2013

Impact of lambdacyhalothrin on arthropod natural enemy populations in irrigated rice fields in southern Brazil

Leila Lucia Fritz
Universidade do Vale do Rio dos Sinos

Elvis Arden Heinrichs
University of Nebraska – Lincoln

Vilmar Machado
Universidade do Vale do Rio dos Sinos

Tiago Finger Andreis
Universidade do Vale do Rio dos Sinos

Marciele Pandolfo
Universidade do Vale do Rio dos Sinos

See next page for additional authors

Authors
Leila Lucia Fritz, Elvis Arden Heinrichs, Vilmar Machado, Tiago Finger Andreis, Marciele Pandolfo, Silvia Martins de Salles, Jaime Vargas de Oliveira, and Lidia Mariana Fiuza

International Journal of Tropical Insect Science Vol. 33, No. 3, pp. 178–187, 2013
doi:10.1017/S1742758413000192

Impact of lambdacyhalothrin on arthropod natural enemy populations in irrigated rice fields in southern Brazil

Leila Lucia Fritz[1]*, Elvis Arden Heinrichs[2], Vilmar Machado[1], Tiago Finger Andreis[1], Marciele Pandolfo[1], Silvia Martins de Salles[1], Jaime Vargas de Oliveira[3] and Lidia Mariana Fiuza[1,3]

[1]Programa de Pós-Graduação em Biologia, Laboratório de Microbiologia e Toxicologia, Universidade do Vale do Rio dos Sinos (UNISINOS), São Leopoldo, RS 93001-970, Brazil; [2]Department of Entomology, University of Nebraska – Lincoln (UNL), Entomology Hall, Lincoln, NE 68583-0816, USA; [3]Estação Experimental do Arroz, Instituto Rio Grandense do Arroz (IRGA), Cachoeirinha, RS 94930-030, Brazil

(Accepted 21 May 2013)

Abstract. The present study aimed to determine the selectivity of the pyrethroid lambdacyhalothrin on arthropod natural enemy populations in irrigated rice fields in Rio Grande do Sul, Brazil. The study was conducted at three sites: districts of Cachoeira do Sul, Eldorado do Sul and Capivari do Sul during the crop years of 2007/2008 and 2008/2009. Each site consisted of two subareas divided into four plots. One of the subareas received a spray application of 150 ml/ha of lambdacyhalothrin CS 50, while the other subarea was untreated. Arthropods were collected at 2, 15, 30 and 45 days after the application of the insecticide to assess its impact on natural enemy populations. The results indicated consistent differences in natural enemy populations between the treated and untreated areas, especially within the first 2 weeks after the application of the insecticide. Principal components analysis together with χ^2 analysis revealed differences in the populations of Tetragnathidae, Anyphaenidae, Araneidae, Coccinellidae, Phytoseiidae and Coenagrionidae between the treated and untreated areas. This study indicated the existence of a great diversity of arthropod natural enemies in irrigated rice fields in a subtropical environment similar to that reported previously from rice fields in tropical environments. In addition, lambdacyhalothrin was shown to be a rapid acting insecticide, with a significant initial decrease in natural enemy populations followed by a rapid recovery beginning at 2 weeks after the application of the insecticide. Especially disconcerting is the severe impact of the insecticide on Phytoseiidae and Araneidae, which are considered key natural enemies for the management of rice pests in southern Brazil.

Key words: insecticide, beneficial arthropods, rice field, subtropical areas, biodiversity

Introduction

Modern agriculture faces several important challenges. One of the challenges is to develop pest management strategies that increase agricultural production but do not have a negative impact on the biodiversity of agro-ecosystems. This challenge has resulted in numerous studies being conducted to develop strategies that conserve and even augment arthropod diversity when integrated

*E-mail: leilafritz@gmail.com

into intensive agricultural practices (Whittingham, 2007, 2011; Leng *et al.*, 2010; Smith *et al.*, 2010; Krauss *et al.*, 2011).

The use of insecticides in the control of insect pests is a major factor contributing to the loss of biodiversity in agro-ecosystems (Heinrichs, 2005; Teodorescu and Cogãlniceanu, 2005; Heong *et al.*, 2007; Desneux *et al.*, 2007; Boutin *et al.*, 2009; Geiger *et al.*, 2009; Das *et al.*, 2010; Falcone and DeWald, 2010). The loss of biodiversity includes the decimation of arthropod natural enemies in the orders Coleoptera, Araneae and Acarina (Fountain *et al.*, 2007; Amalin *et al.*, 2009; Das *et al.*, 2010). The negative impact of insecticides on natural enemies in tropical rice fields has been documented in studies conducted in Asia (Heinrichs, 1994; Heong and Schoenly, 1998; Heong *et al.*, 2007; Gangurde, 2007).

Brazil is among the world's major rice producers, occupying the eighth position on a global scale (USDA, 2011) with more than 50% of the Brazilian rice being produced in the states of Rio Grande do Sul and Santa Catarina in subtropical, southern Brazil. Rice production at 7 tons/ha in southern Brazil is among the highest in the world (CONAB, 2011). In spite of these high yields, insect pests have become important factors that prevent even higher yields as they attack rice from germination to harvest (Ferreira and Martins, 1984; Link *et al.*, 1987; Martins *et al.*, 1989; Oliveira and Kempf, 1989). Because of higher yields, the potential economic losses due to pests are also higher (some countries have rice yields of less than 2 tons/ha). Thus, even low pest populations in Brazil can have a significant impact on economic yield losses.

Key insect pests in irrigated rice fields of Rio Grande do Sul include the rice water weevil *Oryzophagus oryzae* (Costa Lima) (Coleoptera: Curculionidae), the stink bugs *Tibraca limbativentris* (Stål) and *Oebalus poecilus* (Dallas) (both Hemiptera: Pentatomidae) and the noctuids *Spodoptera frugiperda* (J.E. Smith), *Pseudaletia adultera* (Schaus) and *Pseudaletia sequax* (Franclemont) (all Lepidoptera: Noctuidae). The application of synthetic insecticides is the major method used to control these pests in Brazil (Oliveira and Freitas, 2009), and one of the most commonly used insecticides is the pyrethroid lambdacyhalothrin. The insecticide attacks their nerve membranes, which are connected to sodium channels, thereby instantly stopping the transmission of nerve impulses, promoting the loss of muscle control and causing death of the insect (Davey *et al.*, 1992).

The aim of this study was to evaluate the impact of lambdacyhalothrin on communities of arthropod natural enemies in irrigated rice fields in the subtropical zone of southern Brazil. In addition, the diversity of these arthropods present in the irrigated rice agro-ecosystem was evaluated.

Materials and methods

Study area

The study was conducted during the crop years 2007/2008 and 2008/2009 in irrigated rice fields located in the districts of Cachoeira do Sul (30th 13′ 31.12″S; 52nd 56′ 44.23″ W), Eldorado do Sul (30th 00′ 53.14″S; 51st 24′ 28.19″W) and Capivari do Sul (30th 09′ 41.14″S; 50th 30′ 53.9″W), all located in the state of Rio Grande do Sul, Brazil. In each location, the experiment was conducted in two subareas of 1200 m^2, each subarea consisting of four plots each with an area of 300 m^2. One of the subareas received 150 ml/ha of lambdacyhalothrin CS 50, while the other subarea was untreated. Lambdacyhalothrin was chosen because it is widely used by rice farmers in Rio Grande do Sul. To avoid the contact between the subareas, the treated and untreated subareas were separated by a mud levee and preventive measures to minimize the effects of the contamination of untreated subareas were observed, including wind direction and product application in days without rain. During the vegetative stage of rice growth, the insecticide was applied via a sprayer propelled by CO_2 with a pressure set at 35 lb/in^2 and equipped with four-cone-type nozzles spaced equidistant at 0.5 m.

Collection and identification of natural enemies

Arthropods were collected with the aid of a sweep net (40 × 36 cm) by making 50 swinging movements per plot across the canopy of the rice plants. The use of this type of net is recommended for capturing insects that inhabit the leafy portion of the plant as in rice fields. Sweep net samples were collected at 2, 16, 31 and 45 days after the application of the insecticide. The sweep net sampling ensures the collection of a significant number of the insects from which it is possible to determine the relative abundance and diversity of the arthropods (Arida and Heong, 1992; Azevedo Filho and Junior, 2000). Sweep net samples were obtained in January and February 2007/2008 and 2008/2009 by two separate sampling expeditions carried out for each month. Subsequently, the samples were individualized by placing in plastic bottles containing 70% alcohol and taken to the UNISINOS laboratory (São Leopoldo, Brazil). In the laboratory, the arthropods were counted and taxonomically identified to the family level using a standard stereoscopic microscope and dichotomous keys (Borror *et al.*, 1989; Heinrichs, 1994; Heinrichs and Barrion, 2004). Some specimens were submitted to taxonomic specialists with expertise in identifying specific groups.

Data analyses

The impact of the insecticide on the communities of arthropod natural enemies was analysed by comparing the abundance of the orders and families in the treated *versus* untreated plots at each site. We first employed the factorial analysis of variance to compare the total abundance of arthropods and the abundance of the more frequent orders in each site. Shannon's index of diversity was used to compare these treatments.

Next, the dates were organized into two matrices: one with the data collected in the first 2 weeks of the experiment and the other with the data collected in the last 2 weeks of the experiment. This procedure was adopted because preliminary results suggested that the insecticidal impact on insects was most accentuated in the first 50 days after the application of the insecticide. This process was followed to verify whether the distance between the treated and untreated areas decreased with time. This showed that the impact of the insecticide was most severe at 15 days after the application of the insecticide. In these analyses, we included only the families present in all areas and all sites.

Principal components analysis (PCA) was used to analyse the distribution pattern of these families between areas, sites and years (Jongman *et al.*, 1995; Legendre and Legendre, 1998). The values were transformed by the expression $\log_{10}(x+1)$ to compensate for the deviations caused by low abundance and higher densities of insects (TerBraak, 1995). PC-ORD 4.0 (McCune and Mefford, 1999) was utilized for these analyses. For the PCA, the correlation matrix was used since the variables were estimated by different units of measurement. Only eigenvalues >1 were used as criteria for the extraction of principal components. To facilitate the interpretation of results, data were analysed using the varimax rotation matrix method. Only 17 families were utilized for these analyses, and the taxa with low frequencies and those not present in all the sample sites were excluded from analyses.

Results

Data on the abundance of the main arthropod orders collected during this study are presented in Table 1 by site, year and area. A total of 7498 specimens of arthropod natural enemies were collected, with 2090 insects in the treated areas and 5408 insects in the untreated areas. The frequency data showed that Acarina, Odonata, Hymenoptera and Araneae were the dominant orders in both years and in both insecticide-treated and untreated areas (Fig. 1).

Statistical analyses of the total abundance of natural enemies during the four sample dates showed significant differences between the treated and untreated areas in Cachoeira do Sul 2007/2008 ($F = 6741$, df $= 1, 24$, $P = 0.016$) and 2008/2009 ($F = 6423$, df $= 3, 24$, $P = 0.002$); Eldorado do Sul 2007/2008 ($F = 5429$, df $= 3, 24$, $P = 0.005$) and 2008/2009 ($F = 8165$, df $= 3, 24$, $P = 0.001$) and Capivari do Sul 2008/2009 ($F = 4662$, df $= 1, 24$, $P = 0.041$). Only in Capivari do Sul 2007/2008, the difference between the treated and untreated areas was not significant (Fig. 2). The statistical analyses of the abundance of the main orders of natural enemies also showed similar patterns (F values not shown).

There was also a significant ($P < 0.005$) interaction between arthropod abundance and sample days in Eldorado do Sul and Capivari do Sul. Before proceeding to grouping, the two samples were compared using a χ^2 test and the differences were not significant. As a result of this interaction, we

Table 1. Number of specimens of arthropod natural enemy taxa captured by site (CAP, Capivari do Sul; CAC, Cachoeira do Sul; ELD, Eldorado do Sul), year (2007/2008; 2008/2009) and area (T, treated; U, untreated)

	2007/2008						2008/2009					
	CAP		CAC		ELD		CAP		CAC		ELD	
Taxa	T	U	T	U	T	U	T	U	T	U	T	U
Coleoptera	2	7	12	6	6	14	12	23	6	4	6	65
Acarina	90	59	35	272	26	398	6	2	301	1831	100	118
Neuroptera	12	4	12	20	3	3	2	2	8	3	10	21
Odonata	39	84	63	97	66	161	98	123	34	66	19	30
Hymenoptera	88	84	72	92	105	218	53	58	20	16	132	186
Dermaptera	0	0	2	4	1	11	0	0	1	1	0	1
Heteroptera	0	0	3	3	3	4	0	0	0	1	2	1
Araneae	59	78	61	177	264	504	75	133	99	349	82	74
Shannon_H	1.485	1.503	1.682	1.471	1.226	1.405	1.337	1.278	1.076	0.6259	1.423	1.588
Evenness_e^H/S	0.7357	0.749	0.672	0.5443	0.4259	0.5094	0.634	0.5985	0.419	0.2337	0.593	0.612

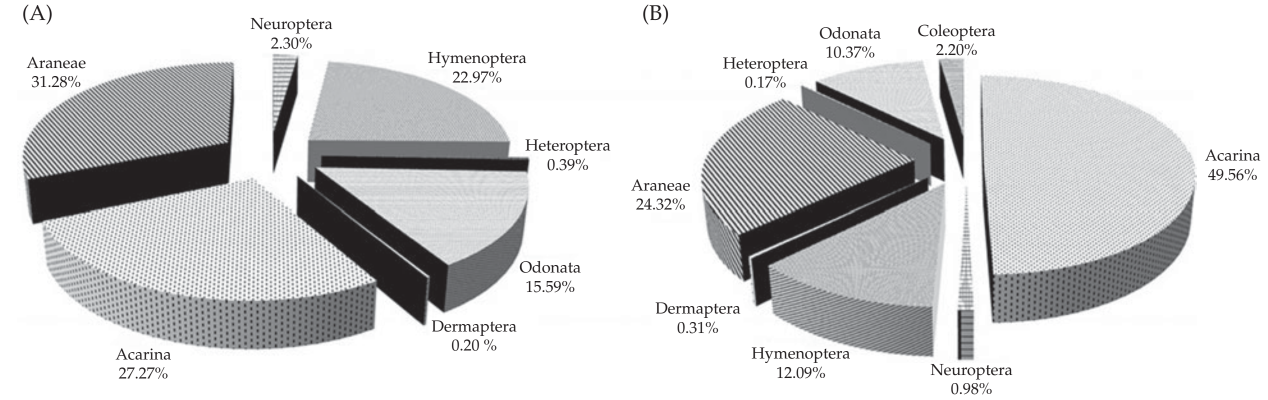

Fig. 1. Relative abundance (%) of the major arthropod natural enemies in (A) the insecticide-treated and (B) untreated irrigated rice plots.

divided our dataset into two subsets: subset 1 comprising the 2nd and 16th day collection data and subset 2 containing the 31st and 45th day collection data.

To get a more detailed view of these differences, we employed the PCA. The matrix for the PCA was constructed using the samples obtained from the three sites at the different sampling points (treated and untreated). In total, 12 samples and 17 variables (families) were analysed in two subset matrices (Tables 2 and 3). The PCA indicates the existence of five principal components only weakly correlated among themselves, but with a strong correlation within each subset of data.

For each subset, there were five components that explained 85% of the variance observed (Table 4). In Table 5, the variables with a correlation greater than 0.7 with their respective principal components are italicized. The separation of the areas analysed based on principal components for the first dataset is shown in Fig. 3. A good separation between the treated and untreated areas in each site, with the exception of Capivari do Sul in the first year, is shown in Fig. 3A. The separation of the areas analysed based on principal components for the second dataset is shown in Fig. 3B. It shows that the treated and untreated areas of the same sites are generally closer. The only exception occurred in Cachoeira do Sul (CAC_2_T and CAC_2_U) in the second year.

In the aforementioned analysis, it should be noted that there are three sources of variation: insecticide, year and sites. Thus, the distribution of the sample sites in the biplot graphic is influenced by treatment effect, localization of the site (spatial variation) and the year of sampling (temporal variation). To identify the families that contributed most to the differences between the treated and untreated areas, we compared the observed and expected values in each site and year using the χ^2 statistic. The families that showed significant differences between the treated and untreated areas were Araneidae ($\chi^2 = 10.526$, df = 1, $P < 0.001$) (CAP_1); Tetragnathidae ($\chi^2 = 13.931$, df = 1, $P < 0.001$) and Araneidae ($\chi^2 = 12.737$, df = 1, $P < 0.001$) (CAP_U_2); Araneidae ($\chi^2 = 23.040$, df = 1, $P < 0.001$), Tetragnathidae ($\chi^2 = 36.646$, df = 1, $P < 0.001$), Coenagrionidae ($\chi^2 = 15.242$, df = 1, $P < 0.001$) and Phytoseiidae

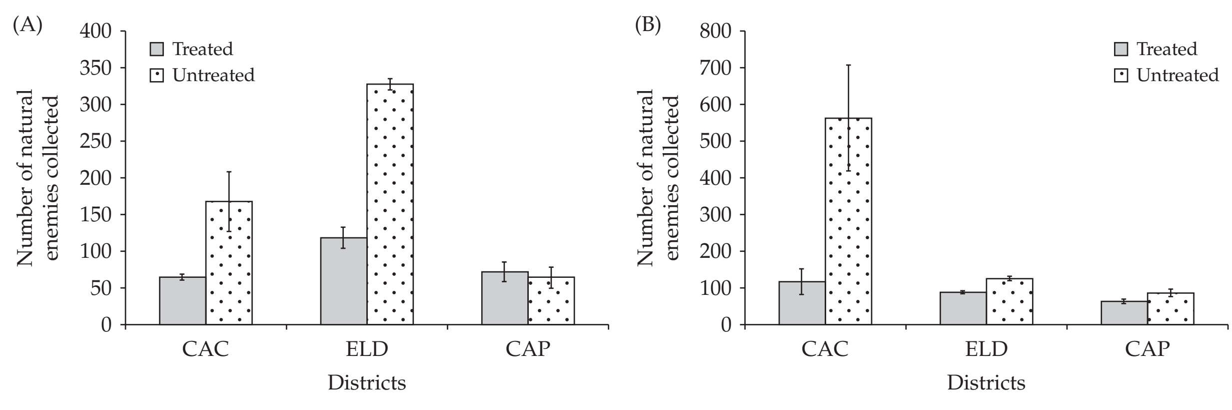

Fig. 2. Abundance of arthropod natural enemies in the insecticide-treated and untreated areas of each district in (A) 2007/2008 and (B) 2008/2009. CAC, Cachoeira do Sul; ELD, Eldorado do Sul; CAP, Capivari do Sul.

Table 2. Number of specimens of various arthropod families in the first data subset used in the PCA

	2007/2008						2008/2009					
	CAP		CAC		ELD		CAP		CAC		ELD	
Taxa	T	U	T	U	T	U	T	U	T	U	T	U
Coccinellidae	0	3	0	0	1	9	7	3	3	1	3	57
Eulophidae	26	15	0	5	27	81	44	30	4	6	75	72
Ascidae	0	0	0	0	0	0	0	0	0	0	31	36
Braconidae	1	6	1	2	2	5	0	7	0	1	5	58
Phytoseiidae	20	9	0	6	0	28	3	1	92	32	49	81
Araneidae	9	29	4	41	31	107	8	30	10	29	23	28
Thomisidae	0	1	0	2	4	3	0	0	0	0	0	3
Salticidae	0	0	0	1	2	5	0	1	0	2	0	0
Tetragnathidae	1	8	3	50	16	76	5	30	5	50	8	20
Oxyopidae	1	0	1	1	6	6	0	6	9	5	4	2
Anyphaenidae	8	3	2	3	13	10	10	20	10	19	5	11
Chrysopidae	10	4	3	7	1	3	2	1	1	1	3	17
Platygastridae	12	15	9	19	13	43	4	4	3	0	13	26
Libellulidae	2	1	9	8	9	16	21	16	9	6	3	6
Coenagrionidae	17	14	26	69	17	107	55	71	15	37	7	16
Lycosidae	6	2	19	1	12	9	7	11	8	0	6	1
Linyphiidae	14	6	1	0	14	9	16	9	14	1	22	4
Shannon_H	2.237	2.277	1.873	1.877	2.384	2.186	2.015	2.179	1.843	1.96	2.18	2.35
Evenness_e^H/S	0.7203	0.696	0.592	0.467	0.723	0.556	0.625	0.589	0.486	0.55	0.59	0.65

CAP, Capivari do Sul; CAC, Cachoeira do Sul; ELD, Eldorado do Sul; T, treated; U, untreated.

Table 3. Number of specimens of various arthropod families in the second data subset used in the PCA

	2007/2008						2008/2009					
	CAP		CAC		ELD		CAP		CAC		ELD	
Taxa	T	U	T	U	T	U	T	U	T	U	T	U
Coccinellidae	1	2	12	4	1	0	5	6	2	2	2	1
Eulophidae	14	11	19	19	26	41	1	10	3	2	11	11
Ascidae	0	0	0	0	0	4	0	0	4	0	3	0
Braconidae	2	6	6	11	3	6	0	2	2	1	0	0
Phytoseiidae	70	50	35	266	22	366	3	0	205	1799	17	1
Araneidae	4	8	4	29	92	168	4	15	29	162	4	3
Thomisidae	0	1	2	0	8	4	0	0	0	0	0	0
Salticidae	0	1	2	2	1	2	2	0	0	1	0	0
Tetragnathidae	5	2	10	15	34	70	9	1	6	13	5	0
Oxyopidae	2	1	4	6	11	14	2	0	1	5	1	0
Anyphaenidae	7	14	8	11	5	12	9	10	6	60	0	0
Chrysopidae	2	0	9	13	2	0	0	0	7	2	7	4
Platygastridae	11	20	32	28	32	39	1	0	4	1	11	8
Libellulidae	8	4	3	3	3	4	4	17	0	2	5	1
Coenagrionidae	12	7	25	17	37	34	18	19	10	21	4	7
Lycosidae	0	1	1	11	12	5	0	0	0	0	0	0
Linyphiidae	2	1	0	2	1	1	0	0	0	1	4	0
Shannon_H	1.799	2.006	2.305	1.605	2.146	1.663	2.047	1.846	1.1	0.56	2.25	1.77
Evenness_e^H/S	0.465	0.496	0.668	0.332	0.534	0.3517	0.704	0.791	0.25	0.12	0.79	0.73

CAP, Capivari do Sul; CAC, Cachoeira do Sul; ELD, Eldorado do Sul; T, treated; U, untreated.

Table 4. Eigenvalues and percentages of variance explained and accumulated as found by the PCA method for each data subset

	First subset of data			Second subset of data		
	Rotation sums of squared loadings			Rotation sums of squared loadings		
Component	Total	Percentage of variance	Cumulative %	Total	Percentage of variance	Cumulative %
1	3583	21.076	21.076	4760	28.001	28.001
2	3481	20.475	41.551	4099	24.113	52.114
3	2875	16.910	58.461	2154	12.669	64.783
4	2434	14.318	72.779	1915	11.264	76.047
5	2115	12.443	85.222	1566	9.211	85.258

($\chi^2 = 29.032$, df = 1, $P < 0.001$) (CAC_U_1 and CAC_U_2); and Coccinellidae ($\chi^2 = 28.000$, df = 1, $P < 0.001$), Phytoseiidae ($\chi^2 = 28.000$, df = 1, $P < 0.001$), Araneidae ($\chi^2 = 41.855$, df = 1, $P < 0.001$), Tetragnathidae ($\chi^2 = 39.130$, df = 1, $P < 0.001$), Eulophidae ($\chi^2 = 27.000$, df = 1, $P < 0.001$), Braconidae ($\chi^2 = 48.600$, df = 1, $P < 0.001$), Linyphiidae ($\chi^2 = 10.667$, df = 1, $P < 0.001$) and Coenagrionidae ($\chi^2 = 65.323$, df = 1, $P < 0.001$) (ELD_U_1 and ELD_U_2) in the first subset of the data. In the second subset of the data, the number of families that showed significant differences was smaller. Only Phytoseiidae ($\chi^2 = 175.749$, df = 1, $P < 0.001$ in CAC_1; $\chi^2 = 1267.882$, df = 1, $P < 0.001$ in CAC_2; and $\chi^2 = 304.990$, df = 1, $P < 0.001$ in ELD_2) and Araneidae ($\chi^2 = 17.471$, df = 1, $P < 0.001$ in CAC_1; $\chi^2 = 91.228$, df = 1, $P < 0.001$ in CAC_2; and $\chi^2 = 22.215$, df = 1, $P < 0.001$ in ELD_1) had significantly higher frequencies in the untreated areas than in the treated areas at 45 days after the application of the insecticide in the first and second years. Phytoseiids were represented by *Neoseiulus paraibensis* (Moraes and McMurtry), an important Acarina predator. The other families in the PCA (Table 5, italicized) are related to spatial or temporal variations in the rice ecosystem.

Discussion

Our results show consistent differences between the treated and untreated areas in the abundance of arthropod natural enemies primarily in the first 2 weeks after the application of the insecticide. After this period, the number of natural enemies in most arthropod families recovered to levels similar to those of the untreated plots. These results are consistent with other studies showing the negative impact of lambdacyhalothrin on beneficial

Table 5. Correlation matrix between the biological variables and principal components selected using the varimax rotation method for each data subset

	Rotated component for the first dataset					Rotated component for the second dataset				
Family	1	2	3	4	5	1	2	3	4	5
Coccinellidae	*0.914*	0.084	0.027	0.173	−29	−62	−177	*−863*	0.149	−171
Eulophidae	*0.788*	0.289	0.143	0.000	0.274	−65	*0.909*	0.087	−130	0.198
Ascidae	*0.753*	−9	−118	−405	−78	0.012	0.011	*0.740*	0.266	0.083
Braconidae	0.695	0.424	−257	−129	−156	0.497	0.577	−298	0.077	0.187
Phytoseiidae	0.533	−26	0.252	−448	−389	*0.749*	−9	0.239	0.392	0.416
Araneidae	0.253	*0.885*	0.200	0.063	−193	*0.801*	0.110	0.414	−67	−30
Anyphaenidae	0.355	0.046	*0.778*	0.302	−27	*0.868*	−240	−274	−208	0.045
Oxyopidae	0.034	0.350	*0.797*	−80	0.116	*0.780*	0.532	0.156	0.057	0.057
Tetragnathidae	0.110	*0.737*	0.277	0.366	−435	*0.776*	0.428	0.259	0.046	0.030
Coenagrionidae	−154	0.309	0.038	*0.867*	−162	*0.724*	0.349	−124	−253	−397
Thomisidae	0.229	*0.823*	−257	0.054	0.044	0.338	*0.775*	0.215	−166	−312
Salticidae	−170	*0.780*	0.409	0.361	−56	0.678	0.373	−328	0.050	−162
Chrysopidae	0.431	0.078	*−729*	−234	−232	−161	0.157	−145	*0.854*	0.239
Platygastridae	0.305	0.568	−624	−128	0.362	0.065	*0.881*	0.104	0.297	0.204
Libellulidae	0.026	0.050	0.267	*0.871*	0.189	−112	0.117	−331	−823	0.323
Lycosidae	−200	−115	0.016	0.180	*0.908*	0.444	*0.798*	0.001	0.050	0.042
Linyphiidae	0.406	−182	0.356	−202	*0.736*	0.039	0.243	0.241	−19	*0.889*

$^{+}$The families indicated in bold font are the main families used to show the difference between the insecticide-treated and untreated areas. Variables with a correlation >0.7 are italicized.

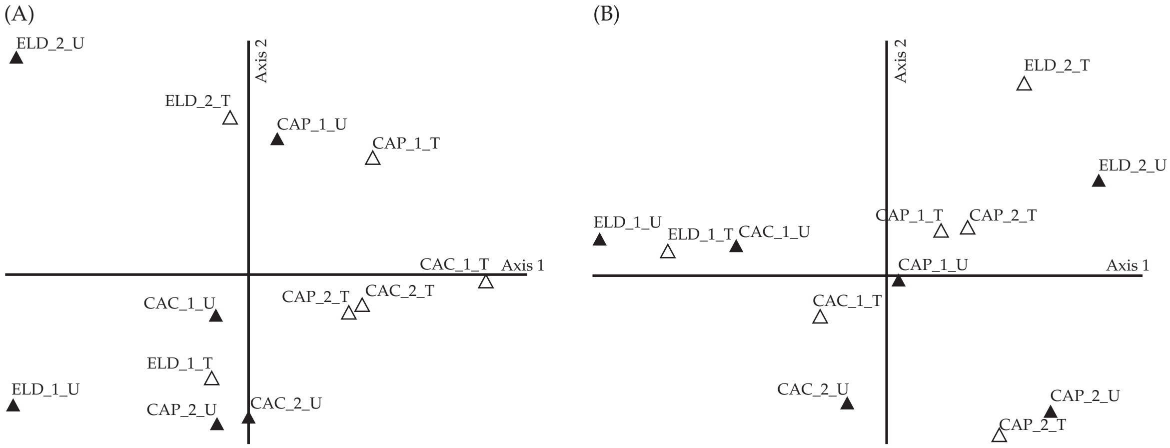

Fig. 3. Ordination of the insecticide-treated and untreated communities according to the two main components of the principal components analysis using the frequency of 17 families as variables. (A) Subset 1 and (B) subset 2. ▲, Untreated areas; Δ, treated areas. CAP, Capivari do Sul; CAC, Cachoeira do Sul; ELD, Eldorado do Sul.

arthropods in agro-ecosystems (Costa and Link, 1999; Kharboutli *et al.*, 2000; Colignon *et al.*, 2001; Costa, 2007). Wick and Freier (2000) and Hand *et al.* (2001) showed that lambdacyhalothrin has a high initial impact, but low persistence.

The impact of lambdacyhalothrin on Phytoseiidae and Araneidae is of special interest. In contrast to other families, even at 45 days after the application of the insecticide, populations of these families did not recover. The differences in the abundance of these two families are indicated by the distance between them in the biplot graphic (Fig. 3B). Pyrethroids such as lambdacyhalothrin usually show high toxicity on predatory phytoseiids (Rock, 1979; Croft, 1990; Raudonis, 2006) and spiders (Wick and Freier, 2000; Martins *et al.*, 2009). These facts are of major concern because Arachnidae are the most abundant arthropods in agro-ecosystems (including our study) and predators of a wide range of insect pests (Marc *et al.*, 1999). Several studies have demonstrated the importance of spiders in the reduction of prey numbers and their contribution to pest control (Riechert and Lawrence, 1997; Marc *et al.*, 1999; Nyffeler and Sunderland, 2003; Oberg, 2007; Seyfulina, 2010).

The present study revealed a great diversity of natural enemies in rice fields in the subtropical environment in southern Brazil, similar to that found in tropical environments. Natural enemies are an important component in integrated pest management (IPM), so it is important to reduce the impact of insecticides in an effort to conserve these biocontrol agents. Modifications to agro-ecosystems that favour natural enemies have contributed to the success of the biological control approach (Ehler, 1998; Heong *et al.*, 2007). Our results showed a great diversity and abundance of natural enemies present in rice fields in southern Brazil. These factors suggest the need to develop strategies to conserve these arthropods and to utilize them as a key component in the IPM of rice insect pests in Brazil. Such strategies have been developed for the management of rice pests in Asia.

Studies in Asian rice have shown that the pyrethroids cypermethrin (Vorley, 1985), decamethrin (Heinrichs *et al.*, 1982) and deltamethrin (IRRI, 1984) cause resurgence of the brown planthopper (BPH) *Nilaparvata lugens* (Stål) and are highly toxic to natural enemies. It has been shown that deltamethrin when applied three times at a rate of 0.03 kg ai/ha to a BPH-susceptible variety causes a resurgence of *N. lugens* populations, reaching 850 planthoppers/hill compared with the untreated check plot at 60 planthoppers/hill (IRRI, 1984). It has also been reported that the pyrethroid cypermethrin also causes a resurgence of the white-backed planthopper *Sogatella furcifera* (Horvath) in Malaysia (Vorley, 1985).

A number of factors are involved in the resurgence phenomenon in Asian rice including the destruction of the major predators of *N. lugens* and *S. furcifera*: the mirid bug *Cyrtorhinus lividipennis* (Reuter), the ripple bug *Microvelia atrolineata* (Bergroth) and the spider *Lycosa pseudoannulata* (Boes. et Str.) (Lycosidae) (Heinrichs *et al.*, 1982; Fabellar and Heinrichs, 1984; IRRI, 1984; Salim and Heinrichs, 1985). Lambdacyhalothrin is applied early in the vegetative stage for the control of the rice water weevil *Lissorhoptrus oryzophilus* (Kuschel) in California, where it has been reported to be highly toxic to general predators and parasites of rice pests (UC Davis). Lambdacyhalothrin is also used for the control of the rice water weevil *O. oryzae* in southern Brazil, where we have reported that it suppresses populations of natural enemies including predacious spiders.

To cope with the destruction of natural enemies and the subsequent resurgence problem of *N. lugens* in Asia, a number of tactics have been developed:

1. The International Rice Research Institute recommends that farmers should not apply insecticides for the first 40 days after sowing, and should only apply insecticides later after a careful assessment of the need for control applications (Vorley, 1985).
2. Studies have shown that a reduction in the number of insecticide applications and rates contributes to the maintenance of predators in rice fields (Settle *et al.*, 1996; Matteson, 2000; Berg, 2002).
3. Another alternative is the use of highly selective insecticides. In the Philippines, buprofezin (Applaud®) was highly selective, providing an effective control of *N. lugens* and *S. furcifera* nymphs at low rates, but was safe to the predators *L. pseudoannulata* (Boes. and Str.) (Lycosidae), *C. lividipennis* Reuter (Miridae) and *M. atrolineata* (Bergroth) (Veliidae) (Heinrichs *et al.*, 1984). In California, the growth regulator diflubenzuron (Dimilin®), when applied to rice, has been reported to be moderately toxic to general predators and with low toxicity to parasites (UC Davis).
4. The breeding of rice varieties with resistance to early season pests, an important tactic, permits a delay in the application of insecticides for 40 days and allows a build-up of natural enemies.

A combination of these tactics must be integrated into a pest management strategy specifically targeted at southern Brazil. With the rice water weevil *O. oryzae* being a major early season pest, some modifications of the Asian strategy must be developed for southern Brazil.

Conclusion

This study, similar to the one by Wilby *et al.* (2006), confirms the great diversity and high population levels of arthropod natural enemies in rice fields in southern Brazil. However, the insecticide lambdacyhalothrin shows a negative impact on beneficial arthropods in this agroecosystem, suggesting the need to develop strategies to conserve these arthropods and to utilize them as a key component in the IPM of rice insect pests in Brazil. The combination of IPM techniques successfully used in other countries (Heinrichs *et al.*, 1984; Vorley, 1985; UC Davis) for the management of *N. lugens* must be integrated into a pest management strategy tailor-made for southern Brazil. Among others, it should include (1) the development of insect-resistant rice varieties suitable to southern Brazil, (2) the reduction in the number of application of insecticides and (3) the identification of selective insecticides with low toxicity to natural enemies, but effective against major pests.

Acknowledgements

We thank the following experts for their assistance in arthropod identification: Everton Nei Lopes Rodrigues, for the identification of the Araneae order; Maria Helena Mainieri Galileo, André Franco Franceschini and Luciano de Azevedo Moura of the Museu de Ciências Naturais da Fundação Zoobotânica do RS, for the identification of some coleopteron specimens; Jocélia Grazia and Caroline Greve of the Universidade Federal do Rio Grande do Sul (UFRGS), for the identification of the Heteroptera; Celso Oliveira Azevedo and Marcelo Tavares of the Universidade Federal do Espírito Santo, for help in identifying the Hymenoptera; and Noeli Juarez Ferla and Liana Johann of the Museu de Ciências Naturais da Univates in Lajeado, Rio Grande do Sul, for the identification of mites. We acknowledge the Fulbright Foundation USA/Brazil for the fellowship provided to Dr Heinrichs to conduct this study at UNISINOS.

References

Amalin D. M., Peña J. E., Duncan R., Leavengood J. and Koptur S. (2009) Effects of pesticides on the arthropod community in the agricultural areas near the Everglades National Park. *Proceedings of the Annual Meeting of the Florida State Horticultural Society* 122, 429–437.

Arida G. S. and Heong K. L. (1992) Blower-vac: a new suction apparatus for sampling rice arthopods. *International Rice Research Newsletter* 17, 30–31.

Azevedo Filho W. S. and Junior P. H. S. P. (2000) *Técnicas de coleta e identificação de insetos*, 2nd edn. EDIPUCRS, Porto Alegre. 97 pp.

Berg H. (2002) Rice monoculture and integrated rice–fish farming in the Mekong Delta, Vietnam – economic and ecological considerations. *Ecological Economics* 41, 95–107.

Borror D. J., Triplehorn C. A. and Johnson N. F. (1989) *An Introduction to the Study of Insects*, 6th edn. College Publishing, State College, Pennsylvania. 875 pp.

Boutin C., Martin P. A. and Baril A. (2009) Arthropod diversity as affected by agricultural management (organic and conventional farming), plant species and landscape context. *Ecoscience* 16, 492–501.

Colignon P., Hastir P., Gaspar C. and Francis F. (2001) Effects of insecticide treatments on insect density and diversity in vegetable open fields. *Meded Rijksuniv Gent Fak Landbouwkd Toegep Biol Wet* 66, 403–411.

CONAB [Companhia Nacional de Abastecimento] (2011) Comparativo de área, produtividade e produção. Available at: http://www.conab.gov.br/OlalaCMS/uploads/arquivos/11_09_09_08_55_35_boletim_setembro_-_2011.pdf

Costa E. L. N. (2007) Ocorrência de artrópodes e seletividade de inseticidas na cultura do arroz irrigado. PhD Dissertation, Federal University of Rio Grande do Sul, Porto Alegre, Brazil. 60 pp.

Costa E. C. and Link D. (1999) Efeito de inseticidas sobre predadores em arroz irrigado. *Revista Faculdade Zootecnia Veterinária e Agronômica* 5/6, 24–31.

Croft B. A. (1990) *Arthropod Biological Control Agents and Pesticides*. Wiley Interscience, New York. 723 pp.

Das S., Roy S. and Mukhopadhyay A. (2010) Diversity of arthropod natural enemies in the tea plantations of North Bengal with emphasis on their association with tea pests. *Current Science* 99, 1457–1463.

Davey R. B., Ahrens E. H. and George J. E. (1992) Efficacy of cyhalothrin and lambdacyhalothrin against *Boophilus microplus* (Acari: Ixodidae). *Journal of Economic Entomology* 85, 2286–2290.

Desneux N., Decourtye A. and Delpuech J. M. (2007) The sublethal effects of pesticides on beneficial arthropods. *Annual Review of Entomology* 52, 81–106.

Ehler L. E. (1998) Conservation biological control: past, present, and future, pp. 1–8. In *Conservation Biological Control* (Edited by P. Barbosa). Academic Press, New York.

Fabellar L. T. and Heinrichs E. A. (1984) Toxicity of insecticides to predators of rice brown planthoppers, *Nilaparvata lugens* (Stål) (Homoptera: Delphacidae). *Environmental Entomology* 13, 832–837.

Falcone J. F. and DeWald L. E. (2010) Comparisons of arthropod and avian assemblages in insecticide-treated and untreated eastern hemlock (*Tsuga canadensis* [L.] Carr) stands in Great Smoky Mountains National Park, USA. *Forest Ecology and Management* 260, 856–863.

Ferreira E. and Martins J. F. S. (1984) *Insetos prejudiciais ao arroz e seu controle*. EMBRAPA/CNPAF, Goiânia. 67 pp.

Fountain M. T., Brown V. K., Gange A., Symondson W. O. C. and Murray P. J. (2007) The effects of the insecticide chlorpyrifos on spider and Collembola communities. *Pedobiologia* 51, 147–158.

Gangurde S. (2007) Aboveground arthropod pest and predator diversity in irrigated rice (*Oryza sativa* L.) production systems of the Philippines. *Journal of Tropical Agriculture* 45, 1–8.

Gardiner M. M., Landis D. A., Gratton C., Fonzo C. D. D., O'Neal M., Chacon J. M., Wayo M. T., Schmidt N. P., Mueller E. E. and Heimpel G. E. (2009) Landscape diversity enhances biological control of an introduced crop pest in the north-central USA. *Ecological Applications* 19, 143–154.

Geiger F., Wãckers F. L. and Bianchi F. (2009) Hibernation of predatory arthropods in semi-natural habitats. *BioControl* 54, 529–535.

Hand L. H., Kuet S. F., Lane M. C. G., Maund S. J., Warinton S. and Hill I. R. (2001) Influences of aquatic plants on the fate of the pyrethroid insecticide lambda-cyhalothrin in aquatic environments. *Environmental Toxicology and Chemistry* 20, 1740–1745.

Heinrichs E. A. (1994) *Biology and Management of Rice Insects*. Wiley Eastern/IRRI, Los Baños/New Delhi. 799 pp.

Heinrichs E. A. (2005) A new paradigm for implementing ecologically-based participatory IPM in a global context: the IPM CRSP Model. *Neotropical Entomology* 34, 143–153.

Heinrichs E. A. and Barrion A. T. (2004) *Rice-Feeding Insects and Selected Natural Enemies in West Africa: Biology, Ecology, Identification*. International Rice Research Institute (IRRI)/The Africa Rice Center (WARDA), Los Baños/Abidjan. 243 pp.

Heinrichs E. A., Basilio R. P. and Valencia S. L. (1984) Buprofezin, a selective insecticide for the management of rice planthoppers (Homoptera: Delphacidae) and leafhoppers (Homoptera: Cicadellidae). *Environmental Entomology* 13, 515–521.

Heinrichs E. A., Reissig W. H., Valencia S. L. and Chelliah S. L. (1982) Rates and effect of resurgence-inducing insecticides on populations of *Nilaparvata lugens* (Homoptera: Delphacidae) and its predators. *Environmental Entomology* 11, 1269–1273.

Heong K. L., Manza A., Catindig J., Villareal S. and Jacobsen T. (2007) *Changes in Pesticide Use and Arthropod Biodiversity in the IRRI Research Farm. Outlooks on Pest Management*. International Rice Research Institute (IRRI), Los Baños. 5 pp.

Heong K. L. and Schoenly K. G. (1998) Impact of insecticides on herbivore–natural enemy communities in tropical rice ecosystems, pp. 381–403. In *Ecotoxicology: Pesticides and Beneficial Organisms* (Edited by P. T. Haskell and P. McEwen). Kluwer Academic Publishers, Dordrecht.

IRRI [International Rice Research Institute] (1984) *Proceedings of the FAO/IRRI Workshop on 'Judicious and Efficient Use of Insecticides on Rice'*. The International Rice Research Institute and Food and Agriculture Organization of the United Nations Intercountry Programme for Integrated Pest Control in Rice in South and Southeast Asia, Los Baños. 180 pp.

Jongman R. H. G., Ter Braak C. J. F. and Van Tongeren O. F. R. (Eds) (1995) *Data Analysis in Community and Landscape Ecology*. 2nd edn. Cambridge University Press, New York. 324 pp.

Kharboutli M. S., Allen C. T., Capps C. and Earnest L. D. (2000) Insecticides for early-season tarnished plant bug control, pp. 161–166. In *Proceedings of the 2000 Cotton Research Meeting and Summaries of Cotton Research in Progress. AAES Special Report 198* (Edited by D. M. Oosterhuis). Arkansas Agricultural Experiment Station, Fayetteville, Arkansas.

Krauss J., Gallenberger I. and Steffan-Dewenter I. (2011) Decreased functional diversity and biological pest control in conventional compared to organic crop fields. *PLoS ONE* 6, 502. DOI: 10.1371/journal. pone.0019502.

Legendre P. and Legendre L. (1998) *Numerical Ecology (Developments in Environmental Modelling)*. Elsevier, New York. 870 pp. ISBN: 978-0-444-89249-2.

Leng X., Musters C. J. M. and de Snoo G. R. (2010) Synergy between nature reserves and agri-environmental schemes in enhancing ditch bank target species plant diversity. *Biological Conservation* 143, 1470–1476.

Link D., Costa E. C. and Marchesan E. (1987) Avaliação preliminar de diferentes densidades de *Oebalus poecilus* (Dallas, 1851) sobre o rendimento do arroz. *Reunião da cultura do arroz irrigado* 17, 229–232.

Marc P., Canard A. and Ysnel F. (1999) Spiders (Araneae) useful for pest limitation and bioindication. *Agriculture, Ecosystems and Environment* 74, 229–273.

Martins J. F. S., Ribeiro A. S. and Terres A. L. S. (1989) Danos causado pelo percevejo-do-grão ao arroz irrigado. *Reunião da cultura do arroz irrigado* 18, 396–404.

Martins G. L. M., Toscano L. C., Tomquelski G. V. and Maruyama W. I. (2009) Inseticidas no controle de *Anticarsia gemmatalis* (Lepidoptera: Noctuidae) e impacto sobre aranhas predadoras em soja. *Revista Brasileira Ciências Agrárias* 4, 128–132.

Matteson P. C. (2000) Insect pest management in tropical Asian irrigated rice. *Annual Review of Entomology* 45, 549–574.

McCune B. and Mefford M. J. (1999) *PC-ORD. Multivariate Analysis of Ecological Data, version 4*. MJM Software, Gleneden Beach. 237 pp.

Nyffeler M. and Sunderland K. D. (2003) Composition, abundance and pest control potential of spider communities in agroecosystems: a comparison of European and US studies. *Agriculture, Ecosystems and Environment* 95, 579–612.

Oberg S. (2007) Diversity of spiders after spring sowing – influence of farming system and habitat type. *Journal of Applied Entomology* 131, 524–531.

Oliveira J. V. and Freitas T. F. S. (2009) Trio de peso. *Revista Cultivar* 123, 14–16.

Oliveira J. V. and Kempf D. (1989) Avaliação de dano ao arroz irrigado pelo percevejo do grão, *Oebalus poecilus* (Dallas, 1851). *Reunião da cultura do arroz irrigado* 18, 405–409.

Raudonis L. (2006) Comparative toxicity of spirodiclofen and lambdacyhalothrin to *Tetranychus urticae*, *Tarsonemus pallidus* and predatory mite *Amblyseius andersoni* in a strawberry site under field conditions. *Agronomy Research* 4, 317–322.

Riechert S. E. and Lawrence K. (1997) Test for predation effects of single versus multiple species of generalist predators: spiders and their insect prey. *Entomologia Experimentalis et Applicata* 84, 147–155.

Rock G. C. (1979) Relative toxicity of two synthetic pyrethroids to a predator *Amblyseius fallacis* and its prey *Tetranychus urticae*. *Journal of Economic Entomology* 72, 293–294.

Salim M. and Heinrichs E. A. (1985) Relative toxicity of insecticides to the whitebacked planthopper *Sogatella furcifera* (Horvath) (Homoptera: Delphacidae) and its predators. *Journal of Plant Protection in the Tropics* 2, 45–47.

Settle W. H., Ariawan H., Astuti E. T., Cahyana W., Hakim A. L., Hindayana D. and Lestari A. S. (1996) Managing tropical rice pests through conservation of generalist natural enemies and alternative prey. *Ecology* 77, 1975–1988.

Seyfulina R. R. (2010) The spider assemblage (Arachnida, Araneae) in agroecosystems of the Kuban Plain: species composition, spatial distribution, and seasonal dynamics. *Entomological Review* 90, 494–510.

Smith H. G., Öckinger E. and Rundlöf M. (2010) Biodiversity and the landscape ecology of agri-environment schemes. *Aspects of Applied Biology* 100, 225–232.

Teodorescu I. and Cogãlniceanu D. (2005) Rapid assessment of species diversity changes after pesticide application in agricultural landscapes. *Applied Ecology and Environmental Research* 4, 55–62.

Ter Braak C. J. F. (1995) Ordination. In Jongman R. H. G., Ter Braak, C. J. F. and Van Tongeren O. F. R. (eds). *Data Analysis in Community and Landscape Ecology*, pp. 91–173. Cambridge, Cambridge University Press.

UC Davis - University of California, Davis (2006) How to reduce Bee Poisoning from Pesticides. Available at: http://www.ipm.ucdavis.edu/PDF/PMG/pnw591.pdf

USDA - United States Department of Agriculture (2013) Table 9 - Rice Area, Yield and Production. Available at: http://www.fas.usda.gov/psdonline/psdreport.aspx?hidReportRetrievalName=BVS&hidReportRetrievalID=893&hidReportRetrievalTemplateID=1

Vorley W. T. (1985) Spider mortality implicated in insecticide-induced resurgence of whitebacked planthopper (WBPH) and brown planthopper (BPH) in Kedah, Malaysia. *International Rice Research Notes* 10, 19–20.

Whittingham M. J. (2007) Will agri-environment schemes deliver substantial biodiversity gain, and if not why not? *Journal of Applied Ecology* 44, 1–5.

Whittingham M. J. (2011) The future of agri-environmental schemes: biodiversity gains and ecosystem service delivery? *Journal of Applied Ecology* 48, 509–513.

Wick B. M. and Freier B. (2000) Long-term effects of an insecticide application on non-target arthropods in winter wheat – a field study over 2 seasons. *Anzeiger für Schädlingskunde* 73, 61–69.

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