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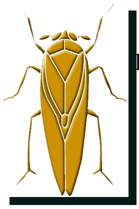

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Are planthopper problems due to breakdown in ecosystem services?

K.L. Heong
International Rice Research Institute
Los Baños, Philippines.

Introduction

Pest outbreaks are sudden explosive increase in the pest populations 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 spays. 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, in 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 harvesting food efficiently and their population regulated to near the carrying capacities of the habitats. Southwood and Comins (1976) developed a synoptic model (Figure 1) to describe the associate spectra of biological strategies and habitat characteristics which can be used to consider pest management.

The r-strategists often become pests and a common characteristic features are high migratory tendency, that is essential for movement from the "dying habitat" to a new one. They are exogenous invaders to a particular crop and 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 white backed planthopper (WBPH) are typically r-pests, which feed primarily on rice. They are normally not pests under low densities but can occasionally outbreak causing huge losses from "hopperburn", a symptom due of heavy removal of phloem sap and the virus diseases they carry (Pathak and Khan 1994). Records of rice planthopper outbreaks date back to 18 A.D. and rice shortages and even famines had been attributed to planthopper destructions in Japan (Heinrichs 1994). There are several hypotheses for outbreak causation but what factors trigger planthopper outbreaks in rice? Are planthopper outbreaks due to 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 the ecosystem services framework to consider planthopper outbreaks and their management.

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 (Figure 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 man with aesthetic and spiritual values, education and recreation and the regulating services include water purification, climate and flood regulation. Regulating services relating directly to sustainable agriculture are pollination, pest invasion resistance, natural biological control, pest and disease regulation. Biodiversity is the foundation of ES contributing to food provisioning through crop and genetic biodiversity (Figure 3). In addition, biodiversity through ecological functions contributes to regulating services, such as pollination, invasion resistance, natural biological control, pest and disease regulation. For instance loss in species richness of bees and syrphids are 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 biodiversity of predators and parasitoids. The ES concept has been adopted as an integrative framework for natural resource management research as it can integrate the 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 has been strongly emphasized > 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 be Bosch et al (1973), chemical based pest management have three ecological backlashes, target pest resurgence, secondary pest outbreaks and pesticide resistance. In rice, insecticide sprays at the community level were found to disorganize predator-prey relationships and the food web structure 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 the leaf folders. These sprays tend to favor the development of secondary pests, such as planthoppers. Secondary pest outbreaks occur where insecticides applied to control target pests, such as the leaf folder, 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 the 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 folds from 100 to 400 kg/ha, BPH populations increased by 40 folds (Figure 3) when predation is negligible. Thus intensive rice production systems that are homogenous and with 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 Philippines are 40 to 100 times more resistant to fipronil. This has been attributed to the high use of fipronil to control leaf folders 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 (Figure 4). Resistance to buprofezin has also been recently recorded in BPH. Secondary pest outbreaks in turn contribute directly to increase in insecticide resistance because outbreaks often bring upon 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 due to this (Bosch et al 1973). Similar experiences had been recorded in cotton in NE Mexico, California’s Imperial Valley, Canete and several places in Peru, Colombia and Central America (Bottrell and Adkisson 1977) and more recently in Thailand (Castella et al 1999). In fact it had been these experiences in “pesticide addiction” where ecosystem services had been so badly deteriorated that had 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” cases and where insecticide stresses were removed, planthopper problems are reduced. In the 1970s and 1980s planthoppers had been the serious threat (IRRI 1979, Heinrichs and Mochida, 1984) but today in several SE Asian countries, where IPM has been implemented and insecticide use reduced, either through training or media campaigns, planthopper problems had 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 theses areas and wherever they become problematic, there had been close links to 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; Schoenly et al 1996) and favored the development of r-pests, such as the planthoppers (Heinrichs & Mochida 1984; Heong & Schoenly 1998). Even brown planthopper (BPH) resistant varieties treated with insecticides have increased BPH densities (Gallagher et al 1994). Clearly the current planthopper problems require a broader ecological approach. In northern China, Korea and Japan where the planthoppers do not over-winter, planthopper populations may be started by initial immigrants carried by wind, rice crops with sufficient "invasion resistance", a regulating ecosystem service, may be less vulnerable to population build ups 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 addictions.

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 reduced by > 95% from 1994 to 2005 because of strict implementation of IPM (Figure 4) and as a result arthropod biodiversity significantly increased (Table 1 and Figure 5) (Heong et al 2007). Predator species richness after rarefaction, increased from 38 to 65, parasitoid species richness also increased from 17 to 38. Species richness of detritivores increased 5 folds, probably because insecticides had the most devastating impacts on these mostly aquatic species. Herbivores also increased in biodiversity from 14 to 36, but most the "new" species were minor pests such as thrips, plant lice, beetles and leafhoppers. Planthoppers had remained in low densities of < 5 hoppers/hill.

Based on research results, both experimental and field, and related literature materials, it is evident that planthopper outbreaks are secondary pest problems due to 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. They may work singly or in combination. Among these factors, perhaps pesticide applications are the most common and within man's control. In Vietnam through mass media campaigns, farmers in the Mekong Delta reduced their insecticide sprays by 53% and had sustained the reduction for > 10 years and during this period yields were slightly increased 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 may be further enhanced through habitat manipulation or ecological engineering strategies (Gurr this conference) that will increase invasion resistance and natural biological control. However for the positive benefits of ecological engineering to work, there are needs for corresponding reduction in negative and ecologically destructive forces, like unnecessary pesticide use.

References

Barbosa, P. and Schultz, J.C. (eds.). 1987. Insect Outbreaks. Academic Press, Inc, San Diego, Cal.

Beismeijer, J.C., Roberts, S.P.M., Reemer, M., Ohlemuller, R., Edwards, M., Peeters, T., Schaffers, A.P., Potts, S.G., Kleukers, R., Thomas, C.D., Settele, J. and Kunin, W.E. 2006. Parallel declines in pollinators and insect-pollinated plants in Britain and the Netherlands. *Science*, 313-354.

Bosch, van den, R., Messenger, P.S. and Gutierrez, A.P. 1973. *An Introduction to Biological Control*. Plenum Press, N.Y.

Bottrell, D.G. and Adkisson, P.L. 1977. Cotton insect pest management. *Annul Rev Entomol*, 22, 451-481.

Castella, J.C. 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, Ecosys, Environ*. 72, 17-34.

Cohen, J.E., Schoenly, K., Heong, K.L., Justo, H., Arida, G., Barrion, A.T. & Litsinger, J.A. (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.*, 31:747–63.

Daily, G. 1997. *Nature's Services: Societal Dependence on Natural Ecosystems.* Washington, DC: Island Press.

Escalada, M.M., Heong, K.L., Huan, N.H. & 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, K.D., Kenmore, P.E. and Sogawa, K. 1994. Judicial use of insecticides deter planthopper outbreaks and extend the life of resistant varieties in Southwest Asian rice. Pp 599 – 614. In Denno, R.F. and Perfect, T.J. (eds.) *Planthoppers – Their Ecology and Management.* Chapman & Hall, London.

Gotelli, N.J. & Entsminger, G.L. (2005). *Ecosim: Null Models Software for Ecology*. Version 7.72. Acquired Intelligence Inc, & Kesey-Bear. <http://www.uvm.edu/~biology/Faculty/Gotelli/Gotelli.html> 1 June 2007.

Gurr, G.M., Wratten, S.D. and Altieri, M.A. 2004. Ecological engineering: a new direction for agricultural pest management. AFBM Journal 1(1): 26 – 31. http://www.afbmnetwork.organge.usyd.edu.au/afbjournal/

Heinrichs, E.A. and Mochida, O. 1984. From secondary to major pest status: the case of insecticide-induced rice brown planthopper, *Nilaparvata lugens*, resurgence. *Protect. Ecol*, 7, 201-218.

Heinrichs, E.A.1994. Impact of insecticides on the resistance and resurgence of rice planthoppers. Pp 571-598. In Denno, R.F. and Perfect, T.J. (eds.) *Planthoppers: their Ecology and Management.* Chapman & Hall, NY.

Heong, K.L. and Schoenly, K. 1998. Impact of insecticides on herbivore-natural enemy communities in tropical rice ecosystems. 381–403. In P.T. Haskell & P. McEwen (eds.) *Ecotoxicology: Pesticides and beneficial organisms*. Chapman & Hall, London, UK.

Heong, K.L., Manza, A., Catindig, J., Villareal, S. And Jacobsen, T. 2007. Changes in pesticide use and arthropod biodiversity in the IRRI research farm. *Outlooks on Pest Management* October 2007. 2229 – 2233.

Huffaker, C.B. 1971. *Biological Control*. Plenum Press, NY.

Huffaker, C.B. 1980. *New technology of Pest Control.* Wiley-Interscience, NY.

IRRI (International Rice research Institute). 1979. *Brown planthopper: Threat to rice production in Asia.* IRRI, Los Banos, Philippines.

IRRI (International Rice Research Institute). 2006. *Bring Hope, Improving Lives. Strategic Plan 2007 – 2015*. IRRI Los Banos, Philippines.

Lu, Z.X., Heong, K.L., Yu, X.P. and Hu, C. 2004. Effects of plant nitrogen on fitness of the brown planthopper, Nilaparvata lugens Stal. in rice. J. Asia Pacific Entomology, 7, 97-104.

MA (Millennium Ecosystem Assessment) 2005. *Ecosystems and Human Well-being: Biodiversity Synthesis*. Word Resources Institute, Washington, DC.

Mac Arthur, R.H. and Wilson, E.O.1967. The Theory of Island Biogeography. Princeton University Press, Princeton, N.J.

Matsumura, M., Takeuchi, H., Satou, M., Otuka, A., Watananbe, T. And Thanh, D.V. 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, P.C. 2000. Insect pest management in tropical Asian irrigated rice. Annu. Rev. Entomol. 45, 549-574.

Matteson, P.C., Gallagher, K.D. and Kenmore, P.E. 1994. Pp 656 -685. In Denno, R.F. and Perfect, T.J. (eds.) *Planthoppers: their Ecology and Management*. Chapman & Hall, NY.

Pathak, M.D. and Khan, Z.R. 1994. Insect Pests of Rice. IRRI, Los Banos, Philippines.

Rombach, M.C. and Gallagher, K.D. 1994. Pp 693 – 709. In Heinrichs, E.A. (ed.) *Biology and Management of R ice Insects*. The brown planthopper: Promises, problems and prospects. Wiley Eastern, New Dehli, India.

Settle, W.H., Hartiahyo, A., Endah, T.A., Wilyastama, C., Arief, L.H., Dadan, H., Alifah, S.L. & Pajarningsih. (1996). Managing tropical rice pests through conservation of generalist natural enemies and alternative prey. Ecology, 77:1975–88.

Southwood, T.R.E. 1977. The relevance of population dynamics theory to pest status. Pp 35-54. In Cherrett, J.M. and Sagar, G.R. (eds) Origins of Pest, Parasite, Disease and Weed Problems. 18th Symposium of the British Ecological Society, Bangor 12-14 April 1976. Balckwell Scientific Publications, Oxford.

Southwood, T.R.E. and Comins, H.N. 1976. A synoptic population model. *J Anim. Ecol*., 45, 949-965.

Way, M.J. and Heong, K.L. 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.

Table 1: Comparison of arthropod biodiversity in 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

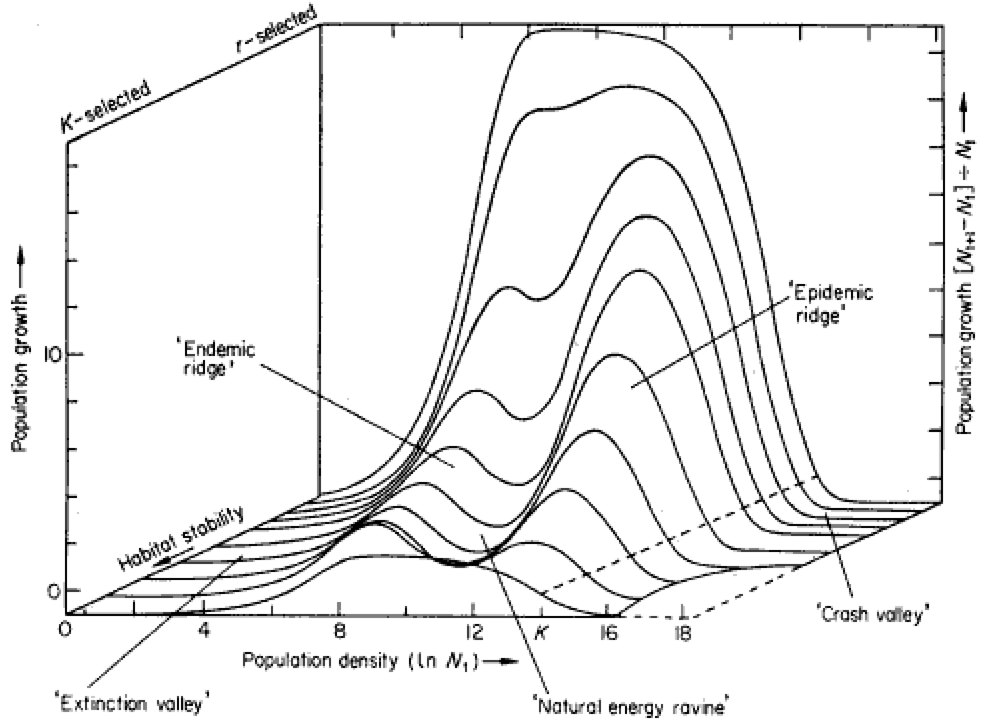

FIG. 1. **The landscape of the synoptic model of population growth.**

(After Southwood and Comins 1976)

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 heritages
Lowland under specific management		
• Food production, non rice 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 then 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		

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

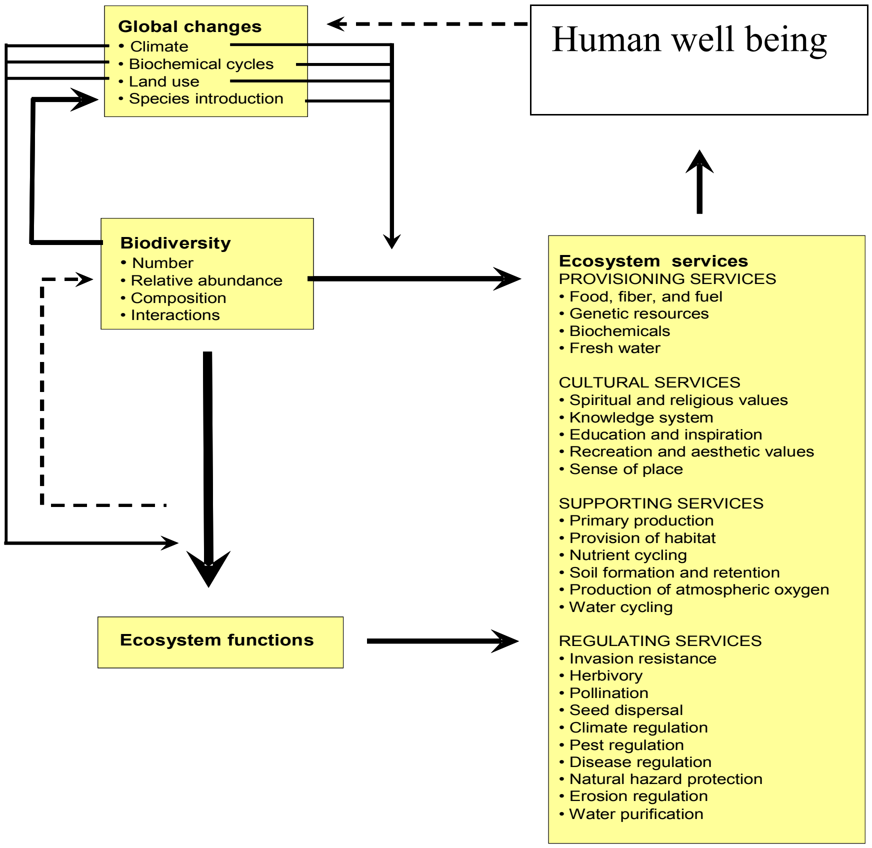

Figure 3. Biodiversity, ecosystem functioning, and ecosystem services (After MA 2005)

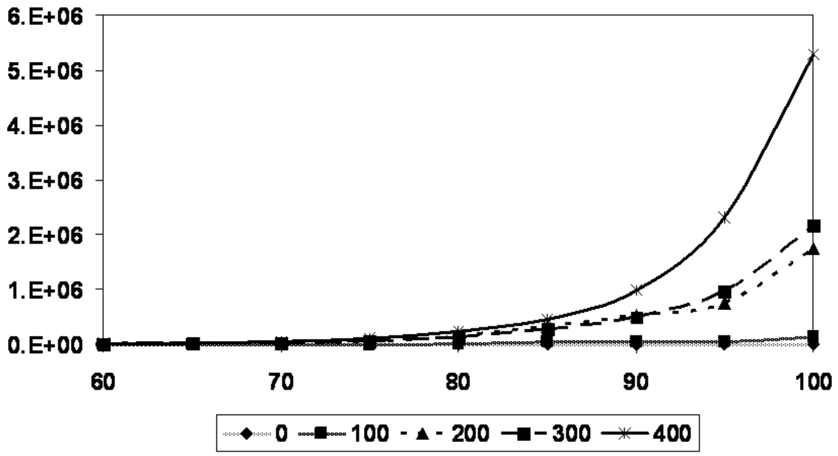

Figure 4: Simulations of brown planthopper density increases in scenarios of Nitrogen enrichment ranging from 0N to 400N.

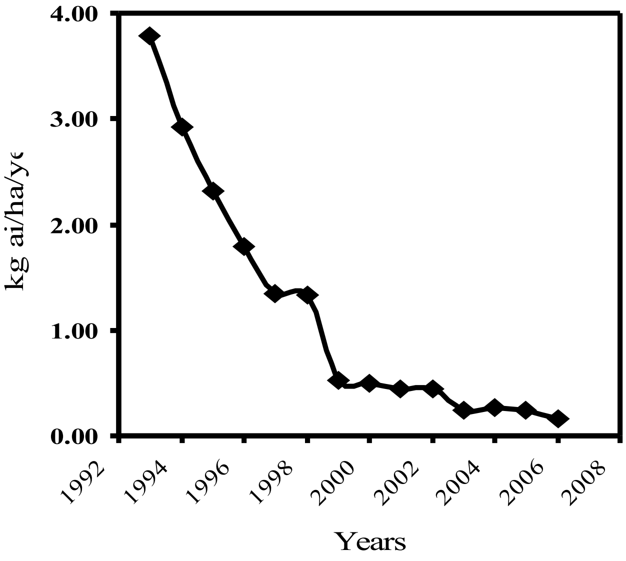

Figure 5: Decrease in insecticide usage from 1994 to 2006 in IRRI farm

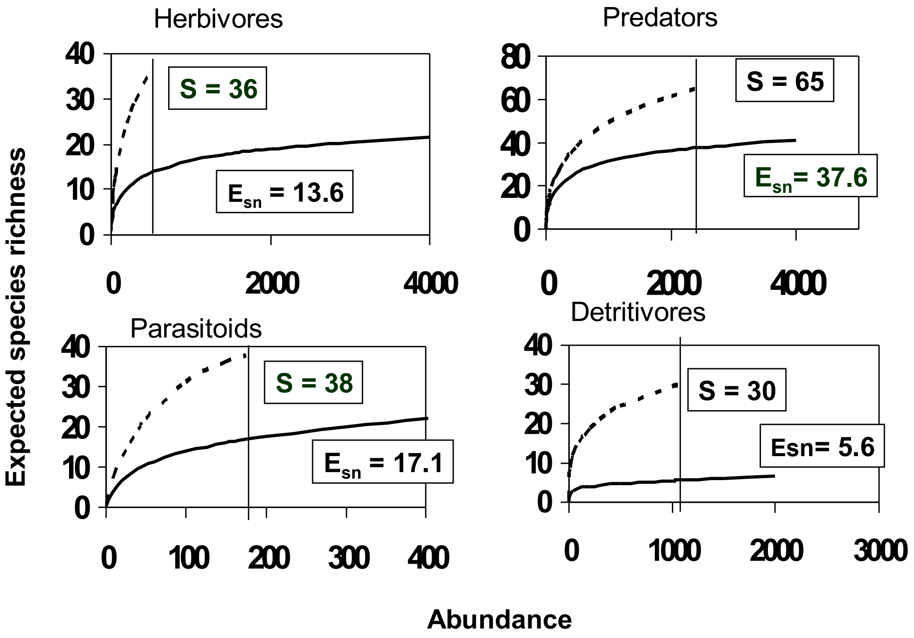

Figure 6: Rarefaction curves of arthropod guild of samples collected in 1989 and 2005. Rarefaction estimates Esn were computed using ECOSIM (Gotelli & Entsminger, 2005).