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Arthropod responses to peat land ecosystem development: Their value as agro-environmental indicators

(Tindak balas artropod terhadap pembangunan ekosistem tanah gambut: Nilainya sebagai petunjuk persekitaran pertanian)

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Abstract

Agro-environmental indicators would be useful to monitor the effect of peat land development on the environment. Arthropod populations have been widely used as indicators to monitor the impact of human activities on the agro-ecosystem. In this study, the responses of ground beetles, tiger beetles, ants and spiders to the changes in transforming peat land ecosystem to agro-ecosystem were monitored with pitfall traps. Their spatial-temporal distribution patterns were investigated to indicate their suitability as agro-environmental indicators. Ground beetles were adversely affected when the peat land was cleared, suggesting its potential for monitoring immediate peat land development. Spiders and ants were abundant in the early peat land development but did not show much spatial response to changes in the landscape. They may still be useful for agro-environmental indicators, but have to be investigated in greater detail at the species level and/or a larger study area. Tiger beetles were also abundant in the early peat land development and their populations responded spatially to the landscape changes. They appeared to have the highest potential as agro-environmental indicators in early peat land development. Tiger beetles seemed to be associated with ecosystem with diverse vegetations. It is useful to delve into their ecological processes in newly disturbed peat land to further ascertain their suitability as agro-environmental indicators for wise peat land use.

Introduction

Sustaining the ecosystem functions is one of the serious challenges in managing peat land for agriculture. The ecosystem functions reflect the interactions of living organisms, including humans with their environment (Naeem et al. 1999). When peat land is developed, its biodiversity declines and its ecological processes change. There is a loss in some of the ecosystem functions such as predation, pollination and water filtration (Welch and Graham 1999). Thus, proper planning in developing peat land to agriculture can avoid the loss of ecosystem functions and thus increase peat land productivity.

The major constraint in sustainable peat land development is the difficulty in predicting the organism responses to the peat land changes because of the complex interactions involved. Consequently, it is useful to have agro-environmental indicators to assess the impacts of human activities on the peat ecosystem. An agro-environmental indicator is a scientific measure to assess the ecological status and trends in the

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health of an ecosystem and its components (Rigby et al. 2001). The indicators should respond quickly to the environmental stress, have a short generation time, require only easy sampling and identification, and have integrative effects over time (Noss 1990).

Arthropods perform important roles in ecosystems. They are important elements in food chains, being the most diverse group of organisms, and have been used as general indicators of ecosystem health (Oostermeijer and van Swaay 1998). The application of any agro-environmental indicator would require detailed knowledge of its basic ecology. It is believed that the spatial-temporal pattern of an arthropod population in its habitat is governed by the ecological processes acting at the landscape level (Jansen 1995). Hence, quantifying the spatial-temporal patterns of the arthropod can reveal much of its ecological information enabling its count to be used as an agro-environmental indicator for the status of biodiversity in the agro-ecosystem (Andersen 1993; de Bruyn 1999).

The purpose of this study was to gather basic ecological information of selected arthropod families *vis-à-vis* the level of biodiversity in developed peat land ecosystems. The ultimate goal was to develop an agro-environmental indicator to monitor the state of biodiversity and ecological functions in the developed peat land ecosystem. The study focused on four taxa of arthropods considerably different in mobility and ecological requirements – ground beetles (Coleoptera: Carabidae), tiger beetles (Coleoptera: Cicindelidae), ants (Hymenoptera: Formicidae) and spiders (Arachnida: Araneae). All these taxa are common in peat land (Mohd Norowi 2003). Their populations in a developed peat ecosystem at Sessang, Sarawak (1º 54' 50"N, 111º 14' 03"E) were monitored with pitfall traps. Functionally, they are generally predators and detritivores (Marc et al. 1999; Irmler 2003; Dunn 2008)

Materials and methods

Study sites

Two sites of developed peat land were selected. Both sites were located side by side at Sessang, Sarawak. The first was in MARDI Research Station (MRS) and the second in a field of matured oil palm (MOP) adjacent to MRS. The MRS site was newly developed – cleared in 2001 and planted in 2005 with pineapple, papaya, sweetpotato and fruit trees. The MOP site was cleared in 1990 and planted with oil palm in 1995. Plots measuring 200 m x 700 m (MRS) and 170 m x 100 m (MOP) were demarcated for sampling the arthropod populations.

Figure 1 shows the trap set-up and land use pattern at the two sites. At MRS, there were 104 sampling points in a grid of 13 rows x 8 columns (50 m between rows and 26 m between columns). It was surrounded by various vegetation types – fallow land to the north and south, regenerated bush to the east and newly planted fruit trees, herbal plants and regenerated bush to the west. Remnant peat forest can be found at the south-east and south-west corners. In addition, a main field road passes by the north and south. An internal drain (stream) passes about one-third to the north and an inner field road passes about one-third to the south traverse the site. Initially, the area was planted with pineapple, sweetpotato and papaya. Except for the pineapple area, the other crops were rotated with pineapple or the area left fallow.

The MOP site is part of a larger area of matured oil palm. There is a stream in the east running through the developing peat land and a main field road on the eastern edge. Thirty traps were arranged in a grid of 5 rows x 6 columns, 35 m between rows and 25 m between columns – dictated by the planting distance of the palms.

Description of selected arthropods

Ground beetles (GB) GB are general predators, found in just about any habitat with small organisms for them to prey. They are most diverse and common in forests, marshes and swamps. The larvae usually live in decaying detritus on the surface soil. GB have been used to monitor human impact on several agro-ecosystems (Burel and Baudry 1995; Doring et al. 2003).

Tiger beetles (TB) TB are principally diurnal insects with individuals readily observed foraging in exposed habitats (Pearson and Vogler 2001). Adult TB occur in open forests, preferring the sunny spots, especially small sandy patches. The eggs are deposited singly in shallow depressions, the larvae remaining in the soil until pupation and adult emergence. Thus, the activity of peat land development was expected to affect TB behaviour.

Ants Ants are commonly used as ecological indicators in agricultural landscapes (Andersen 1993; de Bruyn 1999). They are considered 'good' indicators

Figure 1. Superimposed pitfall trap coordinates on aerial photos of MRS and MOP sampling sites. The MRS site was surrounded by various vegetations such as fallow land (FL), newly planted fruit trees (FT), herbal plants (HB), regenerated bushes (BS), remnant peat forest (FR). The MOP site was under matured oil palm except a stream to the west and developing peat land beyond. Main field road (MFR) bordered to the north of the area

because of their quick response to the changing environment, short generation time, easy sampling and identification, and integrative effects over time (Noss 1990). In addition, ants improve soil aeration (Andersen 1993).

Spiders Spiders are also 'good' indicators being so abundant in many agro-ecosystems (Marc et al. 1999). They are general predators on several agricultural pests.

Data collection and analysis
All the four insect taxa were sampled with pitfall traps, commonly used for inventory taking of arthropods which are slow moving and ground-dwelling (Powell et al. 1996). The trap is just a smooth-sided container (plastic cup 7.5 cm diameter x 8 cm height) sunk into the ground with its open top flush with the ground surface. Arthropods moving on the soil surface accidentally fall in and are unable to climb out due to the smoothness of the cup. The traps were placed in the area at predetermined points in a grid of X m x Y m (*Figure 1*).

Sampling at MRS started in December 2005 and was done on alternate months until April 2008, while MOP started in June 2007 and was done on alternate months as with the former site. On each sampling date, the traps were set up for 3 days, filled one-third with water with some detergent added to preserve the trapped arthropods. All the traps had a 'roof' of a 12-cm diameter plastic plate to keep out the rain. On the third day of sampling, the trapped arthropods were collected and brought to the laboratory for identification and counting. Due to shortage of help, the arthropods were only identified to the 'family' level.

The temporal pattern was determined by the variation in count over time. The number of each taxon was converted to density/m^2 and plotted for each date. The spatial pattern was determined with the SADIE system (Perry et al. 1996; Perry 1999) which is independent of the numeric properties. The SADIE system calculated the mean and variance of the counts, the spatial pattern being the arrangement of counts for the minimum effort by the individuals in the population to move to a completely regular arrangement with equal counts in all the sampling units. In practice, this effort equates to the minimum distance, D, to move to complete regularity. Dividing D by the mean from several hundred such randomizations gives an index of aggregation, I_a. Ecologically, I_a = 1 indicates random counts, while I_a <1 and I_a >1 respectively indicates regular and aggregation of the counts in clusters.

However, I_a does not encompass all the facets of spatial pattern in an arrangement. Two more indices were needed, v_i and v_j, and the methods to derive them were explained in detail by Perry (1999). Basically, v_i and v_j indicate the patches of above-average density and gaps of below-average density respectively. SADIE classifies the sampling area into regions in which the counts, c, are either effectively random or clustered, i.e. neighbourhoods of similar-sized counts near together. Denoting the sample mean as m, a cluster with $c > m$ is a patch and one with $c < m$ a gap. Areas with $v_i = 1$ are random and with $v_i > 1$ patches, while areas with $v_j = -1$ are also random and with $v_j < -1$ gaps. The tests for non-randomness are based on random occurrence of the counts throughout the sampling points, so the index is unaffected by the magnitude of the individual counts. Therefore the local cluster index is independent of the counts (Perry and Dixon 2002).

Local clusters were mapped and contoured with SURFER 8.0 software (Golden Software Incorporated 2002). They were depicted on maps as contours within which the estimated indices were $v_i > 1.5$ or $v_j < -1$, which corresponded to the 95th percentile of the respective randomization distributions. Before they were mapped, the clusters were interpolated using a linear kriging algorithm with 0 nugget variance. The resulting output was overlaid on a map of the sampling area to enable identification of the patches and gaps (Winder et al. 2000). Interpolation was only used to help visualization, and not for inference. The contour maps of patches and gaps produced depict the strength of the spatial pattern, not the abundance or distribution of the arthropods.

Stability of spatial pattern

The spatial association between sampling dates of significance I_a >1 was tested to determine the stability of the clusters in the area. The spatial pattern between sampling dates may be spatially associated, disassociated or random of each other. The extent to which the cluster indices of the arthropods (either v_i or v_j) 'agree' at each point is a measure of the local spatial association, X_p. X_p >0 (p <0.025) indicates a positive spatial association and X_p <0 (p >0.975) the opposite. X_p >0 can arise from coincidences of patches or of gaps indicated in both counts, and X_p <0 from opposite forms of spatial pattern. The significance of X_p was tested by randomization, with values of the local cluster indices reassigned among the sites, after allowance for small scale spatial auto correlation between the local indices from both dates. In this way, the SADIE method intrinsically allows for the spatial pattern in each component population. When the results indicated significant positive spatial associations, the associations were mapped with SURFER 8.0 software to indicate their locations.

Results and discussion

Temporal pattern of arthropod counts

Figure 2 (a–c) shows the temporal distribution of the arthropod taxa. GB were not considered in the analysis as their density was very low and only encountered in some of the sampling dates. Ants were the most abundant (*Figure 2*A). Based on their density peaks, four cycles of ant population were detected at the MRS site. The density at each peak increased successively except in the final cycle. The highest density of 0.191 ants/m^2 was recorded on June 2007 at the peak of the third cycle, after which the density declined and levelled-off. At the MOP site, ant density was lower, the highest occurring in August 2007 with only 0.024 ants/m^2 recorded. Thereafter, the counts decreased drastically.

TB were the next most abundant (*Figure 2*b). It also showed cyclic temporal distribution. Considering its density peaks, there were at least three cycles of TB recruitment at the MRS site. The first cycle peaked in August 2006 with 0.002 TB/m^2 recorded, the second cycle in February 2007 with the same density, and the third in October 2007 with the density considerably lower that was less than 0.001 TB/m^2. At the MOP site, a peak density of 0.001 TB/m^2 was recorded in December 2007, and then decreased as the agricultural ecosystem stabilized. The spider density (*Figure 2*c) was low at about 0.0003 spiders/m^2 and almost similar on all the sampling dates and sites.

Spatial pattern of arthropod counts

Table 1 summarises the SADIE analysis of arthropod counts. Only ants and TBs had significant aggregated counts (I_a >1) on more occasions at the MRS site. The ant counts were significantly aggregated on three dates – December 2005, April 2007 and August 2007. In December 2005, patches occurred at the northern part and gaps occurred at the southern part of the site (*Appendix 1*). However, on April and August 2007, patches were noted on the southern and middle site and gaps in the north.

The TB indicated I_a values were significantly above unity on five dates (December 2005, February 2006, April 2006, June 2006 and December 2006). TB aggregation occurred only in the early study at the eastern and middle site (*Appendix 1*). In the later study, TB was distributed randomly.

At the MOP site, ants and spiders presented in low numbers while not a

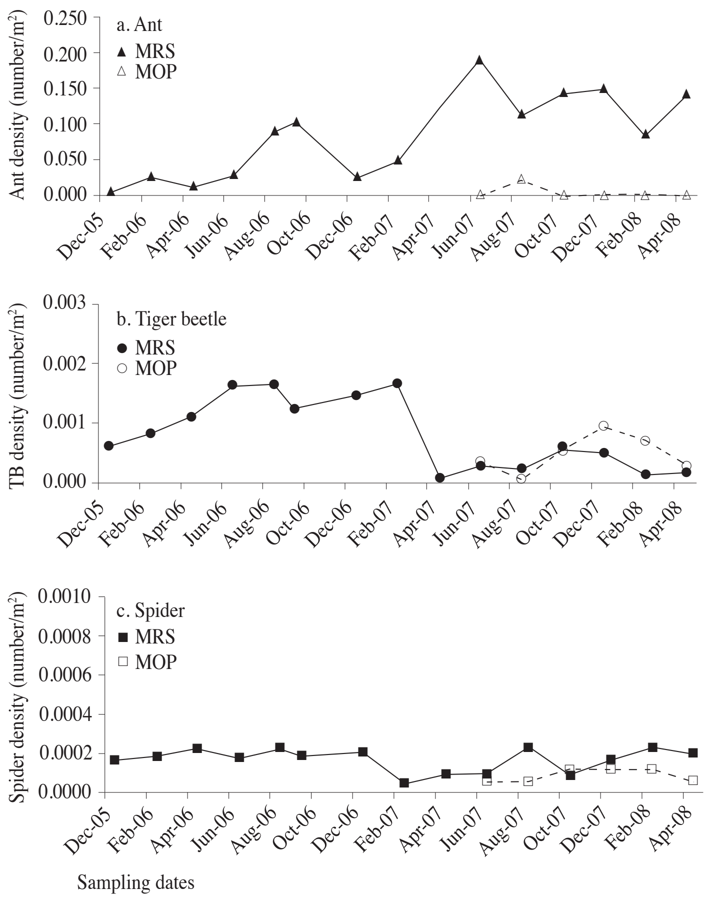

Figure 2. Temporal distribution of ant tiger beetle (TB) and spider recorded at MARDI Research Station (MRS) and matured oil palm plantation (MOP)

single GB was caught. TB had significantly aggregated counts on June 2007, in the north-east of the site (*Appendix 1*).

Stability of spatial patterns

Table 2 shows the spatial analysis of ant clusters from the sampling dates with I_a >1 (December 2005, April 2007 and August 2007). The clusters in December 2005 were significantly disassociated from the clusters on the other two dates. However, the clusters in April 2007 were significantly associated with the clusters in August 2007. This meant that the ant population at December 2005 was different from those in April 2007 and August 2007, while the populations from the two later samplings could be the same. This suggests that the ant population was relatively unstable.

Figure 3a shows the locations of significantly disassociated ant populations between December 2005 and April 2007 (black areas) and *Figure 3b* the locations of the significantly associated populations between April and August 2007. Area of positive spatial association located at the southern part of the site was contributed by cluster of patches while area of positive spatial association in the middle was due to cluster of gaps.

Table 3 shows the spatial association analysis of TB clusters at the sampling dates

Table 1. Spatial analysis (with SADIE system) of arthropod counts from MARDI Research Station (MRS) and matured oil palm (MOP) sites

Sampling date	MRS											
	Ground beetles (GB)			Ants			Tiger beetles (TB)			Spiders		
	Mean count per trap	I_a	$P_{(a)}$	Mean count per trap	I_a	$P_{(a)}$	Mean count per trap	I_a	$P_{(a)}$	Mean count per trap	I_a	$P_{(a)}$
December, 05	0.010	0.887	0.656	8.144	1.709	0.019	0.827	1.618	0.033	0.221	0.809	0.786
February, 06	0.019	0.830	0.688	34.442	1.044	0.339	1.115	2.189	0.002	0.240	0.917	0.545
April, 06	0.000	–	–	16.1058	1.092	0.280	1.490	1.866	0.011	0.298	0.970	0.470
June, 06	0.000	–	–	37.875	1.342	0.108	2.192	1.861	0.011	0.240	0.891	0.595
August, 06	0.029	1.070	0.309	120.961	0.905	0.566	2.231	1.074	0.331	0.298	1.184	0.180
September, 06	0.010	1.180	0.229	138.875	1.485	0.050	1.663	1.298	0.126	0.250	1.660	0.023
December, 06	0.000	–	–	34.567	1.083	0.278	1.981	1.558	0.043	0.279	0.896	0.578
February, 07	0.000	–	–	66.385	1.141	0.218	2.231	1.392	0.079	0.067	0.883	0.600
April, 07	0.000	–	–	167.048	2.118	0.002	0.115	0.907	0.550	0.125	0.827	0.742
June, 07	0.000	–	–	257.673	0.023	0.344	0.385	1.301	0.114	0.125	1.059	0.318
August, 07	0.000	–	–	151.913	2.578	0.001	0.317	1.411	0.075	0.308	1.339	0.096
October, 07	0.000	–	–	192.808	0.244	0.135	0.760	1.218	0.169	0.125	0.937	0.488
December, 07	0.000	–	–	201.904	0.038	0.327	0.683	1.146	0.236	0.221	0.982	0.418
February, 08	0.000	–	–	189.433	0.878	0.633	0.683	1.143	0.235	0.308	1.027	0.335
April, 08	0.000	–	–	113.702	0.056	0.301	0.240	1.043	0.385	0.269	0.814	0.784

(cont.)

Table 1. (*cont.*)

Sampling date	MOP					
	Ants			Tiger beetles		
	Mean count per trap	I_a	$P_{(a)}$	Mean count per trap	I_a	$P_{(a)}$
December, 05	–	–	–	–	–	–
February, 06	–	–	–	–	–	–
April, 06	–	–	–	–	–	–
June, 06	–	–	–	–	–	–
August, 06	–	–	–	–	–	–
September, 06	–	–	–	–	–	–
December, 06	–	–	–	–	–	–
February, 07	–	–	–	–	–	–
April, 07	–	–	–	–	–	–
June, 07	13.367	0.931	0.555	0.200	1.490	0.028
August, 07	–	–	–	0.033	0.798	0.931
October, 07	–	–	–	0.323	0.662	0.913
December, 07	0.333	1.226	0.117	0.533	0.915	0.626
February, 08	–	–	–	0.400	1.059	0.295
April, 08	–	–	–	0.167	1.256	

I_a = Index of aggregation
$P_{(a)}$, = Probability of index aggregation being >1

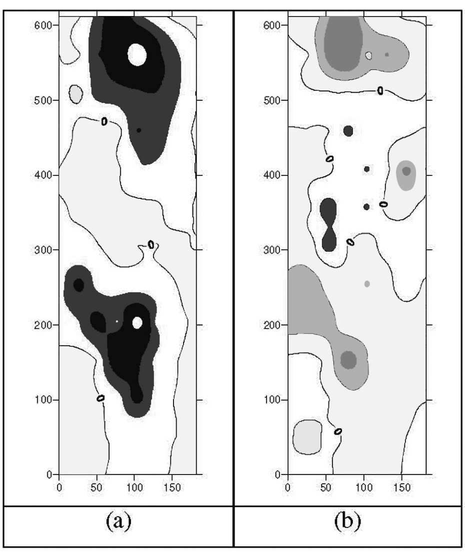

Figure 3. Spatial association of ant counts between sampling dates of (a) December 2005 and April 2007 and (b) April 2007 and August 2007. Black colour indicated spatial dissociation and grey colour indicated spatial association

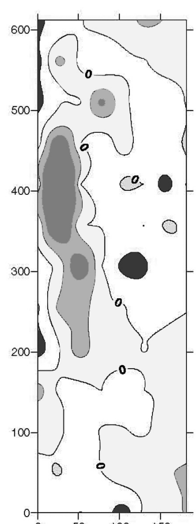

Figure 4. Typical spatial association of ant counts between sampling dates of significant aggregated population. Grey colour indicated where spatial association took place and black colour indicated spatial dissociation

Table 2. Spatial association between significant (I_a >1) clusters of ants at different sampling dates

Sampling dates with I_a >1	Apr-07	Aug-07
Dec-05	–0.5013	–0.5403
Apr-07		0.2622

Positive numbers indicate significant association (p <0.025) and negative numbers indicate significant disassociation (p >0.975)

Table 3. Spatial association between significant (I_a >1) clusters of TB at sampling dates

Sampling dates with I_a >1	Feb-06	Apr-06	Jun-06	Dec-06
Dec-05	**0.2545**	0.1472	**0.5589**	**0.534**
Feb-06		–0.1276	0.1657	–0.636
Apr-06			**0.3287**	0.365
Jun-06				**0.674**

Positive numbers indicate significant association (p <0.025)

(December 2005, February 2006, April 2006, June 2006 and December 2006) with significant aggregation (I_a >1). Except for February 2006, all the TB clusters from the other dates had significant positive spatial association, suggesting that the patches and gaps were very stable, especially in the early study. This implied that TB consistently aggregated in the same area, except in February 2006. At this time, the area was being prepared for replanting pineapple, and the open area possibly suited for TB foraging. *Figure 4* depicts a typical location of positive association of TB clusters with significant aggregated counts between sampling dates. Positive association occurred towards the eastern and southern sites. The eastern area had patches and the southern area had gaps. The eastern area was close to semi-natural habitat which is rich in biodiversity of flora of remnant forest that served as refuge for the TB.

Responses of arthropods to peat ecosystem conversion

GB, TB, ants and spiders exhibited different spatial-temporal patterns. This suggests their different responses to the conversion of peat land ecosystem to agro-ecosystem. All four organism counts were higher at MRS than MOP. Their occurrence seemed closely related to the biodiversity level that appeared higher at MRS than MOP. Higher level of biodiversity at MRS was mainly due to the higher level of biodiversity of flora within the area and area surrounding the MRS site. The biodiversity level within the area might attribute to the developmental stage of the area and agricultural practices adopted.

Peat land ecosystem is rich with biodiversity especially arthropods (Suzuki et al. 1991). When it was developed, its biodiversity level fluctuated considerably. It started off with being extremely low with the forest cover cleared. Its biodiversity then gradually increased with the natural vegetation reestablishment and crops planted (Thomas and Marshall 1999; Salma et al. 2007). Finally, its biodiversity may reach a steady state when vegetation within and outside the area were minimally changed. Cultural practices within the area may also affect biodiversity in the area. Poly-culture would generate greater biodiversity than monoculture (Stamps and Linit 1997), and using insecticides would reduce the arthropod diversity (Way and Heong 1994).

The change in biodiversity could affect the habitat quality of many organisms as the biodiversity would affect the availability of food, mates, natural enemies and other factors that affect their survival and reproduction (Turchin 1999). Hence, the change in biodiversity level may result in change in some of their ecological process (Lindenmayer et al. 2001). The change in their ecological process may reflect in their spatial-temporal distribution (Pickett and Cadenasso 1995). Consequently, the spatial-temporal pattern of arthropod counts in agricultural landscape may be an indicator of the state of biodiversity in the area.

This study suggested that there were three biological phases, each differentiated by its period of development and level of biodiversity when peat land ecosystem was transformed to agro-ecosystem. The early phase was when the peat vegetation was cleared followed by the second phase when the crops were introduced and finally the third phase was the establishment of the agro-ecosystem.

The MRS site reflects the first and second phases since the peat land was just cleared less than 5 years earlier, and after a few crop cycles, the biodiversity had plummeted and was just beginning to increase. The third phase was represented by the MOP site which had stable state of biodiversity, as it was planted with oil palm for more than 10 years. Since the site was dominated by monoculture of oil palm, the biodiversity was low, exacerbated by the lack of undergrowth.

Knowing the arthropod response to land use would be useful to establish competent environment indicators for conservation and sustainable use of peat land. Overall, GB could be a good indicator for the immediate impact of development as the early phase of peat land development. Its population declined when biodiversity was reduced due to clearing activities. Spiders and ants need to be investigated at the species level and a larger area is needed for them to be meaningful indicators. It was possible that foraging areas for spiders and ants were larger than the study areas. It has been argued that the sampling area should be species-dependent (Wiens 1989; Mohd Norowi et al. 2000). Many species of spiders and ants are abundant in agro-ecosystems (Andersen 1993; Burel and Baudry 1995), but the inability to separate them into species might be the cause of the inability to detect their spatial patterns in this study.

TB seems a better indicator for the second and the third phases of peat land development. Its habitat quality may be related to the presence of natural vegetation and foraging areas. TB responded well to the landscape structures, forming patches and gaps in almost the same area. Their patches and gaps were stable and they consistently aggregated adjacent to semi-natural habitat. The semi-natural habitat adjacent to the MRS site might have had a positive effect on TB as is known for certain insects (Holland and Fahrig 2000). In addition, the openness of the area might have been better for them to forage. A positive relationship between the spatial pattern of arthropods and physical conditions of the land has been frequently observed (Mohd Norowi et al. 1999). They may relate to the gradient of a particular factor like proximity to a natural habitat or moisture. According to Pearson and Vogler (2001), TB are specific in their habitat choice. They prefer sand dune and open forest floor. TB seemed not to prefer the MOP site as its diversity was low and there is lack of openness under matured oil palm trees.

Conclusion

Tiger beetle is a potential agro-environmental indicator for monitoring biodiversity level of peat land development. Its population increases and decreases with the biodiversity level. Tiger beetle also suit Noss's (1999) criteria for a good indicator which suggest that the indicator should respond quickly to the environmental stress, require only easy sampling and identification, and have integrative effects over time. However, their long generation time (about 2 years) is a negative. Nevertheless, as their spatial-temporal pattern can still be related to the level of biodiversity in the area, it may be useful to follow up on this work to further explore their potential.

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Abstrak

Petunjuk persekitaran pertanian amat diperlukan bagi memantau kesan pembangunan tanah gambut terhadap persekitaran pertanian. Populasi artropod telah banyak digunakan sebagai petunjuk untuk mengesan impak aktiviti pertanian terhadap perubahan ekosistem pertanian. Kajian ini meneliti tindak balas kumbang tanah, kumbang harimau, semut dan labah-labah terhadap perubahan kepelbagaian biologi disebabkan aktiviti penerokaan bagi mentransformasikan ekosistem tanah gambut kepada ekosistem pertanian. Tindak balas dari segi perubahan corak taburan semasa dan setempat telah dikenal pasti berdasarkan bilangan populasi mereka yang terperangkap dengan perangkap “pitfall”. Corak taburan semasa dan setempat telah dijadikan asas untuk menilai kesesuaian mereka sebagai petunjuk persekitaran pertanian. Kumbang tanah telah menunjukkan kesan negatif sebaik sahaja ekosistem tanah gambut diterokai, menunjukkan mereka berpotensi dijadikan petunjuk pada peringkat awal pembangunan tanah gambut. Labah-labah dan semut pula banyak terdapat di awal penerokaan tanah gambut tetapi tidak menunjukkan tindak balas yang jelas terhadap perubahan corak landskap. Mereka mungkin berpotensi untuk dijadikan petunjuk persekitaran pertanian tetapi memerlukan kajian yang lebih terperinci sama ada di peringkat taksonomi ataupun menggunakan petak kajian yang lebih luas. Populasi kumbang harimau juga tinggi di awal penerokaan tanah gambut dan mereka menunjukkan tindak balas yang jelas terhadap perubahan corak landskap. Kumbang ini sangat berpotensi untuk dijadikan petunjuk persekitaran pertanian pada awal pembangunan tanah gambut. Mereka didapati berkait rapat dengan persekitaran pertanian yang agak tinggi kepelbagaian tanamannya. Kajian terperinci terhadap proses ekologi kumbang ini di kawasan tanah gambut yang baru dijadikan kawasan pertanian perlu dijalankan untuk memastikan kesesuaian mereka sebagai petunjuk persekitaran pertanian yang jitu bagi menjamin penggunaan lestari ekosistem tanah gambut.

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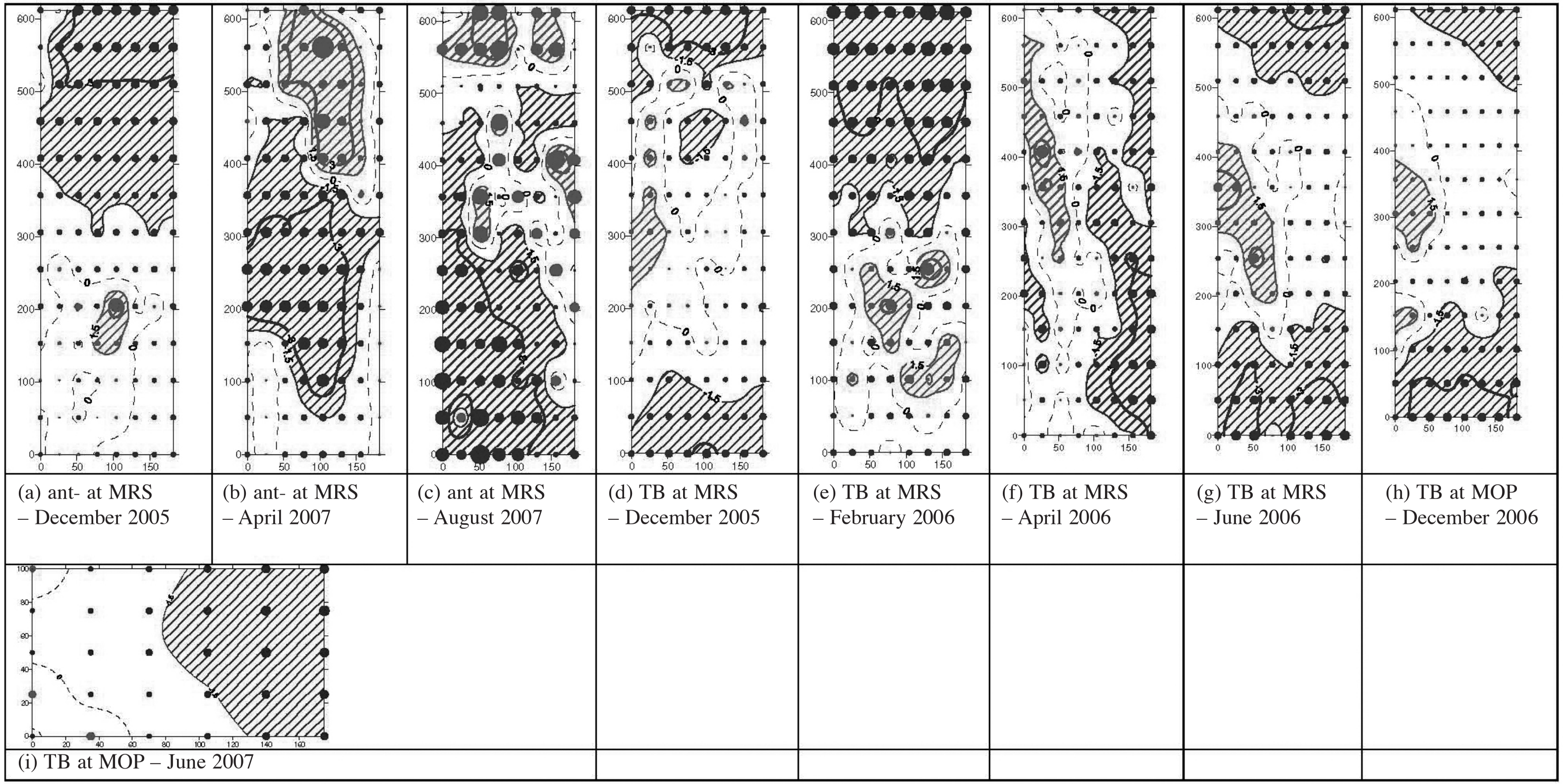
Appendix 1. Spatial patterns of ant counts at MRS site (a-c) and tiger beetles (TB) at MRS (d-g) and MOP (i) sites. The maps are of $I_a > 1$ ($p \leq 0.05$)



(a) ant- at MRS – December 2005

(b) ant- at MRS – April 2007

(c) ant at MRS – August 2007

(d) TB at MRS – December 2005

(e) TB at MRS – February 2006

(f) TB at MRS – April 2006

(g) TB at MRS – June 2006

(h) TB at MOP – December 2006

(i) TB at MOP – June 2007

Note: The size of dots (either black or grey) indicated contribution of each sampling point to the patch clusters (grey) or gap clusters (black)