaniel and Bohls 1984). *E. grylli* was occasionally reported from lepidopteran and dipteran hosts. *E. grylli* has globose to pyriform multinucleate conidia with prominent papillae. Brady (1979a) provides a description. Grasshoppers infected with *E.grylli* climb to the top of plants and grasp the plant with the front pair of legs; large numbers of infected grasshoppers are mostly found attached to plants during epizootics. In rice *E. grylli* was found on unidentified species of grasshoppers in Indonesia (R. A. Humber, pers. comm, 1984) and Bhutan (B. M. Shepard, pers. comm. 1987). Weiser *et al.* (1985) reported it from *Oxya hyla intricata* (Stahl) a rice pest in Vietnam, where the fungus infected 85-90% of the population. Roffey (1965,1968) listed the fungus on a number of minor grasshopper pests of rice from Thailand.

2.3 FUNGI ON PREDATORS

Several entomogenous fungi infect beneficial insects (predators) and spiders in rice fields. The fungi infecting beneficials are all specific for certain insects or spiders, and always occur at low levels; epizootics of these fungi have not been reported.

Gibellula leiopus (Vuill.) Mains and *G. pulchra* (Sacc.) Cavara were commonly found on spiders in rice fields (Fig. 11B, 8C). *G. leiopus* has a compact appearance due to the short synnemata and the short conidiophores (Fig. 11B). In recent collections the fungus was found on small spiders (e.g., *Callitrichia* spp.); it has not been reported from lycosids, one of the most important groups of predators in rice. Not much ecological information on *Gibellula* spp. is available. Samson and Evans (1973) concluded that *G. pulchra* was an important mortality factor for spiders on cacao trees in Ghana. In our experience these fungi are a minor mortality factor for spider populations in rice, with infection levels never exceeding 1% of the population.

Hirsutella (Synnematium) jonesii (Speare) Evans and Samson was described from *Mezira* sp. (Hemiptera). It was collected on rice in the Philippines on *Anthicus* sp. (Coleoptera), and on *Cyrtorhinus lividipennis* (Reuter) (Hemiptera) (M. C. Rombach, unpubl.) (Fig. 11C). However, the incidence of this fungus was always below 1%, even in dense *Cyrtorhinus* populations.

3. ENTOMOGENOUS BACTERIA

3.1 BACILLUS THURINGIENSIS

Bacillus rhutingiensis Berliner (B.t.) is the most widely used microbial for control of insects (Burges 1982, Samson *et al.,* 1986). B.t. produces endogenous spores and toxins (Fig. 16). The resistant spores enhance survival in the field and in storage, which facilitates formulation and application of

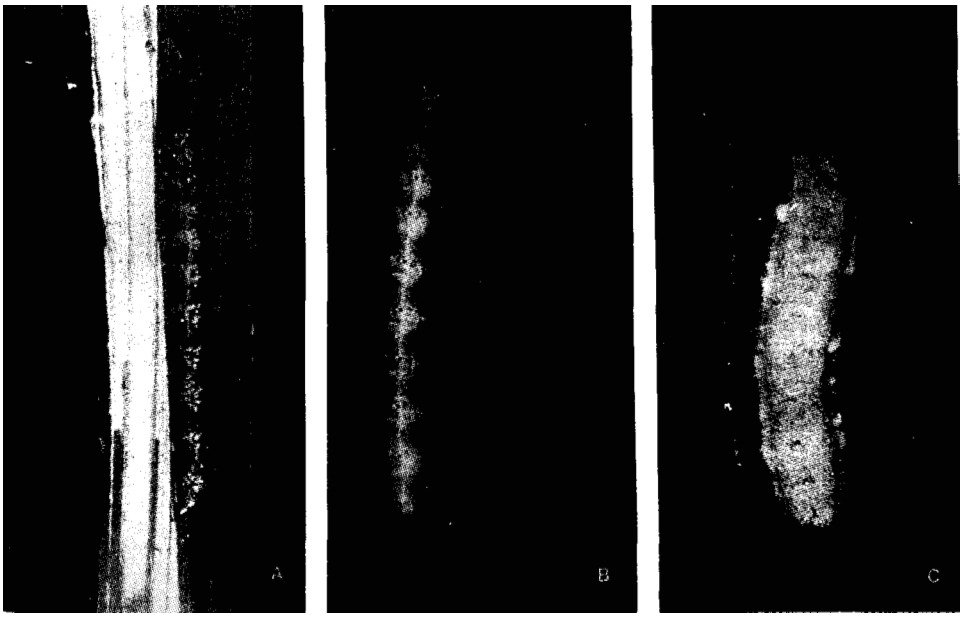


Fig. 15. *Zoophthora radicans* (Brefeld) Batko. Stages of infection of the rice leaffolder, *Cnaphalocrosis medinalis* Guenee. **A.** A healthy larva; **B.** vegetative fungus growth inside the host; and **C.** sporulation on the cadaver.

the B.t. products. The spores, and endotoxin, have to be ingested by the insect and thus toxicity for non-phytophagous fauna is negligible. Microbial control with B.t. products can safely be combined with biological control by natural enemies. Also, nearly all B.t. entomotoxins are safe for man and other mammals. A list of non-target fauna not susceptible to B.t. is provided by Burges (1982).

B.t. is the most commercially successful insect pathogen. At present about US $40 million worth of B.t. products are sold worldwide. Most of these materials are used against lepidopteran pests on a number of field crops, and for mosquito larva control. Recently B.t. strains isolated from coleopteran hosts were reported from Germany and the USA. Products containing spores of these strains will soon be available.

After ingestion of the spores and protein endotoxin crystals the insect gut and mouthparts are paralyzed, feeding is arrested and no further crop damage occurs. The insect dies soon thereafter. Reports of epizootics of B.t. in natural insect populations are rare (Burgerjon and Martouret 1971). This is probably because the lethal bacterial structures, such as spores and toxic crystals, appear only in small quantities in insect cadavers (Angus l968). Thus recycling of B.t. in insect populations is practically absent and repeated application is necessary for control.

B.t. grows on simple artificial media and can be produced by solid and liquid fermentation processes. Several commercial products with different B.t. varieties and serotypes have been produced.

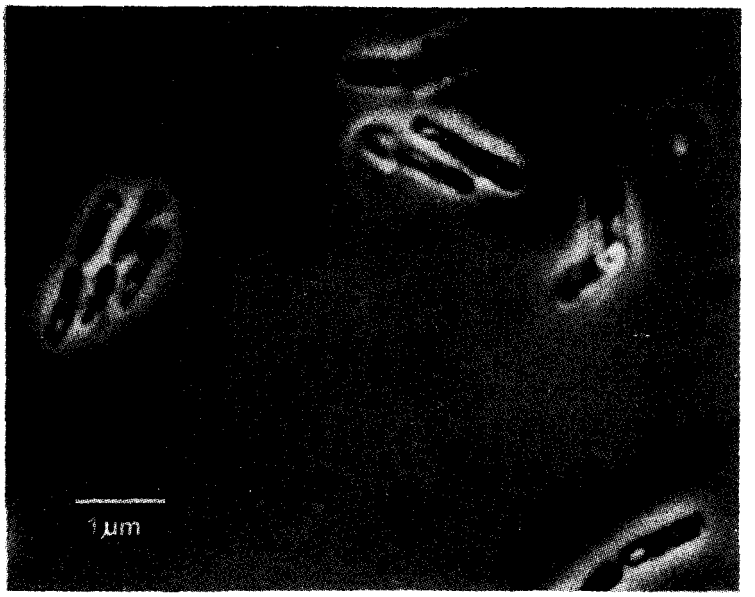


Fig. 16. *Bacillus thuringiensis* Berliner. Note the "footprint" appearance, *i.e.* the spore with the parasporal inclusion body.

The prerequisite of oral uptake limits the host range of B.t. In rice primary targets are lepidopteran larvae such as leaffolders, armyworms, hairy caterpillars and, to a lesser extent, stem borers. B.t. was described from *Anagasta (Ephestia) kuhniella* Zell., a stored product pest (Berliner 1915). Other lepidopteran pests of stored products have been effectively controlled by B.t. (Burges 1964). Recently, B.t. products were approved for use in stored grains in the United States. It is very effective against the Indian meal moth, *Plodia interpunctella,* and almond moth, *Ephestia cautella* (McGaughey 1976,1978), however, few studies on stored rice insects are reported.

The leaffolder *Cnaphalocrocis medinalis* Guenee was controlled by four commercial B.t. products (Srivastava and Nayak 1978a). The authors claim significantly higher mortality by similar doses of Dipel® and Thuricide® as compared to Bactospeine® and Cajrab®

Bioassay techniques to test the effectiveness of B.t. materials for the striped stem borer *Chilo suppressalis* (Walk.) were developed by Rombach *et al.,* (1989a). B.t. products incorporated in artificial diet of the stem borer larva greatly inhibited feeding, but mortality was relatively low.

Nayak *et al.,* (1978b) reported control of the stem borers *Scirpophaga incertulas* (Wlk.), *Sesamia inferens* W., and *Chilo* sp. by Thuricide®. All larval stages can be infected by the product by a cut stem technique in which a small piece of rice stem is soaked in B.t. spore suspension prior to feeding. Yadava (1978) obtained high larval mortality of the pink stem borer, *S. inferens* using this technique.

Internal parts of rice stems are, in general, free of pathogens. Thus, in the field, only neonate stemborer larvae are exposed to B.t. when they feed on the stem or on the leaves before tunnelling

into the stem. Nayak *et al.,* (1978b) sprayed a 1% Thuricide suspension in the greenhouse during egg hatching. Dead hearts and numbers of living larvae in tillers were reduced by 76%, and white heads by 67% respectively. Product activity persisted for 15 days. However, under field conditions the spores and crystals will rapidly deteriorate due to UV light and weekly sprays may be necessary to kill neonate larvae before stem invasion. This would be prohibitively expensive for practical use, unless a method of precise timing can be developed.

Adverse effect of sunlight on B.t. was tested in China (Anonymous 1981). A spore preparation was applied to rice infested with second instar leaffolder larvae at 8:00 a.m. and at 4:00 p.m. Morning treatments resulted in 22-39% mortality and afternoon treatments in 58-72% mortality.

Bounias and Guennelon (1974) tested B.t. for control of the striped stem borer *C. suppressalis.* This stem borer was introduced into Camarque (France), and its populations were mostly free of natural enemies. High mortality of larvae was obtained when fed artificial diet with B.t. spores. The authors conclude that B.t. can be used for stem borer control only if a two-month period of plant coverage is ensured during egg hatching. We estimate that, under tropical conditions, this will require at least four to five B.t. applications.

B.t. research in Japan was delayed for more than a decade due to quarantine measures for protection of the sericultural industry (Aizawa 1967). Recently B.t. strains with low toxicity for silkworms and high toxicity for target pests were developed through selection (Aizawa *et al.,* 1975). Also, strains were selected that were capable of producing the endogenous entomotoxins but no spores (Nishiitsutsuji-Uwo *et al.,* 1975). These strains will not disperse from the treated crop to mulberry trees with silkworm larvae. In Japan B.t. was effective against the rice plant skipper, *Pamara guttafa* (Aizawa 1976).

In China B.t. is intensively researched for control of insect pests on rice (Chiu 1984, Hussey and Tinsley 1981). Good control of rice skipper larvae *(Pamara* spp.) was reported after only one B.t. application. Combinations of B.t. with low dosages of a chemical insecticide (e.g. trichlorfon at 10-20% of the recommended rate) were reported to be most effective.

China is one of the world's largest B.t. producers, and production is mainly carried out on the village level using solid fermentation on wheat bran, corn meal, soybean, and cotton seed cake. However, recently large production facilities using liquid fermentation were installed.

Hussey and Tinsley (1981) estimated that in China about 2,500 metric tons of B.t. are produced annually; most of this material is used for control of lepidopteran pests in forests.

3.2 OTHER ENTOMOGENOUS BACTERIA

Philip and Jacob (1982) reported *Bacillus cereus* Frankland & Frankland from the leaffolder *C. medinalis. Bacillus subtilis* (Ehrenberg) Cohn was reported from the green horned caterpillar, *Melanitis leda ismene* Cramer (Nayak and Srivastava 1978b). These bacteria produce spores but not entomotoxic protein crystals. *B. subtilis* is a common soil bacterium (Schroth and Hancock 1981). Its insect pathogenicity is doubtful; it is an opportunistic invader of weakened insects. The value of *E. cereus* and *B. subtilis* in biological control of rice pests is probably limited.

Some non-sporulating bacteria are insect pathogens (Buchner 1963). Srivastava and Nayak (1978b) reported the red pigmented *Serratia marcescens* Bizio from field collected larvae of the green horned caterpillar *Melanitis leda ismene* Cramer and pink stem borer *S. inferens.* Isolations infected three different stem borer species, a leafroller and the rice skipper in the laboratory. These test insects were continuously fed with the pathogen (Srivastava and Nayak 1978b, Narayanan and Jayaraj 1974). However, this bacterium does not produce spores or entomotoxins; therefore its killing action is slow and mass-production and storage is virtually impossible. We consider *S. marcescens* of doubtful insect pathogenicity and probably of no value in biological control of insects.

Occasionally planthoppers and leafhoppers are found infected by entomogenous bacteria such as *B. thuringiensis* (Li 1982) and *S. marcescens* (Rao and Rao 1979). However, these bacteria are not effective against sucking insects which feed in the vacular tissues where these pathogens do not occur.

4. ENTOMOGENOUS VIRUSES

Over 1,200 virus-insect relationships in more than 800 insect and mite species were reported by Martignoni and Iwai (1981) and Martignoni and Longston (1960), and numbers have increased since. Many insect viruses possess promising properties for biological control, especially the baculoviruses and reoviruses, which have stable inclusion bodies (Entwistle 1978). In some instances the viral pathogens can be introduced for insect control, and can recycle efficiently from one insect generation to another. But in some annual cropping systems the insect viruses are applied similar to a chemical insecticide (i.e. repeated applications when pest numbers increase). This type of control is often employed in unstable agricultural systems where insect populations decline at the end of cropping seasons. Examples of this method are control of cotton bollworm by Elcar® and control of *Heliothis zea* Boddie on soybean (Ignoffo *et al.,* 1978). Payne (1982) reported six insect families with viruses and reviewed the ecology and insect control efforts using these microbials.

Insect viruses are classified into families according to morphology of the virus particle, chemical and physical nature of the nucleic acids, and presence or absence of inclusion bodies.

Transovum transmission of nuclear polyhydrosis viruses (NPVs; Baculoviridae) from generation to generation has been demostrated. However, transmission by oral uptake of the infective particles by the host is more common, and thus the insect stages feeding on plants are most vulnerable to infection. Sucking insects such as planthoppers and leafhoppers and hemipteran insects are not infected by insect viruses.

The family Baculoviridae contains the subgroups of the nuclear polyhedrosis viruses (NPVs), granulosis viruses (GVs), and *Oryctes* viruses. Both NPVs and a GVs are represented in rice insects.

Baculovirus species (Baculoviridae) are bacilliform, contain circular double stranded DNA and can form proteinaceous inclusion bodies. No viruses with a similar morphology have been observed in plants or in vertebrate hosts (Payne 1982).

The NPVs have inclusion bodies produced in the insect tissues at the terminal stage of infection (Summers 1977). Viral particles embeded within the inclusion body are released in alkaline pH

(e.g. in insect guts). The main difference between the NPVs and the GVs is the presence in the majority of GVs of only one single virus particle in each 'capsule' or inclusion body. In NPVs a variable number of virus particles are embedded in the matrix of the polyhedra.

Reoviridae are represented by a cytoplasmic polyhedrosis virus (CPV) of the rice leaffolder *C. medinalis.* Baculoviridae and Reoviridae are promising for microbial control because they produce stable inclusion bodies.

Iridoviridae are represented by the *Chilo* iridescent virus (CIV). The virus does not produce inclusion bodies; its utility in biological control is limited.

4.1 NUCLEAR POLYHEDROSIS VIRUSES (NPVs)

An NPV produced polyhedral inclusion bodies in tissues of laboratory reared pink stem borer *Sesamia inferens* (Godse and Nayak 1983). The NPV infected larva has a whitish ventral side, gradually progressing to the end of the body and most prominent at the intersegmental membranes. A few days after infection the host dies. The dead larva is whitish brown. Cadavers lodge within the plant or hang on the outside of the stem. The liquefied body contents contain numerous polyhedral inclusion bodies with an average size of .84 μm. Rod shaped viral particles with a size of 35 × 215 nm are present in the inclusion bodies. Virus particles are bundled in envelopes in groups of 2-3; bundles are randomly distributed in the inclusion body.

Other NPVs infected *Spodoptera mauritia* Boisduval (Jacob *et al.,* 1973), grass webworm, *Herpetogramma licarsisalis* (Walker), corn semilooper *Chrysodeixis chalcites* Esper (Im *et al.,* 1989a) and the rice moth *Corcyra cephalonica* St. (Rabindra 1973), the rice skipper *Pelopidas* (Pamara) mathias (Fabr.) (Nayak and Srivastava 1979a) and the common cutworm *Spodoptera litura* (Fab.) (Tsai *et al.,* 1978, Im *et al.,* 1989a). Pathogenicity and histopathology of the latter virus was reported by Im *et al.* (1989a). No further information on these viruses is available.

Over 70 years ago Chapman and Glaser (1915) reported 'wilt disease', an NPV, in the armyworm *Pseuduletia unipuncta* (Haworth), and natural epidemics still frequently occur (Diliwari *et al.,* 1981). *Mythimna separata* was reported to suffer from an NFV (Neelgund and Mathad 1972, Im *et al.,* 1989b) (Fig. 17). The virus was multiplied and effectively controlled *M. separata* in the field (Neelgund 1975, Mathad and Neelgund 1973). The larvae die in a peculiar position, hanging down with the prolegs clinging to the plant (Fig. 4D). Manjunath and Mathad (l978,1979,1981a, 1981b) studied the effect of sunlight and temperature on *Mythimna* NPV in preparation for field application. Bioassay tests to determine the virulence of the pathogens were reported by Neelgund and Mathad (1974,1978) and Watanabe and Tanada (1972a, b). Dhaduti and Mathad (1978,1979,1981) tested the effect of *Mythimna* NPV on silkworm. No significant infestation was obtained. These NFVS are promising biological control agents, and should be pursued further for rice armyworm control.

4.2 GRANULOSIS VIRUSES (GVs)

The GV of the rice brown semilooper, *Mocis frugalis* was first reported from Palawan Island in the Philippines (Im *et al.,* 1986a). Infected larvae were yellowish, but slowly darkened when the

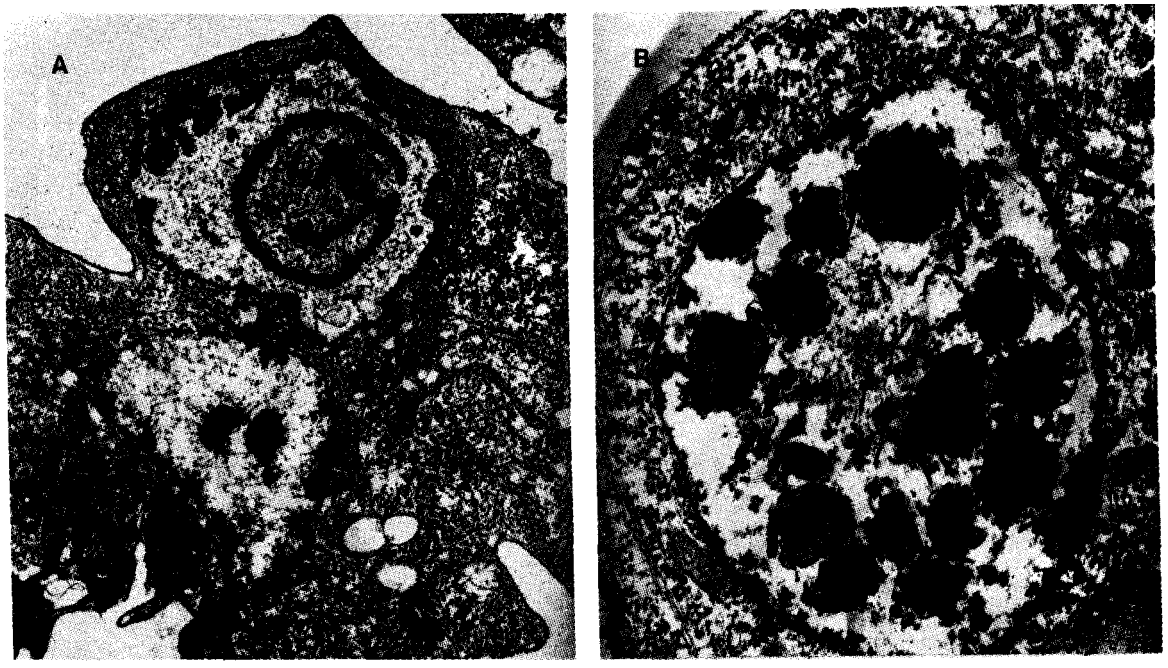


Fig. 17. *Mythimna separata* (Wlk.) nuclear polyhedrosis virus (NPV): **A.** In 1st instar larva 2 days post infection. The lower hypodermis cell is healthy, the upper one is infected with a virogenic stroma and NPV virions; **B.** At 4 days post infection. Polyhedral inclusion bodies and virions.

infection progressed. Refractive granules were found in the fluid of the fat bodies. The virus was purified and capsules were ellipsoidal but some were irregular and sickle shaped with varying lengths. The capsules measured 433 × 243 nm, and contained a single virion of 301 × 83 nm. Eighteen amino acids occurred in the capsules, including basic amino acids (lysine and arginine) and acidic amino acids (aspartic acid and glutamic acid). However, low quantities of histidine, cystine, methionine, alanine, tyrosine and tryptophan were found (Im *et al.,* 1986b).

A GV of the rice leaffolder, *Cnaphalocrocis medinalis* (Guenee) was also reported from the Philippines (Im *et al.,* 1989b) and India (Jacob *et al.,* 1971). The virus capsules were ellipsoidal in shape and measured 413 × 234 nm. The size of the virions of this virus was 280-320 × 56-62 nm.

4.3 IRIDESCENT VIRUSES (IVs)

IVs are a heterogeneous group of larger viruses pathogenic to insects. IVs are described as icosahedral cytoplasmic desoxyriboviruses (Kelly and Robertson 1973). The particles are isometric, contain linear double stranded DNA, and no inclusion bodies are produced. The group derives its name from a physical property of the virus particles — if light strikes the compact virus pellets in host

tissues a violet, green, or blue hue is produced. Tinsley and Kelley (1970) concluded that this is a constant feature of all known viruses in the group and suggested that the group name be retained.

The *Chilo* IV (CIV, or iridescent virus type 6) was described from stem borers (Fukaya and Nasu 1966). No information is available on the dispersion and infection of hosts under natural conditions. Multiplication of the virus was carried out by contamination of artificial diet and feeding of *Chilo* larvae. After 12 days the larvae became milky white although heavily infected larvae had a bluish cast. Diseased larvae survived for a considerable time. Electron microscopic examination revealed large enveloped virus particles (160μm). Ishikawa and Muroga (1976) tested the influence of CIV on larval development of *C. suppressalis,* and the greater wax moth, *Galleria mellonella* L. Both insects were easily infected by virus injection and severe abnormalities during pupation were observed. Replication of CIV was studied by Kelly and Tinsley (1974a, 1974b), the activity of its ribonucleic acid polymerase by Kelly and Tinsley (1973) and biochemical aspects of its non-structural proteins were reported by Kelly and Tinsley (1972).

5. ENTOMOGENOUS NEMATODES

Pathogenic nematodes can control some insect pests (Poinar 1979). Commercial products contain *Heterorhabditis* sp. for control of the black vine weevil, *Otiorhynchus sulcatus* F. in greenhouses (W. R. Simons, pers. comm. 1985), *Neoaplectana carpocapsae* Weiser for control of various terrestrial insects, and *Romanomermis culicivorax* Ross & Smith for mosquito control. For steinernematid and heterorhabditid nematodes a novel mass rearing method is now available (Bedding 1984). Keys to insect nematode species and information on their ecology and applications is given by Poinar (1979).

5.1 NEMATODES ON HOPPERS

In rice the nematode *Agamermis unka* Kaburaki & Imamura is a parasite of adults and nymphs of leafhoppers (Nasu 1967), but its incidence in natural populations is low. The natural incidence of parasitism by indigenous insect nematodes on brown planthopper, *Nilaparvata lugens* (Fig. 18), whitebacked planthopper, *Sogatella furcifera,* and green leafhopper, *Nephotettix virescens,* was monitored at twelve sites in Laguna Province, Philippines, during the wet and dry seasons from 1982-1984 (Pena and Shepard 1985). The highest incidences of parasitism were 36% and 50% for the whitebacked and brown planthopper, respectively. Parasitism levels were highest in the wet season. This is probably due to the higher relative humidity, which is important for nematode survival. Mean levels of parasitism during this season across all the locations revealed that only 19% of the brown planthoppers and 17% of the whitebacked planthoppers were parasitized. It is unlikely that these low parasitization levels have a significant impact on hopper populations.

5.2 NEMATODES ON STEM BORERS

Species of *Agamernis* spp., *Amphimermis, Cordius* sp., and *Mermis* sp. were reported on rice stem borers (Lippold 1972). Strain DD-136 of *Steinernema feltiae* Filipjev is the only nematode reported-

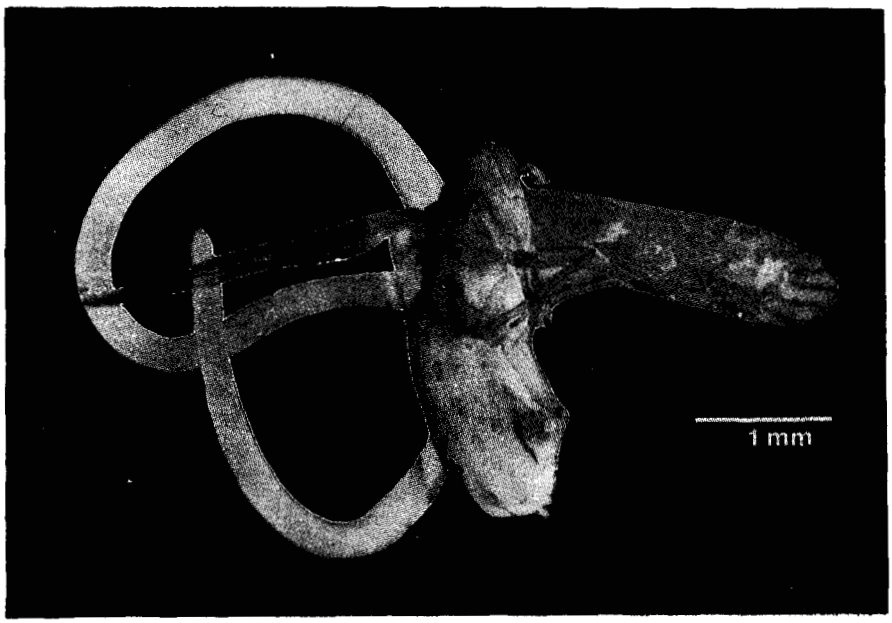


Fig. 18. Brown planthopper, *Nilaparvata lugens* (Stal) infected with an entomogenous nematode.

ly tested on rice insects. The bacterium *Achromobacter nematophilus* Poinar & Thomas is associated with this nematode. Ramakrishnan and Kumar (1981) review stem borer research with this nematode in India and Meneses-Carbonell (l983) reports on experiments of water weevil control with DD-136 in Cuba. Control of the cutworm, *Platysentra (Cirphis) compta* (Walker) with DD-136 was reported by Israel *et al.,* (1969). However, this approach was not widely adopted, Other target insect pest species for DD-136 were *Scirpophaga incertulas* (Walker) (Yadava and Rao 1970, Torii 1975, Rao *et al.,* 1971), and *Chilo suppressalis* (Torii 1975, Torii and Yasumatsu 1973). Treatments of small field plots with a nematode suspension failed to reduce *S. incertulas* populations, although some infected larvae were observed (Rao *et al.,* 1971). Numbers of 'white-heads' (panicles with empty grains) were not significantly reduced in nematode (DD-136) treated plots. However, sprays with nematodes were effective in reducing numbers of *C. suppressalis* larvae (Yadava and Rao 1970). The lack of prevention of whiteheads is attributed to the cryptic nature of stem borer larvae and the fact that they enter the stem and cause damage even after they are infected with nematodes.

Insect nematodes can infect several insect pests of rice; they surely contribute to the overall mortality levels of pest insects. Stem borer control is complicated and virtually no effective control measures are available; the use of entomogenous nematodes, *S. feltiae* in particular, should receive further research emphasis.

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9

Insecticide Management in Rice

S. CHELLIAH AND M. BHARATHI
Tamil Nadu Rice Research Institute
Aduthurai, Tamil Nadu, India

1. INTRODUCTION

INSECTICIDES SERVE AS IMPORTANT components in the management of rice insect pests. Insecticides are the only tool in the pest management strategy that is reliable for emergency action when insect pest populations approach or exceed the economic threshold. In the words of the Committee on Plant and Animal Pests, National Academy of Sciences, "a major technique such as the use of pesticides can be the very heart and core of integrated systems. Chemical pesticides will continue to be one of the most dependable weapons of entomologists for the foreseeable future" and this is true for rice insect pest management also. Conversely, insecticide use results in several undesirable effects. Frequent and continuous insecticide use leads to development of insecticide resistance in pests, sudden outbreak of major and secondary pests after insecticide application, destruction of beneficial insects, and human and animal poisoning. Added to these, the escalating cost of insecticides is another factor which discourages the use of insecticides for crop protection. This paper deals with the status and strategies of insecticide use in rice.

Insecticide use on traditional rice cropping systems was minimal. However, in the last two decades, insecticide use on rice has greatly increased, as improved varieties with greater yields, and profit potential have been planted.

The evolution of chemical control in rice since the later part of the middle period in Japan has been recorded by Suenaga and Nakatsuka (1958) and Matsuo (l96l). The use of whale oil which was found effective in 1670, had spread throughout the country by 1840. Kerosene began to replace whale oil in 1897. Japan, Taiwan and China have used insecticides to control rice insect pests since modern insecticides were introduced after World War II.

The introduction of DDT and BHC in the late 1940s and of parathion in the 1950s established the technical basis for pest control with insecticides in Japan. Organophosphorus insecticides were first used in 1952. Diazinon and malathion soon replaced parathion. Since 1964, carbamate insecticides have been used in Japan. The insecticides were effective against stem borers, leafhoppers and planthoppers. To increase rice production in the 1950s, the Japanese government subsidized insecticides and application equipment and provided technical support to farmers which resulted in wide scale use of insecticides for rice insect pest control. A similar revolution also occurred throughout tropical Asia.

It was estimated in 1980 that $3.9 billion was spent on insecticides worldwide and $563 million (14.4%) for rice alone (Lim and Heong 1984). Yield increases attributed to insecticide use have been experienced under varied conditions in many rice growing countries. As early as 1967, it was estimated that an average of 44% yield increase was obtained in rice in Taiwan as a result of insecticidal protection for the rice crop (Tao and Yu 1967). Ku *et al.* (1980) reported that in Taiwan, the increase in yield of insecticide treated crops over that of untreated ones ranged from 8.9 to 23.4% in the first crop and 13.8 to 54.2% in the second crop. At the International Rice Research Institute (IRRI), yield increases of 2.7 t/ha due to insecticide use were reported in experiments conducted during 1964-1971 (Pathak and Dyck 1974). Similar experiments on farmers' fields in the Philippines showed a 20-25% yield increase. In the Philippines, rice yield increases ranging from 0.44 to 3.19 t/ha due to insect pest control by insecticides have been reported (IRRI 1975, 1977; Heinrichs 1978; Litsinger *et al.,* 1980).

In Malaysia, Lim (1972) reported that insecticides increased rice yields ranging from 0.72 to 1.35 t/ha. Gunasena *et al.* (1977) observed a yield increase of 0.7 t/ha in farmers' fields in Sri Lanka, due to insecticide use. As high as 2.6 t/ha increase in rice yield occurred in Bangladesh (Ahsan and Hoque 1977). In Japan, yield loss decreased from 419 kg/ha in 1949-1951 when insecticide use for rice insect pest control just began to 153 kg/ha in 1979-1981 when chemical use had become extensive (Ishikura 1984).

Insecticide use in rice has several advantages and disadvantages; the advantages are:

- Insecticides afford the only practical control measure for insect pest populations approaching or at the economic threshold.
- Insecticides have rapid curative action in preventing economic damage.
- Insecticides offer a wide range of properties, uses and methods of application.
- Benefit/cost ratios for insecticide use are generally favorable.
- Insecticides are generally readily available for pest control.

Disadvantages are:

- Development of resistance in the pests to the insecticides used — both cross resistance and multiple resistance. Resistance to pesticides has been reported in the brown planthopper, green leafhopper, whitebacked planthopper, smaller brown planthopper, striped stem borer, rice bug and rice water weevil.
- Resurgence of primary and secondary pests,

- Adverse effects on non-target species (*e.g.,* natural enemies, honey bees, other pollinators, fish and wildlife).
- Hazards of pesticide residues in food products and in the environment acting as potential 'hidden costs.'
- Human poisoning.
- Increased cost of chemicals and application equipment.
- Phytotoxicity due to application of the wrong pesticide, improper pesticide mixtures, incorrect timing of application, wrong formulations, using insecticides at more than the recommended dosage, inadverdent application of sediments from the spray tank and use of brackish water for insecticide mixing.

Although there are no insecticides to be pronounced as completely safe chemicals, there are safe ways to use even the most toxic agents. In this context, there should be a harmonious management approach in using insecticides for pest control.

2. Chemical Control of Rice Insect Pests

2.1 PLANTHOPPERS

Planthopper pests in Asian rice include the brown planthopper (BPH), *(Nilaparvata lugens),* whitebacked planthopper (WBPH), *(Sogatella furcifera)* and smaller brown planthopper (SBPH), *(Laodelphax striatellus).*

2.1.1 Effective Insecticides

Several insecticides of various groups have been reported to be effective against the BPH. Chlordimeform and isoprocarb at 0.5 kg ai/ha (Velusamy *et al.,* 1978) and carbofuran, quinalphos, phosphamidon and chlorpyriphos (Rao and Rao 1979a) were effective in BPH control. Mixtures of HCH (BHC) and parathion when applied in rice fields, were very efficient in controlling BPH but adversely affected predator populations in China (Li *et al.,* 1983). Riddell (1982) stated that carbosulfan gave maximum control of BPH both in greenhouse and field tests in Malaysia. In India, the field tests conducted at Kerala revealed that carbosulfan effected quick knock down effect of BPH (Pillai *et al.,* 1983). Granular insecticides such as carbofuran, phorate and isofenphos yielded a high degree of BPH control (Koshaiya *et al.,* 1981). Patnaik *et al.,* (1986) reported that the granular formulations of BPMC and carbofuran consistently gave high control of BPH.

Growth regulating compounds having juvenile hormone and molting hormone effects have also been used for rice pest control. Kajihara *et al.* (1982) reported that buprofezin (NNI-750) possessed good insecticidal activity against BPH nymphs and adults. Mortality generally occurred as a result of the nymphs being unable to emerge fully from the exuviae during molting (Asai *et al.,* 1983). The compound at 250 ppm when sprayed reduced the egg hatch from 100% to 43.3% and when the

compound was used at l000 ppm, egg hatch was only 9.7%. It was also known to have sterilizing effects on the adults.

Hirao *et al.* (1983) stated that a mixture of 1% buprofezin + 2% BPMC formulated as a driftless dust, significantly reduced populations of BPH for an extended period if the application was made immediately after the main wave of immigration into Japan. Also, application of 1.5% buprofezin as a driftless dust formulation was very effective in limiting the incidence of the grassy stunt disease transmitted by BPH and stripe disease transmitted by the SBPH.

Third instar nymphs of BPH, GLH *(Nephotettix* sp.) and WBPH died at molting when they had been sprayed with 0.075% buprofezin (Valencia *et al.,* 1983). Heinrichs *et al.* (1984) reported that buprofezin had a longer residual effect against the major hopper pests of rice than currently used carbamate insecticides, and was safe to their predators, *Lycosa pseudoannulata, Cyrtorhinus lividipennis* and *Microvelia atrolineata.*

Plant extracts from the roots of *Eclipta alba* and leaves of *Azadirachta indica* cause high BPH mortality (Rao and Rao 1979b). Seed oil of chinaberry, *Melia azadirach,* at concentrations of 0.01-0.04% had marked antifeedant and some systemic effect against BPH and WBPH (Jianzhang *et al.,* 1983). Application of a mixture of neem cake and urea at a rate of 120 kg N/ha reduced the food intake of newly emerged BPH females and also reduced the build up of nymphs and adult populations to a certain extent (Saxena *et al.,* 1984).

2.1.2 Factors Affecting the Efficacy of Insecticides

Proper placement of foliar sprays is important in obtaining effective control. BPH feed primarily at the base of rice tillers and hence insecticidal sprays applied above the canopy often provide poor control of the pest. With a non-systemic insecticide *(e.g.,* ethylan) increased control of BPH was achieved when the spray was directed to the base of the plant rather than on the canopy (Aquino and Heinrichs 1978).

High reproductive capacity and oviposition behavior renders the insecticidal control of BPH and WBPH difficult. The eggs of these pests are inserted into the stem tissues at the base of the plant, where sprays and dusts do not penetrate. Hence, insecticides with ovicidal action can be used to kill eggs. Heinrichs and Valencia (1978a and 1981) found that carbofuran, triazophos, methyl parathion and bufencarb reduced BPH egg hatch significantly. Rao and Rao (1979c) reported that carbofuran applied on paddy water, and BPMC, carbaryl and isoprocarb (MIPC) applied to water or soil inhibited BPH egg hatching.

Additional factors that complicate the use of insecticides in the control of BPH are the following:

- The BPH is a phloem feeder and systemic insecticides move primarily through the xylem. Insecticide accumulates in the leaf tips and little of it accumulates in the leaf sheath area where BPH feed.
- It is extremely difficult to control adults migrating from adjacent outbreak areas. Even when fields are sprayed, the insects are capable of laying eggs before they are killed. Many

insecticides do not kill the eggs and when they hatch, the residual activity of the insecticide is not sufficient to kill the hatching nymphs and, thus additional applications are required. Timing of application is critical.

- Because of the high reproductive rate, BPH rapidly develops resistance to insecticides.
- Many insecticides applied at sublethal rates cause BPH resurgence. Because many farmers use sublethal rates, these insecticides have caused serious problems.
- Physiologically different BPH populations or biotypes have been identified. Biotypes have differential susceptibility to the commonly used insecticides such as carbofuran, metalkamate, diazinon and methyl parathion in contact toxicity tests (Heinrick and Valencia 1978b).

2.1.3 Timing of Insecticide Application

Irrespective of chemical type, formulation or application method, careful and appropriate timing of application is the simplest way to enhance insecticide effectiveness. Kiritani (1972) suggested that appropriate timing will achieve insecticide specificity. In the case of BPH, where eggs are difficult to kill, it is best to apply insecticides when the majority of nymphs are in the 3rd or 4th instar stages. In the People's Republic of China, three BPH generations occur on the first crop and damage is caused by the third generation. Most effective control was obtained by treating the second generation (Anonymous 1977).

Timing of insecticide application should take into consideration the natural enemy population in the field. Cheng *et al.* (1973-1975 unpubl.) estimated the rice yield loss caused by insecticide application on natural enemies. Their results showed more predacious spiders and more egg predation in unprotected plots than in plots where insecticides were applied as needed, and fewer spiders and less parasitism in plots where insecticides were applied at 15 day intervals. Heinrichs *et al.* (1981) suggested that, based on light trap catches and field surveys, the best time to spray for BPH is about two weeks after peak trap catches, provided the economic threshold has been reached.

Methyl parathion and deltamethrin caused a population of BPH to resurge when these compounds were applied as sprays 50 or 60 days after transplanting (DT), but earlier applications caused no resurgence (Heinrichs *et al.,* 1982a).

The use of an economic threshold (ET) is critical to the minimum but effective use of pesticides. Use of the appropriate insecticide at the economic threshold level (ETL) places pest control on a sound economic basis with minimum ecosystem disruption. In different countries, various ETLs have been reported. Dyck and Orlido (1977) suggested an economic injury level of one BPH/tiller or about 25 BPH/hill as a rough guide for practical BPH control operations throughout a crop period. In Taiwan, Yen and Chen (1977) showed that 25 BPH/hill was a practical control threshold, based on insecticide application experiments.

Yokoyama (1979) recommended insecticide application at a population of more than 20 adults/100 hills at about one month after the peak immigration of adults at tillering stage and when more than 10 adults/100 hills occurred during the post-booting to heading stage. Ooi (1982) suggested the economic threshold for the BPH to be 7 adults or 15 nymphs per hill in Malaysia.

Sellammal Murugesan and Chelliah (1982b) reported that an average of 2.5 insects/tiller resulted in severe economic damage in a susceptible variety, TN 1, while even a mean of 2.6 insects/tiller did not cause economic damage in a moderately resistant variety, CO 42. They further reported that the damage in the resistant variety ASD 11 was low at the above population levels. Thus it is necessary to develop ETLs depending on the level of resistance a variety possesses. Sellammal Murugesan and Chelliah (1982a) further observed that in moderately resistant varieties, CO 42 and Triveni, at the same level of BPH population, the yield loss was relatively lower in 60-day-old plants than that of the 45 day-old plants. Thus it is suggested that the ETL should be assessed taking also into consideration the level of insect resistance of the variety, stage of the crop, the natural enemy population and the climatic conditions that prevail in a region.

2.1.4 Insecticide Application Methods

Foliar sprays. Efficient application methods are necessary to make insect control an effective and economical proposition.

With a non-systematic insecticide (*e.g.,* ethylan), increased control of BPH was achieved when the spray was directed to the base of the plant rather than on the canopy (Aquino and Heinrichs 1978) (Table 1). Application of high volumes (300-1000 l/ha) of water as required in the commonly used knapsack sprayer is a drudgery. However, when the canopy has closed, high spray volumes of 1000 1/ha are recommended for BPH control in the Philippines (Mochida and Heinrichs 1980). A greenhouse test comparing the effect of spray volumes of several insecticides on BPH control indicated that for most insecticides all the tested spray volumes (*i.e.,* 250, 500 and 1000 l/ha) provided similar initial control, but the highest spray volume provided the longest residual toxicity (Fig. 1) (Heinrichs and Valencia 1979).

TABLE1

Placement of foliar sprays in brown planthopper (BPH) control. IRRI, 1977 wet season. (Aquino and Heinrichs 1978)

Treatment[1]	BPH/4 linear m row sampled with a D-vac suction machine[2]		*Percent Control*[3]
	Before application	*2 days after application*	
Applied above the rice canopy			
Metalkamate	4,766[a]	1,183[a]	74
Monocrotophos	8,213[a]	3,168[b]	60
Ethylan	7,342[a]	2,589[b]	63
Control	6,190[a]	5,893[b]	5
Applied below the rice canopy			
Metalkamate	11,241[a]	947[a]	92
Monocrotophos	6,723[a]	2,074[b]	69
Ethylan	7,521[a]	335[a]	96
Control	7,805[a]	8,811[c]	0

[1] Hopper resurgence was induced by spraying twice with 30 g a.i/ha decamethrin, starting 15 days after planting. Insecticides tested were applied at 750 g a.i/ha at 70 days after planting.
[2] In a column, means followed by a common letter are not significantly different at 5% level (DMRT).
[3] Values adjusted using Abbott's formula.

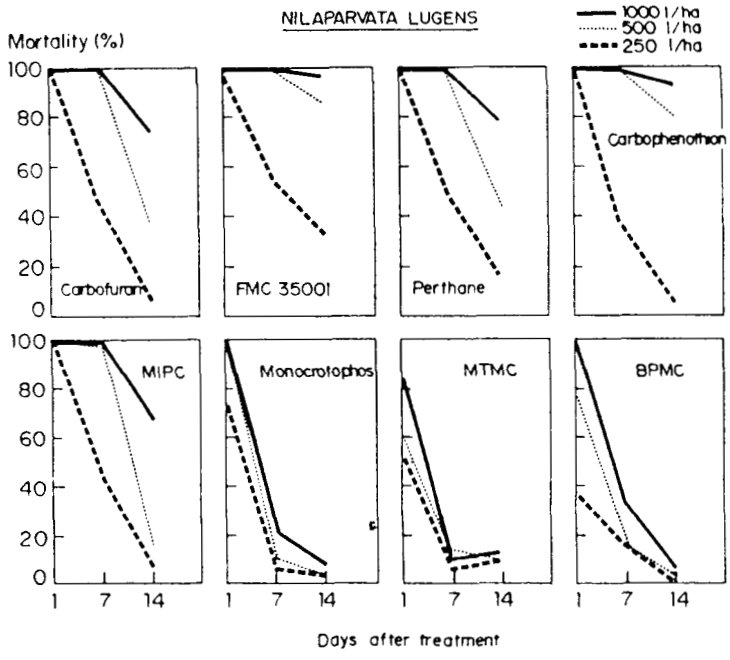


Fig. 1. Effect of three spray volumes on mortality of the green leafhopper, *Nephotettix virescens* and the brown planthopper, *Nilaparvata lugens.* Mortality readings taken at 24 hours after caging insects on treated plants. Other groups of insects were caged at 1, 7 and 14 days after treatment. All insecticide was applied at the rate of 0.75 kg a.i./ha except for carbofuran which was applied at 0.25 kg a.i./ha. IRRI greenhouse. 1979. (Heinrichs and Valencia 1979).

Studies at IRRI have indicated that the deposition of insecticide at the BPH feeding site with an ultra low volume (ULV) applicator is similar to the application with a knapsack sprayer (Pick *et al.,* 1981). High wind speeds, however, cause drifting of the small droplets emitted by the ULV sprayer. Electrostatic sprayers that add an electrical charge to the droplets, that is opposite to the charge of the rice plant, show promise in overcoming the drift problem because the droplets are attracted to the plant. Insecticides applied as foliar sprays, when exposed in the field, have extremely short residual activity. Micro-encapsulation of insecticides provides a means of slow release, thus increasing residual activity and also decreasing the hazard to the applicator (Mochida and Heinrichs 1980).

Dusts: Dust formulations are easy to apply. However, because dusts act mainly through contact toxicity, the natural enemy population is likely to be affected. Mixtures of insecticidal dusts containing 2% MTMC and 2% phenthoate applied at 33.6 kg/ha from a knapsack duster fitted with a long vinyl tube with regularly spaced openings, caused heavy mortality of BPH nymphs. However, predators were adversely affected by the treatment (Lim *et al.,* 1978).

Paddy Water Application of Granules: The use of a granular formulation, that can easily and safely be broadcast by hand, eliminates many of the application problems encountered with foliar sprays. Granules, however, are expensive and the number of effective insecticides in granular formulation is limited. Carbofuran and diazinon granules have been commonly used for BPH control.

Root-zone Application. Root-zone application provides much longer residual activity than foliar sprays and broadcast of granules (Fig. 2). Root-zone application is more effective against the GLH, *Nephotettix virescens,* than against the BPH. Another disadvantage of the root-zone method is that application is most convenient at or shortly after transplanting and the BPH does not infest the field until about 30 days after transplanting when the residual activity of the insecticide has substantially decreased.

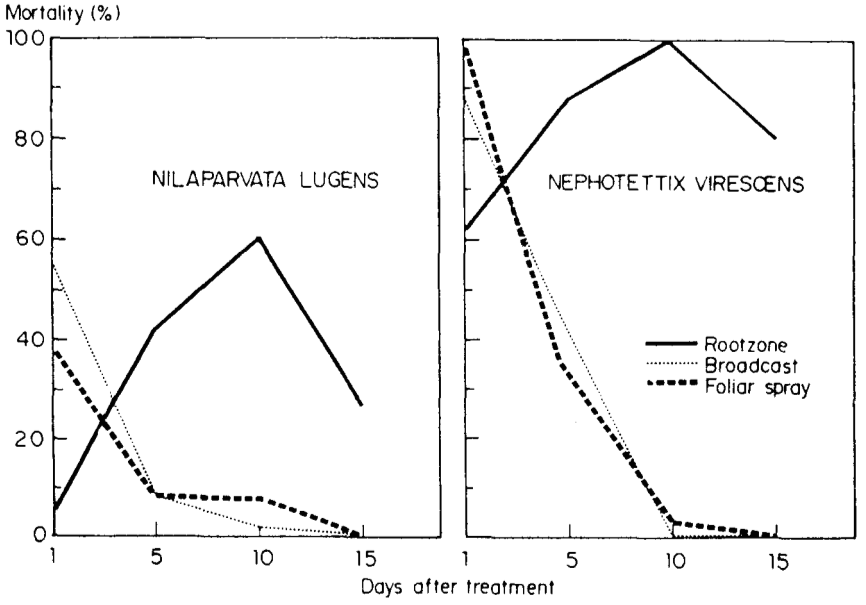


Fig. 2. Field evaluation of three methods of isazophos application at 0.5 kg a.i./ha. In the root-zone treatment, insecticide was placed in a gelatin capsule and inserted into the soil near the root-zone and in the broadcast method granules were broadcast into the paddy water. Mortality readings were taken 48 hours after caging hoppers on treated plants and adjusted using Abbott's formula. Variety IR22. IRRI, 1979. (Heinrichs and Arceo 1979).

2.1.5 Selective Uses of Insecticides

Populations of planthoppers, as well as the natural enemies, are to be taken into consideration for effective and judicious use of insecticides. Insecticide selectivity results from the intrinsic toxicity of

the materials and from various operational factors. Insecticides moderately toxic to BPH predators and at the same time very effective against the BPH have been reported (IRRI 1977). Negligible toxicity to the predatory spider *Lycosa pseudoannulata* was observed when applying insecticides through improved application techniques (Heinrichs *et al.,* 1979a). Such techniques also made it possible to culture fish in rice fields treated with insecticides (Heinrichs *et al.,* 1978a). Chang *et al.* (1979) reported that two insecticides, isoprocarb and pyridafenthion, have the desired selective toxicity for BPH and relative safety for the spider, *Pirata subpiraticus.*

Root-zone application of carbofuran at 1.5 kg ai/ha effectively controlled GLH and BPH. Granules were effective against BPH for 30 DT without adversely affecting the stem borer egg-larval parasite, *Platygaster* sp. (Chiu *et al.,* 1980). Root-zone application of carbofuran and BPMC had an inhibitory effect on hatching of BPH eggs (Rao and Rao 1980a).

2.1.6 Resistance to Insecticides

Continuous use of insecticides has resulted in BPH resistance to insecticides in Taiwan (Lin *et al.,* 1979), Japan (Nagata 1979) and the Philippines (Heinrichs 1979). Resistance to insecticides in WBPH and SBPH has also been reported (Nagata 1979). BPH resistance to HCH dusts was reported in Japan as early as 1967 (Nagata and Moriya 1969). Topical doses of HCH in the laboratory increased resistance sevenfold within five generations. Studies by Ozaki indicated that BPH had developed resistance to fenthion, fenitrothion, diazinon and malathion (Heinrichs 1979).

At IRRI, the effectiveness of diazinon markedly declined in 1969 (IRRI 1970) after it had been used continuously for ten successive crop seasons. Studies indicated that the loss of effectiveness was due to increase in resistance to the insecticide and to microbial degradation (IRRI 1971).

After several years of use, carbofuran's effectiveness against BPH declined at IRRI. Application of 2 kg ai/ha at 14 day intervals failed to control the pest. The responses of field-collected insects to paddy water and to root-zone application of carbofuran at 1 kg ai/ha were compared with the response of a susceptible greenhouse culture. The field collected hoppers showed an extremely low mortality thus indicating that they were resistant compared to greenhouse cultured insects (Heinrichs 1979). Contact toxicity tests also indicated that the field population was distinctly more resistant to carbofuran than the susceptible greenhouse culture (Heinrichs and Valencia 1978c) and it was reported that the field strain was seven times as resistant as the greenhouse strain.

The BPH was reported to have developed resistance to various other insecticides *(i.e.,* monocrotophos and isoprocarb) (Heinrichs and Tetangco 1978). Chung *et al.* (1982) reported that by continuous selection of a field strain, BPH developed 1183-fold resistance to malathion in 9 generations and 41-fold resistance to isoprocarb in 16 generations, and both of these selected strains were equally resistant to propoxur and permethrin but remained susceptible to fenvalerate. Ozaki and Kassai (1982) found that under field conditions, BPH developed resistance to fenthion (30– to 32-fold), fenitrothion (22- to 23-fold), cyanofenphos (145- 423-fold) and malathion (20- to 31-fold) in a period of 6-7 years. Development of carbamate-resistance was also reported but occurred at a slower rate.

Kassai and Ozaki (1984) reported that a malathion-resistant strain developed 5- to 26-fold cross resistance to naled, tetrachlorvinphos, monocrotophos, propaphos, fenthion, fenitrothion, diazinon, isoxathion, pyridafenthion and carbaryl. They further stated that a fenitrothion-resistant strain was found to have developed various increased levels of cross resistance to the above insecticides and also malathion. Sun and Dai (1984) observed that BPH developed 1000-fold resistance in Taiwan to permethrin while the resistance levels to other pyrethroids (i.e. cypermethrin, deltamethrin, fenvalerate) were much lower, ranging from 10- to 50-fold.

Development of insecticide resistance has also been reported in case of SBPH to malathion in Korea (Choi *et al.,* 1975) and Japan (Nagata and Mochida 1984), and in WBPH in Sri Lanka (Wickremasinghe and Elikawela 1982) and in Japan (Nagata 1979).

2.1.7 Insecticide-Induced Brown Planthopper Resurgence

A major factor that has contributed to the number and severity of BPH outbreaks in the last two decades has been widespread and indiscriminate use of insecticides in the rice ecosystem. The degree of resurgence is dependent on an interaction of factors consisting of the insecticide and its effects on the rice plant, the BPH populations, and the natural enemies of the BPH (Heinrichs and Mochida 1984) (Fig. 3).

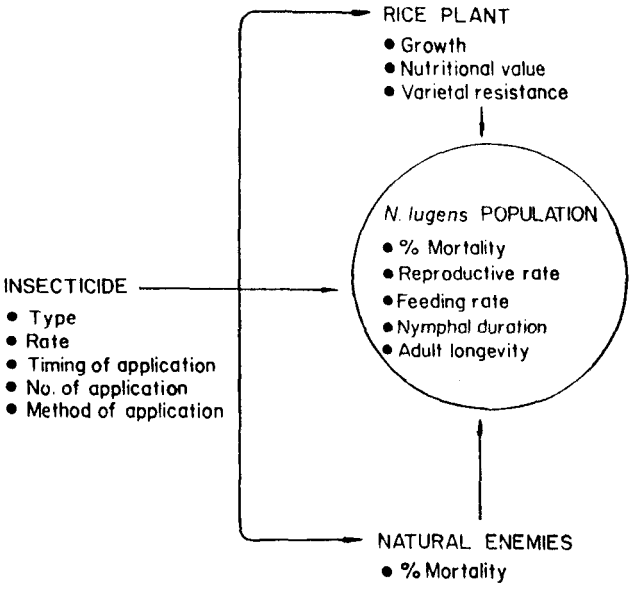


Fig. 3. Diagrammatic explanation of how insecticide management determines the degree of brown planthopper, *N. lugens* resurgence through a direct effect on the BPH populations and *via* the host plant and natural enemies of the BPH.

Numerous BPH resurgence-inducing insecticides have been identified in field tests at IRRI (Heinrichs *et al.,* 1982b; Reissig *et al.,* 1982a, b) and in national programs. Studies have shown that resurgence-inducing insecticides include representatives of the phosphate, carbamate, and pyrethroid classes (Heinrichs and Mochida 1984). Insecticide type and rate, and the number and method of insecticide applications all influence the degree of BPH resurgence (Fig. 3). Factors contributing to BPH resurgence consist of the direct effects of the insecticide on the BPH population and the indirect effects on the BPH population *via* the host plant and natural enemies.

The success of the 'green revolution' in rice in Asia has been limited by the problems caused by insecticides that induce the resurgence of BPH populations. Because of the severe economic effect of BPH resurgence, it is important that rational insecticide management programs be established and integrated with other BPH control tactics in an integrated pest management approach.

2.2 GREEN LEAFHOPPER SPECIES

There are three important green leafhopper species; *Nephotettix virescens, N. nigropictus* and *N. cincticeps*. Because these species are vectors of rice virus diseases, insecticides should have immediate knockdown effects.

2.2.1 Timing of Insecticide Application

Insecticides are not necessary unless the virus diseases transmitted by GLH are prevalent. In India, 10 GLH/4 net strokes or 5/hill at the vegetative stage and 10/hill at the post flowering stage were listed as thresholds (Heinrichs *et al.* 1979b). A threshold of 2 GLH/hill has been suggested in tungro endemic areas, in Tamil Nadu, India (Anonymous 1985).

22.2 Insecticide Application Methods

A liquid band applicator developed at IRRI facilitated root-zone application and provided effective control of early season pests such as whorl maggot and GLH (Heinrichs *et al.,* 1979b). The incorporation of carbofuran granules into the root-zone at the time rice is planted controlled tungro virus disease by preventing feeding by the vector *N. virescens* (Basilio and Heinrichs 1981). Root-zone application was more effective for the control of GLH than BPH (Mochida and Heinrichs 1980).

Seedling root coating and root soaking with carbofuran just prior to planting gave 100% GLH mortality even at 50 DT (Seiber *et al.,* 1977). They also reported that the root-coat treatment technique provided excellent control of tungro virus incidence in the field up to 40 DT.

2.23 Resistance to Insecticides

Insecticide resistance in GLH is a serious problem in Japan (Nagata and Mochida 1984). Malathion resistance in *N. cincticeps* was reported in 1960-61 and methyl parathion resistance in 1962. 'Malathion and parathion were replaced by carbamate insecticides.

Ku and Wang (1978) observed development of insecticide resistance in *N. cincticeps* to the carbamates BPMC, carbaryl, CPMC, carbofuran and isoprocarb. Fabellar *et al.* (1981) reported low levels of insecticide resistance in the GLH to acephate and methyl parathion in the Philippines. Resistance-ratios ranging from 27 to 451 for malathion, 32 to 875 for methyl parathion and 12 to 79 for carbaryl have been reported in the GLH population in Taiwan (Kao *et a1.,1981).* Resistance-ratios for the same populations were found to be 1-55 for permethrin and 1-2.4 for fenvalerate.

Miyata *et al.* (1981) reported that the major factors involved in resistance to malathion in the GLH were increased malathion-degrading carboxylesterase activity and reduced sensitivity of AchE to malaoxon. Glutathione -S transferase was thought to be involved in resistance to fenitrothion and for the carbamates the main resistance factor was reduced sensitivity of AchE rather than carbamate metabolism. The major resistance mechanism in the GLH to malathion was enhanced degradation by carboxylesterases while for BPMC, it was reduced sensitivity of AchE (Saito and Miyata 1982).

The most common method of managing insecticide resistant insect populations is to use new insecticides with no cross resistance to the old insecticide. Malathion and parathion were first used for GLH control, then replaced with carbamates. Carbamates were again replaced with OP chemicals such as diazinon and propaphos to which malathion- or parathion-resistant GLH showed no cross resistance. Mixed formulations of organophosphates and carbamates also have been used to overcome carbamate resistance (Hama and Iwata 1973). All of these insecticides are losing effect because GLH is developing multiple resistance. Few promising chemicals are now available to destroy resistant GLH populations except some pyrethroids.

2.3 STEM BORERS

Important species of stem borers of rice are the yellow stem borer (YSB), *Scirpophaga incertulas,* and the striped stem borer (SSB), *Chilo suppressalis,* among which the former is a major pest of rice in South Asia and the latter is important in Southeast Asia.

2.3.1 Factors Affecting the Efficacy of Insecticides

The yellow stem borer lays eggs covered in a hairy matrix that prevents insecticide penetration and hence the ovicidal action of the toxicant is nullified. After hatching, the larvae bore into the stem rendering the action of contact insecticides ineffective. Hence, systemic insecticides that move through the plant system are most effective against the borers.

2.3.2 Timing of Insecticide Application

Careful timing of insecticide application can significantly reduce the amount of material used and increase selectivity. In China, foliar sprays for the control of YSB were more effective during egg hatch than during peak adult emergence (Chiu 1979). In areas where stem borers occur in distinct broods, application of insecticides in relation to brood emergence was reported to be more effective than calendar based schedules (Heinrichs *et al.,* 1979b). The insecticides can be applied when the

stem borer damage reaches the ETL. An ETL of 5-10% deadhearts has been suggested for stem borers (Heinrichs *et al.* 1979b).

2.3.3 Selective Uses of Insecticides

Insecticides that are safe to natural enemies may lead to an effective and durable suppression of the pest. Spraying the rice crop with metalkamate did not hamper parasitization of the stem borer egg masses (IRRI 1976). Application of carbofuran granules was very effective in controlling the stem borer and sparing hymenopterous parasites, but it severely reduced the population of predatory spiders and other predators *(e.g. Cyrtorhinus lividipennis* and damselflies) (Khusakul *et al.,* 1979). Miyata and Saito (1982), reported that malathion and pyridafenthion were less toxic to predators of *Chilo suppressalis (i.e., Paradosa astrigera, Conocephalus maculatus)* because of low cuticular penetration.

2.3.4 Resistance to Insecticides

Stem borers have developed resistance to insecticides. Resistance of the striped stem borer to BHC and parathion in Japan has been reported (Nagata and Mochida 1984).

2.4 DEFOLIATORS

Major defoliator pests of rice include the leaffolder, *Cnaphalocrocis medinalis,* rice caseworm, *Nymphula depunctalis* and rice armyworms, *Spodoptera* spp.

2.4.1 Factors Affecting the Efficacy of Insecticides

The larvae of leaffolders remain in leaf folds and feed on the tissue by scraping. Hence, insecticides applied on the foliage often do not contact the larvae. Along with *C. medinalis,* other species of leaffolders *(i.e, Marasmia patnalis* and *M. ruralis)* have been reported to occur in rice fields in Madurai (Gunathilagaraj and Gopalan 1986) and at Aduthurai, Tamil Nadu, India (Personal unpublished data). Because of the mixed occurrence of these leaffolder species, insecticides should be screened against each species in determining their efficacy and making recommendations.

Caseworm larvae shelter inside leaf cases into which insecticide penetration is limited. The insect migrates by falling on to the water surface and moving along with irrigation water. Thus insecticide applied on the foliage has limited influence on caseworm larvae.

The armyworm feeds on foliage during night but hides in soil cracks and crevices in the day time. Mature larvae are less susceptible to insecticides than early instars thus necesitating insecticide application when the insects are in early instar stages.

2.4.2 Timing of Insecticide Application

The economic threshold for the leaffolder was reported in India as 10-15% damaged leaves. In China, 10 eggs/100 plants or 20 damaged leaves per 100 plants was considered as the threshold (Heinrichs *et al.* 1979b). Threshold levels of 10% damaged leaves in the vegetative phase and 5% of

flag leaf damage at the flowering stage have been reported in Tamil Nadu, India (Anonymous 1985). Feeding by leaffolder and armyworm is extensive during night and hence, to achieve better control, insecticides should be sprayed during the evening hours.

2.4.3 Insecticide Application Methods

To control leaffolder larvae that are present inside the leaf folds, insecticide should be applied in such a way that the entire foliage is covered by the insecticide spray. For armyworm control, insecticide should be applied on to the base of the rice plant and soil crevices where the larvae remain during day time. Heavy damage by leaffolder is often seen in patches in shady areas, particularly under trees. Insecticides can be spot applied in these patches and thus further spreading of damage can be avoided.

2.5 GALL MIDGE

The rice gall midge, *Orseolia oryzae,* is one of the major rice pests in India, Thailand and Sri Lanka. Maggots of the gall midge feed on the shoot apex resulting in the suppression of the apical meristem and formation of radial ridges from the inner most of the leaf primordium which is followed by the elongation of the leaf sheath leading to the formation of an onion leaf-like structure.

2.5.1 Factors Affecting the Efficacy of Insecticides

The presence of the gall midge is only evident after damage has been done. Insecticides applied after the appearance of the gall-like symptoms are evident will only check further incidence of the damage. Because the gall midge maggot remains inside the gall, insecticides having contact action have little effect on the maggots. Systemic insecticides are most effective.

2.5.2 Timing of Insecticide Applications

Maximum damage by this pest is caused up to 60 days after transplanting and hence, chemical control should be applied at an early growth stage. Insecticide timing can be determined as based on catches of adults in a light trap. Insecticide should be applied a few days after the peak periods of adult catches in the trap. In areas where the gall midge is a chronic pest, applications in the nursery and applications at transplanting may be warranted.

2.5.3 Insecticide Application Methods

Granular insecticides applied on the water surface and seedling root dip in insecticidal solution are effective application methods for the control of the gall midge. Root dipping in isofenphos 0.02% solution for 12 h yielded relatively better control than dipping in 1 h (Misra *et al.* 1981). Samalo *et al.* (1983) reported that seedling root dip for 12 h with 0.02% chlorpyriphos or isofenphos followed by one application of ethoprophos granules at 1 kg ai/ha after 30 DT gave good control and allowed a fairly high level of parasitization by *Platygaster oryzae.*

2.6 RICE BUGS ON PANICLES

The rice bugs *Leptocorisa* spp. cause damage by feeding on the sap of the milky grains and turn them chaffy. In controlling this pest, care should be taken that the insecticide residues do not remain on the grains after harvest.

2.6.1 Timing of Insecticide Application

An economic threshold of 5 bugs/100 panicles at flowering and 16 bugs/100 panicles at the milky stage to grain maturity is recommended in Tamil Nadu, India (Anonymous 1985). Insecticides should be applied when the bugs are in their early instars as they are more susceptible than later instars.

3. Environmental Impact of Insecticide Use in Rice

3.1 EFFECT ON BENEFICIAL INSECTS

Some insecticides used in rice are more toxic to beneficial insects *(e.g.,* natural enemies and pollinators), fish species, and other non-target organisms than to the targeted pest species. Adverse effects of insecticides on beneficial insects are due to various factors such as the wrong choice of insecticides that are inherently more toxic to natural enemies than to pest insects, improper method of insecticide application and incorrect timing of application.

Choi *et al.* (1978) observed that among three methods of carbofuran application (root-zone application with capsules, soil injection as a liquid formulation and 2-4 broadcasts in the irrigation water) for control of leaf- and planthoppers, the predaceous spider population was reduced in all the three methods of application, but the reduction was greatest in the capsule placement.

Choudhury and Alam (1979) found that 0.2% diazinon spray controlled rice pests effectively but was very toxic to the mirid predator *Cyrtorhinus lividipennis* and the predatory spiders. The dust formulations of propoxur and MTMC were toxic to *C. lividipennis* (Ooi 1979). Carbofuran was very effective in controlling the stem borer and spared the hymenopteran parasites. However, it severely reduced populations of predatory spiders *(eg., Tetragnatha* sp., *Oxyopes* sp., *Lycosa pseudoannulata), C. lividipennis,* and damselflies (Khusakul *et al.,* 1979). The insecticide pyrimioxythion was reported to be highly toxic to the parasite of rice gall midge *Platygaster oryzae,* whereas chlordimeform was less toxic. Joshi and Venugopal (1983) indicated endosulfan spray to be very toxic to the gall midge parasite, *P. oryzae,* while phosalone was relatively safe.

Fabellar and Heinrichs (1984) reported that cypermethrin and deltamethrin were highly toxic to BPH predators *Microvelia atrolineata, Lycosa pseudoannulata* and *C. lividipennis.* Chelliah and Rajendran (1984) found that endosulfan was least toxic to *C. lividipennis* while quinalphos, chlorpyriphos, phosalone, and monocrotophos were highly toxic.

Aguda *et al.* (1984) observed that the insecticides causing BPH resurgence *(i.e.,* methyl parathion and azinphos ethyl) greatly reduced spore germination of the entomogenous fungi

Metarhizium anisopliae and *Beauveria bassiana* which commonly attack BPH. Hence, it is advisable to use whenever possible insecticides that are selective, effective, and safe to insect pathogens, parasites and predators.

3.2 INSECTICIDE RESIDUES AND TOLERANCE LIMITS

Insecticides used for rice pest control may remain in the environment as residues in food, cattle feed, water, or in the atmosphere and thus, pose multivarious health hazards, both long and short term. Although few studies have been conducted to determine residues of insecticides remaining in rice plants and the rice ecosystem after insecticide application, residues do not appear to be a major problem.

Teimoory and Shekarabi (1979) estimated the residues of diazinon 10% granules applied at 20 kg/ha. The residues in water ranged from 0.062 ppm to 0 ppm from the day of application to the 10th day after treatment, respectively. When phosphamidon was applied at 0.75 l/ha, residues in the field water ranged from 0.114 pprn to 0 ppm and that of lindane from 0.79 to 1.05 ppm from 0 to 10th day after treatment, respectively.

Out of five treatments with carbofuran only the high rate of 6 broadcast applications of 1 kg ai/ha at 14-day intervals caused grain residues above the allowable level. The U. S. environmental Protection Agency (EPA) has set a tolerance limit of 0.20 ppm in grain for carbofuran plus its metabolite 3 hydroxy carbofuran (Heinrichs *et al.,* 1978b). Studies conducted by Rao and Rao (1980b) showed that residues of carbofuran were highest in grains, straw and soil when three applications were made at 10, 40 and 70 DT but were below the tolerance limit fixed by the EPA.

Lindane at 0.75 kg ai/ha was found to be effective against the rice bug, *Leptocorisa oratorius.* Residues in the harvested grains were well below the tolerance limit (Argente and Heinrichs 1983). It is necessary to analyze for residue levels for various insecticides at various rates of usage and methods of application and to establish the tolerance limits to avoid/minimize the toxic hazards of chemical pesticides.

3.3 HUMAN HAZARDS

Hazards to humans by insecticide use occur in two ways; (1) direct hazards that occur during handling and application and poisoning due to internal consumption and (2) indirect hazards of pesticide residues in the usable products and the environment.

Granular insecticides *(e.g.,* carbofuran and phorate) have high dermal toxicity and cause skin irritation and allergenic symptoms. Some of the sprayable insecticides (*eg.,* ethyl parathion) are extremely toxic to humans during spray operations.

Although few chlorinated hydrocarbon insecticides are now used, it is important to mention that some of them have high persistence in the environment and cause chronic toxicity. They accumulate in the fat tissue of animals and humans and are found in milk and dairy products. Organochlorines can be transferred from mother to fetus and consequently, babies may be born with pesticide residues in their bodies. Milk from such mothers will also contain chemicals. These

pesticides accumulate in smaller quantities in organisms at lower trophic levels and because humans are at higher trophic levels, accumulation of these insecticides in human bodies increases at an exponential rate.

4. Integration of Insecticides with Other Control Methods

In rice IPM, insecticides can be integrated with biological control, resistant cultivars and cultural controls.

4.1 INSECTICIDES AND BIOLOGICAL CONTROL

To date, successes of classical biological control have been few. Numerous failures have been reported (Nickel 1967, Yasumatsu and Torri 1968, Lim 1974). However, the use of biocontrol methods, when integrated with insecticides, can be highly effective. In South China, *Trichogramma* parasites are being mass reared and released to control leaffolders. Insecticides are used only when necessary and usually for controlling other pests such as stem borers, thrips and planthoppers (Chiu 1980). *Bacillus thuringiensis* has also been integrated with low dosages of insecticides (0.1-0.2 of the normal strength) to provide effective control of lepidopterous pests in Kwangtung Province (Chiu 1980).

4.2 INSECTICIDES AND RESISTANT CULTIVARS

Insecticides are highly complementary to resistant varieties. Often, rice varieties are resistant to a few insect species and need insecticides for control of other pests. In the Philippines, IR 26 was resistant to BPH, but insecticide protection was necessary against other insects (Heinrichs *et al.,* 1979b).

On moderately resistant varieties, developing insects may be less vigorous, smaller and less fecund and may succumb more readily to insecticidal treatments. For example, stem borer infestations on moderately resistant varieties receiving only one or two insecticidal treatments were similar to or lower than those observed on susceptible varieties receiving twice the number of insecticide treatments (Saxena 1980).

Biotype selection is a major problem in the use of resistant varieties, especially in BPH control. However, Panda and Heinrichs (1982) have identified tolerant rice varieties with no major genes for BPH resistance (IR 46, Kencana, Triveni and Utri Rajapan). Though only moderately resistance, they are believed to be stable to BPH stress. Such tolerant varieties, when supplemented with insecticides on a need basis, can be expected to produce stable yield and a profitable economic return.

4.3 INSECTICIDES AND CULTURAL CONTROL

Close planting in rice not only contributes to rapid increases of pests such as BPH (Oka 1979), but it also prevents foliar sprays from reaching target pests under the canopy. However, wide spacing

can significantly reduce yields. If IPM programs are to be successful, appropriate integration of good cultural practices with control methods such as insecticides are necessary (Lim and Heong 1984).

Cultural practices along with insecticides can play a significant role in a complementary way. The spraying of susceptible trap crops has proved successful (IRRI 1978). Because a cultural practice may have differential effects on various pests (Kiritani 1972, Lim and Heong 1976), insecticides could be integrated into such circumstances. The cultural practice could be used to control key pests while chemicals are used to control less important species.

5. CONCLUSION

Insecticides will continue to serve as an essential component in the management of rice insects for several years. However, their use should be based on sound economical principles. It is justifiable to use insecticides only when benefit-risk ratios are in favor of insecticide use. Development of insecticide resistant populations, resurgence and adverse effects on non-target organisms are to be understood in greater depth in order to use insecticides most effectively in rice insect control. Thus, the insecticides are double-edged swords and using them in an unscientific manner may bring catastrophic results.

Worldwide regulations on the release of new insecticides are becoming increasingly more stringent. It is thus obvious that we cannot afford to lose the currently available compounds. It is imperative therefore, to develop appropriate insecticide management strategies to extend the commercial life of the existing insecticides, as well as to protect human health and the environment.

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10

Integration of Rice Insect Control Strategies and Tactics

C. MICHAEL SMITH
Department of Plant, Soil and Entomological Science
Division of Entomology
University of Idaho
Moscow, Idaho

1. INTRODUCTION

DURING THE PAST THREE decades, significant shifts in the insect pest complexes of Asian rice producing nations have occurred. Agricultural scientists in these nations have gained the knowledge necessary to manage these insects, and have synthesized various control tactics that are now in use in the form of integrated pest management (IPM) programs. These programs are usually carried out through the efforts of each nation's national program staff for agriculture. Examples of such program activities exist in India, Indonesia, Japan, Malaysia and the Philippines. In these countries, IPM programs utilize traditional chemical, biological and cultural control measures to varying degrees, depending on the nature of the pest insect complex and the socioeconomic conditions existing in the areas where IPM is carried out. In the Peoples' Republic of China, IPM programs are quite comprehensive, utilizing biological, chemical and cultural controls linked to extensive surveillance programs.

One form of cultural control, the development and cultivation of insect resistant rice cultivars, has been tremendously successful, due to the cooperative efforts of rice researchers throughout the world. More than 20 million ha of rice in Asia are now planted to cultivars with resistance to the brown planthopper, *Nilaparvata lugens* Stal, and an additional 10 million ha of cultivars with resistance to various other insect pests are planted throughout the world (IRRI 1982). Sources of

resistance to several of the major rice diseases and insects have been identified, cataloged, and are currently in various stages of varietal development (Khush 1980,1984).

The purpose of this chapter is to examine instances where the different types of IPM tactics have been successfully integrated and to suggest requirements for the continued development of IPM programs for control of rice insects.

2. Cultivar Resistance and Chemical Control

With the advent of the Green Revolution, insect pest problems in rice have generally intensified, and as a result, insecticide use patterns have increased. In some instances, insecticides significantly enhance the yield of rice cultivars with insect resistance (Heinrichs *et al.,* 1986b). Heinrichs *et al.* (1979) demonstrated that carbofuran treatment of IR26, a cultivar with brown planthopper biotype 1 resistance, gave control of the rice whorl maggot, *Hydrellia* philippina, and increased yields by 15%. Kulshreshtha (1979) demonstrated 35-71% yield increase in IR 26 rice after insecticidal treatment for the yellow stem borer, *Scirpophaga incertulas* (Walker), in India. Similar results were reported by Heinrichs *et al.* (1984,1986b) with insecticides applied to moderately resistant cultivars for control of the whitebacked planthopper, *Sogatella furcifera* (Horvath), and the green leafhopper, *Nephotettix virescens* (Distant).

However, insecticides may be of no practical value in the cultivation of some resistant cultivars. Research in India (Prakasa Rao 1974) and Thailand (Tirawat 1975), indicates that cultivars with high levels of resistance to the gall midge, *Orseolia oryzae* (Wood-Mason), received no benefit from insecticide treatment. Kalode (1980) indicated that cultivars with *O. oryzae* resistance in India yielded similarly, regardless of whether or not insecticides were applied prophylactically, as determined by surveillance, or not at all (Table 1). Studies by Reissig *et al.* (1981) in the Philippines with *N. lugens* and *N. virescens* also indicate that insecticide treatments of IR36, a multiple insect and disease resistant cultivar, do not increase rice yields or farmers' net profits.

TABLE 1

Control of *O. oryzae* and yields of Shakti (resistant) and Jaya (susceptible) rice cultivars under different pest management practices. Sambalpur, Cuttack and Bhubaneswar, India 1977-1978

	Cultivar			
	Shakti (R)		*Jaya (S)*	
Insecticide treatment method	*Silver shoots (%)*	*Yield (t/ha)*	*Silver shoots (%)*	*Yield (t/ha)*
Surveillance-based	2.3	3.5	12.7	2.2
Prophylactic	1.0	3.3	9.8	2.3
None	2.7	3.3	21.7	1.8

[1] From Kalode (1980).

Increased insecticide use has also caused increased misuse, either from improper insecticide application, formulation, timing or rate. In rice production, insecticides can have several negative effects. Insecticides may kill beneficial insects, causing resurgence of pest insect populations, may

cause the development of insecticide-resistant pest populations, or kill non-target vertebrates (Litsinger 1983). Reissig *et al.* (1982) demonstrated that applications of insecticides for outbreaks of non-target insect pests on rice cultivars with resistance to a key insect pest cause resurgence of the key pest. This practice also creates a greater possibility of key pest biotype development and destroys beneficial predators and parasites.

Insecticides also induce changes in pest insect behavior that alter the levels of cultivar resistance of pests. Salim and Heinrichs (1987) demonstrated that more *S. furcifera* adults are attracted to plants of resistant, moderately resistant, and susceptible rice cultivars treated with deltamethrin insecticide than to untreated plants (Fig. 1). As a result, *S. furcifera* nymphal growth, survival, and population development were all greater on treated resistant plants than on untreated resistant plants.

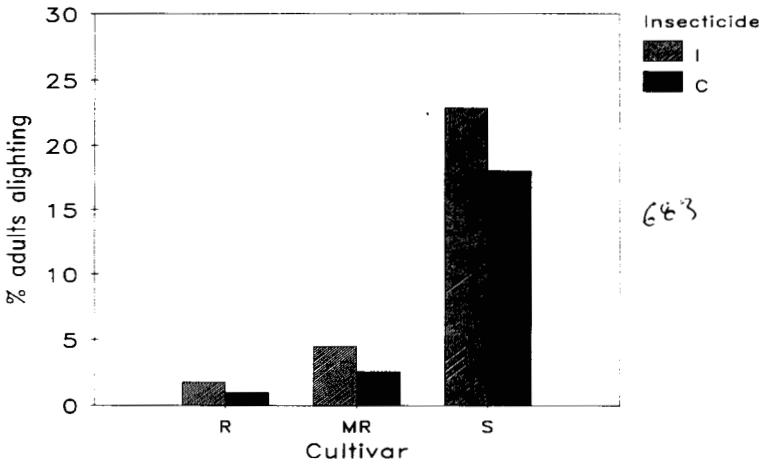


Fig. 1. Effect of deltamethrin insecticide-treated (I) and untreated (C) rice cultivars (R = resistant, MR = moderately resistant, S = susceptible) on *Sogatella furcifera* behavior (from Salim and Heinrichs 1987).

The rice cultivars described above have multiple component resistance based on two or more monogenic sources. The ease with which biotypes of *N. lugens* have developed virulence to monogenic resistant cultivars has shown the need for the development of more moderately resistant cultivars with a broader genetic base of resistance. Recent research at the International Rice Research Institute (Heinrichs *et al.,* 1984) has shown that *N. lugens* reared on cultivars with only moderate resistance suffer higher mortality when treated with insecticides than those reared on susceptible cultivars (Table 2). Mortality is not different between hoppers reared on resistant and moderately resistant cultivars when treated with insecticides. Thus, the use of moderate resistance is of value in reducing the degree of selection pressure causing biotype development.

TABLE2

Insecticide-induced mortality of biotype 2 *N. lugen* reared on moderately resistant, and susceptible, rice cultivars, IRRI, 1980[1]

Insecticide	*Mean mortality(%)*[2]		
	TNl (S)	*ASD7* (MR)	*Sinna Sivappu* (R)
Carbofuran 12F	64b	94a	95a
Carbosulfan 20EC	66b	93a	94a
BPMC 50EC	46b	79a	90a
Control	10b	18a	23a

[1]From Heinrichs *et al.* 1984.

[2]24 h mortality; means in a row with the same letter are not significantly different at the P = 0.05 level by Duncan's multiple range test.

3. Cultivar Resistance and Biological Control

Complexes of biological control agents have been identified for almost all major insect pests of rice (Chiu 1979). Many of the these predators, parasites and pathogens work effectively to regulate rice insect pest populations (Kenmore 1980). Because insecticides have detrimental effects on predators and parasites, IPM research is beginning to determine the interaction of cultivar resistance with biological control. Early research (IRRI 1975) demonstrated that predation of *N. lug*ens by predators on hopper-resistant cultivars gave better *N. lug*ens control than either the predator or the resistant cultivars alone. The effects of moderately resistant cultivars combined with those of the spider predator *Lycosa pseudoannulata* (Boes *et al.* Str.) and the mirid bug, *Cyrtorhinus lividipennis* Reuter keep *N. virescens* (Fig. 2), *N. lugens* (Fig. 3), and *S. fu*rcifera populations below economic threshold levels (Myint *et al.,* 1986, Kartohardjono and Heinrichs 1984, Salim and Heinrichs 1986). These results demonstrate how two major IPM tactics can be combined for more efficient insect control in rice.

4. Cultivar Resistance and Cultural Control

Varying the cultural practices in a rice production system is a management tactic that was first used by Chinese farmers, over 2,000 years ago, when adjusted planting dates and crop stubble burning were used to reduce the buildup of insect pest populations (Flint and van den Bosch 1981). There are few documented examples of the integration of cultural practices with plant resistance, but most cultural practices integrate well in IPM systems.

4.1 PEST AVOIDANCE

Planting the rice crop in a manner that avoids the peak pest insect population generally gives some degree of pest control. Heinrichs *et al.* (1986a) found that *N. lugens* populations and hopper-predator ratios on early-maturing rice cultivars were significantly lower than those on later (mid-

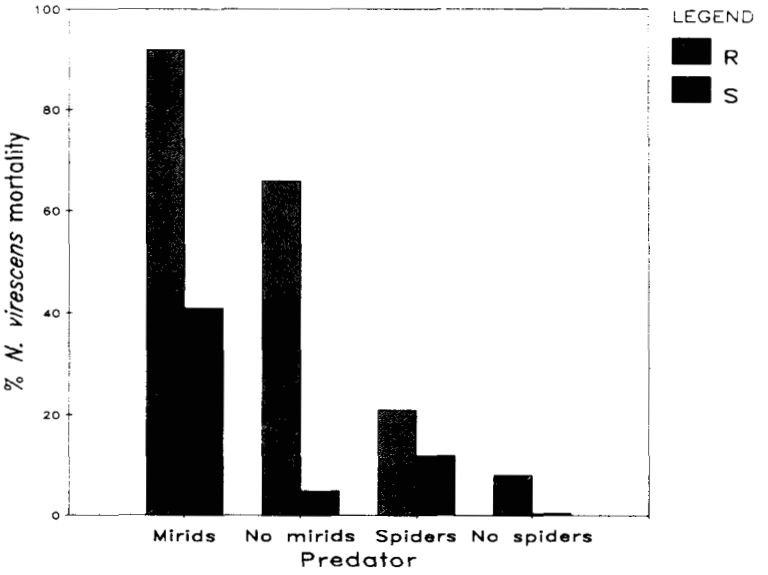


Fig. 2. Mortality of *Nephotettix virescens* due to rice cultivar (R = resistant, S = susceptible) and predation by *Cyrtorhinus lividipennis* (minds) and *Lycosa pseudoannulata* (spiders) (from Myint *et al.,* 1986).

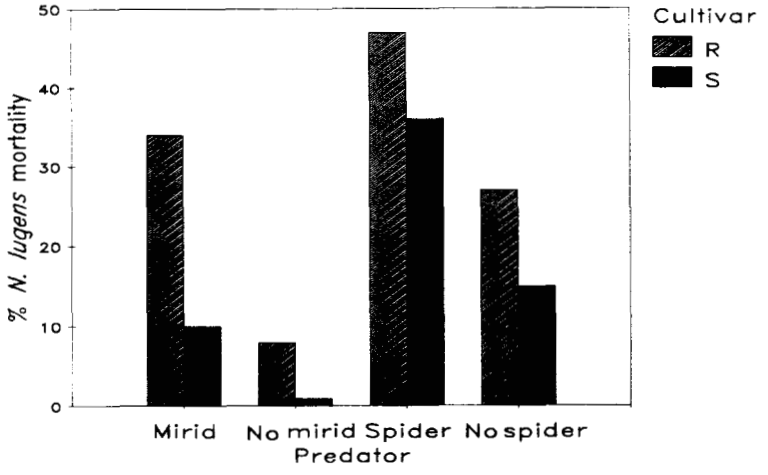


Fig. 3. Mortality of *Nilaparvata lugens* due to rice cultivar (R = resistant, S = susceptible) and predation by *Cyrtorhinus lividipennis* (minds) and *Lycosa pseudoannulata* (spiders) (from Kartohardjono and Heinrichs 1984).

season) maturing cultivars. These results indicate that the incorporation of *N. lugens* resistance into early maturing cultivars would serve to increase rice crop protection. The same relationship exists with cultivars resistant to *O. oryzae.* Sen *et al.* (1984) determined that cultivars with a maturity of medium duration had less *O. oryzae* damage than cultivars with maturities of long duration.

Oka (1983) suggested that the incorporation of cultivars into a synchronized rice planting scheme would further reduce the buildup of economically damaging *N. lugens* populations. Planting of a rapid-maturing, secondary (legume) crop between the two rice crops was suggested as an additional means of disrupting and suppressing *N. lugens* populations (Fig. 4). The planting of

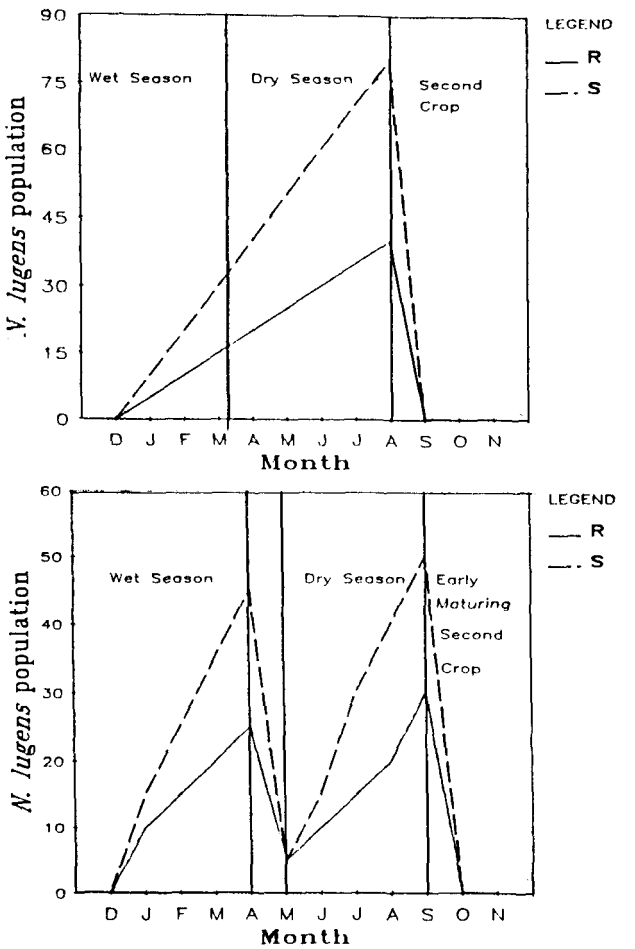


Fig. 4. Current (upper) and suggested (lower) irrigated rice cropping systems using resistant (R) and susceptible (S) rice cultivars and second crops to reduce *Nilaparvata lugens* populations (from Oka 1983).

insect-resistant rice cultivars was further suggested as a means of reducing pest insect incidence in this cropping system.

Delaying rice planting until after emergence of the first generation of *S. incertulas* allows growth of rice at a time of low borer incidence. In Pakistan, farmers are prohibited by law from planting until after emergence of first generation moths (FAO 1979). Shifting planting dates has also helped minimize damage from various borer species in India, Indonesia and Malaysia (Khan 1967). In Japan, however, the striped rice borer, *Chilo suppressalis* (Walker), has become adapted to a modified schedule of late planting (FAO 1982). This insect-crop interaction indicates the need for close monitoring of insect populations even when planting dates are changed to avoid damage. If changes in insect emergence do not occur, populations may be further depressed if resistant cultivars are used in delayed, synchronous plantings.

4.2 FERTILIZER MANAGEMENT

Populations of rice insect pests increase with increased rates of nitrogen fertilization, regardless of the level of and type of insect resistance (Heinrichs and Medrano 1985). However, the use of increased amounts of nitrogen has been one of the major factors contributing to the success of high-yielding rice cultivars. Reissig *et al.* (1985) state that split applications of nitrogen are more beneficial than single nitrogen applications. The first application is used more efficiently by the rice plant and keeps weed growth to a minimum until a second application is made. A reduction in the amount of nitrogen applied at each application also prevents the buildup of insect populations during rice vegetative growth, a factor that will synergize the performance of moderately resistant cultivars (Reissig *et al.* 1985). These findings indicate that combining insect resistance with fertilizer responsiveness is best accomplished by selecting cultivars with moderate levels of insect resistance that are fertilizer responsive.

43 SANITATION

Removal of rice stubble and weeds from rice fields and surrounding areas are practices of crop sanitation which can work synergistically with the planting of insect resistant cultivars. Cutting, burning, and plowing rice stubble during the post-harvest period are methods which have been shown to provide varying degrees of control (60-80%) of larvae of the white stem borer, *Scirpophaga innotata* (Walker) and *C. suppressalis* (FAO 1979, Grist 1953, Khan 1967, Shin-Foon 1980). All methods of stubble removal are labor intensive, however. A detrimental side effect of both stubble destruction and weed removal from in and around fields is the destruction of natural enemies and their habitats (Oka 1979). Though sanitation and insect resistance may be effective in pest population reduction, field sanitation as an IPM tactic requires further study to determine if benefits outweigh detriments.

4.4 TRAP CROPS

Planting a small portion of the rice field earlier than normal to an insect-susceptible cultivar to trap incoming pest populations is a practice that has potential for integration with planting of resistant

cultivars. Saxena (1982) demonstrated that fields with a trap crop planted 20 days ahead of the main crop, attracted more *N. lugens* and *N. virescens,* gave significantly higher yields, and preserved more natural enemies than control fields without trap crops (Table 3). Crop recommendations in China suggest early planting of a small area of rice with a susceptible cultivar, followed by treatment with insecticide before planting of the main crop (IRRI 1978).

TABLE 3

Pest incidence and yields of rice fields with and without trap crops. IRRI, 1977[1]

	Mean virus incidence (%)			
Treatment	*Grassy stunt*	*Ragged stunt*	*Tungro virus*	*Total yield (t/ha)*[2]
Trap crop[3]	1.9	13.8	1.3	–
Main Crop	1.2	13.8	0.5	2.8a
Control	2.5	22.1	1.7	1.9b

[1] From Saxena 1982.
[2] Duncan's multiple range test, P = 0.05.
[3] Planted 20 days before main crop.

4.5 WATER MANAGEMENT

Flooding of infested fields reduces populations of several rice insects and aids the adverse effects of resistant cultivars on insect populations. In China, early spring flooding of rice stubble has effectively been used to control overwintering *C. suppressalis* larvae. Mortality is very high (95-100%) due to increased metabolic activity of larvae at that time of year and greater penetration of stubble by flood water (Shin-Foon 1980).

Conversely, draining water from rice fields decreases populations of *N. lugens* (Dyck 1974a) and the rice water weevil, *Lissorhoptrus oryzophilus* Kuschel (Isely and Schwardt 1934). For *N.* lugens control, removal of water when the crop is near maturity is practical. However, drainage of fields for *L. oryzophilus* control is expensive, due to loss of paddy water and fertilizer. The primary consideration in determining whether water management practices integrate with plant resistance should be the effect on growth patterns and yields of resistant cultivars when water management practices are altered.

5. Chemical Control and Biological Control

The nature of these two control tactics makes them, by definition, incompatible. A limited amount of research has shown that under certain conditions, however, this is not necessarily true. Dyck (1974b) found that population levels of the *N. lugens* mirid predator, *C. lividipennis,* were adversely affected by spray application of methyl parathion, but relatively unaffected by applications of granular insecticides. Shin-Foon (1980) demonstrated a similar response of spider populations in China to foliar spray and root-zone insecticide application. Low rates of granular insecticides applied to rice in Japan have little toxicity to spider predators that help regulate leafhopper populations (Kiritani *et al.,* 1972).

Insecticides such as ethylan, endosulfan, and BPMC are more selective and have less toxicity to the predators *C. lividipennis, L. pseudoannulata,* and *Microvelia atrolineata* (Bergoth) than insecticides such as deltamethrin (Fabellar and Heinrichs 1984, 1986; Heinrichs *et al.,* 1982; Salim and Heinrichs 1985). In China, Li-Ying (1982) noted differential mortality of the *S. incertulas* parasites *Trichogramma japonicum* and *T. dendrolimi* in response to treatment with various insecticides. The obvious way to combine the maximum possible effect of chemical and biological control agents on rice insect pests is to use selective insecticides, and to use them only when action thresholds of pest population levels have been exceeded.

6. Problems in Integrating Control Strategies

As evidenced by this review, various insect control methods are beginning to be integrated in the rice producing areas of the world. However, there are both social and technical requirements necessary for this trend to continue before true IPM programs can be established. From a social standpoint, there is great need for continued government support of both research and extension programs at the international, national and local levels. Support to extension is necessary for continued development of local farmer IPM teams, trained to grow rice using proven IPM tactics (FA0 1982, Oka and Soenardi 1978, Reissig *et al.,* 1985).

From a technical standpoint, plant resistance as a control tactic itself, will require further development. Sources of resistance to the rice bug *Leptocorisa oratorius* F., the rice caseworm *Nymphula depunctalis* Guenee, the armyworm *Mythimna separata* (Walker), and certain other insects are yet to be identified. Higher levels of resistance to *S. incertulas, C. suppressalis, L. oryzophilus,* and several other species also need to be identified. The need for *S. incertulas* resistance is especially critical due to the key pest status of this insect. For most insects, the need remains for the development of cultivars with horizontal, multigenic resistance, to both slow the rate of biotype development and broaden the genetic base of resistance.

Though significant accomplishments have been made in biological control, additional research is necessary to demonstrate the function of biological control agents alone (Lowe 1982) or in an integrated role with cultivars, cultural practices (Pathak and Dhaliwal 1981) and insecticides. Certain cultural practices have been observed to contribute positively to rice insect pest control but few have been verified to do so experimentally (FAO 1982). Due to the possibility of negative effects of cultural practices on biological control, more research is necessary to define the interaction of cultural and biological control when combined with resistant cultivars.

7. Future Strategies

Several strategies for the future improvement of rice integrated insect pest management emerge from the discussion in the preceding section. A major strategy in future rice IPM programs should revolve around the combined use of existing biological control agents and insect resistant rice cultivars that possess moderate levels of resistance. Moderate antibiosis or antixenosis rice resis-

tance is effective, because it places less stress from plant allelochemical or morphological factors on beneficial insect predators and parasites. Tolerance resistance in rice plants also has the same type of beneficial effect on natural enemies, because it involves only plant growth characteristics, and does not rely on increased plant chemical or morphological factors. An added benefit of all three forms of resistance results from the fact that they place less selection pressure on pest insect populations to develop resistance-breaking insect biotypes.

In addition to existing biological control efforts, new biocontrol agents may also prove to be the basis of an additional strategy for future rice insect pest management. Several new fungal pathogens have been shown to cause mortality in rice insect pests (see chapter 8), however, none of these agents have been evaluated for their effectiveness of integration with other insect management tactics such as insect resistant rice cultivars, insecticidal controls, or other biological control agents.

A new type of rice insect pest management strategy involving the integration of plant resistance and an insecticide may also soon be possible, due to the adaptation of rice plant molecular gene transfer techniques. These techniques allow integration of the two control tactics by insertion of the toxin from the crystal protein gene produced by *Bacillus thuringiensis* (BT) into crop plants. BT toxin strains with specificity for both Coleoptera (BT *san diegoensis)* and Lepidoptera (BT *kurstaki)* have been successfully incorporated into tomato and potato plants. Although this technique is now only possible in these two Solanaceous crops, rapid technological advances may soon allow the same type of combination of management tactics in rice cultivars. As with all types of insecticides, however, the development of cultivars that cause extremely high levels of mortality should be avoided, in order to conserve natural enemies of rice insect pests and to avoid the rapid onset of BT resistance. Resistance to BT has been documented to occur in the Indian meal moth in a single season (McGaughey and Beeman 1988).

Finally, the development of an additional new strategy in rice insect pest management is also possible by integrating altered cultural practices with other insecticidal, biological, or cultivar management tactics. As mentioned previously in this chapter, alterations in existing cultural practices may have a real impact on lessening rice insect pest management problems and prolonging the life of rice cultivars. The practice of synchronous cultivation of rice to disrupt pest insect population levels and the production of legume or vegetable crops in between rice crops to conserve beneficial natural enemy levels warrant continued evaluation as possible key components of an integrated program of rice insect management. The acceptance and implementation of these tactics and others discussed in this chapter will be dependent on the efforts of national agricultural programs to effect change in both sociological and technological practices of rice production.

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11

The Brown Planthopper: Promises, Problems, and Prospects*

MICHIEL C. ROMBACH**
Insect Pathology Resource Center
Boyce Thompson Institute for Plant Research at Cornell
Tower Road, Ithaca, NY, USA

KEVIN D. GALLAGHER**
Department of Entomology, Division of Biological Control
University of California at Berkeley
Albany, California, USA

Planting rice is lots of fun,
Rice for all and everyone,
Let's all join and till the field,
There's good life for all your yield
It's so nice, planting rice
(Philippine song to make school children rice-conscious, 1967)

1. INTRODUCTION

RICE FIELDS DESTROYED BY the brown planthopper (BPH), *Nilaparvata lugens* (Stal) (Fig. 1A) are a shocking sight — brown, dry stalks, and yellow lifeless straw remain where healthy stems and lush greenery were before. At the start of the rice growing season small rice seedlings are carefully transferred from the nurseries into the field — in perfectly straight rows, by hand, and one by one.

* This chapter reviews results of research only. Mention of any proprietary product does not constitute an endorsement or recommendation for its use by the International Rice Research Institute, the Boyce Thompson Institute for Plant Research, nor by the University of California at Berkeley.

* *Present address:* Department of Entomology, International Rice Research Institute, Los Banos, Laguna, P.O. Box 933. Manila, The Philippines.

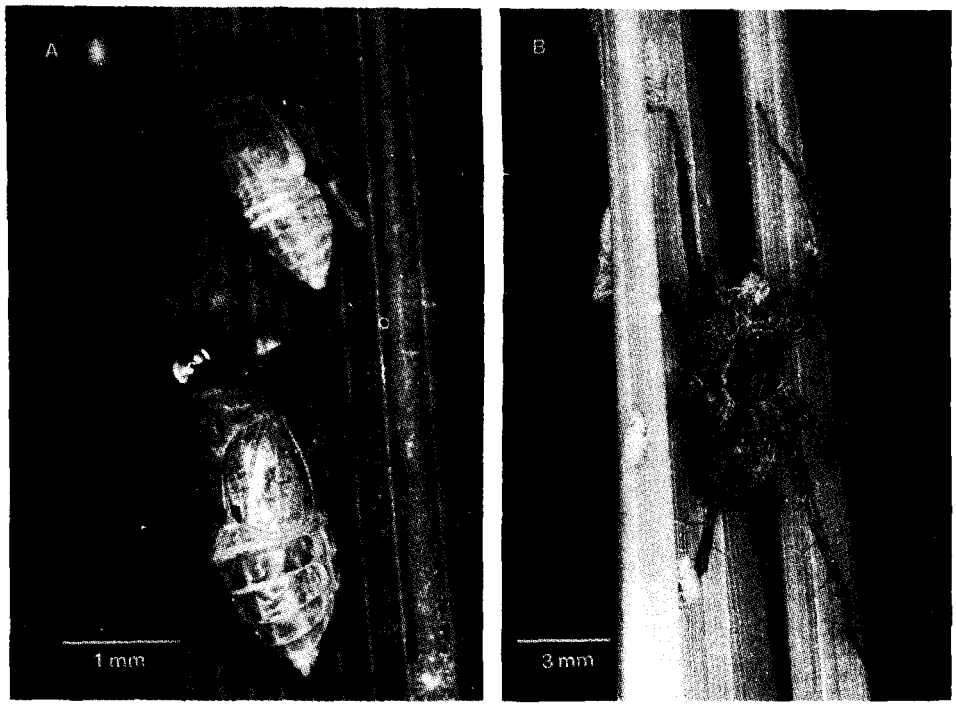


Fig. 1. (A) Brown planthopper (BPH) nymphs feeding on a rice stem and (B), a spider *(Lycosa* sp.) feeding on BPH nymphs.

After transplanting financial burdens for the farmer remain high, regular applications of fertilizers and insecticides are made and often hand weeding is necessary.

Destruction of the field by BPH, close to harvest, is a tragic occurrence - and has repercussions for the farmer, his family, and his country. The large scale resurgence of the BPH is one of the most important effects accompanying the introduction of the successful "green revolution" practices in tropical Asian rice.

First, it should be noted that it is beyond doubt that the "green revolution" programs have filled millions of empty rice bowls, prevented large scale famine, and saved the Asian region from disrupting political upheavals. However, a less desirable effect of the modern practices was the emergence of several new insect pests. Of these BPH was the most visible protagonist. We believe that BPH can be suppressed, without losing any of the advantages gained by the green revolution. The green revolution, some of its gains and drawbacks, and a strategy to solve the BPH impasse will be discussed under headings of Promises, Problems, and Prospects.

The world stage. – From the heavy dependence on the new broad spectrum insecticides in the 40s and the 50s the Western world moved into the decades of integrated pest management (IPM) (Perkins 1982, Wheatley 1987). Reduction of pesticide pressures while maintaining yield levels was

the most important task. However, in recent years most Western crop production has moved from occasional shortages to huge surpluses. Therefore, gross national yields have ceased to be the primary target for Western agricultural research; achieving optimum yield with minimum insecticide inputs are no longer primary research objectives.

This is not the case in the developing world. Most tropical countries, from cotton in the Sudan to rice in Southeast Asia should adopt a pest control philosophy typical of the 1955-1965 decade of the Western world (Brader 1986): reliance on broad spectrum persistent chemicals is being discredited, and a change to integrated control with less persistent and selective insecticides encouraged. Throughout the third world serious problems with broad spectrum chemical insecticides have arisen – and one of these problems is BPH resurgence on rice.

2. PROMISES

The Philippines has been a rice importing country for decades. Large quantities of rice were bought from neighboring countries, particularly Indonesia, China, and Thailand.

However, economic and social problems intensified with continuing dependence on rice imports. The combination of an increasing population of 32 million by 1965 and nationwide low and unstable food production lead to growing unemployment in the rural areas, social unrest, and massive migrations to the larger cities. To counteract these unfavorable social trends a national program for self-sufficiency in rice was given maximum government priority with the change in presidency and government in 1966.

2.1 THE ASIAN RICE REVOLUTION

The Philippine Rice and Corn Administration initiated the national Rice Sufficiency Program in 1966 (Barker 1984, Salas 1985) (Table 1). This program aimed to create a rice surplus by 1969 by increasing irrigation and yields by at least 50%. Farmers were recommended to plant only the modern high yielding varieties (HYVs) such as IRRI's "miracle" rice variety IR8. This variety was followed by other IRRI and national rice varieties. Farmers were also encouraged to use large quantities of fertilizers, and to apply insecticide on a routine basis. To assist farmers financially with these high input production schemes the Economic Development Program and national banks arranged for low interest credit structures without collateral. The high fertilizer and insecticide inputs caused high pre-harvest expenses. On a national level several international development organizations and development banks arranged for large loans to the Philippine government to pay for the program. Also, donations of equipment *(e.g.,* irrigation pumps), helped in the success of the development program.

The HYV seeds were distributed through government channels such as the Social Security System to reach private farmers, and the Government Service Insurance System for government employees. After harvest the government assured a solid price floor by procurement of all surpluses of the 1967 wet season crop. Farmers' acceptance of the new HYVs and the accompanying cultural practices was virtually immediate. This was not in the least due to nationwide on-farm demonstra-

tions, massive advertisement campaigns, and rice yield contests, in which one farmer proudly proclaimed the unlikely harvest of over 12 tons of rice from his 1 ha farm.

TABLE 1

Important events in BPH history in the Philippines

Date	*Event*
PIX-1967	BPH rare rice insect - damage negligible.
1967	Rice Sufficiency Program initiated. For the first time the wet season harvest exceeds the demand. Screening for resistant varieties - Mudgo is found BPH resistant.
1963-73	First large scale BPH outbreaks reported.
1970	*Bph1* and *bph2* genes found.
1973	Masagana 99 Program initiated. Technology packages transferred to the farmers.
1974	Introduction of IR26 *(Bph1* gene) - immediate BPH suppression over large areas.
1976	Outbreaks on IR26.
1976	Introduction of IR36 and IR42 *(bph2* gene) - immediate BPH suppression. Masagana 99 government support decreases.
1977	*Bph3* and *bph1* genes found.
1980	Recognition of natural enemies in BPH suppression.
1982	Outbreaks on IR42.
1982	Introduction of new varieties with *Bph3* gene - immediate suppression.
1987	Introduction of varieties with *bph4* gene.
1988	BPH multiplies on IR66 *(bph4* gene) in Negros, the Philippines - outbreaks expected.

The Philippine rice production drive under the Rice Sufficiency Program (1967-1969) and Masagana 99 Program (Tagalog for 'plentiful', and 99 refers to 'cavans', unit of weight of rice per ha) started in 1973 and is a true 'green revolution' success story. The Philippines became the main protagonist for Asia's rice revolution. Rice harvest nearly doubled, and the irrigated area increased from 250,000 ha in 1968 to over 450,000 ha in 1969 (Salas 1985). The Manilan Evening News (17 Nov., 1967) reports that "a new prosperous-looking rice farmer is emerging on the scene: the high yielding varieties farmer". The 1967 wet season harvest exceeded the Philippine demand and for the first time in decades the Philippines exported a small tonnage of rice. In 1968 an impressive 77,000 MT of rice was exported to Indonesia. Due to these national programs the rice harvest rose from a meager 4.1 million MT in 1965 to an impressive 7.8 million MT in 1979. According to Dr. Norman Borlaug, a driving force behind the green revolution: "Never before in the history of agriculture has a transplantation of high yielding varieties coupled with an entirely new technology and strategy been achieved on such a massive scale in so short a period of time and with so much success".

2.2 CHEMICAL INSECTICIDES

Crucial measures were taken in the context of insect control and the subsequent BPH problems that emerged during the Philippine rice revolution (Tables 1,2). Farmers purchased broad spectrum organophosphate and carbamate insecticides at tax free rates with their low interest loans - an insecticide subsidy regulation in disguise. Insecticides were also supplied by international aid programs; in 1967 alone the Japanese government supplied 5,000 MT of broad spectrum insec-

ticides for use on rice. Most important, insecticide use was artificially increased by forcing farmers to purchase insecticides along with the heavily subsidized fertilizers in their loan package — even if insecticides were not required.

At the same time Indonesia experimented with management of large areas of rice culture by western style corporations under government contract (for social consequences see also Feder, 1983). From 1965 to 1970 companies like Ciba-Geigy, Hoechst, and Mitsubishi provided management, credit, seeds, fertilizers, and insecticide applications for over 2.5 million ha of irrigated rice. In some areas farmers were forced to conform with synchronous planting schemes so that insecticides could be applied by airplane at set schedules and insecticide use became extreme. In most other Asian countries insecticide subsidies were installed, because insecticides were, with HYV seeds, regarded as absolute pre-requisites for a successful rice revolution. Routine insecticide treatments were often made to control insect populations that were far too low to cause economic damage.

To control rice insect pests various insecticides were recommended under the technical advice schedules of the Philippine Masagana 99 program; a compilation of this pesticide regime is given in Table 2. The package of technology recommended calendar based insecticide treatments. For a few pests crude thresholds were suggested, such as for stem borers at 10 or more deadhearts/m^2, 2 rice bugs *(Leptocorisa* spp.)/m^2 and 25 hoppers/rice hill. The list of recommended insecticides contained carbamate, organophosphate, and chlorinated hydrocarbon insecticides (Table 2). These were the government recommended products. Field observations, however, show that the following insecticides were most widely used (pers. comm. Entomology Dept. Staff, IRRI; see also Goodell 1979): monocrotophos (all around insecticide), chlorpyrophos + BPMC (mix for stem borers and plant- and leafhoppers), carbofuran (all around insecticide), BPMC (for hoppers), MIPC (for hoppers), azinphosethyl + MTMC (for stem borers and hoppers), and MTMC (for hoppers).

Heavy use of insecticides gained rapid acceptance amongst rice farmers boosted by the subsidies. Farmers can in general not distinguish between pests and natural enemies, and they do not know thresholds. They prefer chemicals which decimate pests immediately when either the insect itself or its damage is evident. Rapid-action insecticides, such as those listed above are the obvious choice to ensure dramatic, albeit short-term, control.

2.3 BPH CONTROL BY PLANT RESISTANCE

As early as 1967 varieties resistant to BPH were found by mass screening at IRRI (Pathak *et al.,* 1969) (Table 1). Two genes for resistance were named: the dominant *Bph*1 gene and the recessive *bph*2 gene. Later two other genes for resistance were identified: the dominant *Bph*3 gene and the recessive *bph* 4. The *Bph* l and *bph* 2 genes are closely linked (Lakshminarayana and Khush 1977) as are the *Bph*3 and *bph*4 genes (Sidhu and Khush 1979, Ikeda and Kaneda 1981). Closely linked genes cannot be easily incorporated into the same plants.

TABLE 2

Insecticides and applications as recommended in the Philippine Masagana 99 program

Before transplanting (BT):		
25 days BT:	Soaking of seeds in carbofuran	
21 and 14 days BT:	Broadcast:	carbofuran diazinon BHC + carbaryl MIPC
21, 14, and 7 days BT:	Spray:	azinphosethyl parathion chlorpyrifos thioquinox diazinon endosulfan malathion fenitrothion mercaptophos monocrotophos phophamidon toxaphene + parathion
Afer transplanting (AT):		
30 days AT		
for stem borer:	Broadcast:	carbofuran diazinon BHC + carbaryl MIPC BHC lindane
	or spray:	azinphosethyl chlorpyrifos thioquinox diazinon endosulfan fenitrothion malathion mercaptophos BHC lindane phosphamidon toxaphene + parathion
For any leaf damage:	Spray parathion	
50 days AT:	Broadcast any insecticide as mentioned under 30 days AT, for stem borer control IR20: as above, but only at 10 deadhearts/m^2	
75 days AT:	Broadcast any insecticide as mentioned for stem borer under 30 days AT	
For hoppers and rice bugs	Spray parathion	

The genes for resistance were transferred to breeding lines in countries with BPH problems. Varieties with genes for BPH resistance became the principal tool for BPH control (Pathak and Saxena 1980). In the Philippines the various genes were present in many rice varieties registered by the Philippine Seed Board (Table 1). IR26 was an early BPH resistant variety with the *Bph* 1 gene – it saved Philippine rice production from massive BPH damage in 1972-73. The BPH outbreaks were so serious that rice cultivation was prohibited in some areas until IR26 was distributed to farmers.

The resistant varieties in combination with the chemical insecticides superbly suppressed BPH for several years. During this time new resistant varieties were developed for subsequent distribution.

2.4 PUBLICATIONS ON BPH

The prospects of controlling BPH by plant resistance and chemicals seemed bright. To illustrate the level of activity in resistance and chemical research we examined 1,291 publications dealing with BPH published from 1967 to 1985. The publications were classified into the broad subject categories of (1) plant resistance and chemical BPH control, and (2) biological and cultural BPH control and (3) others (*e.g.,* on taxonomy, migration, physiology). Most BPH research has focused on plant resistance and chemical control (Fig. 2).

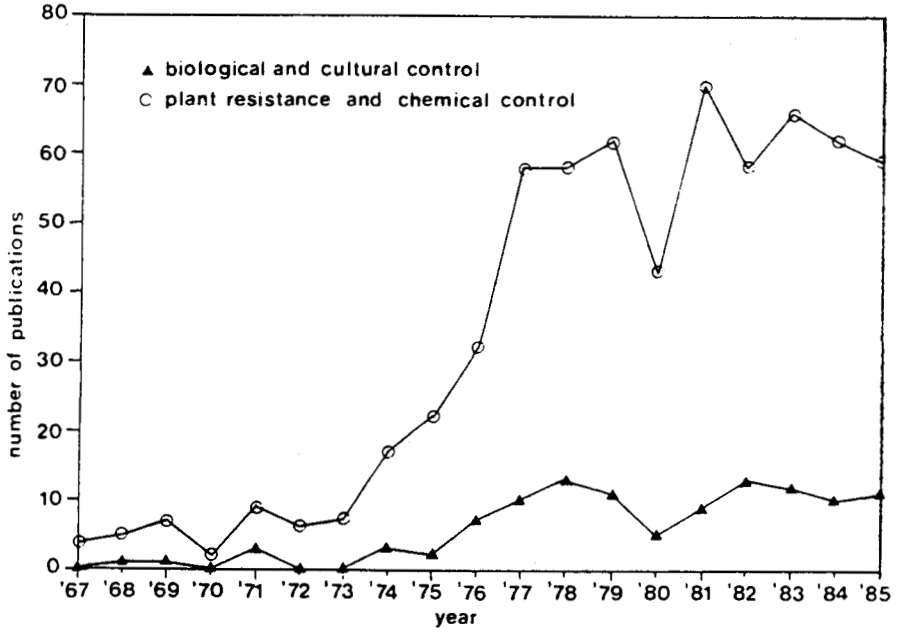


Fig. 2. Number of publications on BPH research (1967-1985) arranged to topic.

3. PROBLEMS

3.1 BIOLOGICAL CONTROL

Natural biological control, or natural control, is a common phenomenon - natural enemies regulate pest populations at lower densities than otherwise occur. Populations in all natural systems, being tropical, temperate, terrestrial or marine, are invariably influenced by some form of natural biological control. Introduction of new pests in areas where its natural enemies do not occur, or removal of natural enemies with insecticides mostly results in pest outbreaks (DeBach 1964, van den Bosch *et al.,* 1982). BPH is normally kept under biological control by diverse communities of natural enemies - a fact to which little attention is given (Greathead 1979). Lists of BPH biological control publications and natural enemies exist (Yasumatsu and Torii 1968, Greathead 1979, Chiu 1979), but few report on their ecology and effectiveness (see chapter 7).

The natural enemies of rice pests include predators (Fig. 1B) and parasites (Yasumatsu and Torii 1968, Chiu 1979, Nickel 1964, Kenmore 1980, Kenmore *et al.,* 1984, Ooi 1986), and insect pathogens (Rombach 1987, Rombach *et al.,* 1987). The specific roles of most of the natural enemies in rice are not well understood. Their combined action remarkably suppresses RPH and other pests. Although Walker (1962) lists more than 1,400 insects attacking rice, only few ever cause economic damage - and about one hundred species can attain a pest status (Kisimoto 1984). Even most of these species generally occur in very low numbers and only occasionally escape control.

3.2 KEY PESTS OF RICE

Taking the numbers of insects feeding on the crop into account, there are only few key insect pests of rice. Key pests occur on a regular basis, and cause substantial damage, even when not directly provoked by man's activities. Of course, all pests of cultivated crops can simply be regarded as a result of man's activities — he planted the crop as a monoculture in the first place. However, virtually all rice pests, including BPH are pests because of crucial changes in agricultural practices. These practices include: mismanagement of chemical pesticides, cultural measures such as double cropping, wide spread planting of one or few genetically similar rice varieties, planting of long-duration rice varieties, rattoon practices (growth of a second and third crop from stubbles of the first crop), and excessive use of fertilizers. Important key pests are stem borers (Pyralidae and Noctuidae), the leaffolders *Cnaphalocrocis medinalis* (Guenee), *Marasmia* spp., and, infrequently, armyworms such as *Spodoptera* spp. and *Mythimna separata* (Walker) and semiloopers and hairy caterpillars (Noctuidae).

3.3 RESURGENCE

Destruction of natural enemy populations *(e.g.* by insecticide applications) can lead to secondary pest outbreaks where former relatively rare insects become primary pest species (DeBach 1964, Huffaker and Messenger 1976). In general BPH is such a secondary pest. Large BPH populations build up in the field after insecticide applications (Kenmore 1980, Kenmore *et al.,* 1984). Broad spectrum insecticides kill natural enemies, in addition to BPH. BPH has a faster rate of increase

compared to most natural enemies and in sprayed fields BPH populations explode. Therefore, insecticides are blamed for evoking BPH resurgence on rice in tropical southeast Asia (Heinrichs *et al.,* 1982, Heinrichs and Mochida 1984, Reissig *et al.,* 1982, Kenmore 1980, Nishida 1975, Ooi 1980).

Predators are the major biological control agents of BPH. They include spiders (Lycosidae, Tetrangnathidae, and Micryphantidae), crickets (Gryllidae), and small hemipterans such as *Cyrtorhinus lividipennis.* Information on their population dynamics is given by Kenmore *et al.* (1984).

Parasites of BPH are abundant; Chiu (1979) lists 19 species of parasites of BPH eggs, and 16 attacking nymphs and adults. The parasites undoubtedly have an influence on BPH numbers, but whether they significantly suppress populations is not known. However, due to their size and active habit parasites are, in general, very sensitive to pesticides.

3.4 BPH PEST STATUS

BPH rarely occurs as an economic pest in the tropics and is not a key pest. BPH was already a pest in Korea and Japan before chemical insecticides were used. However, the ecology of BPH in these temperate areas is different from tropical areas in that the seasonal massive immigration of BPH in the temperate zones upsets the natural balance in favor of the pest. Similarly, BPH can be an economic pest on tropical rice after immigration from resurgence areas; however, this resurgence is caused by insecticides.

3.5 AGRONOMICAL ASPECTS

In tropical rice, double or triple cropping can enhance BPH population growth (Mochida and Suryana 1979), and allows multiple generations of other pests, such as the leaffolder, to develop. The green revolution with its irrigation projects and other cultural measures promoted planting of several crops per year and insect pests, including BPH, increased. Synchronized planting and crop rotation were suggested as a measure to control BPH (Oka 1979). This practice results in a fallow period over large areas — which will lead to unstable pest and natural enemy populations. It can be argued that pest species with a high biotic potential *(e.g.,* BPH) benefit more from instability than do predators and parasites — and field experiments at IRRI and in Mindanao (Philippines) do suggest this effect. However, the minimum area for synchronous planting experiments should be about 1,200 ha, an estimation based on BPH dispersal data (Loevinsohn 1984). Clearly, research on this aspect of BPH population dynamics is needed to clarify the effectiveness of synchronous planting in BPH control. However, although changing planting schemes might be *technically* useful, it is *socially* unacceptable — planting dates are based on a myriad of factors, of which BPH risk is only a minor one.

3.6 PRESENT PROBLEMS

Curing the 1970s and the early 1980s the BPH posed tremendous problems, and was referred to as "a threat to Asian rice production" (IRRI 1979). However, recently BPH populations decreased in some areas, including the Philippines, for reasons not well understood, but a decrease in insecticide

use after the Masagana 99 'insecticide boom' is probably the major reason. Insecticide applications rose more than 500% from 1966 to 1979 in Central Luzon, Philippines (Loevinsohn 1987). This was also the period when BPH became a serious problem. A similar situation was reported for Malaysia (Ooi 1986). Despite the present slowdown insecticide use on tropical rice is still massive: In 1982 US $13.3 billion worth of pesticides were sold worldwide, of which about 30% (US $4 billion) was sold in the developing world (GIFAP 1983). This represents about US $1.3 billion in insecticides for Asia and we estimate that the southeast Asian rice farmers, excluding the Chinese, spend at least US $250-500 million/year on insecticides. China now produces several insecticides, including monocrotophos and chlorinated hydrocarbons and Chinese insecticide usage is steeply increasing.

3.7 CASE STUDIES

3.7.1 Guadalcanal, Solomon Islands

A decade of heavy insecticide use against the cutworm, armyworm, and BPH (resurgence populations) decimated populations of natural enemies in the isolated rice growing area on Guadalcanal. A dozen insecticide applications were made per crop (equivalent to about 1 spray per week). Broad spectrum insecticides such as malathion, parathion, BHC, and toxaphene were used. The populations of natural enemies were destroyed to such an extent that interruption of chemical treatments resulted in almost total yield loss to hopperburn, even when BPH resistant rice varieties were planted. The problems increased to such a degree that rice cultivation on Guadalcanal was terminated in 1987. The Solomon Islands are now importing rice bought on the world market.

3.7.2 Java and Sumatra, Indonesia

Insecticides were subsidized in Indonesia, and their use on rice became extreme. They were often applied when not needed. Consequently, BPH became a major pest over vast areas in Java and on Sumatra. In 1985-86 the point was reached that no resistant rice varieties were available, pesticide use was extreme, and still hopperburn severe. Also, BPH vectored virus diseases, ragged stunt and grassy stunt, became serious. This situation dominated large rice growing areas on Java and Sumatra, an estimated 100,000 to 200,000 ha, probably Asia's largest area ever afflicted by this insect. Increased insecticide use only worsened the situation. In 1986 President Soeharto issued a decree which officially adopted integrated pest management and natural enemy conservation as the state policy for insect control on rice; it banned the use of 59 insecticides for use on this crop. Only a few moderate to highly selective insecticides can now be used.

3.8 RICE RESISTANCE TO BPH

During 1972-1973 IR 26 was widely planted all over the Philippines. This variety has the first identified gene *(Bphl)* for resistance. However, within two years BPH was able to damage IR26 in Mindanao, an area where the variety originally was resistant (Feuer 1976). Soon BPH outbreaks on other varieties with the *Bph*1 gene were reported from many other areas of the Philippines.

The introduction of IR36, IR42 and other varieties with the *bph2* gene brought immediate and successful control of the BPH outbreaks. IR42 lasted six years before it also became susceptible in

1982 in the Philippines (Peralta *et al.,* 1983). Similar cycles of BPH outbreaks on varieties with the *Bph*1 and *bph*2 genes have occurred in other countries in southeast Asia (IRRI 1979). Recently varieties with the *Bph*3 and *bph*4 genes were released. These have not yet been damaged by BPH in the Philippines. However, moderate BPH populations can survive on plants with the *Bph*3 gene (IR60, in Mindanao, Philippines) and high populations thrive on plants with the *bph*4 gene (IR66, Negros, Philippines). So, over the past 15 years each new gene for BPH resistance broke down within several generations and needed replacement by a new gene. In the greenhouse Pathak and Heinrichs (1982) selected a virulent population that overcame resistance conferred by the *bph* 2 gene within 7 generations; similar adaptation rates were found by other researchers *(e.g.,* Lee and Choi 1981).

In the Philippine rice fields the widespread planting of varieties with the *Bph*1 gene led to high BPH mortality in 1973. However, BPH quickly adapted to the gene and IR26 was destroyed in 1976. The BPH genes that allowed it to multiply on rice varieties with the *Bph*1 gene have high probability of fixation (Hedrick 1983) in BPH populations; IR26 and related varieties were grown extensively and immigration from other genotypes was negligible. IR36 and IR42 (*bph*2) were planted in areas where IR26 was destroyed. This again led to high mortality, but BPH also adapted to the *bph*2 gene. Recent results indicate that adaptation has not been lost after almost 10 years absence of *Bph*1 varieties (K.D. Gallagher, unpublished 1987). Therefore, adaptation to the *bph*2 gene occurs without loss of adaptation to the Bphl gene. BPH able to survive and multiply on varieties with the *Bph*3 and *bph*4 genes were recently found. From past experience, it is likely that BPH will thrive on these varieties without losing past adaptations. If new resistant genetic materials will be incorporated in future varieties the "boom and bust'' cycle (Robinson 1975) is expected to continue. Planting rice varieties with vertical (unstable) resistance to BPH simply sets the selection and adaptation procedure in motion. Thus rice breeding programs should emphasize the development of rice varieties with stable resistance to BPH. Plant resistance is one of the various tactics for BPH control that should be integrated with other tactics in a strategy primarily based on biological control by natural enemies.

4. PROSPECTS

4.1 CONSERVATION OF NATURAL ENEMIES

On tropical rice the conservation of natural populations of predators and parasites is the prime strategy for stable BPH control. The judicious use of chemical pesticides is the key to natural enemy conservation. However, key pests will continue to infest fields and cause crop damage. Therefore, efforts to control key pests without harming natural enemies are more relevant to BPH management than controlling BPH populations after natural enemies are destroyed and BPH has resurged. Therefore, selective control agents for lepidopteran key pests must be developed.

We are all aware of the consequences of pesticide resistance in insects, environmental Pollution on a vast scale and, last but not the least, general cost increases of chemical pesticides. Therefore, the importance of biological control, within an IPM framework, cannot be overstated.

4.2 PLANT RESISTANCE

Plant resistance for BPH control has a place in the total rice IPM package. New genes for BPH resistance are found by screening and genetic analysis (Martinez and Khush 1974, Khush 1979). The genes are mainly present in Assam rice types from north eastern India which is one of the areas of *Oryzae* origin (Khush *et al.,* 1986). New resistant varieties will continually be released in the future.

However, reliance of plant resistance as a sole tool in BPH management is unstable. Gene rotation, and use of multilines have been suggested as strategies for gene release (Saxena and Barrion 1985). In gene rotation a scheme is devised in which varieties with the different genes for resistance are planted sequentially. However, BPH populations do not lose adaptation, and the final population will be adapted to all genes. Recent experiments in Indonesia confirm these implications (K. Sogawa, pers. comm., 1987).

New resistant rice varieties should be used sparingly. Selective pesticides can be used to contain small scale outbreaks. The use of broad spectrum pesticides should definitely be discouraged; these compounds hasten BPH adaptation to the resistant plants.

4.3 PESTICIDES AND BPH ADAPTATION

Natural enemies may slow the rate of adaptation of BPH populations on resistant varieties. The reason for this phenomenon is as follows: Adapted insects live longer (Gallagher 1988) and therefore lay more eggs compared to less adapted insects. The fitness differential increases each day the insect lives and can produce more offspring. This is true in the absence of mortality factors. However, natural enemies shorten the lives of all insects. They have thus a relatively more profound impact on longer living insects, *(i.e.,* the chance of being eaten in 5 days is 5 times as high as the chance for 1 day). Thus, natural enemies will delay BPH adaptation to resistant rice varieties. Broad spectrum insecticides remove natural enemies as a mortality factor. Large BPH populations will occur in the absence of natural enemies and large populations mean increased probabilities of adaptation. Thus, broad spectrum insecticides hasten BPH adaptation to plant resistance.

4.4 INSECTICIDE APPLICATION AND TIMING

Proper choice of insecticide and timing of the insecticide application can maximize the impact on BPH and minimize effects on natural enemies (Aquino and Heinrichs 1985). Also, granular applications of systemic insecticides have a wide spectrum for phytophagous insects and carry less risk for BPH resurgence. Granules affect predators less than sprays; this partly explains the popularity of carbofuran for use on rice. However, most granular insecticides emit insecticidal vapors, and can kill natural enemies dwelling on the water or the lower parts of the plant (Koyama 1971). Indeed, BPH resurgence after carbofuran applications of granules was occasionally observed at IRRI.

Heinrichs (1979) provides a table which compares the contact and systemic activity of various rice insecticides. In general, carbamates are more toxic to BPH than organophosphate and chlorinated hydrocarbon insecticides (Fukuda and Nagata 1969). Unfortunately, BPH has a general

low susceptibility for insecticides compared to other insects such as the green leafhopper (GLH *Nephottetix virescens* (Choi and Lee 1976). At present over 35 different insecticides are recommended for use against BPH all over Asia, based on effectiveness and commercial availability. Organophosphates (diazinon) and several carbamates (BPMC, carbofuran and carbaryl) are most widely used.

4.5 BPH SELECTIVE INSECTICIDES

Few moderate to highly selective insecticides for BPH control are available. Several carbamate products (*e.g.,* BPMC) can be used to suppress populations without major natural enemy destruction. However, buprofezin is highly selective and is the suggested compound for BPH control. Routine use of this product is probably not economical. However, BPH is a rare problem in well managed tropical rice fields, and buprofezin can be used as an emergency tool for its control on a small scale.

4.6 JAPAN AND KOREA

In temperate Korea and Japan BPH does not overwinter and immigrates yearly (Kisimoto 1979). Therefore, the development of populations of pests and natural enemies differs substantially from tropical rice cultivation where populations of host and prey are continually present. In temperate areas epidemics of BPH are initiated by long-distance migration from mainland China and the immigrating BPH populations can overwhelm populations of natural enemies. Here serious crop loss can be prevented by applications of insecticides in late July and early August (Kisimoto 1971, 1976). However, in both countries spray decisions are based on early season immigrant numbers from light traps and not on actual field populations at time of spray. We think that applications with selective pesticides and spray decisions based on actual field population numbers will reduce applications. Furthermore, fewer applications will conserve natural enemies and thus even further reduce the need for chemicals. Large scale field tests to compare these strategies with conventional practices are needed.

4.7 INSECTICIDE-PLANT RESISTANCE PACKAGE

The combination of high levels of rice resistance for BPH and chemicals is unfortunate because the deleterious effects of the insecticides are not noticeable as long as the plants remain resistant. But, high levels of insect resistance in rice tends to break down (Gallagher 1988) due to selection of virulent populations.

In practice, farmers are, unaware of the effect that insecticides have on natural enemies and the importance of their conservation because plant resistance masks the deleterious effects of insecticides on populations of natural enemies. Over time, BPH populations adapt to the plant resistance, and their numbers explode in the absence of natural enemies. The importance of natural enemies is not recognized by the farmer, because "the insecticides worked", while in reality his BPH populations were kept low (*despite* insecticides) by plant resistance. This farmer conditioning leads to a grossly distorted BPH management concept.

The few examples above illustrate that chemical pesticides alone are not the panacea for rice pest problems. However, specific and effective chemical insecticides are available and have a role in the BPH management strategy. For example, Dimilin, which contains diflubenzuron, is a molting inhibitor for use against leaf feeding lepidoptera, and Applaud, which contains buprofezin, is a contact action molting inhibitor for use against plant- and leafhoppers. In addition some insect pathogens are available, and these products are highly specific for one pest species or a group. Several insect pathogen products were tested on rice (a review of these tests is given by Rombach *et al.,* 1987). Products containing *Bacillus thuringiensis* Berliner are probably most promising for selective lepidoptera control; B.t. products are already used to some degree in China (Hussey and Tinsley 1981). These safe and specific chemical and microbial insecticides should be included in IPM programs if any sprays are necessary.

Buprofezin is recommended for use and has been applied in BPH infested areas in Indonesia, with favorable results on both BPH and populations of natural enemies; the spider community was relatively unharmed while BPH populations were severely affected by the chemical.

5. CONCLUSION

We can conclude that (1) control of BPH with plant resistance and pesticides is not stable, and that (2) biological control is stable in itself, but can be destroyed by mismanagement of pesticides. The key to BPH control is selective control of other rice pests. This will conserve natural enemies, and BPH problems will be minimized.

This conclusion has been known for many years, published, and discussed in various forums. However, BPH outbreaks still occur on a large scale. Obviously, farmers are still making inappropriate decisions and misusing pesticides.

Sufficient scientific information is available for implementation of basic rice IPM systems in all Asian rice areas; if necessary, fine tuning of these systems can be carried out on a local level. However, local decision makers, policy makers, farmer advisors, and farmers need training in IPM concepts and techniques. Training and extension are now the most important aspects of Asian rice IPM.

IPM is fundamentally different from other technological packages such as distribution of rice seeds or pesticides. In IPM the farmer makes a control decision based on levels of insects and natural enemies in his field. Relatively simple sampling decision models were recently developed for several rice pests (Shepard *et al.,* 1988); the decisions are based on numbers of pests as well as natural enemies. The farmer should be aware of the consequences of his actions, especially when pesticides are involved. The farmer must be familiar with the local environment, pest insects, and natural enemies. Farmer training must be recognized and incorporated into national programs.

One decade ago the Western world started to move from a dependence on large scale heavy industry to societies based on information and services (Toeffler 1980). In rice production we have an analogous situation; the era of Asian BPH control by technological packages of seeds and

pesticides has passed with successes and failures – the era of information on local decision making, farmer training, and fine tuning of IPM programs has just started. The Asian farmer needs full support to make this change.

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IV. IMPLEMENTATION OF RICE IPM SYSTEMS

12

Development and Implementation of Rice IPM in Japan

KEIZI KIRITANI
Division of Entomology
National Institute of Agro-Environmental Sciences
Yatabe, Tsukuba, Ibaraki, 305, JAPAN

KUNIHIKO NABA
Division of Entomology
Hiroshima Prefectural Agricultural Experiment Station
Higashihiroshima, Hiroshima, 739-01, JAPAN

1. NEED FOR RICE IPM IN JAPAN

A CROPPING RESTRICTION ON RICE has been enforced in Japan since 1970 due to an oversupply of domestic rice. During the last three decades, a total of 3,170,000 ha of rice fields in 1967 was decreased by 30% to 2,250,000 ha in 1983. Concurrently, the aim of the national rice production program has been changed from increasing the rice yield to the labor-saving production of better quality rice. Because some 80% of Japanese rice producers manage less than 2 ha of rice fields they depend on incomes from non-agricultural sources and spend a minimum amount of time in rice farming. Therefore, labor-saving rice production practices have the highest priority in Japan.

Since World War II, the gain of rice yield per ha has been closely linked to an increase in the amount of pesticide produced (Fig. 1). This suggests that the increase in rice yield was achieved partly by the increasing use of pesticides. The recent demand for high grain-quality rice has encouraged the preventative application of insecticides to control heteropterous bugs. Additionally, the price of domestic rice is relatively higher, *i.e.,* 3 and 6 times as high as in the EC and USA, respectively; the relative cost of pesticide application is very low. Rice IPM in Japan has to be

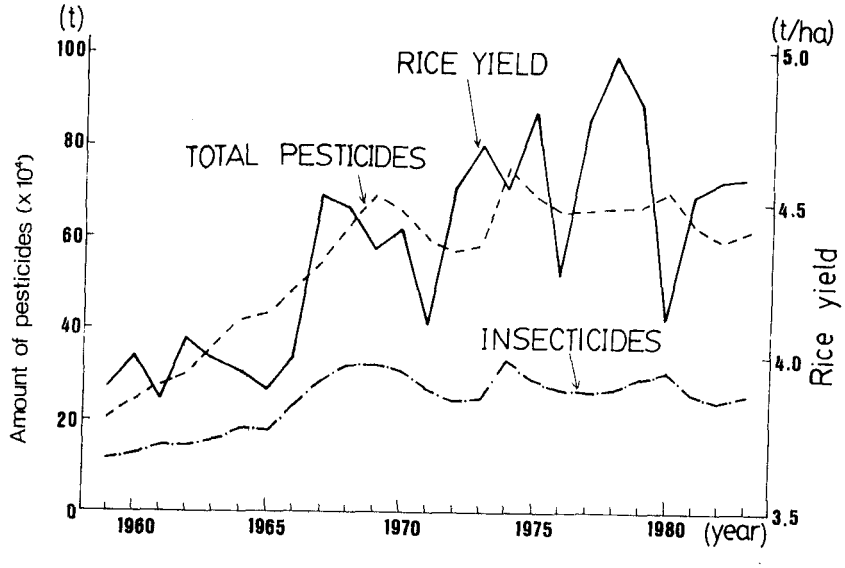


Fig. 1. Annual changes in rice yield, and the amount of pesticides and insecticides produced in Japan. Insecticides for rice total about one-half of the total amount of insecticides produced.

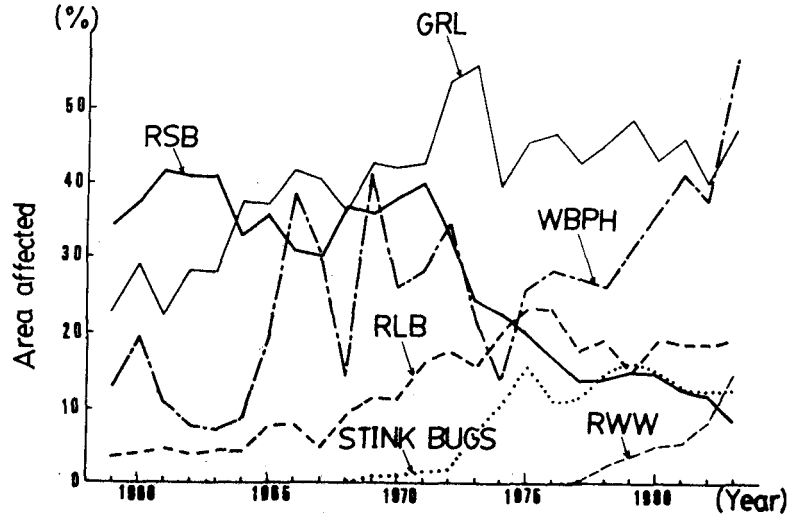


Fig. 2 Percentage of rice area affectcd by major insect pests in Japan. RSB: striped stem borer, GRL: green rice leafhopper, WBPH whitebacked planthopper, RLB: rice leaf beetle, RWW: rice water weevil.

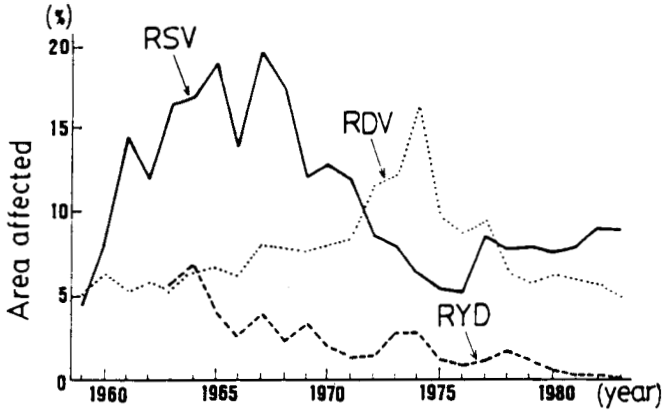


Fig. 3. Percentage of rice area affected by insect-borne disease in Japan. RSV: Stripe, RDV: Dwarf, RYD: Yellow dwarf.

developed by compromising the following demands: reduction of production cost, including the minimum use of pesticides and fertilizer, and the use of labor-saving techniques.

2. Shift of Target Pests since Around 1970

Since the early 1970s, significant savings of labor have been attained by the mechanization of both transplanting and harvesting. Mechanization has caused a significant change in the status of insect pests and insect-vectored diseases compared to that of the 1960s (Figs. 2 and 3).

2.1 PEST STATUS BEFORE 1970

The yellow stem borer, *Scirpophaga incertulas* which is monophagous on rice, disappeared from southern Japan after the introduction of organochlorine insecticides. Some univoltine insects such as the black rice bug, *Scotinophara lurida,* and the rice stink bug, *Lagynotomus elongatus,* also decreased remarkably before 1960.

The striped stem borer, *Chilo suppressalis,* was the most serious pest throughout Japan until 1960 and at its peak level infested 42% of the total area of rice fields. Accordingly, this species developed resistance to BHC and parathion because of heavy insecticide applications to control it. An ever-decreasing trend in the infested area, however, has been observed since the late 1960s and this insect occurred in less than 10% of the rice fields in the 1980s. This decrease was attributed to changes in such agronomical practices as the early planting of rice, use of high tiller-number type varieties and mechanization of both transplanting and harvesting rather than to the intensive use of insecticides (Kiritani 1979).

By contrast, populations of the green leafhopper, *Nephotettix cincticeps,* the small brown planthopper, *Laodelphax striatellus,* and the heteropterous stink bugs, which are polyphagous and

m ultivoltine, have remained constant or increased since 1970. *N. cincticeps* populations began increasing on early-season rice in southern Japan in the 1950s when the insecticides were introduced in rice fields for the control of *C. suppressalis*. *N. cincticeps,* having developed resistance to organophosphates by the early 1960s and then to carbamates by the early 1970s (Hama 1975, Asakawa and Kazano 1976), affected 40-50% of the rice fields annually during the last two decades (Fig. 2).

2.2 PEST STATUS AFTER 1970

2.2.1 Change in Pest Status due to Machine Planting

The machine planting of early maturing rice varieties has resulted in shifting the transplanting date forward and in increasing plant density. It induced changes in pest status of some species which reproduce at the vegetative stage of rice growth. Although 100,000-200,000 ha of rice fields had been annually infested by the rice leaf beetle, *Oulema oryzae,* in eastern Japan during the 1960s, the infested area increased to some 600,000 ha in the middle 1970s after the introduction of machi ne planting. Moreover, the rice plant weevil, *Echinocnemus squameus,* and the small rice miner, *Hydrellia griseola,* have increased in abundance over the country, particularly in northern Japan, since the late 1970s. The rice skipper, *Parnara guttata,* which was abundant in the late planted rice, has decreased recently.

Since the early 1970s, the machine planting of rice was followed by the nursery tray insecticide treatment, where granules are applied onto seedlings just before transplanting. The nursery tray treatment is very effective in controlling early season insect pests *(e.g., O. oryzae)* and insect-borne virus diseases. Consequently, the area infested by these pests began to decrease or level off. The incidence of *O. oryzae* in some regions in the Tohoku district decreased from one-sixth to one-eighth of its maximum.

The nursery tray treatment has several advantages compared to that of conventional broadcasting. It requires only one half of the conventional insecticide rate and less labor, and has a longer residual effect. However, because it is prophylactic, it is not economical if the incidence of target pests is less than the control threshold.

2.2.2 Change in Occurrence of Insect-Borne Virus Diseases

In the 1960s, epidemics of rice stripe disease vectored by *L. striatellus* occurred in association with the introduction of early planting middle-season rice. But an ever-decreasing cultivation of wheat and barley, the host plants for the first generation of the vector, resulted in reduction in the incidence of stripe since the late 1960s. However, the increased cultivation of wheat and barley since the late 1970s promoted the recent prevalence of stripe in some districts. Consequently, newly released stripe resistant varieties have rapidly replaced conventional varieties over a large hectarage in the Kanto district. Because these varieties are resistant only to stripe, but are susceptible to *L. striatellus,* an increase of the vector population on these varieties is becoming a problem particularly for growers of the conventional varieties (Takayama 1984).

In southern Japan two epidemic periods of the rice dwarf disease vectored by *N. cincticeps* have occurred during the last 40 years (Kiritani 1983). The first epidemic, 1953-1966, coincided with an extension of early rice cultivation, while the second, 1967-1974, started when the area planted to wheat and barley was less than half of the previous maximum. The second epidemic was characferized by the spread of dwarf disease to middle-season rice areas. However, from 1973 when the infested area attained a maximum of 330,000 ha, the incidence of dwarf continued to decline as a result of the encouragement of winter and spring ploughing of fallow paddy fields and winter cropping. The wide adoption of the nursery tray treatment also contributed to a decrease in the incidence of dwarf to less than one-third of maximum incidence.

Rice yellow dwarf disease, of which the causal agent is a mycoplasma, is transmitted by *N. cincticeps.* It occurred in over 200,000 ha in the early 1960s and 30,000 ha in the 1970s and then decreased to 5,000 ha in the 1980s. This decrease was due to the destruction of the transmission cycle by early harvesting, ploughing down infected ratoon plants, and the nursery tray treatment.

2.23 Increase in Occurrence of Long-Range Migratory Insects

The whitebacked planthopper, *Sogatella furcifera,* the brown planthopper, *Nilaparvata lugens,* and the rice leaffolder, *Cnaphalocrocis medinalis,* are long-range migratory insect pests that are believed to immigrate from mainland China. Before the 1960s, these oversea migrating pests were chemically controlled simultaneously with the first generation of *C. suppressalis.* The omission of *C. suppressalis* control due to the current reduced infestation appears to have encouraged outbreaks of these migrating pests. Though *C. medinalis* was a minor pest until the early 1960s, its high incidence has continued since 1967 when the first outbreaks were observed in the Kyushu and Hokuriku districts.

The first sign of resistance to organophosphorous insecticides in *S. furcifera* was recognized in 1985 (Hosoda unpublished). *N. lugens* had developed resistance to organophosphates by the early 1970s and then to carbamates by the late 1970s (Nagata *et al.,* 1979, Hosoda 1983). These patterns of resistance are considered to reflect the insecticide applications in the place of origin of these migrating insects.

2.2.4 Build-up of Insect Pests Affecting Grain Quality

Production of better grain-quality rice has been emphasized since 1970. If there are more than two spotted grains per 1,000 grains, the lot of rice is ranked at a lower grade in proportion to the percentage of spotted grains. The cause of spotted grains is mainly heteropterous stink bugs, but sometimes the rice plant weevil, *Echinocnemus squameus,* the rice thrips, *Baliothrips biformis,* and the rice white-tip nematode, *Aphelenchoides besseyi* are responsible for the spotted grains. These pests have induced increasing frequency of pesticide application after rice heading. Especially, the calendar-based control of the heteropterous stink bugs became common for early-maturing varieties grown in the mountainous areas. The prevalence of stink bugs is believed to have resulted from the increase of fallow paddy fields as a result of the rice cropping restriction.

The control threshold for stink bugs is so low that rice growers control them prophylactically. For example, in the case of the southern green stink bug, *Nezara viridula,* the control threshold corresponding to 0.1% of spotted grains is two adults per 50 net strokes at the milky stage of rice plant growth (Nakasuji 1973). The control of stink bugs also involves the difficult task of protecting rice from their continuous attacks from heading until harvest.

2.2.5 Invasion of the Rice Water Weevil

The rice water weevil, *Lissorhoptrus oryzophilus,* a species indigenous to America, was first discovered in Aichi prefecture in central Japan in 1976 (Tsuzuki and Isogawa 1976). *L. oryzophilus* is believed to be the first exotic species established in the history of rice cultivation in Japan, All of the rice insect pests, except such overseas migrant species as *N. lugens,* are endemic in Japan. After ten years of its first occurrence, the area invaded by 1985 amounted to 770,000 ha of rice fields covering Honshu, Shikoku, Kyushu and the Nansei islands. In 1986, this weevil was discovered in Hokkaido, the last uninfested prefecture remaining in Japan. No effective natural enemies of this weevil have been recorded in Japan.

Recommendations to control *L. oryzophilus* are delay of transplanting to evade peak incidence of immigrants and management of water with intermittent and shallow irrigation to prevent oviposition and feeding by adults. These cultural methods, however, have not commonly been practiced because of problems associated with water availability. Instead, chemical control by the nursery tray treatment and/or the application of granules onto the surface of irrigation water have widely been practiced. Thus, the invasion of *L. oryzophilus* resulted not only in an increase of control costs but also in the nation-wide utilization of the nursery tray treatment.

3. Components for the Rice IPM Program

The IPM program should be carried out as shown in Fig. 4. The current status of available components for IPM are described below.

3.1 MONITORING AND FORECASTING

The nation-wide forecasting network for rice pests is composed of approximately 600 staff members who work at the Prefectural Agricultural Experiment Stations and the District Plant Protection Service Stations. The locality-based information concerning the occurrence of rice pests and control recommendations are delivered to rice growers through wire-relays, telephone service and television, by way of local governments, the Agricultural Cooperatives and the Agricultural Mutual Aid Associations. Since the late 1970s, the pest surveillance data in several prefectures have been processed with computer simulation models for use in forecasting.

During 1960-75, several ecology-oriented research studies were conducted on natural populations of such rice pests as *N. viridula* (Kiritani and Hokyo 1970), *N. lugens* (Kisimoto 1965, Kuno 1968), *S. furcifera, N. cincticeps and L. striatellus* (Kuno 1968), *N. cincticeps* (Hokyo 1972) and *N. cincticeps* and the rice dwarf virus disease (Kiritani *et al.,* 1970; Nakasuji and Kiritani 1972; Nakasuji

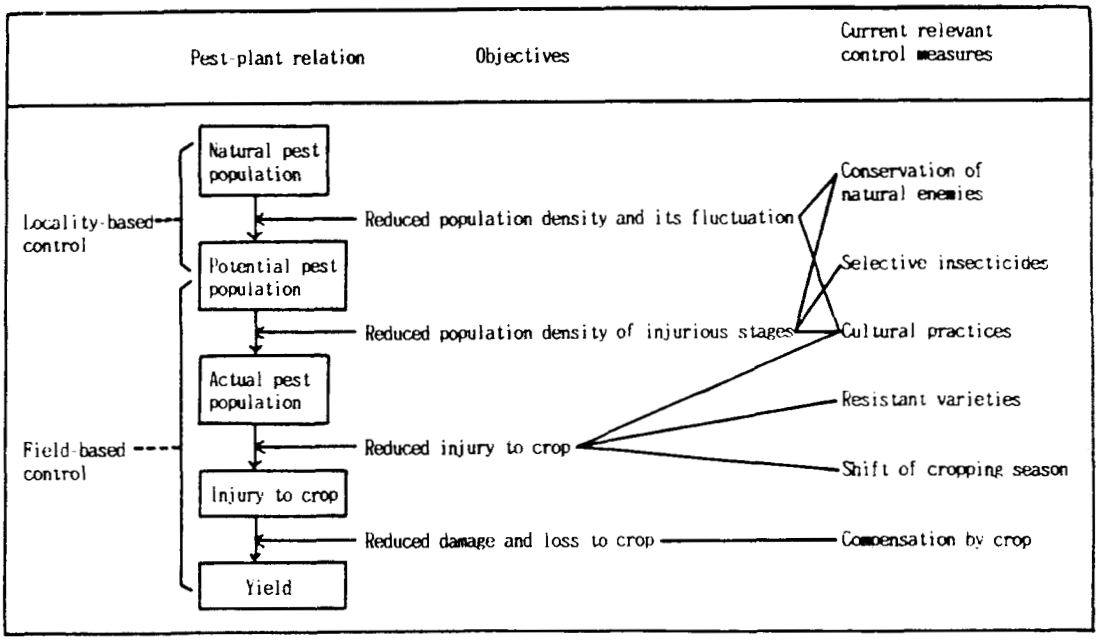


Fig. 4. General flow-chart of implementing IPM programs for rice in Japan (adapted by modifying Kiritani 1976).

et al., 1975,1985). Kiritani and his co-workers applied the systems approach to the IPM system of rice dwarf disease by incorporating the interactions among rice plants, *N. cincticeps,* spiders and virus, These studies contributed to more precise prediction of pest occurrence by elucidating the regulatory mechanism of population density.

A systems model of rice dwarf virus epidemiology was first proposed by Nakasuji and Kiritani (1972) and developed by Nakasuji *et al.* (1975) and Kiritani and Nakasuji (1977). However, some of the relationships involved in these models were empirical. Thus, they are regarded as tactic models that cannot be applied to different localities in their original forms. Although it is important to develop such tactic models that are applicable to other localities, the necessity of time-and-labor consuming studies precludes further development. Development of strategic models analyzing the general behavior of systems by mathematical equations is also needed. Such a study has recently been published by Nakasuji *et al.* (1985).

3.2 ECONOMIC INJURY LEVEL (EIL) AND CONTROL THRESHOLD (CT)

3.2.1 Establishment of the EIL

Twenty-two EILs of ten insect pests of rice were calculated assuming a gain threshold of 5% (Andow and Kiritani 1983). Except for the EILs of *O. oryzae* (Emura and Kojima 1978, 1980; Kojima and Emura 1979) and *C. suppressalis* (Koyama 1977), that were developed from life-table data, these static EILs were calculated from loss assessment experiments.

A dynamic EIL incorporating models of plant growth, insect population dynamics and weather conditions has not yet been developed for rice insect pests. Kiritani (1973) has suggested a tabular key for decision-making in controlling planthoppers aiming at the dynamic EIL. The key arranges CTs as a function of rice cropping seasons, planthopper species, wing type of adults and their density. Because rice yields are predicted by the product of four components (see Table 1) arranged along the time axis of plant growth, the quantitative analysis of the relationship between these components and amount of damage due to insect pests will be another fruitful approach toward the dynamic EIL.

TABLE 1

Rice insect pests affecting yield components

Insect Pests	Panicles/m^2	Grains/Panicle	Ripened Grains(%)	1000-Grain Weight
SSB, 1st generation	•			
SSB, 2nd generation	0		•	0
RDV vectored by GRL	•			
Sap sucking by GRL			•	0
RSV vectored by SBPH	•	0	•	0
RWW	•			
RLB	•			
WBPH		•	0	
BPH			•	•

Note: Heavy damage: •, Light damage: 0

SSB: Striped stem borer, GRL:green rice leafhopper, RDV Dwarf, SBPH: small brown planthopper, RSV Stripe, RWW: rice water weevil, RLB: rice leaf beetle, WBPH whitebacked planthopper, BPH: brown planthopper.

3.2.2 Use of the CT

Each prefecture annually publishes a pest control guide that is utilized by technical officials at the Agricultural Extension Service Office and the Agricultural Cooperative Associations. Table 2 shows the number of prefectures specifying the CTs in their guides for 1985. Most of the CTs have been established since the early 1970s. Almost all of the prefectures in western Japan, however, published the CTs for *S. furcifera* and *N. lugens* in the 1960s.

Although an increasing number of prefectures are recommending the CTs, CTs for *N. lugens* and *L. oryzophilus,* for example, appeared in the guides of only 20 and 12 prefectures, respectively, corresponding roughly to one-half and one-quarter of the prefectures concerned. The reasons that prefectures do not recommend CTs are as follows: (a) difficulty in predicting pest damage due to lack of research on loss assessment; (b) many CTs so far developed are of the static type and only applicable to a specific growth stage of rice plants; (c) deep-rooted thought of perfect control or "sterilization" of the crop without permitting even slight damage prevents rice growers from accepting the concept of CT (their overdependence on insecticides has been supported by the relatively low control cost as compared to the monetary value of rice); (d) prophylactic controls

TABLE 2
Use of the control threshold (CT) for major rice insect pests in Japan

District	*No. of prefectures*	*No. of prefectures specifying CT in the pest control guide*							
		SSB	*WBPH*	*BPH*	*GRL*	*SBPH*	*RWW*	*RLB*	*Stink Bugs*
Hokkaido	1	0	0	–	–	0	–	0	0
Tohoku	6	5	2	0	1	0	2	3	0
Hokuriku	4	2	1	0	1	0	2	1	0
Kanto, Tokai	13	0	5	6	1	0	3	1	1
Kinki, Chugoku	11	2	4	8	2	2	5	2	0
Shikoku, Kyushu	12	1	5	6	1	1	0	0	0
TOTAL	47	10	17	20	6	3	12	7	1

Note: No occurrence (–)

SSB: striped stem borer, WBPH: whitebacked planthopper, BPH: brown planthopper, GRL: green rice leafhopper, SBPH: small brown planthopper, RWW: rice water weevil; RLB: rice leaf beetle.

such as the nursery tray treatment and aerial applications of insecticide carried out according to the prefixed flight schedules of helicopters, negate the utilization of CTs.

3.3 SELECTIVE INSECTICIDES

Use of selective insecticides that are only effective against target but not against non-target species is very important in the implementation of rice IPM. Buprofezin, registered in Japan in 1984, showed selective toxicity to several species of Homoptera by inhibiting the biosynthesis of chitin. Because this insecticide is reported as being safe to spiders, predacious mites and wasps (Shibuya 1984), the risk of *N. lugens* resurgence may be kept to a minimum.

3.4 RESISTANT VARIETIES

Resistant varieties form another key component in rice IPM. The widespread planting of varieties resistant to the rice stem maggot, *Chlorops oryzae* since around 1960 has greatly reduced damage caused by this fly. Replacement of susceptible varieties with resistant ones also contributed to the elimination of waika, a tungro-like disease, from Kyushu in the early 1970s (Shinkai 1977). As mentioned earlier (Sec. 2.2.2), an increasing cultivation of varieties resistant to rice stripe disease has been practiced in northern Kanto since 1982 and the area planted to these varieties reached 66,000 ha in 1985. Because these varieties are resistant only to the disease, but not to the vector, the omission of chemical control has allowed an increasing vector density on these resistant varieties. This in turn may result in a high incidence of the disease among susceptible varieties grown near the disease resistant varieties. Thus, breeding of varieties resistant to both stripe disease and the vector is needed.

4. IMPLEMENTATION OF RICE IPM PROGRAMS: CASE STUDY

There have been significant advances in the development of individual components to be utilized for rice IPM programs (*e.g.,* studies on pest population dynamics and the development of control measures). On the other hand, the implementation of IPM programs by farmers is only partial because of the various reasons mentioned earlier. Nonetheless, IPM oriented practices or campaigns have been in progress somewhere in Japan at varying degrees as discussed below.

4.1 REDUCTION IN FREQUENCY AND RATES OF INSECTICIDE APPLICATION AND UTILIZATION OF INSECTICIDES LESS TOXIC TO NATURAL ENEMIES

The widespread use of BHC for controlling rice insect pests including *C. suppressalis* during the 1950-60s induced the build-up of *N. cincticeps* as a result of disruption of natural enemies *(e.g.,* spiders). Also it resulted in the development of resistance to BHC in *C. suppressalis* and BHC residues caused contamination of the environment including food and human milk. Kiritani and his co-workers at the Kochi Prefectural Institute of Agricultural and Forest Science experimentally demonstrated that even BHC granules lethally affect spiders through food-chain toxicity *(i.e.* from irrigation water through rice plants and leafhoppers to wolf spiders) (Kiritani and Kawahara 1973).

As a result, the use of BHC for rice pest control was restricted in Kochi prefecture in 1969, two years before the nation-wide ban on the use of BHC.

The first IPM pilot project started in Kochi and was aimed at enlightening the importance of IPM to extension officers and scouts at agricultural cooperatives (Kiritani *et al.* 1971, 1972). The objectives of this project were to demonstrate the (1) feasibility of the replacement of BHC with organophosphates in the control of *C. suppressalis;* (2) effectiveness of selective insecticides; and (3) feasibility of reducing rates and frequency of insecticide application. This project, using demonstration fields located in different regions, was carried out by participation of persons from various agricultural sectors including farmers. The three-year project demonstrated the following results: (1) Organophosphates *(i.e.,* MEP and diazinon) were more effective in controlling *C. suppressalis* and gave rise to a greater yield than the conventional control using BHC; (2) In the selective insecticide plot, where BPMC was used for control of *N. cincticeps* and chlordimeform, MEP and cartap for *C. suppressalis,* the ratio of prey (mainly *N. cincticeps)* to spiders changed in favor of the predators after insecticidal treatment. The rice yield of the IPM plot was nearly equal to the plot with the conventional control schedule in spite of the fact that the frequency of applications was reduced by 1-3 times and the rate was lowered to one-half; (3) Satisfactory control of rice dwarf disease was attained by the nursery tray treatment with ethylthiometon at a rate of one-half that of the conventional treatment (Kiritani 1974). This method was not only labor saving but also as effective as that of 2-3 broadcast applications of insecticide in the rice field.

4.2 DECISION-MAKING USING CTS FOR SIMULTANEOUSLY OCCURRING PESTS

Damage due to *C. suppressalis* has been declining in Akita prefecture as in other parts of Japan since around 1970. Nevertheless, there was no sign of reduction in the aerial spray against *C. suppressalis*. Koyama (1973, 1975, 1977, 1978) at the Akita Prefectural Agricultural Experiment Station determined the CTs for the first generation of *C. suppressalis* and *O. oryzae* which occur simultaneously. If the occurrence of these two pests is less than the respective CTs, aerial control is deleted.

The process of implementing the program is as follows: (1) A high correlation between the percentages of injured leafsheaths and dead hearts occurred in the first generation. This is because larval densities during the corresponding period were relatively stable. Therefore, the CT for *C. suppressalis* was determined as 12% injured leaf sheaths at the time of insecticidal application. (2) A total of 245 fields located in the prefecture were regularly surveyed for the occurrence of *C. suppressalis* from 1971 by staff members of the District Plant Protection Service Stations. The survey showed that the annual incidences of *C. suppressalis* and *O. oryzae* were always below the CTs established for both species (Kobayashi and Koyama 1977). Eventually by 1977, aerial spray against the first generation of *C. suppressalis* was suspended (Fig. 5). (3) Chemical control including aerial sprays against the second generation has continued due to the absence of a CT for this generation.

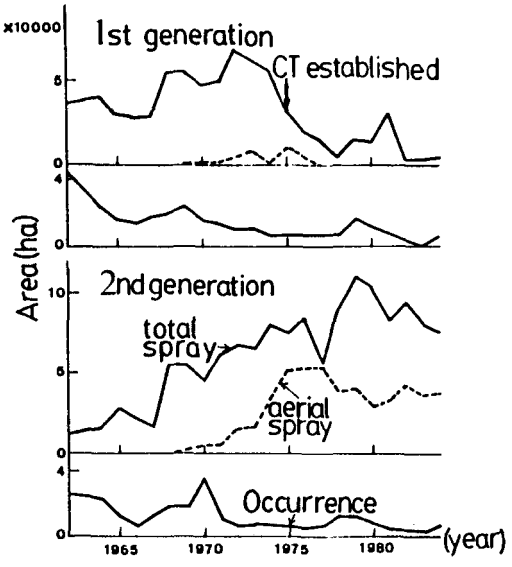


Fig. 5. Changes in the area of occurrence of *Chilo suppressalis* and area treated with insecticides in Akita prefecture (Koyama 1985).

4.3 PARTICIPATION OF FARMS IN PEST SURVEILLANCE FOR THE DECISION-MAKING OF LOCALITY-BASED CONTROL

In view of the decreasing occurrence of *C. suppressalis* in Niigata prefecture since the early 1970s, monitoring of *C. suppressalis* by teams of technical staff at the Agricultural Cooperative Associations and the Agricultural Mutual Aid Associations and by voluntary farmers has been initiated. On the basis of these data, decision-making for the community-based control of *C. suppressalis* was made after group discussions led by the staff of the District Plant Protection Service Station. Further details of this "bottom-up" approach are explained below.

The follow-up surveillance for damage due to *C. suppressalis* was initiated on 1,500 ha in 1968 after insecticide application had been discontinued. This campaign was supported by rice growers and the area subjected to surveillance increased greatly after 1975. As a result, Kojima and Emura (1983) at the Niigata Agricultural Experiment Station standardized the monitoring procedure to determine the practical CT for the first generation of *C. suppressalis* . Accordingly, pest surveillance (see Table 3) in 1984 was extended to 52% of the municipalities in the prefecture covering 89,000 ha *(i.e.,* 61% of the total rice fields). The surveillance showed that in 54,000 ha of rice fields. *C. suppressalis* control was not necessary. The final decision for omission of control, however, was made by agreement of all concerned farmers. It is worthy to mention that many active farmers participated voluntarily in monitoring *C. suppressalis* in nine municipalities in 1984.

TABLE 3

Decision chart for control of the first generation of *Chilo suppressalis* used by Ojiya City Plant Protection Association in Niigata prefecture (Emura 1982.)

Monitoring time:	Grade	Injured hills (%)	Guidelines for control decision
Late June (First generation of *C. suppresalis*)	Null	0	Control is unnecessary
	Light	1-10	Continued scouting for rice fields with a higher % of injured hills
		11 - 29	Collective area-wide control
	Medium	30 - 59	Treat heavily injured fields followed by collective area-wide control
	Severe	60 - 89	Treat all the early planted fields followed by collective area-wide control
	Very severe	90 or more	Conduct collective area-wide control twice

Note: Sample size is 25 hills per rice field.

In the area where control for the first generation of *C. suppressalis* was recommended, sudden outbreaks of the second generation occurred over 15,000 ha in 1984. The outbreaks confirmed the importance of surveillance. It was also revealed that the outbreaks were partly due to the development of resistance in *C. suppressalis* to some organophosphates. In the advanced municipalities, *O. oryzae* and rice blast disease, in addition to *C. suppressalis,* have been monitored in reference to the practical CTs for these pests.

4.4 COMMUNITY-BASED CONTROL OF THE RICE WATER WEEVIL USING THE CT

Earlier, the complete extermination of *L. oryzophilus* was attempted when its distribution was still limited to a few localities. Presently, it has extended its distribution throughout Japan. Meanwhile, a CT was established for this species by Tsuzuki *et al.* (1983). In 1983 when *L. oryzophilus* was first discovered in Hiroshima prefecture, the CT was used for the decision-making of insecticidal control by the local plant protection teams composed of technical officers of various agricultural bodies and active farmers. The teams as a whole worked about 850 man-days per year to monitor the population density of immigrating adults and the percentage of injured hills in about 8,000 sample rice fields chosen at a rate of 2-3 fields per 10 ha.

Decisions for chemical control in each locality were based on the incidence of various rice pests, including *L. oryzophilus,* with reference to the transplanting date. Decisions were made through discussion participated in by all members of the monitoring teams and technical officers of the District Plant Protection Service Station and the Agricultural Improvement Extension Service Office. Consequently, where the nursery tray treatment against *O. oryzae* was already being practiced additional control against *L. oryzophilus* in the newly invaded area was omitted. Similarly, rice fields planted after mid-June were not treated with insecticides, because little damage was expected in the late planted rice. In spite of an increasing infested area and density of *L. oryzophilus,* the area of untreated rice fields amounted to 23%, 60% and 21% of the total infested area in 1983,1984 and 1985, respectively.

4.5 COMPREHENSIVE PLANT PROTECTION APPROACH BY ACTIVE FARMER GROUPS

To minimize pesticide use and to avoid human poisoning, the treat-when-necessary control of rice pests has been practiced in Fukuoka prefecture by groups of 200 rice growers under the leadership of Une (1984) at the Fukuoka Agricultural Improvement Extension Service Office since 1980. The objectives are as follows: (1) Transfer of technical information on rice IPM to farmers; (2) Implementing pest control with the minimum use of pesticides; (3) Monitoring leaf- and planthoppers and natural enemies by means of a sight counting board (Fig. 6); (4) Promoting sales of the rice produced.

This campaign assisted by the Agricultural Cooperative Association had made a drastic change in the pesticide-application-calendar. The 1985 calendar recommended 1 and 3-4 applications in the nursery tray and production field, respectively, while as many as 7 and 5 applications in the

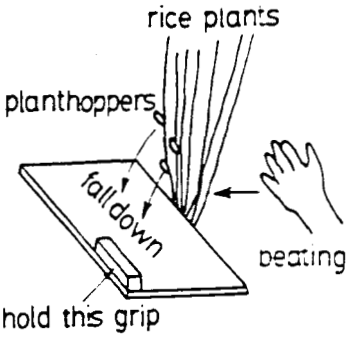


Fig. 6. Use of the sight counting board. Rice plants are beaten and the number of insects that fall on the board are estimated (Une 1984).

nursery tray and field, respectively, were recommended in 1980. The rice produced in this way has been on the market since 1983 and amounted to 360 tons annually in 1984 and 1985.

5. Future Strategy and Prospects

5.1 Proposal of the Statistical EIL to Minimize Insecticide Application

In the Philippines, the gain threshold (=cost of control/market value of rough rice) for *C. medinalis* is calculated as $29.30 (U.S. dollars) per ha/$0.15 per kg = 195 kg/ha (Bautista *et al.,* 1984). This value is equivalent to 8.5% of the average rice yield in the Philippines *(ie.,* 2,300 kg/ha in 1982). Mochida (1986) also calculated it as 6.6% for black bug control in the Philippines. Because the price of rice and the rice yield per unit area in Japan are 5 and 2.5 times as high as those in the Philippines, respectively, the estimated gain threshold is as low as 1% of the rice yield. This surprisingly low level of the gain threshold is due to the government supported rice price.

Therefore, even if the amount and number of insecticide applications increase further in the near future, their effects on production cost in Japan would be little. The diverse and complicated insect pest fauna from the seed bed to harvest and the demand for high quality rice grains would stimulate the more intensive use of insecticides. However, the price of rice has recently approached its support limit, so labor-saving and low-cost technologies are required in rice production. Rice growers are also becoming more prudent in use of pesticides for various reasons already mentioned.These factors will encourage the development of EILs and CTs for various pests and their wider use in the future.

Because pest control recommendations are utilized over a wide area and include several thousand rice growers, they are made in favor of chemical treatment. When an overall density of pests in one locality is just equal to the CT or EIL, the pest density in half of the fields would be less than CT or EIL. Consequently, Kidokoro and Kiritani (1982) have proposed the use of a statistical

EIL for small size farm conditions. This gives a statistical projection for the probability that a given field has a pest density greater than the EIL (Fig. 7). With a within-field-EIL of 30% hill infestation for *C. suppressalis,* the proportion of fields with greater than 30% infestation can be calculated. We can make recommendations to individual growers concerning the insecticide control with the probability of risk that his field has a pest density greater than the EIL.

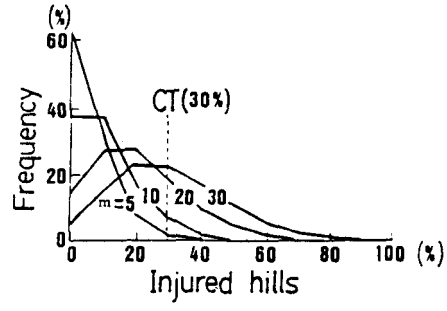


Fig. 7. Frequency curves of *Chilo suppressalis* injury to paddy fields, for four within paddy mean injury levels (m). The frequency distribution follows a poisson distribution (Kidokoro and Kiritani, 1982). The area under the curves that is to the right of the CT gives the proportion of paddies with infestations causing economic damage.

5.2 COMBINATION OF CONTROL MEASURES FOR RICE IPM PROGRAMS

In developing and implementing the IPM system for rice in Japan, some socio-economic as well as technological problems rather specific to Japan should be taken into consideration. In other words, the IPM system should be tailored to fit Japanese conditions.

Rice is the staple food for Japanese, so the government policy is self-supporting of domestic rice. The total area planted to rice is 2,246,000 ha, which is equivalent to 55% of the total arable land in Japan. The average yield of rice is 4,590 kg/ha. The number of rice growers is 3.7 million, so 85% of the farmers are growing less than 1 ha of rice (MAFF 1984). The production cost of rice in Japan is estimated to be 5-6 times higher than that in the USA and the high price of rice in Japan reflects this situation.

The small scale and intensive system of rice cultivation in Japan requires further reduction of production costs through the saving of both labor and resources *(e.g.,* pesticides), without reduction in yield. The recent demand for the high-quality rice, however, likely works in favor of overuse of insecticides, particularly after heading. On the other hand, the nursery tray treatment contributed not only to the reduction of insecticide applications in terms of amount and frequency, but also to the saving of labor. The prophylactic nature of this technique remains to be solved.

Consequently, development of EILs for important rice pests is urgently needed. The corresponding CTs can be established by population dynamics studies of the pests. The introduction

of the statistical EIL being associated with the field inspection by growers themselves will contribute to the rational use of pesticides.

Because major rice insect pests in Japan are endemic, the efficacy of introduced natural enemies will be limited. The ecological balance between insect pests and native natural enemies should be maintained in favor of the latter through the manipulation of environmental conditions. In this connection, utilization of more selective insecticides that are safer to natural enemies as well as aquatic organisms and wildlife is important.

Many rice varieties of the japonica type are highly susceptible to rice leaf- and planthoppers and insect-borne virus diseases. Utilization of pest resistant varieties is most promising for reducing the production cost of rice as well as reducing the use of pesticides. Integrated use of resistant varieties with pesticides and natural enemies will be the final IPM program in Japan. Additionally, international cooperation on forecasting and control of the long-ranged migratory insect pests will become increasingly important among the neighboring countries irrespective of their political regimes. The development of IPM for rice in Japan should be approached from domestic and international viewpoints.

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13

Development of an Integrated Pest Management System for Rice in Latin America

G. WEBER
Centro Internacional de Agricultura Tropical
Apartado Aereo 6713
Cali, Colombia.

O. PARADA
Federacion Nacional de Arroceros
Apartado Aereo 52772
Bogota, Colombia.

1. INTRODUCTION

RICE IS ONE OF THE MAJOR food crops in Latin America with an averageper capita consumption of 28 kg white rice per year. The highest consumption is in Guyana (112 kg/yr) and the lowest is in Guatemala (4 kg/yr) where maize is still the staple food crop. Total production in 1983/85 (FAO 1986) was about 16.5 million mt of unhulled (paddy) rice with average yield of 2.4 mt/ha for favored upland rice, 4.2 mt/ha for irrigated rice, and 1.0 mt/ha for unfavored upland rice (CIAT 1985). Average production costs were 161 US$/mt of paddy in 1984/1985, varying between 209 US$/mt in Colombia and 90 US$/mt in Chile (Pulver 1985).

Total production costs for irrigated rice, expressed in equivalents of kg paddy/ha to allow for more easy comparisons between countries, has in tropical countries like Colombia and Ecuador reached 5,160 kg/ha and 4,000 kg/ha respectively. This has caused low profitability of rice cropping because average yields in these countries are around 5,230 kg/ha and 4,140 kg/ha, respectively. Plant protection costs in Colombia and Ecuador contribute 24.9% and 18.4% respectively to the total cost of production. Pest control expenses are thus a major cause for increasing costs and

decreasing profitability of rice cropping in these countries. (FEDEARROZ-ICA-CIAT 1986, PNA-INIAP-CIAT 1987).

The average number of insecticide applications is 5.2 per crop in Colombia, 3.5 in Costa Rica and 3.7 in the Dominican Republic. These applications are not only a matter of economic concern, taking into account that 60-80% are preventive calendar-scheduled sprayings (Weber 1987) but they are also a cause of considerable concern because of their ecological and toxicological effects. Insecticide resistance, for example has been shown to occur in at least three rice insect species in the Americas; *Spodoptera frugiperda, Tagosodes orizicolus* (Diego Trujillo 1988 unpublished) and *Lissorhoptrus oryzophilus* (Bowling 1972). Resurgence of the rice planthopper *T. orizicolus* can easily be induced by certain organophosphate or pyrethroid insecticides (ICA 1983 unpublished, Weber 1986). Insecticide residues in grain oil and straw have been found in Brazil and Colombia (ITA 1982, Ramos *et al.,* 1986). Thus present pest control practices are not acceptable from an economical, ecological or toxicological point of view.

Although information on pest biology, pest damage and tolerance of rice to insects has been available in the Americas for the last two decades, only recently has an integrated pest management concept been developed and implemented in close cooperation with several institutions in the tropical zone. The following describes the development and implementation of rice IPM in Latin America.

2. Development of the IPM-Concept

A short characterization of some basic IPM components is given. This is followed by a discussion of the integration of these components for the management of some major and minor phytophagous insects.

2.1 CHARACTERIZATION OF IPM COMPONENTS

2.1.1 General Plant and Crop Characteristics

Sixty two per cent of the favored upland and 72% of irrigated rice in Latin America is planted to modern semidwarf varieties, whereas traditional varieties dominate under unfavored conditions mainly in the cerrados of Brazil (CIAT 1985). Most of the modern varieties have three general characteristics that increase their tolerance to insect attack:

- High initial vigor allows plants to quickly pass through the early seedling stage and thus escape deleterious damage by leaf-mining *(Hydrellia)* and leaf-feeding *(Spodoptera)* insects; additionally this assures good recovery from previous attack.
- High tillering increases crop plasticity and provides tolerance to attacks by certain early seedling pests *(Euetheola, Phyllophaga, Spodoptera)* stem boring pests *(Diatraea)* and stem sucking pests *(Tibraca, Euschistus)* .
- Medium duration varieties of 120-130 days assure a vegetative growing period of 60-65 days, which again increases the plants capacity to recover from early damage.

- Almost all of the rice area in Latin America is direct seeded in dry or puddled soils. Only a few countries like Ecuador, Peru and Dominican Republic have some transplanted rice areas. Direct seeded rice crops generally have two critical periods:
  - The early seedling stage, when pests such as leaf miners *(Hydrellia),* leaf-feeders *(Spodoptera),* plant cutting *(Euetheola)* and sucking insects *(Tagosodes, Hortensia, Draeculacephala)* immigrate into the crop before beneficial arthropods have established an ecological equilibrium.
  - The reproductive stage from booting to flowering, where the plant concentrates its resources increasingly on panicle development and shows less capacity to tolerate or recover from certain damage. However, well established biological control reduces the risk of pest attack by leaf feeding *(Mocis, Thioptera),* leaf rolling *(Syngamia, Marasmia),* leaf sucking *(Tagosodes),* grain sucking *(Oebalus, Nezara)* and stem boring *(Diatraea, Rupela)* insects.

2.1.2 General Characteristics of Phytophagous Insects

Several key parameters are used for a general characterization of phytophagous insect biology, ecology and epidemiology. They provide guidance in evaluating the insect's damage potential and in analyzing key aspects of its management (Table 1).

Ecological Strategy: All phytophagous insects are classified according to their general ecological strategy on the r-K continuum. Plant- and leafhoppers and spider mites are rather typical r-species with high capacity for population increase, wide density fluctuations and wide genetic adaptability. The rice water weevil is a typical K-species with a rather low fecundity, high longevity and an extreme adaptation to its special ecological niche. Whereas the management of r-type species requires a reduction of short-term population fluctuations, breeding varieties that tolerate the normal fluctuations and strengthening natural, density dependent antagonists, the K-type species is managed by reducing populations below the economic threshold by altering environmental conditions to make them less favorable for their survival.

Damage in Plants: Most insects affect the plant directly through their feeding and additionally cause indirect damage by transmitting plant pathogens and/or increasing the risk of higher weed infestations. The attack by most foliage damaging pests during the seedling stage causes little direct damage because the plant usually recovers from even a 100% loss of leaf area. However, the reduced capacity of the crop to compete against weeds is an important indirect effect in upland and irrigated rice under direct seeding conditions.

Field Colonization: Some pests are already in the field at planting time. Early season upland soil pests including *Euetheola, Phyllophaga* or *Neocutilla* should be monitored and controlled before planting. Most phytophagous insects in rice, however, immigrate into the field after planting and their short-term importance depends on the size of the immigrating population. Stink bugs, for example, cause immediate crop damage upon their arrival by sucking grains. Their reproduction and population build-up occurs in graminaceous weeds rather than in rice and the major biological control organisms attack the egg and nymphal stages. Thus the size of the immigrating population

TABLE 1

General characterization of some phytophagous insects in rice fields in Latin America

Insect species (common name)	*Ecological strategy*	*Crop damage*		*Field colonization*	*Biological control*		*Damage potential*	*Pest status*
		Direct	*Indirect*		*Potential*	*Stability*		
Tagosodes orizicolus (rice planthopper)	r	Phloem sucking	Virus trans.	Immigration + multiplication	High	Medium	High	Major
Hydrellia spp. (whorl maggot)	r-(K)	Leaf mining	Reduction of plant vigor	Immigration + oviposition	Low	Medium	Medium	Occasional (irrigated)
Spodoptera frugiperda (fall armyworm)	r	Leaf feeding	Reduction of plant vigor	Immigration + oviposition	High	Low	Medium	Occasional
Oebalus spp. (stink bug)	(r)-K	Grain sucking	Grain discol.	Immigration	Low	Low	Medium	Occasional
Euetheola spp. (black beetle)	K	Seedling pest	Reduction of crop density	Present in soil or immigration	Low	–	Medium	Occasional (regional)
Phyllophaga spp. (white grubs)	K	Seedling pest	Reduction of crop density	Present in soil	Low	–	Medium	Occasional (regional)
Syngamia spp. (leaf roller)	r-K	Leaf rolling	–	Imigration + oviposition	High	High	Medium	Occasional
Elasmopalpus lignosellus (corn stalkborer	r-K	Seedling cutting	Reduction of crop density	Immigration + oviposition	Low	–	Medium	Potential
Diatraea spp. (sugarcane borer)	r-K	Dead hearts	–	Immigration + oviposition	High	Medium	High	Potential (regional)
Tibraca limbativentris (stink bug)	r-K	Dead hearts	–	Immigration	Medium	–	High	Potential (regional)
Hortensia similis (leafhopper)	r	Xylem sucking	–	Immigration + oviposition	High	High	Low	Potential
Panoquina spp. (leaf roller)	r-K	Leaf rolling	–	Immigration + oviposition	High	High	Low	Potential
Lissorhoptrus spp. (water weevil)	K	Root cutting	Fungal infections	Immigration + oviposition	Low	–	High	Potential
Rupela albinella (stem borer)	r-K	Stem boring	Lodging	Immigration + oviposition	High	High	Low	Potential

basically defines the damage in the rice crop and in managing this pest it is necessary to concentrate on reducing the build-up in natural hosts and minimizing immigration into the rice fields. Most lepidopterous pests (*e.g. Spodoptera, Mocis, Thioptera, Syngamia* and *Diatraea*) immigrate as adults and only the late larval stages may affect the crop by their feeding activity. Biological and cultural control mechanisms have time to reduce the population density during the egg and early larval stages. Thus management of these pests requires the strengthening of mortality causing factors during these early development stages.

Insects with short generation cycles (*e.g. Tagosodes, Hortensia* and *Hydrellia*) may complete several generations within the same crop. Their field colonization is by immigration and subsequent multiplication and their management requires a strengthening of all factors that regulate pest densities in a density-dependent manner and preventing a population build-up with special attention to the risk of inducing resurgence.

Biological Control: A characterization of the effectiveness of biological control for every pest in the rice field requires the evaluation of two basic aspects; the potential of existing biocontrol agents to control and regulate the pest population and their stability, that is their capacity to reduce density fluctuations in the medium term. Most phytophagous insects in rice fields in Latin America have a high potential of biological control with a medium to high stability. However, some soil inhabiting pests (*e.g. Euetheola, Phyllophaga* and *Lissorhoptrus*) have a rather low potential of biological control under most conditions. The increase of this potential has to be a long term research goal. High potential of biocontrol by itself does not automatically assure high stability as in the case of *Spodoptera frugiperda,* where the low stability of biological control, closely linked to the strategy of the insects to 'escape' by migrating, is the major factor contributing to pest densities that cause plant damage.

The above mentioned characteristics provide a general description of the damage potential of the major rice insects. In *Tagosodes, Diatraea, Tibraca* and *Lissorhoptrus* the damage potential is especially high because of the capacity for extreme population fluctuations and/or their severe damage to rice plants. Only *Tagosodes* can presently be considered as a widespread major pest. *Diatraea, Tibraca* and *Lissorhoptrus* have regional importance as major pests but are potential pests all over Latin America (Table 1).

2.1.3 Varietal Characteristics

Breeding for insect resistance is only part of the overall strategy for developing commercially acceptable rice varieties. Breeding efforts require the prior identification and availability of resistant parents, an adequate level of resistance and efficient screening methods. Genetic resistance to rice insects in Latin America has been identified for at least *Tagosodes orizicolus, Hydrellia griseola, Diatraea saccharalis, Lissorhoptrus oryzophilus, Syngamia* sp., *Spodopterafrugiperda, Elasmopalpus lignosellus, Chaetocnema* sp., and spider mites. Analyzing the efforts required for breeding resistant varieties and comparing them with the availability of alternative control measures, has justified germplasm screening for *T. orizicolus, H. griseola, D. saccharalis,* and *L. oyzophilus.* In the case of leaf rollers, *S. frugiperda, Chaetocnema* and spider mites the selection of highly susceptible varieties is avoided on the basis of field observations.

For every insect a certain type of resistance is desired (Table 2). In the case of the *T. orizicolus,* germplasm with tolerance to mechanical damage is selected, and all lines that possess some medium to high degree of antibiosis against the insect are discarded. This concept of selecting only tolerant material is based on greenhouse experiments that show a high probability of selecting new biotypes in a relatively short time by growing varieties with antibiosis. Seventy six per cent of the presently grown varieties in Latin America and more than 90% of the varieties in the tropical zone are tolerant to the planthopper, and no biotype outbreaks are known although some of these varieties have been grown on a large scale for more than 10 years. Differences in general aggressiveness seem to exist. Present varieties tolerate the natural pest fluctuations and allow the beneficial arthropods to regulate population density below economic thresholds. Field results from 20 commercial fields all over Colombia indicate that no insecticide applications were required for *T. orizicolus* in the tolerant varieties. However, maximum insect densities passed the economic threshold for susceptible varieties in 35% of the fields. Thus, because of varietal tolerance direct damage by *T. orizicolus* was insignificant and biological control was allowed to regulate population densities below the thresholds (Fig. 1).

TABLE 2

Type of resistance desired in an intergated pest management approach for rice in Latin America and present status of resistance in the 54 major commercial varieties.

Insect species	*Type of resistance*	*Modern commercial varieties resistant (%)*
Tagosodes orizicolus	Tolerance to mechanical damage	76
Hydrellia spp.	Intermediate resistance	46
Diatraea spp.	Antibiosis and tolerance	87
Lissorhoptrus spp.	?	-
Syngamia sp.	Prevent high susceptibility	92[1]

[1]Data for only 13 of the commercial varieties.

Hydrellia leaf mining attacks are restricted to irrigated rice with major attacks during the rainy season. These attacks can destroy direct seeded fields if they occur during the 1-3 leaf stage. About 46% of the present varieties have intermediate resistance against the leaf miner and general germplasm screening started in 1986 in order to increase the number of resistant varieties. The type of resistance widely available in the germplasm bank is a combination of intermediate resistance to larval attack and good recovery of damaged plants.

Diatraea is presently not considered as a pest in most areas of Latin America because 87% of the widely grown varieties are resistant. However, some varieties and parents from unfavored upland rice such as IAC 165, IRAT 124 and TOX 1011-4-1 are highly susceptible to this stem borer. Therefore breeding lines having a *Diatraea* susceptible parent have to be screened in order to prevent the release of *Diatraea* susceptible varieties and *Diatraea* thus becoming a new insect problem in irrigated or favored upland rice. Antibiosis against larval feeding in the leaf sheath before penetrating the stem and tolerance to attack by high tillering are the major mechanisms of resistance.

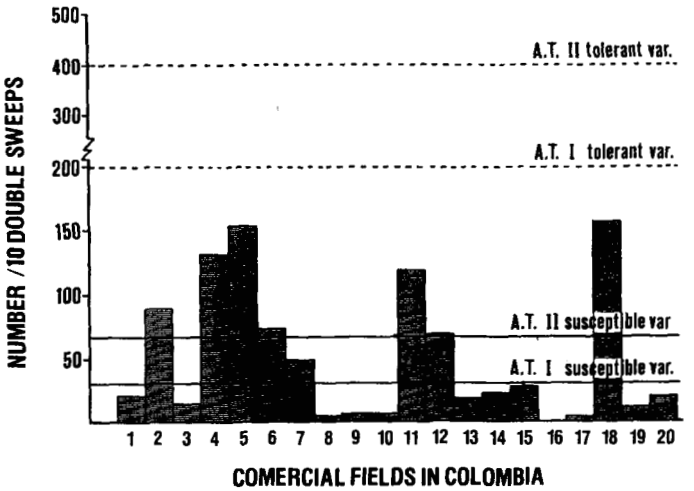


Fig. 1. Maximum number of *Tagosodes orizicolus* encountered in 20 commercial fields all over Colombia in relation to action thresholds (A.T.) for susceptible and tolerant varieties in the seedling stage (A.T.I.) and advanced growing stage (A.T.II) (Source: FEDEARROZ 1987).

The rice water weevils, *Lissorhoptrus, Onychilus, Oryzophagus, Helodytes* and other genera are increasing in importance regionally. Germplasm evaluation for resistance is still in the early research stages.

2.1.4 Agronomic Practices

Many agronomic practices that have favorable or adverse effects on certain phytophagous insects are available (Table 3). In some insects the use of adequate crop management can reduce their economic importance to insignificant levels. The integration of pest management into an overall concept of crop management must be carried out on a regional level.

Most phytophagous insects on rice in Latin America are not monophagous on this host plant and may reach higher populations on other host plants. If the sequence of rotated crops is not planned adequately, crop rotation may build up potential pests like *Diatraea, Blissus* or *Nezara* to economically damaging populations in maize or soybeans. These pests then migrate into rice.

2.1.5 Chemical Control

The use of insecticides that are most compatible with other control tactics is one of the recommended short-term control measures for rice pest management. Data from the European OILB-research group on the side-effects of pesticides on beneficial arthropods is incorporated into the IPM-field guide, although more adequate data on selectivity of pesticides against the major beneficial arthropods in rice fields in Latin America would be desirable (Hassan 1984). The use of resurgence-inducing insecticides is discouraged.

TABLE 3

Crop management practices and their effects on insect pests in rice.

Crop management practice	*Effect on insect species*	
	Increasing	*Decreasing*
Land preparation at beginning of dry season	–	*Euetheola*
Fine grained seedbed		*Phyllophaga*
High seeding density		*Neocutilla*
High water level	*Elasmopalpus*	*Spodoptera*
		Agrotis
	Spodoptera	
	Hortensia	
	Hydrellia	*Spodoptera*
	Lissorhoptrus	*Euetheola*
	Ochetina	*Neocutilla*
		Elasmopalpus
		Phyllophaga
		Chaetocnema
Poor land levelling	*Hydrellia*	
	Lissorhoptrus	
	Ochetina	
Deficient homogeneity in seeding density		*Hydrellia*
High nitrogen fertilization	*Syngamia*	
	Marasmia	
	Hortensia	
	Draeculacephala	
Deficient control of weeds		–
Echinochloa		–
Setaria	*Oebalus*	–
Brachiaria	*Mocis*	–
	Aeneolamia	–
	Zulia	–
	Deois	–
Andropogon	*Sipha*	
	Mocis	
Crop rotation		*Diatraea*
Rice-rice	*Tagosodes*	*Blissus*
	Hydrellia	*Nezara*
	Rupela	*Tagosodes*
Rice-maize	*Spodoptera*	*Hydrellia*
	Diatraea	*Rupela*
	Blissus	*Nezara*
	Elasmopalpus	*Tagosodes*
Rice-soybean	*Nezara*	*Hydrellia*
	Acrosternum	*Rupela*
	Diabrotica	*Diatraea*
		Blissus
		Phyllophaga

TABLE 4

Integration of IPM components to manage some insect pests of rice in Latin America.

Insect species	*Adequate variety*	*Crop management*	*Biological control*	*Chemical control*
Tagosodes	Tolerant to insect, resistant to hoja blanca ++	–	Protect beneficials ++	Do not cause resurgence +
Hydrellia	Intermediate resistance ++	Homogenous seeding density, adequate levelling ++	Protect beneficials	Economic threshold +
Spodoptera	High initial vigor	Excellent seedbed preparation, adequate seeding density, water management	Protect stability of biological control +	Water management ++
Euetheola and Phyllophaga	High initial vigor, high tillering	Land preparation at beginning of larval infestations; crop rotation with legumes ++	–	Economic threshold ++
Oebalus	–	Efficient weed control +	–	Economic threshold ++
Syngamia	Prevent high susceptibility	Adequate fertilization with N ++	Protect beneficials ++	Economic threshold
Diatraea	Resistant ++	Adequate crop rotation	Protect beneficials ++	

+ + Essential component, + major component, – complementing component.

2.2 INTEGRATION OF COMPONENTS

The integration of the control tactics into an overall pest management concept is being done on a regional basis. For the tropical zone, examples of integrated management programs for some pests are shown in Table 4.

The risk of economic damage from *T. orizicolus* and hoja blanca virus was high until the 1970s, when traditional or improved varieties susceptible to the insect and to the virus predominated. With the introduction of *T. orizicolus* tolerant varieties in the 1970s, the risk of mechanical damage from hopperburn decreased. The additional incorporation of an intermediate level of resistance against the virus in the 1980s has reduced the risk of virus outbreaks. The development and introduction of integrated crop management including insect monitoring and economic thresholds since 1985 has reduced the probability of insect outbreaks to extremely low levels mainly by reducing the number of insecticide applications and by preventing the use of resurgence-causing insecticides. Also, the introduction of virus-resistant varieties together with a predictive system of vector-percentages on a regional level in 1989-1990 reduced the risk of virus outbreak to low probabilities (Table 5).

TABLE 5

Consecutive steps to an intergrated management of *Tagosodes,* hoja blanca, and *Hydrellia*

Tagosodes

	Varietal resistance		*Crop management*	*Probability of damage*	
Time scale	*Tagosodes*	*Hoja blanca*		*Tagosodes*	*Hoja blanca*
Before 1968	Susceptible	Susceptible	Conventional	High	High
1970-80	Tolerant	Susceptible	Conventional	Medium	High
1980-85	Tolerant	Intermediate	Conventional	Medium	Medium
1985-90	Tolerant	Intermediate	Adequate	Low	Medium
After 1990	Tolerant	Resistant	Adequate + predictive system	Low	Low

Hydrellia

Varietal resistance	*Crop management*	*Probability of damage*
Susceptible	Conventional	High
Susceptible	Adequate	Medium
Intermediate	Adequate	Medium-Low
Intermediate	Adequate + early egg monitoring	Low

Routine evaluation of germplasm for *Hydrellia* resistance started in 1986, although many earlier released varieties have moderate resistance similar to IR 40. Combining adequate crop management practices like homogeneous seeding densities and adequate field levelling with moderately resistant varieties reduces the risk of *Hydrellia* damage to medium-low probabilities. In order to prevent destructive attacks of very early immigrating *Hydrellia* in the 1-2 leaf stage, field monitoring including an evaluation of the percentage of plants with eggs is required (Table 6).

Similar recommendations are incorporated into the IPM manual on the basis of present knowledge to provide control in the short term and to manage populations in the medium to long term. For most secondary pests field monitoring and use of economic thresholds has shown that these insects are of very low economic importance.

3. Implementation of IPM in Colombia

3.1 PROCESS OF IMPLEMENTATION

The Colombian National Federation of Rice Growers (FEDEARROZ), the National Research Institute (ICA) and CIAT in 1986 initiated a cooperative effort to design and implement an integrated pest management system for rice farmers in Colombia. After an analysis of current pest control practices, pests and recommendable alternatives (FEDEARROZ-ICA-CIAT 1986), an IPM field guide was designed and tested by local field technicians in confirmation trials in commercial fields throughout Colombia. Commercial fields of 5-10 ha size were divided in two parts, one managed conventionally according to the farmer's traditional practices and the other part according to the IPM field guide.

Based on analysis of the results of the confirmation trials the original IPM-field guide was modified to suit more closely the needs and problems in the different regions of Colombia. The addition of risk thresholds allowed a reduction in the number of required field visits from 13 to 7, with visits focussing on the critical crop stages. The field guide consists of three parts:

Field Evaluation: There is an evaluation sheet for seven different crop stages indicating the required samples. For most insects indirect sampling methods are required. This involves evaluating the number of leaves damaged by defoliating, mining, rasping or rolling insects and tillers damaged by stem cutting or boring insects. The farmer is not expected to identify the insect species but rather has to recognize the different types of damage. Only planthoppers, leafhoppers and beneficial spiders have to be collected with the insect net and counted and stink bugs are evaluated during flowering by counting the number of insects per m^2.

Decision: Critical thresholds are indicated for all pests using a sequential threshold for optimal sample size, a risk threshold for intensity of sampling and an action threshold for the need of control (Table 6).

Action: If pest attack passes the action threshold, the farmer has to identify the adequate action to control the insect on the short term and the adequate management to prevent similar attacks in the future. The action part, therefore, includes tables indicating pest characterization, control and management methods on the short and medium term, a characterization of pesticides including their effect on beneficials and a characterization of varieties.

TABLE 6

Integrated pest management of rice in Colombia. Decisions according to critical thresholds.

Sample	*Evaluation*	*Thresholds according to crop stage 0 to 3*								
A. SOIL INSECTS										
Sample: 12 × 1 m lineal 0.20 × 0.25 cm = 3 m^2	No. of white grubs in 3 m^2	Risk threshold: More than 30 larvae at beginning of dry season								
	No. of black beetles in 3 m^2	Action threshold More than 5 adults before planting								
	No. mole crickets in 3 m^2	Action threshold: More than 3 mole crickets before planting;								
		Emergence-seedling 0–1			Seedling-tillering 1–2			Tillering-elongation 2–3		
B. INSECTS IN FOLIAGE		ST	RT	AT	ST	RT	AT	ST	RT	AT
Sample: 5 times 10 tillers	No. damaged tillers in 5 × 10 tillers	2	2–5	6	2	2–5	6	4	5–7	
Sample: 5 times 10 tillers with 3 youngest leaves	No. leaves with eggs of *Hydrellia*			50						
	No. leaves damaged by *Hydrellia*			30			60			60
	No. leaves damaged by leaf feeders	15	15–30	30	30	30–60	60			60
	No. leaves damaged by leaf rollers						25			25
	% leaf area affected by rasping	20	20–30	30	20	20–30	30			30
C. SWEEP NET										
Sample: 3 times 10 double sweeps	No. approx. of planthoppers			200			400			400
	No. approx. of leafhoppers			250			500			500

(contd.)

TABLE 6 (contd.)

Sample	*Evaluation*	*Thresholds according to crop stage 3 to 7*								
		Elongation-booting 3—4			Booting-Pan.emerg 4—5			Pan.emere-Flowerine 5—7		
B. INSECTS IN FOLIAGE		ST	RT	AT	ST	RT	AT	ST	RT	AT
Sample: 5 times 10 tillers	No. damaged tillers in 5 × 10 tillers	4	5-7	8	2	–	3			
Sample: 5 times 10 tillers with 3 youngest leaves	No. leaves damaged by leaf feeders			40						
	No. leaves damaged by leaf rollers			25						
Sample: 10 times 10 tillers with flag leaf	No. leaves damaged by leaf feeder	4		4-12	12	4				12
	No. leaves damaged by leaf roller	4		4-12	12	4				12
C. SWEEP NET										
Sample: 3 times 10 double sweeps	No. approx. of planthoppers			400			400			
	No. approx. of leafhoppers			500			500			
D. PANICLE PESTS										
Sample: 10 times 1 m^2	No. of stink bugs per 10 m^2						40			40

ST = Sequential threshold – If attack passes over this level, take two more samples.

RT = Risk threshold – If attack passes over this level, take another sample in 3-5 days.

AT = Action threshold – If attack passes over this level, take control action.

3.2 FIELD RESULTS FROM COLOMBIA

Managing 20 commercial fields in Colombia during 1986–87 according to the IPM field guide required a control action in 10 cases (FEDEARROZ 1987). *Hydrellia* leaf mining was the most common problem, because the predominating variety, Oryzica 1, is highly susceptible. Dead hearts and leaf rasping mainly caused by stem sucking pentatomids and flea beetles respectively, passed action thresholds in 10% of the upland fields. *Spodoptera* and *Mock* caused leaf feeding damage in seedlings and flag leaves, respectively, surpassing thresholds in 5% of the fields (Table 7).

TABLE 7

Percentage of 20 commercial fields located throughout Colombia, where insect attacks passed economic thresholds

Insect/attack	*Cropstage*	*Fields passing threshold (%)*
White grubs in soil	Before planting	0
Black beetles in soil	Before planting	0
Mole crickets	Before planting	5
Cut seedlings	Seedling stage	0
Eggs of *Hydrellia*	Seedling stage	0
Leaf mining	Seedling stage	15
Leaf rasping	Seedling stage	10
Dead hearts	Tillering-booting	10
Leaf feeding	Tillering-booting	5
Leaf rolling	Tillering-booting	0
Flag leaf feeding	Booting-flowering	5
Flag leaf rolling	Booting-flowering	0
White panicles	Flowering	0
Stink bugs	Flowering	0

Source: FEDEARROZ 1987

An average of 0.5 applications per crop was required when using IPM against the countrywide average of 5.2 applications of insecticides in conventionally managed fields in 1985. Applications and insect control costs were reduced by more than 90%, permitting savings in production costs of 80 to 120 US $/ha.

Field IPM demonstrations are part of a general approach to improved crop management in Colombia, including the demonstration of adequate weed control, disease management and seeding practices. Total savings from integrated crop management are between 170 and 225 US $/ha or an equivalent of 0.8–0.9 tons of paddy per ha (Table 8). These possible savings and the increase in profitability attract the farmers' attention and guarantee a high level of success in transferring the integrated crop management concept as a general alternative to present practices.

4. CONCLUSIONS

Rice is a relatively young crop in the Americas and only a few insects can be mentioned as major or potentially destructive pests. This is in clear contrast to the current practice of 2–6 preventive insecticide applications in rice all over the tropical zone, Central America and the Caribbean.

TABLE 8

Present production costs in kg of paddy rice/ha for planting, weed, insect and disease control compared to costs when following an integrated crop management system (ICMS) in Colombia.

Practice	*Central Zone*			*Coastal Zone*			*Llanos*		
	Present	*ICMS*	*Savings*	*Present*	*ICMS*	*Savings*	*Present*	*ICMS*	*Savings*
Planting	513	308	205	513	308	205	513	308	205
Weed control	474	263	211	395	263	132	395	263	132
Insect control	407	115	292	256	29	227	289	73	216
Disease control	322	89	233	356	97	259	576	245	331
Total	1716	775	941	1,520	697	823	1,773	889	884

Source: FEDEARROZ-ICA-CIAT, 1986.

An adequate characterization of the plant and crop development and the ecology of the phytophagous insects as well as the possible control methods is the first step in developing an IPM concept. In order to assure stability and reliability of pest management no single control method should be used. Therefore, antibiosis resistance is avoided in the highly adaptive rice planthopper, *T. orizicolus,* preferring instead the combination of varietal tolerance to the mechanical damage of the insect, varietal resistance against the virus and adequate protection of beneficials to prevent pest resurgence.

Field results from Colombia show large potential savings in combining of IPM with other adequate crop management practices. Therefore, the incorporation of IPM into an overall crop management approach that demonstrates to farmers a considerable increase in crop productivity and profitability is essential in order to attract farmers' attention.

Similar efforts in other countries such as Ecuador also show considerable savings by using adequate crop management practices. The urgent task of demonstrating the use of IPM in the farmers' fields lies ahead for rice IPM proponents in Latin American countries.

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