IMPLICATIONS OF AN UNINTENDED AREA-WIDE IPM FOR *CHILO SUPPRESSALIS* IN JAPAN

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ABSTRACT

This paper discusses the success of an unintended area-wide integrated pest management (IPM) for Chilo suppressalis in Japan. Chilo was considered as one of the country's major rice insect pests that caused significant yield loss during the pre-war period, along with Scirpophaga incertulas. Chilo population density declined through the years, which was believed to be caused by modern farming technologies associated with various improved agronomic practices, particularly farm mechanization, primarily aimed at increasing rice production and saving labor rather than decreasing Chilo population. Based on the case of Japan, the following are other factors associated with the low population of Chilo: a) the duration of the IPM scheme, either intended (planned) or unintended, that should at least cover a full decade (10 years); b) the width of the area that could cover population displacement of Chilo stem borers; and c) IPM of key pests could be implemented to complement modern farming technologies. It was also noted that environmental factors associated with the maintenance of low density of Chilo must be considered in developing rice management strategy to avoid extinction of the species which is not considered a pest anymore. This includes maintaining a balance between IPM and conservation of the paddy ecosystem, also known as the integrated biodiversity management (IBM).

Key words: *Chilo supressalis*, integrated pest management (IPM), rice insect pests, integrated biodiversity management (IBM)

INTRODUCTION

The integrated pest management (IPM) was defined by Smith and Reynolds (1966) as "a pest population management system that utilizes all suitable techniques in a compatible manner to reduce pest populations and maintain them at levels below those causing economic injury." The IPM definition involves three key concepts: first is the utilization of all available control techniques; second is the use of economic injury level for control decision; and third is maintenance of pest population density below the economic injury level (EIL). The EIL concept was originally developed with the objective of reducing insecticide use. Thus, EILs have always been an important factor in most application with insecticidal control measures (Pedigo *et al.* 1986). In addition, IPM was developed for implementation at the single-field level. Most of the decision-making tools, such as EILs and monitoring systems, were designed for single-field use (Norris *et al.* 2003).

In the single-field approach of IPM, the third concept on maintaining key pest population density below the EIL over a wide area for successive cropping seasons is very difficult to realize. This is because many pests are highly mobile and the occurrence in one field is likely to influence events in neighboring fields.

Knipling (1979) was an early proponent of the concept of insect pests' suppression in large areas, instead of the field-by-field approach of contemporary pest control programs. The area-wide pest management projects should a) be conducted on large geographic areas; b) be coordinated by organizations rather than by individual farmers; c) focus on reducing and maintaining key pest populations at acceptable low densities; and d) involve active grower participation through environmentally sound, effective, and economical approaches (Knipling 1979, Calkins 1996, Kogan 1998). Area-wide pest management projects use all of the technological tools available, including mating disruption by sex pheromone, biological control with parasitoids, predators and pathogens, the sterile insect technique, agricultural practices, and insecticides. Examples against codling moth, corn rootworm (*Diabrotica* spp.), cotton bollworm and Mediterranean fruit fly in the USA were found in those projects (Calkins 1996).

Temperate countries in Asia often encounter rainfall in huge rice fields. Unlike in the USA, most Asian rice growers are small-scale farmers with a limited area of fields. For example, the number of rice growers in Japan is 3.7 million, and 85% of the farmers are growing less than 1 ha of rice (Kiritani and Naba 1994). Hence, area-wide pest management projects in Asia, particularly in Japan, require a close coordination between farmers and organizers of the projects.

The terms strategy and tactic are the two fundamental components of any IPM system. In IPM, tactics are the methods available for pest control and ways to integrate them to manage the within-field pest population below the EIL specific to each grower. Strategies are the various ways the tactics are deployed to suppress and maintain the population under the EIL in a wide area for successive cropping seasons. Strategic approaches are necessary for many insect-borne virus diseases and for some mobile insects and nationwide key pests, and require the cooperation of farmers (Frans 1993). In extreme cases, some growers have to leave their farms free from insecticides either to secure the persistence or to propagate natural enemies in the locality concerned. Strategies might include monitoring or prediction, feasibility studies, and management or regulation strategies.

THE TWO SPECIES OF RICE BORERS

Control of rice insect pests has been the central problem among farmers in Asia who depend primarily on rice as a subsistence crop. In Japan, the endemic damage caused by the rice borers *Scirpophaga incertulas* (or *Scirpophaga*) and *Chilo suppressalis* (or *Chilo*) and the sudden occurrence of epidemics of the brown planthopper, *Nilaparvata lugens*, were the major causes of loss in rice yield during the pre-war period (Kiritani 1979). *Scirpophaga* is monophagous on rice having three generations per year and was widespread in Southern Japan, while *Chilo* is oligophagous having two generations that occur all over Japan.

The outbreaks of *Scirpophaga* were observed during 1945 to 1950 and again to a lesser extent in the early 1960s. The major factor responsible for the outbreaks was the staggered planting of rice. Suppression of *Scirpophaga* was conducted through late planting of rice and chemical control using BHC and parathion. It began to decrease sharply between the years 1952 and 1953; no measurable *Scripophaga* infestation has been reported since 1965 and it was believed to be extinct from Japan (Fig. 1).

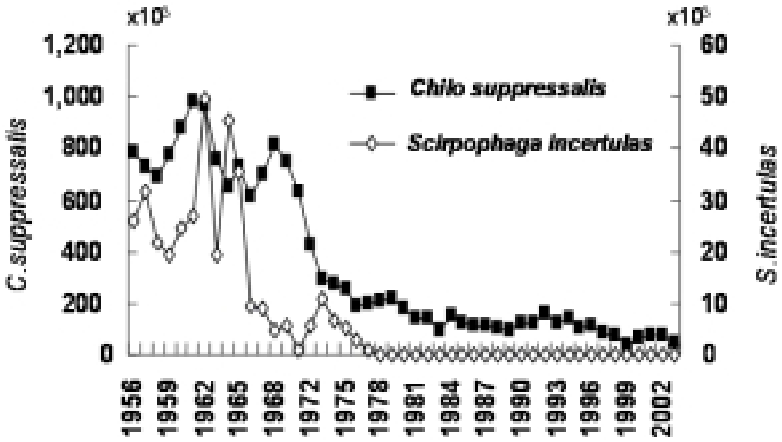

Fig. 1. Decline in hectarage of rice fields infested by borers.

The remarkable effect of insecticides in preventing borers' damage encouraged the nationwide campaign for chemical control. There have been some disputes about the role of insecticides in suppressing the *Chilo* population. For example, some localities in Shizuoka Prefecture conducted jointly the cooperative area-wide control of *Chilo* by treating farms with parathion twice a year for 10 consecutive years. As a result, the annual light-trap catches were reduced to around 1,000 moths as compared with over 4,000 moths before the initiation of the cooperative control (Miyashita 1982). Although pesticide treatment had been effective in protecting rice from *Chilo* larvae, there was a limitation in controlling the *Chilo* population itself.

DECLINE OF *CHILO* POPULATIONS IN JAPAN

This paper refers to *Chilo* as a case study of an area-wide IPM that has been unintentionally achieved in Japan. The decline in numbers of *Chilo* started 15 years after the decrease in the number of *Scirpophaga* occurred. The sign of the decreasing *Chilo* population was first observed in the early 1960s and further became evident in the 1970s. The decline is considered to have been induced by the following factors: a) the cultivation of early planted rice since 1955; b) replacement of heavy panicle-type varieties with panicle number types that have more tillers of slender, stiff, and short stalks since the late 1950s; c) use of BHC granules since 1960; d) two to three weeks early harvest of middle-season rice since 1960; e) increase in the amount of slag ($CaSiO3$) by two to three times since 1965; f) the mechanical harvesting with combined harvesters associated with burning straw since 1965; and g) the nursery tray insecticide treatment in association with machine planting since 1970 (Table 1).

Individually or jointly, these factors reduced the survival rate of either overwintering or growing larvae of *Chilo.* Except for the use of BHC granules, new technologies have been aimed mainly at increasing rice production and saving labor (Kiritani, 1979). From the early planting of rice in 1955 to the initiation of mechanization of rice culture in 1970, the decline of the Chilo population became evident in Japan after 15 years.

Table 1. Factors responsible for the population decrease in *Chilo suppressalis* (Kiritani, 1988).

Factors	Stage of larvae affected	Year
Cultivation of early planted rice	Overwintering larvae in the second generation	1955
Replacement of panicle weight type with panicle number type varieties*	Growing larvae of the first and second generations	1955
Use of BHC granules	Growing larvae of the first and second generations	1960
Utilization of stalks as manure for vinyl house culture	Overwintering larvae in the second generation	1960
Early harvest of middle season rice by 2-3 weeks	Overwintering larvae in the second generation	1960
Increase in amount of slug by 2-3 times	Growing larvae of the first and second generations	1965
Introduction of combined harvester in association with burning stalks	Overwintering larvae in the second generation	1965
Nursery tray insecticide treatment in association with machine planting	First generation larvae	1970

*Panicle weight type: big (heavy) panicles, but less in number of panicles.
Panicle number type: more panicles, but each panicle is smaller.

DECLINE OF *CHILO* IN TEMPERATE ASIAN COUNTRIES

Decreases in *Chilo* population were observed first in the early 1960s in Japan, followed by the same pattern in Taiwan, Korea and Guanzhou, China. Any decrease in abundance became evident first in the light trap catches, then in the reduction of the area infested by borers (Kiritani 1990 and 2005b).

As one of the indices of modern farming technology, the numbers of mechanized rice transplanters introduced in the following three countries were compared; the mechanization first began in Japan, followed by Taiwan, and Korea (Kiritani 1990). The decline in *Chilo* population occurred in this order as well. Among the factors contributing to the decline in the number *Chilo*, the early planting of rice was suggested to be a common factor being associated with various agronomic practices, especially the utilization of machinery which further accelerated the decline in the number of *Chilo* over an extended area (Kiritani 1990).

MECHANISM THAT MAINTAINS LOW DENSITY OF *CHILO* WITHOUT EXTINCTION

Effects of withdrawal of insecticidal control against the first generation of *Chilo* in 17 ha paddy fields for five successive years were examined in terms of the percentage of injured sheaths caused by *Chilo* (Table 2). Apparently, the results showed no significant difference in the percentage of injured sheaths from those in the conventional control areas (Emura and Kojima 1979). This indicated that some environmental factors other than the insecticides contribute to the maintenance of a low density of *Chilo*.

If an ever-decreasing trend of *Chilo* was to continue, the extinction of *Chilo* population could be expected locally somewhere in Japan. However, there has been no report of such local extinction. Therefore, it is reasonable to look for some density-dependent factors that are preventing *Chilo* from extinction.

Chemical control of *Chilo* also brought about a great change in its larval parasitoid complex. Specialists that include *Temelucha biguttula, Chelonus munakatae* and other species which had been predominant and were characterized by solitary parasitism with relatively narrow host range having one to two generations per year were replaced almost completely by a generalist, *Apanteles chilonis*, which is gregarious, polyphagous, and multivoltine. This change first took place in southern Japan in the late 1950s, several years earlier than in northern Japan, due to more intensive use of insecticides in the former region (Table 3) (Kiritani 1973).

Table 2. Comparison between the areas with and without insecticidal control in terms of injured sheaths caused by *C. suppressalis* in Niigata Prefecture (Emura and Kojima, 1979).

Year	No insecticide treatment (17 ha)	Conventional control area (1,200 ha)
1975	First year of experiment	First year of experiment
1976	2.5*	2.5*
1977	2.1	3.1
1978	2.0	3.5
1979	2.3	3.7

* Paddy fields were examined for injured sheaths before the chemical treatment.

Table 3. Time when *Apanteles chilonis* became dominant among larval parasitoids of *C. suppressalis* in Japan (Kiritani, 1988).

Prefecture	Time	References
Fukuoka	1955-57	Gyotoku 1960, Tateishi 1962
Fukui	1962	Tomonaga and Imamura 1966
Tochigi	around 1964	Katayama 1971
Aomori	1963	Toki, Fujimura and Fujita 1974

This paper presents data on the percentage of parasitism of overwintering *Chilo* larvae for 23 years in Aomori, a northern prefecture in Japan. Before 1964, when the moth catches exceeded 1,000 per year, the percentage of parasitized larvae showed a negative correlation with moth density as reflected in the numbers of the insects trapped. This relationship then became positive density-dependent after 1965, when catches fell to less than 1,000. This means a new regulatory mechanism or natural control by a larval parasitoid came into operation for *Chilo* populations, which were forced to fluctuate in a new lower domain of population dynamics (Fig. 2).

The current situation of *Chilo* can be illustrated by a reproduction curve with higher and lower points of equilibrium (Fig. 3). *R* indicates a release point, of which escape from natural enemy action can be expected, corresponding to the annual catches of 1,000 moths in the northern Japan. A low density induced by modern farming technology seems to provide an arena where the interaction system between parasitoids, mainly *Apanteles*

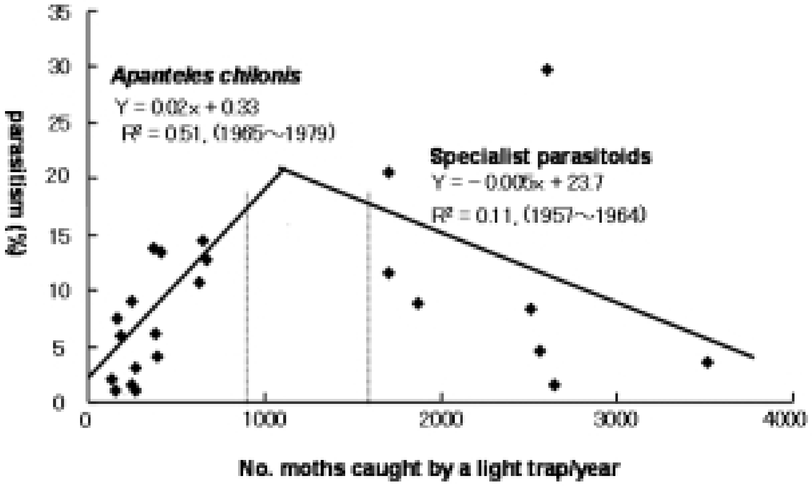

Fig. 2. Larval parasitism (%) in relation to the annual moth catches in Kuroishi, Aomori Prefecture.

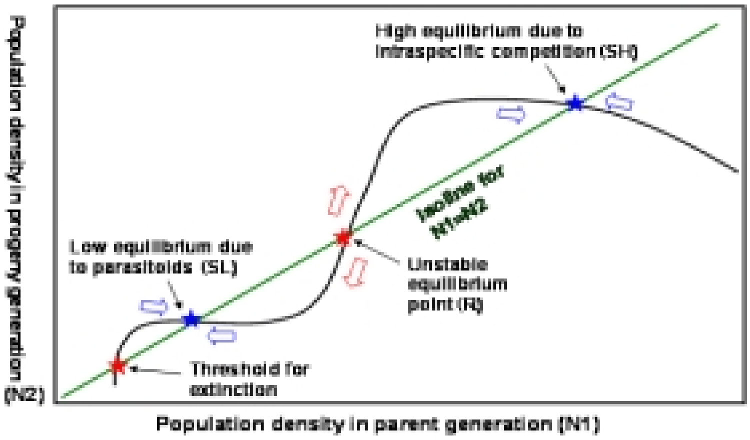

Fig. 3. A hypothetical reproduction curve for *Chilo suppressalis.*
S_L : Low equilibrium due to parasites.
S_H : High equilibrium due to intraspecific competition.

and *Chilo*, works around a new low equilibrium point, indicated by *SL* in the curve.

So far, there have been no cases of successful biological control of rice borers in the world (Kiritani 1979). The current status of *Chilo* might illustrate the feasibility of biological control of rice borers through a more sophisticated manipulation of the agroecosystem (Kiritani 1988). When *Chilo* density was too low to parasitize, the generalist parasitoid, *A. chilonis*, might select *Chilo* larvae, inhabiting *Zizania latifolia* as one of its alternative hosts.

AREA TO BE COVERED BY AN AREA-WIDE IPM

The exact size of area needed to implement an area-wide IPM for *Chilo* is not clear. An administrative district used to be selected for the implementation of IPM. In the study of outbreaks of *Chilo*, their spatial limitations have often been neglected as compared to the intensity or the duration of the outbreaks.

Outbreaks of *Chilo* infestations occurred in 1953 in almost all of the south-western Japan. Kiritani and Oho (1961) analyzed the catch records of *Chilo* moths by light traps in 30 stations located in Kyushu Island and found that the peak years of catches did not synchronize even among observatory points located in the same prefecture. The 1953 outbreak was only observed in the north-western part of Kyushu Island with a remarkable spatial limitation. The first peak of the outbreak was in the second (summer) generation of 1953 at Saga and Shirota located at the center of Saga Plane. Then the occurrence of peak generation was delayed as the area became more remote from the center until the outbreak came to an end at Hirado, 70 km west of Saga, where the peak of outbreak occurred at the second generation of 1956 (Fig. 4). Stations with the same outbreak year were encircled, as shown in Fig. 4. The centrifugal extension of outbreaks took its way to southward coastal region rather than to northward mountainous region.

It has been claimed that outbreaks of *Chilo* were triggered by a low temperature during the larval period of first generation or in late July. Larval mortality was mainly due to high temperatures of irrigation water. The peak density was reached at the first generation of the following year and crashes in the second generation (Miyashita 1982 & Kiritani 2005b). Low temperatures in July preceded the 1953 outbreak, from 1950 to 1952. It is impossible, however, to explain the delayed occurrence of outbreaks in centrifugal manner through the climatic release theory. Dispersal of moths was strongly suggested for this phenomenon. The fact that the coverage of the 1953 outbreak was within 150 km in diameter also rejects the possibility of delayed occurrence of climatic factor. The geographical limitation of the 1953 outbreak in Kyushu suggested the region to be covered when the area-wide IPM of *Chilo* was planned.

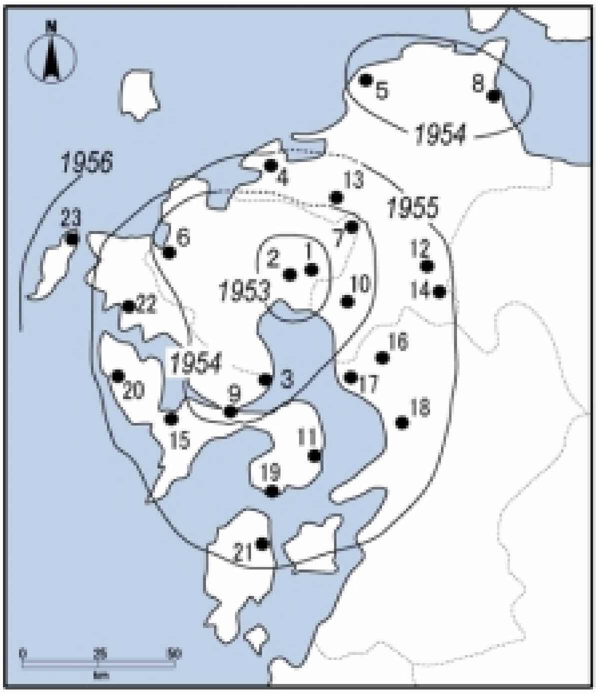

Fig. 4. Centrifugal extension of the 1953 outbreak of *Chilo suppressalis* in Kyushu. 1 Shirota; 2 Saga; 3 Tara; 4 Itoshima; 5 Munakata; 6 Imari; 7 Tosu; 8 Yukuhashi; 9 Isahaya; 10 Chikugo; 11 Shimabara; 12 Asakura; 13 Futsukaich; 14 Ukiha; 16 Togitsu; 17 Kikuchi; 18 Kumamoto; 19 Kuchinotsu; 20 Seto; 21 Amakusa; 22 Sasebo; 23 Hirado.

SINGLE-FIELD AS AGAINST AREA-WIDE EIL AND MONITORING SYSTEM

Carlson (1979) described a dilemma of centralized pest control decisions: what level of control should be provided, and how should the members of the group be charged? Pest severity is not likely to be equal on all farms in the areas, and farmers differ in their tolerances for pest damage or risk of pest damage. Therefore, one of the major problems for the implementation of an area-wide pest management program is determining an appropriate level of pest suppression to be provided (Kiritani, 1992).

Because pest control recommendations are utilized over a wide area and include thousands of rice growers, they tend to be in favor of chemical control. When an overall density of pests in one locality is just equal to the CT or EIL, the pest density in half of the fields would be less than CT or EIL. Consequently, Kidokoro and Kiritani (1982) proposed the use of statistical EIL for small-size farm conditions. Since the frequency distribution of *Chilo* injury to paddy fields in a particular area has been shown to follow a Poisson distribution, this gives a statistical projection for the probability that a given field has a pest density greater than the EIL. With a within-field-EIL of 30% hill infestation for *Chilo*, the proportion of fields with greater than 30% infestation can be calculated (Fig. 5). Recommendations can be given to individual growers on the insecticide control with the probability of risk that his field has a pest density greater than the EIL (Andow and Kiritani, 1983).

IPM PERSPECTIVE IN RELATION TO BIODIVERSITY

In the past, most studies on paddy ecosystems have focused on productivity and its stability in terms of rice yields. Arthropods in paddy ecosystems can be classified into three main groups according to their ecological requirements: 1) resident species adapted to the continuous cropping of rice in the same field, e.g. *Chilo*; 2) migratory species adapted to exploit rice as an annual crop, e.g. plant hoppers; and 3) aquatic species in wetlands originating from still water habitats. Regarding groups 1 and 2, IPM programs, which primarily aim to maximize economic profit in the farm, have been implemented with various degrees of success. Although IPM is becoming widespread, insects (Tada-no-mushi are species of unknown or uncertain function that routinely occur in the habitat) with no direct economic impact on rice production have been mostly ignored as an important element in the rice ecosystem. Consequently, some aquatic insects are in danger of extinction, thus, requiring conservation. It is recommended to adopt IPM strategies and tactics that are compatible with conservation (Kiritani, 1979 and 2000; Kiritani and Naba, 1994).

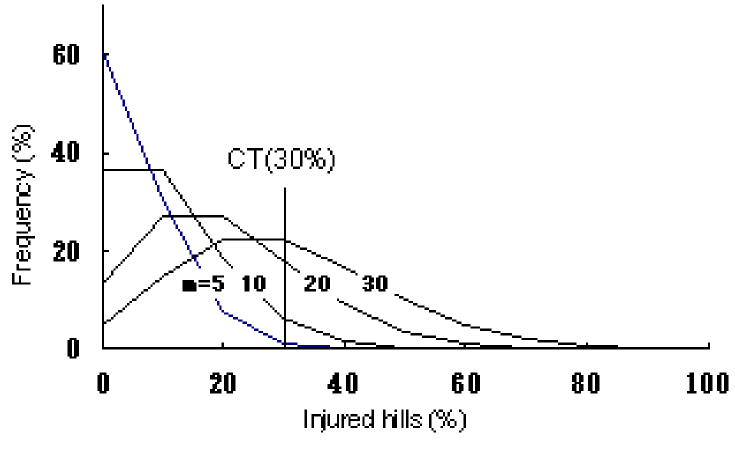

Fig. 5. Frequency curves of *Chilo suppressalis* injury to paddy fields, for difference within paddy mean injury levels (*m*). The frequency of distribution follows a Poisson distribution. The area under the curves to the right of the CT gives the proportion of paddies with infestations causing economic damage (5% yield loss).

A new concept, integrated biodiversity management (IBM), has been proposed under which IPM and conservation are reconciled and made compatible with each other (Kiritani 2000). IPM requires that densities of each pest species be kept below their specific EIL. In conservation, target species have to be managed to remain above a specific extinction threshold level (Fig. 6). IPM could change the status of a pest species into a Tada-no-mushi (minor or non-target insect), which can function as potential food for generalist predators or parasitoids. *Scirpophaga* is currently almost extinct in Japan. From the viewpoint solely of an economically oriented IPM, however, this is of little consequence because *Scirpophaga* was an important rice pest to be controlled. However, in view of IBM, relatively rare species such as *Scirpophaga* and some aquatic insects can be considered a target for conservation.

Farm management techniques that make the difference between the population levels for an EIL and an extinction threshold as great as possible should be introduced in the IBM system. As an alternative to the EIL, we could use another EIL in which "E" refers to "ecological or environmental." This new EIL, however, has yet to be established (Kiritani, 2005a).

In general, global warming may work in favor of natural enemies (except for spiders) by increasing the number of their generations (Kiritani, 1999). Biological control is expected to become a more important control tactic in the future. Parasitism and predation are expected to increase through this numerical response and to enhance natural control. However, uncertainty remains regarding the extent to which host-parasitoid phenology will be synchronized after an increase in the number of generations.

CONCLUSION

Experiences in Japan, as well as in other temperate Asian countries presented in this paper strongly suggest that: a) cultural practices should be the center of implementing the pest management system for *Chilo*; b) an effective pest management system requires at least one decade, even under a planned scheme; c) the area should be large enough to cover population displacement of rice stem borers; and d) the integrated management of the key pest could be achieved under a high-technology system of rice production without impairing the yield.

The paddy field is not only the habitat of rice arthropods, but it is also an alternative habitat for many endangered aquatic insects associated with vanishing natural wetlands. Therefore, the rice management strategy should strike a balance between IPM and conservation, which is referred to as IBM (Kiritani, 2000 & 2005a). This is a prerequisite to develop an area-wide sustainable agriculture system in paddy ecosystems.

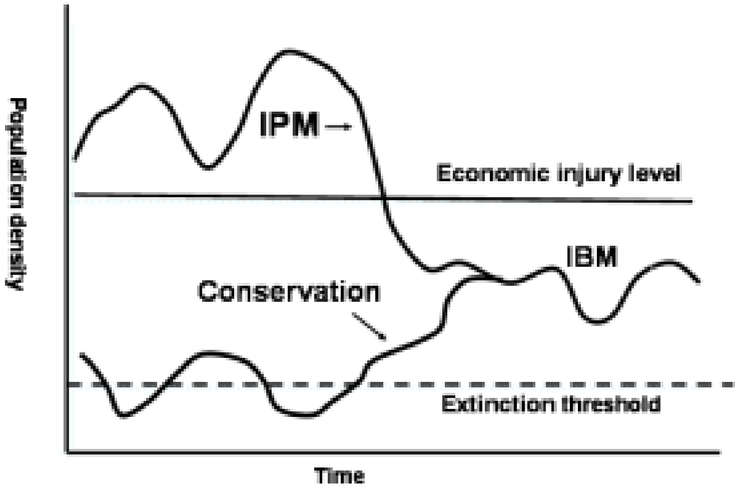

Fig. 6. Illustration of the concepts of IPM, conservation, and IBM.

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