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Spatio-temporal distribution of planthopper and predator mirid in two rice granary areas of Malaysia

(Taburan merata dan bertempoh bagi serangga benah dan pemangsa mirid di dua kawasan jelapang padi di Malaysia)

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Key words: planthopper, *Cyrtorhinus lividipennis*, non-rice habitat, spatial pattern, spatial association

Abstract

Spatial and temporal distributions of planthopper and predator mirid bug were analysed and quantified. The study, conducted at Pasir Panjang and Limbat, was to evaluate the roles of non-rice habitats on the conservation of beneficial arthropods in rice ecosystem. The landscape of the rice ecosystem differed at these two sites whereby the non-rice habitat was larger at Limbat than at Pasir Panjang.

The temporal pattern of planthopper was dissimilar between the two sites. At Pasir Panjang, planthopper populations varied between and within season. Its peak adult densities were 3 planthoppers/m^2 in the first season and increased to 45 planthoppers/m^2 in the third season. Population of predator mirid bug (PMB) was low and lagged behind the planthopper population. At Limbat, the density of planthopper adult was consistently low. Its peak density was less than 5 planthoppers/m^2 in all seasons. PMB density was relatively higher at Limbat.

Analysis of the spatial pattern and spatial association between planthopper and PMB indicated that planthopper patches consistently occurred in the middle of the area at both sites. Generalist predators inhibiting the non-rice habitat might have killed the planthopper present near the vicinity resulting in the formation of gaps. However, these predators were slow to move to the middle of the field resulting in the formation of patches of planthopper in the central areas. These results suggested that spatial heterogeneity, in the form of non-rice habitats within rice landscapes could be manipulated to conserve predator populations and help control the planthopper population in the rice ecosystem.

Introduction

Rice planthoppers (Homoptera: Delphacidae) which consist mainly of brown planthopper (*Nilaparvata lugens* (Stal) and white back planthopper (*Sogatella furcifera* Hovarth) remain important rice pests in Malaysia (Nik Mohd. Noor and Hirao 1987; Mohd Norowi 2001). Their problems in the rice production systems are affected by several factors such as ecological and biological features, control measures, the rice growth patterns, and interactions with other factors such as social, economic and institutional features of the farming

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communities (Dyck and Thomas 1979; Settle et al. 1996). Consequently, the occurrence of planthopper infestation varies greatly between locations. For instance, their outbreaks are more prevalent in the western part of the rice growing areas i.e. Tanjung Karang Irrigation Scheme (TKIS) and Muda Agricultural Development Authority (MADA) but less prevalent in the northeastern areas i.e. Kemubu Agricultural and Development Authority (KADA) and Besut areas (Ooi and Heong 1988; Nik Mohd. Noor 2005).

Pesticides remain one of the methods to control planthopper infestations. However, due to several environmental hazards of pesticide applications, more efforts have been initiated to rely on natural control of planthopper. Several generalist predators, such as *Cyrtorhinus lividipennis* Reuter, *Microvelia douglasi atrolineata* Bergoth and spiders are associated with planthopper population in the rice ecosystem (Heong et al. 1992; Way and Heong 1994). Long term stable relationships between pest and natural enemy are crucial in the management of pest population (Godfray et al. 1994). Spatial heterogeneity within crop field is an important feature contributing to stable relationship between pest and natural enemy in the agroecosystem (Dennis and Fry 1992). This heterogeneity could be due to physical factors such as size or shape of crop habitats, distances between crop and non-crop habitats, soil surface roughness, or botanical factors such as vegetation type and density (Andow and Imura 1994; Powell et al. 1995).

One of the main challenges of an ecologist is to identify the types of spatial heterogeneity within rice ecosystem and quantify its benefits and utility for pest management. Vegetation in non-rice habitats such as bunds in rice ecosystem is believed to favour the proliferation of generalist predators that are capable of suppressing planthopper population in rice fields (Way and Javier Jr. 2001). These non-rice habitats impinge on the movement of predators within rice fields, especially for slow moving predators (Way and Heong 1994). It is interesting to investigate the role of non-rice habitats on spatio-temporal distribution of planthopper and predators such as the predator mirid bug, PMB, *Cyrtorhinus lividipennis* Reuter (Hemiptera: Miridae) in rice ecosystem. PMB is believed to be an important predator of planthopper (Sivapragasam and Asma 1985; Heong et al. 1992). Both adult and nymph prey on planthopper nymphs and eggs (Cook and Perfect 1985).

Although it is believed that the complex action of predator population is more important to control planthopper population rather than to depend on single taxon of predator (Way and Javier Jr. 2001), it is difficult to quantify their interactions at once. This paper reports the study on the spatial relationship between planthopper and PMB. The understanding of the interaction between planthopper and PMB obtained from this study could serve as a model to interpret the similar interactions for other predators and pests in the rice ecosystem. Even though the relationship between PMB and planthopper in rice ecosystem is well-documented, the effects of spatial heterogeneity on their interactions have received little attention. Such spatial information is recently suggested as crucial information to predict pest and natural enemy movements between and within crops (Winder et al. 2000; Ferguson et al. 2003) as well as to underpin the development of control strategies in which application of pesticides may be spatially targeted to minimise their negative impact (Sylvester-Bradley et al. 1999). The information is also crucial for the sustainable management of PMB population within the rice ecosystem.

In this study, the spatial and temporal patterns of planthopper and PMB population in TKIS and KADA areas were compared. If non-rice habitats play significant roles on beneficial insects, it is expected that the pattern of planthopper and PMB distribution would be different between the two areas.

Materials and methods

Experimental site

The experiments were conducted at two sites – Pasir Panjang in TKIS area and Limbat in KADA area in 2000 and 2001 rice seasons. At Pasir Panjang, an area of 70 m x 230 m was selected and arbitrarily divided into 35 equal sized plots. At Limbat, an area of 60 m x 180 m was selected and arbitrarily divided into 40 equal sized plots. These 40 plots comprised seven small rice fields that were separated by small size bunds. At both locations, the experiments were conducted for three seasons. At Pasir Panjang, rice was broadcasted on 8 Mar. 2000, 21 Sept. 2000 and 22 Feb. 2001 for first, second and third season, respectively. At Limbat, rice was broadcasted on 30 May 2000, 11 Dec. 2000 and 25 Dec. 2001 for first, second and third season, respectively.

The two sites represented two rice granary areas in Malaysia and they differ in their landscape. The landscape pattern at TKIS area is relatively more homogenous as it contains fewer patches of non-rice habitats. The only main non-rice habitat area was the two big bunds of the irrigation canals (to drain out irrigation water) located at the south side of the area. They were covered by several species of weeds and volunteer rice. In addition, small size bunds at the west and east of the area also served as non-rice habitat. In contrast, the landscape pattern at KADA is more heterogeneous as it contains larger patches of non-rice habitats. There was a main patch of non-rice habitat in the form of semi-natural habitat situated on the west side of the area, big bund at the north, medium-size bunds at the east and south of the area, and six small size bunds within the area-rice habitat. Trees and shrubs occupied the semi natural habitat, while several species of weed and volunteer rice were found on big, medium and small bunds.

Rice cropping practices

The experiments were carried out in the farmers' fields. The standard rice production practices were carried out according to actual farmer practices in the areas. The recommended cultural practices in both areas were basically similar. However, the implementation of the practices differed. The farmers in TKIS area were more advance therefore they tended to follow the recommended practices closely. For that reason, rice cropping practices are relatively more synchronized in TKIS area. In contrast, farmers in the KADA area tended not to follow the recommended practices, especially in the application of insecticide. In the recommendation, farmers were asked to examine the pest status before deciding to apply insecticide. However the farmers tend to spray on calendar basis. In TKIS area, farmers normally applied insecticide about four times, 30, 50, 70 and 90 days after sowing (DAS). In KADA area, the farmer applied insecticide 2–3 times, one or two at 40 DAS and another after heading stage.

Insect sampling

Planthopper and PMB population were sampled from 36 and 40 determined plots for Pasir Panjang and Limbat, respectively. Samplings were carried out 4–6 times in each rice season, and the first sampling began at three weeks after broadcast. The sampling dates were targeted at various stages of rice growth, i.e. crop establishment, maximum tillering, booting, flowering, milking, heading and ripening stages. On each sampling date, an enclosure (0.25 m x 0.25 m x 0.90 m) made up of Perspex was placed at random in each plot. All planthoppers and PMB inside the enclosure were sucked up using a modified car vacuum cleaner. Insects were vacuumed for 2–4 min at each sampling point depending on the age of the crop. Captured insects were killed and kept in 70% alcohol. The insects were identified and counted in the laboratory.

Data analysis

Temporal patterns of planthopper and PMB were determined by plotting their adult and nymph densities per metre square for each sampling date. Their spatial distribution was determined by analysing their spatial patterns for each sampling date carried out between 25–70 DAS. These dates were chosen since the management of planthopper population in rice ecosystem is crucial within this period. In the analysis, the counts of adult and nymph of planthoppers and PMB were added. The data were analysed and modelled with statistical methodology termed SADIE (Spatial Analysis by Distance IndicEs) system (Perry 1998). This technique is unique compared to conventional statistical methods as it enables the spatial characteristics of observed distribution to be assessed and compared by randomization procedures, using indices and tests of randomness. Detailed explanation on how this system works is explained in several literatures (Perry 1999; Perry and Dixon 2002; Perry et al. 2002). Basically, SADIE system is developed explicitly for the spatial analysis of ecological data in the form of spatially reference counts such as those collected from this study.

The system was introduced to provide a means of describing the spatial features of such a set of counts, independently of their numeric properties. The method works through equating the degree of spatial pattern in an observed arrangement of counts to the minimum effort that the individuals in the population would need to expend to move to a completely regular arrangement in which abundance was equal in each sample unit. In practice, this effort is equated with the minimum distance, D, required to move to complete regularity. Division of the observed value of D by the mean value from several hundreds such randomization gives an index of aggregation, I_a. Ecologically, values of I_a=1 indicate randomly arranged counts, while I_a>1 indicates aggregation of observed counts into clusters. However, I_a, does not encompass all the facets of spatial pattern in an arrangement. Thus, two more indices were developed, *v*i and *v*j (Perry 1999). Basically, *v*i and *v*j indicate patches of above-average density and gaps of below-average density.

When I_a statistically indicated significantly greater >1 ($P_a < 0.05$), their cluster of patches and gaps were mapped with SURFER 8.0 software (Golden Software Incorporated 2002) to visualize where exactly the patches and gaps are situated. To determine the spatial relationship between planthoppers and PMB, their spatial association was determined with the extended version of SADIE (Winder et al. 2000). The extent to which the cluster indices of planthopper and PMB (either *v*i or *v*j) ‘agree’ at each point provides a measure of spatial association, χ_p, locally. $\chi_p > 0$ ($p < 0.025$) indicated positive spatial association and $\chi_p < 0$ indicated otherwise. The spatial association was determined between spatial pattern of planthoppers and PMB from the same sampling date to detect immediate response of PMB to planthopper population, and from different successive sampling dates to detect lagging response. This lag analysis was aimed to detect the possibility of delay response of PMB to planthoppers. When the result indicated significant positive spatial association, their associations were mapped to visualize where they were situated.

Results

Temporal pattern of planthoppers and predator mirid bug

Temporal pattern of planthopper counts in two experimental areas were identical *(Figure 1)*. Planthopper began to colonize rice crops at about four weeks after sowing. This first generation peaked at about 30 DAS, the second generation 50 DAS, and the third generation 70 DAS. The peak of the third generation normally coincided with the reproductive stage of rice crops. Similar pattern was observed by Nik Mohd. Noor and Hirao (1987) and Ooi and Heong (1988). If farmer mismanaged the early generation of planthopper, it would result in higher number of planthopper in its third

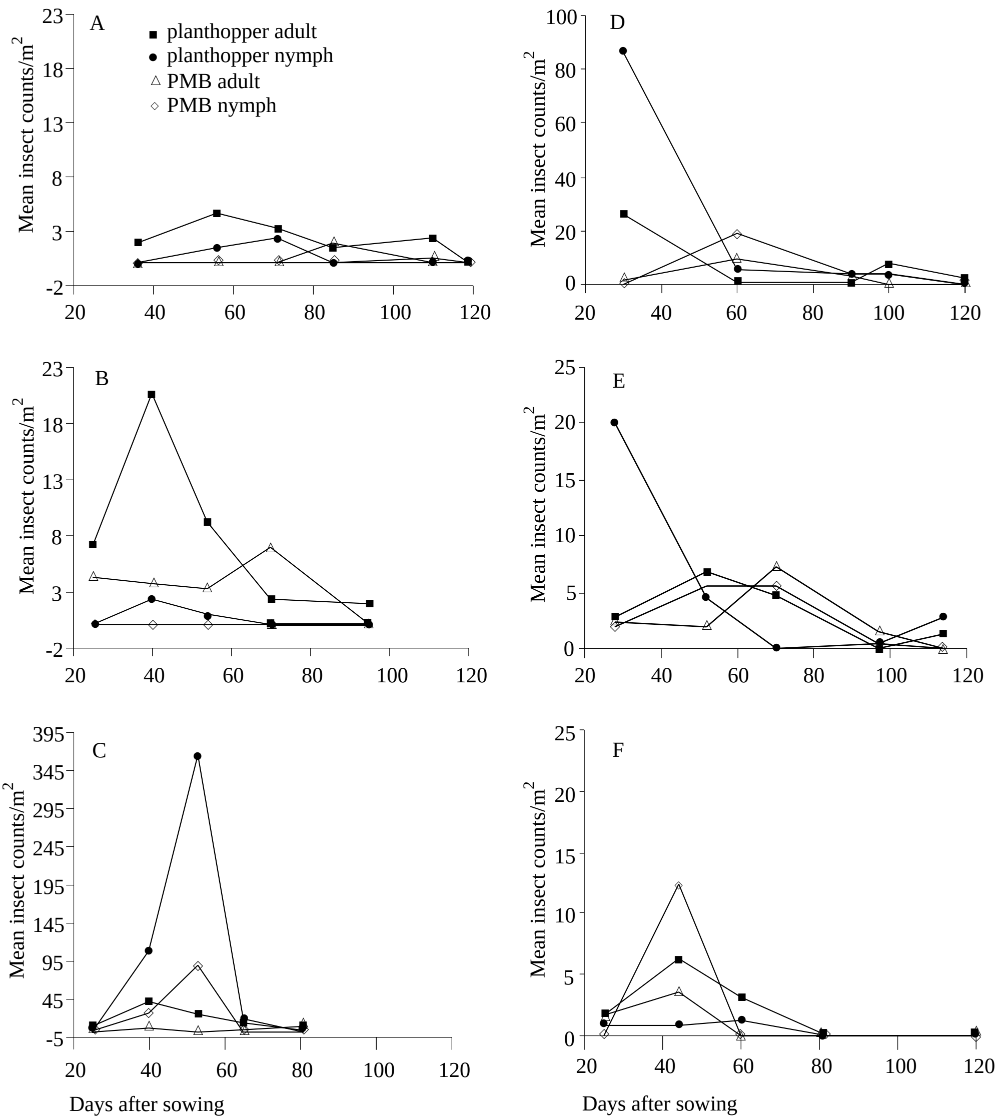

Figure 1. Temporal pattern of planthopper and predator mirid bug (PMB) populations for three season experiments conducted at Pasir Panjang in 2000–2001. (A, First season; B, Second season; C, Third season) and Limbat (D, First season ; E, Second season ; F, Third season)

generation. If this happened, hopperburn, the symptom of planthopper damage on rice would occur as rice crop was not able to compensate (Mohd Norowi 2001).

Although planthopper temporal pattern was similar at both sites, their densities were more variable in Pasir Panjang than in Limbat area. At Pasir Panjang (*Figure 1A–C)*, planthopper adult density was low in the first season of experiment (3 planthoppers/m^2). The peak densities increased to 20 and 45 planthoppers/m^2 in the second and third seasons, respectively. The pattern of planthopper nymph population development was similar to its adult. In the first and second seasons, the peak of planthopper nymph densities was lower than its parents. However, in the third season, it increased drastically to almost nine folds of its parent *(Figure 1C)*. For PMB counts, its pattern seemed to follow the host population counts, except its density was lower than its host and its peak lagged behind. At Limbat *(Figure 1D–F),* planthopper adult population was almost similar in the three seasons of experiments. Its peaks density was less than 5 planthoppers/m^2. A similar pattern was also noted for planthopper nymph. The pattern of PMB densities also seemed to follow its host population. In the third season, however, its density peaked at the same time and exceeded the host density. This population was able to suppress planthopper population drastically in the following generation. It appeared that both planthopper and PMB colonize the rice field earlier at Limbat site.

Spatial distribution of planthoppers and predator mirid bug

Table 1 and *Figure 2* summarize the result of SADIE analysis for planthopper and PMB counts on various sampling dates at Pasir Panjang. It indicated that planthopper counts were strongly aggregated (I_a >1.5). Majority of planthopper patches (red area) were situated in the middle of experimental area while the majority of its gaps (blue area) were situated at the edge of the area, i.e. near irrigation bund *(Figure 2A–C)*. No spatial trend was observed on the formation of patches of PMB counts *(Figure 2D–F)*, but at 45 DAS in the third season, big patches were established near the bund area *(Figure 2E)*.

Table 2 and *Figure 3* show the spatial pattern of planthopper and PMB in Limbat. Planthopper counts were less aggregated, but in cases when they aggregated, their patches were also situated in the middle of the area, and gaps were also consistently situated at the edge of the area *(Figure 3)*. PMB seemed to aggregate toward the east side of the area (*Figures 3C–D*).

Table 1. Summary of result from spatial pattern analysis with SADIE system for planthopper and predator mirid bug (PMB) counts from Pasir Panjang site

Season	Days after sowing	Insects	Mean counts	SADIE parameters					
				I_a	P_a	V_j	P_j	V_i	P_i
First	36	Planthopper	0.11	0.82	0.722	–0.81	0.722	0.82	0.713
		PMB	0.00	–		–		–	
	56	Planthopper	0.37	1.64	0.032	–1.70	0.026	1.58	0.038
		PMB	0.00	–		–		–	
	71	Planthopper	0.34	1.17	0.210	–1.17	0.201	1.12	0.244
		PMB	0.00	–		–		–	
Second	25	Planthopper	0.43	0.89	0.591	–0.90	0.574	0.83	0.723
		PMB	0.26	0.87	0.606	–0.87	0.613	0.93	0.503
	40	Planthopper	1.43	1.41	0.090	–1.42	0.077	1.17	0.198
		PMB	0.23	0.72	0.932	–0.72	0.923	0.73	0.911
	54	Planthopper	0.63	1.31	0.121	–1.28	0.134	1.23	0.157
		PMB	0.20	1.70	0.027	–1.71	0.031	1.70	0.033
	70	Planthopper	0.14	0.65	0.996	–0.64	0.995	0.70	0.982
		PMB	0.43	0.74	0.906	–0.73	0.920	0.73	0.923
Third	25	Planthopper	0.49	0.91	0.538	–0.98	0.420	0.84	0.689
		PMB	0.11	0.89	0.571	–0.89	0.563	0.85	0.639
	45	Planthopper	9.23	1.34	0.116	–1.35	0.113	1.41	0.092
		PMB	1.94	1.95	0.009	–2.02	0.007	2.23	0.002
	53	Planthopper	24.23	1.97	0.006	–1.96	0.007	2.05	0.005
		PMB	5.54	1.77	0.019	–1.84	0.018	1.69	0.030
	65	Planthopper	1.89	1.05	0.352	–1.11	0.285	0.95	0.453
		PMB	0.23	0.80	0.771	–0.80	0.774	0.77	0.848

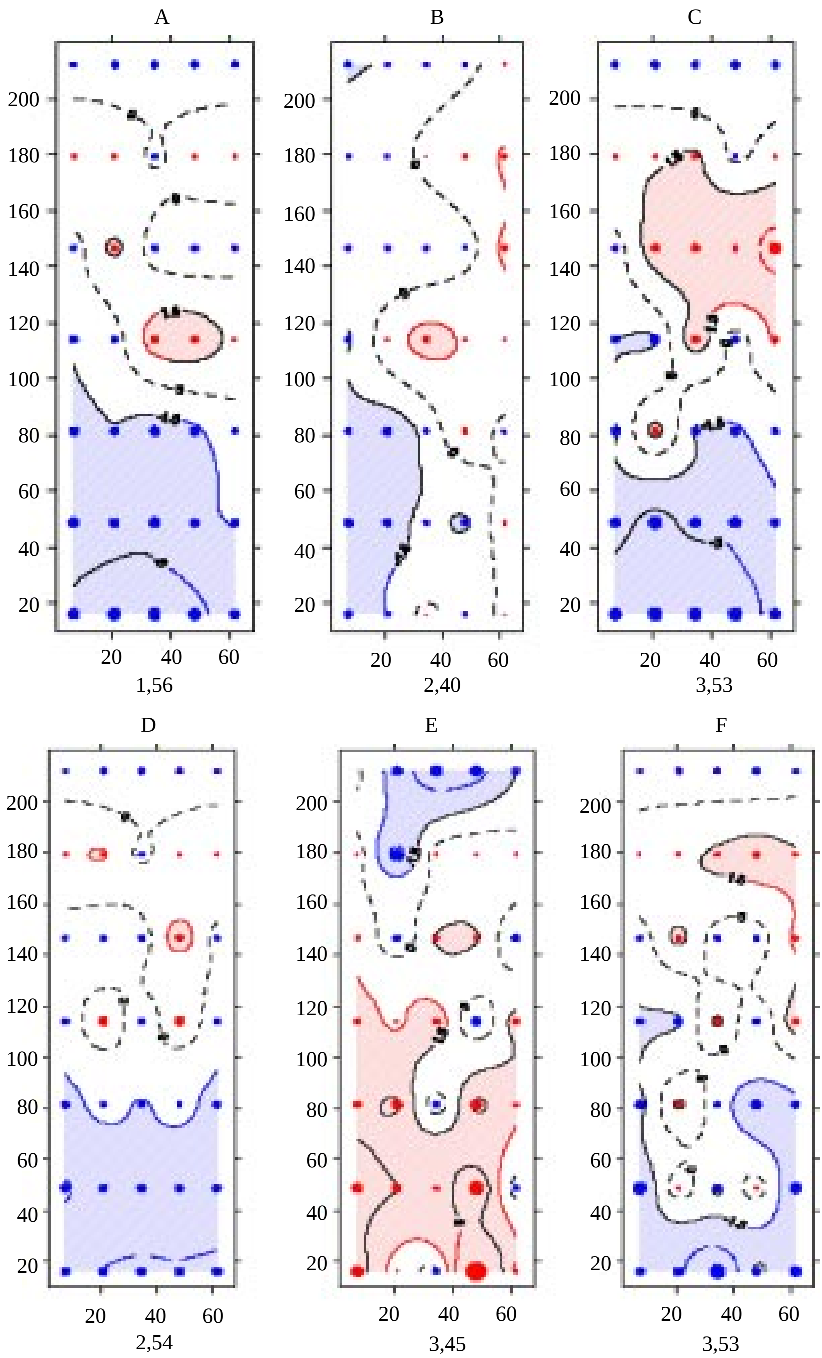

Figure 2. Maps of clustering for planthopper (A–C) and predator mirid bug (D–F) that were significantly aggregated, I_a >1 (P_a<0.05) from Pasir Panjang site. Values of clustering indices v_i <1 (below expectation), 1.0 < v_i <1.5 (slightly above expectation) and 1.5< v_i (well above expectation) shown as red circles. Bold lines are contour enclosing patches (red slant with red circles) of 1.5< v_i or gap (blue slant with blue circles) of v_j <–1.5. Areas within contour with absolute value of >1.5 indicate strong clustering (Number below maps indicated season number and number of DAS when insect sampling was conducted)

Table 2. Summary of result from spatial pattern analysis with SADIE system for planthopper and predator mirid bug (PMB) counts from Limbat site

Season	Days after sowing	Insects	Mean counts	SADIE parameters					
				I_a	P_a	V_j	P_j	V_i	P_i
First	30	Planthopper	7.03	1.50	0.048	–1.49	0.055	1.50	0.052
		PMB	0.10	0.79	0.824	–0.78	0.828	0.82	0.740
	60	Planthopper	0.38	1.16	0.223	–1.17	0.203	1.16	0.192
		PMB	1.78	1.00	0.394	–1.02	0.370	1.00	0.385
	90	Planthopper	0.28	0.76	0.913	–0.75	0.927	0.77	0.905
		PMB	0.40	0.41	0.408	–1.02	0.382	1.02	0.360
Second	28	Planthopper	1.43	1.47	0.050	–1.47	0.051	1.13	0.212
		PMB	0.28	0.85	0.672	–0.87	0.651	0.87	0.626
	52	Planthopper	0.70	0.87	0.633	–0.88	0.609	0.87	0.664
		PMB	0.48	0.93	0.547	–0.96	0.488	1.01	0.407
	70	Planthopper	0.30	1.11	0.249	–1.09	0.268	1.26	0.132
		PMB	0.80	1.71	0.019	–1.67	0.025	1.74	0.012
Third	15	Planthopper	0.15	1.30	0.126	–1.28	0.133	1.21	0.170
		PMB	0.10	1.49	0.059	–1.49	0.060	1.50	0.059
	44	Planthopper	0.40	0.92	0.533	–0.93	0.499	0.83	0.702
		PMB	1.00	0.76	0.902	–0.75	0.915	0.67	0.957
	60	Planthopper	0.28	1.04	0.338	–1.08	0.280	1.03	0.344
		PMB	0.00	–	–	–	–	–	–

Analysis of spatial association suggested that planthopper and PMB were only positively associated when analysis was conducted from the same sampling dates *(Figure 4)*. When they were positively associated, the location where they were associated differed between Pasir Panjang and Limbat. At Pasir Panjang, the positive association was detected from the second (54 DAS, $\chi_p = 0.47$, $p = 0.003$) and third (53 DAS, $\chi_p = 0.68$, $p < 0.001$) seasons. No spatial trend was observed *(Figure 4A–B)*. However, at Limbat the positive association was only detected in the second season (28 DAS, $\chi_p = 0.75$, $p < 0.001$). The area of positive association located at the edge of the area where gaps of both planthopper and PMB were formed *(Figure 4C)*.

Discussion

Results of this study substantiated previous studies that suggested non-rice habitat is important for conservation of generalist predators within rice ecosystem (Way and Heong 1994; Schoenly et al. 1998; Way and Javier Jr 2001). Conservation of generalist predator population in rice ecosystem is vital to keep planthopper population below the economic damage (Heong et al. 1992; Way and Heong 1994). PMB as well as other predators could be conserved in non-rice habitat, such bunds and semi natural habitats, especially between rice seasons when no rice crop is planted.

In this study, PMB was consistently present in the early season at Limbat site, which were able to keep the planthopper populations at low density for all seasons of experiment. In contrast, lack of non-rice habitat at Pasir Panjang might result in high and variable planthopper density such as observed in the third season of experiment. The exact explanation for the explosive planthopper population in the third season (at Pasir Panjang) is not well understood. However, it gave the impression that one of the practices carried out by a farmer such as regular pesticide spraying at this site for this particular season had favoured planthopper population. This was obvious as the nymph population increased nine folds compared to its adult. As suggested by Way and Heong

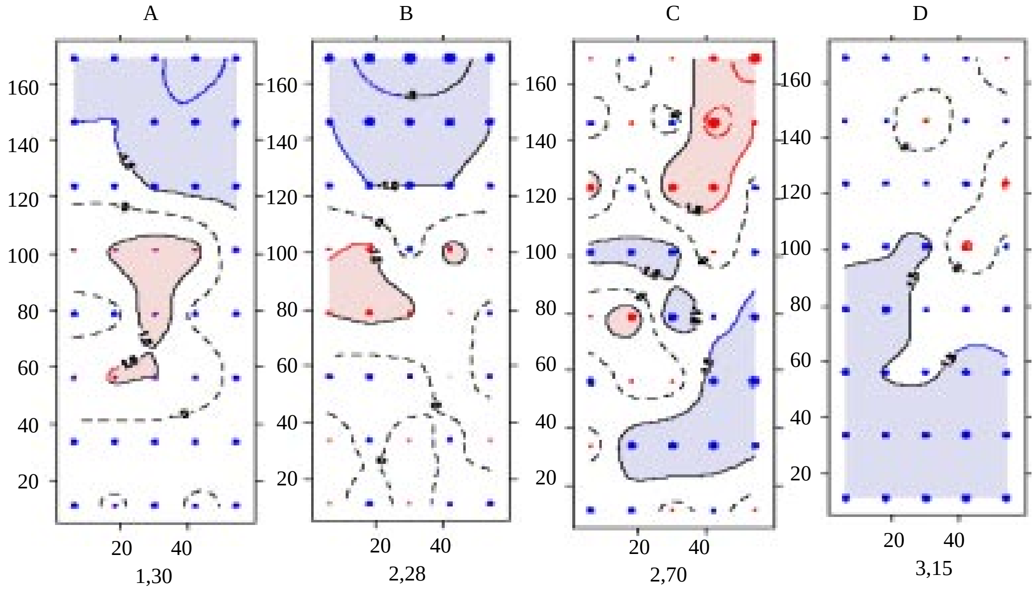

Figure 3. Maps of clustering for planthopper (A–B) and predator mirid bug (C–D) that were significantly aggregated, I_a >1 (p_a <0.05) from Limbat site. (Number below maps indicated season number and number of DAS when insect sampling was conducted)

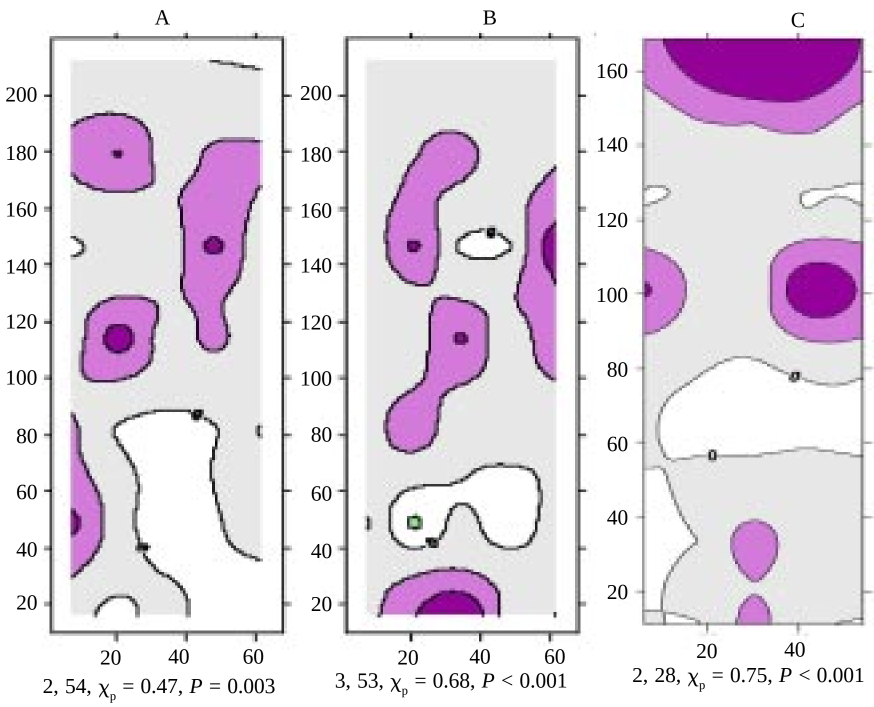

Figure 4. Maps of spatial association between planthopper and predator mirid bug at Pasir Panjang (A–B) and Limbat (C). Dark plum colour indicated both planthopper and predator mirid bug occurred or not occurred together and green colour indicated otherwise. (Number below maps indicated respectively season number, number of DAS of cluster of spatial pattern used for the analysis, χ_p value and probability of respective χ_p)

(1994), the application of pesticide and the removal of vegetations on bunds could interrupt the stable relationship between planthopper and its predators that could result in resurgence of planthopper population.

The above conclusion was further supported by the result of spatial pattern analysis. At both sites, the patches of planthopper occurred further away from non-rice habitat area and its gaps occurred near the non-rice habitat. The possible explanation was that planthopper colonized rice field at random, however predators that reside in the non-rice habitat preyed on those planthopper adults in the vicinity. In other words, planthopper could only establish itself in the area further away from non-rice habitat but failed to establish in areas near to non-rice habitat. This finding supports the idea that habitat diversity such as non-rice habitat in rice ecosystem is important for rice pest management (Sheehan 1986; Way and Heong 1994). Other studies have also indicated that the size and composition of non-crop habitat adjacent to crop fields have the positive effect on natural enemy within crop fields (Thomas and Marshall 1999; Mohd Norowi et al. 2000).

This study, conducted at two sites with different features of non-rice habitats, showed complex pattern of high and low planthopper density within rice crops. Although population of predators were not monitored, previous studies (Way and Heong 1994; Schoenly et al. 1998; Way and Javier Jr 2001) widely indicated that rice area with large non-rice habitat could conserve high density of beneficial arthropod such as PMB, *Microvelia douglasi atrolineata*, gryllidae and spiders that are able to suppress planthopper population. It was also shown that the distribution of non-rice habitat is also important to increase the effectiveness of these predators. This information may provide the opportunity to manipulate habitat diversity for conservation of beneficial arthropod in rice ecosystem (Xiaoping 2001). It may also provide potential for spatial application of insecticide (Sylvester-Bradley et al. 1999), reduced amount of insecticide used and thus reducing the negative impact on beneficial insects (Heong et al. 1994). Understanding the interplay between environment and behavioural factors, which determine the spatio-temporal distribution of pests and beneficial insects, could lay the foundations for push-pull strategy (Pickett et al. 1997) in the management of rice pests.

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Abstrak
Taburan merata dan bertempoh benah dan pemangsa mirid dikaji dan ditentukan. Kajian dijalankan di Pasir Panjang dan Limbat bertujuan menilai peranan kawasan bukan padi dalam pemuliharaan populasi arthropod berguna dalam kawasan padi. Kedua-dua tempat ini berbeza dari segi kedapatan kawasan habitat bukan padi. Di Limbat, kawasan habitat bukan padi lebih luas daripada di Pasir Panjang.

Corak bertempoh benah tidak serupa antara kedua-dua tempat ini. Di Pasir Panjang, kepadatan benah berubah-ubah antara musim dan dalam musim. Kepadatan tertinggi bagi benah dewasa ialah 3 ekor benah/m^2 pada musim pertama dan meningkat kepada 45 ekor benah/m^2 pada musim ketiga. Populasi pemangsa adalah rendah dan tiba terlewat berbanding dengan populasi benah. Di Limbat, kepadatan benah dewasa adalah rendah dan hampir sama pada ketiga-tiga musim, dengan terdapat kurang 5 benah/m^2. Kepadatan populasi pemangsa mirid pula adalah agak tinggi di Limbat.

Penganalisisan corak merata menunjukkan tompok-tompok benah sentiasa berlaku di tengah kawasan percubaan di kedua-kedua tempat ini. Pemangsa umum yang berada di kawasan bukan padi mungkin telah membunuh benah yang berada berdekatan dengan kawasan ini. Walau bagaimanapun pemangsa ini bergerak agak perlahan ke kawasan yang lebih jauh dari kawasan bukan padi tersebut menyebabkan kelompok benah terbentuk di tengah-tengah kawasan. Keputusan ini mengutarakan bahawa ketidakserupaan (heterogeneity) merata yang berbentuk tompok-tompok di kawasan bukan padi dalam landskap padi boleh dimanipulasikan untuk pemuliharaan populasi arthropod berguna bagi mengawal populasi benah.

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