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Biodiversity, ecosystem services and pest management

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Abstract

Ecosystem services are benefits that humanity obtains from ecosystems. These are conditions and ecological processes through which ecosystems and the species within them sustain life. Through processes that regulate and support primary ecosystem functions, such as soil formation, oxygen production, water and nutrient cycling, pollination and regulation of pests, diseases, erosion and climate, humans derive an important service and that is to produce goods, such as food, fresh water, fuel and genetic resources. In addition there are also cultural services that are essential to human well being, such as spiritual attachments, diversity of cultures, aesthetic and inspirational values and recreation.

Biodiversity can be both, a response affected by ecosystem changes as well as a factor that modifies ecosystem processes and services. Biodiversity represents the foundation of ecosystems that, through the services they provide, affect human well-being. It reflects the number, variety and variability of living organisms and includes diversity within species (genetic diversity), between species (species diversity), and between ecosystems (ecosystem diversity). Biodiversity is important in all ecosystems, including managed agricultural production systems as it provides a diversity of functional substitutability options. When an impact such as elevated temperature creates the loss of one or more species within a functional group this function can be compensated for by other species. Some species might have unique contributions to the ecosystem function and their loss would be of greater concern.

In agricultural systems, biodiversity is generally altered and pest management practices, particularly those that rely on pesticides can have significant negative effects on biodiversity and ecosystem services. However, there is often sufficient functional diversity to retain pests at tolerable levels. Pesticides, biocides by design, have variable effects on the functional groups. For instance insecticides tend to have greater effects on spiders and hymenopteran parasitoids thus reducing predation and can cause “natural enemy” releases favoring pest outbreaks. Areas with heavy pesticide use will tend to have lower natural enemy biodiversity and weaker biological control services and may be vulnerability to pest invasions. Habitat manipulation techniques can positively increase natural enemy biodiversity and strengthen biological control services. However for these techniques to be effective there is need to adopt ecological engineering principles, manage pesticide use to avoid negative impact so as to maximize biological control services.

Pollinators such as bees and syrphids are also vulnerable to pesticides and in parts of China pollination services in fruit orchards are performed by humans. In Europe the loss of pollinator diversity has been attributed to high pesticide usage.

Agriculture will need adopt ecological engineering principles for design so as to balance the provisional services for human needs and maintain adequate biodiversity and preserve the other ecosystem services.

INTRODUCTION

In the 1960s and 1970s, the world was preoccupied with the problem of feeding a rapidly increasing world population (Conway and Barbier 1990). The obvious solution then was to increase food production and the resulting green revolution had a dramatic effect on the developing countries, in terms of increasing yields of staple cereals, such as rice, wheat and maize. However it also contributed negative consequences such as non equity, instability and sustainability of production. For instance intensive monocropping has made production systems vulnerable to environmental stresses. Many agricultural systems are focused primarily on production by adding large inputs in the form of fertilizers and pesticides, and paying little attention to environmental degradation and human health risks (Gliessman 2001).

The UN Conference on environment and development in Rio in 1992 which developed the Agenda 21 to address environmental concerns marked a significant turning point in development. The importance of biodiversity, the environment and ecological functions was emphasized. More recently in 2001 the UN launched the Millennium Ecosystem Assessment (MA) to provide an integrated assessment of the consequences of ecosystem change for human being and analyzed options available to reverse the degradation trends and enhance the conservation of ecosystem contributions to human needs. The MA used the ecosystem services concept in its assessment framework that provides mechanisms to understand ecological and management relationships and trade offs involved and to identify options at both the field and governance levels (http://www.millenniumassessment.org/en/index.aspx).

Pest management in many situations is strongly influenced by the agrochemical era that developed in parallel with the green revolution of the 1960s and 1970s. Routine prophylactic insecticide campaigns were components of production intensification programs, such as the Masagana 99 in the Philippines and the BIMAS in Indonesia (Heong and Schoenly 1998). Through agricultural subsidy and loan schemes farmers were encouraged to apply insecticides on regular schedules. The large scale implementation of these practices led to pest outbreaks, such as the rice brown planthopper (BPH) in the 1970s and 1980s threatening rice production in Asia (Conway and Pretty 1991). Similar experiences in plantation crops, such as oil palm have been described by Brian Wood.

The paper will discuss biodiversity and its significance in providing ecosystem services that are essential for sustainable pest management. Most of the examples will be drawn from rice ecosystems in Asia.

Biodiversity

The term biodiversity is used to describe the richness and variety of life on Earth. It includes variation within species at the genetic level, such as between individuals and varieties, the diversity of species and the diversity of habitats and ecosystems in the landscape. Biodiversity encompasses more than variation in appearance and composition, it also includes diversity in abundance, such as the number of genes, individuals and habitats, their distribution in time and space and in behavior, including interactions between species such as between pollinators and plants or between predators, parasitoids and preys. Thus biodiversity forms the foundation of the vast array of ecosystem services to which mankind is linked. Sometimes biodiversity is presumed to be relevant to only the unmanaged ecosystems, such as the virgin forests, nature reserves or national parks. This is incorrect. Managed systems, like plantations, farms, croplands, aquacultures and even urban parks, have their own biodiversity. Since cultivated systems account for more than 24% of the earth's terrestrial systems, it is important that management strategies should focus on enhancing biodiversity. In pest management, biodiversity contributes towards pest dynamics in several ways. In rice, reliable natural biological control action depends on the continuous supply of natural enemies from both neighboring rice crops and non rice habitats (Way and Heong 1994). Such continuity can be disrupted by environmental stresses, such as climatic hazards, like floods and droughts, but more commonly by unnecessary use of prophylactic pesticide applications (Heong and Schoenly 1998).

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 1). 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 directly linked to ES contributing to food provisioning through crop and genetic biodiversity (Figure 2). In addition, biodiversity through ecological functions contributes to regulating services, such as pollination, invasion resistance, natural biological control, pest and disease regulation. For instance the loss in species richness of bees and syrphids are directly linked to loss in pollination services in Europe (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 and biodiversity concepts thus provide a framework for natural resource management research as it can integrate the

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 1. Ecosystem services of lowland rice (after IRRI 2006)

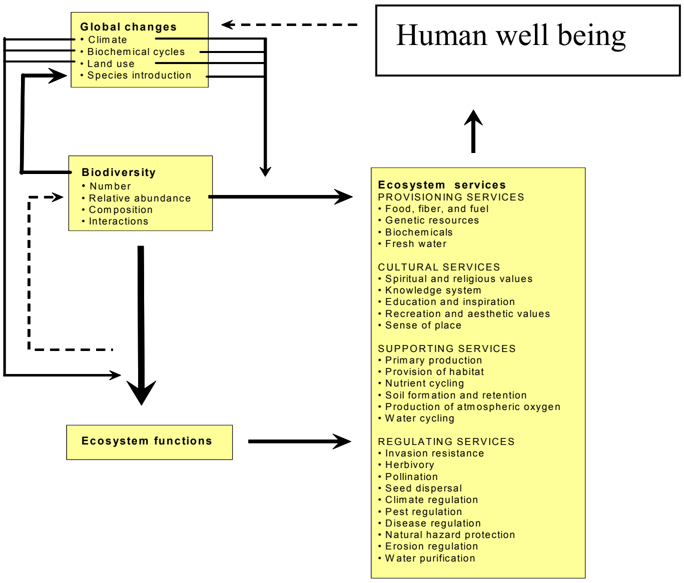

Figure 2. Biodiversity, ecosystem functioning, and ecosystem services (After MA 2005)

ecological, social and economic dimensions and can also include agricultural production as well as conservation objectives (MA 2005).

The contributions of biodiversity dependent ecosystem services to national economies can be substantial. Although the science of valuating ecosystem services is still developing, Costanza et al (1997) estimated that ecosystem services can be valued at about US$ 33 trillion per annum which is nearly twice the global gross national product of US$ 18 trillion. Various assessments have indicated that there is progressive degradation of ecosystem services which can threaten sustainability and stability of agricultural production.

Sustainable Pest Management

Natural biological control is linked to the ecosystem services, pest regulation and invasion resistance, and its importance has been 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) who showed that sustainable pest management can be achieved by manipulating a few manageable components of diversity, such as durable plant resistance, continuity of natural biological control and avoiding unnecessary pesticide disruptions. 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, planthopper pest populations increased by 40 folds 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.

Another backlash indicator of ecosystem breakdown is the development of insecticide resistance. Work done by Matsumura et al (2007) showed that some planthopper 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 planthopper populations of China, Vietnam and Japan. For instance BPH populations in the Mekong

Delta are at least 250 times more tolerant than populations in the Philippines. Resistance to buprofezin has also been recently recorded in planthopper. 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 where excessive use of pesticides have led to production instability 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 pests are not serious problems 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 ecosystem 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 in rice ecosystems has inherent resilience and capacity to increase when the suppressing factors are removed. At the IRRI farm insecticide use reduced by more than 95% from 1994 to 2005 because of strict implementation of IPM (Figure 3) and as a result arthropod biodiversity significantly increased (Table 1) (Heong et al 2007). Predator species richness 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 less than 5 hoppers/hill.

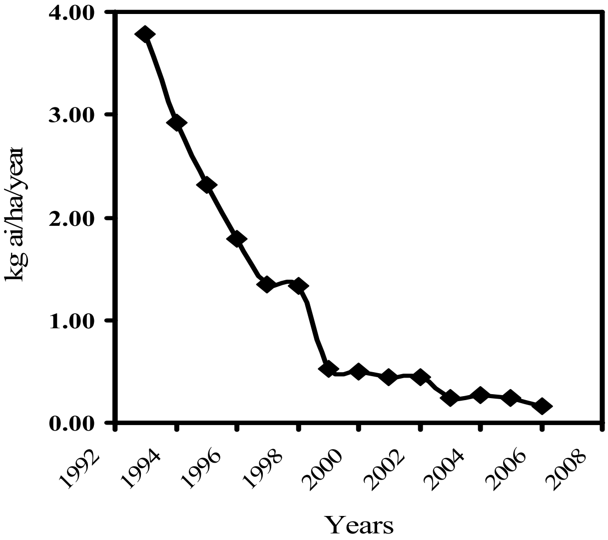

Figure 3: Decrease in insecticide usage from 1994 to 2006 in IRRI farm

Based on research results, both experimental and field, and related literature materials, it is evident that planthopper outbreaks are insecticide induced pest problems due to deterioration of important ecosystem services, such as natural biological control and invasion resistance. These services can also 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 more than 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 et al 2004) 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.

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

References

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.

Conway, G.R. and Barbier, E.B. 1990. *After the Green Revolution*. Earthscan Publications Ltd, London.

Conway, G.R. and Pretty, J.N. 1991. *Unwelcomed Harvest: Agriculture and Pollution.* Earthscan Publications Ltd, London.

Costaza et al 1997. The value of the world's ecosystem services and natural capital. Nature 287, 253 – 260.

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.

Gliessman S.R. 2001. Agroecosystem Sustainability – developing Practical Strategies. CRC Press Boca Raton, Fl.

Gurr, G.M., Wratten, S.D. and Altieri, M.A. 2004. *Ecological Engineering for Pest Management – Advances in habitat manipulation for arthropods*. CABI Publishing, Wallingford, Oson, UK.

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.

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.

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. 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.