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Biological Control of Rice Stem Borers: A Feasibillty Study

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The International Rice Research Institute
Los Baños, Laguna, Philippines

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FOREWORD

The rice stem borers are important pests of rice throughout Asia and in many other rice-growing regions of the world. Tropical regions with even climatic conditions are theoretically favorable for an effective utilization of parasites, predators, and various pathogens in the control of these pests. The International Rice Research Institute, therefore, felt that the existing information on biological control should be reviewed to provide background information for developing a program of research in this field.

Dr. John L. Nickel, formerly entomological adviser to the Agency for International Development in Cambodia and now with the College of Agriculture of the University of California, Berkeley, was requested to undertake this review. While on a temporary assignment as a visiting scientist at the Institute, he studied thoroughly the published information on the subject. He also traveled in Japan, Taiwan, India, Pakistan, Thailand, and Cambodia to assess the possibilities of biological control in these countries and to discuss the problem with other entomologists.

This paper, the second in a series of technical bulletins published by the Institute, presents Dr. Nickel's extensive review of the subject, together with his recommendations for initiating a research program in this field, The Institute hopes that this review will prove valuable to scientists working on the biological control of the rice stem borers.

Robert F. Chandler, Jr.
Director
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BIOLOGICAL CONTROL OF RICE STEM BORERS A FEASIBILITY STUDY

ABSTRACT

The introduction of foreign parasites and predators has resulted in a significant degree of sustained, self-perpetuating control of more than 100 insect pests over the world. In at least half of these cases, the degree of control has been great enough to render all other control practices unnecessary. Successful biological control has been achieved in many countries and over a broad range of geographic and climatic conditions. Those regions in which the greatest numbers of successes have been achieved are where a sustained effort has been made. Although the successes in the introduction of exotic agents for permanent biological control have been many, the failures have been more. Most failures probably resulted because ecological information was incomplete or ignored. The current trend is towards a more careful consideration of these factors before attempting introductions.

The relatively equable, year-round climate and the practice in some areas of continuous rice culture favor biological control of rice stem borers in the Philippines. The relatively low borer populations which can be economically tolerated and the increasing use of foliar insecticide sprays are negative factors. The major rice stem borers in Asia apparently have existed in the various countries for so long that, for practical purposes, they can be considered as native pests throughout their, range. Consequently, the classical application of biological control, in which the natural enemies of an introduced pest are sought in the native habitat of the pest, do not apply. Instead, biological control depends on analysis of the natural enemy fauna in various geographically separated regions. A preliminary listing of these fauna indicates that there are many species of borer parasites and that a considerable diversity exists between regions. Although many species of larval and pupal parasites have been reported from Asia, the total larval parasitization is usually very low. Only the egg parasites inflict high percentages of parasitization, and those only at relatively high host population levels. Larval and pupal parasites appear to be more effective on related borer genera in Africa and tropical America. Infohation regarding predators is sparse. Although they may play a significant role in the natural control of stem borers, the literature reveals no promising predators for introduction as biological control agents.

Efforts at biological control of rice stem borers have been limited, and a large portion of these efforts has been devoted to the questionable practice of mass-rearing and release of indigenous species of Trichogramma. Only a few attempts have been made at introduction of exotic natural enemies, and these have generally been single, non-sustained attempts which have failed. The only successful case has been the complete control of Chilo suppressalis in Hawaii by parasites introduced from China and Japan.

The greatest promise for biological control of rice stem borers lies in the inter-regional diversity in parasitic fauna. A project aimed chiefly at introduction of exotic, parasitic insects is recommended. Too little is known about diseases of rice stem borers for a conclusion on the use of pathogens, but most information so far has negative implications. The use of indigenous natural enemies gives erratic and temporary results and should receive less consideration than the

importation of foreign parasites. Eradication by irradiation and mass-release of sexually sterile males does not appear feasible at present. Use of sex lures and other chemical attractants should be investigated.

Biological control is not likely to solve completely the rice stem borer problem -- neither can chemical control or control by host-plant resistance make such a claim. Fortunately, these various approaches to pest control are not mutually exclusive. The ultimate aim of a rice stem borer research program should be to make these methods mutually compatible and integrate them in such a way as to best protect the crop at minimum cost.

The importation of exotic rice stem borer parasites must be preceded by a thorough survey of the natural enemies now present in the Philippines. Introductions should be made from places having climates similar to those in the release areas. Releases should be made in sufficient numbers and under proper host and meteorological conditions to assure the maximum chances for establishment. Evaluation of results of parasite introductions must be well-planned and initiated in advance of such introductions. A biological control project would require special facilities for quarantine work, biological studies, and rearing for release. Cooperation with international organizations engaged in similar work is urged.

BIOLOGICAL CONTROL – GENERAL DISCUSSION

Introduction

Insects have a phenomenal reproductive capacity. Theoretical calculations of the potential numbers of offspring from a single pair of adults over a period of a season or a year result in astronomical figures. The fact that insects do not increase infinitely obviously attests to the fact of natural control. Biotic and physical factors limit the abundance of all organisms. Certain of these factors increase the intensity of their action as the population density increases and relax as this density falls. Such factors prevent a given population from increasing indefinitely or decreasing to extinction. The combination of environmental factors which produce population fluctuation within certain limits is called natural control. Biological control, as used in this study, refers to direct or indirect manipulation by man of living natural control agents to increase their attacks on pest species (Beirne, 1963), This involves the additionor augmentation of parasites, predators, or diseases of the pests for the purpose of reducing economic losses.

The basic premise for most biological control activities is the equilibrium which exists between plant and animal populations in their undisturbed native habitats. When man disrupts this equilibrium by transporting plants and their pests to new environments, a more destructive situation often arises. Most biological control activities have been directed at correcting such disequilibria. Various modifications also have been adapted to other situations.

Advantages of Biological Control

Biological control, when it can be satisfactorily employed, holds several distinct advantages over other pest control methods. These are:

1. Self-perpetuation: In contrast to chemical control, which only temporarily reduces the pest population and must be repeatedly applied, most successful biological control involves the introduction of new natural control factors into the environment, thus permanently reducing the pest population to a new equilibrium level. The use of biological control agents for temporary pest reductions,much like insecticides, also is used in some cases, and will be discussed later. Although large expenditures may be necessary to find, study, and

introduce permanent biological control agents, once established they continue to control the pest indefinitely without additional efforts.

2. Lack of resistance: One of the great disadvantages of chemical control is the ability of insects to develop strains resistant to insecticides. A single case of an insect pest developing resistance to the attack of an imported parasite has been recorded (Muldrew, 1953). In general, however, the lack of resistance to biological control agents is a distinct advantage.

3. Lack of adverse side effects: The chief adverse side effects of insecticidal control are: (a) induced increases in the population of non-target pests or the resurgence of target pests after a period of control due to the destruction of natural enemies; and (b) toxic hazards of pesticides to man and domestic animals. Biological control agents generally are quite specific, attacking one or several phytophagous pests species without disturbing beneficial forms. As biological control does not produce toxic residues, it avoids either of these adverse side-effects.

The advantages listed above are accentuated in tropical, developing countries. Under conditions in which there is no dormant season, disequilibrium brought about by insecticidal destruction of natural enemies may persist for a long time and necessitate prolonged repetition of insecticidal treatments. In developing counti-ies, insecticides usually are imported, resulting in higher costs to the farmer as well as a drain on the foreign exchange. Even when efficient and economical means of chemical or cultural control of a given pest are developed, many farmers in remote and primitive areas may not adopt these practices. Successful biological control, on the other hand, provides more universal benefits.

Recognizing these advantages, and recognizing also that the successful transfer of living organisms to new environments is not easily achieved or to be entered into lightly, The International Rice Research Institute asked the writer to study the feasibility of applying biological control principles to control the rice stem borers. This paper presents the results of that study.

As a basis for understanding the principles and methods involved in biological control, a historical review of biological control of insect pests follows. This will be followed by a more detailed discussion of the possible use of biological control methods as they apply specifically to rice stem borers.

Historical Review

The cases in which natural enemies have been used in pest control are too numerous to be discussed in detail here. However, several outstanding examples of biological control which demonstrate various principles will be described. These will be followed by a tabular listing of recorded cases of successful biological control. The case histories which follow, and those listed in the tables, pertain only to instances in which permanent effects were achieved through use of exotic biological cantrol agents. Theae will be followed by a brief description of the use of native or exotic agents for temporary control.

A. Permanent Control

The first recorded case of successful suppression of a pest by the international movement of a natural enemy was the introduction, in 1762, of the mynah bird [Acridotheres tristis (L)] from India to the island of Mauritius to control the red locust, Nomadacris septemfasciata Serv.. This locust, which caused severe damage, has not been reported as an important pest since the introduction of the mynah birds (Moutia and Mamet, 1946).

No discussion of biological control would be complete without mention of the classic example of control of the cottony-cushion scale, Icerya purchasi Mask., by the vedalia beetle, Rodalia cardinalis (Muls,). It was this sensational success which first drew attention to biological control and spurred efforts in its utilization. The cottony-cushion scale was introduced accidentally into California from Australia about 1869. Without its natural enemies, it spread rapidly and by the early 1880's threatened to destroy the California citrus industry. In 1888, an entomologist went to Australia to seek natural enemies of this pest in its native habitat, The vedalia ladybird beetle predator and a parasitic fly, Cryptochaehun iceryae (Will.), were sent to California where they became established quickly and spread rapidly. Within 2 years, the cottony-cushion scale was no longer of economic importance in California (Fleashner, 1957). Although the parasitic fly is also an effective enemy of the cottony-cushion scale, its effect has been largely overshadowed by the sensational control by the vedalia beetle. In areas such as the San Francisco Bay region where climatic conditions are unfavorable to the predaceous beetle, the parasitic fly controls the scale. For many years, the control of the cottony-cushion scale was so complete that it became rare. The extensive use of new organic insecticides for other pests, however, has in some cases destroyed its natural enemies, resulting in a destructive resurgence of this pest. This has necessitated the recolonization of the vedalia beetle after the toxic residues dissipated (Clausen, 1956a).

The sustained and complete control of the cottony-cushion scale was equalled by that of the citrophilus mealy bug, Pseudoccoccus gahani Green. This major pest of citrus in California was first obsemed in 1913. A study of its distribution indicated the Australian region as its probable home. Several naturil enemies were introduced from Australia in 1928, of which the parasitic wasps, Coccophagus gurneyi Comp, and Tetracnemus pretiosus (Timb.), were established (Compere and Smith, 1932). They effectively controlled the pest in the entire area within 2 years. These parasites were so effective that it has become difficult to find the mealy bugs (Clausen, 1958).

Partial control of the olive scale, Parlatoria oleae Colvee, in California by parasites introduced from Iran was less sensational but demonstrated the importance of detailed biological studies (Doutt, 1953). Stocks of parasites of the species, Aphytia maculicomis (Masi),were imported from India, the Middle East, and the Mediterranean region. Careful laboratory studies demonstrated that, while all were morphologically indistinguishable, three distinct strains existed. These strains, designated as Spanish, Indian, and Persian, differed greatly in biological attributes, such as rate of development and egg-laying capacity. The Persian strain was proved most effective in controlling the olive scale in California.

Another illustration of ,the importance of geographic races is the control of the fig scale, Lepiclosaphes ficus (Sign.) by Aphytis mytilaspidis (Le Baron) from Italy. The same species of parasite was already present in California but exercised little control over the fig scale. Introduction of the European strain greatly reduced fig scale injury (Flanders, 1957).

Natural enemies of the coffee mealy bug, Planococcus kenyae Le Pelley, were sought in many tropical and sub-tropical countries of the world without success, because of an earlier misidentification. When this mealy bug was identified as a new species native to east Africa, effective parasites soon were found in the neighboring countries of Uganda and Tanganyika (Le Pelley, 1943). This case demonstrates the necessity of accurate taxonomic work in biological control.

An example of the rewards of seeking biological control agents in the native habitat of their host is found in the work of Myers (1932). He determined the native home of the sugar cane borer, Diatraea saccharalis (F.), to be floating grasses in the lower Amazon region of Brazil. In this natural setting, it was attacked by several species of parasites, one of which was the well-known "Amazon fly," Metagonistylum minense Tns., which has subsequently partially controlled D. saccharalis when introduced into British Guiana and the British West Indies (Myers, 1934; Box, 1939).

The island of Fiji has been the site of several outstanding cases of biological control, Two of these involved control of native pests by introduced parasites of different, but related, species. The first of these was the control of the coconut moth, Levuana irridescens Bethume-Baker by the tachinid fly, Ptychomyia remota Aldrich. The larvae of this pest caused severe defoliation of coconut and were considered to be indigenous to Fiji (Taylor, 1955). The parasitic fly was imported from Malaya, where it was parasitic on a related moth in another genus. Field control resulted in many areas only 6 months after release of the parasites, and general economic control over the entire island was achieved in 2 years (Tothill, et al., 1930).

Another outstanding example on Fiji was the control of the coconut leaf-mining beetle, Promecotheca reichei (Baly). This native pest was originally in equilibrium with its natural enemies at sub-economic levels. The natural enemies depended on overlapping generations of the beetle to produce a constant supply of the susceptible stage for parasitization. The accidental introduction of a predaceous mite caused periodic elimination of all larval stages, thus separating the successive generations of the beetle and destroying the effectiveness of the native parasites. This resulted in a devastating upsurge in the beetle population, Before undertaking foreign exploration for parasites, a careful analysis determined the attributes required of a parasite for it to be successful under the new conditions. The parasite, Pleurotropis parvulas Ferr. was selected from Java, where it was a parasite of another species of Promecotheca. The usual practice of importing the most plentiful parasite of a given host was not followed in this case. Although P. parvulas was not the most important parasite of its host in Java, it best met all the pre-determined requirements. Its release on Fiji resulted in complete economic control of the beetle in less than a year (Taylor, 1937). This case demonstrates not only the rare instance of complete biological control of an endemic pest, but also the benefits of a thorough study of prospective biological control agents. The disruption of the original natural control of this pest by the accidental introduction of an additional mortality factor also serves as a warning against careless insect introductions.

The sugar cane industry in Hawaii is the best example of the fruits of concerted, sustained efforts in biological control. Since 1904, entomologists have systematically sought and introduced natural enemies of sugar cane pests (Pemberton, 1948), with the result that currently no chemical control of sugar cane insects is necessary in Hawaii. The impressive list of entomologists engaged in these activities and the accounts of how success was achieved (Pemberton, 1948), demonstrate that these results are more than fortuitous. The sugar cane leafhopper, Perkinsiella saccharicida Kirk., is an outstanding example of the 10 sugar cane pests brought under full control by biological means (Pemberton, 1953). This pest was so severe that it threatened to destroy the sugar cane industry. The original home of the leafhopper was not known until its tiny eggs were discovered in some cuttings arriving from Queensland, When it was learned that this species existed on sugar cane in Queensland without inflicting appreciable damage, a search for parasites was undertaken there. Between 1904 and 1916, several effective species of parasites from Queensland and Fiji were dntroduced and became established. Although these excellently controlled the pest in most areas, severe outbreaks continued to occur in areas of heavy rainfall. In 1920, the astute observation of collapsed leafhopper eggs in the midribs of cane leaves in Australia led to the discovery of the predaceous bug, Crytorhinus mundulus (Bredd.) which sucks out the contents of the eggs. As this bug belongs to the same family as some important plant pests, it was introduced only after careful studies showed it to be solely entomophagous. After its introduction in 1923, the leafhopper subsided to a level of unimportance, where it has remained since (Pemberton, 1948).

A review of the literature revealed the cases of confirmed success in biological control listed in Appendices A and B. These relate only to permanent control by introduction of exotic entomophagous insects. Although degree of success is hard to define, these have been arbitrarily divided into cases of "complete" and "partial" control. Complete control refers to cases in which the introduced biological control agents have reduced the pest to a level at which other methods of control are no longer necessary. Partial control indicates that although other control methods are still required, the frequency of treatment or the degree of crop injury has been substantially reduced by the introduced natural enemies.

Appendices A and B list all the cases of confirmed successful biological control the writer could find in a review of the literature. These lists are not complete, DeBach (1961) no doubt had access to additional information when he stated that there had been 214 cases of complete or partial biological control in the world, of whic: 116 had been in the Pacific region as follows: Australia, 10; Bali, 1; Bismarck Archipelago, 2; British Columbia, 9; Caroline Islands, 1; Celebes, 3; Chile, 5; Columbia, 1; Costa Rica, 2; Ecuador, 1; Fiji, 5; Guam, 4; Japan, 4; Marianas, 1; Mexico, 2; New Zealand, 10; Panama, 1; Peru, 5; Ponape, 1; Tasmania, 7; U.S.A. (California), 17; U.S.A. (Hawaii), 24. In attempting to find a common denominator for success, he concluded that "over a period of time, the number of successes attained will be proportional to the amount of research and importation work carried out." In his opinion, the fact that few or no successes had been achieved in some countries did not necessarily indicate that these countries lacked the proper climatic or geographic conditions for success. Rather, biological control had largely been neglected as a control approach. Therefore, such countries probably offer the greatest promise in biological control due to the large number of unexplored possibilities.

B. Temporary control.

Although lacking the chief advantage of self-perpetuation, the use of biological control agents to achieve temporary pest reductions has in a few cases proved useful. Temporary biological control can be divided into the following categories.

1. Mass releases of indigenous parasites and predators to supplement numbers or distribution of natural populations, or to improve synchronization of parasite and host stage.

2. Periodic mass releases of exotic natural enemies which are unable to become permanently established under local climatic conditions.

3. Distribution of insect pathogens to cause direct quick mortality or to initiate epizootics.

Mass release of indigenous natural enemies for pest control is not a new practice. Fleshner (1959) indicated that this practice dates back for centuries in Chinese citrus culture in which predatory ants were aided and/or reared and released to protect trees from pests. He also cited eighteenth and nineteenth century references to the gathering of predaceous ants from mountain colonies each year in Yemen to protect date palms from harmful ants. Similar practices of gathering lady beetles from hibernating colonies in the mountain valleys and releasing them by millions in melon fields in the Imperial valley af California have proved useless.

In general, the aritificial rearing or gathering and release of large numbers of indigenous natural enemies is contrary to ecological principles and often is disappointing. Population levels are at certain levels at a given time through a complex interaction of physical and biotic elements in the environment. Artificially increasing the natural enemy/host ratio can at best produce only fleeting results, and examples of confirmed success are rare.

One example of successful application of Category "1" (above) has been the mass rearing and release of <u>Macrocentrus</u> <u>ancylivorus</u> Rohw against the oriental fruit moth, <u>Grapholitha</u> <u>molesta</u> (Busk.) in the United States. This native parasite of the strawberry leaf roller has adapted itself to the introduced oriental fruit moth. Brunson and Allen (1944) showed that mass rearing and release of this parasite when natural populations were inadequate resulted in high parasitization and reduced fruit losses.

Species of <u>Trichogramma</u> are common egg parasites of many pest species. Because of poor searching ability, they generally cause a high percentage of parasitization only late in the season when host populations have reached high levels, Because these parasites can be rather easily reared in large numbers on the eggs of several species of stored products pests, they have been mass-reared and released against various pests in many parts of the world with highly variable results. Their use against graminaceous borers is discussed in more detail on pages 32–35.

An example of Category "2"(above) is the lady beetle, Cryptolaemus montrouzieri Muls., which was introduced into California from Australia. It was unable to maintain itself under California conditions, but it was reared in great numbers in insectaries and periodically released. In this way, it partially controlled the citrophilous mealybug until more effective permanent control was achieved with other parasites (Compere and Smith, 1932).

Use of insect pathogens for microbial control is another important aspect of biological control. In most cases, the organisms employed are native or cosmopolitan species occurring in the normal pest population at low levels of incidence except for occasional outbreaks at high host population densities. Except for milky disease of the Japanese beetle, induced infections by these disease organisms have not been self-perpetuating and must be classified as temporary biological control.

The best known insect pathogen used for temporary biological control is Bacillus thuringiensis Berl. This spore-forming bacterium can be cultured on artificial media. Several preparations of spores are being sold commercially. It attacks many species of lepidopterous larvae, but must be ingested and does not colonize to produce epizootics. Hence, it must be applied repeatedly and used in a similar fashion to stomach-poison insecticides.

A nuclear polyhedrosis virus is commonly used for control of the cabbage looper Trbhoplusia ni (Hbn.) in Thailand. A preparation of disseased larvae macerated in water will remain viable under refrigeration for at least a year. This preparation is then diluted and sprayed on infestations of the caterpillar. In 4 days, the larvae die and can be field-collected to replenish the virus concentrate supply (Cantelo, 1963). The writer tested such a preparation, brought from Thailand, in Cambodia, and found it effective on the cabbage looper, which was resistant to all insecticides tested against it.

Use of biological agents for temporary control, because they must be repeatedly applied, should be compared with insectikidal control. The fact that parasites and predators can seek out their hosts may be an advantage. Beneficial insects and diseases are generally quite specific and do not leave toxic residues, thus overcoming the adverse side effects of insecticides. The chief disadvantages of the use of these agents are that they are more vulnerable to destruction by adverse weather, require more refined and careful application techniques, and are generally more costly and difficult to prepare than insecticides, To compete favorably with chemical control, their use will chiefly depend on the development of low cost methods of producing the enormous numbers needed.

C. National Program Summaries.

The case histories and tables above cite only the successful cases of biological control, Perhaps a more realistic picture is obtained by viewing the overall results of national programs in biological control of several countries.

1. Continental United States: Clausen (1956a) reported that of the 485 species of imported biological control agents which had been liberated against 77 pest species, 95 had been established on 22 pest species with various degrees of control.

2. Canada: McGugan and Coppel (1962) reported that in biological control attempts against forest pests, 93 species had been introduced and 11 species relocated from one part of North America to another. Of these, 35 species became established in their new locality, of which 12 species achieved a measurable degree of control, 10 species gave doubtful control, and 3 species had been established for too short a period to assess their value.

3. Australia: Wilson (1960) indicated that natural enemies had been introduced against 41 pest species in Australia and Australian New Guinea. Of the 27 pest species on which introduced agents became established, 8 were substantially reduced.in status, 11 were reduced in status, 4 were of doubtfully diminished status, and 4 were of unchanged status.

4. New Zealand: Miller et al. (1936) reported that 24 species of introduced natural enemies had been liberated, of which 11 were known to be established. Two of these keep their hosts under adequate control, while nine provide varying degrees of partial control.

5. Philippines: Baltazar (1964a) listed 48 species of natural enemies introduced into the Philippines, of which 8 had been reported as established.

The degree of control, if any, exercised by the established species is not known.

D. Negative Factors in Biological Control:

Having reviewed the advantages of biological control, and a long list of successful applications of this method, it is necessary also to assess the negative factors. These are:

1. Failures
2. High initial cost
3. Dangers

The above reviews of biological control operations reveal more failures than successes of individual introductions. A high percentage of the natural enemies introduced did not become established. Also, in many cases in which establishment was achieved, little or no control resulted. The failure of an individial species introduction, however, does not necessarily imply a failure in that program. Although the percentage of introduced species which have become established and exercised economic control is low, concerted and continued efforts to control a given pest more frequently have met with success.

Most of the literature does not mention the expenditures involved in achieving the successful control of a given pest. It is estimated that the classical success in control of the cottony-cushion scale in California cost less than $5,000 and benefited the citrus industry by millions of dollars annually (Clausen, 1959a). Generally, however, the costs are high. Most effective programs involve a staff of entomologists, specialized laboratory, insectary, and quarantine facilities, as well as extensive international travel. The costs of the failures plus those of the successes make the price per success rather high. When a measure of permanent biological control is achieved, however, these initial costs generally are warranted when compared with the savings in crop loss and reduced control expenditures calculated for years into the future.

Possible dangers associated with importation of foreign biological control agents would include:

a. Introduction of agents hyperparasitic on native natural enemies, with a resultant increase in the pest population.

b. Introduction of agents with identical ecological niches as native natural enemies, causing competition favoring the pest population.

c. Inadvertent introduction of phytophagous species.

A review of scores of biological control projects involving the importation and release of many millions of individuals in hundreds of species of natural enemies has not revealed the materialization of a single case of the potential dangers listed above. Although the inadvertent importation of a hyperparasite along with the beneficial species has sometimes lessened the effect of that introduction, no case has been recorded in which negative net results have been produced. The instance cited earlier of existing natural control of the coconut leaf-mining beetle being disrupted by accidental introduction of a predaceous mite (Taylor, 1937; Wilson, 1960) was not associated with any biological control activities. Although these potential dangers should provoke vigilance and careful testing with each introduction, the record does not warrant great anxiety over the adverse effects of biological control programs.

Current trends in biological control

With the advent of new and powerful insecticides following World War II, it appeared that chemicals would control insects most effectively. However, insect resistance to insecticides and increasing attention to adverse side effects resulting from the use of these chemicals has stimulated interest more recently in alternatives or supplements to chemical control. Thus, interest in biological control has been renewed in the past decade.

Most of the more striking successes of biological control in the past involved restoration of the natural control which had been disrupted by introducing pest species into new environments without their natural enemies. Many of these unnatural outbreaks now have been controlled. Taylor (1955), therefore, expressed pessimism about the future of biological control, indicating that these situations in which spectacular results could be expected had already been exhausted. Simmonds (1956) strongly refuted this view. While many of the introduced pests which lend themselves to outstanding biological control have been brought under control in countries with large and long established activities in this field, much remains to be done in the developing countries where the potentials barely have been tapped.

Furthermore, much progress probably can be made by introducing more effective strains or species of natural enemies against native, cosmopolitan, or long established pests. Whereas earlier work was often of the empirical, trial and error type, in which all available natural enemies of a given pest were introduced in a "shotgun" approach, the present trend is for more detailed studies of the ecologies of the pests and natural enemies. Bierne (1963) pointed out that, on a world-wide basis, two-thirds of past biological control attempts were failures, mostly because ecological information was lacking. He indicated that there was a current trend to obtain detailed ecological data in advance of each biological control attempt. He pointed out that, whereas until recently, biological control work abroad for Canada was primarily the collection of material for release, in 1963 half of the projects assigned by the Belleville Institute of Biological Control were solely research and half of the remainder included research, Although, as Clausen (1958) pointed out, much of biological control work will continue to be empirical, the trend towards a more thorough understanding of the pests and natural enemies should eliminate many of the mistakes of the past.

FEASIBILITY OF SUCCESSFUL BIOLOGICAL CONTROL OF RICE STEM BORERS

The foregoing review of biological control theory and practice provides the basis for the question at hand: "What are the chances for successful biological control of rice stem borers? Do the facts at hand warrant the necessary expenditure of resources for a major effort in this direction?"

To answer this question, principles which relate directly to feasibility of biological control of these specific pests under the particular conditions in which they are found will be evaluated. This will be followed by a discussion of the relative merits of various approaches and agents. This study will cover biological control of rice stem borers on a world-wide basis. However, as the initial facilities and activities of any future IRRI work on biological control will be located in the Philippines, conditions in this country will be emphasized.

The Borers

A. Asia

The most important rice stem borers of Asia are:

Chilo suppressalis (Wlk.) - (family Pyralidae)
Tryporgza (Schoenobius) incertulas[1] (Wlk.) - (family Pyralidae)
Sesamia inferens (Wlk.) - (family Noctuidae)
Tryporyza (Scirpophaga) innotata[1] (Wlk.) - (family Pyralidae)
Chilo (Chilotraea) polychrysa[2] (Meyr.) - (family Pyralidae)

The first three species are commonly reported as rice pests throughout Asia, with the first two species by far the most important. T. innotata is the most important species in Indonesia and also has been reported as a pest in India, Pakistan, and the island of Mindanao in the Philippines. C. polychrysa is an important species in Malaya. Several other species of Chilo have been reported as rice borers in India and Pakistan.

[1]The generic designation of this species recently has been changed (See Common, 1960).

[2]The generic designation of this species recently has been changed (See Bleszynski and Collins, 1962).

In the Philippines, T. incertulas is dominant in Central Luzon, while C. suppressalis is dominant in the Laguna region (Cendaña, et al.,1961). IRRI (1963) reports C. suppressalis as the most important species in the area around the Institute, with T. incertulas becoming important seasonally for brief periods.

The two species of Tryporyza generally are considered to be specific to rice. C. suppressalis is practically confined to rice but has been reported as attacking several grasses, corn, and millet(Jepson, 1954). S. inferens, on the other hand, has a wide host range and attacks many graminaceous crops. It is a common pest of sugar cane in the Philippines.

The habits of the various borer species are similar in that the eggs are laid in groups or masses on the leaves, and larval and pupal stages are found in tunnels in the stems. Whereas the eggs of the other species are exposed, those of S. inferens are concealed behind the leaf sheaths. This species also pupates outside the stem and is a voraceous feeder, moving from stem to stem within the hill. Chilo larvae feed gregariously in the stems in their early life and disperse to surrounding plants as they grow older. Tryporyza larvae, on the other hand, disperse chiefly as newly-hatched larvae, then feed singly in the stems, often completing their entire development without leaving the plants.

B. America

Stem borers are apparently less of a problem in the Americas than in Asia and Africa. The chief rice stem borer reported from the Americas is Diatraea saccharalis (F.), which is better known there as a stalk borer of sugar cane.

C. Africa

The stem borers reported from rice in Africa are:

Maliarpha separatella Reg. (family Pyralidae)
Parerupa africana (Auriv.) (family Pyralidae)
Adelpherupa sp. (family Pyralidae)
Sesamia calmistis Hmps. (family Noctuidae)
Saluria sp. (family Pyralidae)
Scirpophaga sp. (family Pyralidae)

Chilo partellus[1] (family Pyralidae)
Sesamia botanephaga Tams & Bowden (family Noctuidae)

Information on rice stem borers from Africa is sparse. The first three listed species apparently are the most important (Ingram, 1958; Nye, 1960; Breniere, et al., 1962). M. separatella is specific to rice.

General Principles:

Various workers have set forth principles about the feasibility of biological control of different pest types under various conditions. These mud be analyzed as they relate to rice stem borers in the Philippines. The principles suggest that:

A. Biological control has the best chance of being successful:

1. In tropical climates
2. On islands
3. Against introduced pests
4. On perennial crops

B. Biological Control is most difficult to achieve:

1. Against pests in which a low population can cause economic damage.
2. Where insecticides are being used.

The concept that insular, tropical conditions are best suited to biological control has become almost axiomatic. This is based on observations that the greater proportion of past biological control successes have been in the tropics and/or on geographical or ecological islands. The most obvious explanation for this phenomenon is the generally more equable and constant climate of tropical islands, in which introduced biological control agents are less subject to temperature or moisture extremes. It also has been asserted that insular conditions provide a less complex fauna to which introduced insects can more readily adapt. Taylor (1955) stated that islands have less of a variety of species, resulting in

[1] Formerly Chilo zonellus (Swinh.) (See Bleszynski and Collins, 1962).

less chance for the introduced insect to be preyed upon. Simmonds (1958) challenged this concept, pointing out that the fauna of many larger islands approach the complexity of continental areas. He agreed that an equable climate generally favored the introduction of natural control agents but pointed out that some continental areas also have such a climate, while some islands have seasonal extremes in rainfall. Cendaña (1949) suggested that the areas in the Philippines having extreme seasonal differences in rainfall were less suitable for establishment of introduced natural enemies than areas with a more even annual rainfall distribution. Clausen (1952b) summed up the effect of climate by stating that the frequency of success of biological control attempts is certain to be reduced by any departure from climatic conditions that are constantly favorable throughout the year. Several workers state that the "tropical island" idea has been overworked. The writer agrees that this is an oversimplification and that more emphasis should be placed on a similar, at in climate, In any case, the fact that the Philippines is made up of tropical islands, with large areas of relatively equable climate throughout the year, can be considered a strong favorable factor for biological control.

Most of the outstanding cases of successful biological control have been of pests which were introduced from another country in relatively recent times. Biological control is certainly more simple when the pest has been introduced, and its native locality is known. This does not mean, however, that success cannot be achieved against a native or cosmopolitan species. The complete control of the leaf-mining beetle and coconut moth, two native coconut pests on Fiji, strongly support the view that biological control also can be effective against native pests. Pimentel (1963) pointed out that the natural enemies of pest species in its native habitat already have evolved a state of homeostasis with the pest and that, therefore, introduced parasites of an allied species often are more effective. He listed 10 cases of succesful biological control of native pests by the introduction of a natural enemy of an allied species or genus. Myers (1935a) also indicated that the original concept that biological control would be successful only on pest which had been introduced without their parasitic fauna must be modified. He pointed out that in many cases, an indiganous insect has learned to live on a cultivated crop while its natural enemies have not yet learned to or have been prevented from attacking it on its new host. He suggested that in such cases a more efficient parasite may be introduced from the outside. It appears, therefore, that succesful biological control is possible on native or cosmopolitan pests. The same principle which causes pests introduced without their natural enemies to become damaging also should apply to biological control agents, which, when transferred to a new locality without their natural enemies, may become more effective control agents.

The origin of the rice stem borers has not been clearly determined. It is obvious that they have not been introduced in the last century. The Tryporyza species, being specific to rice, are believed to have the same native home as the rice plant. Manickavasugur and Miyashita (1959) considered this to be around Orissa in India. As Chilo has slightly broader host range, it is possible that it moved over to rice from native grasses.

Regardless of the origin of rice or the various species of stem borers, it is clear that the major Asian rice borer species do not fit the classical pattern for biological control of recently introduced pests. The rice borers, apparently have existed in various regions for so long that their origin is unclear and possibly unimportant. They probably can best be thought of as native wherever they now occur if they have evolved complex and somewhat different natural enemy fauna in geographically isolated regions of their distribution. In the classical type of biological control, one needs merely to find the home of the pest and introduce to the new locality the natural enemies which had been left behind. In the case of the rice stern borers, the emphasis should be on carefully comparing the natural enemy fauna in various isolated regions with the goal of finding effective agents in one region which are not present in another.

A review of the biological control history indicates that most cases of successful control to date have been against pests of trees or other perennials (Lloyd, 1960). The obvious reason for this is the more constant supply of the host species so that the parasite or predator can maintain its population at effective levels without the need for alternate hosts. Athough rice is not usually grown as a perennial, conditions in some regions, in which there are several rice crops per year, provide conditions somewhat similar to that of a perennial crop. Biological control probably will have the best chances for success where continuous and overlapping rice cropping results in the presence of borers in all stages throughout the year. Such conditions are largely met in the area surrounding The International Rice Research Institute.

Probably the most important single factor working against the success of biological control of rice stem borers is the great amount of economic loss resulting from a relatively low borer population. It is a basic tenet of natural control that the intensity of regulating factors increases with an increase in the host population and vice versa. Consequently, the majority of cases of outstanding biological control have been against leaf feeding or sap-sucking species which could be tolerated at relatively high population levels without causing significant economic loss. Taylor (1955) pointed out, and Simmonds (1958) concurred, that it is practically impossible to achieve satisfactory biological control of those insect pests of which a few insects can cause great economic loss (e.g., insect vectors of virus diseases). This is because population levels needed to maintain natural enemy populations are higher than can be economically tolerated. Rice stem borers probably fall somewhere between the two extremes described above, IRRI (1963) has shown that a moderately high borer population can be tolerated in the early stages of rice growth, but that economic losses by relatively low populations are quite high in the later stages. This is because stems killed by borers in the tillering stage (i.e., "dead hearts") are often replaced by new tillers or result in decreased competition for the remaining stems. However, a single larva can destroy the grains of an entire head ("white heads") when it attacks at or just before heading. Because of this factor, biological control activities with stem borers will need to emphasize natural enemies which are effective at low population levels.

The problem relating to the effect of insecticides on biological control is closely related to the matter of economic population levels discussed in the preceding paragraph. If natural enemies do not keep a pest population at sub-economic levels, the necessity of insecticidal applications may interfere seriously with the biological control program. Such a consideration prompted Taylor (1955) to conclude that partial biological control in which some chemical treatments were still necessary was of no benefit. This conclusion is not entirely applicable in developing countries where many farmers do not use insecticides, even though pest populations reach levels at which there is severe economic loss. Even in highly developed regions, Taylor's conclusions are not always applicable because selective materials or selective application methods are being utilized which are not necessarily incompatible with biological control (see discussion on "integrated control" below). As the use of insecticides expands, partial biological control of rice stem borers can succeed only if selective chemicals and application methods are used.

Factors for and Against Success

The principles of biological control enumerated above, when considered in the light of what is known about the rice stem borers and local conditions, suggest the following conclusions:

Factors for Success:

1. The Philippines are tropical islands.
2. There are areas of continuous rice culture.
3. Borer generations overlap.
4. Many fields receive no insecticidal treatment, although high borer populations may be present.

Factors Against Success:

1. Rice borers are long established or indigenous - their home is unknown.
2. A low borer population can produce economic injury.
3. The use of insecticides is increasing.
4. Some regions in the Philippines are subjected to seasonal extremes in rainfall.

Use of Artificial Biological Phenomena

The manipulation of biological phenomena other than natural control agents generally is not considered as part of biological control. The possible use of sterility and attractants, should be considered, however, as a possible means of stem borer control. A brief discussion of the possible merits of these "biological" phenomena follows:

A. Sterility.

The successful eradication of the screwworm fly from the southeastern United States demonstrated the potential of this new approach to insect control. The principle involved is that of neutralizing the reproductive capacity of field females by the release of artificially reared, sexually sterile males. To be effective, the chance of any female mating with a sterile male must be greater than that of mating with a fertile male. With repeated releases of sterile males, the field population decreases each generation until the probability of a female fly mating with a fertile male becomes nil. Based on a theoretically stable population with a 1:1 sex ratio, Knipling (1955) postulated the following results of the periodic inundative release of sterile males.

Assumed natural population of virgin females	No. sterile males released per generation	Ratio of sterile to fertile males competing for virgin females	% females mated to sterile males	Theoretically potential number of females in each successive generation
1,000,000	2,000,000	2:1	66.7	333,333
333,000	2,000,000	6:1	85.7	47,619
47,619	2,000,000	42:1	97.7	1,107
1,107	2,000,000	1,807:1	99.95	less than 1

He pointed out, however, that populations often are not stable. A 2:1 initial ratio of sterile to fertile males may not reduce the population of the subsequent generation if the population is increasing. Therefore, he suggested that a 9:1 ratio should be released, if possible. This can be reduced if the past population is decreasing at the time of the initial release. The following criteria have been given for the successful use of the sterile-male techniques (Knipling, 1955; Christenson, 1962):

1. It must be economically feasible to produce and distribute millions of the sterile insects
2. The insect must be of the type which will readily disperse, so that the sterile males will be as readily accessible to the females in nature as the competing fertile males.
3. Sterilization must not seriously affect the mating behavior or longevity of the sterile males
4. The females must normally mate only once. If females mate more frequently, the spermatozoa from sterile males must be be produced in essentially the same number and compete favorably with those from fertile males. The recent eradica-

tion of the multiple-mating melon fly on the island of Rota by the sterile-male technique has demonstrated that frequent mating will not be an obstacle (USDA, 1963)].

5. There must be an inheritant or induced low population of the pest for it to be feasible to rear and release enough sterile males to overflood the population.

The large expenditures and technical specialization involved in mass rearing, irradiation, and release of millions of sterile males place this technique beyond the reach of farmers as a routine control measure. It can be considered only as a government-operated eradication program. The possibility of eradicating rice stem borers by this technique will be evaluated in relation to the above criteria.

Mass rearing of stern borers has not yet been achieved but is probably feasible, at least for Chilo. Investigations in Japan and at IRRI indicate that Chilo can be reared on aritificial media. To date, this has not been possible for Tryporyza. Adaptation of current methods for Chilo to large scale, mass rearing would probably be possible. However, such factors as the relatively long and irregular larval development of stem borers would make their rearing in large numbers a much more difficult task than that involved with the screwworm or fruit fly. The distribution of the rather fragile pupae over inundated areas also presents a formidable obstacle.

To the writer's knowledge, nothing is known about the effects of a sterilizing dose of radiation on the activity and sexual vigor of male borer adults nor has any report been seen as to whether or not the females mate more than once. Such detailed biological information would have to be obtained after an analysis of other factors indicated that this technique warranted further attention.

Probably the chief deterrent to the eradication of rice stem borers by male sterilization is the relatively high numbers of adults normally present per unit area in the field. Assuming a conservative 5 percent of tillers infested, 10 tillers per hill, 25 x 25 cm spacing, immature development of 4 weeks, male longevity of 1 week, and a 1:1 sex ratio, the calculated number of male adults emerging per week would be 1,000,000 per square kilometer of rice. By comparison, the natural population of screwworm fly males on Curacao was estimated at 100 per square mile (Knipling, 1960). The eradication of the screwworm fly from this tiny island (170 square miles) was achieved by releasing 400 sterile males per square mile weekly (Baunhover, et al., 1955). Even with such a low natural population, the eradication of the screwworm from 75,000 square miles in Florida and neighboring areas required the total release of 3 3/4 billion adult flies. These were reared on 6 1/3 million pounds of horse and whale meat (Smith, 1960). It is concluded, therefore, that the eradication of rice stem borers from even small islands by male sterilization is practically impossible at present population levels. If in the future, chemical and/or biological control methods made possible island-wide population reduction to low levels, the possible combined use of such methods with release of sterile males should be re-evaluated.

The preceding discussion of the utilization of sterility concerned only the mass release of sterile males, Interest has recently developed in the use of chemosterilants. The combination of some of these materials with a powerful attractant may make possible the sterilization of field populations. This approach appears to be more feasible for rice stem borers than the sterile-male release method and should be investigated.

B. Attractants

1. Light

Light attracts the adults of the major species of rice stem borers. Light traps have been employed usefully for a long time as a method of rice stem borer assessment. This method is particularly useful in countries such as Japan and Taiwan, where there are distinct broods, to detect major moth flights for timing insecticidal applications. Although various workers have attempted and advocated trapping as a direct control method, it is now gederally considered to be impractical.

2. Chemical attractants

a. Sex lures

Animals secrete a variety of chemical substances which influence the behavior of other animals. Wilson (1963) referred to these as "pheromones" and reviewed the current knowledge about the substances insects produce. Among the most common pheromones in insects are the sex attractants. These chemicals, emitted from the bodies of females in certain species, assist males in locating a mate. These chemicals are specific and powerful. Those of the silkworm and the gypsy moth have been studied in most detail, Jacobson et al. (1961) isolated the attractants from the gypsy moth and synthesized a chemically similar compound which effectively attracted male moths of this species. To obtain 20 milligrams of the attractant ("gyplure"), it was necessary to process the abdominal tips of 500,000 virgin females. Each moth yielded about .01 microgram of gyplure. They found that this material was attractive in the field at the infinitesimal dose of 10^{-7} micrograms, Wilson (1963) calculated that, with a breeze of 100 cm per second, a single moth would advertise her presence over an ellipsoidal area up to 200 meters wide and 4 1/2 kilometers long.

The only information noted about sex attractants in rice borers was the study by Kaburaki et al. (1939), indicating that Chilo suppressalis males are attracted to females. Further research in this field should be conducted. If a sex attractant can be isolated from rice stem borers, it should be tested as a lure, either in traps or mixed with a toxicant or chemosterilant, to effect control through male depletion or sterilization.

b. Other Chemical Attractants

A number of chemicals, other than those produced by insects, have been found to attract specific insects and are useful as lures in traps or in toxic baits. Investigations along this line have been conducted, chiefly with fruit flies. Methyl eugenol proved to be a strong attractant for males of the oriental fruit fly. Male flies alight on the treated surfaces and avidly eat the methyl eugenol. A mixture of this material and a toxic chemical as a bait resulted in the eradication of the oriental fruit fly from the small Pacific island of Rota (USDA, 1963).

Screening of possible attractants to stem borer adults is a suggested possible research project. If an effective and relatively inexpensive attractant can be found, it would be useful in detection and possibly, control.

<u>Use of Natural Control Agents</u>

A. Pathogens

Insects, like other organisms, are the victims of a variety of pathogenic diseases. The first case of animal disease experimentally shown to be caused by a microorganism was an insect fungus disease, <u>Beauveria bassiana,</u> on the silkworm described by Bassi in 1834. However, Insect Pathology, as a distinct, formal discipline is only about 20 years old. Consequently, our knowledge of insect disease is limited. Steinhaus (1960) stated that about 1,100 species of pathogens (80 bacteria, 215 viruses, 460 fungi, 250 protozoa, and 100 nematodes) have been reported from insects and that this is probably only a small proportion of what actually exists. The study of these diseases is of more than academic interest. Several diseases have been used in insect control, and at least two are now available in commercial preparations.

In general, the disease organisms used in pest control have been native or cosmopolitan species. An exception is the introduction of viruses of forest sawflies from Europe to the United States and Canada. In this case, however, the spraying of forests with the virus preparations had the same beneficial effect in the native habitat in Europe as in North America (Franz, 1961). Most applications of disease organisms have not resulted in epizootics and, therefore, have reduced pest populations only temporarily, behaving merely as "microbial" insecticides. One exception has been the use of milky disease of Japanese beetles. This gives localized permanent control; the residual spores from diseased grubs kill the immigrating grubs. The forest sawfly viruses also have shown some spread by natural means from one year to the next (Bird, 1953). Steinhaus (1960) believed that, although pathogens have mostly been used to date as microbial insecticides, more attention would in the future be given to the introduction and colonization of pathogens for long-lasting results. The properties of each of the major types of pathogens and how they relate to rice stem borers are discussed below:

2. <u>Viruses</u>

Viruses have a great potential in biological control because of their high virulence, remarkable durability, high specificity, and relative safety (Steinhaus, 1960). Their chief disadvantage is the difficulty in mass production because they require living cells for multiplication. For internal feeders such as stem borers, viruses have the added disadvantage in that infection takes place by ingestion. The only virus disease reported to date from graminaceous borers has been a granulosis disease of C. suppressalis on rice in Japan (Aizawa and Nakazato, 1963). This disease is reportedly found only rarely in the field. It appears that virus diseases do not play a significant role in the natural control of rice stem borers.

2. Bacteria

Bacterial diseases have tile advantage of rapid action. Their ability to be cultured on artificial media and the spore-forming property of many species renders this group more suitable far mass production and distribution. Bacteria are usually less specific than viruses. The commercially produced Bacillus thuringiensis has a wide host range, especially among the Lepidoptera. However, as with viruses, the host larvae become infected with bacteria by feeding on contaminated tissue, which renders their use difficult in the case of stem borers. The only reference seen regarding natural infection of stem borers by a bacterial disease was that of Shiraki (1917) who reported larvae of T. incertulas suffering from an unidentified bacterial disease, possibly Stoleptococcus sp.

3. Fungi

The fungi generally have wide host ranges. They are sporadic and variable in their effect on insect populations, probably because they are so sensitive to environmental conditions. Generally, the fungi are effective only at high humidities. This group appears to have the greatest potential for stem borers, both because fungus diseases have been reported most often from stem borers and because the mode of infection is through the integument. A negative factor, however, is the fact that fungus diseases appear to do best at higher population densities than those of stem borers. The fungus diseases which have been reported of pyralid and noctuid borers of graminaceous crops are listed in Appendix C.

Except for Isaria farinosa in Japan, the percentage of parasitization was generally low, and these diseases were not reported as important mortality factors. I. farinosa infects a high percentage of hibernating larvae and pupae in Japan and is considered an important factor in regulating the population of the springbrood. However, as studies have shown that this fungus grows best on the body fluids of over-wintering larvae (Yasuda, 1960), it is of questionable value in tropical regions.

Because of the generally warm and humid cohditions prevailing in flooded paddy fields of the tropics, the conditions appear favorable for the use of fungus diseases. The fact that fungus diseases appear to play such a minor role in the regulation of borer populations in the field, however, suggests that, unless a more efficient fungus is discovered in and introduced from another area, the production and distribution of fungus diseases would at best have only a temporary effect.

The cosmopolitan fungus, Beauveria bassiana, has given moderately good control of the European corn borer when artificially cultured and applied to infested corn plants (Beal, et al., 1939). Dunn and Mabhulas (1963) believed that this fungus has good potential as a microbial insecticide. They indicated that it is probably not suitable for colonization and the production of epizootics, but can possibly be used for temporary control in the way that Bacillus thuringiensis is now being used.

4. Protozoa

Protozoan parasites are common in insects. They often do not kill the host but merely weaken it or reduce its longevity or fecundity. Affected insects become easier prey for predators, hence, are eaten and often go unnoticed. Protozoan parasites are still not well studied but they are considered a promising new field in biological control. Because they form resistant spores, it may be possible to use them as microbial insecticides (Weiser, 1958). They share with viruses the disadvantage of requiring living cells for multiplication. No protozoan diseases of stem borers have been reported. Their utility against this group does not appear promising, because, like viruses and bacteria, they infect the host through ingestion.

5. Nematodes

A great pumber of species of nematodes are known to attack insects. Steinhaus (1960) considered nematodes to be still largely unexplored but having vast potentialities. Little is know about the life history and mode of entry of many species, Although entrance is believed also to take place through the body wall, there is more evidence that eggs and young nemas gain entry by mouth (Sweetman, 1958). Several Bpecies have been reared on artificial media. Generally, the nematodes require free moisture, kill hosts quickly, have a broad host range, have a rather poor searching ability, can survive for long periods without hosts, and are resistant to insecticides (Schmiege, 1963). Nematode species reported from rice stem borers are listed below:

Species	Host	Country	Reference
Agamermis unka	C. suppressalis	Japan	204
Agamermis sp.	T. incertulas	India	154
Amphimermis zuimushi	C. suppressalis	Japan	184
Gordius sp.	T. incertulas	Taiwan	161
Mermia sp.	T. incertulas	Malaysia	138

In most of the references, the percentage of borers attacked was low. However, in a survey of paddy borer parasites in India, Rao (1964) found parasitic nematodes playing a major role in the natural control of T. incertulas in Kerala state during the months of July and August. In these months, up to 17.6 percent of the borer larvae were parasitized by nematodes. As future surveys reveal the relative importance and distribution of various parasitic nematode species, they should be considered for possible introduction in the same way as entomophagous insects.

It appears to be too early in the development of knowledge regarding insect pathogens to consider the feasibility of their use against rice stem borers. The information on pathogenic diseases of the borers is too spotty and incomplete to be concluaive. However, what is known at this point has negative implications. Borers are internal feeders; this largely protects them from pathogens or any organism without some mobility and searching capacity. Bucher (1958) pointed out that tunnelling and sucking insects do not lend themselves to control with diseases. Tanada and Reiner (1960) showed that the internal-feeding artichoke plume moth was susceptible to Bacillus thuringiensis, Beauveria bassiana, and a nematode in the laboratory. Yet none of these resulted in significant mortality when applied to infested plants in the field. Bucher (1958) also pointed out that diseases are most effective against insects which congregate or are present at high population densities. These conditions are not met with rice stem borers.

B. Entomophagous Insects

Parasitic and predatory insects are the most obvious and commonly reported natural control agents of rice stem borers. A consideration of how to manipulate these agents to decrease stem borer injury is of primary importance. This subject can be divided into the use of native and the use of exotic entomophagous insects. In making this distinction, the designation as native or exotic refers to natural distribution which is based on geographical rather than political boundaries. Thus, the transfer of a parasite from the Eastern United States to California, or from one island in the Philippines where it exists to another where it does not, must be classified as the use of exotic natural enemies.

1. Native

Biological control with native parasites and predators refers to their manipulation and use in their natural habitats. Before importing exotic biological control agents, it is logical to ask: What are the existing natural control agents, and how can they be made more effective? The use of native entomophagous insects can be discussed in three general categories:

a. Conservation
b. Augmentation
c. Artificial supplementation

Conservation involves actions aimed at protecting natural enemies of crop pests from destruction. Augmentation refers to promotion or intensification of natural enemy effectiveness by various practices which modify the environment in favor of the entomophagous insects. Both of these methods require far more knowledge of the ecology of the natural enemies than is generally available. The current interest in integrated control is stimulating more emphasis on this important aspect of natural control. More details regarding conservation and augmentation will be reviewed. below in discussions of the integration of biological and other control methods.

<u>Artificial supplementation</u> refers to the release of large numbers of a given species of parasite or predator to supplement seasonally low numbers or to produce better synchronization with host development. Natural enemies for such releases are obtained through mass rearing, accumulation, or field collection. Mass rearing is most common.

Phytophagous host and natural enemy population levels are in a state of dynamic equilibrium resulting from a complex interaction of environmental factors. To increase artificially the number of a given natural enemy species without changing any of the factors which caused it to be low can produce only temporary results. This does not necessarily mean that this practice is worthless, but its limitations must be recognized. If the inundative release of a certain parasite can increase the mortality of a given host long enough to halt an incipient harmful increase, this can be useful. Because of its temporary character, however, its merits must be weighed in relation to other temporary control methods. When effective, mass-released entomophagous insects have the advantage over insecticides of being selective, non-toxic, and of being able to seek out the pest in places difficult to reach with chemicals. Use of biological agents for temporary control is regulated primarily by the cost of producing the large numbers needed (Clausen, 1958). These costs should include the diversion of qualified staff from other biological control work and must be relatively competitive with the cost of chemical control. (Flanders (1949) and Fleshner (1959) have discussed thoroughly the details of mass-rearing techniques.

A major portion of all biological control work against tropical graminaceous borers has been the mass-culture and release of <u>Trichogramma</u> egg parasites. The choice of <u>Trichogramma</u> is probably due to a combination of the fact that this is the most common parasite of borers (and many other pests), and the fact that it can be reared on the eggs of several species of common, stored-products moth pests. Thus, it can be produced in large numbers in a small space, without highly specialized equipment, and at relatively low cost. This concludes its advantages. Trichogramma is short-lived and delicate, searches poorly, and is prone to superparasitism (i.e., the simultaneous parasitism of a host by more parasites than it can support). Consequently, the results of such releases varied greatly and provoked considerable controversy.

In the southern United States and Latin America, Trichogramma minutum hae been mass-produced and released for many years against Diatraea saccharalis on sugar cane. In Barbados, Tucker (1939) reported that after 20 years of release, the incidence of D. saccharalis was reduced by about one-half. Hinds and Spencer (1930) showed a much higher rate of parasitism in release as compared to check fields in Louisiana. They credited the release of 20,000 T. minutum parasites per acre from May 28 to June 24 with control of D. saccharalis. In Peru, Smyth (1939) observed marked reductions of borer incidence and damage in fields receiving artificially reared Trichogramma. Box (1951) reported that mass rearing and release of T. minutum against D. saccharalis for 20 years had not substantially reduced infestations in Peru. Wolcott (1943) reported the results of a 5-year investigation on the effects of mass releases of T. minutum against D. saccharalis in Puerto Rico. He concluded that such releases are useful only when a high host egg population is present. However, he found that when host egg populations were high, natural T. minutum populations usually increased rapidly, making artificial distribution unnecessary. He concluded that Trichogramma releases were useful only in the rare fields in which a high borer egg population was found without a corresponding abundance of parasitization. Box (1932) studied the results of Trichogramma releases in Antiqua and concluded that it was economically impractical.

In Malaya, large numbers of T. japonicum were reared and released in 1931–32 against rice stem borers. Up to 1,300,000 parasites were released per acre, but this activity was later discontinued as being economically impractical (Lever, 1955).

In India, Trichogramma releases have been made for years, but opinions differ as to their utility. Khan and Murthy (1955) noted that T. minutum releases against Tryporyza incertulas on rice in Hyderabad failed to give satisfactory results. However, Katiyar (1962) reported that T. minutum releases against Chilo partellus on corn and sugar cane had resulted in 93.1 percent parasitization in the release area as compared to 38.6 percent parasitization in a non-release area. Adding the other mortality factors, he calculated a 99.91 percent total mortality in the release area compared with 96.05 percent in the check. Subba Rao (1964) considered that the failures with Trichogramma releases to date may have resulted from the production of unnaturally weak parasites because of high rate of super parasitism in the laboratory cultures. He also believed that the parasites reared under artificial conditions were possibly not well adapted to conditions in the field.

Chen (1963) reported the results of releases of artificially reared T. australicum against sugarcane stalk borers in Taiwan. These trials, conducted on 2,000 hectares and repeated for more than 8 years, gave good results. From 1957 through 1960, approximately 40,000 parasites were released annually per hectare. In 1960, he observed 80 percent less bored joints and 62 percent less bored stalks in the release than in the control (check) areas. As insecticidal control of sugarcane stalk borers is difficult, he considered mass-rearing and release of Trichogramma the best control approach.

In Japan, T. japonicum was mass-produced and released against Chilo suppressalis on rice for a number of years but has been discontinued. Iyatomi and Sugino (1955) followed the percentages of parasitization of C. suppressalis eggs by T. japonicum from 1937–1940 and related these percentages to borer incidence. On the basis of these detailed studies, they considered mass release of T. japonicum to be ineffective. They found that a great number must be released to affect the percentage of parasitization and that this may have adverse effect on the parasitization in the succeeding generation. The cause of such adverse effects probably are explained by Iyatomi's later studies (1958). He found that when enough T. japonicum were released to produce more than 83.5 percent parasitization, the percentage of single parasitization decreased and super parasitism increased. He also showed that super parasitism decreased the vigor, size, and fecundity of the parasites. These tended to draw an artificially high parasite population down to its natural level.

The highly variable and apparently contradictory results obtained with Trichogramma against graminaceous borers point out an important factor in the artificial supplementation of native natural enemies. Because they are living organisms, their effect varies greatly in relation to many complex factors. Slight differences in rearing techniques, field environments, or host densities may greatly affect longevity, fecundity, mating habits, and degree of parasitization. The modification of highly adjusted biotic balances cannot be accomplished simply. Although it may be rather easy to rear millions of parasites, the task is far more complex than that. If artificial supplementation of native natural enemies is to give more consistent results, a good deal of effort in detailed ecological studies probably will be required. Where funds and competent personnel are limited, it would appear prudent to use these on projects with greater potential value. Although there is undeniable evidence that mass-reared Trichogramma can under the right conditions affect a substantial borer reduction, this is clearly temporary in nature. The result is seasonal damage control rather than permanent population control. The latter can be achieved only by introducing new natural control factors into the environment. Consequently, as far as biological control activities against rice stem borers in the immediate future are concerned, time and personnel should not be wasted on mass-rearing of Trichogramma. The principal efforts should instead be directed towards the importation of exotic natural enemies.

2. Exotic

Factors considered so far strongly suggest that the area of greatest potential value in the biological control of rice stem borers is the importation and colonization of entomophagous insects to regions in which they do not now occur. Establishment of exotic natural enemies will add new mortality factors to the existing environmental resistance of the stem borers. If successful, such introductions will result in permanent reductions of the stem borer population to a new equilibrium level at which crop losses will be less and other control practices leas frequently necessary. In consideration of the feasibility of such activities, it is necessary to review what is now known about the natural enemy fauna of the borers and the results of importations attempted to date.

a. Parasites

(1) Borer parasites reported to date

Earlier in this report, it was concluded that the rice stem borers had been established for such a long time in various countries that, for purposes of this study, they should be considered as native in each of these regions. Thus, any parasite importation program would involve a careful comparison of the parasitic fauna in each region and the subsequent exchange of promising species from regions in which they occur to those where they do not. As a basis for such consideration, what is now known about the world-wide parasitic fauna of pyralid and noctuid borers of rice and other tropical graminaceous crops is summarized in Appendices D, E, and F. This information represents a review of the literature and consultations with

Asian entomologists engaged in biological control activities. These lists are not complete and the writer cannot vouch for the identifications. As future national surveys are conducted, many species probably will be added and the distribution and host range of listed species expanded. As the confused taxonomic state of the various groups is worked out, some parasites reported here as separate species probably will be found to be the same. Many of the parasite species appear in the literature under several names. To avoid repetition, an attempt has been made to list these synonyms under the currently accepted names. These synonyms are based on statements to that effect in various references cited. In a number of cases in which the stage attacked was not given in the literature, the writer deduced this information from the known activity of related species, Where doubt remained as to the probable stage attacked, a question mark was inserted.

Appendix D lists all species reported from rice stem borers, many of which also attack borers of other graminaceous crops. The species listed in this table are clearly the most important parasite species for consideration in an importation program. As pointed out by Lloyd (1960), a parasite probably is attracted first to the plant attacked by its host, then to the particular phytophagous insect species. Consequently, if a given parasite species attacks a certain borer species in sugar cane but is never found on that species in rice, it is unlikely that it will be effective when introduced into another country againgt rice borers.

Appendix E lists parasites of pyralid and noctuid borers of other tropical graminaceous crops. Most of these are from sugar cane borers. Because sugar cane growers often are well organized and have long sponsored extensive research activities, much more work has been done on biological control of sugar cane borers than on rice stem borers. Consequently, some of the parasite species reported only from sugar cane also may occur unnoticed on related borer species of rice. The literature on sugar cane borers is particularly rich in dipterous parasites, which are generally lacking in the rice literature.

Appendix F summarizes distribution and host information from Appendices D and E for parasites reported from rice borers. Species occurring in Appendix D on which information was limited or questionable (i.e., species referred to in review articles for which no original reports were seen by the writer and species referred to many years ago and not reported in more recent reports from those regions) have been omitted. This appendix is presented as a tentative "shopping list" for those interested in parasite exchanges, Although future surveys will no doubt fill in some of the blank areas, the information in Appendix E tends to confirm the hypothesis that the parasitic fauna of the rice stem borers differ significantly from region to region. These interregional differences strongly suggest that biological control through importation of exotic parasites is feasible.

(2) The importance of rice stem borer parasites

The long list of parasites attacking rice stem borers (Appendix D) does not present an accurate picture of the role parasitization plays in the population dynamics of rice stem borers. Actually, although many species are involved, the percentage of parasitization throughout Asia is generally low. Although many references give percentages of parasitization, these vary extremely and fluctuate greatly depending on the host population. As few workers relate parasitization figures to host densities or other mortality factors, the percentage of parasitization figures are of limited value. However, a few generalizations can be made on the basis of a review of the references listed in Appendix D.

Egg parasitization figures vary the most. Kuwana's (1930b) report of 4 to 72 percent parasitization of C. suppressalis eggs by T. beneficiens and T. japonicum is typical. Low figures generally are recorded early in the season and high figures later in the season on high host-egg densities. This indicates'that egg parasites are probably important regulating factors at high borer population levels, but are less important in low or moderate populations than some of the high parasitization figures suggest.

Cendaña and Morallo (1960) reported an overall average larval parasitization of rice stem borers of 2.3 percent. This is typical of most figures from Asia. Rao (1964) reported similar and lower figures for parasites throughout India. Although many species of larval and pupal parasites were reported, their incidence generally was low. One exception was the tachinid, Sturmiopsis inferens, which parasitized up to 80 percent of Sesamia inferens, on graminaceous crops.

Information on parasitization of Diatraea saccharalis on rice in tropical America is limited but more encouraging, Scaramuzza (1933) reported 38.8 percent parasitization by Agathis stigmatera in Cuba. In British Guiana, Agrothereutes diatraeae has been reported parasitizing 50 percent of D. saccharalis when 2.8 percent of the stems were infested with this borer (Squire, 1936).

The highest larval and pupal parasitization appears to be in Africa. Appert (1953) reported that P. africana does little damage in Senegal, being held down by a Combination of at least six larval parasites (Bracon antennatus, Bracon sp., Apanteles sp., Rogas., Charops sp., and Elasmus tolli). He indicated that many counts had shown the overall larval parasitization to be approximately 75 percent. In Cameroun, Descamps (1956) reported 25 percent parasitization of P. africana by 3 pupal parasites (Calocentrus sp., Tetrastichus soudanensis and Hyperchalcida soudanensis) and 60 percent larval and pupal parasitization of Adelpherupa sp. by the pteromalid wasp Dinarmus sp. In Sierra Leone (Jordan, 1964), the population of rice stem borers in 1963 was low. The few lepidopterous borers found in a preliminary investigation apparently were highly parasitized. Identification of the borer and parasite species involved is in progress. This situation should be carefully investigated because of the potentially important implications for rice stem borer control elsewhere.

b. Predators

There are few references in the literature to predators of borers of rice or other graminaceous crops. Shiraki (1917), in his monograph on Tryporyza incertulas in Taiwan, described several predators. Two of these, Pheidole noda Smith and Tetramorium quineense F., were ants which were active chiefly when there was no water in the fields. He considered the former, which fed on both eggs and larvae, an important natural enemy. The latter fed on young larvae in their tunnels. He also reported a chloropid fly (Anatrichus erinaceous Lw.) and two staphylinid beetles (Paederus idae Lewis and P. mixtus Sharp) as predators. Wyatt (1957) reported another species of Paederus (P. fuscipes) as a predator of rice stem borers in Malaya. An anthocorid bug, Euspudaeus sp. has been reported as an important predator of Chilo suppressalis pupae and adults emerging after overwintering in rice straw (Oho, 1954). Another anthocorid (probably Scolopscelis parallelus Motsch.) was reported by Diakonoff (1941) as a predator of sugar cane borers in Indonesia. Spiders are considered to be important predators of rice stern borers in Japan (Yasumatsu, 1964).

In addition to these few scattered reports is a list of predators compiled by Walker (1959). As this list includes such broad spectrum predators as birds, frogs, and dragon flies, and contains no discussion as to the activity or relative importance of the listed species, it is difficult to use in formulating conclusions.

From the sparsity of reports of predators, one might conclude that they are unimportant in the natural control of stem borers. This may not be entirely true. Predators consume their prey and move on and therefore are less conspicuous and not as often implicated as parasites, which can be reared from their hosts. Therefore, they may be more important than they appear to be. Although predators may play a significant role in natural control of stem borers, there is little evidence pointing to any species as a potentially important exotic agent for introduction. The literature does not suggest any predator specific to or preferring borers over other prey. Having a broad host range gives a predator the advantage of being little affected by the temporary absence of a particular prey species. However, if the host range is too broad, the effect of the predatory activity is disippated over too many species for efficient control of any one. Predators generally have a longer life cycle than parasites and require far more prey to complete their development. As a consequence, they usually become effective control agents only at high host densities, such as found in aphid or scale populations. Unless future investigations reveal species specific to or preferring borers or borer eggs, predators are of little potential value as exotic biological control agents.

c . Hyperparasites

When entomophagous insects are reared from field-collected borers, they generally are assumed to be parasites of the borers. This is not always true. Some are actually hyperparasites which have consumed and emerged from primary borer parasites. The accidental importation of hyperparasites is one of the principal dangers in parasite importation work. Appendix G is a compilation of hyperparasites reported from pyralid and noctuid borers of graminaceous crops. It is given as a preliminary guide to species which should be avoided and not confused with primary parasites.

Most of these were reported by two workers (Risbec and Ghani from Sudan and Java). As there is no reason to believe that those countries have more hyperparasites than others, similar careful investigations no doubt will reveal many more and may change the status of some species listed as primary parasites in Appendices D–F. As indicated partially in Appendix G and discussed by Sweetman (1958), hyperparasites are most likely to be found in the following hymenopterous families: Chalcidae, Elasmidae , Encyrtidae, Eupelmidae, Eurytomidae, Pteromolidae, and Torymidae .

d. Importation attempted to date

(1) Against rice stem borers

A review of the literature reveals only a few attempts at establishment of exotic natural enemies for control of rice stem borers. The only one of these which can definitely be classified as a success was the control of Chilo suppressalis in Hawaii. This borer first appeared in Hawaii in 1928. It is thought to have been introduced with rice straw from the Orient. By 1929, 4,700 acres of rice were reported as severely affected. In addition, six species of wild grasses were attacked heavily by this species. In the same year, the following parasites were introduced against it:

Trichogramma japonicum (egg parasite) - from Japan
Bracon chinensis (larval ectoparasite) - from China
Eriborus sinicus (larval endoparasite) - from China

All of these species became established. By the following year, the rice harvest returned to normal. The rice stem borer has not been reported as a pest since, and since 1937 has not been found. The fact that the total rice acreage has been reduced in Hawaii to about 200 acres may be a factor (Swezey, 1931; Pemberton, 1948; Bess, 1964).

Bracon chinensis was introduced into Java from China for C. suppressalis control in 1929 and 1930 but did not become established (van der Goot, 1948; Jepson, 1954). Yet, Watanabe (1932) reported this species from S. inferens in Java. As B. chinensis has a rather wide distribution throughout much of Asia, it may have existed in Java previously. If so, then a different biological race may exist in Java which does not attack C. suppressalis.

Spathius fuscipennis a larval parasite of C. suppressalis from the Philippines, was introduced to Japan in 1928–30 without becoming established (Ishii, 1953).

Paratheresia claripalpis was sent to Malaya from Trinidad, where it is an important larval parasite of sugar cane borers. It was reared successfully in the laboratory in Malaya on the larvae of C. polychrysa. When it was released against this pest in rice fields, however, it was not recovered. Lever (1956) suggested that its failure to establish itself probably resulted from the fact that the rice plants were at the wrong stage of development and that T. incertulas instead of C. polychrysa was the dominant borer at the time of the release.

One attempt has been recorded in Africa. Pelerents (1957) reported that tachinid parasites were brought to the Belgian Congo from Nigeria to control the pyralid rice borer, Eldana sacchari Wlk. These were rendered ineffective, however, because of hyperparasitism by Encyrtus sp.

(2) Against other graminaceous borers

Extensive studies and many introduction attempts have been made in Latin America and the southern United States for biological control of D. saccharalis on sugar cane. The Cuban fly (Lixophaga diatraeae), a native of the Greater Aantilles, has been established successfully and exercises a significant degree of control in Antigue, Florida, and St. Kitts. It failed to become established in Barbados, British Guiana, Louisiana, Mexico, and Peru (James, 1947; Jepson, 1954; Clausen, 1956a; Abarca, et al., 1958; Simmonds, 1958). The Amazon fly (Metagonistylum minense), a parasite of D. saccharalis in its native habitat on wild marsh grasses in the Amazon basin, has been established and exercises some control over this pest in British Guiana, Florida, Puerto Rico and St. Lucia. Attempts at establishment have failed in Barbados, Cuba, Louisiana, Mexico, and Trinidad (James, 1947; Jepson, 1954; Clausen, 1956a; Abarca, et al., 1958). The results in British Guiana are noteworthy because they show that the effect on a pest of the addition of relatively small mortality factor may be considerable. In a survey of 2,000 sugar cane fields in 1952–53, Bates (1958) found a considerable reduction in the numbers of bored stalks and a great reduction in the proportion of this boring attributable to D. saccharalis, since the introduction of M. minense against this pest in 1933. This occurred in spite of the fact that the percentage of parasitization by the Amazon fly has never been great in British Guiana.

Another tachinid parasite, Parathesia claripalpis, has been found to exist as different biological races in several Latin American countries. Although attempts to establish it in other countries generally have failed, there is interesting activity in hybridization of the various strains to tailor its requirements to various conditions (Jepson, 1954). The introduction of several braconid parasites (Iphiaulex grenadensis, I. rimac, I. tucumanus) from their home to other countries in the Americas generally has been unsuccessful (Jaynes, 1933; 1938; Tucker, 1936; Dohanian, 1937). Another braconid, Agathis stigmaterus, has been established successfully in Puerto Rico and Florida but not in Louisiana and Barbados (Tucker, 1936; Jepson, 1954).

Several parasite species (Xanthopimpla stemmator, Apanteles flavipes, and Bracon albolineatus from Ceylon; Euvipio rufa from Madagascar; Lixophaga diatraeae and Metagonistylum minense from the West Indies) have been introduced against sugar cane borers in Mauritius (Vinson, 1942; Jepson, 1954). Of these, only X. stemmator has been established on cane borers. B. albolineatus has been recovered from Sesamia on rice but apparently without significant effect (Moutia and Courtois, 1952).

In the Philippines, three species of Trichogramma (T. australicum from Taiwan, T. japonicum from Japan, and T. minutum from the United States) have been introduced, mass-reared, and released against a number of pests, particularly borers of graminaceous crops. These all have been recovered in the field and are considered to be established (Baltazer, 1964a). T. australicum has been recovered from the eggs of sugar cane borers; T. japonicum from the eggs of C. suppressalis and T. incertulas on rice; and T. minutum from the eggs of many pests, including C. suppressalis on rice. The degree of control exercised by these species has not been determined. Earlier reports (Appendix D) that T. japonicum already was present in the Philippines complicate evaluation of its status. The Cuban fly also has been introduced from Taiwan and is being reared in the laboratory and released against sugar cane and rice borers. It is too early to know whether it has become established. If it should succeed in rice, this would be the first record of the Cuban fly attacking rice borers in the field. Attempts to establish the European corn borer parasite, Lydella stabulans griscens R. D., on sugar cane borers in the Philippines were unsuccessful (Baltazar, 1964a).

Ishida (1927) reported that Telenomus beneficies var. elongatus and Diatraeophaga stritialis were introduced into Taiwan from Java in 1916. D. stritialis failed to become established. A later report (Anonymous, 1928) listed T. beneficiens as parasitizing about 25 percent of stalk borer eggs in 1917, and 1918. In view of the questionable nature of T. beneficiens identifications (Yasumatsu, 1950) it is uncertain whether the later report referred to a native or introduced species. More recently, effort has been renewed to introduce foreign parasites of sugar cane borers in Taiwan. The Cuban fly was first introduced from Louisiana in 1955. After 5 years of laboratory propagation and field release (1958–1963), it appears to be well established, on C. infuscatella, parasitizing up to 32.6 percent with an average of 6 percent (Chen, 1963). Two other species, introduced later from India (1961–1963), also appear to be established in the field, though it is a bit too early to be certain of permanent eatablishment or to know how effective they will be. These are the ichneumonid ectoparasite, Isotima javensis, and the tachinid fly, Sturmiopsis inferens. Other species which have been released but not recovered are Metagonistylum minense, Paratheresia claripalpis and Agathis stigmaterus from tropical America, and Goniozus indicus, Rhaconotus scirpophagae, and Bracon hebetor from India.

A species of Apanteles was introduced from Japan to West Pakistan in July, 1962. It became established and spread rapidly as n parasite of C. partellus on corn. By the end of 1963, it was parasitizing up to 37 percent of this borer and was collected more than 80 miles from its release point (Ghani, 1964), The British Museum identified the introduced species as A. flavipes; Watanabe now believes that the Japanese species is actually A. chilonis (Yasumatsu, 1964). The A. flavipes native to West Pakistan was reported as attacking only Sesamia on wild hosts and not C. partellus on corn (Carl, 1962). Therefore, whether the introduced species is different from the native A. flavipes or not, it appears to be biologically different,

Integration of Biological Control with Other Control Methods

Most entomologists will agree that no single approach to insect control is adequate by itself. Each control method -- biological, chemical, cultural, or host plant resistance -- has its own deficiencies. The recognition of this fact and the acknowledgment that the various approaches to insect control are not mutually exclusive have led to recent interest in what is most commonly called the "integrated control" approach. With this approach, the field entomologist no longer considers the pest or the pest/host-plant interaction in a vacuum. Instead, he views their relation to their total environment, in order to integrate various control practices to complement each other.

An example of the useful combination of biological control and plant : resistance is that of thhe control of the wooly apple aphid in Australia. This pest attacks both the roots and foliage of the trees. The use of resistant variety effectively controlled the sub-surface infestations. Then, a parasite, (Aphelinus mali) was introduced from the United States which gave effective above-ground control (Wilson, 1960).

Probably the best known case of integrated control is that of the spotted alfalfa aphid in California. It is an excellent example of the results of a thorough study of all the factors involved and the blending of various types of control with careful consideration as to how they relate to each other. The spotted alfalfa aphid first appeared in California in 1954 and soon became a serious threat to the alfalfa crop. As a result, this pest became the focus of intensive research by various disciplines of applied entomology. Since that time, it has been reduced to a level of minor importance by integration of the following aspects of control (van den Bosch, et al., 1957; Hall and Dietrick, 1957; Lehman, et al., 1963; Peterson, 1963; Smith and Hagen, 1959; Stern and van den Bosch, 1959).

1. A selective aysternic insecticide was applied when, and only when the aphid population approached economic levels. The dosage of insecticide used was purpoeely low – just enough to reduce the aphids below economic levels without serioualy affecting natural enemies.

2. Fungus diseases were disseminated and augmented by changes in irrigation practices.

3. Resistant varieties of alfalfa were developed.

4. Strip-cutting was employed so as to preserve a supply of parasites and predators in the field.

5. Several species of parasites were introduced.

It is unlikely that biological control alone will effect complete control of rice stem borers. As other methods of control will probably also be necessary, how can these be integrated with biological control and each other? R. F. Smith (quoted by Peterson, 1963) has set down the following basic principles of integrated control:

1. Consider the ecosystem (i.e., the total complex of the organisms and their environment).

2. Utilize economic levels. Prophylactic or schedule treatments should be avoided and chemical control should not aim at complete local extermination.

3. Avoid disruptive actions. The pest population must be brought to sub-economic levels without upsetting the other parts of the ecosystem and thereby creating additional or more aerious problems.

The employment of these principles requires a thorough knowledge of the pest and its relation to its environment. Studies on the seasonal fluctuation of the pest and its natural enemies are essential. An example of such a study with rice borers is that of Yoshimeki and Sasaki (1954). The effects of various pesticides on the natural enemies must be known. The work of van der Laan (1951) on the egg parasites of T. innotata and T. incertulas is an example of this type of work. The current trend in Canada and Russia (Beirne, 1963) to find ways to modify practices to encourage existing natural enemies also is noteworthy. In such studies, for example, it has been determined that the longevity and fecundity of certain hymenopterous parasites are enhanced greatly by feeding the flowers of certain wild plants. Such studies with natural enemies of rice borers would certainly be desirable.

The stage already is being set for integrated control of rice stem borers. The use of systemic insecticides applied in the irrigation water for stem borer and leafhopper control is showing much promise in Japan and at The International Rice Research Institute, Philippines. This method will be much more compatible with biological control than foliar applications. The use of resistant varieties also shows considerable promise at The International Rice Research Institute. This is another way to reduce borer populations and economic losses which is compatible with natural control agents. If exotic natural enemies can be introduced which will effect a partial reduction in the borer population and resistant varieties planted, where possible, to reduce losses further, the need for chemical control should be lessened. If then, the insecticides are used only when necessary and are selected and applied so as to least disturb the natural enemies, truly integrated control can be achieved. One possible problem is that, if insecticides and resistant varieties are used to keep borer populations below the level which will incur economic injury in the white head stage, it may be difficult to maintain an effective natural enemy fauna at such low borer population levels. One possible solution is suggested in the observations that some varieties can support moderately high borer populations in the early stages of growth without corresponding crop loss (IRRI, 1963).

Conclusions

A review of biological control achieved against various crops pests shows the great benefits which already have been derived through manipulations of natural control factors in crop protection. It also shows that biological control activities fail rather frequently. A review of biological control principles as they relate to rice stern borers indicates several factors which favor and some which predicate against success. The relatively constant, equable climate in much of the Philippines and the practice of continuous rice culture appear well suited for biological control. The low borer papulation which can be economically tolerated will make it more difficult to achieve. The information available about natural enemies of rice stern borers and related borers reveals a large and diverse parasitic fauna in various regions. Now, all these factors must be brought together to form some conclusions about the feasibility of the biological control of rice stem borers.

To the question "is biological control of rice stem borers feasible, i. e. , possible of realization'?" there can be no direct answer based on a literature review alone, Whether successful results will be achieved can be determined only by trial. It would be naive to predict the results of the interaction of complex living organisms without experimentation. Consequently, the question to be asked in a feasibility study of this sort would more appropriately be "does the information available warrant the expenditure of resources on a biological control project". To this question, the writer concludes affirmatively. Indeed, the advantages of biological control are so great and the potential benefits so far reaching, that the question might best be put in the negative: "is the evidence against success, or are the potential dangers involved, great enough to warrant the omission of a biological control project from a well-rounded stem borer control research program?" Experimental research on biological control of rice stem borers must be done and it should be done where funds, personnel, and facilities are available to do it well.

The information available on parasite distribution and the results achieved with other borers suggest that, in a concerted program of introduction of exotic parasites, the chances for the establishment of some species are good. What degree of control these additional parasites will effect cannot be predicted. The fact that in Asian countries rather large parasitic fauna have been described from the borers with only a low degree of total parasitism suggests the possibility of a high degree of homeostasis evolved through long association. It is possible that the re-shuffling of some of these parasites within Asia may result in more effective parasitism. What appears even more promising is the introduction of new factors from related genera in Africa and tropical America.

Although the importation of exotic entomophagous parasites of rice stem borers is the factor which contributes most towards the feasibility of a biological control project, once the staff and facilities have been established, other related work also should be encouraged. Ecological studies aimed at finding cultural practices which will increase the effectiveness of native parasites is one such activity which may contribute valuable information towards an integrated program. Importation of parasites of other rice pests also could be conducted with the same facilities.

Experience clearly reveals that the degree af success achieved in biological control is related to the amount of effort put into it. Positive results should not be expected from haphazard or half-way efforts. A biological control project against rice stem borers should be a well-planned, concerted effort. To assist in the planning of such a project and to give administrative personnel an idea of what would be involved, some procedural considerations are discussed below.

Finally, it should be emphasized clearly that quick or sensational results should not be expected from a biological control project. While a drastic reduction in borer populations through parasite introductions is hoped for and may occur, subtle results are more likely. If success is achieved, it probably will come only after years of detailed studies and, possibly, initial discouraging results.

PROCEDURAL CONSIDERATIONS

The following discussion on the implementation of a rice stem borer biological control program is directed particularly to such project in the Philippines. Most aspects, however, also would apply to many other ricegrowing countries.

Activities

A. Survey

The first year of this project should be devoted chiefly to a thorough survey of natural control agents of rice stem borers throughout the Philippines. A detailed knowledge of the existing natural enemy fauna is an essential prerequisite to any importation. A lack of accurate preliminary survey data results in wasted effort and renders future evaluation difficult, if not impossible. Surveys reported by Delfinado (1959) and Cendatia and Morallo (1961) already provide valuable information on the natural enemy fauna of rice stem borers in the Philippines. This data must be supplemented witn a more extensive and detailed species census plus information on the degree of parasitization of the various borers under different environmental conditions and host population levels. To obtain this information, the following procedures are recommended:

1. Survey areas representative of all major ricegrowing regions in the Philippines at various stages of rice growth throughout an entire year. Select a few areas for further sampling in future years.

2. Record degree of parasitization by each species. Simmonds (1948) devised a formula to correct inherent errors in percentage of parasitization figures resulting from the removal of hosts from further possible attack and variations in duration of a given host stage because of parasitization. Parasitization figures for eggs should not be based merely on the numbers of host larvae and parasite adults which emerge. This produces errors because of egg mortality from other causes and the fact that one egg often contains more than one parasite. Iyatomi and Sugino (1955) presented a formula for determining the actual percentage of egg parasitization. In the case of egg parasitization, it also is important to record not only the total percentage of eggs parasitized but the proportion of individual egg masses destroyed.

3. Relate parasitization data to host borer population levels.

4. Sample in fields with various degrees of borer infestation. It is a natural tendency to sample the most severely attacked fields. If only such fields are inspected, important data will be lacking as to which parasite species are able to persist at low host population levels.

5. Sample in sprayed and unsprayed fields to ascertain the effects of insecticides on various natural enemies.

6. Examine field-collected larvae for signs of disease and isolate disease organisms. Diseases developing in larvae being reared under the artificial laboratory conditions probably are not typical of those which occur under field conditions.

7. Because of the danger of listing hyperparasites as primary parasites, confirm borer parasitism by questionable species by laboratory trials and cast-skin observations,

8. Attempt to determine the value of predators. This can be done by careful field observations of the feeding habits of various predators and by alimentary canal studies,

9. Have natural enemies identified by taxonomic specialists. Arrange with the most competent taxonomist in each taxonomic group to identify specimens as quickly as possible. From these determinations prepare an identified collection to facilitate routine local identification of the common species. Whenever the identity of a natural enemy is in doubt, give it a number designation and record data for that number until a species determination is made,

10. Prepare a key to enable field personnel to identify host species and the major parasite species in the immature stages.

B. Ecological Studies

Detailed ecological studies should be conducted on the natural enemy species which the field survey indicates are most important. These should be initiated as soon as possible after the major species are known, the techniques for the survey have been developed, and a routine established. A thorough knowledge of the ecology of the important native natural enemies is essential for several reasons:

1. To discover cultural or other practices which will encourage, augment or protect native natural enemies in an integrated control program.

2. As a basis for selecting exotic natural enemies.

3. For use by biological control workers in other countries who wish to exchange natural enemies and information.

The information obtained should, if possible, include data on:

1. Host range of parasite

2. Stage of host attacked

3. Duration of parasite life cycle as compared with that of host

4. Adult food habits, especially as related to longevity and fecundity

5. Adult behavior, (dispersal, mating habits, searching capacity, host selection, multiple parasitism)

6. Hyperparasitism

7. Insecticidal susceptibility

In addition to studies of the indigenous natural enemies, certain ccological studies of the borers are important prerequisites to parasite introductions. Particularly important to biological control operations is a better understanding of intraspecific competition among borer larvae and its relation to immature mortality. Closely related to this is the need for a better understanding of larval dispersion patterns. Such data would be useful in determining the best type of parasites to import. It generally is acknowledged that there is a high larval mortality in the first instar of C. suppressalis before the larvae enter the plant, and another mortality peak at a later stage, when the larvae migrate to other plants. As only a limited number can survive in a single stem, and crowding probably affects the degree of migration, a given percentage of parasitization may have drastically different effects on the net survival depending on whether it takes place in the egg, early larval, or later larval and pupal stages.

C. Natural Enemy Introductions

After a thorough survey has provided a fairly complete picture of the native parasitic fauna of the rice stem borers, this should be compared with what is known about the parasites existing in other countries and an introduction and colonization program should be initiated. The criteria for selecting parasites for importation will be discussed separately below. Here some of the mechanisms of introduction, rearing, and release will be reviewed.

1. <u>Introduction of Parasites</u>

a. Procurement. In the past many of the natural enemies introduced in biological control programs were coilected by the organization's ento— mologists on expeditions in foreign countries. Today, with trained entomology staffs working in most countries, arrangements frequently can be made, on an exchange or contract basis, to have entomologists in the country of origin collect material and send it to the recipient country. In many cases they also can supply useful ecological data about the parasites. Whenever possible, laboratory-reared material should be sent inetead of field-collected material to avoid introduction of hyperparasites.

b. Shipment. Transport of living natural enemies has been facilitated greatly by air travel. Most shipments are possible by air freight in a period of a few days. Whenever possible, an inactive stage, usually the pupa, is sent. When emergence is anticipated enroute, food and water must be provided for the adults. In any case, provision must be made to maintain proper humidity in the cage, and the package must be clearly marked to avoid exposure to extreme temperatures. Details regarding shipping containers and food substances must be developed for each species. Such details already have heen described for some of the major parasite species and are in tile references cited.

c. Reception. It is most important that authorities in recipient countries do not delay shipments of parasites in customs or quarantine. Before any biological control program is initiated in the Philippines, it is imperative that an agreement be reached with government authorities to permit beneficial insect shipments to be brought in without delay or being opened. When the living material arrives at the biological control laboratories, it must be opened in special quarantine facilities and transferred to other laboratories or the field only after proper precautions have been taken to avoid dissemination of hyperparasites or foreign host material. Such precautions are especially important when the material has been field-collected. If the parasites have been laboratory-reared in the country of origin, the dangers are minimized.

2. <u>Rearing</u>

a. Safety. Whenever possible, the parasites should be reared through at least one generation in the quarantine facilities to eliminate hyperparasites. Some parasites are extremely difficult to rear so this may not always be possible. If a parasite species does not lend itself to laboratory culture, it is best. not to introduce it. However, this rule may eliminate some potentially useful species. If field-collected larvae or pupae are received, the adults ahould at least be allowed to emerge in the laboratory and be segregated from hyperparasites before release.

b. Study. Additional rearing to study the biology of the parasites is highly desirable, especially if this has not been done in the country of origin. The same type of data suggested above for native species should be determined. The possibility of laboratory selection and hybridization to produce more adaptable or effective parasite strains also should be investigated.

c. Increase. A newly released parasite faces hazards of weather, natural enemies, inability to find a mate, and inability to find a host. For this reason, the chances for establishment and the rate of dispersal are improved if large numbers can be released. In some biological control programs, notably in California, imported parasites often are released by the millions. Yet some of the successful cases of biological control have been accomplished by the release of just a few individuals. Although millions usually may not be necessary the release of hundreds or thousands appear desirable. Consequently, it is useful to develop methods of rearing parasites in the laboratory for increase before release. Often this can be accomplished through use of a factitious host, Flanders (1949), Sweetman (1958), Chen and Hung (1959), Fleshner (1959), and Rao and Krishnaswamy (1961) give examples of some such methods.

3. Release

One of the most crucial steps in the importation of a biological control agent is its field release. If the agent is not adapted to its new country or host, no amount of pampering will bring about its establishment. However, the biological control worker must avoid a situation in which an exotic natural enemy which might have been successful fails to become established because of careless release methods. Many past failures in establishment probably can be attributed to release of agents in insufficient numhers or under unfavorable conditions. Flanders (1959) gave a number of useful suggestions regarding release of exotic agents. These included:

a. Make tile release under favorable meteorological conditions.

b. Make the release when the host is present in a susceptible stage.

c. Release against a static or increasing host population rather than against a declining population, if possible.

d. Release large numbers in sequences.

e. If only small numbers are available, release them in a confined area to facilitate mating, and protect them from predators, such as ants and spiders.

f. On a monoculture, make releases in areas with various stages of crop growth.

C. Evaluation of Results

A careful evaluation of the benefits, or lack of them, resulting from the introduction of natural enemies is an important aspect of biological control which often is done incompletely or initiated too late, For best results, evaluation studies should be started well in advance of parasite introciuctions. At the time of the pre-introduction Survey, areas slated to receive the introduction should be selected, Fields selected in these areas should be surveyed in greater detail than other fields to provide as complete and long a backlog as possible of information regarding borer populations and natural control factors. If such regular counts of the entire host and natural enemy fauna are started well before and continued after parasite releases, a clearer understanding regarding the effects of such releases on the borers and their native natural enemies will be possible. The Philippines, with its many islands, affords a splendid opportunity for such studies. The possibility should be explored at the outset of a biological control program of obtaining the cooperation of rice farmers on one or more small, conveniently located islands. If releases could be made first on such islands, the chances of establishment might be improved, the effect of such releases could be much better evaluated than on larger islands, and a ready source of material would be available for more extensive release of su— cessful agents.

Smith and De Bach (1942) pointed out the important fact that establish.-ment alone is not a sure sign of success. Even the destruction of large numbers of the host insect by the introduced agent does not necessarily affect the net survival of the host population, as the introduced agent may simply have replaced another mortality factor. This is why detailed evaluation studies are both important and difficult. The above workers indicated that the degree of control by the added factor should be determined by:

1. Gross field data indicating that its establishment and spread from place to place has been followed in each case by an appreciable decrease in host population.

2, Gross field data indicating that after the general establishment of the entomophagous species has taken place, the general host population level has remained at a much lower level than the average level before establishment.

3. Detailea experimental data showing a decidedly higher host sur-viva1 when protected in some way from attack by the introduced biological control agent (De Bach, 1958, suggests various ways of conducting such experiments). To satisfy points 1 and 2 above, accurate information on borer damage should be avail-able in the release areas for several years prior to parasite importation.

<u>Selection of Parasites for Introductions</u>

A. Type of Parasite

I. <u>Stage Attacked</u>

Generally an attempt is made to introduce parasites which will fill existing gaps in the parasitism sequence, to provide a full complement of natural enemies attacking the host' in each stage of its development. Which stages of rice stem borers are least attacked by indigenous parasites in the Philip–

pines will be better known after completion of the initial survey.

Egg parasites appear to be the most common and affecting the greatest percentage of parasitization of rice borers. Several species have been recorded in the Philippines. They are probably the chief biotic factor regulating the borer populations at high host population levels. However, the normally high larval mortality not attributable to parasites mxy be reduced by lessened competition resulting from a reduced egg hatch. Pickles (1936) demonstrated a direct correlation between the number of eggs per stool and tne larval mortality of Diatraea saccharalis on sugar cane. If this applies to rice borers, 25 percent egg parasitization would affect the reproduction rate of the borers much less than a similar rate by larval or pupal parasites. This is particularly true in the case of parasites which produce an average of 25 percent egg parasitization by parasitizing about one-fourth of each egg mass as opposed to those which produce the same percentage by destroying one in four egg masses entirely. Species of Trichrogramma are of the former type. Tetrastichus schoenobii, however has been reported always to kill all tile eggs in each mass of T. incertulas attacked (Shivashankara Sastry and Appana, 1959). This is a wide-spread species already present in the Philippines, However, it has been reported only from T. incertulas, except in India, where it has also been recorded from C. suppressalis, C. partellus, and S. inferens. If a species or strain of egg parasite can be established in the Philippines which will parasitize C. suppressalis eggs in this manner, it should be useful.

Egg parasites do not appear useful for Sesamia control since the eggs of the noctuid borers are protected under the leaf sheaths.

2. Other Qualities

Parasites which are highly host-specific are generally tnought to be most effective. Less specific parasites nave the advantage of being able to maintain themselves on other hosts when the target host or crop is temporarily absent or at a low level. However, in areas where rice is cultivated throughout the year and borers are usually present, a broad host range is not necessary, and a parasite which will concentrate its attack on rice stem borers is preferred. As the dominant species of borer attacking rice seems to vary with ihe region and season, parasites which will attack several species of rice borer would be most desirable.

As discussed above, populations of rice borers which can be economically tolerated are quite low, For this reason, emphasis should be placed on those parasite species which are effective at low host population levels.

Sweetman (1958) and Doutt (1950) discussed other useful criteria for choosing a biological control agent.

B. Source Country and Crop

A review of biological control attempts indicates that the chances for successful establishment are best if the exotic agent comes from a region having a climate similar to that of the recipient region. Although some parasites from temperate areas may prove to be effective, history and common sense dictate that the bulk of parasite introductions to the Philippines should be from tropical regions. Probably the best place to start would be from other islands in the Philippines. It is possible that differences in the parasite fauna of the borers have developed on isolated islands. If the preliminary survey reveals such differences, exchange of parasites between climatically similar regions on different islands should be attempted Regional differences in climate within the Philippines, especially regarding the severity of the dry season, also will have to be considered in selecting natural enemies. Those suitable for one region may not be adapted to another on the same island.

Priority also should be given to imports from tropical Africa where there appears to be a rich and somewhat more effective fauna of parasites of related rice borer genera. Several species from tropical America which have been reported as quite effective on D. saccharalis (e.g., Agathis stigmaterus and Agrothereutes diatraeae) also should be tested, Although species not occurring in the recipient legions probably will have priority, promising parasites with the same species designation as native parasites should not be neglected in introductions from other tropical Asian countries, as these may represent different biological races. Introductions should be made of parasites from different parts of their geographic ranges and these studied separately to detect differences in biological attributes which may affect their effectiveness in the field.

Parasites introduced against rice stem borers should come chiefly from borers on rice. Even if a parasite attacks the same species of borer on rice and another plant host, races may exist and the parasites collected on borers on rice will have the best chance of establishment.

C. Extent of Importation

How many species of parasites are to be introduced against a given host species is a common, pertinent question. If only a few species are introduced, the most effective may be overlooked. If many are introduced, unnecessary inter-. specific competition may result. Simmonds (1956) indicated that, as it is impossible to predict which biological control agent will be the most effective, as many as possible should be given a chance. This approach has been advocated and practiced by many other biological control workers. Smith (1929) discussed various types of competition and the possible adverse effects of multiple parasitism (i.e., the parasitization of a single host by more than one parasite, in many cases with only one surviving) resulting from the importation of more than one parasite species apparently occupying the same ecological niche. He concluded that such practices were not harmful but often advantageous because sudden environmental changes affecting one species are unlikely to affect the other in exactly the same way. Evidence favoring this view is found in the case of parasite introductions against the Mediterranean fruit fly in Hawaii (Sweetman, 1958). The four major species of parasites introduced against this pest are in close competition so that one is usually dominant. However, a stability has developed resulting from the face that in years when conditions are unfavorable for the dominant species, one of the others takes its place. As a result, the average incidence of infested fruit showed a marked decrease during the period of the study.

The same data, however, points out the dangers of multiple introductions. Opius humilus Silv. , which appeared at first to be superior, was greatly reduced after the other species became established, due to its inability to compete under conditions of multiple parasitism, No one can be sure of what effect this species alone would have had on the fruit fly population. Taylor (1937) I in his description of the biological control of the coconut leaf-mining beetle, gave another example in which the less desirable of two parasites was favored in competition between the two species.

Sweetman (1958) provides an example of the benefits of adding new natural enemies to an already complex system. A survey of sugar cane fields in Hawaii revealed 20 species of parasites and predators of the sugar cane leafhopper. Yet the leafhopper was inflicting heavy damage. The introduction of four additional parasites brought about a great reduction in leafhopper abundance. After the introduction of a fifth exotic agent, the leafhopper ceased to be an important pest.

A review of the literature reveals many cases in which a large number of introductions were necessary before a key control factor was found. Although it may be necessary to import many species before a degree of control is achieve, the introduction of all natural enemies of stem borers is not feasible and may be harmful. The careful choice of a few agents at a time, to be tested thoroughly before more are introduced, is recommended.

Facilities

A. Physical

The size and complexity of physical facilities will largely be governed by funds available and details can best be worked out by architects in consultation with the personnel who will use the facilities. The following are intended as general guidelines:

1. Quarantine reception facilities must be available. Packages containing parasite shipments should be opened here and preliminary studies conducted to avoid the introduction of hyperparasites and to establish the host relations of the exotic agents. The quarantine section should be a separate building or connected to the other facilities in a manner to provide maximum safety. Facilities to incinerate or otherwise dispose safely of foreign host plant material must be provided within the quarantine area. Safety features such as double-door entrance, well-sealed doors, and fine-mesh window screening should be installed to prevent the escape of any insects from the quarantine area. Several rooms in the quarantine facilities will enable the simultaneous study of material from more than one country. Preferably, these rooms should be so designed as to permit individual fumigation.

2. The main biological control facilities should provide space and equipment for rearing and biological studies of native and introduced natural enemies. Many small rooms are better than a few large rooms so that different species or races can be kept separate more easily. A larger area for mass-rearing operations also would be useful.

3. All facilities should be air-conditioned with temperature control and some degree of humidity control. Filters in the air ducts should be installed in a manner to prevent contamination from room to room or to the outside.

4. Greenhouse space should be available to supply host material.

5. Large, screened cages will be useful for limited, pre-release field studies.

B. Personnel

The biological control project should be headed by an entomologist trained and experienced in the handling, rearing, and study of live insects, He should be able to segregate and maintain cultures of biological races of parasites which are morphologically indistinguishable (Fleshner, 1959). He should have a thorough understanding of population dynamics and other aspects of insect ecology.

Included in the biological control staff, or readily available to it, should be a competent taxonomist. The proper identification of natural enemy and host species is an essential part of biological control activities. A number of past failures in biological control attempts are attributable to incorrect identification of native or exotic natural enemies. The best arrangement probably wald be to provide for the identification of specimens by taxonomists in various countries who are best qualified in the various groups, then to train a young entomologist (B. S. or M. S. in systematic entomology) by sending him to work for brief periods with each of the specialists. On his return, he should be competent to perform the necessary routine identifications, using a reference collection of specimens identified by the specialists.

If possible, one of the research assistants should be trained in microbiology to isolate and study insect pathogens. Several research assistants will be needed for biological studies and a field survey crew must be trained and assigned to various localities. The details and extent of such a staff will depend on availability of funds and qualified personnel.

International Cooperation

There are a number of national and international organizations in other countries engaged in biological control activities. Cooperation with such agencies is desirable and essential.

A cooperative project between Kyushu University in Japan and the University of Hawaii recently has been initiated for the purpose of biological control of rice stem borers. Their activities will be aimed chiefly at biological control in Japan, but the information and parasites they obtain also will be useful here. One member of this team is now beginning a 2-month study of rice borer parasites in Africa, and others are planning extensive surveys in Japan and Thailand. The results of these surveys will be pertinent to the biological control work here. Information and material obtained by a survey in the Philippines also will be useful to them. Therefore, arrangement for the exchange of information and material would be mutually profitable and avoid unnecessary duplication of effort.

The Commonwealth Institute of Biological Control has a number of stations over the world, The writer has visited the Asian stations (Bangalore, India; Rawalpindi, West Pakistan) and found them to be well equipped to conduct surveys and provide information and material. These stations are designed to serve various biological control operations. They are conducting extensive surveys of borer parasites in their respective countries and can conduct detailed biological studies, develop rearing and shipping techniques, and ship consignments of specific natural enemies on a cost basis. In countries where the C. I. B. C. has stations, it will be possible to obtain useful biological data on parasites before they are sent to the Philippines and, when desired, consignments of laboratory-reared parasites.

When staff and facilities are available, the rice stern borer biological control project in the Philippines also should be able to provide services to other countries. Parasite lists, ecological information on native parasites, and consignments of biological control agents should be made available to agencies in other countries. With such international cooperation, the biological control of rice stem borers may provide lasting benefits to rice farmers over the world.

APPENDIX A

Summary of cases of complete control of insect pests by introduction of exotic entomophagous insects.

Natural Enemy Introduction		General Category of:			Reference
To	From	Host plant	Pest	Natural enemy	
Australia	East U. S.	Apple	Wooly aphid	Parasitic wasp	72
Australia	Europe (?)	Grasses	Springtail	Predatory mite	178
Australia	California S. Africa	Fruit trees	Scale (black)	Parasitic wasp	211
Australia	Fiji	Coconut	Leaf-mining beetle	Parasitic wasp	211
Australia	California (?)	Grapes	Scale (vine)	Parasitic wasp	211
Australia	New Zealand	Ornamentals	Whitefly	Parasitic wasp	211
Br. Columbia	Nova Scotia	Apple	Mealybug	Parasitic wasp	121
California	Australia	Citrus	Cottony scale	Lady beetle predator	45
California	S. Africa	Ornamentals	Scale (nigra)	Parasitic wasp	43
California	?	Citrus	Scale (soft)	Parasitic wasp	69
California	Australia	Citrus	Mealybug (citrophilus)	Parasitic wasp	69
California	India	Alfalfa	Aphid (pea)	Parasitic wasp	176
Canada	Europe	Wheat	Sawfly	Parasitic wasp	121
Canada	England	Greenhouse ornamentals	Whitefly	Parasitic wasp	120
Canada & US	Europe	Ornamental tree	Leaf cater-pillar (Brown tail moth)	Parasitic wasp	45
Canada & US	Europe, Japan	Forest and ornamental trees	Leaf cater-pillar (Gypsy moth)	Parasitic wasp	45
Canada & US	Europe	Forest and ornamental trees	Leaf cater-pillar (Satin moth)	Parasitic fly and wasp	100
Ceylon	?	Coffee	Leaf cater-pillar	Parasitic wasp	187
Costa Rice	Malaya	Citrus	Blackfly	Parasitic wasp	43

Natural Introduction		General Category of:			Reference
To	From	Host plant	Pest	Natural enemy	
Cuba	Malaya	Citrus	Blackfly	Parasitic wasp	43
Egypt	Australia	Citrus	Cottony scale	Lady beetle predator	104
Egypt	England	Apples	Wooly aphid	Parasitic wasp	104
Egypt	Java	Ornamentals	Mealybug	Parasitic wasp and lady beetle predator	104
Europe (Southern)	Australia	Citrus	Cottony scale	Lady beetle predator	74
Fiji	Trinidad	Coconut	Scale	Lady beetle	185
Fiji	Malaya	Coconut	Leaf cater-pillar	Parasitic fly	189
Fiji	Java	Coconut	Leaf-mining beetle	Parasitic fly	186
Guam	Mexico	Citrus	Whitefly	Parasitic wasp	178
Guam	Philippines	Taro	Leafhopper	Predatory bug	75
Guam[1]	Japan	Corn	Borer	Parasitic fly	144
Guam	Australia (?)	Citrus	Cottony scale	Lady beetle predator	13
Hawaii	China, Japan	Rice	Stem borer (<u>Chilo</u>)	Parasitic wasp	179
Hawaii	Australia	Sugar cane	Leafhopper	Predaceous bug	142
Hawaii	Philippines	Sugar cane	Mealybug (pink)	Parasitic wasp	142
Hawaii	Philippines	Sugar cane	Mole cricket	Parasitic wasp	142
Hawaii	Australia California	Sugar cane	Aphids	Parasitic wasp and lady beetle predators	142
Hawaii	Philippines	Sugar cane	Beetle grubs	Parasitic wasp	142
Hawaii	Continental US	Sugar cane	Army worm	Parasitic wasp and fly	142

[1] Gave complete control for years then parasite suddenly disappeared and borer again became a pest.

Natural Enemy Introduction		General Category of:			Reference
To	From	Host plant	Pest	Natural Enemy	
Hawaii	New Guinea	Sugar cane	Beetle borer	Parasitic wasp	142
Hawaii	Philippines	Taro	Leafhopper	Predatory bug	75
Hawaii	Australia	Fern	Weevil	Parasitic wasp	142
Hawaii	Guam	Coconut	Scale	Lady beetle predators	142
Hawaii	Australia	Coffee, citrus, mango and other hosts	Bug	Parasitic wasp	142
Hawaii	Malaya	Various hosts	Grasshopper	Parasitic wasp	142
Hawaii	Mexico	Avocado	Mealybug	Parasitic wasp	142
India	Australia	Citrus	Cottony scale	Lady beetle predator	154
Japan	China	Citrus	Whitefly	Parasitic wasp	112
Madagascar	Australia	Eucalyptus	Weevil	Parasitic wasp	178
Mauritius	Australia	Eucalyptus	Weevil	Parasitic wasp	178
Mauritius	Ceylon, Java	Coconut	Scale	Lady beetle predator	126
Mauritius	Madagascar	Sugar cane	Rhinoceros beetle	Parasitic wasp	126
Mexico	India, Pakistan	Citrus	Blackfly	Parasitic wasp	47
New Zealand	Australia	Eucalyptus	Weevil	Parasitic wasp	178
New Zealand	United States	Oak	Scale	Parasitic wasp	124
New Zealand	United States	Apple	Wooly aphid	Parasitic wasp	124
Pakistan	Australia	Citrus	Cottony scale	Lady beetle predator	78
Panama	Malaya	Citrus	Blackfly	Parasitic wasp	43
Puerto Rico	?	Bamboo, papaya	Various scale	Lady beetle predator	213
Seychelles	India, East Africa	Coconut	4 spp. of scales	Lady beetle	202
South Africa	Australia	Eucalyptus	Weevil	Parasitic wasp	178
United States	Japan	Deciduous fruit	Mealybug	Parasitic wasp	51

APPENDIX B

Summary of cases of partial control of insect pests by introduction of exotic entomophagous insects.

Natural Enemy Introduction		General Category of:			Reference
To	From	Host plant	Pest	Natural Enemy	
Antigua	Cuba	Sugar cane	Stalk borer	Parasitic fly	22
Australia	Egypt	Vegetables	Stink bug	Parasitic wasp	98
Australia	Ceyion	Cabbage	Aphids	Parasitic wasp	98
Australia	Europe	Crucifiers	Leaf cater- pillars	Parasitic wasp	211
Australia	Egypt	Vegetables	Stink bug	Parasitic wasp	211
Br. Guiana	Brazil	Sugar cane	Stalkborer	Parasitic fly	131
California	Hong Kong	Fruit trees	Scale (purple)	Parasitic wasp	72
California	France	Olive	Scale	Parasitic wasp	61
California	Italy, France	Figs	Scale	Parasitic wasp	62
California	Sicily	Citrus	Mealybug	Parasitic wasp	69
California	South Africa	Citrus	Scale (black)	Parasitic wasp	66
California	China	Citrus	Scale (red)	Parasitic wasp	47
California	Japan	Citrus	Scale (Yellow)	Parasitic wasp	47
California	Australia	Avocado	Mealybug	Parasitic wasp	67
Canada	England	Forest	Sawfly	Parasitic wasp	119
Canada	Europe	Forest	Wooly aphid	Beetle predator	119
Canada	England	Forest	Scale	Parasitic wasp	79
Canada	England	Forest	Case worm	Parasitic wasp	80
Celebes	Java	Coconut	Leaf-mining beetle	Parasitic wasp	6
Europe	United States	Apple	Wooly aphid	Parasitic wasp	74
Europe (Southern)	?	Fruit trees	Mealybugs	Lady beetle predator	74
Europe	?	Peach	Scale	Parasitic wasp	74
Europe	?	Forest trees	Leaf cater- pillar (Gypsy moth)	Parasitic wasp	74

Natural Enemy Introduction		General Category of:			Reference
To	From	Host plant	Pest	Natural Enemy	
Europe	?		Scale	Parasitic wasp	74
Hawaii	Malaya	Fruits	Fruit fly (oriental)	Parasitic wasp	42
Hawaii	United States	Sugar cane	Army worm	Parasitic wasp	143
Hawaii	Philippines	Pineapple	Field cricket	Parasitic wasp	142
Hawaii	UnitedStates	Sweet potato	Leaf miner	Parasitic wasp	143
Hawaii	Philippines New Cele-donia	Household	Cockroaches	Parasitic wasp	142
Hawaii	Mexico	Beans	Sap-sucking bug	Parasitic wasp	143
Hawaii	California	Potatoes	Tuberworm	Parasitic wasp	143
Indonesia	New Zealand	Crucifers	Leaf cater-pillar	Parasitic wasp	164
Italy & France	E. United States	Mulberry	Scale	Parasitic wasp	149
Kenya	Uganda, Tan-ganyika	Coffee	Mealybug	Parasitic wasp	115
Mauritius	Java	Sugar cane	Beetle	Parasitic wasp	126
New Zealand	United States	Crucifers	Leaf cater-pillar	Parasitic wasp	127
New Zealand	Australia	Eucalyptus	Scale	Lady beetle predator	124
New Zealand	France	Pear	Leaf-cutting midge	Parasitic wasp	64
Philippines	Australia	Pineapple	Mealybug	Lady beetle predator	7
Russia	Israel	Citrus	Mealybug	Lacewing predator	74
Saipan	Java, Malaya	Coconut	Leaf-mining beetle	Parasitic wasp	60
St. Lucia	Brazil	Sugar cane	Stalk borer	Parasitic fly	21
United States	Europe	Forest trees	Sawflies	Parasitic wasp	74
U. S. (eastern	Japan	Ornamentals	Leaf cater-pillar	Parasitic wasp	63

Natural Enemy Introduction		General Category of:			Reference
To	From	Host plant	Pest	Natural Enemy	
U.S. (southern)	Hawaii	Sugar cane	Mealybug	Parasitic fly	142
U.S. (western)	Italy	Alfalfa	Weevil	Parasitic wasp	45

APPENDIX C

Fungus diseases of pyralid and noctuid borers of graminaceous crops.

Fungus	Host	Crop	Country	Reference
Aspergillus flavus	P. indicus	sugar cane	India	174
Asperfillus parasiticus	S. nivella	sugar cane	India	174
Aspergillus sp.	C. suppressalis	rice	Japan	184
Beauveria bassiana	S. nivella	sugar cane	India	154
Botrytis delacroixi	D. saccharalis	sugar cane	Argentina	96
Cordyceps sp.	C. suppressalis	rice	Philippines	154
Empusa-like fungus	D. lineolata	corn	Trinidad	106
Isaria (Cordyceps)	D. grandiosella	corn	Br. Guinea	53
Isaria (Cordycep)	C. suppressalis	rice	Japan	183
Mucor botryoides	D. saccharalis	sugar cane	Argentina Peru	96
Mycesoma sp.	S. inferens	rice	Japan	110
Spicaria soki	C. suppressallis	rice	Japan	184

APPENDIX D

Parasites reported from rice stem borers,

Parasite Species[1]	Host borer species on rice	Stage[2]	Distributions[3]	References
Diptera				
Bombyliidae				
Geron sp.	Saluria sp,	L	Cameroun	56
Tachinidae (Larvaevoridae)				
Sturmiopsi inferens Tns.	Sesamia inferens (Walk.)		India, Indonesia	103, 154
semiberbis (Bezzi) (Winthemia semiberbis)	Chilo (Chilotraea) auricilia[4] Dudgeon C. suppressalis) (Walk.) S. inferens		Java, India, Malaya	50, 99, 116
Phoridae				
Megaselia sp.	Tryporyza incertulas (Walk.)	L	China	122
Pipunculidae				
Pipunculus risbeci Seguy	Parerupa africana (Auriv.)	?	Sudan	156
Sarcophagidae				
Sarcophaga calicifera Boett.	Chilo (Chilotraea) polvchrvsa[4] (Meyr.)		Malaya	204
orientalis Part.	S. inferens (Walk.)		Malaya	204

[1] Names in parenthesis are other names by which the given species has been referred to in the literature.

[2] Stage of host parasitized. E = Egg, L = Larva, L-P = Parasite host laid egg in host larva and adult emerged from host pupa. P = Pupa (many reported as pupal parasites are probably of the L-P type.)

[3] Countries in parentheses indicated countries into which the parasite has been introduced.

[4] Names of Crambinae are taken from a recent revision by Bleszynski and Collins (1962).

Parasite Species	Host borer species on rice	Stage	Distributions	References
Hymenoptera				
Bethylidae				
Goniozus				
indicus Mues.	T. incertulas	L	India Philippines	24, 154
proceras Risbec	P. africana Saluria sp. Scirpophaga sp.		Cameroun	57
Braconidae				
Agathis				
stigmatera (Cresson)	Diatraea saccharalis (F.)		Argentina, Barbados, Brazil, Br. Guiana, Cuba, Dominican Repub– lic, (Florida), French Antilles, Grenada, Haiti, Peru, (Puerto Rico), St. Kitts, St, Lucia, St. Vincent, Trinidad, Venezuela, Jamaica	24, 52 97, 99 131
Apanteles				
boaris	C. auricilia	L	India	154
chilonis Munakata[5] (A. chilocida)	Chilo partellus (Swinhoe) C. suppressalis		Japan, (Pakistan)	218
flavipes Cam. (A. nonagriae) (A. simplicis)	C. suppressalis C. inferens T. incertulas T. innotata (Walk.)	L	Ceylon, India, Java, Malaya, Mauritius, Pakistan, Philippines, Queens- land, Taiwan, Thailand	24, 29, 77, 90 110, 113, 125, 138, 184, 203, 205, 209

[5]It is likely that A. chilonis and not A. flavipes is the proper name for this species in Japan and introduced from Japan to Pakistan (see text, page 43).

Parasite species	Host borer species on rice	Stage	Distribution	References
Braconidae (cont'd.)				
Apanteles				
procerae Risbec	P. africana	L	Sudan	156
ruficrus (Hal.)	P. africana	L	Australia, Cambodia, Cameroun, China, Egypt, Fiji, India, Japan, Java, Malaya, Philippines, Sudan, Taiwan	24, 8, 57, 122, 134, 156, 204,
schoenobii (Wilk.)	T. incertulas	L	India, Philippines, Thalland	29, 90 122
sesamiae Cam.	S. calmistis Hmpsn.	L	Cameroun, Kenya, South Africa, Tanganyika, Uganda	57, 87 135, 197
syleptae Ferr.	P. africana	L	Sudan	156
Aulosalphes unicolor (Ashm.)	C. suppressalis	L	Philippines	34
antennatus Granger	P. africana	L	Sudan, Senegal	5, 156
Bracon				
chinensis (Szeps.) (Amysoma chilocida) (A. chilonis) (A. chinensis) (B. albolineatus) (Microbracon chinensis) (M. chilocida) (M. chinensis)	C. auricilia C. partellus C. suppressalis T. incertulas S. inferens	L	Ceylon, China, (Hawaii), India, Japan, Java, ((Mauritius) Pakistan, Philippines, Taiwan, Thailand	24, 29, 31, 56, 86, 90, 99, 110, 125, 126 133, 154, 161, 179, 180, 203
onukii (Watanabe) (Microbracon onukii)	C. suppressalis	L	China, Japan, Korea	86, 204, 205
quadratinotatus Granger	S. inferens	L	Cameroun	57, 156
testaceorufatus Granger	Maliarpha separatella Rag.	L	Madagascar	25
Bracon sp.	T. incertulas	L	India, Pakistan	31, 188

Parasite Species	Host borer species on rice	Stage	Distributions	References
Braconidae (cont'd.)				
Chelonus curvimaculatus Cam.	P. africana	L	Senegal, Sudan	204
munakatae Munakata	C. suppressalis	L	China, Japan	86, 110, 182, 192
Chelonus sp.	T. incertulas	L	Pakistan	31
Hecabolus sp.	Rupela albinella (Cram.)	L	Br. Guiana	172
Merinotus sp.	C. suppressalis	L	India	177
Microgaster russata Hal. (Microplitus aomoriensis)	C. suppressalis T. incertulas	L	Japan	177, 205
Phanerotoma saussurei Kohl.	M. separatella	L	Madagascar	25
Rhaconotus niger (Szep.)	M. separatella	L	Madagascar	25
oryzae Wilk.	C. suppressalis T. incertulas	L	India, Java, Philippines	90, 122
schoenobivorus (Roh.) (R. schoenobii)	C. suppressalis T. incertulas	L	India, Java, Philippines	24, 34, 90, 154
nr. signipennis (Walk.)	T. incertulas	L	India	154
sudanensis Wilk.	?	L	Sierra Leone	101
Rogas sp.	C. suppressalis	L	Philippines	196
Rogas sp. (Rhogas sp.)	P. africana	L	Senegal	5
Spathius fuscipennis Ashm.	C. suppressalis	L	Philippines	56, 91
Stenobracon deesae Cam.	C. suppressalis	L	India	123, 99, 154
nicevillei (Bingh.) (S. trifasciatus) (S. maculata) (Macrocentrus javanicus) (Bracon nicevillei)	S. inferens T. incertulas T. innotata	L	China, India, Indonesia, Japan, Philippines, Taiwan	8, 38, 56, 90, 110, 113, 154, 180, 190

Parasite Species	Host borer species on rice	Stage	Distributions	References
Braconidae (cont'd.)				
Tropobracon schoenobii (Vier.) (T. luteus) (Shirakia dorsalis) (S. schoenobii)	C. auricilia C. suppressalis T. incertulas T. innotata	L	Cambodia, China, Indonesia, Japan, Pakistan, India, Philippines, Taiwan	8, 31, 34, 56, 110, 134, 152, 154, 161
Chalcididae				
Brachymeria feae Masi	Sesamia sp.	P	Nigeria	83
Hyperchalcida soudanensis Stef. (Euchalcida soudanensis)	P. africana	P L-P L	Cameroun Senegal, Sudan Uganda	57, 87, 156
Elasmidae				
Elasmus albopictus Cwfd.	T. incertulas	L	China, India	122, 154, 177
tolii Risbec	P. africana (may be hyperparasite)	?	Senegal	5
Eulophidae				
Cirrospilus sp. nr. ingenuus Gahan	C. polychrysa C. suppressalis	L-P	Malaya	116
Euplectrus sp.	C. suppressalis	L	India	154
Pediobius furvum (Gahan) (Pleurotropis furvum)	Sesamia sp.	L	Cameroun	57, 83
Pediobius sp.	C. partellus S. botanephaga Tams and Bowden S. calmistis Hmpsn.	L-P	Uganda	87
Syntomosphyrum israeli Kurian	T. incertulas	P	India	177
Tetrastichus atriclavus Wtstn.	Sesamia sp.	?	Nigeria	83

Parasite species	Host borer species on rice	Stage	Distribution	References
Eulophidae (cont'd.)				
Tetrastichus ayyari Rohw.	C. auricilia C. partellus C. suppressalis S. inferens	P	China, India, Philippines	34, 39, 86, 154
israeli (Mani and Kurian)	T. incertulas	P	India, Java	177
procerae Risbec	P. africana		Sudan	156,
schoenobii Ferr .	C. partellus C. suppressalis S. inferens T. incertulas I. innotata	E	Ceylon, China, India, Indo-China, Indonesia, Philippines, Thailand	24, 29, 90, 162, 188, 201
Trichospilus diatraeae Cherian and Margabandhu	S. inferens	P	India	154
Eurytomidae				
Eurytoma lepidopterae Risbec	Adelpherupa sp . P. africana Saluria sp.	L	Cameroun	57, 156
Eupelmidae				
Eupelmus sp.	C. auricilia	L	India	154
Ichneurnonidae				
Agrothereutes diatraeae (Myers) Spilocryptus diatraeae)	D. saccharalis	?	Br. Guiana	24, 172, 191
Amauromorpha accepta accepta Tosquinet (Eripternimorpha scirpophagae)	T. incertulas T. innotata	L	India, Indonesia	154, 191
accepta metathoracica	T. incertulas	L	China, Java, Philippines, Thailand	34, 90, 191

Parasite species	Host borer species on rice	Stage	Distribution	References
Ichneumonidae (cont'd.)				
Amauromorpha accepta schoenibii Vier. (Eripternimorpha schoenobii) (Amauromorpha schoenobii) (A. metathoracica schoenobii)	C. auricilia C. partellus C. suppressalis S. inferens T. incertulas T. innotata	L	India, Japan, Java, Philip- pines, Taiwan	24, 56 110, 154
Caleocentrus sp.	P. africana	P	Cameroun	57
Centeterus alternecoloratus Cush.	C. auricilia C. suppressalis	L	China, India	90, 154, 192
Charops sp.	P. africana	L	Cameroun, Senegal, Sudan	5, 57, 156
Cryptus sp. (Trachysphyrus sp.)	C. suppressalis	L	Philippines	147
Diadegma akoensis (Shir.) (Eripternus akoensis) (Horogenes akoensis) (Angitia akoensis) (Nythobia akoensis)	T. incertulas	L	Taiwan	161, 191
Eriborus giganteus (Szep.)	S. inferens (Walk.) T. incertulas	?	China, Europe, Micronesia, USA	191
sinicus (Holmg.) (Angitia lineata) (A. chilonis) (Nythobia lineata) (N. chilonis) (Horogenes lineatus) (Trathala flavopedes)	C. suppressalis T. incertulas	L	China, (Hawaii), Japan, Philippines,	24, 56, 90, 161, 179, 180, 190, 191, 192
Goryphus apicalis Holmg.	C. suppressalis	L	Java, Philippines,	90, 191,
basilaris Holmg. (Exetastes longicornis) (Mesostenus longicornis)	C. suppressalis	L	China, Ryukus Taiwan	24, 90, 191

Parasite species	Host borer species on rice	Stage	Distribution	References
Ichneumonidae (cont'd.)				
Goryphus mesoxanthus maculipennis (Cam.) (G. maculipennis)	T. incertulas	L	India, Indonesia, Malaysia	122, 191
ornatipennis Cam. (Melcha ornatipemis)	T. incertulas	L	India	156
Isochnojoppa luteator (F.)	T. incertulas	L	Australia, Burma, Celebes, Ceylon, China, India, Indonesia, Japan, Malaysia, Taiwan, Philip- pines	152, 191
Isotima dammermani (Rohw.) (Eripternimorpha dammermani) (Grambroides dammermani)	T. incertulas T. innotata	L	India, Java, Philippines	90, 99, 113, 154
javensis (Rohw.) (Eripternimorpha javensis)	T. incertulas	L	India, Java, (Taiwan)	2, 81, 154, 155
Itoplectis naranyae (Ashm.) (Nesopimpla naranyae)	C. suppressalis	L	China, (Hawaii) Japan, Mexico, Ryukus, Taiwan	180, 191
Temelucha biguttula (Mats.) (Cremastus biguttulus)	C. suppressalis	L	China, Japan, Hawaii, Taiwan	86, 111, 191
japonica Ashm. (Cremastus japonicus)	C. suppressalis	L	China, Japan	191
philippinensis Ashm.	C. suppressalis T. incertulas	L	Philippines	
shirakii (Sonan) (Crernastus shirakii) (Trathala shirakii)	T. incertulas	L	China, Japan,	56, 86, 171

Parasite species	Host borer species on rice	Stage	Distribution	References
Ichneumonidae (cont'd.)				
Temelucha sp. (Cremastus sp.)	S. inferens (Walk.) T. incertulas	L	India	154
Trathala flavo-orbitalis (Cam.) (Cremastus flavo-orbitalis) (C. biguttulus) (C. hymeniae) (Tarytia flavo-orbitalis)	C. suppressalis	L	Burma, Ceylon, China, (Fiji), (Guam), (Hawaii), India, Japan, Philippines, Singapore, Taiwan	24, 41 90, 153, 171, 182, 191
Xanthopimpla emaculata Szep. (X. enderleini)	C. suppressalis	P	India, Indonesia, Micronesia, Pakistan, Philippines	24, 56, 191
modesta (Smith) (X. kuchingensis)	C. suppressalis	L	Borneo, Celebes Indonesia, Philippines, Sarawak, Taiwan	56, 191
punctata (F.)	C. suppressalis	L	Afghanistan, Ceylon, China, India, Indonesia, Japan, Malaysia, Mauritius, Pakistan, Philippines, Ryukus, Taiwan	41, 56, 191
punctator (L.) (X. pedator)	C. suppressalis	?	Borneo, Celebes, China, India, Indonesia	191
stemmator (Thnbg.) (X. nursei)	C. suppressalis	L	Borneo, Ceylon, China, India, Java, (Mauritius) Pakistan, Philippines, Ryukus	24, 31 34, 56, 77, 126, 180, 191
Mymaridae				
Lymaenon sp.	T. incertulas	?	Malaysia	140
Paranagrus optabilus Perk.	C. polychrysa	E	Malaysia	50, 138

Parasite species	Host borer species on rice	Stage	Distribution	References
Pteromalidae				
Dinarmus (2 spp.) (Bruchobius)	Adelpherupa sp.	L & P	Cameroun	57
Eupteromalus sp.	T. incerlulas	E & L	China, Malaysia	122, 140
Habrocytus sp.	T. incertulas	E	Java	90
Norbanus ruschkae (Masi)	C. suppressalis	?	Philippines	34
Prototrupidae				
Trissolucas soudanensis Ris.	P. africana	?	Sudan	156
Scelionidae				
Platytelenomus hylas Nixon	Sesamia sp.	E	Cameroun Mauritius	57, 125
Telenomus beneficiens (Zehnt.)[6] (Phanurus beneficiens) (Ceraphron beneficiens)	C. auricilia C. polychrysa C. suppressalis T. incertulas T. innotata	E	China, India, Indonesia, Japan, Malaysia, Mauritius, Philip-pines, Thailand (Taiwan)	24, 29 137, 161 162, 192, 195, 200 201, 217
dignoides Nixon	T. incertulas	E	Java, India, Pakistan, Taiwan	31, 154, 217
dignus (Gahan) (Telenomus beneficiens)	C. suppressalis T. incertulas T. innotata	E	Cambodia, China, India, Philip-pines, Japan	90, 122, 134, 154, 196, 217
rowani (Gahan)	T. incertulas	E	India, Indo-China Java, Philippines, Taiwan, Thailand, Japan	29, 90 134, 196, 217, 218
tolli Risbec	Scirpophaga sp.	E	Cameroun	57
ulyetti Nixon	Scirpophaga sp.	E	Cameroun	57

[6] Yasumatsu (1950) indicated that T. beneficiens was a parasite of only Scirpophaga nivella (F.) in Java, and possibly Taiwan, and that all other references to T. beneficiens were misidentifications of other Telenomus species especially T. dignus. Consequently, the status of the scelionid egg parasites of the borers in various countries needs to be re-examined.

Parasite species	Host borer species on rice	Stage	Distribution	References
Scelionidae (cont'd.)				
Telenomus sp.	M. separatella	E	Madagascar	25
Trichogrammatidae nr. Bloodiella sp.	Scirpophaga sp.	E	Cameroun	57
Trichogramma australicum Gir.	T. incertulas T. innotata	E	Madagascar, Indonesia, Mauritius, Philippines, Taiwan	30, 36, 113, 126, 150, 201
dendrolimi Mats.	C. suppressalis	E	China	86
japonicum Ashm. (T. chilonis) (T. nanum)	C. polychrysa C. suppressalis T. incertulas	E	China, (Hawaii) Indo-China, Indonesia, Japan, Philippines, Taiwan, Thailand	86, 90, 92, 110 111, 116, 122, 138, 140, 150, 161, 190, 192, 201
Trichogramma minutum Ril. (T. evanescens)	C. suppressalis	E	Central and S. America, Ceylon China, India, Malaya, (Philippines), U.S.A.	19, 24, 86, 95 105, 126, 139, 188, 214, 218
Xanthoatomus ethiopicus Ris.	P. africana Scirpophaga sp.	E	Cameroun	57

[7] Above synonyms are not settled.

[8] Recent studies by Burks (1964, personal communication) indicate that T. minutum does not occur in orient unless introduced from America. These species could be either japonicum, australicum, evanescens or semifumatum.

APPENDIX E

Parasites reported from pyralid and noctuid stalk borers of tropical graminaceous crops other than rice.[1]

Parasite species[2]	Host borer genus	Stage[3]	Distribution[4]	References
Diptera				
Empididae				
Drapetis sp.	Chilo	L	India	154
Tachinidae (Larvaevoridae)				
Diatraeophaga striatalis Tns. (Schistochilus aristatum)	Proceras	L	Java	77, 89
Jaynesleskia jaynesi (Aldr.) (Leskiomima jaynesi)	Diatraea	L	Argentina Colombia	24, 99
Leskiopalpus diadema Wied.	Diatraea	L	Brazil, Brit. Guiana, Trinidad, Venezuela	18, 23, 24, 95, 131
Lixophagaea diatsaeae (Tns.)	Diatraea	L	(Antigua), Cuba, Dominican Republic, (Florida) (Guadalupe) Haiti, Jamaica, (Peru) Puerto Rico (St. Kitts)	24, 45, 129, 157, 164

[1] Those parasites also reported from rice borers are indicated with asterisks (*). The asterisks are located wherever data has been omitted because it can be found under the same species in Appendix D.

[2] Names in parentheses areother names by which the given species has heen referred to in the literature.

[3] Stage of host from which parasite was obtained. E = Egg, L = Larvae, L-P = Parasite host laid egg in host larva and adult emerged from host pupa. P = Pupa (Many reported as pupal parasites are probably of the L-P type).

[4] Countries in parentheees indicate countries into which the parasite has been introduced.

Parasite species	Host borer genus	Stages	Distribution	References
Tachinidae (cont'd.)				
Metagonistylum minense Tns.	Diatraea	L	Brazil, (Br. Guiana), (Florida), Peru, (Puerto Rico), St. Lucia) (Venezuela)	9, 10, 24, 45, 95, 130, 165
Palpozenillia diatraeae Tns.	Diatraea	L	Brazil	24
palpalis (Aldr.)	Diatraea	L	Br. Guiana, Mexico, Venezuela	24
Paratheresia claripalpis (Wulp) (P. signifera) (Sarcophaga diatraeae) (Theresia claripalpis)	Chilo Diatraea	L	Argentina, Bolivia, Brazil, Br. Guiana, Colombia, Costa Rica, Guatemala, Mexico, Panama, Peru Trinidad, Venezuela	1, 23 24
Parkerella parva Tns.	Diatraea	L	Brazil	24
Parthenoleskia parkeri Tns.	Diatraea	L	Brazil	24
Sturmiopsis inferens Tns. (*)	Chilo, Sesamia Scirpophaga	L	*	*
Sarcophagidae				
Sarcodexia sternodontis Tns.	Diatraea	L	Cuba, Puerto Rico, Venezuela	24
Sarcophaga pedata Aldr.	Diatraea	L	Cuba	24
rapax Walk.	Diatraea	L	Louisiana, Puerto Rico, Cuba	24

Parasite species	Host borer genus	Stages	Distribution	References
Sarcophagidae (cont'd.)				
Sarcophaga *surrubea* Wulp.	*Diatraea*	L	Cuba	24
Bethylidae				
Goniozus *indicus* Mues.	*Chilo*, *Proceras* *Scirpophaga* *Sesamia*	L	*	*
Braconidae				
Agathis *parvifasciata* (Cam.)	*Diatraea*	L	*	*
sacchari (Myers				
stigmatera (Cresson) (*)	*Diatraea*	L	*	*
Apanteles *diatraeae* Mues.	*Diatraea*	L	Cuba, Fr. Antilles, Haiti, Jamaica, Mexico, St. Domingo, Trinidad	52, 53, 85, 106
flavipes Cam.	*Chilo*, *Diatraea* *Eucosma*, *Proceras*, *Sesamia*	L	*	*
guamensis (Holmg.)	*Sesamia*	L	Guam	204
impunctatus Mues.	*Diatraea*	L	U.S.A	24
ruficrus (Hal.)	*Sesamia*	L	*	*
sesamiae Cam.	*Chilo*, *Sesamia*	L	*	*
xanthopus (Ashm.)	*Diatraea*	L	Argentina, Brazil	24, 96
Bracon *brevicornis* Wesm.	*Chilo*, *Sesamia*	L	India, Morocco	76, 99 105
chinensis Szep. (*)	*Chilo*, *Proceras*, *Sesamia*	L	*	*
greeni Ashm.	*Scirpophaga*	L	India	154
Campyloneurus *erythrothorax* Szep.	*Proceras*	L	Java	77
saitis (Cam.)	*Proceras*	L	Java	77

Parasite species	Host borer	Stages	Distribution	References
Braconidae (cont'd.)				
Chelonus				
albicinctus Ashm.	Eucosma	L	Philippines	24
narayani Subba Rao	Emmalocera	L	India	154
pectinophorae Cushm. (C. nitobei)	Eucosma	L	Taiwan	24
sonorensis Cam.	Chilo	L	Mexico	24
Chelonus sp.	Chilo	L	Pakistan	31
Iphiaulax (Ipobracon)				
abancay (Wolc.)	Diatraea	L	Peru	24
amabilis (Brethes)	Diatraea	L	Argentina	24
dolens Cam.	Diatraea	L	Br. Guiana Trinidad	24
famulus ? (Bingh.)	Scirpophaga	L	India Philippines	24
grenadensis (Ashm.)	Diatraea	L	Br. Guiana, Dutch, Guiana, Peru, Trinidad, Venezuela	24, 95, 193
pennipes (Myers)	Diatraea	L	Br. Guiana	24
puberloides (Myers)	Diatraea	L	Br. Guiana	24
rimac (Wolcott)	Diatraea	L	Peru	97
saccharalis (Turner)	Diatraea	L	Br. Guiana	18
sikkimensis Cam.	Scirpophaga	L	India	154
tucumanus Brethes	Diatraea	L	Argentina	97
Macrocentrus				
jacobsoni Szep.	Scirpophaga	L	Formosa	206
nicevillei	Sesamia	L	India	154
Macrocentrus sp.	Proceras	L	Java	77
Macrocentrus sp.	Scirpophaga	L	Philippines	147
Rhaconotus				
roslinensis Lal	Bissetia Scirpophaga	L	India	24, 154
schoenobivorus (Roh.) (*)	Scirpophaga	L	*	*

Parasite species	Host borer genus	Stage	Distribution	References
Braconidae (cont'd.)				
Rhaconotus scirpophagae (Wilk.)	Bissetia, Emmalocera, Proceras, Scirpophaga	L	India, Java, Pakistan, Tanganyika	24, 31, 77, 208
signipennis (Walk)	Proceras	L	*	*
Rogas sp.	Chilo	L	*	*
Stenobracon deesae (Cam.) (*)	Chilo Scirpophaga Sesamia	L	*	*
karnalensis Lal	Scirpophaga	L	India	24
nicevillei (Bingham)	Chilo, Bissetia, Proceras, Scirpophaga	L	*	*
Tropobracon schoenobii (Vier) (*)	Sesamia	L	*	*
yokohamensis (Cam.)	Scirpophaga	L	Formosa	24
Chalcididae				
Spilochalcis dux (Walk.)	Diatraea	?	Br. Guiana, Mexico, Trinidad	19, 24
Brachymeria sp.	Scirpophaga	P	India	154
Hyperchalcida soudanensis Stefan	Chilo	L-P	*	*
Elasmidae				
Elasmus zehntneri Ferr.	Bissetia, Scirpophaga	L	India, Java Philippines Taiwan, Pakistan	24, 77, 151, 154
Elasmus sp.	Scirpophaga	L	Philippines	147
Eulophidae				
Pediobius sp.	Busseola, Chilo Sesamia	L–P	*	*
Tetrastichus ayyari Rohw.	Chilo, Sesamia Scirpophaga	P	*	*

Parasite species	Host borer genus	Stage	Distribution	References
Eulophidae (cont'd.)				
Tetrastichus israeli (Mani and Kurian)	Chilo	P	*	*
schoenobii Ferr.	Scirpophaga	E	*	*
Trichospilus diatraeae Cherian and Margabandhu	Sesamia	P	*	*
Trichospilus pupivora Ferr.	Proceras	?	Ceylon	126
Ichneumonidae				
Agrothereutes sp.	?	?	Java	77
Amauromorpha accepta accepta Tosq. (*)	Chilo Proceras		*	*
accepta schoenabii Vier. (*)	Scirpophaga		*	*
Anomalon sp.	Scirpophaga	?	India	154
nr. Chasmias sp.	Chilo	L–P	Uganda	87
Ctnichneumon sp.	?	P	Java	77
Enicospilus antankarus (Sauss.)	Proceras Sesamia	L	Mauritius	126
sakaguchii Mats and Uchida	Sesamia	L	Ryukus, Taiwan	180, 191
Enicospilus sp. (Amesopilus sp.	Sesamia	L	Madagascar	30
Eriborus sinicus (Holm.) (*)	Chilo Eucosma Sesamia	L	*	*
Goryphus basilaris Holmgr. (*)	Proceras Scirpophaga	L	*	*

Parasite species	Host borer genus	Stage	Distribution	References
Ichneurnonidae (cont'd.)				
Isotima chilonis Townes (Gambrus rufithorax) (Gambroides rufithorax)	Chilo Proceras	L–P	Taiwan	191
dammermani Rohw	Scirpophaga	L-P	*	*
javensis Rohw (*)	Proceras Scirpophaga	L-P	*	*
Isotima sp.	Chilo Bissetia Scirpophaga	L P	India,	31 154
Itoplectis naranyae (Ashm.)	Sesamia	L–P	*	*
Kriegeria sp.	Scirpophaga		India	154
Stauropoctonus mauritii (Sauss.)	Sesamia Proceras	L	Mauritius	126
Syzeuctus sp.	Chilo	L–P	Uganda	135
Syzeuctus sp.	Scirpophaga	L	India	154
Temelucha sp.+	Scirpophaga	L	*	*
Trathala flavo-orbitalis (Cam.) (*)	Chilo	L	*	*
Xanthopimpla citrina (Holmg.)	Proceras Sesamia	P	Mauritius	24
emaculata Szep. (*)	Sesamia	P	*	*
punctata F. (*)	Chilo		*	*
punctator L. (*)	Chilo Scirpophaga	P	*	*

Parasite species	Host borer genus	Stage	Distribution	References
Ichneumonidae (cont'd.)				
Xanthopimpla stemmator (Thunb.) (*)	Chilo Proceras Scirpophaga Sesamia	P	*	*
Scelionidae				
Platytelenomus hylas Nixon	Sesamia	E	*	*
Telenomus alecto (Cwfd.) (Prophanurus alecto) (Phanurus alecto)	Diatraea	E	Argentina, Br. Guiana, Colombia, Fr. Antilles, Grenada, Peru, Puerto Rico, St. Lucia, St. Vincent	24, 52, 95, 99
beneficiens[6] Zehnt. (*)	Chilo Proceras Scirpophaga Sesamia	E	*	*
dignoides Nixon	Scirpophaga	E	*	*
Trichogrammatidae				
Trichogramma australicum Gir.	Chilo Proceras	E	*	*
evanescens West.	Sesamia	E	Egypt, Europe	99, 130
japonicum Ashm. (*)	Chilo	E	*	*
minitum Ril. (*)	Diatraea	E	*	*
nanum Zehnt. (may be synonym of T. japonicum)	Chilo Eucosma Proceras	E	India, Indonesia Philippines, Taiwan	24, 99, 195

[6] See footnote 6, Appendix D, page 78.

Parasite species	Host borer genus	Stage	Distribution	References
Trichogrammatidae (cont'd.)				
Ufens niger (Ashm.)	Diatraea	E	Cuba, Puerto Rico	24

APPENDIX F

Summary of borer host and distribution of selected insect rice stern borer parasites.

Parasite species	Type Borer Host				Distribution[1]							
	Rice Stem borers		Other Graminaceous borers									
	Pyralids	Noctuids	Pyralids	Noctuids	Japan-Taiwan	China Mainland	Philippines	Indonesia	Indo-China, Thailand Malay Peninsula	Ceylon, India, Pakistan	Africa	Tropical America
Pipunculidae (Diptera)												
<u>Pipunculus risbeci</u>	x										x	
Tachinidae (Diptera)												
<u>Sturmiopsis inferens</u>		x	x	x				x		x		
<u>Sturmiopsis semiberbis</u>	x	x						x	x	x		
Bethylidae (Hymenoptera)												
<u>Goniozus</u> <u>indicus</u>	x		x	x			x			x		
<u>Goniozus</u> <u>proceras</u>	x										x	
Braconidae (Hymenoptera)												
<u>Agathis</u> <u>stigmatera</u>	x		x									x
<u>Apanteles</u> <u>boaris</u>	x									x		
<u>Apanteles</u> <u>flavipes</u>	x	x	x	x	x		x	x	x	x		
<u>Apanteles</u> <u>procerae</u>	x										x	
<u>Apanteles</u> <u>ruficrus</u>	x			x	x	x	x	x	x	x	x	
<u>Apanteles</u> <u>sesamiae</u>		x	x	x							x	

[1] Does not include countries to which the parasites have been purposely introduced.

Parasites species	Type Borer Host: Rice Stem borers: Pyralids	Type Borer Host: Rice Stem borers: Noctuids	Type Borer Host: Other Graminaceous borers: Pyralids	Type Borer Host: Other Graminaceous borers: Noctuids	Distribution: Japan-Taiwan	Distribution: China Mainland	Distribution: Philippines	Distribution: Indonesia	Distribution: Indo-China, Thailand Malay Peninsula	Distribution: Ceylon, India, Pakistan	Distribution: Africa	Distribution: Tropical America
Braconidae (Hymenoptera) (cont'd)												
Apanteles syleptae	x										x	
Aulosaphes unicolor	x						x					
Bracon antennatus	x										x	
Bracon chinensis	x	x	x	x	x	x	x	x	x	x		
Bracon quadratinotatus		x									x	
Bracon testaceorufatatus	x										x	
Chelonus munakatae	x				x	x						
Phanerotoma saussurei	x										x	
Rhaconotus niger	x										x	
Rhaconotus schoenobivorus	x		x				x	x		x		
Rhaconotus signipennis	x		x							x		
Rogas sp.	x										x	
Spathius fuscipennis	x						x					
Stenobracon deesae	x		x							x		
Stenobracon nicevillei	x	x	x	x	x	x	x	x		x		
Tropobracon schoenobii	x				x	x	x	x	x	x		

Parasite species	Type Borer Host: Rice Stem borers: Pyralids	Type Borer Host: Rice Stem borers: Noctuids	Type Borer Host: Other Graminaceous borers: Pyralids	Type Borer Host: Other Graminaceous borers: Noctuids	Distribution: Japan-Taiwan	China Mainland	Philippines	Indonesia	Indo-China, Thailand Malay Peninsula	Ceylon, India, Pakistan	Africa	Tropical America
Chalcidae (Hymenoptera)												
Brachymeria feae		x									x	
Hyperchalcida soudanensis	x		x								x	
Elasmus albopictus	x					x	x			x		
Eulophidae (Hymenoptera)												
Cirrospilus sp.	x								x			
Euplectrus sp.	x									x		
Pediobius furvum		x									x	
Pedobius sp.	x	x	x	x							x	
Tetrastichus atriclavus		x									x	
Tetrastichus ayyari	x	x	x	x		x	x			x		
Tetrastichus procerae	x										x	
Tetrastichus shoenobii	x	x	x		x	x	x	x	x	x		
Tetrastichus soudanensis	x										x	
Trichospilus diatraeae		x		x						x		
Eurytomidae (Hymenoptera)												
Eurytoma lepidopterae	x										x	
Eupelmidae												
Eupelmus sp.	x									x		

Parasite species	Type Borer Host: Rice Stem borers: Pyralids	Type Borer Host: Rice Stem borers: Noctuids	Type Borer Host: Other Gramina-ceous borers: Pyralids	Type Borer Host: Other Gramina-ceous borers: Noctuids	Distribution: Japan-Taiwan	Distribution: China Mainland	Distribution: Philippines	Distribution: Indonesia	Distribution: Indo-China, Thailand Malay Peninsula	Distribution: Ceylon, India, Pakistan	Distribution: Africa	Distribution: Tropical America
Ichneumonidae (Hymenoptera)												
Agrothereutes diatraeae	x											x
Amauromorpha accepta accepta	x							x		x		
A. a. metathoracica						x	x	x	x			
A. a. schoenobii	x	x	x		x		x	x		x		
Caleocentrus sp.											x	
Centeterus alternecolo-ratus	x					x				x		
Charops sp.	x										x	
Diadegma akoensis	x				x							
Eriborus sinicus	x		x	x	x	x	x					
Goryphus apicalis	x						x	x				
Goryphus basilaris	x		x		x	x						
Goryphus m. maculipennis	x							x	x	x		
Isotima dammermani	x		x				x	x		x		
Isotima javensis	x		x					x		x		
Temelucha biguttalus	x				x	x						
Temelucha japonica	x				x	x						
Temelucha philippinensis	x					x						
Temelucha shirakii	x				x	x	x					
Temelucha sp.	x	x								x		

Parasite species	Type Borer Host: Rice Stem borers		Type Borer Host: Other Gramina-ceous borers		Distribution							
	Pyralids	Noctuids	Pyralids	Noctuids	Japan-Taiwan	China Mainland	Philippines	Indonesia	Indo-China, Thailand Malay Peninsula	Ceylon, India, Pakistan	Africa	Tropical America
Ichneurnonidae (Hymenoptera)												
Trathala flavo-orbitalis	x				x	x	x		x	x		
Xanthopimpla emaculata	x			x			x	x		x		
Xanthopimpla modesta	x				x		x	x	x			
Xanthopimpla punctata	x		x		x	x	x	x	x	x		
Xanthopimpla punctator	x		x			x		x		x		
Xanthopimpla stemmator	x		x	x		x	x	x		x		
Pteromalidae (Hymenoptera)												
Bruchobius sp.	x										x	
Norbanus ruschkae	x						x					
Proctotrupidae (Hymenoptera)												
Trissolucus soudanensis	x										x	
Scelionidae												
Telenomus beneficiens	x		x	x	x	x	x	x	x	x		
Telenomus dignoides	x		x	x	x			x		x		
Telenomus dignus	x		x		x	x	x		x	x		
Telenomus rowani	x				x		x	x	x	x		
Telenomus tolli	x										x	
Telenomus ulyetii	x										x	
Trichogrammatidae (Hymenoptera)												
Nr. Bloodiella sp.	x										x	

Parasite species	Type Borer Host: Rice Stem borers – Pyralids	Type Borer Host: Rice Stem borers – Noctuids	Type Borer Host: Other Graminaceous borers – Pyralids	Type Borer Host: Other Graminaceous borers – Noctuids	Distribution: Japan-Taiwan	Distribution: China Mainland	Distribution: Philippines	Distribution: Indonesia	Distribution: Indo-China, Thailand Malay Peninsula	Distribution: Ceylon, India, Pakistan	Distribution: Africa	Distribution: Tropical America
Trichogrammatidae (Hymenoptera)												
Trichogramma australicum	x		x		x			x			x	
Trichogramma japonicum	x		x		x	x	x	x	x			
Trichoaramma minutum	x		x			x			x	x		x
Xanthoatomus aethiopicus	x										x	

APPENDIX G

Hyperparasites reported from graminaceous stem borer parasites.

Hyperparasite species	Parasite Host	Borer Host	Country	References
Braconidae:				
Chelonus curvimaculatus Cam.	Bracon antennatus	P. africana	Sudan	156
Perilitus sp.	Bracon antennatus	P. africana	Sudan	156
Chalcidae:				
Hockeria sp. nr. testaceitarsis Cam.	Diatraeophaga stritialis	P. saccharalis	Java	77
Diapridae:				
Trichopria cubensis Font.	P. claripalpis	D. saccharalis	Trinidad	159
Trichopria tachimidarum Fer.	Diatraeophaga stritiallis	P. saccharalis	Java	77
Scelionidae:				
Ceraphron braconiphaga Ghesq.	Apanteles ruficrus Apanteles syleptae Charops sp.	P. africana	Cameroun Sudan	57 156
Elasmidae:				
Elasmus senegalensis Ris.	Bracon antennatus	P. africana	Sudan	156
Elasmus tolli Ris.	Apanteles procerae Apanteles syleptae	P. africana	Sudan	156
Eulpelmidae				
Anastus sp.	Diatraeophaga	P. saccharalis	Java	77
Eulophidae				
Syntomosphyrum	Diatraeophaga stritialis	P. saccharalis	Java	77
Eurytornidae				
Eurgtoma browni	Braconidae	T. incertulas	India	154
Eurytoma sp.	?	C. suppressalis	Japan	90

Hyperparasite species	Parasite Host	Borer Host	Country	References
Pteromalidae				
Habrocytus sp.	?	C. suppressalis	Japan	90
Spalangia drosophilae Ashm.	P. claripalpis	D. saccharalis	Trinidad	159
Scelionidae				
Ceraphron fijiensis	Bracon sp.	T. incertulas	India	154

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