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Are planthopper problems caused by a breakdown in ecosystem services?

K.L. Heong

An insect outbreak is an explosive increase in abundance that occurs over a short period. Such outbreaks of rice planthoppers often have devastating economic impacts when crops are completed destroyed. Outbreaks are rare and occur when the natural control ecosystem services are compromised, either by natural events such as floods and drought or agronomic practices, such as excess use of fertilizers and pesticides. Planthoppers are monophagous insects moving from rice fields to invade other fields and, in fields that are vulnerable, they increase exponentially to outbreak proportions. Thus, when outbreaks occur frequently, it is a sign of instability in the production environment. Another sign is the rapid development of insecticide resistance caused by pesticide abuse. High ecosystem services in rice fields are derived from sufficient arthropod biodiversity, especially in the species richness of predators and parasitoids. On the IRRI farm when insecticide use decreased by 95%, arthropod biodiversity was restored and planthopper outbreaks became negligible. Since planthoppers are r-strategists, which have high migratory ability, high reproductive capacity, and a short life span, their populations would be more effectively managed at the regional scale. Ecological engineering techniques can be used to enhance local biodiversity to increase ecosystem services.

Pest outbreaks are a sudden explosive increase in a pest population, often associated with changes in the ecosystem brought about by external environmental disturbances. These disturbances include warm or dry weather, elevated temperatures, floods, gales, and pesticide sprays. Outbreaks are generally rare and may be considered abnormal since most fields do not always experience them (Barbosa and Schultz 1987). However, pest outbreaks often receive a great deal of attention because of their sudden and devastating effects. Ecologists have been concerned about the diversity of life strategies and Mac Arthur and Wilson (1967) coined the r-K continuum, a rather simplified way, but still very useful, of providing some insights into population characteristics of pests. The r-strategists are opportunists, selected for their characteristic of maximizing food intake and exploiting their ephemeral habitats. The K-strategists, on the other hand, are selected for their efficient food-harvesting behavior and their populations are regulated

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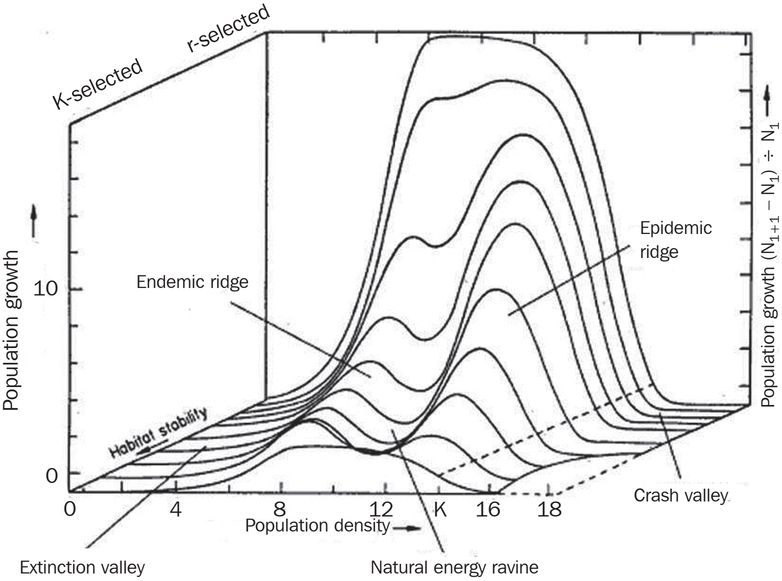

Fig. 1. The landscape of the sypnotic model of population growth.

to near the carrying capacity of the habitat. Southwood and Comins (1976) developed a synoptic model (Fig. 1) to describe the associated spectra of biological strategies and habitat characteristics, which can be used to evaluate pest management.

The r-strategists often become pests and a common characteristic feature is a high migratory tendency, which is essential for movement from the "dying habitat" to a new one. They are exogenous invaders to a particular crop. Thus, because of the ephemeral nature of the crop, it is more useful to consider managing their population on a regional scale (Southwood 1977). The brown planthopper (BPH) and the whitebacked planthopper (WBPH) are typically r-pests, which feed primarily on rice. They are normally not pests under low densities but can occasionally increase exponentially, causing huge losses from "hopper burn," a symptom from the heavy removal of phloem sap and the virus diseases they carry (Pathak and Khan 1994). Records of rice planthopper outbreaks date back to A.D. 18 and rice shortages and even famines were attributed to planthopper destruction in Japan (Heinrichs 1994). There are several hypotheses for outbreak causation, but what are the factors that trigger planthopper outbreaks in rice? Are planthopper outbreaks caused by deteriorated ecosystem services? Are frequent planthopper outbreaks signs of unsustainable practices? What are the root causes of planthopper outbreaks and how can they be prevented or reduced? A better understanding of the underlining ecological processes that create such population abnormalities is important for developing sustainable management strategies. This paper explores the use of an ecosystem services framework to consider planthopper outbreaks and their management.

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Provisioning Products from the ecosystems	**Regulating** Benefits from regulation of ecosystem processes	**Cultural** Nonmaterial benefits from ecosystems
In most lowland rice		
• Nitrogen fixing • Food production	• Water regulation Flood storage • Climate regulation Raise local humidity Anaerobic soils store C	• Spiritual and religious values • Cultural heritage
Lowland under specific management		
• Food production, nonrice crops, fish • Wood and straw for fuel • Genetic resources, wild rice	• Water regulation Soil salinity management • Climate regulation • Purification of polluted water • Soil organic matter maintenance •Biological control—pest and disease regulation • Pest invasion resistance	• Aesthetic • Inspirational • Educational • Recreation and ecotourism
Supporting services Services necessary for the production of all other ecosystem services, including soil formation, nutrient cycling, and primary production. These services depend heavily on connectivity/flows between rice fields and surrounding habitats.		

Fig. 2. Ecosystem services of lowland rice (after IRRI 2006).

Ecosystem services

Ecosystem services (ES) are broadly defined as “benefits that people obtain from ecosystems” (MA 2005) and they include services related to provisioning, regulating, supporting, and cultural functions (Fig. 2). First proposed by Daily (1997), the ES concept has gained considerable following and “ecological engineering” has emerged as a new direction for agricultural pest management (Gurr et al 2004). Provisioning services include production of food, fresh water, fuel, wood, and fiber. The supporting services basically provide maintenance to the resource base and include nutrient cycling, soil formation, and primary production. Cultural services provide humans with aesthetic and spiritual values, education, and recreation, and regulating services include water purification and climate and flood regulation. Regulating services relating directly to sustainable agriculture are pollination, pest invasion resistance, natural biological control, and pest and disease regulation. Biodiversity is the foundation of ES contributing to food provisioning through crop and genetic biodiversity (Fig. 3). In addition, biodiversity through ecological functions contributes to regulating services, such as pollination, invasion resistance, natural biological control, and pest and disease regulation. For instance, loss in species richness of bees and syrphids is directly linked to loss in pollination service (Beismeijer et al 2006). In pest management, the two ecological functions of importance are predation and parasitization and they are linked to the biodiversity of predators and parasitoids. The ES concept has

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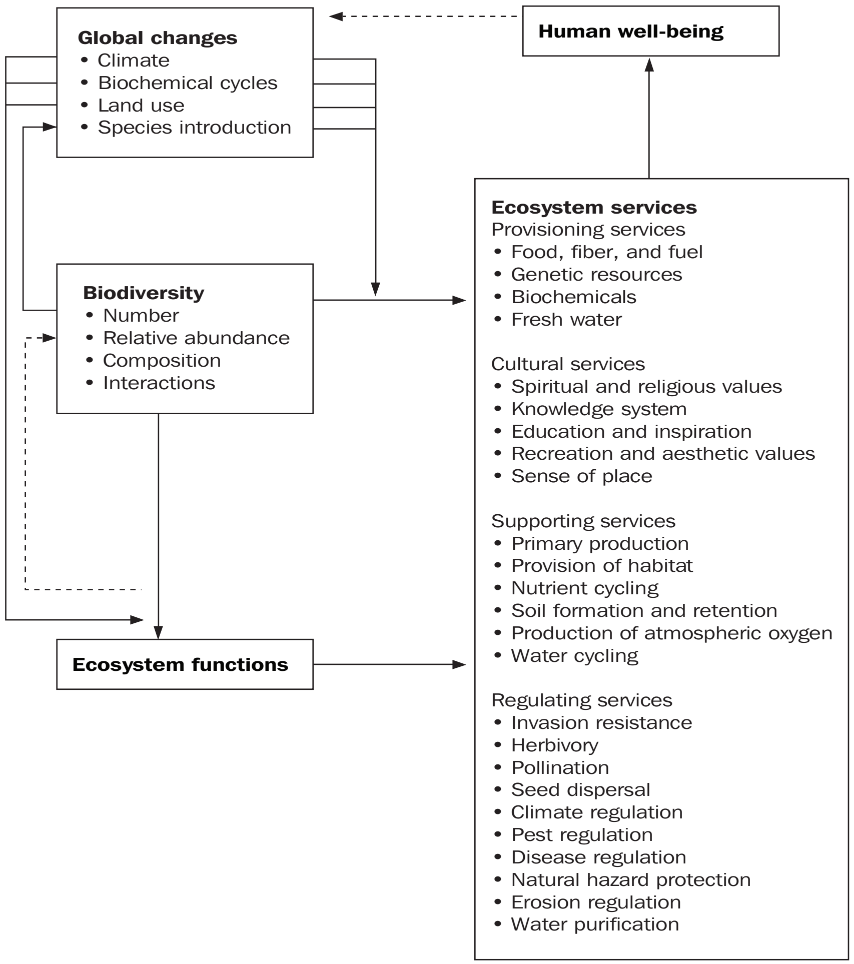

Fig. 3. Biodiversity, ecosystem functioning, and ecosystem services (after MA 2005).

been adopted as an integrative framework for natural resource management research as it can integrate ecological, social, and economic dimensions and can also include food production as well as conservation objectives.

Planthoppers are secondary pests

Natural biological control is linked to the ecosystem services pest regulation and invasion resistance and its importance was strongly emphasized more than 30 years ago by Bosch et al (1973). The important role of biodiversity in rice had also been discussed by Way and Heong (1994). As pointed out by Bosch et al (1973), chemical-based pest management has three ecological backlashes: target pest resurgence, secondary pest

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outbreaks, and pesticide resistance. In rice, insecticide sprays at the community level were found to disorganize predator-prey relationships and the food web structure, thus favoring r-strategist pests, such as planthoppers (Heong and Schoenly 1998). Very often, insecticides in the early crop stages are either applied as prophylactics or are directed at leaf feeders, such as leaffolders. These sprays tend to favor the development of secondary pests, such as planthoppers. Secondary pest outbreaks occur when insecticides applied to control target pests, such as the leaffolder, destroy biodiversity and natural control services, thus making the ecosystem vulnerable to pest invasions. The ecological fitness of the pest species increases due to "release from natural enemies" (Southwood and Comins 1976). Ecological fitness of secondary pests is further enhanced if the crops are enriched with high nitrogen applications (Lu et al 2004). In a computer simulation study, when N inputs were increased 4-fold from 100 to 400 kg ha^{-1}, BPH populations increased by 40-fold (Fig. 4) when predation was negligible. Thus, intensive rice production systems that are homogeneous and have high N inputs tend to be vulnerable to pest invasions and vulnerability is further enhanced if these fields are sprayed in the early crop stages.

Development of insecticide resistance

Another backlash is the development of insecticide resistance. Work done by Matsumura et al (2007) showed that some WBPH populations in China, Taiwan, Vietnam, and the Philippines are 40 to 100 times more resistant to fipronil. This has been attributed to the high use of fipronil to control leaffolders and stem borers. Resistance to imidacloprid is also extremely high in BPH populations of China, Vietnam, and Japan. For instance, BPH populations in the Mekong Delta are at least 200 times more tolerant than populations in the Philippines (Fig. 4). Resistance to buprofezin has also been recently recorded in BPH. Secondary pest outbreaks in turn contribute directly to an increase in insecticide resistance because outbreaks often bring on heavier and more frequent treatments that will speed up genetic selection for resistance.

Many examples of such "pesticide addiction" situations were illustrated in the 1970s (Huffaker 1971). The spider mite problem worldwide was a clear example of a secondary pest becoming a serious one (Bosch et al 1973). Similar experiences were recorded in cotton in northeastern Mexico, California's Imperial Valley, Cañete and several places in Peru, Colombia, and Central America (Bottrell and Adkisson 1977) and more recently in Thailand (Castella et al 1999). In fact, these experiences in pesticide addiction in which ecosystem services had been so badly deteriorated triggered the development of integrated pest management (IPM) (Huffaker 1980). The IPM approach to rationalize and use pesticide only as a last resort is primarily aimed at conserving natural biological control, which is the foundation of sustainable pest management.

The rice planthopper problem in Asia has similar characteristics of pesticide addiction and, when insecticide stresses were removed, planthopper problems decreased. In the 1970s and 1980s, planthoppers had been a serious threat (IRRI 1979, Heinrichs and Mochida 1984), but now, in several Southeast Asian countries, where

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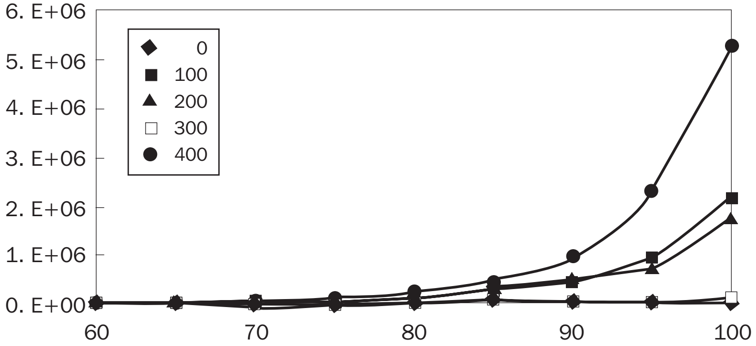

Fig. 4. Simulations of brown planthopper density increases in scenarios of nitrogen enrichment ranging from 0 N to 400 N.

IPM has been implemented and insecticide use reduced, either through training or media campaigns, planthopper problems have been insignificant (Matteson 2000, Matteson et al 1994, Rombach and Gallagher 1994, Escalada et al 1999). Planthopper problems are not serious pests in most of these areas and, wherever they become problematic, there have been close links to an increase in unnecessary insecticide usage. Field plot experiments have shown that insecticide sprays destroyed natural enemies (Heinrichs 1994), destroyed detritivores (Settle et al 1996), disorganized predator-prey relationships and food chain linkages (Cohen et al 1994), and favored the development of r-pests, such as the planthoppers (Heinrichs and Mochida 1984, Heong and Schoenly 1998). Even brown planthopper–resistant varieties treated with insecticides have increased BPH densities (Gallagher et al 1994). Clearly, current planthopper problems require a broader ecological approach. In northern China, Korea, and Japan, where brown planthoppers do not overwinter, populations may be started by initial immigrants carried by wind. Thus, rice crops with sufficient "invasion resistance," a regulating ecosystem service, may be less vulnerable to population buildups and outbreaks. Planthopper outbreaks in temperate regions may in fact be due to local deterioration of these services as a result of habitat biodiversity loss and pesticide addiction.

Arthropod biodiversity

Arthropod biodiversity in rice ecosystems has inherent resilience and capacity to increase when the suppressing factors are removed. At the IRRI farm, insecticide use declined by more than 95% from 1994 to 2007 because of strict implementation of IPM (Fig. 5). As a result, arthropod biodiversity increased significantly (Table 1 and Fig. 6) (Heong et al 2007). Predator species richness after rarefaction increased from 38 to 65, and parasitoid species richness increased from 17 to 38. Species richness of detritivores increased 5-fold, probably because insecticides had the most devastating effects on these mostly aquatic species. Herbivores also increased in biodiversity from

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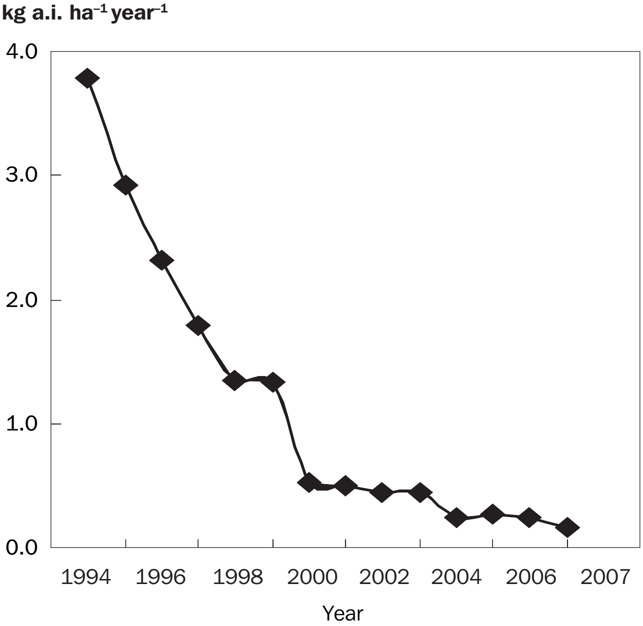

Fig. 5. Decrease in insecticide usage from 1994 to 2007 on IRRI farm.

14 to 36, but most "new" species were minor pests such as thrips, plant lice, beetles, and leafhoppers. Planthoppers remained at low densities of < 5 hoppers per hill.

Based on research results, both experimental and field, and related literature, it is evident that planthopper outbreaks are secondary pest problems because of the deterioration of important ecosystem services, such as natural biological control and invasion resistance. These services can be affected by several system perturbations, such as droughts, floods, extreme weather changes, and pesticide applications, working singly or in combination. Among these factors, perhaps pesticide applications are the most common and within people's control. In Vietnam, through mass media campaigns, farmers in the Mekong Delta reduced their insecticide sprays by 53% and sustained the reduction for more than 10 years and, during this period, yields increased slightly and planthopper outbreaks were negligible (Escalada et al 1999). Thousands of farmers trained through farmer field schools had similar experiences (Matteson 2000). Besides reducing pesticides, ecosystem services in rice production can be further enhanced through habitat manipulation or ecological engineering strategies (Gurr, this volume) that will increase invasion resistance and natural biological control. However, for the positive benefits of ecological engineering to work, there is a need for a corresponding reduction in negative and ecologically destructive forces, such as unnecessary pesticide use.

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Table 1. Comparison of arthropod biodiversity on the IRRI farm in 1989 and 2005.

Guilds	Biodiversity parameters	1989	2005
Herbivores	% abundance	46.2	11.6
	Species richness, S or E_{sn} (rarefaction)	13.6	36.0
	Log series index α	3.10	8.97
	Reciprocal Simpson's (1/D)	2.25	2.56
	Exp Shannon or Hill N_1	3.46	5.75
Predators	% abundance	40.0	58.0
	Species richness, S or E_{sn} (rarefaction)	37.6	65.0
	Log series index α	6.38	12.28
	Reciprocal Simpson's (1/D)	5.12	6.50
	Exp Shannon or Hill N_1	8.25	11.70
Parasitoids	% abundance	5.6	4.3
	Species richness, S or E_{sn} (rarefaction)	17.1	38.0
	Log series index α	5.41	14.67
	Reciprocal Simpson's (1/D)	2.57	13.25
	Exp Shannon or Hill N_1	5.37	20.91
Detritivores	% abundance	8.1	26.1
	Species richness, S or E_{sn} (rarefaction)	5.6	30.0
	Log series index α	0.88	5.70
	Reciprocal Simpson's (1/D)	1.19	8.02
	Exp Shannon or Hill N_1	1.46	10.80

References

Barbosa P, Schultz JC, editors. 1987. Insect outbreaks. San Diego, Calif. (USA): Academic Press, Inc.

Beismeijer JC, Roberts SPM, Reemer M, Ohlemuller R, Edwards M, Peeters T, Schaffers AP, Potts SG, Kleukers R, Thomas CD, Settele J, Kunin WE. 2006. Parallel declines in pollinators and insect-pollinated plants in Britain and the Netherlands. Science 313:351-354.

Bosch R van den, Messenger PS, Gutierrez AP. 1973. An introduction to biological control. New York, N.Y. (USA): Plenum Press.

Bottrell DG, Adkisson PL. 1977. Cotton insect pest management. Annu. Rev. Entomol. 22:451-481.

Pp 221-232 IN Heong KL, Hardy B, editors. 2009. Planthoppers: new threats to the sustainability of intensive rice production systems in Asia. Los Baños (Philippines): International Rice Research Institute.

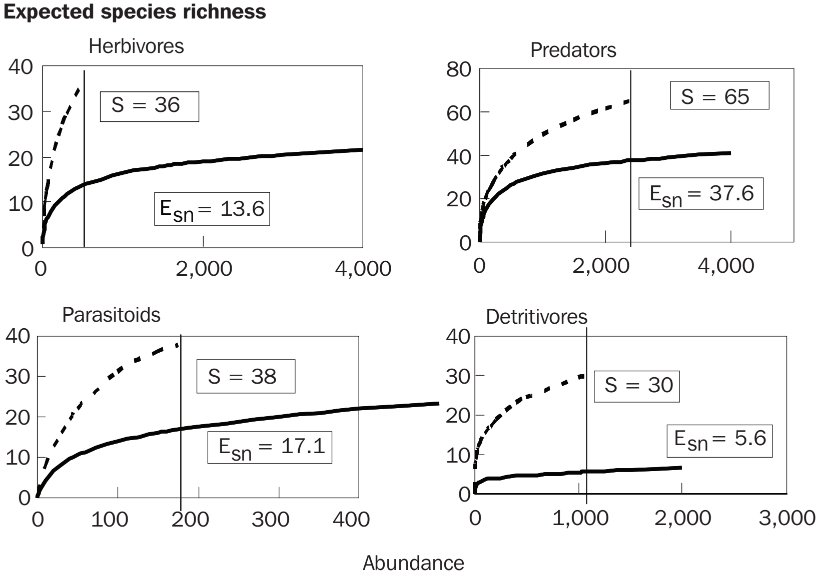

Fig. 6. Rarefaction curves of arthropod guild of samples collected in 1989 and 2005. Rarefaction estimates (E_{sn}) were computed using ECOSIM (Gotelli and Entsminger 2005).

Castella JC, Jourdain D, Trebuil G, Napompeth B. 1999. A systems approach to understanding obstacles to effective implementation of IPM in Thailand: key issues for the cotton industry. Agric. Ecosyst. Environ. 72:17-34.

Cohen JE, Schoenly K, Heong KL, Justo H, Arida G, Barrion AT, Litsinger JA. 1994. A food web approach to evaluating the effect of insecticide spraying on insect pest population dynamics in a Philippines irrigated rice ecosystem. J. Appl. Ecol. 31:747-763.

Daily G. 1997. Nature's services: societal dependence on natural ecosystems. Washington, D.C. (USA): Island Press.

Escalada MM, Heong KL, Huan NH, Mai V. 1999. Communications and behavior change in rice farmers' pest management: the case of using mass media in Vietnam. J. Appl. Commun. 83:7-26.

Gallagher KD, Kenmore PE, Sogawa K. 1994. Judicial use of insecticides deter planthopper outbreaks and extend the life of resistant varieties in Southwest Asian rice. In: Denno RF, Perfect TJ, editors. Planthoppers: their ecology and management. Chapman & Hall, London. p 599-614.

Gotelli NJ, Entsminger GL. 2005. Ecosim: null models software for ecology. Version 7.72. Acquired Intelligence Inc, & Kesey-Bear. www.uvm.edu/~biology/Faculty/Gotelli/Gotelli.html, 1 June 2007.

Gurr GM, Wratten SD, Altieri MA. 2004. Ecological engineering: a new direction for agricultural pest management. AFBM J. 1(1):26-31. www.afbmnetwork.organge.usyd.edu.au/afbjournal/.

Heinrichs EA, Mochida O. 1984. From secondary to major pest status: the case of insecticide-in-

Pp 221-232 IN Heong KL, Hardy B, editors. 2009. Planthoppers: new threats to the sustainability of intensive rice production systems in Asia. Los Baños (Philippines): International Rice Research Institute.

duced rice brown planthopper, *Nilaparvata lugens*, resurgence. Prot. Ecol. 7:201-218.

Heinrichs EA.1994. Impact of insecticides on the resistance and resurgence of rice planthoppers. In: Denno RF, Perfect TJ, editors. Planthoppers: their ecology and management. New York, N.Y. (USA): Chapman & Hall. p 571-598.

Heong KL, Schoenly K. 1998. Impact of insecticides on herbivore-natural enemy communities in tropical rice ecosystems. In: Haskell PT, McEwen P, editors. Ecotoxicology: pesticides and beneficial organisms. London (UK): Chapman & Hall. p 381-403.

Heong KL, Manza A, Catindig J, Villareal S, Jacobsen T. 2007. Changes in pesticide use and arthropod biodiversity in the IRRI research farm. Outlooks Pest Manage. October 2007, p 2229-2233.

Huffaker CB. 1971. Biological control. New York, N.Y. (USA): Plenum Press.

Huffaker CB. 1980. New technology of pest control. New York, N.Y. (USA): Wiley-Interscience.

IRRI (International Rice Research Institute). 1979. Brown planthopper: threat to rice production in Asia. Los Baños (Philippines): International Rice Research Institute.

IRRI (International Rice Research Institute). 2006. Bringing hope, improving lives. Strategic Plan 2007-2015. Los Baños (Philippines): International Rice Research Institute.

Lu ZX, Heong KL, Yu XP, Hu C. 2004. Effects of plant nitrogen on fitness of the brown planthopper, *Nilaparvata lugens* Stål, in rice. J. Asia Pacific Entomol. 7:97-104.

MA (Millennium Ecosystem Assessment). 2005. Ecosystems and human well-being: biodiversity synthesis. Washington, D.C. (USA): World Resources Institute.

Mac Arthur RH, Wilson EO. 1967. The theory of island biogeography. Princeton, N.J. (USA): Princeton University Press.

Matsumura M, Takeuchi H, Satou M, Otuka A, Watananbe T, Thanh DV. 2007. Recent status of insecticide resistance of the rice planthoppers in East and Southeast Asia. Poster presented at the International Plant Protection Congress, Glasgow, Scotland. October 2007.

Matteson PC. 2000. Insect pest management in tropical Asian irrigated rice. Annu. Rev. Entomol. 45:549-574.

Matteson PC, Gallagher KD, Kenmore PE. 1994. Extension of integrated pest management for planthoppers in Asian irrigated rice: empowering the user. In: Denno RF, Perfect TJ, editors. Planthoppers: their ecology and management. New York, NY (USA): Chapman & Hall. p 656-685.

Pathak MD, Khan ZR. 1994. Insect pests of rice. Los Baños (Philippine): International Rice Research Institute.

Rombach MC, Gallagher KD. 1994. The brown planthopper: promises, problems and prospects. In: Heinrichs EA, editor. Biology and management of rice insects. New Dehli (India): Wiley Eastern. p 693-709.

Settle WH, Hartiahyo A, Endah TA, Wilyastama C, Arief LH, Dadan H, Alifah SL, Pajarningsih. 1996. Managing tropical rice pests through conservation of generalist natural enemies and alternative prey. Ecology 77:1975-1988.

Southwood TRE. 1977. The relevance of population dynamics theory to pest status. In: Cherrett JM, Sagar GR, editors. Origins of pest, parasite, disease and weed problems. 18th Symposium of the British Ecological Society, Bangor, 12-14 April 1976. Blackwell Scientific Publications, Oxford. p 35-54.

Southwood TRE, Comins HN. 1976. A synoptic population model. J. Anim. Ecol. 45:949-965.

Pp 221-232 IN Heong KL, Hardy B, editors. 2009. Planthoppers: new threats to the sustainability of intensive rice production systems in Asia. Los Baños (Philippines): International Rice Research Institute.

Way MJ, Heong KL. 1994. The role of biodiversity in the dynamics and management of insect pests of tropical irrigated rice: a review. Bull. Entomol. Res. 84:567-587.

Notes

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Pp 221-232 IN Heong KL, Hardy B, editors. 2009. Planthoppers: new threats to the sustainability of intensive rice production systems in Asia. Los Baños (Philippines): International Rice Research Institute.