
Biodiversity and Conservation **13:** 1715–1753, 2004.

Biodiversity associated with an irrigated rice agro-ecosystem in Sri Lanka

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Received 28 January 2003; accepted in revised form 17 June 2003

Key words: Arthropods, Biodiversity, Biological control, Rice field

Abstract. Irrigated rice fields are temporary wetland agro-ecosystems, managed with a variable degree of intensity. A survey was carried out in Sri Lanka to document the overall biodiversity associated with this unique agro-ecosystem, using a combination of sampling techniques to document different groups of fauna and flora. The total number of biota recorded and identified from the rice field ecosystem during the entire study period consisted of 494 species of invertebrates belonging to 10 phyla and 103 species of vertebrates, while the flora included 89 species of macrophytes, 39 genera of microphytes and 3 species of macrofungi. Of the total species documented, 15 species of invertebrates and one weed species are new records to Sri Lanka. Arthropods were the dominant group of invertebrates (405 species), of which 55 species were rice pest insects, and 200 species were natural enemies of pest insects. The fauna and flora recorded from the rice field were observed to follow a uniform pattern of seasonal colonization and succession during successive rice cultivation cycles. The biodiversity of the irrigated rice agro-ecosystem interests both agroecologists and conservation biologists. Therefore, 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 agro-ecosystem.

Introduction

Until the late 1980s, the prime focus of biological conservation was on undisturbed natural habitats, including protected areas that cover only about 5% of the world land area. However, the focus on undisturbed habitats was challenged at the dawn of this decade, when attention was called to the fact that at least two-thirds of the terrestrial environment of the planet consisted of managed ecosystems, including agricultural systems, forestry systems and human settlements (Western and Pearl 1989; McNeely 1995). Hence, a large portion of the world's biological diversity coexists in these ecosystems. Since then, scientists have begun to focus their attention on agricultural and forestry systems. There is growing evidence that traditional agro-ecosystems such as rice fields contribute to sustain the regional biodiversity of many invertebrate and vertebrate species (Lawler 2001). The study of biodiversity associated with agro-ecosystems such as rice fields is of significance for agroecologists and conservation biologists, since maintenance of biological diversity is essential for productive agriculture, and ecologically sustainable

agriculture is in turn essential for maintaining biological diversity (Pimental et al. 1992).

Rice has been grown in Sri Lanka from time immemorial. It is generally believed that rice cultivation in Sri Lanka was started by Indo-Aryan immigrants circa 540 BC (more than 2500 years ago), where it was probably grown as a dryland crop (Grist 1965; Perera 1980). This was a period during which a settled civilization developed in the dry zone and an elaborate irrigation system was established for rice cultivation. The total area under rice at present is about 780,000 ha (approximately 12% of the total land area), which is distributed over all the agroecological regions except for areas located at very high elevation. Based on the water regime, rice fields in Sri Lanka fall into three major categories; those under major irrigation schemes (41%), minor irrigation schemes (25%) and rainfed ricelands (34%) (Gunatilleke and Somasiri 1995). In most areas where adequate water is present, rice is cultivated during two annual cropping seasons; the *Maha* (October–February) and *Yala* (April–August) seasons. The former is recognized as the major cropping season, as it receives more rainfall from the northeast monsoon producing rain throughout the island, while the latter is the minor cropping season (Panabokke 1996).

Irrigated rice fields, being temporary aquatic habitats with a generally predictable dry phase, can be scientifically defined as an agronomically managed temporary wetland ecosystem (Bambaradeniya 2000). They are temporary and seasonal aquatic habitats, managed with a variable degree of intensity (Halwart 1994). The rice ecosystem consists of two physically and morphologically distinct habitats; the rectangular or similar shaped flooded fields comprising mainly of the rice plants, and the surrounding bunds (levees) which harbor weeds. Under irrigated conditions, this mosaic system is connected with irrigation canals and ditches, while sump ponds, marshes and tanks serve as contiguous aquatic habitats. Although being a monoculture agro-ecosystem, a rice field undergoes three major ecological phases; aquatic, semi-aquatic and a terrestrial dry phase, during a single paddy cultivation cycle (Fernanado 1995). Physically, the aquatic phase has a shallow fluctuating water depth of 5–30 cm. The physical status of floodwater is variable during a cycle; there is consecutive flow through, stagnation and drying off in the aquatic habitat as the seasons progress (Fernando 1993). The physico-chemical composition of the floodwater changes accordingly. These changes are made more complex by agronomic practices such as application of fertilizer and biocides. As a whole, the ecology of rice fields is characterized by rapid physical, chemical and biological changes (Bambaradeniya 2000).

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 1995, 1996). The variety of organisms inhabiting rice field ecosystems includes a rich composition of fauna and flora. Although the species composition of terrestrial arthropod pests and natural enemies in rice fields throughout the world is relatively well documented, only a few studies have examined the overall biodiversity in rice fields. Among them, Heckman (1974, 1979)

has carried out comprehensive studies on rice-field organisms in Laos and Thailand. The work of Heong et al. (1991) and Schoenly et al. (1996) carried out in the Philippines provides an insight into the arthropod communities and their guild structure in irrigated rice fields. Previous studies on the rice field biota in Sri Lanka mainly deal with agronomic aspects, where the rice pests, their natural enemies and weeds have been surveyed extensively. Among the earliest published records on the subject, Weerakoon (1957) has given a brief popular account on the ecology of rice field animals in Sri Lanka. The benthos of rice fields have been studied by Weerakoon and Samarasinghe (1958). 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. Several researchers have worked on specific groups of rice field organisms in Sri Lanka, such as aquatic invertebrates (Fernando 1977; Neale 1977; Amerasinghe 1993), terrestrial invertebrates (Rajendram and Devarajah 1990), fish (Fernando 1956) and flora (Velmurugu 1980; Weerakoon and Gunawardena 1983; Chandrasena 1987, 1988, 1999; Seneviratne et al. 1992). This paper intends to highlight the overall species richness of organisms associated with an irrigated rice field ecosystem in Sri Lanka, based on an extensive field survey.

Materials and methods

The study was carried out in an irrigated rice field ecosystem (1 ha) at Bathalagoda, in the Kurunegala district, belonging to the Intermediate Zone of Sri Lanka, 7°30′ N, 80°28′ E, 100 m a.s.l. elevation. Field sampling of the rice field began in November 1995 and continued until March 1998, encompassing five consecutive rice cultivation cycles. Sampling was carried out at fortnightly intervals throughout the above study period, from 0700 to 1300 h. Accordingly, there were 62 sampling days during the entire study. Both the vertebrate as well as the invertebrate fauna inhabiting/visiting the rice field were documented by sampling. Since the rice field ecosystem encompasses three sub-habitats, the soil, water and vegetation, different sampling methods had to be used to document the overall biodiversity. Furthermore, different types of organisms inhabiting each sub-habitat commanded specific sampling methods.

Representative soil samples were collected on each sampling day from eight randomly selected sites in the rice field along the gradient of water flow using a standard soil corer (height: 12 cm, diameter: 6 cm). These soil samples were remixed separately in the laboratory, and eight sub-samples of approximately 225 cm^3 each were separated for extraction of soil-dwelling/benthic invertebrates, using a modified Baermann funnel technique (Walker and Wilson 1960) and subsequent sieving (mesh size 100 µm–1 mm). Water was sampled for zooplankton, according to the methods of Eaton et al. (1995), where eight water samples (5 l each) were collected from random locations in the rice field along the gradient of water flow, using a standard dipper (12 cm diameter, 6 cm depth, 400 ml capacity). These water samples were sieved through a plankton net (mesh size 80 µm).

Aquatic insects were sampled by collecting water from random locations in the rice field using a standard dipper and subsequent sieving (mesh size 160 μm). Aquatic molluscs inhabiting the water surface, submerged vegetation and the mud layer were collected manually, from 10 randomly selected sites of the rice field, using a $0.3\,m^2$ quadrat. The terrestrial arthropod fauna consisting of insects and spiders inhabiting the rice (field proper) and the non-rice (bund) habitats was sampled using a portable 'Blower-Vac' suction device (Arida and Heong 1992) and a standard sweep net, respectively. A plastic enclosure (height: 65 cm, diameter: 45 cm, fitted with a nylon net on top) was placed in 10 random locations in the rice field proper and the bunds, respectively, and the arthropods inhabiting the rice plants and weeds were suctioned out using the Blower-Vac device. The arthropods inhabiting the bund habitat were also sampled using a standard sweep net, by making 20×5 sweeps while walking along the bund, a single sweep covering a distance of 1 m. Specimens of different groups of invertebrates were preserved using standard techniques, and examined under a binocular stereoscopic microscope.

Among the vertebrates, fish and amphibians in rice fields and canals were captured using a hand net and a standard minnow trap. Birds in the field were identified with the naked eye as well as with a pair of binoculars (magnification: 7×35). Reptiles encountered in the field were captured manually and identified in the field itself. Presence of mammals was recorded by both direct and indirect observations such as tracks and feces. Standard baited traps were kept overnight in the field to capture and identify rodents and shrews which colonize the field.

Weed flora (macrophytes and microphytes) in the rice field proper and in the bunds were collected for preparation of voucher specimens. Aquatic microflora were documented by collecting water samples using a standard dipper, and subsequent sieving (mesh size 100 μm). These were observed under a binocular stereo microscope and sorted into different groups.

The different groups of fauna and flora were provisionally identified using standard keys and guides. The soil benthos were identified using Brinkhurst and Jamieson (1971), Costa (1967), Goodey (1963), Pennak (1978) and Fernando and Weerawardhena (2002). Among the aquatic invertebrates, zooplankton (micro-crustacea, rotifera and protozoa) were identified using Fernando and Weerawardhena (2002) and Pennak (1978), aquatic insects using Fernando and Weerawardhena (2002), Amerasinghe (1992, 1995, 1996), and de Fonseka (1998), aquatic molluscs using Naggs (1996), and macro-crustaceans using Fernando (1960) and Arudpragasam and Costa (1962). For the identification of terrestrial arthropods, the work of Barrion and Litsinger (1994) was used for rice pests, their predators and parasitoids. The Homeoptera were further clarified using the keys of Wilson and Claridge (1991). The Lepidopteran pests and non-pest visitors were identified using Nishida and Tori (1970) and D'Abreira (1998), respectively. The Odonata were identified using the work of de Fonseka (1998). The Araneae were identified using the works of Barrion and Litsinger (1995) and Tikader (1987).

The different groups of vertebrates were identified using the following guides: freshwater fish – Pethiyagoda (1991), amphibians – Dutta and Manamendra-

Aarachchi (1996), serpentoid reptiles – De Silva (1990), tetrapod reptiles – Deraniyagala (1953), birds – Henry (1978), mammals – Phillips (1980).

The microphytes were identified up to the generic level, using keys of Abeywickrema (1979) and Abeywickrema et al. (1986). The macrophytic weeds were identified up to species level, using the keys of Chandrasena (1990) and Soerjani et al. (1987).

The provisionally identified specimens of arthropods were compared with curated reference specimens held at the Department of Zoology, University of Peradeniya, collection at the Entomology Museum of Horticultural Research and Development Institute, Gannoruwa (HORDI), collections at Rice Research and Development Institute, Bathalagoda and the National Museum, Colombo. The identity of most specimens of arthropods was confirmed by local and foreign authorities and Institutions. The voucher specimens of flora were compared with herbaria specimens at the Department of Botany, University of Peradeniya and at the National Herbarium of the Royal Botanical Gardens, at Peradeniya. The provisionally identified macrophytes were confirmed by an authority at the National Herbarium. Voucher specimens of arthropods and macrophytes were deposited at the Museum of the Department of Zoology, University of Peradeniya, Sri Lanka.

Results

Overall biodiversity expressed as species richness

The total number of biota recorded and identified from the rice field ecosystem during the entire study period consisted of 494 species of invertebrates belonging to 10 phyla (Appendix 1) and 103 species of vertebrates (Appendix 2), while the flora included 89 species of macrophytes, 39 genera of microphytes and 3 species of macrofungi (Appendix 3). It is interesting to note that of the total species of invertebrates and macrophytic weeds documented, 15 species of invertebrates and one weed species are new records to Sri Lanka. The newly recorded invertebrates consisted of 11 species of arthropods (3 micro-crustaceans, 7 spiders, 1 insect) and 4 species of turbellarian platyhelminths, while the weed species was an aquatic dicotyledonous plant. These 16 taxa have been previously documented from other south and southeast Asian countries. The turbellarians belong to four new genera – *Dalyellia*, *Microdalyellia*, *Rhyncoscolex*, and *Bothrioplana* sp. The new micro-crustaceans include *Mesocyclops ogunnus* Onabamiro, *Mesocyclops nr. woutersi* Vander Velde, and *Mesocyclops nr. aequatorialis* Kieser. The seven spider taxa include two species – *Tetragnatha javana* (Thorell) and *Tetragnatha nitens* (Audouin) and five new genera – *Dyschiriognatha*, *Steatoda*, *Gnathonarium*, *Arctosa*, and *Thanatus*. The newly recorded insect species is *Brachystegus decoratus* (Turner) (Hymenoptera, Sphecidae). The new dicotyledonous weed is *Elatine triandra* Schkuhr, which is a hydrophytic species.

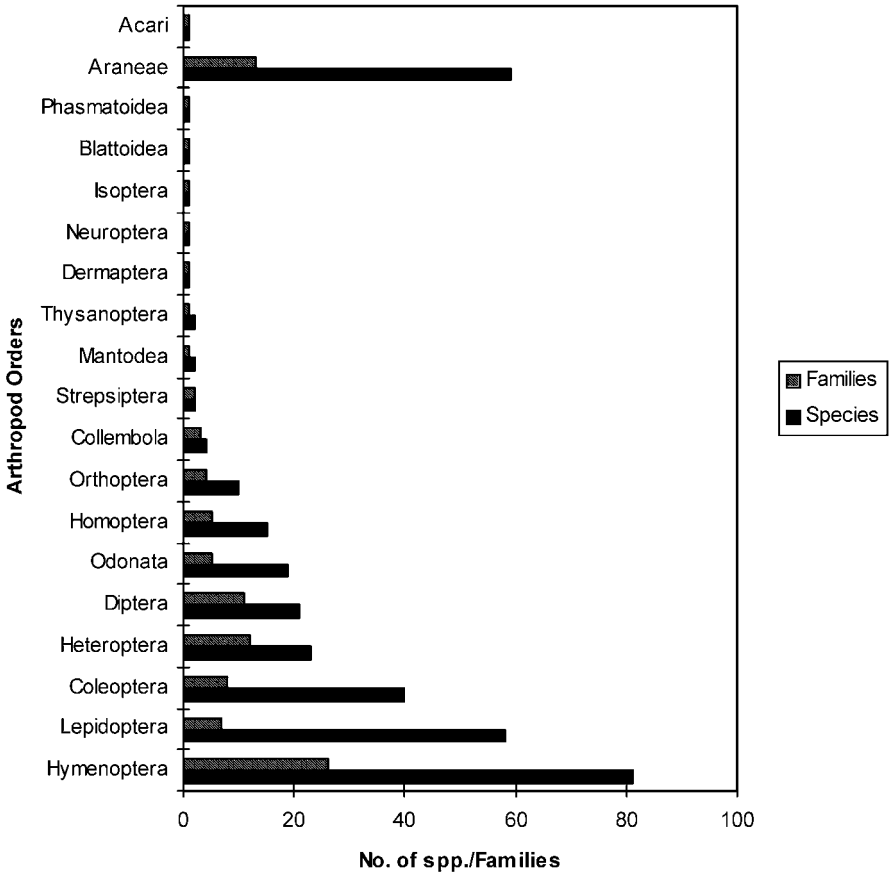

Figure 1. Taxonomic richness of terrestrial arthropods recorded from the irrigated rice field ecosystem in Bathalagoda, Sri Lanka.

Composition and guild structure of arthropods in the rice field

A majority of the invertebrates consisted of arthropods (82%, 405 species), dominated by insects (78%, 317 species). Of the total arthropod species documented, 342 species (282 insects and 60 arachnids) consisted of adults that were adapted to a terrestrial mode of life. Figure 1 shows the taxonomic richness of terrestrial arthropods recorded from the rice field, under different Orders. Among the insects documented, the highest number of species belonged to the Order Hymenoptera (81 species in 26 families), dominated by the Apoidea (bees). The second largest insect Order recorded was Lepidoptera, consisting of 58 species, in 7 families, dominated by the family Nymphalidae (24 spp.).

The arthropod taxa recorded from the rice field ecosystem can be distinguished into four distinct guilds, namely, phytophages, predators, parasitoids and

Table 1. Guild structure of arthropods, based on feeding habits.

Phytophages (rice pests)	
Homoptera	Cicadellidae, Delphacidae, Coccidae, Lophopidae
Heteroptera	Alydidae, Coreidae, Pentatomidae
Thysanoptera	Thripidae
Diptera	Ephydridae, Muscidae, Chironomidae, Cecidomyiidae
Coleoptera	Chrysomelidae, Elateridae, Curculionidae
Lepidoptera	Hesperiidae, Noctuidae, Pyralidae, Nymphalidae
Isoptera	Termitidae
Orthoptera	Acrididae
Phytophages (non-rice pests/visitors)	
Lepidoptera	Papilionidae, Lycaenidae, Pieridae, Nymphalidae, Hesperiidae
Hymenoptera	Halictidae, Anthophoridae, Apidae, Megachilidae
Heteroptera	Coreidae, Pyrrhocoridae, Lygaeidae, Anthocoridae, Aphididae
Coleoptera	Chrysomelidae, Curculionidae
Predators	
Heteroptera	Miridae, Nabidae, Reduviidae, Lygaedae, Veliidae, Mesoveliidae, Hydrometridae
Coleoptera	Coccinellidae, Staphylinidae, Carabidae, Tenebrionidae
Orthoptera	Tettigoniidae, Gryllidae, Tridactylidae
Hymenoptera	Formicidae, Vespidae, Pompilidae, Sphecidae, Eumenidae
Diptera	Ephydridae, Platystomatidae
Odonata	Libellulidae, Gomphidae, Coenagrionidae, Protoneuridae
Dermaptera	Carcinophoridae
Mantodea	Mantidae
Phasmatoidea	Phasmatidae
Neuroptera	Ascalaphidae
Acari	Phytoseiidae
Araneae	Araneidae, Tetragnathidae, Theridiidae, Linyphiidae, Lycosidae, Salticidae, Thomisidae, Oxyopidae, Clubionidae, Heteropodidae, Coriniidae, Philodromidae, Gnaphosidae
Parasitoids	
Hymenoptera	Ichneumonidae, Braconidae, Trichogrammatidae, Eulophidae, Mymaridae, Chalcididae, Pteromalidae, Eupelmidae, Gasteruptiidae, Platygasteridae, Scelionidae, Diapriidae, Bethylidae, Dryinidae, Scoliidae, Mutillidae, Tiphiidae.
Diptera	Pipunculidae, Tachinidae
Strepsiptera	Halictophagidae, Elenchidae
Scavengers/decomposers	
Coleoptera	Meloidae
Diptera	Tabanidae, Sarcophagidae, Anisopodidae, Ceratopogonidae
Blattoidea	Blattoidae
Collembola	Isotomidae, Sminthuridae, Entomobryidae

scavengers, based on food habits (Table 1). Although 131 species of phytophagous insects inhabited the rice ecosystem, only some (55 species) are considered to be rice pests. Among the arthropods, 200 species are biological control agents (154 species of predators and 46 species of parasitoids) of rice pest insects.

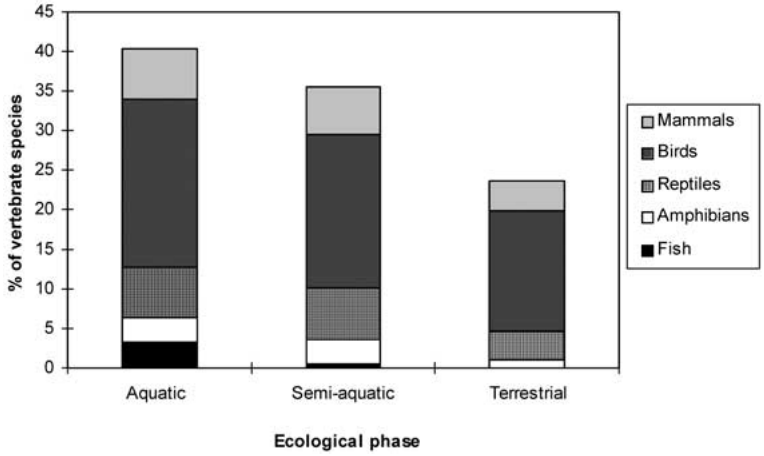

Figure 2. Proportion of different groups of vertebrate species at the three ecological phases of a rice cultivation cycle, in an irrigated rice field in Bathalagoda, Sri Lanka.

Composition and guild structure of vertebrate fauna in rice fields

More than half of the vertebrate species consisted of birds (60 species), including seven migratory species as well. Excluding the migrant birds, the balance represents approximately 16% of the indigenous vertebrate fauna of Sri Lanka. A higher proportion (42%) of vertebrate species were observed during the aquatic phase of the rice fields, while the semi-aquatic and terrestrial dry phases harbored approximately 35 and 23%, respectively (Figure 2). Besides being used as an important feeding site, approximately 32% of the vertebrate species recorded from the rice field utilized this man-made habitat as a breeding site.

The vertebrates recorded belonged to six feeding guilds under three food categories (Table 2). The numbers of species within different groups of vertebrates under three trophic levels are given in Table 2. A majority of the vertebrates (73.5%) fed on animal matter, where the feeding guild was dominated by aquatic carnivores (29.4%), followed by insectivores (25.5%) and terrestrial carnivores (17.6%), respectively. Phytophages (i.e., herbivores and granivores) and omnivorous forms occurred in equal proportions (13.4%). Of the total vertebrate species recorded, approximately 12% function as pests of paddy, while 70% function as biological control agents that feed on pest insects, crabs and rodents.

Composition, structure and distribution of weed flora in the rice field

The macrophytes were dominated by dicotyledons (45 species), closely followed by monocotyledons (42 species) and 2 species of pteridophytes. The monocotyledons were dominated by grasses (family: Poaceae – 21 species), followed by sedges

Table 2. Trophic categories of rice field vertebrate fauna.

Trophic category	Fish	Amphibia	Reptiles	Birds	Mammals	Total
Animal matter						
Aquatic carnivore	3	–	4	22	1	30 (29.4%)
Terrestrial carnivore	–	–	6	8	4	18 (17.6%)
Insectivore	–	8	3	15	1	27 (26.5%)
Plant matter						
Gen. herbivore	1	–	–	–	3	4 (3.4%)
Granivore	–	–	–	7	3	10 (9.9%)
Omnivore	3	–	–	8	3	14 (13.4%)

Table 3. Distribution of the weed flora in the rice field (m = monocots; d = dicots; p = pteridophytes).

Location	Bund	Field	Ditch	Total
Bund only	36 (10m, 26d)	–	–	36(10m, 26d)
Field only	–	5 (2m, 2d, 1p)	–	5 (2m, 2d, 1p)
Ditch only	–	–	–	–
Field and bund	24 (14m, 10d)	24 (14m, 10d)	–	24 (14m, 10d)
Bund and ditch	12 (8m, 4d)	–	12 (8m, 4d)	12 (8m, 4d)
Field and ditch	–	2 (2m)	2 (2m)	2 (2m)
Field, bund and ditch	10 (6m, 3d, 1p)	10 (6m, 3d, 1p)	10 (6m, 3d, 1p)	10 (6m, 3d, 1p)
Total species	82 (38m, 43d, 1p)	41 (24m, 15d, 2p)	24 (16m, 7d, 1p)	89 (42m, 45d, 2p)

(Cyperaceae – 14 species). Among the dicotyledons recorded, the family Asteraceae had the highest number of species (11 species), followed by Scrophulareaceae (7 species). Of the total macrophytes recorded, 45 species (50.5%) were mesophytes (species which grow well under dryland conditions), 41 species (46%) were hygrophytes (species which grow well under water saturated conditions), while three species (3.5%) were hydrophytes (weeds growing well under submerged conditions). The species composition of the weed flora was highest in the rice field bunds (82 species), where 36 species were exclusive to the bund and 27 of these exclusive species were dicots (Table 3). The rice field proper harbored 41 weed species with five species confined to this habitat. Twenty-four weed species occurred in the ditch (water inflow canal), with none being exclusive to it.

Seasonal colonization and succession of rice field biota

The fauna and flora recorded from the rice field were observed to follow a uniform pattern of seasonal colonization and succession during successive rice cultivation cycles. The major arthropod and vertebrate taxa that colonized and/or visited the rice field during different stages/phases of a rice cultivation cycle are presented in Appendix 4. The events of seasonal colonization and succession could be

summarized under two major ecological phases; the aquatic phase and the terrestrial dry phase, as follows.

Aquatic phase. At the beginning of each rice cultivation cycle, practices associated with the preparation of fields resulted in the complete destruction of the fallow vegetation in the field proper and bunds. This resulted in the death of many species of animals that were present in the fallow rice fields, as well as the movement/displacement of some mobile forms such as flying insects into the adjoining non-rice habitats. When the fields were flooded after field preparation, a variety of protozoans, rotifers, turbellarians, and micro-crustaceans colonized the fields via irrigation water. In the same period, phytoflagellates (*Euglena*, *Phacus* and *Chlamydomonas*) started to proliferate and appear as 'blooms' on the water surface. Other ciliates and bacteria also appeared in large numbers, in the photosynthetic aquatic biomass (PAB) consisting of green algae and blue-green algae. These were soon followed by epibenthic filamentous algae, including *Spirogyra* and *Oscillatoria*, which formed dense mats on the floodwater surface during mid-day. During this period voracious predatory ants such as *Odontomachus* spp. and *Leptogenys* spp. raided the fields in large numbers, to feed on the dying arthropods trapped in the mud of ploughed fields. The saprophytic collembolans and dipterans also colonized the field during the early aquatic phase. Certain aerial insects whose larvae are aquatic (odonates, dipterans, ephemeropterans, etc.) were observed flying above the fields and laying eggs in flood water of rice fields, prior to establishment of the crop. Aquatic insects such as heteropterans and coleopterans were observed flying in from surrounding rice fields and other contiguous aquatic habitats such as buffalo wallows, marshes and ponds, while crabs had also colonized the field by this time. Among the vertebrates, fish and amphibians were the first to colonize the flooded rice field. Amphibians belonging to the family ranidae started to breed immediately and lay eggs in the flood water. These in turn attracted aquatic birds such as kingfishers, egrets and herons, as well as aquatic serpents into the flooded rice field. Primary consumers such as mosquito larvae, corixids, chironomids, molluscs and ostracods reached initial peak levels during the early aquatic phase, between 0 and 25 days after transplanting (DAT). During this early period of the rice cultivation cycle, the field was in an open littoral condition, giving rise to an abundance of PAB consisting of algae and other aquatic macrophytes.

Following transplanting and with the establishment of the rice plants, a variety of arthropods colonized the rice fields from surrounding areas, moving in either by flying in (adult insects) or by air dispersal (spiders). *Monochoria vaginalis* and *Marsilia quadrifolia* were the first aquatic macrophytes to appear within the first week after transplanting. These were followed by monocot weeds such as *Ischaemum rugosum, I. timorense, Isachne globosa, Cyperus haspan, Fimbristylis miliaceae* and *Echinochloa* spp. and the dicot species *Sphenoclea zeylanica* which emerged during the second and third weeks after transplanting. The pest species which colonized the fields during the active tillering stage formed the first wave of rice pests and these included *Orseolia oryzae, Cnaphalocrocis medinalis, Sogatella*

furcifera, and Nilaparvata lugens. Along with these pests arrived their predators such as the grass spiders (*Tetragnatha* spp., *Dyschiriognatha* spp.), carabid beetles (*Opheonia* spp.) and gryllids (*Anaxipha longipennis, Metioche vittaticolis*), and hymenopteran parasitoids such as the Mymaridae and Scelionidae and the collembolan scavengers. The booting stage of the rice plant was colonized mostly by predators, including spiders (*Atypena* spp., *Argiope* spp., Theridiidae, Oxyopidae), *Cyrtorhinus lividipennis, Conocephalus longipennis* and coccinellid beetles, while the rice stem borer *Scirpophaga incertulas* and parasitoid wasps belonging to the Trichogrammatidae also colonized the fields during this period. During the flowering stage of the rice plant, sap feeding hemipteran pests (mainly *Leptocorisa oratorius*) colonized the rice field. With the progress of the aquatic phase of each cycle, the density of the different groups of aquatic and terrestrial invertebrates in the rice field floodwater and vegetation fluctuated due to natural causes and chemical inputs.

Terrestrial dry phase. Draining of water during the grain ripening stage resulted in a short semi-aquatic phase ranging from 5 to 10 days. During this phase, many aquatic invertebrates were found trapped in small puddles of water in the fields and these gradually perished, as the puddles dried. Some of the aquatic organisms escaped into canals, *via* the drained floodwater. Others such as amphibians and crabs disappeared into the soil crevices created in the drying field, and started their aestivation. Hygrophytic as well as hydrophytic weeds started to die off gradually. Mesophytic weeds in the field bunds started to invade the drying fields. Rodent pests such as *Bandicota bengalense* colonized the rice bund habitat at this stage, and these small mammals in turn attracted large serpents such as *Ptyas mucosus* and *Naja naja* that visited the field from surrounding habitats. Insectivorous birds such as prinias constructed nests in the rice canopy. During the mature grain stage, the fields were frequently invaded by flocks of granivorous pest birds such as parakeets and munias. Harvesting of the crop resulted in a drastic disturbance to terrestrial arthropod communities, where many of them either perished or escaped into surrounding terrestrial areas. During the dry fallow period, species of crustaceans (ostracods and cyclopoid copepods – with egg sacs), turbellarians, nematodes, philodinid rotifers, protozoans, molluscs and oligochaetes (tubificids, aeolosomatids) were extracted from dry soil samples. This confirmed the fact that the above aquatic organisms enter the soil when the fields begin to dry, and exist as dormant/resting stages, until the fields are re-flooded during the following cycle. It was also observed that these organisms were occupying mainly the relatively moist soil medium in and around the root system of the dry stubble of the rice plant. The dry rice stubble provided an ideal habitat for stem-nesting insects such as wasps, while certain species of spiders also remained in the field. After the crop was harvested, mesophytic grasses (*P. repens*, *C. dactylon*), sedges (*C. rotundus*, *Kyllinga* spp.) and dicots (*E. prostrata*, *S. indicus*, *Desmodium* spp., *Euphorbia* spp.) which were previously inhibited by the floodwater started to germinate and rapidly colonize the dry fallow fields.

Discussion

The results indicate that the irrigated rice field is an agro-ecosystem that sustains a high species richness of invertebrate and vertebrate fauna. A variety of methods targeting different groups enabled the documentation of rice field biodiversity expressed in terms of species richness. However, certain micro fauna (especially protozoans) and mircoflora (cyanophytes and diatoms) needing rigorous collection and identification techniques have been inadequately documented. In addition to the above biota, microscopic examination of rice field floodwater, soil and decaying organic matter revealed the presence of numerous bacteria and microfungi. The high overall biodiversity documented for the rice field studied does not only support and enhance the findings of previous researchers (Heckman 1974, 1979; Fernando 1977; Heong et al. 1991; Lim 1992), but also confirms the predictions of others, pertaining to the high species richness of natural enemies compared to pests in rice fields (Way and Heong, 1994).

Characteristics of the populations and communities of rice field biota

As stated by Fernando (1993), the ecology of the rice fields is dominated by rapid physical, chemical and biological changes. Environmental heterogeneity is considered as an important explanation for species diversity (Huston 1994). Hence, the higher degree of environmental heterogeneity in the rice field ecosystem, operating on a temporal scale, may be a major contributing factor to its rich and varied biodiversity. The organisms that live in these types of heterogenic habitats have, therefore, to be very well adapted to these rapidly changing conditions, including the loss of water during the dry season. The survival of such organisms depends largely on exceptional physiological tolerance or effective immigration and emigration abilities (Williams 1987). Furthermore, compared to other temporary fresh waters, the organisms in rice fields have to cope with various agronomic practices, which makes its prevailing conditions more complicated.

Heckman (1979) considers that since rice fields have existed for several millennia, many species are adapted to the conditions in rice fields. However, as postulated by Fernando (1993, 1995), it is more likely that organisms inhabiting rice fields are drawn from surrounding marshes and other aquatic habitats and are able to survive the agronomic practices of rice cultivation. Hence, in general, organisms inhabiting the rice field ecosystem are opportunistic biota. Unlike in the natural marsh ecosystem, the colonization and occurrence of organisms in rice fields depend not only on its aquatic conditions, but also on the presence of the rice plants. The initial colonizers such as the microflora (algae), the protozoans consisting of phytoflagellates and saprobic elements and mosquito larvae can be considered as the pioneer taxa of the rice field ecosystem, whose arrival leads to the establishment of other biotic communities. The most abundant organisms in the rice field are the ecological dominants of this ecosystem, which are able to react physiologically and/or behaviorally to the drastic conditions in these temporary

wetlands. As observed during the present study, most communities of organisms in the rice fields possessed the ability to recover rapidly from various disturbances, including chemical inputs. Hence, these organisms could be interpreted as biota with a high resilience stability, which undergo rapid secondary succession during each rice cycle (Odum 1997). It could be assumed that when rice fields replace natural wetlands, only the organisms with high resilience stability survive in these man-made temporary wetlands, while the others perish. Based on the theory of *r*- and *k*-selection (MacArthur and Wilson 1967), the life history patterns of most rice field biota indicate that they are typical *r*-strategists, which have a high reproductive allocation, earlier maturation, high recolonization, short life span and possess effective survival mechanisms to face dry conditions. Almost all invertebrate inhabitants, most weed flora (i.e., annuals), fish, amphibians and rodents which are able to complete their life cycles in rice fields belong to the latter category. The birds, reptiles and other mammals that visit the rice fields for feeding purposes are *k*-strategists, which rely on the greater landscape to complete their life cycles.

Trophic interactions among rice field biota

The higher degree of environmental heterogeneity in the rice field ecosystem operating on a rapid and short-term temporal scale offers a greater variety of changing resources to its rich biota, which occur as many distinct functional types. According to Huston (1994), environmental heterogeneity, in addition to facilitating the coexistence of potentially competing species, also has a major effect on the number of functional types that occur within a local area. Because different functional types use different resources or use the same resources in different ways, greater structural heterogeneity and more types of resources in an environment will increase the number of functional types that can be present. Like in any other ecosystem, the stability of the rice field ecosystem depends on the efficient trophic interactions between the various functional types.

The different species of rice field organisms in the soil, water and vegetation subhabitats belong to distinct functional types such as producers, consumers and decomposers. These functional types interact with each other through a mosaic of grazing and detritivorous food chains, which in turn leads to multiple trophic levels, consisting of resource–consumer–predator food webs. Species that exert a controlling influence on the trophic interactions are the keystone taxa. These species can occur at any trophic level. In the rice field ecosystem, the species that constitute the photosynthetic aquatic biomass (i.e., phytoflagellates, algae) and saprophytic organisms (i.e., collembolans) which initiate the seasonal colonization process, and the predatory arthropods (spiders, odonates, carabid beetles etc.) which control the pest insect populations could be considered as keystone taxa of this temporary wetland agro-ecosystem.

The structure of these food webs operating in the rice field ecosystem is subjected to temporal and spatial variation (Schoenly et al. 1996) in response to the

seasonal succession of biota through the different ecological phases of the rice field ecosystem. As observed by Schoenly et al. (1996), the taxonomic composition and structure of these food webs are broadly similar in irrigated rice fields in different localities. These complex trophic interactions operating in the rice field ecosystem ensure the proper functioning of the ecosystem processes, including nutrient recycling and energy flow. Although such complex trophic interactions occur in natural marsh ecosystems, a major difference of those in the rice field ecosystem is the regular and large scale loss of energy and matter due to the removal of the rice crop. Therefore, these energy and material losses have to be compensated by agronomic practices and measures.

Significance of biodiversity associated with the rice agro-ecosystem

Biological control of rice pests. Recognition of the importance of biological control in rice pest management, particularly in the tropics, is gaining rapid momentum (Ooi and Waage 1994). The present study has provided clear evidence for the fact that arthropod natural enemies of rice pest insects are ubiquitous in tropical rice fields, where almost 50% of the arthropod species consisted of predators and parasitoids. A high species richness among arthropod natural enemies in rice ecosystems has been observed by previous researchers as well (Heong et al. 1991; Ooi and Shepard 1994). In contrast to the relative paucity of natural enemies in irrigated rice fields of temperate countries (Heong et al. 1991; Perfect and Cook 1994), the rich composition of arthropod predators and parasitoids of rice insect pests in tropical rice fields highlights the potential of natural biological control in such countries.

Generation of nutrients for rice cultivation. Traditional rice cultivation, which did not involve the use of chemical fertilizers, maintained a moderate but stable yield for thousands of years (Roger et al. 1991). This was mainly due to the contributions of the rich array of micro-organisms (bacteria, fungi and protozoans) and other soil invertebrates that enabled to maintain soil fertility through the recycling of nutrients, while the nitrate fixed by bacteria and blue-green algae also maintained the soil nitrogen fertility (Moorman and Van Breeman 1978). Recent studies on the blue-green algae (Roger and Kulasooriya 1980) and oligochaetes (Grant and Seegers 1985) in rice fields have shown that these organisms enable increase of the nitrogen content in rice soils.

Consumptive benefits. Apart from the direct benefit of the rice crop, the biodiversity in rice fields can provide other human food items, as illustrated by Heckman (1979) in rice fields of Thailand. During the present study, farmers were observed to gather hygrophytic vegetation such as *Ipomoea aquatica*, *Centella asiatica* and *Alternanthera sessilis* as a vegetable food source, while fish were captured from contiguous irrigation canals and marshes. Fish culture in rice fields is a growing

industry in many countries of southeast Asia (Halwart 1998) and this is a typical example of the practical consumptive functions of rice fields.

Biodiversity conservation. At present, the alarm bells signaling the loss of biodiversity ring loud and clear throughout the world. Conservation biologists and agroecologists are two of the most ardent proponents of biodiversity preservation. Yet, the discourses of the two are surprisingly different; the former being mainly concerned with the origin and maintenance of biodiversity, whereas the latter is concerned with its functions, leading to emphases on different strategies (Vandermeer and Perfecto 1997). The rich biodiversity associated with this unique man-made temporary wetland clearly indicates that rice field agro-ecosystems could be compatible with conservation objectives and meets the requirements/interests/emphases of agroecologists as well as conservation biologists. The rich array of natural biological control organisms of rice pests as well as the diverse soil benthos which enhance and maintain soil fertility by nutrient recycling are two important functional aspects which fulfil the emphases of agroecologists. As with other wetlands, flooded rice fields serve as ecotones that lie between land and water. Hence, they provide an important feeding habitat for waterfowl and other wildlife, as observed during the present study. Therefore, conservation biologists can view flooded rice fields as agronomically managed temporary wetlands that sustain a rich biodiversity outside protected areas, and they also contribute to enhance the biodiversity, especially in urban and sub-urban areas. The comprehensive review on rice fields as temporary wetlands by Lawler (2001) clearly supports and highlights the latter aspect.

Conclusion

The findings of the present survey clearly highlight the contribution of the irrigated rice field agro-ecosystem towards sustaining a rich biodiversity. The results would also be useful to consider changes in a popular paradigm – from integrated pest management (IPM) toward integrated biodiversity management (IBM) in rice fields (Kirtani 2000). 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 meets 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 agro-ecosystem.

Acknowledgements

This work is based on a Ph.D. research conducted by the first author on the ‘ecology and biodiversity in an irrigated rice field ecosystem in Sri Lanka’.

Financial assistance from the National Science Foundation of Sri Lanka is gratefully acknowledged. The authors wish to express their gratitude to Dr. Lionel Nugaliyadde of the Rice Research and Development Institute at Bathalagoda, Sri Lanka for providing logistic and technical support to carry out the project in Bathalagoda. Prof. C.H. Fernando (University of Waterloo, Canada) helped the authors by sending valuable references on the topic. Dr. J.W. Reid, Dr. K.V. Krombein, Dr. Susan Batra, and Dr. Beth Norden (Smithsonian Institution, USA), Dr. A.T. Barrion (International Rice Research Institute, Philippines), Mr. Fred Naggs (British Museum of Natural History), Dr. Masataka Sato (Nagoya Women's University, Japan) and Dr. Robert Jackson (University of Canterbury, New Zealand) are gratefully acknowledged for confirming the identity of several invertebrate species.

Appendix 1

Checklist of invertebrate fauna recorded from the rice field ecosystem at Bathalagoda, Sri Lanka.

Phylum/class/order	Sub-family/family	Genus/species
Protozoa		
Sarcomastigophora	Volvocidae	*Volvox* sp.
		Gonium sp.
		Pleodorina sp.
	Chlamydomonadidae	*Chlamydomonas* sp.
	Euglenidae	*Phacus* sp.
		Euglena sp.
	Amoebidae	*Amoeba* sp.
	Arcellidae	*Arcella* sp.
	Actinophrydae	*Actinophrys* sp.
	Difflugidae	*Difflugia* sp.
Ciliophora	Trachellidae	*Dileptus* sp.
	Parameciidae	*Paramecium* sp.
	Vorticellidae	*Vorticella* sp.
	Lagenophryidae	*Trichodina* sp.
	Colpodidae	*Colpoda* sp.
Cnidaria		
Hydrozoa	Hydridae	*Hydra vulgaris* Pallas
Ectoprocta	Plumatellidae	*Plumatella* sp.
Gastrotricha	Chaetonotidae	*Chaetonotus* sp.
Rotifera	Brachionidae	*Brachionus rubens* Ehrenberg
		B. patalus Muller
		B. falcatus Zacherias
		B. calyciflorus Pallas
		B. quadridentatus Herman
		Keratella tropica Apstein
		Platyias quadricornis (Ehrenberg)

Appendix 1. (continued)

Phylum/class/order	Sub-family/family	Genus/species
	Lecanidae	*Lecane luna* (Muller)
		Lecane ungulata (Gosse)
		Monostyla bulla Gosse
	Trichocercidae	*Trichocerca* sp.
	Euchlanidae	*Euchlanis* sp.
	Philodinidae	*Rotaria* sp. A
		Rotaria sp. B
		Philodina sp.
	Colurellidae	*Lepadella patella* Muller
	Flosculariidae	*Sinantherina spinosa* Thorpe
	Conochilidae	*Conochilus* sp.
Platyhelminthes		
Turbellaria	Dalyellidae	*Dalyellia* sp.
		Microdalyellia sp.
	Typhloplanidae	*Mesostoma* sp.
	Macrostomidae	*Macrostomum* sp.
	Catenulidae	*Catenula* sp.
		Rhynchoscolex sp.
	Stenostomidae	*Stenostomum* sp.
	Planariidae	*Dugesia* sp.
	Bothrioplanidae	*Bothrioplana* sp.
Nematoda		
Dorylaimida	Dorylaimidae	*Dorylaimus stagnalis* Dujardin
Tylenchida	Hoplolaimidae	*Hirschmanniella oryzae* Van Breda de Haan
		Helicotylenchus sp.
Rhabditida	Rhabditidae	Unidentified sp.
	Diplogasteridae	Unidentified sp.
Enoplida	Tripylidae	*Tripyla* sp.
		Trobilus sp.
	Ironidae	*Ironus* sp.
Annelida		
Hirudinea	Hirudinidae	*Dinobdella ferrox* (Blanchard)
		Hirudinaria manillensis (Lesson)
Oligochaeta	Naididae	*Dero digitata* (Muller)
		Dero cooperi Stephenson
		Dero nivea Aiyer
		Aulophorus furcatus (Muller)
		Aulophorus sp. A
		Nais communis Piguet
		Pristina breviseta (Bourne)
		Pristina longiseta Ehrenberg
		Pristina minuta (Stephenson)
		Branchiodrilus semperi (Bourne)
		Chaetogaster sp.
		Allonais sp.

Appendix 1. (continued)

Phylum/class/order	Sub-family/family	Genus/species
	Tubificidae	*Limnodrilus hoffmeisteri* Claparede
		Branchiura sowerbyi Beddard
		Bothrioneurum iris Beddard
	Aeolosomatidae	*Aeolosoma bengalense* Stephenson
		Aeolosoma sp. A
	Ocnerodrilidae	*Malabaria* sp.
	Lumbriculidae	*Lumbriculus variegatus* (Muller)
	Glossoscolecidae	*Pontoscolex* sp.
	Almidae	*Glyphidrilus* sp.
	Megascolecidae	*Pheretima companulata* (Bahl)
	Enchytraeidae	*Mesenchytraeus* sp.
Mollusca		
Stylommatophora	Ariophantidae	*Cryptozona cyix* (Benson)
	Achatinidae	*Achatina fulica* Bowdich
Bivalvia	Unionidae	*Lamellidens testudinarius* (Spengler)
Prosobranchia	Viviparidae	*Bellamya ceylonica* (Dohrn)
		Bellamya dissimilis (Muller)
	Ampullaridae	*Pila globosa* (Swainson)
	Bithynidae	*B. stenothyroides* (Dohrn)
		Mysorella costigera (Kuster)
	Thiaridae	*Melanoides tuberculata* (Muller)
Basommatophora	Lymnaeidae	*Lymnaea luteola* (Lamarck)
	Planorbidae	*Indoplanorbis exustus* (Deshayes)
		Gyraulus sp.
Arthropoda		
Crustacea		
Branchiopoda	Conchostraca	*Cyclestheria hislopi* (Baird)
Cladocera	Macrothricidae	*Macrothrix triserialis* Brady
		Ilyocryptus spinifer Herrick
	Moinidae	*Moinodaphnia macleayi* King
		Moina micrura Kurz
	Chydoridae	*Oxyurella sinhalensis* Daday
		Alona sp.
	Daphniidae	*Ceriodaphnia cornuta* Sars.
		Scapholoberis kingi Sars.
	Bosminidae	*Bosminopsis deitersi* Richard
	Sididae	*Diaphanosoma exasum* (Sars)
Copepoda	Cyclopoida	*Thermocyclops decipiens* Kiefer
		Microcyclops varicans (Sars)
		Mesocyclops aspericornis (Daday)
		Mesocyclops ogunnus Onabamiro
		M. woutersi Van der Velde
		M. aequatorialis Kieser.
	Calanoida	*Phyllodiaptomus annae* (Apstein)
	Harpacticoida	*Elaphiodella bidens* (Daday)

Appendix 1. (continued)

Phylum/class/order	Sub-family/family	Genus/species
Ostracoda		*Cypris subglobosa* Sowerby
		Centrocypris viridis Neale
Malacostraca	Decapoda	
	Parathelphusidae	*Oziothelphusa senex* (F.)
	Atydae	*Caridina nilotica* Bouvier
Arachnida		
Hydracarina	Arrenuridae	*Arrenurus* sp. A
		Arrenurus sp. B
	Hydrachnidae	*Hydrachna* sp.
Acari	Ixodidae	*Rhipicephalus sanguineus* (Latrielle)
	Phytoseiidae	*Amblyseius imbricatus* Corpus et Rimando
Araneae	Araneidae	*Argiope aemula* (Walckenaer)
		A. catenulata (Doleschall)
		Neoscona molemensis Tikader & Bal
		Neoscona nautica (L.Koch)
		Neoscona theisi (Walckenaer)
		Araneus sp. A
		Araneus sp. B
		Larinia sp.
		Gea sp.
		Eriovixia sp.
		Cyclosa sp. A
		Cyclosa sp. B
	Tetragnathidae	*Dyschiriognatha* spp.
		Leucauge sp. A
		Leucauge sp. B
		Tylorida sp.
		T. javana (Thorell)
		T. virescens Okuma
		T. vermiformis Emerton
		T. maxillosa Thorell
		T. ceylonica Cambridge
		T. mandibulata Walckenaer
		T. nitens (Audouin)
	Theridiidae	*Theridion* sp.
		Chrysso sp.
		Coleosoma sp.
		Argyrodes sp.
		Steatoda sp.
		Enoplognatha sp.
		Gnathonarium sp.
	Linyphiidae	*Atypena* sp.
	Salticidae	*Plexippus paykulli* (Audouin)
		Plexippus sp. A
		Carrhotus sp.
		Bianor sp.
		Hasarius sp.
		Mymarachne plateleodes (O.P. -Cambridge)

Appendix 1. (continued)

Phylum/class/order	Sub-family/family	Genus/species
		Phintella sp.
		Harmochirus brachiatus (Thorell)
		Simaetha sp.
	Thomisidae	*Runcinia* sp. A
		Runcinia sp. B
		Thomisus sp. A
		Thomisus sp. B
		Thomisus sp. C
	Lycosidae	*Pardosa pseudoannulata* (Boes. & Strand)
		P. sumatrana (Thorell)
		Hippasa sp.
		Arctosa sp.
	Clubionidae	*Cheiracanthium* sp. A
		Cheiracanthium sp. B
		Cheiracanthium sp. C
	Oxyopidae	*Oxyopes javanus* Thorell.
		Oxyopes sp. A
	Heteropodidae	*Heteropoda* sp.
		Olios sp.
	Coriniidae	*Castianeira* sp.
	Philodromidae	*Thanatus* sp.
	Gnaphosidae	*Zelotes* sp.
Insecta	Apoidea	
Hymenoptera		
	Halictidae	*Nomia* nr. *eburnigera*
		Nomia nr. *oxybeloides*
		Nomia nr. *strigata*
		Nomia sp. A
		Nomiodes nr. *variegata*
		Sphecodes sp.
		Lasioglossum (*Ctononomia*) nr. *cattalum.*
	Anthophoridae	*Ceratina (Pithitis) binghami* Cockerell
		Amegilla puttalama Strd.
	Apidae	*Apis cerana indica* Fr.
		Apis florea Fr.
	Megachilidae	*Megachile* nr. *Gathela*
		Megachile lanata Fabricius
		Heriades binghami Dover
		Coelioxys sp.
	Formicoidea	
	Formicidae	*Camponotus* sp. A
		Camponotus sp. B
		Polyrachis sp.
		Lophomyrmex sp.
		Atta sp.
		Solenopsis sp.
		Pheidologeton sp.
		Odontomachus sp.
		Leptogenys sp.

Appendix 1. (continued)

Phylum/class/order	Sub-family/family	Genus/species
	Ichneumonoidea	
	Ichneumonidae	*Xanthopimpla flavolineata* Cameron
		Charops brachypterum (Cameron)
		Temelucha philippinensis (Ashmead)
		Amauromorpha sp.
		Itolplectis sp.
	Braconidae	*Cotesia (Apantales) flavipes* Cameron
		Cotesia sp. A
		Macrocentrus sp.
		Bracon sp.
		Opius sp.
		Snellenius sp.
	Chalcidoidea	
	Trichogrammatidae	*Paracentrobia yasumatsui* Subba Rao
		Oligosita sp. A
		Oligosita sp. B
	Eulophidae	*Afrostocetus beatus* (Perkins)
		Tetrastichus sp.
		Elasmus sp.
	Mymaridae	*Mymar taprobanicum* Ward
		Gonatocerus sp.
		Anagrus sp.
	Chalcididae	*Brachymeria lasus* (Walker)
		Brachymeria sp. B
		Antrocephalus sp.
	Pteromalidae	*Trichomalopsis* sp.
	Eupelmidae	*Neanastatus oryzae* Ferriere
	Evanioidea	
	Gasteruptiidae	*Gasteruption* sp.
	Proctotrupoidea	
	Platygasteridae	*Platygaster oryzae* Cameron.
	Scelionidae	*Telenomus* nr. *triptus* Nixon
		Telenomus rowani (Gahan)
		Gryon nixoni (Masner)
		Macroteleia crawfordi Keiffer
		Psix spp.
	Diapriidae	*Trichopria* sp.
	Bethyloidea	
	Bethylidae	*Rhabdepyris* sp.
	Dryinidae	*Haplogonatopus* sp.
		Pseudogonatopus sp.
	Sphecoidea	
	Sphecidae	*Ammophila laevigata*
		Sceliphron madraspatanum
		Liris albopilosa Tsun.
		L. aurulenta
		L. flavipennis (Wms.)
		L. subtessellata (Sm.)
		Larra simillima (Sm.)

Appendix 1. (continued)

Phylum/class/order	Sub-family/family	Genus/species
		Bembecinus pusillus (Handl.)
		Brachystegus decoratus (Turner)
		Cerceris pulchra Cam.
		Cerceris sp. A
		Alysson sp.
	Scolioidea	
	Scoliidae	*Scolia picteti* Sauss.
		Scolia affinis Guer.
	Mutillidae	*Petersenidia krombeini*
	Tiphiidae	*Mesa petiolata* (Sm.)
	Vespoidea	
	Eumenidae	*Eumenes* sp.
	Vespidae	*Ropalidia stigma* (Smith)
		Delta campeniformes (Fabricius)
		Euodynerus sp.
	Pompiloidea	
	Pompilidae	*Paracyphononyx incognitus* (Cameron)
Lepidoptera	Papilionidae	*Papilio demoleus* L.
		P. polytes L.
		Pachliopta hector L.
		P. aristolochiae Fabricius
		Graphium agamemnon L.
		Troides darsius Gray
	Lycaenidae	*Zizula hylax* Fabricius
		Zizina otis Fabricius
		Zizeeria karsandra Moore
		Jamides celeno Cramer
		J. bochus Stoll
		Amblypodia anita Hewitson
		Lampides boeticus L.
		Jamides lacteata de Niceville
	Pieridae	*Eurema hecabe* L.
		E. blanda Boisduval
		E. brigitta Stol
		Leptosia nina Fanricius
		Catopsilia pyranthe L.
		C. pomona Fabricius
		Appias lyncida Cramer
		A. albina Boisduval
		Delias eucharis Drury
	Nymphalidae	*Ypthima ceylanica* Hewitson
		Melanitis leda L.
		Mycalesis perseus Fabricius
		M. mineus L.
		Tirumala septentrionis Butler
		T. limniace Cramer
		Parantica aglea Stoll
		Ideopsis similis L.
		Danaus chrysippus L.

Appendix 1. (continued)

Phylum/class/order	Sub-family/family	Genus/species
		D. genutia Cramer
		Junonia iphita Cramer
		J. almana L.
		J. atlites L.
		J. lemonias L.
		Euploea core Cramer
		E. klugii Moore
		Neptis hylas L.
		N. jumbah Moore
		Orsotriaena medus Fabricius
		Pantoporia hordonia Stoll
		Ariadne ariadne L.
		Phalanta phalantha Drury
		Elymnias hypermnestra L.
		Cupha erymanthis Drury
	Hesperiidae	*Pelopidas mathias* Fabricius
		P. subochracea Fabricius
		Potanthus confuscius
		P. pseudomaesa
		Spalia galba
		Suastus gremius
	Noctuidae	*Spodoptera mauritia* Boisd
	Pyralidae	*Sciropophaga incertulas* (Walker)
		S. innotata (Walker)
		C. medinalis (Guerner)
		Nymphula depunctalis Guerner
Homoptera	Cicadellidae	*Caloscarta capitata* Stal.
		Nephotettix virescens (Distant)
		N. nigropictus (Stal)
		N. parvus Ishihara & Kawase
		N. sympatricus Ghauri
		Hecalus sp.
		Exitianus sp.
		Empoascanara sp.
		Cofana spectra Distant
		Recilia dorsalis (Motschulsky)
	Delphacidae	*N. lugens* (Stal)
		S. furcifera (Horvath)
	Lophopidae	*Pyrilla perpusilla* (Walker)
	Aphididae	*Aphis spiraecola*
	Pseudococcidae	*Brevennia* sp.
Heteroptera	Alydidae	*L. oratorius* Fabricius
	Coreidae	*Cletus punctiger* (Dallas)
		Riptortus linearis (Fabricius)
		Sirthenea flavipes (Stal)
	Reduviidae	*Polytoxus fuscovittatus* (Stal)
		Polididus armatissimus Stal
		Scipinia horrida Stal

Appendix 1. (continued)

Phylum/class/order	Sub-family/family	Genus/species
	Pentatomiidae	*Scotinophara lurida* (Burmeister)
		Agonoscelis nubile (Hahn)
		Eysarcoris guttiger (Thunberg)
		Pygomenida bengalensis (Westwood)
		Glaucias virgineus (Stal)
		Nezara viridula (L.)
		Chrysocoris sp.
	Miridae	*C. lividipennis* Reuter
	Pyrrocoridae	*Disdercus cingulatus* (Fabricius)
	Nabidae	*Nabis* sp.
	Lygaeidae	*Geoceris ochropterus* (Fieber)
		Pseudopachybrachius gutta (Dalh)
	Anthocoridae	*Deraecoris* sp.
	Mesoveliidae	*Mesovelia orientalis* Kirk
	Veliidae	*Microvelia douglasii* Bergoth
	Gerridae	*Gerris adelaides* Dohrn
		Limnogonus sp.
	Nepidae	*Laccotrephes* sp.
	Belostomatidae	*Sphaerodema rusticum* (Fabricius)
	Notonectidae	*Anisops* sp.
	Corixidae	*Micronecta* sp.
	Hydrometridae	*Hydrometra greenii* Kirk
Coleoptera	Coccinellidae	*Harmonia octomaculata* (Fabricius)
		Coccinella transversalis (Fabricius)
		Micraspis discolor (Fabricius)
		Brumoides suturalis (Fabricius)
		Liochrimus coccinella (Fabricius)
	Chrysomelidae	*Dicladispa armigera* (Oliver)
		Leptispa pygmaea Baly
		Haltica cyanea Web.
		Monolepta sp.
		Chaetocnema sp.
		Aulocophora sp.
		Colaspis sp.
		Hyphasis sp.
		Lema (S.str.) coromandeliana (Fabricius)
	Carabidae	*Ophionea (S.str.) indica* (Thunberg)
		Ophionea (Setophionea) ishii Habu
		Clivina mustela Andrews
		Clivina castanea Westwood
		Tachys politus Motschulsky
		Tachys sp.
		Tachylopha ovata (Motschulsky)
		Stenolophus sp.
		Abacetus submetallicus (Nietner)
		Bradycellus sp.
		Hololeius ceylonicus (Nietner)
		Perigona nigriceps (Dejean)
		Mimocolliurius sp.

Appendix 1. (continued)

Phylum/class/order	Sub-family/family	Genus/species
		Chlaenius sp.
		Submera latifrons (Dejean)
		Egadroma quinquepustulata Weidem
		Elaphropus sp.
		Anotylus sp.
	Staphylinidae	*Paederus alternans* Walker
	Curculionidae	*Hydronomidius molitor* Faust
		Echinocnemus oryzae Marshall
		Neocleonus sp.
		Myllocerus sp.
	Elateridae	*Aeoloderma brachmana* (Candize)
	Tenebrionidae	*Formicomus braminus* La Ferte
	Meloidae	*Mylabris* sp.
	Dytiscidae	*Copelatus* sp.
		Laccophilus sp.
		Eretes sticticus L.
		Cybister sp.
	Hydrophilidae	*Berosus* sp.
		Hydrophilus sp.
	Noteridae	*Canthydrus* sp.
Orthoptera	Acrididae	*Gastrimaraus africanus* det sago
		Oxya japonica (Thunberg)
		Acrotylus humbertianus Sauss.
		Acrida exaltata Walker
		Gesonula punctifrons det sago
		Atractomorpha crenulata (Fabricius)
	Gryllidae	*M. vittaticolis* (Stal)
		A. longipennis (Serville)
	Gryllotalpidae	*Gryllotalpa orientalis* Burmeister
	Tridactylidae	*Tridactylus* sp.
	Tettigoniidae	*C. longipennis* (de Haan)
Diptera	Culicidae	*Culex tritaeniorhynchus* Giles
		C. bitaeniorhynchus Giles
		C. pseudovishnui Colless
		C. fuscocephala Theobald
		Aedes pipersalatus Giles
		A. pallidostriatus Giles
		Anopheles barbumbroses Strich
		A. vagus Doenitz
		A. barbirostris Van der Wulp
		A. peditaeniatus (Leicester)
		A. culicifacies Giles
		A. pallidus Theobald
		A. nigerrimus Giles
		A. tessellatus Theobald
	Cecidomyiidae	*Orseolia aryzae* (Wood-Mason)
	Muscidae	*Atherigona oryzae* Malloch
	Ephydridae	*Hydrellia philippina* (Fallen)
		Ochthera brevitibialis de Meijere

Appendix 1. (continued)

Phylum/class/order	Sub-family/family	Genus/species
	Anisopodidae	*Sylvicola* sp.
	Ceratopogonidae	*Culicoides* sp.
		Palpomyia sp.
	Pipunculidae	*Pipunculus mutillatus* Loew.
	Tachinidae	*Palexorista lucajus* Walk.
		Phorochosoma sp.
		Prosopodopsis apendiculata de M.
	Chironomidae	*Chironomus* sp.
		Pentaneura sp.
	Corethridae	*Chaoborus* sp.
	Syrphidae	*Paragus* sp.
	Tipulidae	*Erioptera* sp.
	Tabanidae	*Tabanus* sp.
		Haematopota sp. A
		Haematopota sp. B
		Allograpta javana Wiedermann
		Mesembrius bengalensis (Wiedermann)
		Chrysops sp.
	Platystomatidae	*Poecilotraphera taeniata* (macquart)
	Sarcophagidae	*Amobia* sp.
		Senotainia sp.
		Sarcophaga sp.
Odonata	Libellulidae	*Neurothomes tullia* (Drury)
		N. intermedia (Rambur)
		Orthetrum sabina (Drury)
		O. pruinosum (Rambur)
		Pantala flaviscens (Fabricius)
		Diplocodes trivialis (Rambur)
		Potamarcha congener (Rambur)
		Crocothemis servilia (Drury)
		Trithemis festiva (Rambur)
	Gomphidae	*Ictinogomphus rapax* (Rambur)
	Coenagrionidae	*Ceriagrion coromandelianum* (Fabricius)
		C. cerinorubellum (Brauer)
		Ceriagrion sp. A
		Agriocnemis pygmaea (Rambur)
		Ischnura aurora (Brauer)
		Pseudagrion sp.
	Protoneuridae	*Elattoneura caesia* (Selys)
		Ellattoneura sp.
	Lestidae	*Lestes* sp.
Collembola	Isotomidae	*Isotomurus* sp.
	Sminthuridae	*Sminthurides* sp.
	Entomobryidae	*Entomobrya* sp.
		Mesira sp.
Ephemeroptera	Baetidae	*Cloeon* sp.
		Baetis sp.

Appendix 1. (continued)

Phylum/class/order	Sub-family/family	Genus/species
Strepsiptera	Halictophagidae	*Halictophagus* sp.
	Elenchidae	*Elenchus* sp.
Thysanoptera	Thripidae	*Stenchaetothrips biformis* (Bagnell)
		Haplothrips ganglbaueri Schumtz
Dermaptera	Carcinophoridae	*Euborellia* sp.
Plecoptera	Pteronarcyidae	Unidentified sp.
Neuroptera	Ascalaphidae	*Suhpalasca* spp.
Phasmatoidea	Phasmatidae	Unidentified spp.
Blattoidea	Blattoidae	*Blatella germanica* L.
Mantodea	Mantidae	*Archimantis* sp.
		Unidentified sp.
Isoptera	Rhinotermitidae	*Coptotermes* sp.

Appendix 2

Checklist of vertebrate fauna recorded from the rice field ecosystem at Bathalagoda, Sri Lanka.

Phylum/class/order	Sub-family/family	Genus/species
Pisces	Cyprinidae	*Rasbora daniconius* (Hamilton)
		Esomus thermoicos (Valenciennes)
		Puntius bimaculatus (Bleeker)*
		Amblypharyngodon melettinus (Valenciennes)
	Channidae	*Channa punctata* (Bloch)
		Channa guchua (Bleeker)
	Cobitidae	*Lepidocephalichthys thermalis* Valenciennes
Amphibia	Ranidae	*Euphlyctis cyanophlyctis* Achneider
		E. hexadactylus (Lesson)
		Limnonectes limnocharis (Gravenhorst)
		Hoplobatrachus crassus (Jerdon)
	Microhylidae	*Microhyla ornata* (Dumeril & Bibron)
		M. rubrum Jerdon
	Bufonidae	*Bufo melanostictus* Schneider
Reptilia	Agamidae	*Calotes versicolor* (Daudin)
		C. calotes (L.)
	Varanidae	*Varanus salvator* (Deraniyagala)
		V. bengalensis (Daudin)
	Scincidae	*Mabuya carinata* Deraniyagala
	Bataguridae	*Melanochelys trijuga* (Lesson)
	Trionychidae	*Lissemys punctata* Laccapede
	Elapidae	*N. naja* L.

Appendix 2. (continued)

Phylum/class/order	Sub-family/family	Genus/species
	Colubridae	*Amphiesma stolata* L.
		Coluber mucosus (Deraniyagala)
		Xenochrophis piscator (Schneider)
		Atretium schistosum (Daudin)
		Ahaetulla nasatus Lacapede
	Viperidae	*Daboia russelli* (Gray)
Aves	Ciconnidae	*Anastomus oscitans* (Boddaert)
		Mycteria leucocephala (Pennant)
	Ardeidae	*Egretta garzetta* (L.)
		Mesophoyx intermedia (Wagler)
		Casmerodius albus (Gray)
		Ardea cinerea (Gould)
		Ardeola grayii (Sykes)
		Bubalcus ibis (Boddaert)
		Ixobrychus cinnamomeus (Gmelin)
	Threskiornithidae	*Threskiornis melanocephalus* (Latham)
	Charadridae	*Vanellus indicus* (Boddaert)
	Scolopacidae	*Tringa hypoleucos* (L.)**
		T. glareola L.**
		Gallinago stenura (Bonaparte)**
	Rallidae	*Amauromis phoenicurus* (Pennant)
		Gallicrex cinerea (Gmelin)
		Gallinula chloropus Blyth
	Phalacrocoracidae	*Phalacrocorax niger* (Vieillot)
		P. fuscicollis Staphens
	Anatidae	*Dendrocygna javanica* (Horsfield)
	Alcedinidae	*Halcyon smyrnensis* (Boddaert)
		Alcedo atthis Kleinschmidt
		Pelargopsis capensis (Pearson)
	Recurvirostridae	*Himantopus himantopus* Whistler
	Larridae	*Sterna nilotica* (Gmelin)**
		Chlidonias hybridus (Stephens)**
	Accipitridae	*Spilornis cheela* (Blyth)
		Haliaster indus (Boddaert)
		Accipiter badius (Gmelin)
	Caprimulgidae	*Caprimulgus macrurus* Ripley
	Strigidae	*Otus bakkamoena* Pennant
		Glaucidium radiatum (Tickell)
	Meropidae	*Merops orientalis* Whistler
		M. leschenaultii Vieillot
	Coraciidae	*Coracias benghalensis* L.
	Cuculidae	*Centropus sinensis* Stresemann
	Psittacidae	*Psittacula eupatria* L.
		P. kramerii (Bechstein)
		P. cyanocephala (L.)
	Columbidae	*Streptopelia chinensis* (Reichenbach)
		Columba livia (Strickland)
	Muscicapidae	*Turdoides affinis* (Dumont)
		Cisticola juncidis Blyth

Appendix 2. (continued)

Phylum/class/order	Sub-family/family	Genus/species
		Prinia inornata (Legge)
		P. socialis Legge
		Orthotomus sutorius (Pennant)
		Saxicoloides fulicata (Lesson)
		Copsychus saularis (Sclater)
	Dicruridae	*Dicrurus caerulescens* Blyth
	Sturnidae	*Acridotheres tristis* Legge
	Corvidae	*Corvus macrorhynchos* Sykes
	Artamidae	*Artamus fuscus* Vieillot
	Ploceidae	*Passer domesticus* Ripley
		Lonchura punctulata (Hodgson)
		Lonchura striata (L.)
	Hirundinidae	*Hirundo daurica* Blyth
		H. rustica L. **
	Pycnonotidae	*Pycnonotus cafer* (L.)
	Motacillidae	*Motacilla cinerea* (Pallas)**
		Anthus rufulus Eyton
Mammalia	Soricidae	*Suncus murinus* (L.)
	Muridae	*Bandicota bengalensis* Gray & Hardwick
		Rattus rattus L.
		Mus cervicolor Blyth
	Sciuridae	*Funambulus palmarum* L.
	Viveridae	*Herpestes fuscus* Waterhouse
		H. edwardsii (Wroughton)
		Paradoxurus hermaphroditus Pallas
	Carnivora	*Felis viverrina* Bennett
	Mustellidae	*Lutra lutra* F.Cuvier
	Canidae	*Canis aureus* Wroughton
	Suidae	*Sus scrofa* Wagner
	Leporidae	*Lepus nigricollis* Wroughton
	Bovidae	*Bubalus bubalis* L.
	Vespertilionidae	Unidentified spp.

* Endemic species.
** Winter migrants.

Appendix 3

Floristic composition of rice field macrophytes and microphytes in the rice field ecosystem in Bathalagoda, Sri Lanka.

Macrophytes (group/family/species)	Microphytes (phylum/group/genus)
Monocotyledons	Cyanophyta (BGA)
Poaceae	*Aphanothece* Naegeli
Axonopus affinis Chase	*Aphanocapsa* Naegeli
A. compressus (Sw.) Beauv.	*Anabaena* Bory
Chloris barbata Cyanodon dactylon (L.)	*Coelosphaerium* Naegeli

Appendix 3. (continued)

Macrophytes (group/family/species)	Microphytes (phylum/group/genus)
Dactyloctaenium aegyptium (L.) Richt.	*Merismopedia* Meyen
Digitaria ciliaris Schumach.	*Microcyctis* Kutzing
D. longiflora (Retz) Pers.	*Nostoc* Vaucher
Echinochloa colonum (L.) Link	*Oscillatoria* Vaucher
E. crus-galli (L.) Beauv	Chlorophyta
E. stagnina (Retz.) Beauv.	Filamentous algae
Eleusine indica (L.) Gaerth.	*Spirogyra* Link
Eragrostis unioloides (Retz.) Nees ex Steud	Flagellated forms
I. globosa (Thunb.) Kuntze	*Volvox* Linneus
I. rugosum Salisb.	*Gonium* Mueller
I. timorense Kunth	*Chlamydomonas* Ehrenberg
Leptochloa chinensis (L.) Nees	Desmids
Leersia hexandra Sw.	*Ankistrodesmus* Corda
Paspalum conjugatum Berg.	*Cosmarium* Corda
P. commersonii Lam.	*Closterium* Nitzsch
Panicum repens L.	*Docidium* deBrebisson
Setaria geniculata (Lam.) Beauv.	*Euastrum* Ehrenberg
Cyperaceae	*Enteromorpha* Link
Cyperus rotundus L.	*Microspora* Thuret
C. iria L.	*Micrasterias* Agardh
C. difformis L.	*Netrium* Naegeli
C. pilosus Vahl	*Pleurotaenium* Naegeli
C. tenuispica Steud	*Penium* deBrebisson
C. haspan L.	*Protosiphon* Klebs
F. miliaceae (L.) Vahl	*Pediastrum* Meyen
F. dichotoma (L.) Vahl	*Scenedesmus* Meyen
F. schoenoides (Retz.) Vahl	*Tetraedron* Kuetzing
Kyllinga brevifolia Rottboell	Euglenophyta
K. nemoralis (J.R. & G.Forst) Dandy ex Hutchins.	*Euglena* Ehrenberg
Pycreus polystachyos (Rotboell) Beauv	*Phacus* Dujardin
P. pumilus (L.)	Bacillariophyta (Diatoms)
Schoenoplectus juncoides (Roxb.) Palla	*Frustulia*
Commelinaceae	*Navicula*
Commelina diffusa Burm.f.	Macrofungi
C. benghalensis L.	Agaricales
Cyanotis axillaris (L.) Sweet	*Agaricus* spp.
Murdania spirata (L.) Bruckner	*Coprinus* spp.
Pontederiaceae	Lycoperdales
Eichhornia crassipes (Mart.) Solms	*Lycoperdon*
M. vaginalis (Burm.f.) Presl	
Eriocaulaceae	
Eriocaulon thwaitsii Koern.	
Dicotyledons	
Asteraceae	
Epaltes divaricata (L.)	
Tridax procumbens L.	
Ageratum conyzoides L.	
Eclipta prostrata (L.) L	
Eleutheranthera ruderalis (Swartz) Sch. Bip	

Appendix 3. (continued)

Macrophytes (group/family/species)
Eupatorium odoratum L.
Emilia sonchifolia (L.) DC
Mikania cordata (Burm) Robinson
Spilanthes iabadicensis A. H. Moore
Sphaeranthus indicus L.
Vernonia cinerea (L.) Less
Scrophulariaceae
Dopatorium junceum (Roxb.) Buch.-Ham.ex Benth.
Lindernia rotundifolia (L.) Alston
L. anagallis (Burm.f.) Pennell
L. pusilla (Willd.) Boldingh
L. antipoda (L.) Alston
L. crustacea (L.) F.Muell
L. hyssopioides (L) Haines
Malvaceae
Abutilon asiaticum L.
Sida rhombifolia L.
Urena lobata L.
Onagraceae
Ludwigia decurrens Walt.
L. perennis L.
L. hyssopifolia (G.Don) Exell
Fabaceae
Desmodium triflorum (L.) DC
Alyssicarpus vaginalis DC.
Cassia tora L.
Euphorbeaceae
Euphorbia hirta L.
E. hypericifolia L.
E. rubicunda L.
E. indica Lam.
Phyllanthus debilis Klein ex Willd.
Convolvulaceae
I. aquatica Forsk.
I. triloba L.
I. pes-tigridis L.
Rubiaceae
Borreria laevis (Lamk.) Griseb.
Hedyotis corymbosa (L.) Lamk.
Spermococe assungera L.
Lamiaceae
Basilicum polystachyon L.
Leucas zeylanica (L.) R.Br.
Amaranthaceae
A. sessilis (L.) DC
Mimosaceae
Mimosa pudica L.

Appendix 3. (continued)

Macrophytes (group/family/species)
Sphenocleaceae
S. zeylanica Gaerth.
Elatinaceae
E. triandra Schkuhr.
Apiaceae
C. asiatica (L.) Urb.
Pterydophytes
Salviniaceae
Salvinia molesta D.S.Mitchell
Marsiliaceae
M. quadrifolia L.

Appendix 4

The major arthropod (arachnids and insects) and vertebrate taxa that colonised/visited the rice field during different stages/phases of a rice cultivation cycle.

Stage/phase	Major arthropod colonizers	Major vertebrate colonizers/visitors
Field preparation (semi-aquatic)	Phytophages (Visitors): Lepidoptera Predators: Arachnids – *P. pseudoannulata*; Insects –*Solenopsis* spp., *Camponotus* spp., *Odontomachus* spp., *P. alternans*, *Euborellia* spp., *Liris* spp., *D. campeniformes*, *Tridactylus* spp. Scavengers: *B. germanica*, Diptera	Amphibians: *L. limnocharis* Reptiles: *M. trijuga* Birds: *A. grayii*, *A. tristis*, *H. smyrnensis* Mammals: *C. aureus*, *S. scrofa*, *Herpestes* spp.
Nursery (aquatic)	Phytophages (rice pests): *Nephotettix* spp., *R. dorsalis*, *Baliothrips biformis* Predators: Arachnids – *Plexippus* spp., *P. pseudoannulata*; Insects – *Solenopsis* spp., *Camponotus* spp., *P. alternans*	Amphibians: *L. limnocharis* Reptiles: *M. trijuga* Birds: *A. grayii* Mammals: *C. aureus*, *S. scrofa*
Flooded fields prior to transplantation (aquatic)	Predators: Arachnids – *Plexippus* spp., *P. pseudoannulata*; Insects – Odonata, *Microvelia* spp., *Mesovelia* spp., *H. greeni* Scavengers: Diptera, Collembola	Fish: *P. bimaculatus*, *L. thermalis* Amphibians: *L. limnocharis*, *E. cyanophlyctis*, *Hoplobtrachus crassus* Reptiles: *X. piscator*, *A. stolata* Birds: *A. grayii*, *E. garzetta*, *Amaurornis phoenicurus*, *M. intermedia*, *H. smyrnensis* Mammals: *C. aureus*, *F. viverrina*, *Herpestes* spp., *L. lutra*

Appendix 4. (continued)

Stage/phase	Major arthropod colonizers	Major vertebrate colonizers/visitors
Active tillering (aquatic)	Phytophages (rice pests): *O. oryzae*, *C. medinalis*, *S. furcifera*, *N. lugens*, *C. spectra*, Acrididae, Chironomidae Predators: Arachnids – *Tetragnatha* spp.; Insects – *Opheonia* spp., *Dyschiriognatha* spp., Gryllidae Parasitoids: Mymaridae, Scelionidae Scavengers: Collembola	Fish: *Rasbora* spp., *Channa* spp. Amphibians: *Microhyla* spp., *Euphlyctis hexadactylus* Reptiles: *L. punctata*, *X. piscator*, *A. stolata* Birds: *A. grayii*, *E. garzetta*, *A. phoenicurus*, *M. intermedia*, *H. smyrnensis* Mammals: *C. aureus*, *F. viverrina*, *Herpestes* spp.
Booting (aquatic)	Phytophages (rice pests): *S. incertulas* Predators: Arachnids – *Atypena* spp., *Argiope* spp., Theridiidae, Oxyopidae; Insects – *C. lividipennis*, *C. longipennis*, Coccinellidae Parasitoids: Trichogrammatidae	Fish: *Rasbora* spp., *Channa* spp. Amphibians: *Microhyla* spp., *E. hexadactylus* Reptiles: *X. piscator*, *A. stolata* Birds: *A. grayii*, *E. garzetta*, *A. phoenicurus*, *M. intermedia*, *H. smyrnensis* Mammals: *L. nigricollis* (field bunds)
Flowering (aquatic)	Phytophages (rice pests): *L. oratorius* Predators: Insects – Reduviidae Phytophages (Visitors): *Nomia* spp.	Fish: *Rasbora* spp., *Channa* spp. Amphibians: *L. limnocharis*, *E. cyanophlyctis* Reptiles: *X. piscator*, *A. stolata*, *C. mucosus* Birds: *A. grayii*, *A. phoenicurus*, *H. smyrnensis* Mammals: *L. nigricollis* (field bunds), *F. viverrinus*
Milk grain (aquatic)	Phytophages (rice pests): *L. oratorius*, Pentatomidae	Fish: *Channa* spp. Amphibians: *L. limnocharis*, *E. cyanophlyctis* Reptiles: *X. piscator*, *A. stolata*, *C. mucosus* Birds: *A. grayii*, *A. phoenicurus*, *H. smyrnensis* Mammals: *B. bengalensis*, *R. rattus*, *S. murinus*

Appendix 4. (continued)

Stage/phase	Major arthropod colonizers	Major vertebrate colonizers/visitors
Grain ripening (semi-aquatic)	Phytophages (rice pests): *L. oratorius*, Pentatomidae Predators: Insects – Carabidae Scavengers: Collembola	Reptiles: *N. naja*, *C. mucosus*, *V. salvator* Birds: *Prinia* spp., *C. juncidis*, *O. sutorius* Mammals: *B. bengalensis*, *R. rattus*
Mature crop (dry)	Phytophages (rice pests): *Coptotermes* spp. Predators: Insects – Formicidae	Amphibians: *B. melanostictus* Reptiles: *N. naja*, *C. mucosus*, *D. russelli* Birds: *Psittacula* spp., *Lonchura* spp., *Prinia* spp. Mammals: *B. bengalensis*, *R. rattus*
Fallow period (dry)	Phytophages (rice pests): *C. spectra*, *Nephotettix* spp., *Coptotermes* spp. Predators: Arachnids – Theridiidae, *Atypena* spp.; Insects – *P. alternans*, *M. discolor*	Amphibians: *B. melanostictus* Reptiles: *M. carinata* Birds: *S. chinensis*, *C. livia* Mammals: *B. bubalis*

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