ARTHOPOD BIODIVERSITY AND CONSERVATION BIOLOGICAL CONTROL IN RICE

K M Singh and M M Kumawat*

Central Agricultural University, Lamphelpat, Imphal West, Imphal 795004, Manipur
*College of Agriculture, Agriculture University, Jodhpur-342 304, Rajasthan
*Email: kumawatmm@gmail.com (corresponding author)

ABSTRACT

Rice ecosystems have a rich and diverse fauna of arthropods which varied in field in different ecological conditions. Beside the phytophages and detritivores, a large number of predators and parasitoids also exist in the rice ecosystem. Biological control has shown a great potential for reducing the dependence of crop protection on chemical control. Among the predators, spiders are highly abundant in rice fields which feed on variety of insect pests. The different organisms present in the rice ecosystem are linked by food web which can help insect pest management because they clarify the functional interaction between populations. Conservation biological control can be achieved by reducing the pesticide-induced mortality of natural enemies and habitat manipulation to improve natural enemies fitness and effectiveness in the rice fields. There is a plethora of natural enemies in rice ecosystem and conservation biological control plays a major role in reducing pests. The identification of safer chemical pesticides and supplemental food of natural enemies is still needed.

Key words: Rice, conservation, biological control, food webs, trophic relationships, natural enemies, insect pests, habitat manipulation

Rice (Oryza sativa L.) is one of the most important crops in the world. It is the primary staple food for billions of people in Asia and for hundreds of millions of people in Africa and Latin America. This annual grass is widely cultivated from 50° N to 40°S latitude and in areas from sea level to altitude of more than 2,500 metre (Tsunoda and Takahashi, 1984). The major rice ecosystems are wetland (also known as paddy or low land), dryland (or upland) and deepwater. Wetland rice may be irrigated, rain fed and recession rice. Recession rice is grown when rice seedlings are transplanted into receding water which occurs when a lake dries up. Earth embankments (bunds) are prepared in wetland rice fields to retain water. In deepwater rice, standing water deeper than 50 cm remains in the field for one month or longer during the growing season (Catling, 1992). Rice cultivation of high input responsive varieties which necessitate application of increasing amounts of agrochemicals, leading to enhanced environmental degradation and reliance on high capital and production inputs (Tilman, 1998; Matson et al., 1997; Tilman et al., 2002). These escalating usage of the insecticides, fungicides and herbicides eroded the on farm biodiversity (Stark and Banks, 2002; Relyea, 2006) and causes pest resurgence. With development of new biotype of pests, breakdown of resistance becomes a common phenomenon and need to replace the new resistance varieties after every 2-3 years. This leads to genetic treadmill beside the insecticide treadmill. In recent decades, integrated pest management (IPM) has shown great potential for reducing the dependence of crop protection on chemical control methods (Pretty et al., 1998; Atanassov et al., 2002) and biological control is a major component of the IPM programs.

Biological control may involve the inundative release of large number of bio- control agents or the inoculative release of exotic agents. The inundative release is economically liable only for those natural enemies which can be cultured invitro or those with simple mass production technique like Trichogramma spp. Further, availability of these bio- control agents at the farmers label are also a problem as there is limited number of natural enemies production units and difficult to transport for longer distance as they are the living entities. The inoculative release of exotic agents, otherwise known as classical biological control, carries a risk of introducing species that will have severe non-target effects (Howarth, 2000; Twyford, 1991). Beside these around 90% of arthropods releases for arthropod pest control, fails to bring the target under effective control (Gurr et al., 2000). In the attempts to introduced exotic parasitoids against stem borers in Philippines, one parasitoid was established against pink stem borer but no beneficial effect was observed (IRRI, 1971). To control rice black bug, two egg parasitoids was introduced in the Island of Palawan, however, none of the species was established (Ooi and Shepard, 1994).
Considering the problem associated with inundative and inoculative biological control, from the last decade, attention has been drawn toward the conservation biological control. Conservation biological control is defined as ‘modification of the environment or existing practices to protect and enhance specific natural enemies of other organisms to reduce the effect of pests’. Many techniques that can be successful in rice fields for managing the pests are discussed herein.

**Biodiversity in rice ecosystem**

Rice is grown in different ecological conditions thus have varied community structure of arthropods and even in the same field change in the environmental condition favours another community structure of arthropods. Rice ecosystems also have a rich and diverse fauna of arthropods. The arthropod community associated with irrigated rice in Philippines was studied by Heong et al. (1991). They reported that phytophages and predators were predominant in all sites. The phytophages were mainly Homopteran and dominated by the cicadellids *Nephotettix virescens* (Distant), *Nephotettix nigropictus* (Stal), and the delphacids, *Nilaparvata lugens* (Stal) and *Sogatella furcifera* (Horvath). Predetors were mainly Heteropterans which includes the veliid, *Microvelia douglasis atrolineata* Scott, the mesoveliid, *Mesovelia vittigera* Horvath and the miried, *Cyrtorhinus lividipennis* Reuter being the most abundant species. Spiders were the next dominant group which includes *Pardosa pseudoannulata* (Bosenberg & Strand) and three species of *Tetragnatha*.

Survey of farmer’s fields in Laos recorded 435 arthropod species belonging to 266 genera and 121 families in 13 orders (Inthavong et al., 1998). Rai et al., (2000) compiled an inventory of the biodiversity of coleopterans associated with various rice growing ecosystems listed 368 species, which have various kind of associations with rice, both herbivores and non-herbivorous. Biosystematics of these revealed that there are 368 species under 191 genera and 26 families. The families Chrysomelidae, Coccinellidae, Curculionidae and Scarabaeidae comprised major share followed by Anobiidae, Anthicidae, Bostrichidae, Carabidae, Cucujidae, Dascillidae, Dermentidae, Dytsicidae, Elateridae, Heteroceridae, Hydrophilidae, Languriidae, Melryidae, Meloidae, Ptinidae, Silvanidae, Staphylinidae, Tenebrionidae and Trogossitidae. An analysis of their interaction with rice indicated that a great majority of them are pests, either in the field or storage. Many of them were predators, indicating their potential in biological control of pests and can be included in integrated pest management. The arthropod biodiversity is increased with the reduction of chemical pesticides in rice ecosystem (Table 1).

**Table 1. Comparison of arthropod biodiversity after reduction in use of insecticides in International Rice Research Institute farm in 1989 and 2005**

<table>
<thead>
<tr>
<th>Guilds</th>
<th>Biodiversity parameters</th>
<th>1989</th>
<th>2005</th>
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<tbody>
<tr>
<td></td>
<td>Abundance %</td>
<td>46.2%</td>
<td>11.6%</td>
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<td></td>
<td>Species richness, S or E&lt;sub&gt;n&lt;/sub&gt; (rarefaction)</td>
<td>13.6</td>
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<td></td>
<td>Log series index α</td>
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<td>Reciprocal Simpson’s (I/D)</td>
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<td>Exp Shannon or Hill N&lt;sub&gt;1&lt;/sub&gt;</td>
<td>3.46</td>
<td>5.75</td>
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<td>Herbivores</td>
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<td>Exp Shannon or Hill N&lt;sub&gt;1&lt;/sub&gt;</td>
<td>8.25</td>
<td>11.70</td>
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<td>Predators</td>
<td>Abundance %</td>
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<td>Exp Shannon or Hill N&lt;sub&gt;1&lt;/sub&gt;</td>
<td>1.46</td>
<td>10.80</td>
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Source: Heong et al., 2007
Insect pests

Rice is primarily a crop of warm and humid environments where the insect pest problems are very severe and numerous. A good attempt has been made by a number of workers to study the insect pest complex associated with rice crop. Grist and Lever (1969) listed over 800 species of insects damaging rice, either in standing crop or in storage. Pawer (1974) listed 650 species of insect pest collected from rice field in Philippines. Pathak (1977) mention about 100 species of insect attacking rice of which about 20 are major pests. Further, about 159 pest species of rice were identified by Rob (1990) from Bangladesh.

The diversity of pests in the rice ecosystem depends on the environment. The distribution of the monophagous species, Asian rice gall midge, Orseolia oryzae (Wood-Mason) coincides with the distribution of wild rice varieties. Armyworms, Mythimna separate Walker and cutworms, Spodoptera littura (Fab.) attack the pre-flooded crop. As the fields flooded, aquatic species enter the ecosystem such as black bugs, Scotinaphora spp. and rice caseworm Nymphula depunctalis (Guenee). Thrips, Stenchaetothrips biformis (Bagnall) and mealybugs, Brevennia rehi (Lindinger) thrive in rice during droughts. In deepwater rice, yellow stem borer (YSB), Scirpophaga incertulas Walker and rice hispa, Dicladispa armigera (Olivier) are dominant. In dryland rice fields, ants, whitegrubs, black beetles, termites, field crickets, mole crickets, root aphids, mealy bugs, root bugs, seedling maggots, grasshoppers, thrips and seed bugs cause damages. Rice crop grown near maize is prone to Chilo stem borer infestations and rice grown near sugarcane is prone to pink stem borer, Sesamia inferens (Walker). In grasslands near rice fields can serve as a source of armyworms, grasshoppers, whitegrubs and seedling maggots (Jahn et al., 2007). Changes in the environment may favour one pest groups but not another (Loevingsohn, 1997). Flooding a rice field eliminates soil pests whereas aquatic species thrive in ponded conditions. Prolonged droughts in mid-1980s in Indonesia and the southern Philippines (Glanz, 1996) led to a shift in stem borer species from the non-estivating YSB to the aestivating white stem borer (WSB), Scirpophaga innotata (Walker).

Predators

Among the predators, spiders are highly abundant in rice fields preying on a wide array of insect pests and have a major role to play in the natural regulation of insect pests. Spiders have higher host finding ability and greater feeding potential in comparison to other predators inhabiting in the paddy fields. They prey on wide range of insect viz. stem borers, leaf folders, plant hoppers, leaf hoppers and some dipterans. So, they are one of the generalist predators. Barrion and Litsinger (1984) has made a good compilation of field spiders from 12 Asian countries, listing 173 species from the temperate zone (Japan, Korea, China and Taiwan) as compare to 86 species from the tropics (Bangladesh, Burma, India, Indonesia, Malaysia, Philippines, Sri lanka and Thailand). Xu et al., (1987) also reported 167 species falling to 28 families from the rice ecosystem of Zhejinaq, China. Surveys in different part of the northern and western India have revealed that there are more than 20 species of spider which suppress the population of brown plant hopper, white backed plant hopper, green leaf hopper, leaf folder and whorl maggot in rice ecosystem (Bhalial and Dhaliwal, 1990). Thirty-four species of spider belonging to 10 different families from Cuttack, Orissa and 5 species from Assam have also been reported by Rai and Chandrasekar (1979) and Krishnaswamy et al., (1984), respectively. In central India, 13 species of spiders belonging to 8 families were found to be common from the nursery stage to harvest (Bhardwaj and Pawar, 1987).

Aside spiders, several hemipteran predators feeding on various insect pests of rice were also reported from different regions. Cytorhinus lividipennis Reuter and Tythus sp. are important predators of plant hoppers and leafhoppers in different rice growing areas (Balasubramanian et al., 1988; Basilio and Heong, 1990; Peter, 1988). A large population of Hydrometra albo lineata (Scott) feeding on plant and leaf hoppers of rice was observed in Hunan, China (Wu, 1988). Water strider Limnogonous fossarum (F.) is an effective predator of leaf hopper, plant hopper and other pests is present in different water bodies including wetland rice (Rubia and Heong, 1990). The hemipteranpentatomid Amyotea (=Asopus) malabarica (Fab.) predate on the larvae of Melanitis ledaismene (Cramer), Parnara (=Pelopidas) mathias (Fab.), P. naso (Fab.), Spodoptera spp., Mythimna loreyi Duponchel, Mythimna venalba (Moore), Psalispenntula (Fab.), Laelia fasciata (Moore), Euprocis xanthorhoea (Koller), Chilo spp., S. incertulas and S. inferens (Pati and Mathur, 1986). A pyrrhocorid bug, Antilochus nigripes (Burm.) was found feeding on the nymphs and adults of Leptocorisacutes Thumb in Eastern India. Its predation ranged from 1.66 to 5.66 bugs per day (Rao and Prakash, 1999).

Many orthopteran and coleopteran predators were also recorded in the rice ecosystem. The katydids,
Conocephalus longipennis (Haan) and Conocephalus maculates (Le Guillou) predate on the egg masses of lepidopteran pests of rice, leafhoppers, plant hoppers, early instars nymphs of grasshoppers and eggs of Leptocorisa oratorius (Fab) (Deng and Jin, 1985; De Kraker et al., 2001). However, after flowering, the katydids feed on flowering and later on young grains (Manley, 1985). The cricket, Metioche vittaticollis (Stal) prayed on the eggs of a range of insect pests of rice including Chilo suppressalis (Walker), Cnaphalocrosis medinales (Guenée), Hydrellia philippina Ferino, M. separata and to a lesser extent L. oratorius (Rubia and Shepard, 1987; Lee et al., 1997). Shepard and Rapasus (1989), Chander and Singh(2003) observed Paederus fuscipes Curtis, Ophionia indica(Thunberg), Verania (=Mircaspis discolor)(Fab), Micraspis crocea (Mulsant), Coccinella arcuata Fab (=Harmoniaactomaculata), Coccinella septempunctata Linn, Brumus (=Brumoides) suturalis (Fab), Menochilus (=Cheilomenes) sexmaculatus (Fab) and Coccinella transversalis Fabas conspicuous predators in rice fields. Kobayashi et al., 1990 reported carabid, Ophionia indica which predate on Orseolia oryzae. Many dragon flies and damsel flies were also observed on the rice ecosystem by Garg et al. (2002).

Parasitoids

Dey et al. (1999) published a checklist of hymenopterous parasitoids associated with rice agroecosystem. In China and Philippines, Trichogramma spp. plays a vital role in reducing the population of Marasmia patnalis Bradley, C. suppressalis and C. medinalis (Zhou, 1986, Arida and Shaperd, 1990). In Java, the scelionid, Telenomus rowani (Gahan) was the major parasitoid species followed by the eulophid, Tetrastichuschoenobii Ferriere and Trichogramma japonicum Ashmead (Soejito, 1988). She and He (1988) revealed the presence of 19 parasitoid species attacking the pyralid C. suppressalis. The dominant species were T. japonicum, Chelonus munakatae Matsumura, Microgaster russata Hal., Centeterus alternecoloratus Cush. (Auberteterus alternecoloratus) and Erioborus terebrans (=Diadegma terebrans) (Gravenhorst). Mehrub (1993) identified three species of egg parasitoid of S. incertulas from Indonesia. They were T. schoenobii, T. rowani and T. japonicum. In Orissa (India), S. incertulas eggs were parasitized by Telenomus dignoides (Nixon), T. japonicum and T. schoenobii (Ram et al., 1996) and in Punjab, the scelionid, T. dignoides parasitized the egg of S. incertulas. Beside the egg parasitoids several larval and pupal parasitoids of the lepidopteran pests of rice were also reported.

A total of 61 species of hymenopterans was identified as parasitoid of C. suppressalis in Spain, 22 of which was ichneumonoids, 25 braconids and 14 chalcids (Jimenez et al., 1992). The braconid, Apantales cypris Nixon parasitized the larva of C. medinalis in China with an average parasitism of 28.6% (Wei, 1987). In rice fields, the braconid Apantalis ruficus (Haliday) gave good control of Mythimna separata in late March- April and of Naranga aenesoccens Mooreand the hesperiid Parnara guttatus (Bremer & Grey) in late July to Mid August in China (Zhang, 1986). A torymid parasitoid, Podagri on ahlonei Mani & Kaul was recorded for the first time in India as a parasitoid of C. medinalis (Kaul, 1993). Aulosaphes sp. was recorded as the dominant parasitoid of C. medinalis followed by Bracon sp. in Assam. Other parasitoids recorded were Goniozus sp., Cardiochiles philippensis Ashmead and Temelucha (=Temeluchella) sp. (Borah and Saharia, 1989). Mishra and Senapati (1996) reported Goniozus triangularis Kieffer as a larval parasitoid of C. medinalis. Brachymeria lasus (Walker) was reported as a pupal parasitoid of Mythimna separata (Husni et al., 2001). In Uttar Pradesh, India, Apantalis (Cotesia) ruficus (Haliday) was found to cause larval mortality of M. separata upto 75.35% during 1996 (Pandey and Sharma, 1999).

Against leafhoppers and plant hoppers, Huang (1984) reported Pseudogonatopus flavifemur (Esaki & Hashimoto) as an important biocontrol agent of brown plant hopper (BPH) in China. The young stage of the hymenopteran parasitized the pest and adult females prayed on nymphs of the pest. Anagrus flavoleus Waterhouse (Hymenoptera: Mymaridae) is an important egg parasitoid of BPH in Philippines (Chandra and Dyck, 1988) and P. flavifemur a nymphal parasitoid of BPH in Korea Republic (Kim et al., 1988). Gonotocerus cincticpitis Sahad and Paracentrobiaandoi (Ishii) was reported as egg parasitoid of the green leaf hopper, N. cincticeps in Japan (Miura, 1990a and Miura, 1990b). In Sri Lanka, N. jugens were parasitized by the mymarids Anagrus sp. nr flavoleus and A. optabilis and the trichogrammatid, Oligosita sp. Nephotettix spp. eggs were parasitized by the two species of the mymarid genus Gonotocerus and one trichogrammatid genus Paracentrobia. Gonotocerus spp. and Paracentrobia sp. seldom attacked the same Nephotettix egg batch (Fowler et al., 1991). In India, Echthrodelpheh fairchildii (Perkins), Haplogonatopus apicalis Perkins, Pseudogonatopus hospes (Perkins) and a species of the
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Genus *Pseudogonatopus* near *P. pusanus* were recorded attacking *N. lugens* and *S. furcifera* (Yadav and Pawar, 1989).

Morrill and Almazan (1990) reported *Gryon nixoni* Masner (=*G. flavipes*) as an egg parasitoid of *L. oratorius*. The Malayan black bug, *Scotinophara coarctata* (Fab) in Palawan Island, Philippines was attacked by the scelionid egg parasitoid, *Telenomus triptus* (Nixon) which parasitized a mean of 61.4% of the egg masses and a mean of 19.2% of the eggs (Perezet al., 1989). In Bangladesh, rice hispa, *Dicladispa armigera* (Olivier) grubs were parasitized by braconid and eulophid parasitoids (Islam and Rabbi, 1998). *Trichogramma zahiri* Polaszek was reported as an egg parasitoid of the rice hispa, *D. armigera* in Bangladesh (Polaszek et al., 2002).

There are also some reports on the parasitoids of the cecidomyiid pest, *Orseolia oryzae*. In Sri Lanka, five hymenopterous parasitoids were found parasitizing *O. oryzae*. They were *Platygaster oryzae* Cameron, *Platygaster foersteri* (Gahan), *Neanastatus cinctiventris* Girault, *Obtusiclava oryzae* Subba Rao and *Eurytoma* sp. *P. oryzae* parasitized up to 13.5% followed by *N. cinctiventris* (8.7%) (Kobayashi et al., 1990). In Orissa (India), the egg larval parasitoid *P. oryzae* was found to be more active against the rice pest *O. oryzae* and the larval and pupal parasitoid *Propicroscytus mirificus* (Girault), *Eurytoma* spp. and *Neanastatus grallarius* Masi (=*N. cinctiventris*) were more active against the grass midge, *Orseolia mnesitheae* Gagne (Mathur et al., 1991). A solitary *Platygaster* sp. also parasitized *O. oryzae* (Mathur et al., 1988). Rana et al., (2002) reported that parasitism of *P. oryzae* reaches up to 42% with 20.05 to 25.05% silver shoot. In Manipur (India), *P. oryzae* is the predominant parasitoid of *O. oryzae* and the parasitism even reach up to 69.5% (Singh, 2003).

Food webs

Most of the works on the biological control of insect pests of rice are confined on the survey of natural enemies, their extent of predation or parasitism and promoting one or two potential natural enemies. However, in the rice field hundreds to thousands of different species of plants, insects, arachnids, fungi, nematodes, snails, vertebrates and other organisms are present and they are linked by a vast, intrinsic network of feeding relations called food web. According to Cohen et al., (1994), food webs can help insect pest management because they clarify the functional interaction between populations (Fig. 1). Settle et al., (1996) had the opinion that consistently high level of natural biological control may often result from a complex set of community-level interactions that lead to a far more stable and robust system. But only in some cases, agricultural data on pests and their biological control, species have been organized into food webs.

Since 1977, entomologists of the International Rice Research Institute (IRRI) have been describing the food web of Philippines irrigated and rainfed rice fields. The whorl maggot food web comprises 114 taxa including 71 predators, 13 parasitoids and 62 secondary natural enemies (IRRI, 1987). The food web of semi-aquatic

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**Fig. 1.** Trophic relationships in a rice ecosystem (Source: Heong, 2012)
rice caseworm consists of 99 taxa with 78 predators, only 4 parasitoids, but 39 secondary natural enemies (IRRI, 1990). However, no egg parasitoid was recorded against the pest. It may be due to its egg laying site. Among the stem borers, yellow stem borer, *Scirpophaga incertulas* comprises 118 species including 57 predators, 38 parasitoids and 23 secondary natural enemies (IRRI, 1984) and *Chilo* stem borers includes 111 species with 57 as predators, 33 parasitoids, 18 hyperparasitoids and 28 secondary predators (IRRI, 1989). Leaf folders are a group that is heavily attacked by natural enemies (Khan et al., 1988). The food web from the Philippines comprises 163 taxa with 77 predators, 51 parasitoids and 24 secondary natural enemies. Leafhoppers are under heavy pressure from natural enemies beginning with trichogrammatids (*Paracentrobia, Oligosita*) and mymarids (*Gonatocerus, Anagrus*) egg parasitods (Jahn et al., 2007). Predators alone reduce the leaf folder number by 50-70% in field studies (Ooi and Shepard, 1994). The food web of the *Nephotettix* spp. includes 205 taxa with 129 predators, 35 parasitoids, 6 pathogens and 63 secondary natural enemies (IRRI, 1986). Of the brown plant hopper food web, only 11 of the 76 taxa are parasitoids and 11 secondary natural enemies and the remaining are predators dominated by spiders (IRRI, 1980). Schoenly et al., (1996) mentioned the cumulative version of food web of Philippines rice ecosystem contains taxa which includes pathogens, nematodes, mites, spiders, insects, snails, vertebrates and over 10,000 trophic (consumer-resource) links.

**Conservation biological control**

The arthropod diversity and abundance are fundamental components of rice ecosystems that have resistance and resilience to pest attacks. They provide farms with ecosystem services, such as resistance to pest invasions and regulation of pest populations that prevent pest species from increasing to levels that can cause economic loss to farmers. The impetus for better understanding of the role of natural enemies stemmed from widespread and devastating outbreaks of *Nilaparvata lugens*, associated with early Green Revolution Technology in Tropical Asia (Way and Heong, 1994). At first, the tillering and other growth characteristics were largely blamed for the outbreaks (Dyck et al., 1979). However, such outbreaks were also associated with the widespread and intensive used of certain insecticides which are highly destructive to natural enemies. In Thailand, despite intensive insecticide usage, outbreaks of *N. lugens* became increasingly serious upto 1989-90 and it confirm the outbreak of *N. lugens* is associated with insecticide usage not with fertilizers (Den Braber and Meenankanit, 1992). Field experiments in the Philippines indicated that high yields are strongly correlated with good overall crop husbandry but not with the use of insecticides (Way and Heong, 1994). Dead heart caused by the stem borers in the early crop stage does not affect much on the yield as the rice plant can recover the injury. Potentially the most damaging stem borer *Scirpophaga innotata* (Walker) causing whiteheads begins oviposition at about 80 days after transplanting. However, during this time, a rich natural enemy community has already accumulated including the parasitoids and can make a major contribution in stem borer control, unless insecticides are used (Way and Heong, 1994). As an example, when carbofuran was applied for controlling *Scirpophaga innotata*, egg predation and parasitism of the pest was reduced to halve and the number of whiteheads was doubled (Triwidodo et al., 1992).

In the organic matter rich fields of rice, there is abundant population of detritus feeding and plankton feeding insects and they serve as alternative prey for many generalist predators (Fig. 2). These alternative preys can give the predator population a ‘head start’ on later-developing pest populations. This process can strongly suppress pest populations and generally lend stability to rice ecosystems by decoupling predator populations from a dependence on herbivore populations (Settle et al., 1996). Feeding studies on *Atypena formosana* (Oi) by Sigsgaard et al. (2001) suggest that alternative prey such as collembolans may still be more profoundly important. Spider feeding only *N. lugens* or *N. virescens* led to very poor survival of spiders to the adult stage. In contrast, a mixed diet of either hemipteran with collembolans and drosophilas as
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**Fig. 2. Number of detritivores and plankton feeders in Indonesia rice fields**
(Source: Settle et al., 1996)

Gave faster development time and greater survival. This illustrated that availability of prey such as collembolan is essential for the performance of this linyphid, not simply an early-season alternative food resource. Beside the rice pests, some of the insect in the rice ecosystem feeding on wild plants also serves as an alternative host of the many parasitoids and predators. The eggs of *Notiphila latigenis* Hendel and *Notiphila similis* Meijere which were usually laid on the stem of perennial fern *Marsilea minuta* L. and it serve as alternate host of the stem borer parasitoid *Trichogramma* (Barrion and Litsinger, 1986).

Settle et al. (1996) mentioned two ways for disrupting high levels of biological control in the rice ecosystem of Java, Indonesia:

Early season application of pesticides including herbicides keeps down the natural enemies’ population. Insecticide applications are the most important factor causing pest problem. Even the herbicides give negative effects to phytoplanktons and zooplanktons, which give indirect negative effect to the predator population.

Unfavourable landscape design and water use patterns also weaken the system. In rice landscapes characterized by synchronous and large scale planting patterns and preceded by long, dry fallow periods, the arrival of natural enemies is severely delayed. A secondary but important effect of this delay is that generalist predators could not take the advantage of the peak population of alternative prey provided by the detritivores and plankton feeders due to late arrival. The long dry fallow periods can be shortened by planting dry-season crops such as soybeans or green manures or promoting the conservation of straw mulch piles.

The majority of the rice pests are specific or narrowly oligophagous for rice, so there is little chance of harbouring rice pests by the plants surrounding the rice fields except some polyphagous pests like armyworms and locust. On the other hand, non-rice habitats, particularly the narrow vegetation-covered bunds surrounding each field, seem especially important as a source of natural enemies, particularly early arriving species such as spiders. The rice bunds are also abundantly colonized by fireants, *Selenopsis geminate* (F.) and this ant is potentially important predator of *N. lugens* and other rice pests including corn rootworm, *Diabrotica adelpha* Harold (Way et al., 2002). Parasitoids of the rice hoppers commonly parasitized non-rice hoppers species on wild host plants during off season (Way and Heong, 1994). Another important very early arriving predator of plant hoppers, *Cyrtothrinus lividipennis* Reuter can also survive in the off-season as an egg predator of insects on wild plants (Bentur and Kalode, 1987). Beside these non-rice habitats seem likely to be an important source of some other early arriving predators like Gryllidae that can seasonally concentrate on rice (Way and Heong, 1994). Drechsler and Settle (2001) reported that high proportion of vegetable fields in the landscape reduces pest abundance in the rice field. According to Gurr (2009) fruit and timber trees, may serve as sources and sinks for natural enemies. Proximity of such landscape elements is important because many of the generalist predators like wolf and web-building spiders, colonized rice from adjacent habitats.
Different habitat manipulation techniques for conservation of arthropod natural enemies were also developed in different parts of the world. Shepard et al. (1989) suggested for placing rice straw bundles in the rice fields during crop free period. The bundles can be prepared by arranging rice straw into cone-shaped tents about 30 cm in diameter at the bottom which serves as habitat for the predators and prey communities during crop free period. For management of insect pests of rice, straw bundles@ 20 bundles/ha can be placed in the rice fields. The bundles can be first put in sorghum fields for about 15 days to charge the bundles with natural enemies like spiders and rove beetles and then transfer it to the rice field after 15 days of rice transplanting. While placing the straw bundles, it can be fixed with bamboo sticks and the lower portion of the bundle should remained 15 cm above the water level. This technique could increase the spider population in rice ecosystem (Tanwar et al., 2011).

In Japan, mowing of the ridges in the rice fields and cultivation of Chinese milk vetch, *Astragalus sinicus* L. as a green manure crop before rice transplanting increased the number of wolf spiders in rice field ([www.ipmcentres.org](http://www.ipmcentres.org), 2012). Placement of weed residues in upland rice in piles harbour more spider population (Afun et al. 1999). Carabid beetles were significantly more abundant in plots with strips or piles of weeds and staphylinid beetles were most abundant in mulched plots. The rice ratoons were found to be a favourable habitat for natural enemies, especially predators and flooding a field continuously favored predator population (Dela Cruz and Litsinger, 1988). Allowing the growth of weeds in the roundabouts of small dikes in rice fields, especially *Paspalum* sp., *Digitaria* sp. and *Echinochloa* sp. Application of host extract and sugar liquid on rice plant was recommended for management of brown plant hopper ([Atmaja and Laba, 2000](http://www.ipmcentres.org)).

Heong (2012) suggested three planks for ecological engineering to enhance natural biodiversity in the rice ecosystem-

Plank 1: Reduction in insecticide use especially in the early crop stage-

Application of insecticides in the first 40 days after sowing do more harm than by destroying natural enemies and aquatic detritivore prey fauna. It significantly decrease food chain lengths and disorganize predator-prey relationship.

Plank 2: Enhancement of generalist natural enemies through detritivore prey-

Enrichment of organic matter of the soil will increase the population of detritivores and plankton feeders and it serve as the alternate prey of the generalist predators. At the early crop stage, detritivores and plankton feeders are vitally important and need to be conserved. Application of pesticides reduce their population.

Plank 3: Enhancement of specialist natural enemies by habitat manipulation-

The third plank targets at providing resources, shelter and food for the natural enemies, especially the specialist. This may be achieved by populating bund and non-rice habitats with nectar rich flowering plants. In China when nectar rich sesame plants are grown on bunds, parasitoid abundance increased. Sesame flowers also enhance the host searching efficiency by the parasitoids. In Vietnam, flowers on the bunds increased egg parasitism of plant hopper eggs. In Thailand, parasitoid species richness increased when fields are surrounded by flowering plants. In Hainan, Philippines, fields with clean bunds had lower spider biodiversity.

An alternative approach for manipulating natural enemy movement based on chemical ecology may be viable in the future. Natural enemies are attracted to the volatile chemical produce by the plants that are attacked by arthropod herbivores. Some such herivore-induced plant volatiles (HIPVs) have been identified, synthesized and used in slow-released dispensers or sprays. Under field conditions, methyl-salicylate, cis-3-hexen-1-ol, (Z)-3-hexenyl acetate, and benzal dehyde have resulted in elevated catches of biological control agents (James, 2005). Application of jasmonic acid on rice increased the parasitism of *N. lugens* eggs by *Anagrus nilaparvatae* Pang & Wang (Gurr, 2009). Exogenous applications of jasmonic acid to rice plants elevated the levels of several volatiles, including aliphatic aldehydes, alcohols, monoterpenes, sequiterpenes, methyl salicylate and n-heptadecane. Plants treated with such chemicals not only producing HIPVs which attract the parasitoids and predators, it may also affect the pest behavior, making treated plants less attractive to the pests (Karban and Chen, 2007).

Conclusions

Biological control as a main component of integrated pest management (IPM) has shown a great potential for reducing the dependence of drop protection on chemical control methods. Biocontrol approaches like classical biological control and inundative and inoculative
release of natural enemies have certain limitations. Considering the problem associated with other biocontrol approaches, from the last decade, attention has been drawn toward the conservation biological control. Rice ecosystems have a rich and diverse fauna of arthropods. As the crop is grown in different ecological conditions thus have varied community structure of arthropods. Beside the phytophages and detritivores, a large number of predators and parasitoids also exist in the rice ecosystem. Among the predators, spiders are highly abundant in rice fields. Barrion and Litsinger (1984) listed 259 species of spiders from the rice fields of Asian countries. Several hemipteran, orthopteran, coleopteran and odonate predators also available in the rice ecosystems. From different parts of the world, different egg, larval and pupal parasitoids parasitizing the insect pests of rice were also reported.

The different organisms present in the rice ecosystem are linked by a vast, intrinsic network of feeding relations called food web. According to Cohen et al., (1994), food webs can help insect pest management because they clarify the functional interaction between populations. Settle et al., (1996) were of the opinion that consistently high level of natural biological control may often result from a complex set of community-level interactions that lead to a far more stable and robust system. Conservation biological control (CBC) which is one of the four forms of biological control, in practice, is effected by either (1) reducing the pesticide-induced mortality of natural enemies through better targeting in time and space, reducing rates of application or using compounds with a narrower spectrum efficacy, or (2) by habitat manipulation to improve natural enemies fitness and effectiveness (Gurr et al. 2004). Increase in arthropod diversity with the reduction in use of chemical pesticide was already proven by Heong et al. (2007) in IRRI rice farm. Some successful studies were carried out on the management of insect pests of rice through habitat manipulation (Heong, 2012; Settle et al.,1996; Shepard et al. 1989, Tanwar et al., 2011). However, research is still in demand on the identification of safer chemical pesticides, and more suitable physical refugia, alternate host and supplemental food of natural enemies. Studies on the manipulating natural enemies movement based on chemical ecology is still in initial stage and focused studies in this line may open up a viable approach for management of insect pest of rice.

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