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A contribution to the predator and parasitoid fauna of rice pests in Iran, and a discussion on the biodiversity and IPM in rice fields

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A b s t r a c t : Rice fields produce rice, the cereal grain that feeds half the planet. Rice fields are economically important as well as ecologically valuable. A wide range of plant and animal species exist in rice fields. Rice fields are one of the biggest ecosystems that can be found in the tropics, including diverse insect pests and their natural enemies. The species diversity of many natural enemies (predators and parasitoids) was studied in rice fields of Iran especially in northern localities. Totally, 25 predator species of 7 orders and 11 families, and 37 parasitoid species of 2 orders and 8 families were identified. Of these, 11 genera and 23 species are newly recorded from Iran. In addition to the faunistic surveys on natural enemies of rice pests, the biodiversity of invertebrates in rice fields is discussed.

K e y w o r d s : Biodiversity, IPM, Rice fields, Invertebrate, Arthropoda, Predator, Parasitoid, Iran

Introduction

Rice fields are very important because they are environmental buffers. They are a dynamic ecosystem that helps balance temperature and wind. They provide a moderating effect on the surroundings. One can feel the refreshing coolness of rice fields as opposed to the oppressive heat in the concrete jungle of the city. Rice plants produce oxygen during the day, and air moving in rice fields helps circulate the oxygen produced and hastens carbon dioxide exchange. Places with or near rice fields have cooler, fresher air compared with crowded and polluted locations where the air is hot and dirty (ROGEL MARIE 2004).

The rice ecosystem in Asia is indigenous to the region; rice was first domesticated before recorded history, perhaps more than 6.000 years ago (PONTING 1991), while reaching cultivation similar to that of modern days in the sixteenth century (HILL 1977). This lengthy time period means that the rice plant, pests and their natural enemies have existed together and co-evolved for thousands of generations. Rice ecosystems typically include both a terrestrial and an aquatic environment during the season, with regular flooding from irrigation or rainfall. These two dimensions of the rice crop may account for the extremely high biodiversity (COHEN et al. 1994) found in the rice ecosystem and its stability even under intensive continuous cropping – in contrast with the relative instability of rice production under dryland conditions. Irrigated rice systems in Africa, the Americas and Europe also include this aquatic and terrestrial ecosystem with accompanying high levels of biodiversity – and these factors may also provide the relative stability found in these systems.

Generally, grasses and other vegetation in habitats adjacent to rice fields serve as habitats of natural enemies and also provide supplementary and complimentary food, over-wintering, or off-season habitats. The precise composition of plant species that will make the greatest contribution to the conservation of natural enemies of rice insect pests has not yet been determined (KHAN et al. 1991).

There is growing recognition that agricultural biodiversity is being eroded and agro-ecosystems impoverished by the loss of genetic diversity. International agreements such as the Convention on Biodiversity (CBD) and the Ramsar Convention on Wetlands are a response to these concerns. In 2002, the Johannesburg World Summit on Sustainable Development (WSSD) concluded that biodiversity is essential to human well-being and to the livelihoods and cultural integrity of individuals and societies and thus plays a critical role in overall sustainable development and the eradication of poverty. The WSSD Plan of Implementation calls for a significant reduction in the current rate of biodiversity loss by 2010. The agro-biodiversity within the rice-based system presents great opportunities for improved nutrition within rural communities, increased farmer income through crop diversification, and the protection of a wealth of genetic resources for future generations (International Year of Rice 2004).

Insects have the largest number of species present in the rice field. There are more than a thousand insect species found in Iran rice fields. Some of the most familiar insects are the grasshoppers, caterpillars, mealybugs, rice bugs, plant hoppers, and ants (NAJAFI NAVAII & ATTARAN 2004). The most important researches on the natural enemies of rice pests were conducted in Africa (MOHYUDDIN 1990; BONHOF et al. 1997; POLASZEK 1998) and Eastern South Asia (SHEPARD et al. 1987; RUBIA et al. 1990; HEINRICHS 1994), and several natural enemies were determined from these regions. In spite of vast rice fields being present in Iran, the insect fauna of Iranian rice fields was not studied so far. This paper deals with the fauna of natural enemies in the rice fields of northern Iran. Determining the natural enemies and biodiversity of rice fields is the first step to success in biological control and IPPM (Integrated Production and Pest Management) programs. Also, most biological control programs focus on promoting one or two "premier" natural enemies as agents for the suppression of particular pests. In contrast, we argue that consistently high levels 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, vis-à-vis insect pest populations, than has previously been considered. We have arrived at this hypothesis from our own work on pest management in rice agroecosystems.

Materials and Methods

The fauna of natural enemies of northern Iran was studied through 2003-2006. All the predators and many adult parasitoids were sampled by a variety of methods, including visually scanning crops while walking, aerial netting, suction traps, and Malaise traps. Materials were collected from rice seedlings and weeds around and within the rice fields. Additionally, different life stages (egg, larvae, pupae) of rice pests (especially moth pests) were collected and put in optimum condition (25±2; 70±5 % RH; 14:10 photoperiod) for rearing the parasitoids. The collected specimens were put in ethanol and after preliminary determining they were sent to specialists for confirmation.

Species list

The results of faunistic surveys in northern Iran as the centers of rice crop in Iran indicated that there are diverse fauna of natural enemies in these regions. Totally, 62 predator and parasitoid species of 9 orders and 19 families were identified. Among the collected species, 2 genera and 6 species of predators, and 9 genera and 17 species of parasitoids are first records for the Iranian fauna. The list of determined species is given below.

I. Predators

The list of 25 predator species of 2 classes (Insecta, Acari), 7 orders (Mantodea, Orthoptera, Coleoptera, Dermaptera, Neuroptera, Hymenoptera, Prostigmata), and 11 families (Mantidae, Empusidae, Gryllidae, Tettigonidae, Staphylinidae, Malachiidae, Forficulidae, Anisolabidae, Chrysopidae, Sphecidae, Macrochelidae) as follow:

Order M a n t o d e a

Family M a n t i d a e

***Mantis religiosa* (LINNAEUS 1758)**

M a t e r i a l : Mazandaran province: Amol, 2♀♀, 2♂♂, April 2004; Ghaemshahr, 3♂♂, September 2004; Behshahr, 1♀, August 2005; Chalus, 1♀, 2♂♂, June 2005; Joibar, 2♂♂, June 2005; Savadkooh, 2♀♀, 3♂♂, July 2005. Guilan province: Rasht, 1♀, 1♂, April 2006; Astaneh, 1♂, June 2006; Amlash, 2♀♀, 1♂, June 2006; Fooman, 1♀, 1♂, September 2006.

***Hierodula transcaucasica* BRUNNER VON WATTENWYL 1878**

M a t e r i a l : Mazandaran province: Ghaemshahr, 1♀, April 2005; Sari, 1♂, June 2005; Mahmood-Abad, 1♀, 1♂, September 2005. Guilan province: Rasht, 1♀, July 2005. **New record for Iranian fauna.**

Family E m p u s i d a e

***Empusa pectinicornis* BURMEISTER 1838**

M a t e r i a l : Mazandaran province: Amol, 2♀♀; August 2005. Guilan province: Rasht, 1♂; June 2006.

Blepharopsis mendica (FABRICIUS 1775)

Material: Mazandaran province: Amol, 1♀, 1♂, July 2004; Behshahr, 2♀♀, September 2005; Savadkooh, 1♂, April 2006. **New record for Iranian fauna.**

Order Orthoptera

Family Gryllidae

Gryllus bimaculatus de GEER 1773

Material: Ghaemshahr, 1♀, July 2005.

Melanogryllus desertus (PALLAS 1771)

Material: Nooshahr, 1♂, July 2006.

Metioche vittaticolis (STÅL 1861)

Material: Mazandaran province: Ghaemshahr, 2♀♀, 1♂, August 2005.

Stenonemobius cf. *gracilis* (JAKOVLEV 1871)

Material: Amol, 1♂, September 2005.

Tartarogryllus tartarus (SAUSSURE 1874)

Material: Savadkooh, 1♀, August 2006.

Family Tettigonidae

Conocephalus longipennis (de HAAN 1842)

Material: Mazandaran province: Amol, 3♀♀, 2♂♂, July 2004.

Order Coleoptera

Family Staphylinidae

Paederus fuscipes CURTIS 1840

Material: *P. fuscipes* is a cosmopolitan and dominant species in all rice fields of Northern Iran; in this research hundreds of specimens were collected.

***Paederus littoralis* (GRAVENHORST 1802)**

M a t e r i a l : Mazandaran province: Amol, 5♀♀, 3♂♂, August 2005; Behshahr, 7♀♀, 2♂♂, September 2005; Joibar, 8♀♀, 5♂♂, August 2006.

Family M a l a c h i i d a e

***Laius venustus* ERICHSON 1840**

M a t e r i a l : Mazandaran province: Amol, 3♀♀, 2♂♂, August 2005; Behshahr, 2♀♀, July 2005; Fereydonkenar, 4♀♀, 3♂♂, September 2005. **The genus *Laius* is new record for Iran.**

***Colotes bernardi* WITTMER 1970**

M a t e r i a l : Mazandaran province: Amol, 2♀♀, 2♂♂, August 2005; Ghaemshahr, 5♀♀, 4♂♂, June 2005. Guilan province: Rasht, 3♀♀, 4♂♂, August 2006. **The genus *Colotes* is new record for Iran.**

Order D e r m a p t e r a

Family F o r f i c u l i d a e

***Forficula auricularia* LINNAEUS 1758**

M a t e r i a l : Mazandaran province: Amol, 3♀♀, 1♂, April 2004; Savadkooh, 4♀♀, 3♂♂, June 2005; Chalus, 2♀♀, 2♂♂, September 2005; Neka, 1♀, 2♂♂, August 2006; Joibar, 3♀♀, 4♂♂, July 2006. Guilan province: Rasht, 8♀♀, 3♂♂, August 2005; Somesara, 3♀♀, September 2005; Astaneh, 5♀♀, 4♂♂, August 2006; Lahijan, 4♀♀, 1♂, September 2006.

Family A n i s o l a b i d a e

***Euborellia annulipes* (LUCAS 1847)**

M a t e r i a l : Mazandaran province: Ghaemshahr, 2♀♀, 1♂, April 2005; Behshahr, 3♀♀, 3♂♂, July 2005; Sari, 1♀, September 2005; Babol, 2♀♀, 3♂♂, August 2006.

Order N e u r o p t e r a

Family C h r y s o p i d a e

***Chrysoperla carnea* (STEPHENS 1836)**

M a t e r i a l : Mazandaran province: Ghaemshahr, 4♀♀, 2♂♂, June 2005; Babol, 2♀♀, July 2005; Amol, 3♀♀, 1♂, September 2005; Sari, 1♀, August 2006. Guilan province: Rasht, 2♀♀, 1♂, July 2005; Roodsar, 3♀♀, 1♂, September 2006.

Order H y m e n o p t e r a

Family S p h e c i d a e

***Palmodes occitanicus puncticollis* (KOHL 1888)**

M a t e r i a l : Guilan, Rasht, 1♀; June 2005. **New record for Iranian fauna.**

***Sceliphron pietschmanni* KOHL 1918**

M a t e r i a l : Mazandaran, Sari, 1♂; August 2003. **New record for Iranian fauna.**

***Sphex leuconotus* BRULLÉ 1833**

M a t e r i a l : Guilan, Rasht, 1♀; September 2004.

***Sphex oxianus* GUSSAKOVSKY 1928**

M a t e r i a l : Mazandaran, Savadkooh, 1♀; July 2005.

***Podalonia hirsuta hirsuta* (SCOPOLI 1763)**

M a t e r i a l : Guilan, Lahijan, 1♀; June 2005.

***Chalybion* (*Chalybion*) *walteri* (KOHL 1889)**

M a t e r i a l : Mazandaran, Sari, 1♂; August 2003. Guilan, Rasht, 1♀; July 2004.

***Chalybion* (*Chalybion*) *flebile* (LEPELETIER de SAINT-FARGEU 1845)**

M a t e r i a l : Guilan, Rasht, 1♂; September 2004.

Class Acari, Order P r o s t i g m a t a

Family M a c r o c h e l i d a e

***Macrocheles merdarius* (BERLESE 1889)**

M a t e r i a l : Mazandaran province: Amol, 2♀♀, 1♂, September 2005.

II. Parasitoids

The list of 37 parasitoid species of 2 orders (Hymenoptera, Diptera), and 8 families (Bethylidae, Braconidae, Chalcididae, Ichneumonidae, Trichogrammatidae, Phoridae, Sarcophagidae, Tachinidae) as follow:

Order H y m e n o p t e r a

Family B e t h y l i d a e

***Laelius microneurus* (KIEFFER 1906)**

M a t e r i a l : Mazandaran province: Sari, 1♀, April 2005; Savadkooh 1♀, June 2005. **The genus *Laelius* is new record for Iran.**

***Bethylus cephalotes* (FÖRSTER 1860)**

M a t e r i a l : Mazandaran province: Amol, 1♀, 1♂, September 2005. **The genus *Bethylus* is new record for Iran.**

Family B r a c o n i d a e

***Bracon chivensis* TELENGA 1936**

M a t e r i a l : Mahmood-Abad, 1♀, 1♂, September 2005.

***Cotesia flavipes* (CAMERON 1861)**

M a t e r i a l : Behshahr, 2♀♀, 3♂♂, June 2002; Ghaemshahr, 3♀♀, 1♂, August 2003; Fereydonkenar, 1♀, 1♂, September 2004; Amol, 4♀♀, 3♂♂, July 2005.

***Apanteles ruficrus* (HALIDAY 1834)**

M a t e r i a l : Sari, 2♀♀, 1♂, August 2004; Chalus, 1♀, 1♂, September 2005.

Family C h a l c i d i d a e

***Antrocephalus hypsopygiae* MASI 1928**

M a t e r i a l : Mazandaran province: Amol, 2♀♀, 1♂, July 2004. Pupal parasitoid of *Chilo suppressalis*. **The genus *Antrocephalus* is new record for Iran.**

***Hockeria bifasciata* WALKER 1834**

M a t e r i a l : Mazandaran province: Ghaemshahr, 2♀♀, August 2005. Guilan province: Fooman, 2♀♀, September 2005. **The genus *Hockeria* is new record for Iran.**

Family I c h n e u m o n i d a e

***Cratichneumon albiscuta* THOMSON 1893**

M a t e r i a l : Savadkooh, 2♀♀, August 2000. **New record for Iranian fauna.**

***Cyclolabus pactor* WESMAEL 1844**

M a t e r i a l : Shahsavar, 1♀, April 1999. **The genus *Cyclolabus* is new record for Iran.**

***Eutanyacra picta* SCHRANK 1791**

M a t e r i a l : Ghaemshahr, 2♀♀, 2♂♂, August 2001.

***Itoplectis melanocephala* (GRAVENHORST 1829)**

M a t e r i a l : Amol, 2♀♀, Babol, August 2003. **New record for Iranian fauna.**

***Pimpla rufipes* (MILLER 1759)**

M a t e r i a l : Amol, 2♀♀, 1♂, June 2005. Behshahr, 1♀, September 2005.

***Pimpla spuria* GRAVENHORST 1829**

M a t e r i a l : Savadkooh, 2♀♀, August 2006. Fereydonkenar, 1♀, July 2006.

***Acroricnus stylator stylator* (THUNBERG 1824)**

M a t e r i a l : Savadkooh, 1♀, 1♂, July 2005.

***Ischnus alternator* (GRAVENHORST 1829)**

M a t e r i a l : Ghaemshahr, 1♀, September 2005; Behshahr, 2♀♀, July 2006.

***Lysibia nana* (GRAVENHORST 1829)**

M a t e r i a l : Ghaemshahr, 1♀, 2♂♂, August 2005.

***Phaeogenes melanogonus* GMELIN 1829**

M a t e r i a l : Behshahr, 4♀♀, September 2000. **The genus *Phaeogenes* is new record for Iran.**

***Spilothyrateles punctus* GRAVENHORST 1894**

M a t e r i a l : Amol, 1♀, 1♂, June 1998.

***Synechocryptus persicator* AUBERT 1986**

M a t e r i a l : Savadkooh, 2♀♀, June 2005; Amol, 1♂, September 2005.

***Virgichneumon maculicauda* PERKINS 1930**

M a t e r i a l : Sari, 3♀♀, 3♂♂, July 1999. **The genus *Virgichneumon* is new record for Iran.**

***Vulgichneumon bimaculatus* SCHRANK 1893**

M a t e r i a l : Material: Sari, 3♀♀, 3♂♂, July 1999. **New record for Iranian fauna.**

Family T r i c h o g r a m m a t i d a e

Trichogramma brassicae BEZDENKO 1968

M a t e r i a l : Mazandaran province: Savadkooh, Sari, Mahmoodabad, 8♀♀, 14♂♂, August - October 2004. Guilan province: Roodsar, 4♀♀, 9♂♂, July 2006. Egg parasitoid of *C. suppressalis* and *Naranga aenescens* Moore (Lep.: Noctuidae).

Trichogramma evanscens (WESTWOOD 1833)

M a t e r i a l : Mazandaran province: Amol, Fereydonkenar, Babol, Ghaemshahr, Behshahr, 16♀♀, 41♂♂, August - September 2005. Egg parasitoid of *C. suppressalis*.

Order D i p t e r a

Family P h o r i d a e

Megaselia scalaris (LOEW 1866)

M a t e r i a l : Mazandaran province: Amol, Babol, Ghaemshahr, 17♀♀, 6♂♂, July 2005. Guilan province: Rasht, Roodsar, 6♀♀, 2♂♂, August 2006. Parasitoid of Striped stem borer, *Chilo suppressalis* WALKER (Lepidoptera: Pyralidae).

Family S a r c o p h a g i d a e

Sarcophaga (*Liopygia*) *africa* WIEDMANN 1824

M a t e r i a l : Mazandaran province: Ghaemshahr, 3♀♀, 2♂♂, June 2004. Larval parasitoid of *Naranga aenescens* Moore (Lep.: Noctuidae). **New record for Iranian fauna.**

Sarcophaga (*Liopygia*) *argyrostoma* ROBINEAU-DESVOIDY 1830

M a t e r i a l : Mazandaran province: Amol, 1♀, 3♂♂, September 2004; Ghaemshahr, 2♀♀, 2♂♂, July 2005; Savadkooh, 3♀♀, 2♂♂, September 2005. **New record for Iranian fauna.**

Sarcophaga (*Sarcophaga*) *lehmanni* MÜLLER 1922

M a t e r i a l : Mazandaran province: Amol, 2♀♀, 2♂♂, September 2004. Larval parasitoid of *C. suppressalis*. **New record for Iranian fauna.**

Family T a c h i n i d a e

Actia pilipennis (FALLÉN 1810)

M a t e r i a l : Mazandaran province: Behshahr, 2♀♀, June 2005 [collected by sweeping net].

***Compsilura concinnata* (MEIGEN 1824)**

M a t e r i a l : Mazandaran province: Amol, 3♀♀, 2♂♂, August 2005. Larval parasitoid of Rice army worm, *Mythimna unipunta* Haworth (Lep.: Noctuidae).

***Descampsina sesamiae* MENSIL 1956 [sic]**

M a t e r i a l : Guilan province: Roodsar, 1♀, July 2004. Larval parasitoid of *Sesamia* sp. **The genus *Descampsina* is new record for Iran.**

***Exorista larvarum* (LINNAEUS 1758)**

M a t e r i a l : Mazandaran province: Babol, 2♀♀, 1♂, June 2004. Guilan province: Fooman, 2♀♀, 2♂♂, August 2005.

***Linnaemya neavi* (CURRAN 1934)**

M a t e r i a l : Guilan province: Rasht, 2♀♀, August 2005 [collected by sweeping net].

***Peribaea tibialis* (ROBINEAU-DESVOIDY 1851)**

M a t e r i a l : Mazandaran province: Amol, 3♀♀, August 2005. Larval parasitoid of *M. unipunta*.

***Pseudogonia cinerascens* (RONDANI 1859)**

M a t e r i a l : Guilan province: Lahijan, 1♀, 1♂, July 2004. Larval parasitoid of *C. suppressalis*. **New record for Iranian fauna.**

***Smidtia amoena* (MEIGEN 1824)**

M a t e r i a l : Mazandaran province: Noor, 1♀, 1♂, September 2003 [collected by sweeping net]. **New record for Iranian fauna.**

***Sturmiopsis inferens* TOWNSEND 1916**

M a t e r i a l : Guilan province: Chaboksar, 1♀, August 2004. Larval parasitoid of *C. suppressalis*. **The genus *Sturmiopsis* is new record for Iran.**

***Tachina nupta* (RONDANI 1859)**

M a t e r i a l : Mazandaran province: Behshahr, 3♀♀, 2♂♂, September 2005. Larval parasitoid of *M. unipunta*.

Discussion

Insects have the largest number of species present in the rice field. There are more than a thousand insect species found in rice fields of all over the world. Some of the most familiar insects are the greenhorned caterpillars, mealybugs, rice bugs, planthoppers, and ants. Many insects are food for the larger animals, while some are used as medicine (ROGEL MARIE 2004).

Conserving natural enemies is one of the foundations of FAO's approach. Based on their work in Asia, the members of FAO's IPM program were convinced that this was the most important limitation of traditional pest control strategies. They also felt that IPM concentrated on insect pests was a useful entry point for a broader approach to IPM.

Numerous studies and experience have since shown that conserving natural enemies is of tremendous importance in the safe and economical management of insect pests and doing so has to be a major component of a grower's management activities. In simple terms this involves:

1. Minimizing the application of broad spectrum of chemical and natural pesticides.

2. Allowing some pests to live in the field which will serve as food or host for natural enemies.

3. Establishing a diverse cropping system (e.g., mixed cropping).

4. Including host plants providing food or shelter for natural enemies.

Here is a list of some additional specific practices that have shown some success in helping to keep beneficial insect populations high.

Dust suppression: Some studies have shown that dusty conditions prevent many predators from being effective as dust interferes with their searching ability. Some of the steps that can be taken to manage dust include leaving groundcover vegetation and the planning of windbreaks. In rural areas oiling or paving roads has been shown to be effective.

Host/prey inoculation: Host/prey insects can be inoculated into a field when the host is scarce.

Alternate hosts/prey: Alternate hosts or prey have also been supplied to natural enemies.

Non-host foods: Pollen and nectar or food sprays are most commonly involved but living sources of non-host foods can be other crops or non-crop plants. Some rice farmers have had success with Water chestnut, *Eleocharis* sp., can be planted in rice paddies to maintain populations of *Tetrastichus schoenobii* FERRIERE (Hymenoptera: Eulophidae), an important parasite of the rice pest *Tryporyza incertulus* (WALKER).

Intercropping: A summary of intercropping studies found that herbivore populations were reduced in 56 % of the cases examined. . In general, it is believed that intercropping reduces the advantages an herbivore gains in extensive monocultures and provides alternate resources for natural enemies, e.g. pollen as a food prior to host availability.

Sequential cropping: It is also possible in some cases to plant crops sequentially to gain the advantage of maintaining food sources for natural enemies.

Food sprays: Some growers have had success with spraying fields with a carbohydrate source (sugar or honey) or a protein and carbohydrate source (sugar or honey, plus yeast or casein hydrolyzate). In conservation, the food sprays serve primarily as arrestants, retaining the natural enemies in area, hopefully until the pest population begins to increase.

Refugia: Hedgerows, windbreaks and other areas with perennial vegetation can harbor beneficials species that do not migrate long distances. Trees with grass around them are often best. These are most effective on small acreages because the natural enemies must disperse from the refugia. Thus, its impact will be less important on large farms than on small farms.

Cardboard wrapped trees: Some studies have shown that banding trees with corrugated cardboard make good refugia. Such strips have been found to harbor large numbers of predaceous mites and insects and it was observed that 90 % of the residents were entomophagous.

Biodiversity in rice fields: Rice fields, together with their contiguous aquatic habitats and dry land comprise a rich mosaic of rapidly changing ecotones, harboring a rich biological diversity, maintained by rapid colonization as well as by rapid reproduction and growth of organisms (FERNANDO 1996). The variety of organisms inhabiting rice field ecosystems includes a rich composition of fauna and flora. These organisms colonize rice fields by resting stages in soil, by air and via irrigation water (FERNANDO 1993). The fauna are dominated by micro, meso and macro invertebrates (especially arthropods) inhabiting the vegetation, water and soil sub-habitats of the rice fields, while vertebrates are also associated with rice fields. The aquatic phase of rice fields generally harbors a varied group of aquatic animals. Those that inhabit the vegetation are mainly the arthropod insects and spiders. In addition, many species of amphibians, reptiles, birds and mammals visit the rice fields for feeding, from surrounding areas, and are generally considered as temporary or ephemeral inhabitants (BAMBARADENIYA et al. 1998). In relation to the rice crop, the fauna and flora in rice fields include pests, their natural enemies (predators and parasitoids) and neutral forms.

HECKMAN (1979) states that long standing cultivation of rice over several millennia have enabled organisms to become adapted to the rice field aquatic system. However, FERNANDO (1996) states that the marsh, pond, and stream-dwelling organisms colonize and survive in rice fields due to their ability to tolerate drastic changes in the rice field ecosystem and the ready availability of colonizers in contiguous aquatic habitats.

Previous studies on the biodiversity of rice fields deal mainly with agronomic aspects, where the rice pests, their natural enemies and weeds have been surveyed extensively. Comprehensive studies on the ecology and biodiversity of rice fields are scanty. Among the earliest published records on the subject, WEERAKONE (1957) has given a brief popular account on the ecology of rice field animals in Sri Lanka. A preliminary study on fauna and flora of a rice field in Sri Lanka by BAMBARADENIYA et al. (1998) has documented 77 species of invertebrates, 45 species of vertebrates and 34 species of plants. ROGER & KURIHARA (1988) have dealt with the aquatic ecology of rice fields in detail. The aquatic phase of rice fields generally harbors a rich and varied group of aquatic animals and these have been well documented in traditional rice fields in Laos and Thailand by HECKMAN (1979). A compendium of papers dealing with the biodiversity of the Muda rice agroecosystem in Malaysia is provided by NASHRIYAH et al. (1998). Data on the distribution and abundance of terrestrial and aquatic weeds (25 species, 15 families), insects and arachnids (36 families, 10 orders), fish (39 species, 21 families) and birds (11 species, 8 families) are provided in this work. BAMBARADENIYA (2000) has carried out the most recent comprehensive survey on the ecology and biodiversity in an irrigated rice field ecosystem. This survey documented 494 species of invertebrates belonging to 10 phyla, 103 species of vertebrates, 89 species of macrophytes, 39 genera of microphytes and 3 species of macrofungi from an irrigated rice field ecosystem in Sri Lanka. The majority of the invertebrates were arthropods (82 %, 405 species), dominated by insects (78 %, 317 species). The high number of animal and plant species documented in the above survey indicates that the irrigated rice field is an agroecosystem with a high gamma diversity. The above study not only documented the overall biodiversity associated with this unique man-made temporary aquatic ecosystem, but elucidated the spatial and temporal variation of biodiversity, in relation to various governing factors affecting this ecosystem. For instance, using terrestrial arthropods as a surrogate group, the survey clearly documented the spatial variation of rice field biodiversity in two rice fields in the same locality and irrigated by the same reservoir, but differing in agronomic practices. Furthermore, it also highlighted how an increase in the structural complexity of the habitat contributed to a temporal gradient in biodiversity through the progression of each rice cultivation cycle, while significant seasonal variations were less likely to occur in a particular rice field that follows generally similar agronomic practices during each cycle. HEONG et al. (1991) have also highlighted the temporal and spatial variation of rice field arthropod biodiversity in the Philippines.

BARRION & LITSINGER (1994) provide a compendium on the taxonomy of the insect pests of rice and their natural enemies. According to DALE (1994) who has given a comprehensive account of the biology and ecology of insect pests of rice, over 800 species of insects damage rice plants in several ways, although the majority of them cause minor damage. The number of insect species that cause economic damage to rice varies from 20 (PATHAK & KHAN 1994) to 30 (REISSIG et al. 1986). BAMBARADENIYA (2000) recorded 130 species of phytophagous insects in Sri Lankan rice fields, of which the majority (76 species) consisted of visitors or other insects associated with weeds. The researches of Najafi-Navaii and ATTARAN (2004) indicated that 185 arthropod species are active in rice fields of Mazandaran, Northern Iran. They counted the number of different natural enemies as: Braconidae (Hymenoptera) 0.5, Staphylinidae (Coleoptera) 24.6, *Conocephalus* sp. (Orthoptera) 0.5, *Sepedon sfica* (Diptera) 2, spiders 3, and Mantodea 0.33 per 10 m^2. In addition to causing direct damage to rice plants, many rice insect pests also act as vectors of viral diseases of rice, such as the Tungro virus (DALE 1994). The insect pests of rice are either monophagous feeding only on the rice plant, or polyphagous, where they move in and out of adjacent vegetation including largely rice field weeds. LOEVINSOHN (1994) has discussed various forces that determine the presence and abundance of insect pests in rice agro-ecosystems, including their adaptations to the rice environment, the influence of the cropping system and the dynamics of the pest populations in relation to the cultural environment.

Several researchers have worked on specific groups of rice field organisms, and these could be discussed under two main categories included, aquatic invertebrates and terrestrial invertebrates.

<u>Aquatic invertebrate fauna inhabiting rice field ecosystems</u>: Aquatic invertebrate animals inhabiting the rice field water have been broadly divided into <u>neuston</u> that include surface dwelling insects, <u>zooplankton</u> which includes minute organisms such as protozoans, micro-crustaceans and rotifers, <u>nekton</u> which includes aquatic insects and their larvae and <u>benthos</u>, which includes bottom dwelling annelid worms, nematodes and Mollusca (HECKMAN 1979; FERNANDO 1993; HALWART 1994; BAMBARADENIYA 2000). The importance of aquatic invertebrates inhabiting rice fields is evident by the comprehensive bibliography of FERNANDO et al. (1979) and more recently by FERNANDO (1993). These studies clearly indicate that the aquatic organisms in rice fields cover the entire spectrum of fresh water fauna. As most rice fields are converted marshes, they

have inherited the aquatic fauna of these marshes and also receive fauna seasonally via irrigation systems (FERNANDO 1977). Although the various agricultural practices disrupt the aquatic habitat in rice fields, they harbor a great variety of organisms, well adapted to this temporary and highly manipulated ecosystem (FERNANDO 1996). Seasonal succession of aquatic biota occurs through the rice growing season as the system transforms from an open littoral environment to a vegetated littoral system along with the growth of the rice plants and other macrophytes (HECKMAN 1979). FERNANDO et al. (1979) have further discussed the process of seasonal recolonization of the aquatic phase of the rice fields, after a dry phase. HECKMAN (1979) carried out comprehensive studies on rice-field organisms in Laos and Thailand. Arthropod insects were the dominant group of aquatic invertebrates observed during these surveys, in both countries. BAMBARADENIYA (2000) recorded a total of 179 aquatic invertebrate species belonging to 96 families and 10 major phyla, from an irrigated rice field in Sri Lanka. Half of the invertebrate species documented were arthropods (92 species), dominated by insects (65 species). Among the insects, the highest number of species (22) belonged to the Order Diptera, which was dominated by the Family Culicidae (14 species). The arthropods were followed by the Phylum Annelida (23 species), which was dominated by oligochaetes (21 species). The remaining aquatic invertebrates consisted of Rotifera (18 species), Protozoa (16 species), Mollusca (10 species), Platyhelminthes (9 species), Nematoda (8 species), Gastrotricha (1 species), Ectoprocta (1 species) and Cnidaria (1 species). The majority of the species recorded (39 %) belonged to the benthic community, while neuston had the lowest species composition (4 %).

Of the aquatic organisms in rice fields, zooplankton consisting largely of Microcrustaceans and rotifers, are probably the most widely studied group. A survey of the aquatic invertebrate fauna of tropical rice fields by FERNANDO (1977) showed that diverse zooplankton communities occur in rice-fields of West Malaysia, Burma and Sri Lanka. This high diversity has been attributed to the abundance of natural marshes and relatively high precipitation in these countries. Few researchers have studied the seasonal dynamics of crustacean zooplankton in rice fields. LIM et al. (1984) have studied the temporal changes in the population densities of Cladocera in rice fields of Malaysia, subjected to pesticide treatment. ALI (1990) has conducted a comprehensive study on the abundance and seasonal dynamics of Microcrustacean and rotifer communities in rice fields used for rice-cum-fish farming in Malaysia. Simpson et al. (1994a) have studied the seasonal dynamics of micro-crustaceans in rice fields of the Philippines, in relation to pesticide and nitrogen fertilizer applications. A similar study has been carried out by TANIGUCHI et al. (1997) in rice fields of Japan. As in other countries, zooplanktons are the most widely studied group of rice field aquatic invertebrates in Sri Lanka. A comparative study of zooplanktons in aquatic habitats of Sri Lanka, carried out by FERNANDO (1980) revealed that rice fields harbored a diverse fauna similar to ponds, and to have more species than in rivers, streams and villus (river flood plains). A total of 71 species of rotifers and 80 species of micro-crustaceans were recorded from rice fields during Fernando's survey, which is about 53 % of the total fresh water zooplankton taxa (Rotifera - 165 species, Microcrustacea - 122 species) documented in Sri Lanka. The findings of the above study also show that the species composition of zooplanktons in Sri Lankan rice fields is much higher than in Uzbekistan (Rotifera - 83 species, Crustacea - 30 species), Thailand (Rotifera - 50 species, Crustacea - 29 species) and West Malaysia (Rotifera - 56 species, Crustacea - 54 species), as documented by HECKMAN (1979) and

FERNANDO (1977) respectively. The Ostracod crustaceans of rice fields in Sri Lanka were documented by NEALE (1977), who found that these organisms in the central and southern parts of the island are closely related to those in Indonesia. A detailed taxonomical study of the freshwater nonchydorid Cladocera in aquatic habitats of Sri Lanka carried out by RAJAPAKSE (1981), revealed that a higher proportion (91 %) of samples collected from rice fields contained at least one species belonging to the above group, closely followed by those collected from villus (90 %).

Mosquitoes are the most widely studied aquatic insects associated with rice fields, as this ecosystem constitutes the favored breeding sites of several species. LACEY & LACEY (1990) have given a comprehensive review of the mosquitoes in rice fields, covering aspects of their ecology, medical importance and control, and listed 137 species of mosquitoes that breed in rice fields worldwide. AMERASINGHE (1993) reported 26 species of mosquitoes from rice fields of the dry zone in the Eastern Province of Sri Lanka, while BAMBARADENIYA (2000) recorded 14 species from a rice field in the intermediate zone. TAKAGI et al. (1996) have studied the effect of rice plant canopy on the density of mosquito larvae and other insects in rice fields of Japan. Only a few researchers have studied aquatic insects other than mosquitoes in rice fields. YANO et al. (1983) recorded 117 species of aquatic coleopterans, in 14 families from rice fields worldwide. A study in the Muda rice area of Malaysia showed that representatives of the orders Diptera (Families: Chironomidae and Culicidae), Coleoptera (Family Hydrophilidae), Hemiptera (Families: Dytiscidae, Corixidae, Pleidae, Nepidae, Belostomatidae), Odonata (Families: Libellulidae, Coenagrionidae), and Ephemeroptera (Family Baetidae) comprised the aquatic insect fauna. The dominant aquatic insects were from the Families Chironomidae, Dytiscidae, Corixidae and Belostomatidae. One interesting point arising from this study is that the aquatic representatives of the Coleoptera, Hemiptera and Odonata were all predatory insects. A second point is that there was no statistical difference in diversity or abundance of the aquatic insects when insecticide treated (Broadox®, Trebon®) and untreated rice fields were compared (BAMBARADENIYA & AMERASINGHE 2003).

There are very few studies on mollusks, although they are an important component of the aquatic community in rice fields. SIMPSON et al. (1994b) have documented the dynamics of benthic molluscs in rice fields in Philippine. NAYLOR (1996) has given a comprehensive account on the invasion of the Golden Apple Snail in rice fields of Asia. Outside of Asia, GONZALES-SOLIS & RUIZ (1996) have studied the ecological succession of six basommatophoran species of gastropods in rice fields of Ebro Delta, in Spain.

The oligochaetes are an important component of the rice field benthos. SIMPSON et al. (1993) have studied the dynamics of benthic oligochaetes in rice fields of the Philippines. KURIHARA (1989) has carried out a comprehensive study on the benthic tubificid worms in rice fields of Japan. PROT & RAHMAN (1994) have given a comprehensive account of the ecology and economic importance of plant parasitic nematodes associated with rice ecosystems in South and Southeast Asia. WEERAKOON & SAMARASINGHE (1958) have conducted one of the best studies on the quantitative aspects of rice field benthos. They reported that the population density of rice field benthic fauna in Sri Lanka is high compared to ponds, and oligochaetes and chironomid dipteran larvae dominate the fauna. Fresh water crabs are a common component of the rice-field benthos and play a role as scavengers and a source of food for other animals, while some are known to damage rice field bunds.

Terrestrial invertebrate community of rice fields: Arthropods are the main terrestrial invertebrates of rice fields. The arthropod community in rice fields consists mainly of insects and spiders that largely inhabit the vegetation (rice plants and weeds) and soil surface. With respect to rice cultivation and based on the inter relationships between populations, the terrestrial arthropod communities can be further divided into rice pests, their natural enemies (predators and parasitoids) and neutral forms. In rice fields the composition of the terrestrial arthropod communities are known to change with the growth of the rice crop.

The temporal development of arthropod communities in relation to rice cultivation in Philippine rice fields was studied by HEONG et al. (1991), where they examined the guild structure, successional changes and dynamics of important phytophagous and predator arthropod species, providing insights into the arthropod community structure in rice fields. SCHOENLY et al. (1996) went a step further, in describing the above-water food web dynamics of arthropod communities in irrigated rice fields. They determined the trophic links of the cumulative food webs in Philippine rice fields. BAMBARADENIYA (2000) documented a rich terrestrial arthropod fauna comprising 280 species of insects in 90 Families and 16 Orders, plus 60 species of arachnids in 14 Families, amounting to a total of 340 arthropod species from an irrigated rice field ecosystem in Sri Lanka. The majority of the insect species belonged to Order Hymenoptera (81 species), followed by Lepidoptera (58 species). Apart from these key studies, there is a wealth of rapidly growing information on the rice field insect pests and their arthropod natural enemies viewed from a biological control perspective. Some of the relevant aspects on this subject are discussed below.

Biodiversity of arthropod fauna in paddy fields: Infestations by rice borers, *Chilo suppressalis* and *Scirpophaga incertulas*, and the intermittent and sudden occurrences of outbreaks of *Nilaparvata lugens* were the major causes of losses in rice yield in temperate Asia. These were the major pests until around 1965. Thereafter, leaf- and planthoppers and the viral diseases RSLV and RDV transmitted by them were predominant for about 30 years. Meanwhile, the rice water weevil, *Lissorhoptrus oryzophilus*, invaded Japan in 1976 from the United States, inflicting serious damage to rice in the late 1980s. Since 1995, the damage caused by various kinds of stink bugs and mirids has become the most serious problem.

Many species of arthropods with diverse types of life cycles occupy different habitats within paddy agroecosystem. *Sympetrum* dragonflies emerge from paddy fields and stay in coppiced woodlots to mature sexually before returning to paddy fields to oviposit. The eggs hatch in the following spring when irrigation water becomes available. Newly emerged adults of the water scorpion, *Ranatra chinensis*, move from paddy fields to irrigation ponds for overwintering. Oviposition takes place in paddy fields in the next spring. The migratory planthopper pests, *N. lugens* and *Sogatella furcifera*, are annually replenished by a long-range immigration from tropical endemic habitats.

The biodiversity of the paddy agroecosystem therefore depends not only on the paddy fields themselves but also on water channels, irrigation ponds, levees, surrounding fallow fields, neighboring farmlands, secondary forests, wetlands, rivers, and remote hibernating areas (KIRITANI 2000).

Arthropod natural enemies of rice insect pests: The arthropod natural enemies of rice pest insects include a wide range of predators and parasitoids that are important biological control agents. Predators include a variety of spiders, and insects such as carabid beetles, aquatic and terrestrial predatory bugs and dragon flies. Parasitoids include many species of hymenopteran wasps and a few dipteran flies. OOI & SHEPARD (1994) give a comprehensive account of the natural enemies of rice insect pests. They have stated that long histories of rice cultivation in many parts of the world have allowed stable relationships to evolve between rice insect pests and their natural enemies. In most instances, the species richness and abundance of predator populations may be greater than those of the pest populations, when little or no insecticides are used (Way and HEONG 1994). A pioneering study by SETTLE et al. (1996) conducted in Java demonstrated the existence of high levels of natural biological control in tropical irrigated rice systems. BAMBARADENIYA (2000) observed that more than 50 % of the terrestrial arthropod species in Sri Lankan rice fields consisted of predators, with spiders being the dominant predatory group. Previous research related to these natural enemies include taxonomic surveys, seasonality and relative abundance of different species and their impact on specific pest insects of rice.

HEONG et al. (1991) have recorded 46 species of predators (heteropteran bugs and spiders) and 14 species of hymenopteran parasitoids of auchenorrynnchous homopteran pests in Philippine rice fields. BARRION & LITSINGER (1995) have recorded about 342 species of spiders from rice fields in the Philippines and other South-east Asian countries. SETTLE et al. (1996) have documented 765 species of spiders from lowland irrigated rice fields in Indonesia. BAMBARADENIYA & EDIRISINGHE (2001) have documented 60 species of spiders from an irrigated rice field ecosystem in Sri Lanka. In terms of numbers, spiders seem to form one of the most important groups of natural enemies of rice insect pests.

Many species of arthropods, including natural enemies, exist concurrently in rice and non-rice habitats. Vegetation in these habitats serves as an important refuge for oligophagous rice parasitoids and generalist arthropod predators. One such example is *Anagrus nilaparvatae* (Hymenoptera: Mymaridae), an important egg parasitoids of rice planthoppers, which also parasitizes the planthopper, *Saccharosydne procerus* (Delphacidae: Homoptera) of *Zizania caduciflora* (Gramaineae), which is a favorite vegetable for the residents of the Yangtze Rive Delta in China. *Anagrus nilaparvatae* can overwinter in *S. procerus* eggs in *Zizania* fields during the off-season. Such over-wintering is crucial for the maintenance of natural enemy populations in between the seasons (YU et al. 1999).

The impressive works on the natural enemies especially insects in Iranian rice fields were conducted by GHAHARI et al. (2007, 2008, 2009) on Asilidae (Diptera), Syrphidae (Diptera) and predator arthropods' fauna, respectively. Basis of the results of GHAHARI et al. (2007, 2008), totally 26 asilid and 24 syrphid species were collected from Iranian rice fields and around grasslands. Also the results of GHAHARI et al. (2009) indicated that 23 spider species (Araneae), 15 ant species (Formicidae), 35 dragonfly and damselfly species (Odonata), 6 *Orius* species (Het.: Anthocoridae), 7 species of assassin bugs (Het.: Reduviidae), 16 ground beetle species (Carabidae), and 6 ladybird species (Coccinellidae) were collected as the predators of different rice pests.

<u>Threats to the biodiversity of rice fields</u>: The rice fields, being agroecosystems, are managed with a variable degree of intensity and hence agronomic measures and practices affect the abundance of aquatic species and the composition of the aquatic community. Rice production throughout the world (especially in Asia) underwent a dramatic

transformation after the mid 1960's, as a result of the green revolution. The transformation relied on intensification of irrigated rice production systems. Intensification is defined as "an increase in resources devoted to rice cultivation" (LOEVINSOHN 1985). It mainly involved the use of modern high yielding rice varieties responsive to fertilizers and pesticides, and the increase in the number of crops grown per year by planting short duration varieties. Production increases came from more area planted with rice (32 %), from irrigation and double cropping (25 %), from fertilizers (22 %), and from the inherent higher yielding quality of modern varieties (21 %). Increased use of machinery and pesticides were other contributing factors for improved rice productivity. Farmers and policy makers considered pesticides as a guarantee against crop failure, and as a necessary input for modern rice production. Hence, chemical insecticides were widely adopted as primary agents of pest control (PINGALI & GARPACIO 1997; LOEVINSOHN 1985).

Intensive rice monoculture systems popularized by the green revolution created an environment that was conducive to pest growth (PINGALI & GARPACIO 1997). Promoting the widespread and indiscriminate use of insecticides and introducing a limited number of rice varieties for use on a very large scale to replace the diverse array of plant races grown previously were major factors responsible for the rapid multiplication of rice pests and diseases (BAMBARADENIYA & AMERASINGHE 2003). Although rice insect outbreaks have been recorded over the last 1.300 years, they have become much more frequent and the insect pest complexes have changed in the last three decades (HEINRICHS 1994). The long history of rice cultivation in many parts of the world allowed the evolution and maintenance of stable and balanced relationships between rice insect pests and their natural enemies which include predators and parasitoids (OOI & SHEPARD 1994). However, the broad-spectrum biocides, which were introduced as part of the package of technologies of the green revolution, affected the natural enemies that managed insect pests. Although insecticides are known to have rapid curative action in preventing economic damage (CHELLIAH & BHARATHI 1994), indiscriminate use of insecticides has led to the destruction of natural enemies, causing the resurgence of several primary and secondary pest species and the development of insecticide-resistant pest populations (SMITH 1994; OOI & SHEPARD 1994). Other detrimental effects of pesticide misuse include human health impairment due to direct or indirect exposure to hazardous chemicals, contamination of ground and surface waters through runoff and seepage and the transmittal of pesticide residues through the food chains (PINGALI & ROGER 1995).

Pesticides used in rice cultivation to kill rice pests and weeds can have a devastating effect on the living organisms for shorter or longer periods of time (FERNANDO 1996). A number of reviews on the biocide use in rice fields and its impacts on fauna (especially invertebrates) and microflora (LIM 1992; ABDULLAH et al. 1997; ROGER et al. 1994) further discuss this issue at length. The impact of biocides used in rice cultivation on vertebrates inhabiting rice fields and surrounding aquatic habitats have been investigated by researchers in the Philippines (CAGAUAN 1995). The effects of pesticides and fertilizers on specific groups of rice field organisms have been clearly documented in the study conducted by BAMBARADENIYA (2000).

Changes associated with irrigation structures to enhance the efficiency of irrigation water use have also resulted in negative impacts especially to fauna associated with rice fields. For instance, concrete lining of irrigation canals that supply water to rice fields, and directing irrigation water to rice fields via pipes, instead of ditches, has resulted in the loss of habitats for a variety of aquatic invertebrate and vertebrate fauna. The impact of changing irrigation practices in rice fields of Central Japan on amphibians and a group of aquatic birds inhabiting rice fields have been well documented by FUJIOKO & LANE (1997) and LANE & FUJIOKO (1998) respectively.

IPM perspective in relation to biodiversity: One of the key concepts in Rice IPM is that insect pests are rarely a problem in a well managed and healthy rice agroecosystem. In most cases, if insect problems develop, it is because something has been done to reduce natural enemy populations. If pests do reach dangerous levels or damage starts to become severe farmers may turn to insecticides. Key concepts to keep in mind when thinking about managing insect pests is that the best approach is usually to do nothing and that much of the insect damage observed will not affect yields. For example, studies have shown that no yield loss was detected even when 60 % of leaves were damaged by whorl maggots. Japonica rice at tillering stage can compensate for as much as 67 % of leaffolder damaged leaves. IPM in rice is now firmly based on an ecological understanding of the crop and its interaction with soil nutrients and varieties. An ecological overview of our current understanding of how the rice ecosystem operates during the development of the crop and consequent ecological considerations for IPM methods is presented below. In the past, most studies on paddy ecosystems have focused on productivity and its stability in terms of rice yields. Arthropods in paddy ecosystems can be classified into three main groups according to their ecological requirements: (1) resident species adapted to the continuous cropping of rice in the same field, (2) migratory species adapted to exploit rice as an annual crop, and (3) aquatic species originating from Stillwater habitats in wetlands. Concerning groups 1 and 2, integrated pest management (IPM) programs, which have a primary objective of maximizing economic profit on the farm, have been implemented with various degrees of success. Although IPM is becoming widespread, those insects (Tada-nomushi = species of unknown or uncertain function that routinely occur in the habitat) that have no direct economic impact on rice production have been mostly ignored as an important element in the rice ecosystem. Consequently, some aquatic insects are in danger of extinction, thus requiring conservation (KIRITANI 1979, 2000; KIRITANI & NABA 1994).

IPM in rice field has been developing in many countries since the early 1960s. However, much of the development was based on older concepts of IPM, including intensive scouting and economic thresholds that are not applicable under all conditions (MORSE & BUHLER 1997) or all pests (e.g. diseases and weeds), especially on smallholder farms where the bulk of the world's rice is grown and that often operate under a weak or non-existing market economy. During the 1980s and 1990s, important ecological information on insect populations became available, making possible a stronger ecological approach to pest management and greater integration of management practices that went beyond scouting and economic threshold levels for decision-making (KENMORE et al. 1984; GRAF et al. 1992; BARRION & LITSINGER 1994; SETTLE et al. 1996).

Instead, an ecological and economic analysis approach to management has been adopted that takes into consideration crop development, weather, various pests and their natural enemies. Operationally, this approach has been defined to form the guiding principles for IPM implementation, clearly setting out in simple language the actions to be undertaken. These principles were first articulated in the Indonesian National IPM Program but have expanded as IPM programs have evolved and improved. Currently, programs in Africa and Latin America use the term integrated production and pest management (IPPM), and the IPPM principles are: a/ grow a healthy soil and crop; b/ conserve natural enemies; c/ observe the field regularly (e.g. soil, water, plant, pests and natural enemies); d/ that farmers should strive to become experts.

Within these principles, economic decision-making remains at the core of rice IPM but the approach also incorporates good farming practices and active pest control within a production context.

IPM in rice seeks to optimize production and to maximize profits through its various practices. To accomplish this, however, decision-making must always take into consideration both the costs of inputs and the ecological ramifications of these inputs. A particular characteristic of Asian rice ecosystems is the presence of a potentially very damaging secondary pest, the rice brown planthopper (*Nilaparvata lugens*). In the past, large-scale outbreaks of this small but mighty insect have occurred, resulting in disastrous losses (IRRI 1979), although these outbreaks were primarily pesticide induced – triggered by pesticide subsidies and policy mismanagement (KENMORE 1996). In general, however, the brown planthopper remains a localized problem, especially where pesticide overuse and abuse are common, and can therefore be considered as an ecological focal point around which both ecological understanding and management are required to achieve profitable and stable rice cultivation. The brown planthopper has also become the major entry point for all IPM educational programs because it is always necessary to take precautionary measures against an outbreak during crop management. Other pests that interact strongly with input management are rice stem borers and certain diseases (KENMORE 1996; RUBIA et al. 1996).

The green rice leafhopper, *Nephotettix cincticeps*, is 80 % of the diet of a lycosid spider, *Pardosa pseudoannulata*, in paddy fields. No lycosid spiders, however, developed to adults when fed only *N. cincticeps.* When lycosid females were allowed to prey upon mixed species of prey, their fecundity greatly increased (SUZUKI & KIRITANI 1974). Those species such as chironomids and collembola, for example, that are neither pests nor natural enemies, and yet are useful as alternative food of generalist predators, can be referred to as minor, yet important, components of the community (KIRITANI 2000).

Immigration of spiders to paddy fields occurs after the appearance of chironomids. Early insecticide applications to control rice stem borers often result in the resurgence of planthoppers and leafhoppers 1 month later because insecticide treatments simultaneously kill spiders and chironomids (KOBAYASHI 1961). In the tropics, prevention of outbreaks of planthoppers and leafhoppers depends on protection of earlyacting natural enemies by avoiding early insecticide spraying (WAY & HEONG 1994; SETTLE et al. 1996).

Levees are likely to act as refuges for various kinds of natural enemies of arthropod pests that occur in upland crops grown close to paddy fields. A dwarf spider, *Ummeliata insecticeps*, common in paddy fields dispersed from levees by ballooning in late May to uplands remains there until the end of the rainy season. It behaved like a specific predator attacking a newly hatched colony of larvae of *Spodoptera litura* in taro fields (NAKASUJI et al. 1973). Another example is the anthocorid bugs, *Orius* spp., that are effective natural enemies of *Thrips palmi*, a serious invasive alien pest of eggplant. *O. nagaii* and *O. sauteri* occur on rice and on white clover grown on levees, respectively, before invading eggplant fields in early June (OHNO & TAKEMOTO 1997).

Integrated biodiversity management (IBM) in rice fields: A new concept, integrated biodiversity management (IBM), has been proposed under which IPM and conservation are reconciled and made compatible with each other. IPM requires that densities of each pest species be kept below their specific economic injury level. In conservation, target species have to be managed to remain above a specific extinction threshold. Since some presently rare carnivorous aquatic arthropods, such as *Lethocerus deyrollei*, and some large-sized dytiscid beetles have been recorded as pests of fish culture when they were abundant, these species also should be managed to keep their populations below defined economic injury levels (KIRITANI 2000).

The status of a pest species could be changed by IPM into a Tada-no-mushi (minor or nontarget insect), which can function as potential food for generalist predators. *S. incertulas* is currently almost extinct in Japan. From the viewpoint solely of an economically oriented IPM, however, this is of little consequence because *S. incertulas* was an important rice pest to be controlled. But, in view of IBM, such relatively rare species, such as *S. incertulas* and some aquatic insects, can be considered a target for conservation.

The arthropods inhabiting paddies require various habitats for the completion of their life cycles. The relative importance of IPM and conservation changes along a continuum away from the paddy field through the levee, ditch, irrigation pond, and coppiced woodlots. The two lines cross at a point most appropriate for a specific location as well as for the target species concerned (KIRITANI 2000).

The concept of IBM is not limited to the paddy ecosystem, but is also applicable to all types of agricultural systems. Crops range from those that require intense IPM intervention with little consideration of species conservation, for example, greenhouse crops, to those for which high levels of pest control and biodiversity preservation can be attained, for example, a complex home garden or backyard in the tropics.

KIRITANI (1975) stated that the central issue for agriculture in the future would be how to manage and optimize biodiversity, stability, and productivity within agroecosystems. The paddy ecosystem is an integrated, water-dependent system, which can contain many kinds of living organisms: birds, fish, reptiles, amphibia, arthropods, and plants. Paddy fields were originally wetlands that are artificially constructed devices for rice production. Nowadays, very few natural wetlands remain, and many aquatic organisms now depend partly or fully on paddy fields.

To raise both land and labor productivity, the Japanese government has promoted the conversion of poorly drained wet paddy fields into well-drained ones in association with a policy to consolidate fragmented farmlands. U-shaped concrete ditches have replaced traditional earth ditches and irrigation-supply canals have been separated from drainage canals, which effectively reduced the variety of habitats for aquatic organisms.

In general, global warming may work in favor of natural enemies (except for spiders) by increasing the number of generations more than for their host species (KIRITANI 1999). Biological control is expected to become a more important control tactic in the future. Uncertainty remains, however, regarding the extent to which host-parasitoid phenology will be synchronized after an increase in the number of generations. Parasitism and predation, similar to those in paddy fields in the tropics, would be expected to increase through this numerical response and enhance the natural control. It is inevitable that implementation of IBM involves some trial and error. We need an adaptive approach toward IBM. We should not only invite active involvement of persons interested in evaluation and improvement, but should also adopt a modest attitude toward developing and improving an ongoing IBM design.

Future sustenance of the rice field agro-ecosystem and its biodiversity: Although traditional rice cultivation has been carried out in a sustainable manner over many millennia, there is growing evidence that modern rice cultivation that depends heavily on machinery and chemical inputs, together with short term rice varieties, has disrupted the balance of these efficient trophic linkages, and hence poses a threat to the future sustainability of this unique ecosystem (KURIHARA 1989). This situation has been interpreted by ODUM (1997), who states that the pressures of human population growth has transformed agroecosystems from 'domesticated' ones that were relatively harmonious with our general environment, into increasingly 'fabricated' ecosystems that more and more resemble urban-industrial ecosystems in energy and material demands and waste production.

In this regard, there is a conspicuous lacuna in the literature relating to rice field biodiversity. The fauna and flora are reasonably well documented, but we do not know the manner and extent to which biodiversity has been disrupted or enhanced or changed by the replacement of natural habitats by rice ecosystems. There appear to be no comparative biodiversity studies that would yield such temporal (i.e., before - after) or spatial (rice ecosystem vs. adjoining natural ecosystem) information. Interestingly, one of the few longitudinal faunal studies done in an Asian tropical rice ecosystem relates not to rice pests or animals of agricultural or general conservation importance, but to mosquitoes – from the viewpoint of faunal changes related to irrigation development affecting the species composition and abundance of mosquito vectors of human disease. Although in this particular instance mosquitoes are not directly relevant to the present conservation-development debate, the intrinsic value of such longitudinal and/or cross-sectional faunal and floral studies needs to be recognized if we are to assess the directions in which increased food production can be achieved without causing major ecological damage. Given the diversity of rice cultivation systems, their geographic and elevational spread, and the diversity of natural environments that they have replaced, there is ample scope for research into the positive and negative impacts on biodiversity of one of the major food production systems in the world. This would, in turn, stimulate new thinking on how to maximize the biodiversity potential of the rice ecosystem.

Traditional rice fields that have been cultivated over a long period of time may be considered as climax communities. Modern technologies, including the use of chemicals, optimum water and crop management practices and machinery have tremendously increased yields. However, these developments have caused profound modifications to traditional rice-growing environments. In order to meet the food requirements of the fast-growing human population, a 65 % production increase would have to be met with, within the next 30 years, without much expansion of the actual cultivated area (Roger et al. 1994). This increase in rice production in the coming decades should not be achieved at the expense of future generations and should fulfill the concept of sustainability (Roger et al. 1994). It should maintain or enhance the quality of the environment and conserve or enhance natural resources.

Until the late 1980's, the prime focus of biological conservation was on undisturbed natural habitats, including protected areas that cover only a very small proportion of the world land area. However, the focus on undisturbed habitats was challenged at the dawn of this decade, where attention was called on the fact that 95 % of the terrestrial environment consisted of managed ecosystems, including agricultural systems, forestry systems and human settlements. Hence, a large portion of the world's biological diversity coexists in these ecosystems (WESTERN & PEARL 1989). Since then, scientists have begun to focus their attention on agricultural and forestry systems (PIMENTAL et al., 1992). There is growing interest in the concepts of eco-agriculture (MCNEELY & SCHERR 2001) whereby agricultural systems are managed as both a food production and biodiversity conservation system. The surveys on biodiversity associated with the rice field agroecosystem conducted to date have clearly shown that this man-made ecosystem contributes to sustain a rich biodiversity, including unique as well as threatened species, while contributing to enhance the biodiversity in urban and sub-urban areas. Today, biodiversity is viewed as a fundamental principle in agricultural sustainability and studies have been focused on biodiversity as an organizing principle in agroecosystem management (STINNER et al. 1997). As KURIHARA (1989) has pointed out, the rice field ecosystem is one of the most sustainable forms of agriculture, now, unfortunately being imperiled by agribusiness. Since the rice field ecosystem satisfy the interests of both agroecologists and conservation biologists, the integrated efforts of these two groups can result in the formulation of strategies based on biodiversity as an organizing principle in the sustainable management of the rice field agroecosystem.

Conclusion

The physical and biological components of our environment are all interrelated. When one component is damaged, sooner or later the other components will also be affected- from the tiniest organism to the biggest of animals. Thus, the rice fields need to be given the attention they need and deserve. Many of our rice fields are converted to commercial lands that destroy many plant and animal habitats.

Most biological control programs focus on promoting one or two "premier" natural enemies as agents for the suppression of particular pests. In contrast, we argue that consistently high levels 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, vis-à-vis insect pest populations, than has previously been considered. We have arrived at this hypothesis from our own work on pest management in Iranian rice agroecosystems.

It is necessary that a set of elemental habitats be available for completion of the life cycle of many species and that these multiple habitats be within the range of dispersal of these species. A set of habitats, including host plants (prey), shelter, hibernacula, mating places, etc., is essential to ensure the persistence of diverse species. For aquatic insects, irrigation ponds, coppiced woodlots, and poorly drained wetlands are necessary habitats in addition to paddy fields. Because cleaning an irrigation pond could result in the complete destruction of the aquatic fauna in the pond, neighboring ponds that supply the newly cleaned pond with aquatic species should exist within an appropriate distance, for example, 1 km for dragonflies (MORIYAMA 1997).

It is recommended to adopt IPM strategies and tactics that are compatible with conservation.

Preventing alien species from invading the paddy ecosystem is very important. Alien species often jeopardize the conservation of endangered species by competition and inducing additional chemical control applications.

Special consideration should be given to avoid lethal effects on species that are vulnerable to pesticides, such as aquatic, univoltine, and carnivorous or monophagous species. Bioaccumulation of persistent biotoxins is far greater in aquatic systems than in terrestrial systems. Contamination of irrigation water with pesticides must therefore be avoided as much as possible. We can keep the amount of pesticides to a minimum by applying knowledge of the behavioral ecology of the pests.

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

We suggest that detritivore and plankton-feeding insect populations provide a consistent and abundant source of food for large and diverse populations of generalist predators, up to halfway through the season. The patterns of emergence show that populations of detritivores and plankton feeders (in large part made up of chironomids) peak at about 30 d after transplanting (DAT), and then decline over the rest of the season, whereas rice herbivore populations only begin to emerge much later in the growing season (50-60 DAT). This suggests that chironomids are unlikely to interfere with generalist predators feeding on pests. Note that this early-season peak in "others" is mirrored-with a slight delaying on detritivores and plankton-feeding insects early season. High early-season abundances of plankton feeders and detritivores, together with abundant populations of generalist predators, have been observed in Vietnam, India, Bangladesh and The Philippines, and Central China (SETTLE et al. 1996). These patterns show predator populations temporally developing after populations of plankton feeders and detritivores, but before populations of herbivores. This is consistent with our hypothesis that generalist predators are supported in the early season by decomposers and plankton feeders. Of course, we exclude parasitoids for clarity, but they follow after herbivores.

Our government should promote education about rice fields and their importance in our lives. All citizens should be made aware of their responsibility in maintaining our food and income source. Issues and problems about rice fields should be taught in schools. Students should understand what is happening to a vital ecosystem such as rice fields so that they could make a stand and help preserve an important part of our environment and economy. Instead of turning rice fields into real estates and subdivisions, we must improve, cultivate, and take care of them. Rice fields offer many benefits for all of us, like better rice and more food, and better environmental quality. Discover this diversity of plants and animals next time you are in a rice field.

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Zusammenfassung

Die Reisfelder dieser Erde ernähren den halben Planet. Reisfelder sind nicht nur aus wirtschaftlicher sondern auch aus ökologischer Sicht wervoll. Das Artenspektrum an Pflanzen und Tieren, assoziiert mit Reisfeldern, ist groß, dementsprechend groß auch das Heer der schädlichen Insekten und ihrer natürlichen Feinde. Vorliegende Studie widmet sich den Räubern und Parasiten in Reisfeldern, vorwiegend aus Gebieten des Nordirans. 25 Räuber aus 7 Ordnungen und 11 Familien, sowie 37 Parasitoide aus 2 Ordnungen und 8 Familien konnten nachgewiesen werden. Davon stellten sich 11 Gattungen und 23 Arten als Neunachweise für den Iran heraus.

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