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Effects of agricultural abandonment on carabid beetles in paddy fields

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We investigated changes in the species diversity and composition of carabid beetles associated with abandonment of cultivated rice paddies. In addition, we studied the environmental variables that affect carabid assemblages in these habitats. We collected 807 carabid beetles comprising 37 species from the studied habitats and found that the diversity and stability of these beetles increased over time depending on how long the field had been abandoned. Ordination analysis showed that the species assemblages of all habitats could be clearly separated from those of paddy fields, but that the assemblages during the early stages of abandonment showed no differences relative to those of cultivated paddy fields. Canonical correspondence analysis revealed that the most significant environmental variables influencing carabid assemblage were soil pH, organic matter, and the presence of tree cover. For the early stages following abandonment, soil nutrients were the strongest factors influencing the species composition. In contrast, the presence of tree, shrub, or herb cover was associated with an increase in the diversity of carabid beetles in late stages following abandonment. The results of this study suggest that restoration and management of abandoned paddy fields provides an excellent opportunity to improve the diversity and habitat quality of agricultural landscapes.

Keywords: abandonment, paddy field, carabid beetle, management of agricultural landscape, secondary succession

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INTRODUCTION

Abandonment of agricultural land is a phenomenon mostly driven by socio-economic factors such as income inequality between urban and rural communities, labour shortage because of an aging population, and reluctance of the young to remain in rural areas (Baudry 1991). Although the ecological consequences of agricultural abandonment are unintended, they do have an impact on species biodiversity (Benayas et al. 2007, MacDonald et al. 2000). The interest in abandoned agricultural land has recently increased in the field of conservation biology with respect to ecological restoration and succession because abandoned agricultural lands are often the only areas available for new land use needs in an intensive land use area (Hobbs et al. 2006,).

An assessment of the trends and properties of ecological succession following agricultural abandonment is necessary for successful restoration and management (Parker 1997). Generally, the species associated with any abandoned agricultural area undergo changes in composition over time (Carmer et al. 2008). Some species that adapted to intermediate disturbance, such as fertilizing, mowing, harrowing, and harvesting, might decrease in numbers with abandonment that removes such sources of disturbance; however, some species benefit from the advanced early stages of abandonment. In particular, an early successional species often gains an opportunity for rapid colonization (Southwood et al. 1979). These contrasting results are related to past agricultural use, management regime (e.g. non-intervention, intervention followed by natural development, habitat creation), and connectivity with adjunct habitats (Hobbs et al. 2009).

A paddy field is a flooded parcel of arable land that is used for growing rice and other semiaquatic crops. Paddy fields are typical features in the rice-growing countries of East and Southeast Asia. These fields require large quantities of water for irrigation, which can be quite complex when providing water to a highly developed system of paddy fields. Flooding provides water, which is essential for crop growth. These characteristics of paddy fields satisfy the standard definition of wetlands, in that wetlands are areas where water is the primary factor controlling the environment and the associated plant and animal life (Lawler 2001). Therefore, succession after abandonment of paddy fields will differ considerably from that of dry farming fields (Mesléard 1994). Some studies on the effect of agricultural abandonment of paddy fields have focussed on vegetation and environmental factors causing changes in vegetation structure and diversity (Lee et al. 2002, Yamada et al. 2007, Uematsu et al. 2010). Although it has often been assumed that conservation of a plant community will lead to conservation of all associated consumer species, it is now clear that such a generalization is not always true.

We monitored the carabid beetles in abandoned paddy fields. Carabid beetles are sufficiently abundant, taxonomically and ecologically varied, and sensitive to environmental gradients to be a reliable group to monitor; moreover, they have been widely studied in relation to land use throughout the world (reviewed Lövei and Sunderland 1996). Furthermore, in wetland habitats, such as abandoned paddy fields, currently cultivated paddy fields, wet meadows, and riparian zones, which have different higher soil moisture than surrounding areas, lower soil pH, and different vegetation, carabids can be characterized by species diversity, composition and habitat selection (Butterfield & Coulson 1983, Do et al. 2007, Yano et al. 1995).

Our study had two objectives: (1) to examine the community and diversity changes of carabid beetles through ecological succession in abandoned paddy fields, and (2) to identify which environmental variables best explained the composition of the carabid communities along a gradient of abandonment.

MATERIALS AND METHODS

1. Study sites

The study was conducted in 3 types of habitat: currently cultivated paddy fields, abandoned paddy fields and a forest area adjacent to the paddy fields near Yangsan City, Republic of Korea (Fig. 1). We selected 4 paddy field sites (cultivating *Oryza sativa* L.; total area, 1,600 m^2) under intensive rice cultivation. The abandoned paddy fields that we selected were divided into 2 groups: paddy fields abandoned 2 years prior to the study (total area, 500 m^2; 4 sites) and paddy fields abandoned 7 years prior to the study (total area, 800 m^2; 3 sites), the latter of which had reached the initial phases of secondary succession. Determination of the number of years since abandonment was based on a survey of local residents and the status of the vegetation (invasion of tree species). Paddy fields abandoned for 2 years were dominated by annual grass species such as *Erigeron annuus*, *Artemisia prin-*

ceps var. *orientalis*, and *Alopecurus aequalis* var. *amurensis*. *Salix* spp., and *Alnus* spp. had invaded paddy fields that had been abandoned for 7 years.

In forest areas, we selected 4 sites dominated by *Pinus densiflora* Siebold & Zucc. The northeast slope of the abandoned paddy fields adjoined the forest area and the other edge of the abandoned paddy was surrounded by paddy fields that were still actively cultivated.

2. Data collection

Beetles were collected each month from March to November 2007 using pitfall traps. Pitfall traps were installed on the ridges between rice paddies because the inner areas were water filled for growing rice from May to October. In the abandoned paddy field and forest sites, pitfall trapping was conducted within the paddy site itself. Nine pitfall plastic cup traps, 7 cm in diameter and partially filled with propylene glycol to preserve the insects, were installed in a line at 3-m intervals at each site. The ecological characteristics of breeding season, habitat preference, feeding type, and flight ability of each collected carabid species was derived from Do et al. (2007, 2011), Park and Paik (2001), and the Working Group for Biological Indicator Ground Beetles Database (2011). Each species was categorized according to preferred habitat (grass or forest), breeding season (spring or autumn), feeding type (herbivore or carnivore), and flight ability (capable of flight or flightless).

Larger vegetation consisting of low shrubs up to 1.5 m high was sampled in 10 m × 10-m plots and smaller vegetation consisting of herbs was sampled in 1 m × 1-m plots. All vegetation was assessed using percentage cover as a study variable.

Soil samples were collected at a depth of 5–10 cm from each site on 11 April and 28 December 2007 and were used to determine soil chemical properties. Soil temperatures were measured at 5- and 10-cm depths for each site in the morning of a

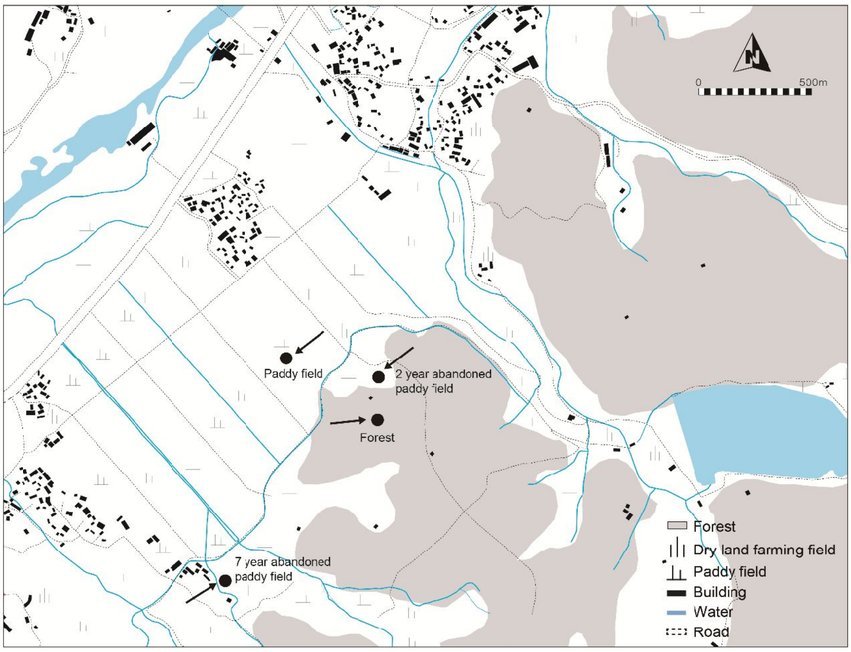

Fig. 1. Location of the sampling sites

typical sunny day. Soil moisture was obtained by subtracting the weight of soil dried at 105°C for 48 h from that of the fresh soil. Organic matter content (%) was determined using ash-free dry weight after ignition in a muffle furnace at 600°C for 4 h. Soil pH was determined using a bench-top probe after mixing the soil 1:5 (w/v) with distilled water and filtering the extract (Whatman No. 44 filter paper). K, Ca, and Mg were extracted using a 1 N ammonium acetate solution (pH 7.0). Exchangeable K, Ca, and Mg contents were measured using inductively coupled plasma mass spectroscopy (ICP-MS, ELAN 9000 model; PerkinElmer).

3. Data analysis

Species richness and diversity among habitats was compared using rarefaction, a statistical method for estimating the number of species present in random subsamples of varying size drawn from a larger sample (Magurran 1988). The Kruskal–Wallis non-parametric analysis of variance was used to assess differences in the species richness and abundance of carabid assemblages among habitats. These analyses were performed using BiodiversityR statistical software (Kindt & Coe 2005), which was developed for the R 2.1.1 statistical language and environment (R Development Core Team 2005).

Detrended Correspondence Analysis (DCA) was used to ordinate the sites and to differentiate carabid beetle assemblages (Jongman et al. 1995) within the ordination. The relationship between environmental variables and species occurrence was investigated using canonical correspondence analysis (CCA) (Jongman et al 1995, ter Braak & Šmilauer 2002), which was performed twice. The first analysis was performed for 4 active paddy field sites, 4 sites in paddy fields abandoned for 2 y, and 3 sites in paddy fields abandoned for 7 y. All 15 study sites were included in the second CCA application. This allowed the determination of any relationships among all environmental variables and this separation allowed confirmation of the strongest variable affecting species distribution for different periods of abandonment. All 10 environmental variables, including vegetation data and soil nutrients were included in the analysis. The significance of these environmental variables in explaining carabid assemblage was tested using Monte Carlo randomizations with 499 permutations. Soil nutrients (K, Ca, Mg), pH, environmental data, and species data were natural log (x + 1) transformed. However, we did not remove the rarest species and give small weights to them from the CCA analysis even though rare species might have a large influence on the analysis (ter Braak & Šmilauer 2002). Because of this, rare species in abandoned paddy field sites can be important for mainly explaining the change in carabid composition through succession after agricultural abandonment. The strong effect of rare species on this analysis is reflected realistically. This analysis was performed using CANOCO 4.5 software.

RESULTS

1. Species diversity

Thirty-one species were identified from currently cultivated paddy fields, abandoned paddy fields and forest sites. The cultivated paddy field contained 9 species, which was the lowest number of species among all the habitat types. In contrast, the 2-y and 7-y abandoned sites contained 11 and 16 species, respectively. The forest sites had the greatest number of species (26). Carabid species richness was statistically significantly different among the habitat types (Kruskal-Wallis test $x^2_{d.f.=3} = 11.25$, $p = 0.01$). Rarefaction curves based on individuals showed that the forest site had the greatest number of rarefied species; comparatively, the site with the lowest number of rarefied species was not found in the paddy field sites. As the number of years of abandonment increased, species richness also increased; however, although the relative abundances did not differ significantly (Kruskal–Wallis test $x^2_{d.f.=3} = 2.40$, $p = 0.49$), the abundance in 2-y abandoned paddy fields was higher than that in currently cultivated paddy fields (Fig. 2).

Carabid abundances within each ecological characteristic (e.g. feeding season, habitat preference, feeding type) were not significantly different among each habitat, particularly between currently cultivated paddy fields and abandoned paddy field sites including those having been abandoned for 2 and 7 y (breeding season F = 0.52, $p = 0.67$, habitat preference F = 2.10, $p = 0.10$, feeding type F = 0.66 $p = 0.58$). However, this result is inconclusive because the number of individuals of each species that had different ecological characteristics in each studied site was insufficient.

Pheropsophus javanus, *P. jesoensis*, and *Dolichus halensis* , which dominated the current paddy fields, were also abundant in the abandoned paddy fields, although the relative abundances were different (cf. Table 1). The abundance of *P. javanus* and *P. jesoensis* constituted 32.5% and 23.0% of species in cultivated paddy fields, increased to maximum levels of 37.5% and 28.57% in the 2-y abandoned paddy fields, and declined to 17.9% and 10.58% thereafter, respectively. In contrast, *D. halensis* (33.5%) was the dominant species in the cultivated paddy fields, decreased to 11.1% in the 2-y abandoned paddy fields but increased to 18.0% in the 7-y abandoned paddy fields. *Platynus impressus* was recorded in both cultivated and abandoned paddy fields, and was highest in the 7-y abandoned paddy fields. Six species—*Calosoma inquisitor cyanescens*, *Nebria chinensis chinensis*, *Synuchus nitidus*, *Amara* spp., and *Chlaenius* spp.—that were found in the 2-y abandoned paddy fields had higher numbers in the 7-y abandoned paddy fields, and were also recorded in the forest sites. In the forest sites, *Carabus sternbergi sternbergi* and *S. nitidus* were the most abundant species at (both 11.2%), but their proportional abundance was relatively less than the dominant species recorded in other habitats. Eight species accounting for less than 2% (approximately 2–3 individuals caught) in the forest sites were considered scarce.

2. Carabid assemblage composition against abandonment

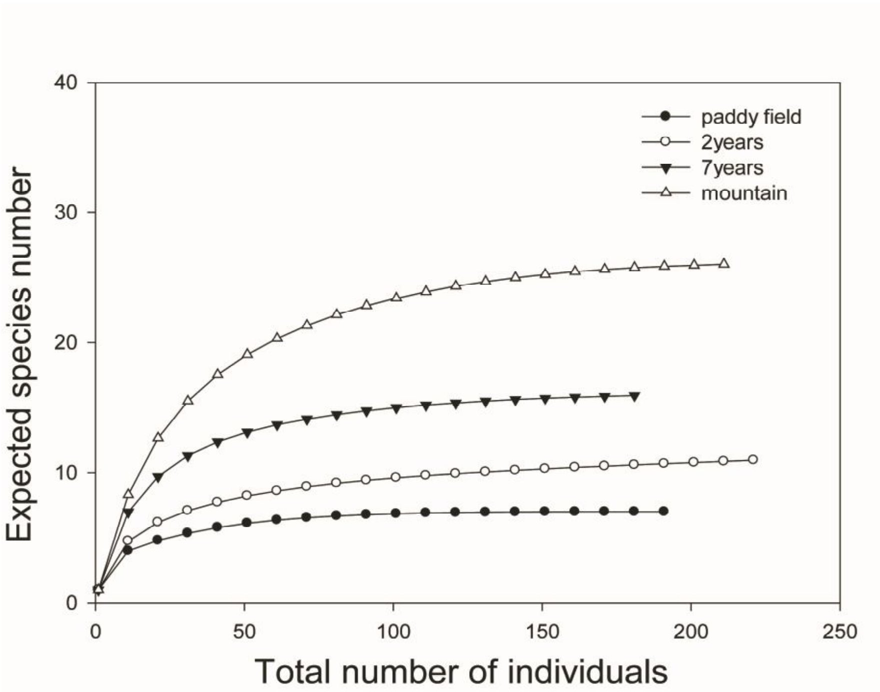

Fig. 2. Rarefaction curves for carabid beetle assemblages in each habitat

Table 1. Inventory of carabid beetles in each habitat

Species names	abbr.	Ecological characters¶	Paddy	2 year	7 year	Forest
Calosoma inquisitor cyanescens	Cin	S/F/P	0	0	1	3
Carabus sternbergi sternbergi	Cst	A/F/P	0	0	0	24
Damaster jankowskii jankowskii	Dja	A/F/P	0	0	0	18
Damaster smaragdinus branickii	Dsm	A/F/P	0	0	0	8
Nebria chinensis chinensis	Nch	A/G/P	0	0	3	4
Lesticus magnus	Lma	S/G/P	0	0	0	10
Trigonognatha coreana	Tco	S/F/P	0	0	0	5
Pterostichus audax	Pau	S/F/P	0	0	0	10
Pterostichus fortis	Pfo	S/F/P	0	0	0	3
Colpodes buchanani	Cbu	A/G/P	0	0	0	3
Platynus impressus	Pim	A/G/P	8	12	22	0
Platynus magnus	Pma	A/G/P	0	0	0	2
Dolichus halensis	Dha	A/G/P	64	25	24	16
Synuchus nitidus	Sni	A/F/P	0	1	2	24
Synuchus melantho	Sme	A/F/P	0	0	0	12
Anisodactylus signatus	Asi	S/G/H	3	4	10	2
Harpalus capito	Hca	A/G/P	5	17	13	13
Harpalus chalcentus	Hch	A/G/P	0	0	3	3
Stenolophus fulvicornis	Sfu	S/G/P	0	0	0	11
Amara ussuriensis	Aus	S/G/H	0	3	7	7
Amara communis	Aco	S/G/H	0	0	10	6
Amara simplicidens	Aim	S/G/H	0	6	8	3
Chlaenius pallipes	Cpa	S/G/P	5	7	12	0
Chlaenius variicornis	Cva	S/G/P	0	1	3	0
Chlaenius bioculatus	Cbi	S/G/P	0	0	6	18
Macrochlaenites costiger	Mco	S/G/P	0	0	0	2
Lebia iolanth	Lio	A/F/P	0	0	0	1
Planets puncticeps	Ppu	S/F/P	0	0	0	4
Brachinus stenoderus	Bst	S/G/P	0	0	0	2
Pheropsophus javanus	Pja	S/G/P	62	84	34	0
Pheropsophus jesoensis	Pje	S/G/P	44	51	33	0
		total number of species	7	11	16	26
		total number of individuals	191	211	191	214

Abbreviations: Paddy=paddy field; 2 year=2-year-old abandoned paddy field; 7 year=7-year-old abandoned paddy field,
¶Breeding season: S=spring, A=autumn; habitat preference: G=grass, F=forest; Feeding type: H=herbivore, C=carnivore

DCA ordination of species data (total inertia = 1.191; eigenvalues Axis 1 = 0.642, Axis 2 = 0.069) separated the habitats on Axis 1. They were divided into 3 clusters: the paddy fields, which included the 2-y abandoned sites; the 7-y abandoned paddy fields; and the forest sites (Fig. 3). A Kruskal–Wallis test performed on Axis 1 scores showed that sites from different habitats differed

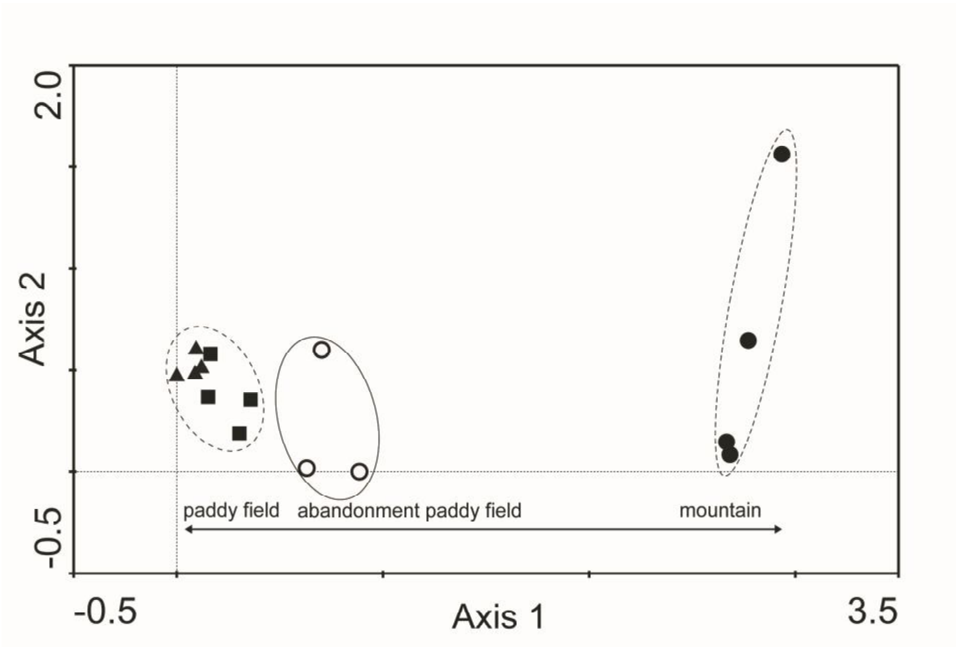

Fig. 3. Detrended correspondence analysis (DCA) of carabid beetle in four different habitats

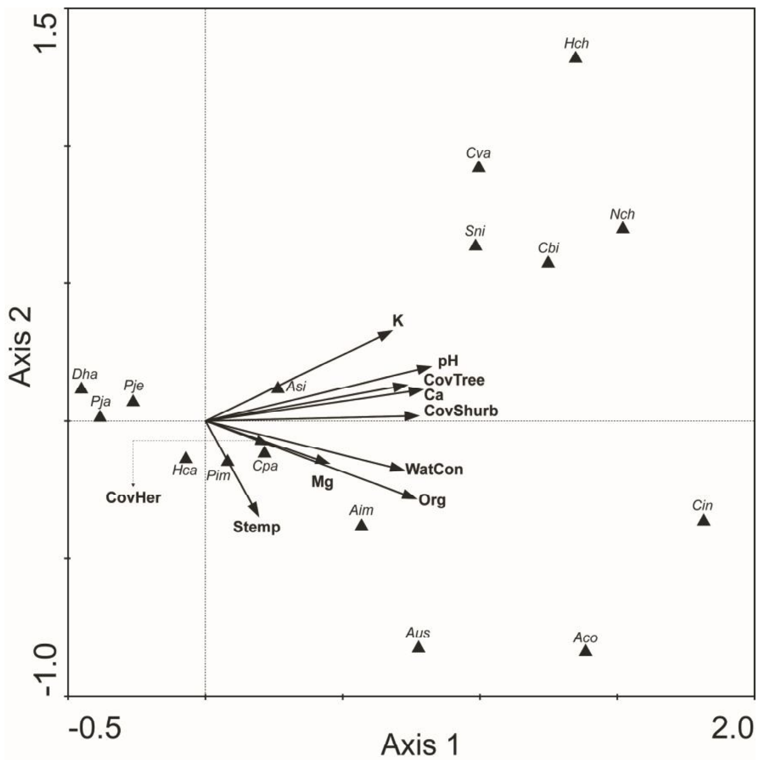

Fig. 4. Canonical correspondence analysis (CCA) Carabid beetle-environmental variable biplot when removal mountain data. Environmental abbreviation used: CovTree=percent cover of tree; CovHer = percent cover of herb; CovHer=percent cover of Herb; WatCon=Water Content; Stemp=Soil temperature; Org=Organic matter

significantly from each other ($x^2_{d.f.=3}$ = 2.40, $p <$ 0.01). The forest sites had significantly higher scores than the cultivated paddy fields and abandoned paddy fields. The plot ordination was strongly related to the increase in number of years since abandonment; however, the cultivated and the 2-y abandoned paddy field sites were more similar because they shared species such as *D. halensis*, *P. impressus*, *Anisodactylus signatus*, *H. capito*, and *C. pallipes*. A Kruskal–Wallis test on Axis 1 scores of cultivated and 2-y abandoned paddy fields showed that there were no significant differences in the assemblage structure between habitats along this Axis ($x^2_{d.f.=1}$ = 2.08, p = 0.149).

3. Environmental variable influence on carabid assemblage

CCA was used to investigate the possible relationships between carabid beetles and the environmental variables. Figure 4 shows that when forest data were removed (total inertia = 0.408; eigenvalues Axis 1 = 0.207, Axis 2 = 0.089), 72.5% of the variation between environmental variables and carabid species was explained. Soil nutrients, specifically pH and organic matter, had a significant effect on carabid assemblages (Monte Carlo permutation tests F = 7.08, p < 0.01; F = 3.10, p < 0.01, respectively). *P. javanus* and *P. jesoensis*, which dominated both cultivated and abandoned paddy fields, were negatively associated with changes in environmental variables. In contrast, *H. chalcentus*, *Ch. variicornis*, *Ch. bioculatus*, *S. nitidus*, and *N. chinensis chinensis* were positively associated with pH and K content. *C. inquisitor*, *A. ussuriensis*, and *A. communis* were positively associated with increasing organic matter. Common species recorded in all habitats, such as *H. capito* and *A. signatus*, were located near the centre of the ordination plot.

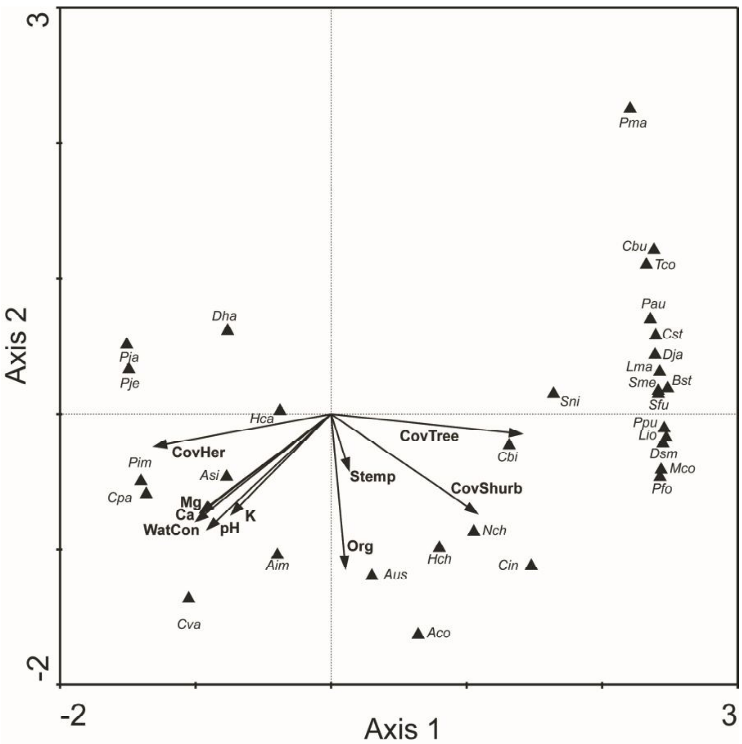

Fig. 5. Canonical correspondence analysis (CCA) Carabid beetle-environmental variable biplot in all habitats. Environmental abbreviation used: CovTree=percent cover of tree; CovHer = percent cover of herb; CovHer=percent cover of Herb; WatCon=Water Content; Stemp=Soil temperature; Org=Organic matter

Figure 5 shows that when the forest data were included (total inertia = 1.1914; eigenvalues Axis 1 = 0.640, Axis 2 = 0.134), 65.0% of the variation between environmental variables and carabid species was explained. Vegetation structure (tree, shrub, and herb cover) provided a stronger response than soil nutrients in determining the carabid assemblages in the forest. In particular, tree cover had a significant influence on species composition (Monte Carlo permutation tests F = 15.64, $p < 0.01$), and pH was significantly correlated with species inhabiting both cultivated and abandoned paddy fields (Monte Carlo permutation tests F = 3.15, $p < 0.01$). Fourteen species recorded in the forest, such as *C. sternbergi sternbergi*, *D. jankowskii jankowskii*, and *D. smaragdinus branickii*, were positively associated with relative tree cover. *C. inquisitor cyanescens* and *N. chinensis chinensis* were related to increased shrub cover. Rare species in the forest (<2–3 individuals caught) were located at the edge of the ordination diagram.

DISCUSSION

We found that abandonment of rice paddies results in the initiation of secondary succession, which can lead to increases in biodiversity. Increasing length of time following abandonment leads to an increase in carabid diversity. In particular, over a short period of investigation, we recorded 9–16 species of carabid beetles in cultivated and abandoned paddy fields although the numbers of collected individuals were relatively low. Species compositions of carabid beetles in abandoned paddy fields were significantly different from those in currently cultivated paddy fields and forest sites, particularly as the number of years since abandonment increased. Do et al. (2011) suggested the succession sere for carabid beetles in abandoned paddy fields. They divided the carabid beetle assemblages into 6 groups (paddy field, paddy field–abandoned paddy field, abandoned paddy field, abandoned paddy field–forest, forest, general species) by considering species composition, species characteristics and appearance patterns using a self-organizing map. In particular, they focused on initial successional species (paddy field–abandoned paddy field and abandoned paddy field groups) that inhabit wet habitats and paddy fields. Fluctuations in the abundance of these species were determined by changes in the condition of the original habitat and the longevity of each species. Environmental variables such as pH, abundance of organic matter, and percentage vegetation cover of vegetation influenced carabid beetle abundance in abandoned paddy fields. Abandonment of these agricultural practices tends to increase soil pH; therefore, currently cultivated paddy fields are maintained at a low soil pH (i.e. acidic conditions). Further, after abandonment, soil moisture and nutrient uptake by crops decreases, which tends to increase soil pH. The significant positive correlation between species richness of the carabid beetle and soil pH can be explained by the absence of species preferring acidic conditions (Petit & Usher 1998, Paje & Mossakowski 1984), and that of pH-specific prey species that could influence the species richness of carabid beetles. Carabid beetles were positively correlated with organic matter content. The main source of soil organic matter is decaying plant material, and it is possible that an increase in organic matter content is an indication of less disturbance in the abandoned paddy fields. Abandoned paddy fields have a significantly greater variety of vegetative structure than cultivated paddy fields, and therefore probably have more organic matter because disturbances such as ploughing, application of agricultural chemicals, and irrigation, all of which can negatively affect the organic matter content of a soil, are removed. Abandoned sites can therefore support a more diverse carabid beetle assemblage.

Although each species in the abandoned sites has different ecological characteristics (e.g. breeding season, habitat preference, feeding type), they were not statistically different regarding the years of abandonment. Phytophagous carabids are generalists and prefer open habitat. Their numbers were slightly higher in paddy fields abandoned for 2 y compared with those in fields currently cultivated. On the one hand, the increasing grass plant cover is positively related to an increase in the abundance of potential prey for carabid beetles. On the other hand, there were indirect effects of herb density and coverage; the high density of herbs decreased the number of species in the carabid assemblage, particularly forest species (Do et al. 2012). A dense coverage of grass plants might prevent movement and food capture of the forest species because these species are not adapted to such conditions (Sanderson et al. 1995).

CONCLUSION

The temporal sequence from currently cultivated to 2 years abandoned to 7 years abandoned to the forest site provides a temporal sequence in abandonment. This temporal development sequence produces an alteration in habitat, which, in turn, is utilized by an increasingly varied assemblage of carabid beetles. This pattern of change is positively reinforcing the biodiversity of the sites. Thus, although the loss of rice paddies from cultivation is not an exceptional practice in terms of productivity, it does provide a secondary benefit. This benefit is that biodiversity improves with time since abandonment. Accordingly, if the pattern of abandonment continues, the benefit in terms increased biodiversity is unlimited, although the increase in biodiversity is primarily in the form of generalist species. This pattern of increasing biodiversity, which appeared in a small number of paddies, needs to be studied on a much larger scale to determine whether it is also evident at the larger scale.

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