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Research paper

Aquatic Insect Diversity of Rice Crop Stages in Gopalganj District of Bihar

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ABSTRACT

Rice is a major food crop of India. The rice cultivation has maintained its priority status in the agricultural sector of the country. The intensive management practices adopted by the practitioners have resulted in genetic erosion, thus affecting the species composition of the rice field ecosystems. There is obvious difference in species composition and community structure in upland and lowland rice fields and lowland fields has minimum pests affecting production of yield per hectare. This paper presents a work carried out on the biological diversity of lowland rice field ecosystems of India, and proposes the need for conservation strategies to ensure the sustainability of these rice growing ecosystems in the long run.

1. Introduction

The vegetative and reproductive stages of rice crop are represented by aquatic phase of the rice field while the semi aquatic and terrestrial dry phases correspond to the grain ripening stage. Therefore, a rice-field ecosystem undergoes through three major ecological phases: aquatic, semi-aquatic and terrestrial dry phase during a single crop cycle (Fernando, 1995). Each of these phases supports a particular type of fauna and flora. Resultantly the rice field has the greatest biodiversity as compared to the other tropical rain fed systems (Schoenly, 1998).

The biodiversity of fauna and flora of rice fields has characteristic of rapid colonization as well as rapid reproduction and growth of organisms. These organisms colonize rice fields by resting stages in soil, by air and via irrigation water (Fernando, 1995; 1996). The fauna inhabiting the vegetation, water and soil sub-habitat of rice field are dominated by invertebrates. Those that inhabit the vegetation are generally insects and spiders. In relation to the rice crop, the fauna in rice field include pests, their natural enemies (predators and parasitoids) and neutral forms etc. The organisms inhabiting the rice field ecosystem can be considered as opportunistic biota with high resilience stability as they holds the ability to recover rapidly from various disturbances, including chemical inputs (Bombaradeniya *et al*., 1998). A rice field is frequently disturbed by farming practices i.e., tillage, irrigation, crop establishment and agrochemical application. Traditional rice systems were sufficiently multifaceted ecosystems and did not involve the use of chemical fertilizers, maintained a moderate but stable yield for thousands of years because a rich array of micro-organisms and other invertebrates enabled them to maintain soil fertility by generation of nutrients through recycling for rice cultivation in contrast to modern rice cultivation (Roger & Simpson, 1991; Lawler, 2001; Ignacimuthu, 2005).

2. Aim and Objectives

However, the current state of knowledge about insect biodiversity associated with rice crop is inadequate and a lot of research is waiting to be done in this field. The changes to the insect biodiversity associated with rice crop would be evaluated with greater precision and confidence in coming decades. Moreover, this study aims not only to establish a baseline data on species richness and distributions to which future surveys and conservation activities could be related but also to assess differences from place to place, under different management systems, or from present to future.

3. Materials and Method

The insects were collected with the help of insect net and evaluated for different community during the study period followed as Shannon & Weaver, 1949; Hill, 1973). Shannon-Weaver diversity index (H) was used to determine which sample has more abundant species. A species diversity study takes into account the number of species (species richness) and the importance of individuals in species evenness. Shannon's index accounts for both abundance and evenness of the species present. The proportion of species *i* relative to the total number of species (p_i) was calculated, and then multiplied by the natural logarithm of this proportion (ln p_i). The resulting product was summed across species, and multiplied by -1. H is a more reliable measure as sampling size increases. The addition of the calculation of evenness (J) or equitability (*EH*) was also applied. Shannon's equitability (EH) was calculated by dividing H by H*max* (here H*max* = lnS). J=EH =H/H max = H/ ln S

The evenness index measures how evenly species are distributed in a sample. When all species in a sample are equally abundant an evenness index will be at its maximum, decreasing towards zero as the relative abundance of the species diverges away from evenness (Sebastian et *al*, 2005). It means evenness assumes a value between 0 and 1with 1 being complete evenness i.e., a situation in which all species are equally abundant.

Simpson's diversity index (D) was used to determine which sample has more rare species. It is a simple mathematical measure that characterizes species diversity (rarity) in a community as;

$$S=(1-D) = 1 - \sum [n_i (n_i-1)/ N (N-1)]$$

where pi is the proportional abundance of the i^{th} species and is given by $p_i= n_i/N$, i= 1,2 ,3,…….S and n_i is the number of individuals of i^{th} species and N is the known total number of individuals for all S species in the population. Simpson's index varies from 0 to 1 and gives the probability that two individuals drawn at random from an infinitely large population belong to the different species. For a given species richness (S), evenness (J) increases as D decreases, and for a given evenness, D decreases as richness increases.

In order to represent number of abundant species in samples and also to represent species maximum in abundance Hill's diversity numbers were used. In equation form, Hill's diversity numbers are;

$$H_\alpha = (\sum p_i^{\alpha})^{1/(1-\alpha)}$$

where pi is the proportion of individuals belonging to ith species. Hill shows that the 0th, 1st and 2nd order of these diversity numbers (i.e., A=0, 1 and 2) coincide with three of the most important measures of diversity. Hills diversity numbers are Number 0: N_0=S, where S is the total number of species, so, N_0 is the number of all species in the sample regardless of their abundance, Number 1: N_1=eH, *where* H is the Shannon's index and N_1 is the measure of number of abundant species in the sample. N_1 will always be intermediate between N_0 and N_2, and Number 2: N_2=1/λ, where λ is Simpson's index and N_2 is the number of species maximum in abundance in a sample.

The species richness was also calculated to determine whether the sampling sites had been sufficiently sampled or not.

4. Results

Temporal variation in insect faunal diversity in the Site 1: The values for S, N, H, D, J were 125, 1026, 3.061, 0.135, 0.554 at pre-nursery; 172, 1840, 3.814, 0.055, 0.652 at nursery; 195, 2950, 4.088, 0.043, 0.685 at tillering-booting; 193, 1480, 4.269, 0.033, 0.716 at flowering-milking; 184, 1045, 4.234, 0.039, 0.716 at grain ripening stage of rice crop (Table 1).

In the Site 1, insect species richness and abundance increased with crop age and reached maximum at tillering-booting stage in the months of July-August and then declined gradually towards crop maturity. The value of (H) increased from pre-nursery stage and reached at its maximum at flowering-milking stage in the month of September and then decreased slightly at grain ripening stage. It means highest number of abundant species N1 (i.e. 88 species in which 30 species were maximum in abundance) was in the month of September (Table 5). The number of rare species (D) was maximum at pre-nursery stage and indicated that most of the species in the month of May (pre-nursery stage) were present in very low number because they had just started to invade the fields where puddling operations had been started. This result was also supported by the fact that at pre-nursery stage abundant species (N1) were least (21) as compared to other crop stages.

For LIP system the values for S, N, H, D, J were 104, 5560, 3.103, 0.110, 0.580 at pre-nursery; 152, 9994, 3.870, 0.0519, 0.676 at nursery; 175, 18090, 3.896, 0.049, 0.665 at tillering-booting; 170, 9800, 4.104, 0.034, 0.704 flowering-milking; 162, 5800, 4.193, 0.036, 0.725 at grain ripening stage, respectively. But in case of HIP the values for S, N, H, D, J were 79, 4414, 2.706, 0.195, 0.535 at pre-nursery; 148, 8850, 3.509, 0.066, 0.645 at nursery; 140, 11572, 4.120, 0.038, 0.730 at tillering-booting; 140, 4806, 4.139, 0.043, 0.734 at flowering-milking; 130, 4700, 3.955, 0.050, 0.711 at grain ripening stage, respectively (Table 2).

4.1 Temporal variation in insect faunal diversity in the Site 2

The values of S, N, H, D, J were 120, 748, 3.554, 0.068, 0.648 at pre-nursery, 173, 1635, 3.634, 0.063, 0.621 at nursery; 204, 3596, 3.986, 0.037, 0.663 at tillering-booting; 208, 1360, 4.338, 0.029, 0.719 at flowering-milking and 188, 1380, 4.030, 0.051, 0.679 at grain ripening stage of rice crop, respectively (Table 3).

The values for S, N, H, D, J in case of LIP system were 99, 536, 3.363, 0.082, 0.635 at pre-nursery; 146, 930, 3.497, 0.082, 0.615 at nursery; 182, 1722, 3.963, 0.040, 0.672 at tillering-booting; 185, 866, 4.233, 0.032, 0.716 at flowering-milking; 159, 811, 3.871, 0.055, 0.671 at grain ripening stage, respectively. However, in case of HIP the values for S, N, H, D, J were 76, 205, 3.491, 0.080, 0.694 at pre-nursery; 124, 706, 3.498, 0.070, 0.634 at nursery; 150, 1675, 3.804, 0.046, 0.667 at tillering-booting; 149, 494, 4.237, 0.032, 0.743 at flowering-milking; 135, 569, 4.005, 0.051, 0.714 at grain ripening stage, respectively (Table 4).

4.2 Temporal variation in insect faunal diversity in the Site 3

The values for S, N, H, D, J was 118, 927, 3.063, 0.114, 0.560 at pre-nursery stage, 172, 1674, 3.491, 0.093, 0.597 at nursery, 201, 4546, 4.01, 0.042, 0.669 at tillering-booting, 210, 1530, 4.195, 0.037, 0.694 at flowering-milking and 204, 1050, 4.425, 0.028, 0.736 at grain ripening stage, respectively (Table 5).

In the Site 3 the values for S, N, H, D, J in case of LIP system were 89, 629, 2.754, 0.145, 0.532 at pre-nursery; 151, 1024, 3.208, 0.122, 0.561 at nursery; 185, 2522, 4.092, 0.033, 0.692 at tillering-booting; 196, 941, 4.028, 0.048, 0.675 at flowering-milking; 183, 692, 4.163, 0.038, 0.705 at grain ripening stage, respectively. In case of HIP the values for S, N, H, D, J were 87, 299, 3.376, 0.076, 0.653 at pre-nursery; 125, 650, 3.694, 0.063, 0.669 at nursery; 154, 2023, 3.713, 0.073, 0.648 at tillering-booting; 152, 590, 4.130, 0.036, 0.722 at flowering-milking; 147, 358, 4.575, 0.020, 0.805 at grain ripening stage, respectively (Table 6).

Table 1 Temporal variation in insects associated with rice crop at Site 1

Crop Stage	S	N	H	D	J	N1	N2
Pre-Nursery	125	1026	3.061	0.135	0.554	11	4
Nursery	172	1840	3.814	0.055	0.652	25	9
Tillering-Booting	195	2950	4.088	0.043	0.685	30	12
Flowering-Milking	193	1480	4.269	0.033	0.716	35	15
Grain Ripening	184	1045	4.234	0.039	0.716	34	13

Table 2 Temporal variation in insect with LIP & HIP rice crop at Site 1

Sites	Inputs	S	N	H	D	J	N1	N2	P-Value
Pre-Nursery	High	79	4414	2.706	0.195	0.535	14	5	0
	Low	104	5560	3.103	0.110	0.580	22	9	
Nursery	High	148	8850	3.509	0.668	0.645	33	15	.34
	Low	152	9994	3.870	0.519	0.676	47	19	
Tillering-Booting	High	140	11452	4.120	0.038	0.730	61	25	0
	Low	175	18090	3.896	0.049	0.665	49	20	
Flowering Milking	High	140	4806	4.139	0.043	0.734	62	23	0.05
	Low	170	9800	4.104	0.034	0.704	60	29	
Grain Ripening	High	130	4700	3.955	0.050	0.711	52	20	0
	Low	162	5800	4.193	0.035	0.725	66	26	

Table 3 Temporal variation in insects associated with rice crop at Site 2

Crop Stage	S	N	H	D	J	N1	N2
Pre-Nursery	120	741	3.554	0.068	0.648	34	14
Nursery	173	1635	3.634	0.063	0.621	37	15
Tillering-Booting	204	3596	3.986	0.037	0.663	53	26
Flowering-Milking	208	1360	4.338	0.029	0.719	76	34
Grain Ripening	188	1380	4.030	0.051	0.678	56	19

Table 4 Insects associated with LIP & HIP rice crop agro-ecosystems in the Site 2

Sites	Inputs	S	N	H	D	J	N1	N2	P-Value
Pre-Nursery	High	76	205	3.491	0.080	0.694	32	14	0
	Low	99	536	3.363	0.082	0.635	28	12	
Nursery	High	124	706	3.498	0.070	0.634	33	14	0.47
	Low	146	930	3.497	0.072	0.615	33	13	
Tillering-Booting	High	150	1675	3.804	0.046	0.667	44	21	0
	Low	182	1722	3.963	0.040	0.672	52	24	
Flowering Milking	High	149	494	4.237	0.032	0.743	69	30	0.42
	Low	185	866	4.233	0.032	0.716	68	30	
Grain Ripening	High	135	569	4.005	0.051	0.714	54	19	0
	Low	159	811	3.871	0.050	0.671	47	18	

Table 5 Insects associated with rice crop agro-ecosystem in the Site 3

Crop Stage	S	N	H	D	J	N1	N2
Pre-Nursery	118	927	3.063	0.114	0.560	21	8
Nursery	172	1674	3.491	0.093	0.597	32	10
Tillering-Booting	201	4546	4.014	0.042	0.669	55	23
Flowering-Milking	210	1530	4.195	0.037	0.694	66	26
Grain Ripening	204	1050	4.425	0.028	0.736	83	34

Table 6 Temporal insects of LIP & HIP rice crop at Site 3

Sites	Inputs	S	N	H	D	J	N1	N2	P-Value
Pre-Nursery	High	87	299	3.376	0.076	0.653	29	13	0
	Low	89	629	2.754	0.145	0.532	15	6	
Nursery	High	125	650	3.694	0.063	0.669	40	15	.34
	Low	151	1024	3.208	0.122	0.561	24	8	
Tillering-Booting	High	154	2023	3.713	0.073	0.648	41	13	0
	Low	185	2522	4.092	0.033	0.692	41	13	
Flowering Milking	High	152	590	4.130	0.036	0.722	62	27	0.05
	Low	196	941	4.028	0.048	0.675	56	20	
Grain Ripening	High	147	358	4.575	0.020	0.805	97	48	0
	Low	183	692	4.163	0.038	0.705	64	26	

Table 7 Insects associated with rice crop agro-ecosystem in the Site 1

Crop Stage	S	N	H	D	J	N1	N2
Pre-Nursery	180	2698	3.345	0.099	0.568	28	10
Nursery	25	5150	3.788	0.061	0.620	44	16
Tillering-Booting	241	11100	4.162	0.034	0.672	64	29
Flowering-Milking	244	4352	4.464	0.025	0.720	86	38
Grain Ripening	242	3490	4.394	0.033	0.710	80	29

Table 8 Temporal variation in insect with LIP & HIP rice crop agro-ecosystems

Sites	Inputs	S	N	H	D	J	N1	N2	P-Value
Pre-Nursery	High	133	945	3.368	0.094	0.603	29	10	0
	Low	155	1750	3.242	0.104	0.565	25	9	
Nursery	High	175	2240	3.760	0.058	0.641	42	17	.0
	Low	210	2914	3.696	0.062	0.612	40	14	
Tillering-Booting	High	202	4546	4.032	0.040	0.672	56	24	0
	Low	230	6254	4.161	0.035	0.679	64	28	
Flowering Milking	High	202	1564	4.439	0.030	0.739	84	38	0.05
	Low	236	2782	4.382	0.028	0.710	80	35	
Grain Ripening	High	195	1398	4.401	0.032	0.738	81	30	0
	Low	229	2080	4.295	0.031	0.701	73	27	

4.3 Temporal variation in insect diversity

In the Sites, the overall values for S, N, H, D, J were 180, 2698, 3.345, 0.099, 0.568 at pre-nursery; 225, 5150, 3.788, 0.061, 0.620 at nursery; 241, 11100, 4.162, 0.034, 0.673 at tillering-booting; 244, 4352, 4.464, 0.025, 0.721 at flowering-milking; 242, 3490, 4.394, 0.033, 0.710 at grain ripening stage, respectively (Table 7).

In the Site 1 the overall values for S, N, H, D, J in case of LIP system were 155, 1750, 3.242, 0.104, 0.565 at pre-nursery; 210, 2914, 3.696, 0.069, 0.612

at nursery; 230, 6254, 4.161, 0.035, 0.679 at tillering-booting; 236, 2782, 4.382, 0.028, 0.711 at flowering-milking; 229, 2080, 4.295, 0.036, 0.701 at grain ripening stage, respectively. In case of HIP the values for S, N, H, D, J were 133, 945, 3.368, 0.094, 0.603, at pre-nursery; 175, 2240, 3.760, 0.058, 0.641 at nursery; 202, 1560, 4.032, 0.040, 0.672 at tillering-booting; 202, 1564, 4.439, 0.025, 0.739 at flowering-milking; 195, 1398, 4.401, 0.032, 0.738 at grain ripening stage, respectively (Table 8).

5. Discussion

The change in diversity with respect to passage of time or along a time scale is called temporal diversity (Sebastian *et al*., 2005; Bombaradeniya & Amarsinghe, 2003). Rice crop during a single cropping season passes through different crop/ecological stages (generally corresponding to a particular month of the growing season) supporting a special type of insect fauna associated with that particular type of crop stage or habitat (Fernando, 1995; Bombaradeniya *et al*., 1998; Bombaradeniya & Amarsinghe, 2003).

The rarity decreased as the crop age increased with minimum at flowering-milking stage. This might be due to the drastic effects by application of agrochemicals (in the end of August or in the start of September) on some sensitive species causing their mortality. As a consequence only abundant species left behind and thus resulted into lower value of rare species. There was, then, a slight increase in the rarity at grain ripening stage in the month of October. The fact was that as the rice crop reached at its maturity, many species including a number of tourist species, visited rice fields to utilize this special type of man-made aquatic habitat for many purposes and contributed to increase in rarity.

Besides this at grain ripening stage, the species left for rice crop because of drastic changes in plant and soil which made rice crop less favorable for many species ultimately there was an increase in the rarity of species as compared to flowering-milking stage. The values of (J) also depicted that evenness increased gradually from pre-nursery to grain ripening stages of rice crop gradually with its maximum value (72%) at flowering milking and grain ripening stages. At tillering-booting stage rarity was high for LIP as compared to that for HIP. This could be due to HIP practices, especially due to the use of insecticides in the end of August, which did not allow all species to behave in the same manner and affected deleteriously to most of sensitive species resulting into disappearance of these low populated species and consequently number of abundant species at tillering-booting stage in HIP system increased. Due to harms (unfavorable conditions) of intensive farming system sensitive species avoided from HIP system and their population did not increase in abundance and remained below a certain level and contributed to more number of rare species.

In the Site 2 the values of S, N, H, D, N1 and N2, changed almost in the same manner as for the Site 1. The insect fauna of rice crop behaved almost in the same manner for both of the sites. However, the values of (J) responded in a different way in comparison with Site 1. These fluctuated throughout the crop stages. However, the species at all crop stages were distributed with almost equal evenness with highest (71%) at flowering-milking stage.

The differences in values of (H) between LIP and HIP systems were significant (P<0.05) at pre-nursery & grain ripening stage for HIP and at tillering-booting stage for LIP. However, these differences were non-significant (P>0.05) at nursery and flowering milking stages. The value of (D) was high at almost all crop-stages (except at tillering-booting) for LIP system with highest at pre-nursery and lowest at flowering-milking stage. This indicated that LIP had more number of rare species. The species in LIP system, as a result, were distributed with comparatively low evenness with lowest value of 61% at nursery stage. Similarly, the number of abundant species and species maximum in abundance were also high at almost all crop stages (except at tillering-booting stage) for HIP system with highest value of 69 species among which 30 were maximum in abundance at flowering-milking stage.

The value of (D) was highest at pre-nursery stage which decreased gradually with crop age. This indicated that rarity decreased with crop age with lowest at grain ripening stage indicating that at this stage most of the species were present in fairly good number. The value of (J) also increased continuously from pre-nursery to grain ripening stage reflecting that even distribution of species increased as the crop progressed and at grain ripening stage evenness reached at its maximum with 73% even distribution of species. From these results it is evident that Site 3 was different from the other two sites because in Site 3 diversity followed a uniform and smooth pattern.

The species richness and H increased as the rice grew towards maturity with the maximum at flowering-milking stage and then there was a slight decline at grain ripening stage due to availability and scarcity of aquatic insects in studied rice fields (Figure 1).

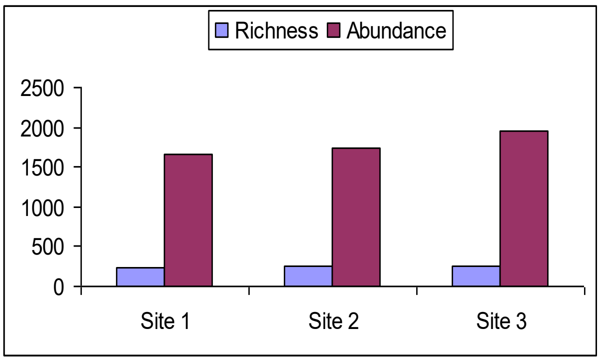

Fig. 1 Comparison of community structure in the Rice Crop ecosystems

These changes in values of (D) indicated that number of rare species decreased as crop matured because with the passage of time all the invading species started to increase their population in rice crop habitat and hence the (J) increased with crop age. The results are in accordance with studies of Heong et al. (1991), Suhling et al. (2000) and Wilby et al. (2006).

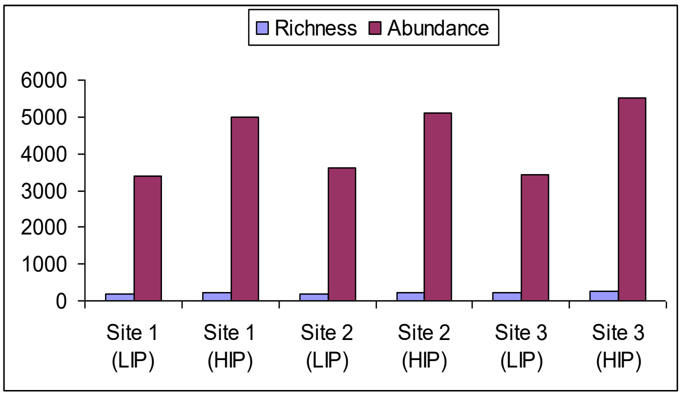

Fig. 2 Insect species (a) richness and (b) abundance in LIP & HIP rice fields

It is evident from observations that the values of S, H, J, N1 and N2 increased at site 2 with crop age and reached at their maximum at flowering-milking stage of the rice crop in September for both HIP and LIP systems and then declined at grain ripening stage in October. The species abundance also increased with crop age and was maximum at tillering-booting stage in July-August for both of the systems and then declined towards crop maturity (Figure 2).

The number of rare species (D) decreased with crop age and was minimum at flowering-milking stage, it then increased slightly at grain ripening stage. These results suggested that maximum number of insect species utilized rice crop agro-ecosystem as a habitat at flowering-milking stage. The values of (H) indicating abundant species in sampled population for both of the systems were also maximum at flowering-milking stage. It is clear that at flowering-milking stage due to high number of abundant species the number of rare species was less. Almost at all crop stages (except at tillering-booting stage) the species were distributed with high evenness for HIP. Similarly, N1 and N2 were also higher at flowering-milking stage. The differences among the values of (H) at all crop stages were significant ($P<0.05$) in favor of HIP system except for tillering-booting stage.

6. Conclusion

The earlier stages of the rice crop colonizes generalist predators and scavengers helped them to establish and spread in the fields before rice pest insects did the same, thereby acting as connecting species. The current study also offered a rare case of ecosystem distress syndrome, in which the overuse of agrochemicals altered insect habitats to the point where biodiversity was drastically reduced. Consequently, the idea that agricultural intensification such as HIP farming techniques has reduced insect biodiversity in rice crop was confirmed. In LIP systems, the ratio of scavengers to prey and parasitoids to hosts was 1.5 times greater than in HIP systems. Although the aquatic Odonata, Hemiptera, and Coleoptera were all predatory insects, it became clear that rice crops host a diverse array of natural enemies that may be used for biological control of pest insects in rice. Consequently, natural biological control should be given more weight in pest management techniques for rice crops.

References

1. Fernando, C.H. (1995). Rice fields are aquatic, semi-aquatic, terrestrial and agricultural: A complex and questionable limnology. Tropical limnology, 1: 121-148.
2. Schoenly, K.G., Justo, H.D., Barrion, A.T., MK Harris, M.K. & Bottrell, D.G. (1998). Analysis of invertebrate biodiversity in Philippine farmer's irrigated rice field. Environ. Ento., 27(5): 1125-1136.
3. Fernando, C.H. (1996). Ecology of rice fields and its bearing on fisheries and fish culture. In: Perspectives in Asian fisheries (Ed: SS de Silva). Manila, Philippines: Asian Fisheries Society, Manila, Philippines.Pp 217-237.
4. Bambaradeniya, C.N.B., Fonseka, K.T. & Ambagahawatte, C.L. (1998). A preliminary study of fauna and flora of rice field in Kandy, Sri Lanka. Ceylon J. Sci., (Biol. Sci). pp. 1-22.
5. Roger, P.A. & Simpson, I. (1991). Effects of pesticides on soil and water fauna and micro-flora of wetland rice fields (In: Effects of rice cultivation on the environment). Rice Research Seminar. Los Banos, Philippines: International Rice Research Institute (IRRI).
6. Lawler, S.P. (2001). Rice fields as temporary wetlands: a review. Israel J. Zool. 47(4): 513-528.
7. Ignacimuthu, S. (2005). Biodiversity and insect pest management. Current Sci., 88(10): 1543-1544.
8. Shannon, C.E. & Weaver, W. (1949). The mathematical theory and communication, University of Illinois press, Urbana.
9. Hill, M.O. (1973). Diversity and evenness: a unifying notation and its consequences. Ecol., 54: 427-431.
10. Sebastian, P.A., Mathew, M.J., Beevi, S.P., Joseph, J. & Biju, C.R. (2005). The spider fauna of the irrigated rice ecosystem in central Kerala, India across different elevational ranges. J. Arachnol, 33: 247-255.
11. Bambaradeniya, C.N.B. & Amerasinghe, F.P. (2003). Biodiversity associated with the rice field agro-ecosystem in Asian countries: a brief review, working paper 63. Colombo, Sri Lanka: Int Water Manag Inst, pp. 6.
12. Heong, K.L., Aquino, G.B. & Barrion, A.T. (1991). Arthropod community structures of rice ecosystems in the Philippines. *Bulletin of Entomological Research* 81, 407-416.
13. Suhling, F., Befeld, S., Hausler, M., Katzur, K., Lepkojusi, S. & Mesleard, F. (2000). Effects of insecticide

applications on macroinvertebrate density and biomass in rice-fields in the Rhone-delta, France. Hydrobiol., 431: 69-79.

14. Wilby A., Lan, L.P., Heong, K.L., Huyen, N.P.D., Quang, N.H., Minh, N.V. & Thomas, M.B. (2006). Arthropod diversity and community structure in relation to land use in the Mekong Delta, Vietnam. Ecosys., 9: 538-549.