

Spatial-temporal distribution of carabid beetles in wetlands

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Abstract

In this study, we investigated carabid beetles residing in the wetlands to understand their ecological adaptation and strategy selection associated with restricted resources and habitat limitation. The species richness, abundance, seasonal activity, and spatial distribution of the carabid beetles between the Mujechi Wetlands (wetland sites) and Mt. Jeongjok (mountain sites) have been compared. A total of 1,733 individual beetles from 30 species were collected and classified at the studied sites. The wetland sites were identified as having lower species richness and abundance for carabid beetles when compared with the adjacent mountain sites, whereas these beetles were observed to be dominant in the wetland sites than in the adjacent mountain sites. *Calosoma inquisitor cyanescens*, *Carabus sternbergi sternbergi*, and *Carabus jankowskii jankowskii* species were dominant in both the wetland and mountain sites. These species showed significantly different seasonal activity patterns in the wetland sites relative to the mountain sites. Although the three listed carabid species were observed to be widely distributed throughout the wetland sites, they still showed preference for drier sites, which clearly shows a distinction in their habitats. The results of the spatial-temporal distribution of carabid beetles in the wetland sites reflect their special strategies regarding space and time partitioning for maintaining their population. The distribution patterns of carabid beetles in the wetland sites also showed the desiccation gradient and environmental changes prevalent in wetlands. Ecological surveys, which use carabid beetles in the wetlands, can then be performed when restoring wetlands and for establishing management practices for improving the habitat quality.

Key words: carabid beetles, distribution, ecological strategy, limitation resource, seasonal activity, wetlands

INTRODUCTION

A wetland is an area where the soil is either permanently or intermittently submerged throughout the year, or for varying times of the year, including the growing season. As a result, hydrology determines soil formation and development (pedology), and in combination, the two variables also affect the structure of the ecological communities present in the wetlands. Because of the dual nature of a wetland, these variables provide conditions that support both aquatic and terrestrial species. The prolonged presence of water creates conditions that favor the growth of specially adapted plants and animals and promotes the development of characteristic wetland soils (Cowardin et

al. 1979, Mitsch and Gosselink 1993).

However, because of their characteristic traits, wetlands create habitat islands in the surrounding landscape matrix, which may or may not be limited in size (areal extent). In typical mountainous areas, wetlands are more isolated and limited in areal extent (Forman 1995), and thus are described as azonal or extrazonal ecosystems relative to the surrounding matrix (Spitzer and Danks 2006). In addition, in wetlands, the climate is cool, precipitation is relatively high, evaporation is often limited, and drainage may be poor. Hence, for terrestrial species that prefer the dry habitats or are nonadapted to wet conditions, the

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aforementioned conditions have a negative effect on their hibernation and reproduction (Andersen 2006). In general, species inhabiting this type of habitats, which have limited resources, could choose special strategies such as temporal, spatial, and food resource partitioning to survive and to maintain their population (Schoener 1974, Niemelä 1993).

We investigated the carabid beetles in wetlands for explaining their survival strategies in wetlands that have restricted resources and limited habitat conditions. The carabid beetles show sufficient variation taxonomically and ecologically, and they are too abundant and sensitive to environmental changes to be considered a reliable monitoring group. Specifically, carabid beetles have been observed to be highly sensitive to wetland types and wetland environmental characteristics (Do et al. 2007b). Their habitat distribution, annual and daily activity patterns, and diet are determined by abiotic factors (e.g., light, moisture, habitat structure) and biotic factors (e.g., competition, food supply) (Williams 1959, Thiele 1977, Loreau 1985, Kang et al. 2009, Do et al. 2011, Jung et al. 2011).

We tested the following predictions: 1) There is a significant difference in the assemblage of carabid beetles in the wetlands when compared with adjacent habitats (e.g., mountain), regarding species richness and abundance. 2) Carabid species that preferred the dry habitats limit their spatial distribution depending on the wet condition of the wetlands. 3) Carabid beetles inhabiting wetlands have different seasonal activities when compared with other habitats to survive and to maintain their population. This article also discusses the wetland environmental changes using the carabid assemblages as ecological indicators, for the establishment of wetland management regimes.

MATERIALS AND METHODS

We studied the seasonal activity and spatial distribution patterns of carabid beetles at the Mujechi Wetlands (wetland sites) of Ulsan Metropolitan City (Republic of Korea) and Mt. Jeongjok (mountain sites). The Mujechi Wetlands (35°27'51.13" N, 129°08'38.94" E) is a 1.5 ha montane peat bog at 520-530 m altitude on Mt. Jeongjok (700 m above sea level), which was designated as a National Wetland Conservation Area by the Republic of Korea in 1997. The wetlands originated from differential weathering and erosion, and it has existed since 1,785 ± 120 y BP (Choi 1998). The annual average temperature and precipitation were approximately 13.8°C and 1,275 mm, respectively, as re-

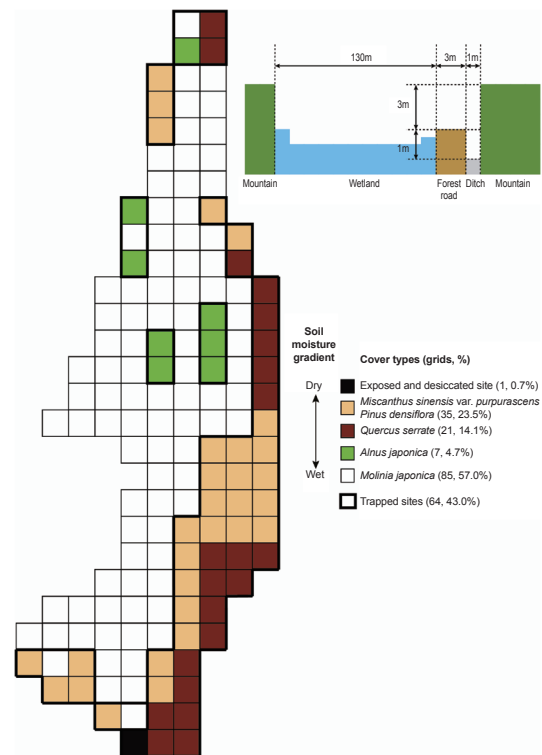


Fig. 1. Simple vegetation map of the Mujechi Wetlands.

corded at the Ulsan Weather Station, 19.4 km away from the Mujechi Wetlands. However, because the weather station is at an elevation of 35 m, it is likely that the actual temperature of the wetlands is lower. Water flows in the wetlands from the south-southwest (SSW) to north-northeast (NNE) direction. The mean groundwater level was -34.7 m, which became shallower with increasing rainfall and deeper with less rainfall (Lee and Kim 2002).

An equal grid map (15 × 15 m quadrats) with simple vegetation, identifying the characteristic vegetation of the Mujechi Wetlands, was used to confirm the sampling sites and environmental variables (Kim and Kim 2003). The dominant wetland plant species are *Molinia japonica*, *Miscanthus sinensis* var. *purpurascens*, *Pinus densiflora*, and *Alnus japonica*, with the surrounding slopes being dominated by *P. densiflora* and *Quercus serrata*.

In the wetlands, *M. japonica* is most dominant covering 85 quadrats (57%). Comparatively, mixed vegetation including *M. sinensis* var. *purpurascens* and *P. densiflora* occupied 35 quadrats (23.5%), whereas *Q. serrata* and *A. japonica* occur in 21 quadrats (14.1%) and 7 quadrats (4.7%), respectively. There is one quadrat, which consists of exposed soil located at the upper edge of the wetlands. The wetland is divided and isolated from the mountain slope by a forest road and ditch (Fig. 1).

Out of a total of 149 quadrats in the wetlands, pitfall traps (plastic cups, 7 cm diameter) were installed in 64 of them (43.0%). Installing pitfall traps in wetland-grass sites is very inconvenient because of the high water level and the protected status of the *M. japonica* community. In the mountainous area, 20 pitfall traps were installed at three sites every 3 m. The sites investigated in this study are designated as Wetland Conservation Areas and, hence, the use of baits and preservation liquids is prohibited for the protection of the species inhabiting the wetlands. As much as possible, the traps were installed in the center of the site in homogenous stands of vegetation at each site. The trapping period covered most of the growing season (from January to December 2005), and the traps were emptied after 48 h.

The carabid species richness was compared between treatments using individual-based rarefaction curves. This technique is based on a random resampling of the pool of captured individuals, and it is used to estimate expected richness at lower sample sizes (Magurran 1988, Gotelli and Colwell 2001). The distribution of the dominant carabid species and large-sized species that inhabit the wetlands were marked on an equal grid map, which designated where the individuals from each species were caught.

The difference in species composition and seasonal activities of carabid beetles between the wetlands and the mountain were tested for statistical significance using a paired *t*-test on data transformed using $\ln(x + 1)$. The spatial distribution of some species in the wetlands was calculated using a paired *t*-test and one-way analysis of variance (ANOVA) on the abundance and appearance of frequency data of the carabid beetles. All statistical analyses were performed using Minitab 16 software (Minitab Inc., State College, PA, USA).

RESULTS

Diversity and assemblages of carabid beetles

A total of 1,733 individual beetles representing 30 carabid beetle species (including brachinid species) were collected from the studied sites (Table 1). The wetland sites had 16 species (53.33% of total species richness), and mountain sites had 26 species (86.66% of total species richness), respectively. The rarefied species richness was observed to be higher for the mountain sites when compared with the wetland sites (Fig. 2). Moreover, carabid abundances between the wetland and the mountain sites

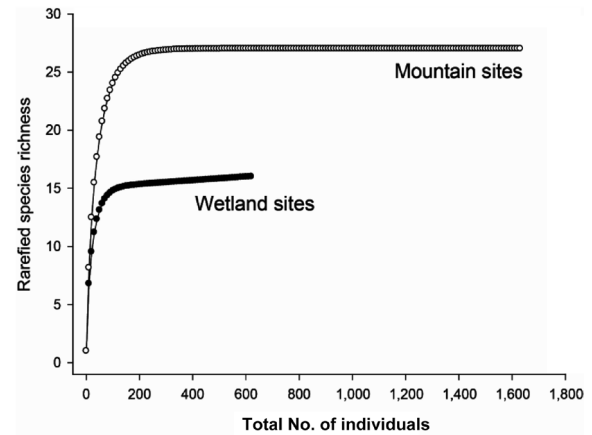


Fig. 2. Rarefied species richness for the wetland and mountain areas.

Table 1. Carabid beetle species list for the wetland and mountain areas

Species name	Bog	Mountain
<i>Calosoma inquisitor cyanescens</i>	36	32
<i>Carabus sternbergi sternbergi</i>	129	265
<i>Carabus jankowskii jankowskii</i>	29	160
<i>Carabus smaragdinus branickii</i>	1	50
<i>Carabus seishinensis seishinensis</i>	0	19
<i>Nebria chinensis chinensis</i> Bates	0	43
<i>Diplous caligatus</i>	14	0
<i>Lesticus magnus</i>	0	39
<i>Trigonognatha coreana</i>	0	26
<i>Pterostichus audax</i>	0	25
<i>Pterostichus fortis</i>	14	26
<i>Colpodes buchanani</i>	0	34
<i>Platynus impressus</i>	16	44
<i>Platynus magnus</i>	17	34
<i>Dolichus halensis</i>	0	25
<i>Synuchus nitidus</i>	20	64
<i>Synuchus cycloderus</i>	24	56
<i>Anisodactylus signatus</i>	0	34
<i>Harpalus capito</i>	23	65
<i>Harpalus chalcidus</i>	0	17
<i>Amara chalcites</i>	34	0
<i>Amara ussuriensis</i>	0	43
<i>Chlaenius pallipes</i>	0	51
<i>Chlaenius bioculatus</i>	26	42
<i>Macrochlaenites costiger</i>	0	34
<i>Cymindis vaporariorum immaculatus</i>	17	0
<i>Demetrias marginicollis</i>	24	0
<i>Lebidia octoguttata</i>	0	17
<i>Planets puncticeps</i>	17	34
<i>Brachinus stenoderus</i>	0	13

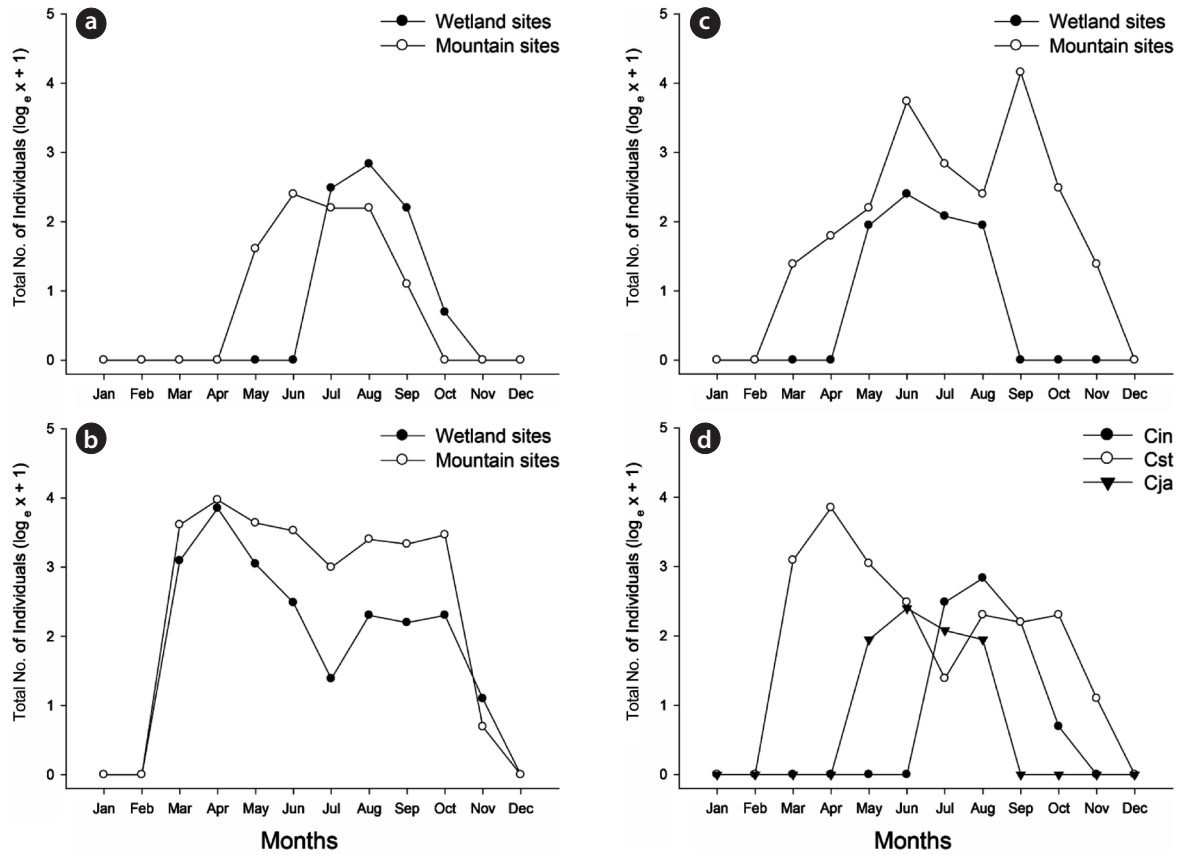


Fig. 3. Seasonal appearance patterns of the three studied carabid beetles in the wetland and the mountain sites. (a) *Calosoma inquisitor cyanescens* (Cin), (b) *Carabus sternbergi sternbergi* (Cst), (c) *Carabus jankowskii jankowskii* (Cja), and (d) three species in the wetlands.

were significantly different (paired *t*-test value = -2.75, *P* = 0.008), although 12 species (70.58% of total species richness in the wetlands) occurred in both areas. Some species such as *Amara chalcites*, *Demetrias marginicollis*, and *Cymindis vaporariorum immaculatus* were found exclusively in the wetland sites.

Both the wetland and mountain sites were dominated by *Carabus sternbergi sternbergi* (29.25% and 20.51%, respectively). Twenty-six species accounted for less than 5% of the caught (less than approximately 50 individuals) (cf. Table 1). In the wetland sites, *Calosoma inquisitor cyanescens*, *A. chalcites*, and *C. jankowskii jankowskii* were relatively abundant species, but their proportional abundances were much lesser in the wetlands when compared with that in the mountain sites. Of the abundant species on the mountain sites, *C. sternbergi sternbergi* and *C. jankowskii jankowskii* accounted for 32.89%, whereas the other species recorded on the mountain sites comprised less than 5% of the total individuals.

Temporal appearance pattern

In this study, we investigated *Calosoma inquisitor cyanescens*, *C. sternbergi sternbergi*, and *C. jankowskii jankowskii*, which were relatively abundant and were the largest sized species on both the wetland and the mountain sites.

C. inquisitor cyanescens showed a single-peak cycle in both the habitats. Seasonal activity patterns of this species showed no statistical differences between the areas (paired *t*-test value = 2.84, *P* = 0.708) (Fig. 3a). However, in the wetland sites, adult *C. inquisitor cyanescens* was active from June to October, and the maximum activity period of the species was very short. However, in the mountain sites, this species was active from May to September, which indicated that this species occurred at an earlier time when compared with the wetland sites.

The main activity period of *C. sternbergi sternbergi* extended from March to November, with two peaks in April and August (Fig. 3b). The maximum activity period of the species was more clearly distinguished in the wetland sites than on the mountain sites. Their seasonal changes in both areas were significantly different (paired *t*-test

value = -3.14, $P=0.009$).

C. jankowskii jankowskii showed significantly different activity patterns in the two areas (paired t -test value = -3.27, $P = 0.007$) (Fig. 3c). In the wetland sites, activity of this species began in May, but peaked in June, and the abundance during May-June was followed by a decline in August. However, on the mountain sites, *C. jankowskii jankowskii* had two peaks in May and September. The mountain sites-resident individuals showed a first period of activity in March-August that was always followed by a phase of inactivity, which was in turn followed by a period of activity again in September when it reached its maximum.

In the wetland sites, the three studied species had significantly different seasonal patterns ($F = 3.73$, $P = 0.035$) (cf. Fig. 3d). They were observed to have different maximum activity periods, with *C. sternbergi sternbergi* dominating, whereas both *C. inquisitor cyanescens* and *C. jankowskii jankowskii* had a comparatively lower population. As a result, maximum activity period of *C. jankowskii jankowskii* was delayed, and thus, the peak activity period did not interfere with that of *C. sternbergi sternbergi*.

Spatial appearance pattern

The three species of carabid beetles were present in 22 quadrats (30.99% of investigated quadrats, 12.86% of total quadrats) in the wetlands (Fig. 4). They occurred in 14 quadrats of *Q. serrata*, 7 quadrats of *M. sinensis* var. *purpurascens* (with *P. densiflora*), and 1 quadrat of exposed soil. The 6 quadrats had two species, whereas the other quadrats recorded just one species (Fig. 4a). The association between each vegetation type (number of quadrats) and each recorded carabid species showed no significant difference ($F = 1.36$, $P = 0.325$) (Fig. 5a), but each vegetation type displayed significantly different abundances of each carabid beetle ($F = 6.626$, $P = 0.0303$) (Fig. 5b).

C. inquisitor cyanescens was distributed in 10 quadrats (5 grids and 6 quadrats of *M. sinensis* var. *purpurascens* and *Q. serrata*, respectively) (Fig. 4b). *C. sternbergi sternbergi* was distributed over the largest area (16 quadrats) of the wetlands (Fig. 4c). This species was recorded in *Q. serrata* (11 quadrats) and *M. sinensis* var. *purpurascens* (4 quadrats) communities, as well as in one exposed soil site (1 quadrat). Both *C. inquisitor cyanescens* and *C. sternbergi sternbergi* showed a linear distribution along the wetland edge, adjoining the forest road. *C. jankowskii jankowskii* showed numerical limitations for only 2 quadrats (Fig. 4d).

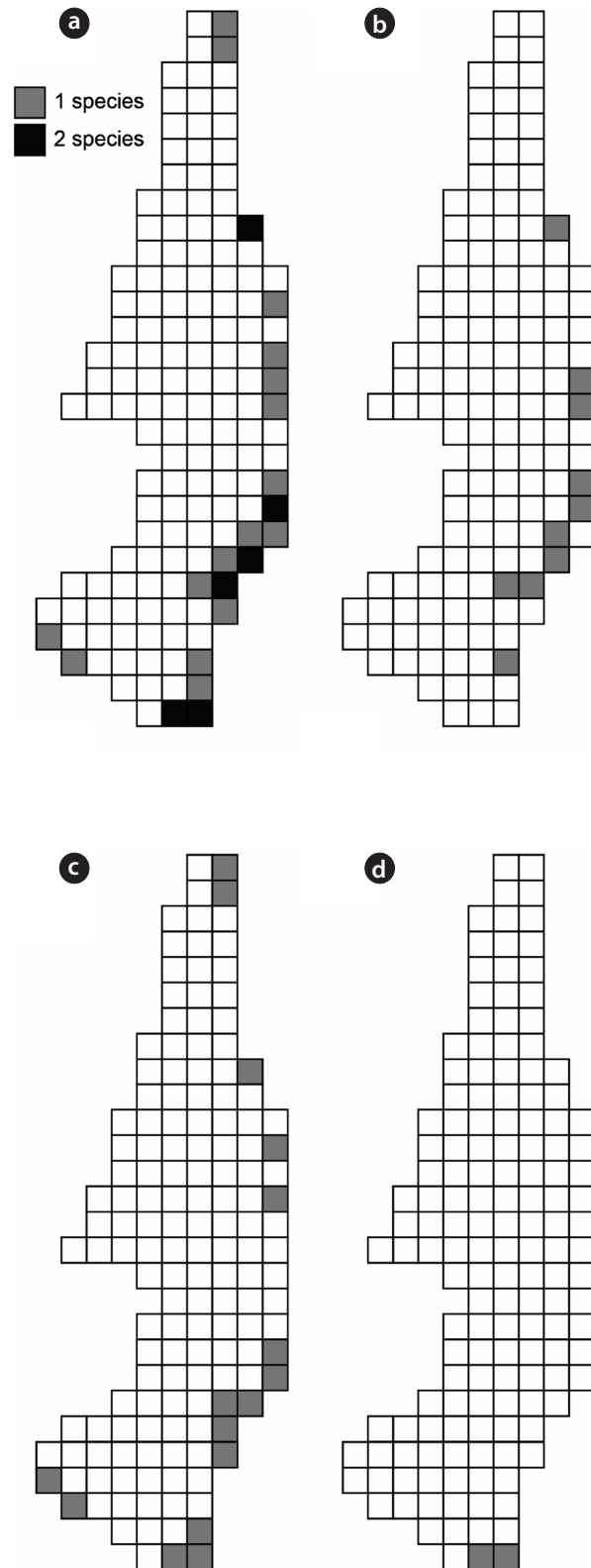


Fig. 4. Spatial distribution of three carabid beetle species in the wetlands. (a) Three species, (b) *Calosoma inquisitor cyanescens*, (c) *Carabus sternbergi sternbergi*, and (d) *Carabus jankowskii jankowskii*.

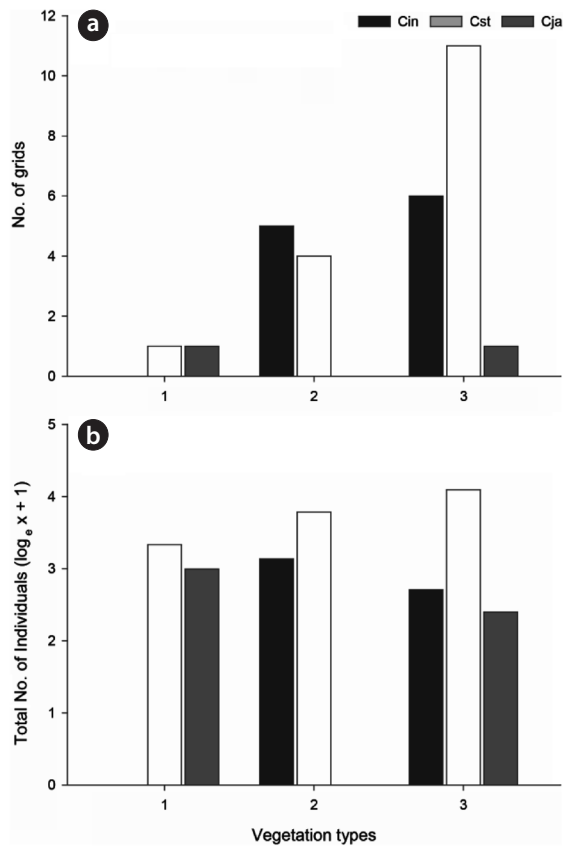


Fig. 5. Number of quadrats (a) and individuals (b) distributed in each vegetation type; 1, exposed soil; 2, *Miscanthus sinensis* var. *purpurascens*; and 3, *Quercus serrata*. Cin, *Calosoma inquisitor cyanescens*; Cst, *Carabus sternbergi sternbergi*; Cja, *Carabus jankowskii jankowskii*.

DISCUSSION

We showed that the ecological characteristics of wetlands affect carabid assemblages. Our results indicate the following: 1) The wetlands have a lower species richness and abundance of carabid beetles when compared with the mountain sites where there are relatively lower number of limiting and disturbance factors. 2) The spatial-temporal distribution of carabid beetles inhabiting wetland sites was clearly different from those inhabiting the mountain sites. These results show that carabid beetles inhabiting wetlands, where adverse habitat conditions are prevalent, have special strategies (e.g., spatial-temporal partitioning) for maintaining their population.

The carabid species richness and abundance can be determined by the soil and vegetation community structure in wetlands (Brose 2003), especially since soil water contents are a major factor affecting the suitability of a habitat for carabid beetles (Luff et al. 1989, Främbs 1990,

Nève 1994). High soil water content is a negative influence during the immature stages of the carabid beetles (Thiele 1977, den Boer 1981). Do et al. (2007a) reported that seasonal flooding of wetlands significantly decreased the species richness and abundance of carabid beetles, although some species adapted and preferred the wet soil condition and were able to recover their population after flooding. Therefore, Mujechi Wetlands, where high soil water contents are present, have lower species richness and abundance of carabid beetles than the mountain sites.

In this article, the seasonal activities of the three carabid species (*C. inquisitor cyanescens*, *C. sternbergi sternbergi*, and *C. jankowskii jankowskii*) were distinguished between the wetland and mountain sites. In the early stages of the season, these activities increased quickly, indicating that the carabid beetles in the wetlands could be selecting a strategy to quickly produce a population within a short time during the productive season in the wetland areas, resource availability being the principal factor affecting productivity. Furthermore, species utilizing similar ecological niches and seasonal activity patterns (spring or autumn breeders) often exhibit divisions in their activity time to reduce competition (Grüm 1986, Sota and Ishikawa 2004).

Although the three carabid species were widely distributed in the Mujechi Wetlands, they showed greater concentration in the drier vegetation areas. It is proposed that the wet habitat acted as an obstacle to the movement of large-sized species, and hence carabid beetles moved linearly along the relatively dry edges. It was demonstrated by Riecken and Raths (1996), who studied movement patterns using the telemetry method (radio tag), that carabid beetles inhabiting wetlands moved linearly because moist sites disturb the movement and diffusion of carabid beetles and drier vegetation types are usually distributed linearly in the wetland edges.

Mujechi Wetlands are undergoing a period of water loss with the soil becoming drier and the wetland thus undergoing terrestrialization. Kim et al. (2005) described the distribution and age of alders in the Mujechi Wetlands. The alders extended from the inside to the outside edge of the wetlands and were associated with terrestrialization of the wetlands. However, it is suggested that the distribution of the carabid beetles progresses from the outside edge to inside of the wetland on the basis of the desiccation of the wetland. If terrestrialization of the wetland progresses further, the distribution of the carabid beetles in the wetland can be extended throughout the wetland. Furthermore, when the wetland dries out, the carabid

composition in the wetland and the adjacent mountain shows increasing similarity. It will result in a distributional range extension, although the carabid species composition of the Mujechi Wetlands was significantly different from the adjacent mountain sites. For improving the wetland habitat quality, the soil and organic matter migrating from the forest road should be prevented, as it promotes the invasion of drier vegetation into the wetlands. In addition, continuous ecological surveys are needed for confirming ecological changes of the wetlands that are associated with anthropogenic and ecological successions.

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