A Comparative Study of Carabid Beetles in Green Spaces and Former Natural Habitats

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Abstract: Urban expansion threatens ecosystems through direct habitat conversion. To secure urban biodiversity and enhance ecosystem services, a common focus of planning and growth management efforts is to establish green spaces. This study aimed to understand the formation process of newly created green spaces after urban development. We investigated the carabid beetle assemblages in its current habitat in a new city and in its former habitats for assessing the loss of species diversity by urban development and to identify the initial status of species assemblages in the current urban habitats, including green spaces. The diversity and composition of the carabid beetle assemblages significantly changed in the new city. The former habitat loss by urban development leaves large numbers of carabid species to dramatically decline. Carabid assemblages in current habitats may show a critical response to habitat loss, although former habitats were converted to green spaces. Some carabid species were only present in current habitats, including the green space from former habitats. In addition, the current habitat, including green spaces and other habitats, have similar carabid assemblages. Our results indicated that the loss of former habitat has a much greater effect on species diversity persistence than changes in habitat configuration and the creation of green spaces. Consequently, most carabid beetles were already lost during development. Urban habitats in new cities, including green spaces, represent simple and homogeneous habitats, although the development was designed and planned to enhance biodiversity. The present design and planning practice for green spaces that destroyed all former habitats to prepare the ground of urban areas and thereby created urban habitats, including green space, may need to be changed to secure biodiversity. Designing and planning the green spaces should consider the species' former habitats, for instance, creating a similar type of green space to agricultural land, forest, and wetland, and thereby the former habitat remains intact to enhance biodiversity and function.

Keywords: Carabidae; habitat loss; historic habitat; new city development; urbanization

1. Introduction

As the urban population is steadily growing, rural and natural areas have been developed into urban areas. The decline of species and habitat diversity resulting in homogenization is an inevitable consequence of urbanization [1]. Green space plays a critical role in mitigating the further loss of biodiversity and safeguarding the human well-being by enhancing ecosystem services in urban areas [2]. Green space also provides a primary contact with biodiversity and the natural environment for urban dwellers [3]. With a growing and increasingly urbanized population, the demand for more green

space for the physical and mental well-being of urban dwellers is increasing [4]. In highly populated cities, a conservation strategy involving securing the required quantity of green space is a priority. Land-use conversion from green space to residential and commercial areas has been disproved for securing the green space by the Land-Use Regulation Act [5]. Rather, the vacant land and a small proportion of land in the urban area are designated to convert to a green space [6]. Networking among green spaces using linear landscape components such as roadside and riparian areas enhances the quality and quantity of biodiversity on urban habitat [7].

Conversely, in a new city that was designed and planned recently, the green space is preemptively allocated a certain area of the city by the associated regulation [8,9]. In quantitative respect, the green space in the new city is rather dominant than in a mature city [10]. The appearance structure and the coverage of green spaces in new cities may look perfect by landscape architecture. However, green spaces in new cities are often infertile habitats since the loss of species and habitat diversity by urban development is extremely serious in comparison with the protection by green space creation. The most efficient practices for mitigating further biodiversity loss using green space creation is for the former habitat to remain intact, however, this may be impossible [11]. Therefore, the conservation practice in the new city with regards to the green space may start over with remnant species in the newly created green space as an essential source [12,13]. Understanding how the assemblage of remnant species is formed in green spaces after urban development would allow us to build experimental knowledge for their management [14]. Due to the fact that many studies on green spaces have been conducted in old and mature cities as stable habitats, the decline of biodiversity by urban development to remnant species in the newly created green spaces is still relatively poorly understood.

We investigated the carabid beetle in its current habitat in a new city and in its former habitats for assessing the loss of species diversity by urban development and to identify the initial status of species assemblages in current urban habitats, including green spaces. Carabids are regarded as reliable indicators, as they are both taxonomically and ecologically sensitive to the impacts associated with urbanization [15]. In particular, carabid assemblages represent different patterns and responses along with the urbanization intensity [16]. Some carabid beetles are adapting and dwelling in particular urban habitats, such as urban dry meadows, parks, landfills, and derelict sites [17–19].

The specific objectives of the study were: (1) To compare the carabid beetle assemblages in current and former habitats of the new city; (2) to compare the carabid beetle species assemblages within current urban habitats including green spaces, industrial, and residential areas; (3) to reveal the sensitivity of the carabid species and their response to urban development, alongside the characteristics of carabid beetles that remained in green spaces after urban development.

2. Methods

2.1. Former and Current Habitats

This study was conducted in a new city of Busan Metropolitan City, South Korea. The new city was planned in 1996 and developed in 2003 to stop the urban sprawl to the suburbs and to supply and aid the expansion of metropolitan cities (Figure 1A). In the new city, residential (68.9% of the total area), commercial (5.6% of the total area), and green areas (25.5% of the total area) of 4.16 km^2 were constructed for 29,000 households (89,000 residents). The population in the new city (area = 4.16 km^2, population density = 13,739.84/km^2 in 2014) has increased 10-fold compared to when it was first developed.

Four habitats, namely, riparian area, agricultural land, forest, and existing residential area, were selected as former habitats in urban areas. Former habitats were identified using land cover maps and aerial photographs (published in 1997 and 2009). Although most former habitats were lost by the development, agricultural land, forest, and existing residential areas were found in a nearby city within 1 km from the center of the new city (cf. Figure 1A). Riparian areas were selected within the middle-lower part of the stream across the new city since the upper-mid part of the stream was modified to the park.

Current habitats were classified into four habitats including parks as green space, residential, industrial, and redevelopment areas (Figure 1B). Due to the fact that current habitats were converted from different former habitats, a total of eight current habitats were investigated. The industrial area was developed in an agricultural area, which was adjacent to a new city (less than 1 km from the center of the new town). Redevelopment areas were redeveloped to apartments from existing detached houses constructed 30~40 years ago.
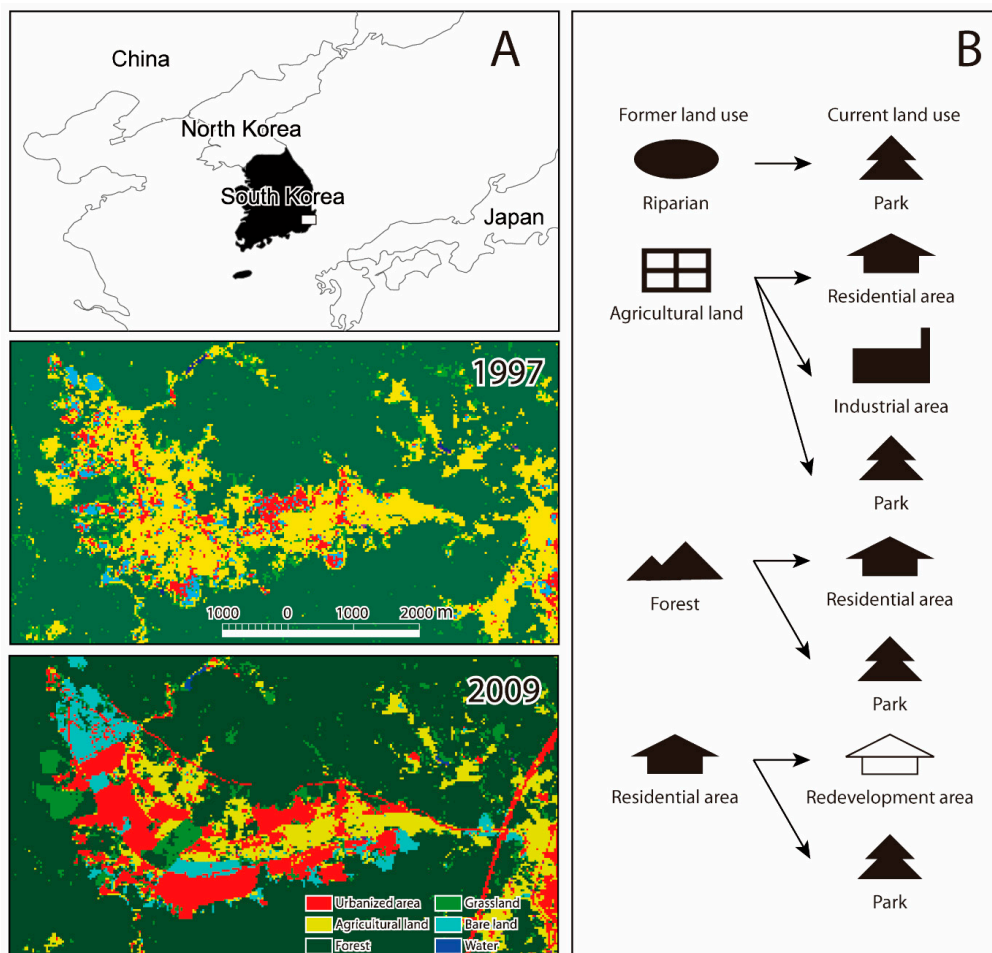

Figure 1. (**A**) Map of study area showing the conversion of land-use after new town development. Most bare land and agricultural land in 2009 were also converted to residential and commercial areas; (**B**) scheme showing the modification from former to current land-use types.

2.2. Carabid Sampling

Carabid beetles were sampled using pitfall traps (8 cm in diameter, 15.5 cm deep), which were partially filled with a propylene glycol-water mixture (50:50). Three traps were installed at three sites in each habitat, including four former and eight current habitats. Traps were covered by aluminum roofs to prevent rain dilution and to protect the traps from damage by small mammals. The trapping period covered most of the growing season (4 May to 30 November 2018), and traps were emptied once a month. The ecological characteristics (e.g., habitat preference and flight ability) of each carabid species collected from all study sites were obtained from the Working Group for Biological Indicator Ground Beetles Database (2011). Each species was categorized according to their preferred habitat (forest, eurytopic, and open land) and flight ability (flight-capable and flightless).

2.3. Data Analysis

Diversity indices, including Simpson's dominance index [20], Shannon's diversity index, and Shannon's evenness index [21], were calculated using PAST (Paleontological Statistics) [22]. To test for differences in carabid species richness, abundance, and diversity indices among the habitats and within former and current habitats, a nested analysis of variance (ANOVA) was performed using data from the individual sites. The differences in species richness, abundance, and diversity indices between green spaces (park) and other habitats (industrial, residential, and redeveloped area) were examined using one-way ANOVA. A generalized linear model (GLM) with a logarithmic link function that follows a Poisson distribution was used to analyze the data of carabid richness and abundance for the sites in former and current habitats and each ecological trait (e.g., habitat preference and flight capability). In addition, the negative binomial regression model was used accounting for overdispersion but the results were not different.

When the GLM revealed a significant difference between the means, the least significant difference test (LSD) was used to perform multiple comparisons among the means. The analyses were performed using PASW Statistics 18.

Habitats were classified by a two-way indicator species analysis (TWINSPAN) based on carabid abundance data of each habitat. The detrended correspondence analysis (DCA) was used to ordinate the land-use type and to differentiate carabid beetle assemblages [23]. This analysis was performed using PC-ORD (version 6, MjM Software Design).

3. Results

3.1. Carabid Diversity among Urban Habitats

A total of 2135 individuals from 20 carabid species were collected from four former habitats and eight current habitats (Table 1). Among the former habitats, agricultural land had the highest carabid diversity ($n = 16$). Although the residential area is a former habitat, carabid diversity is rather lower than the current habitat. Among the current habitats, carabid diversity in parks modified from forests was the highest ($n = 7$), while the industrial area had the lowest carabid diversity ($n = 3$). *Amara chalcites* (12 habitats, 100% of habitats), *Anisodactylus punctatipennis* (11 habitats, 91.67% of habitats), and *Am. congrua* (10 habitats, 83.33% of habitats) were widely distributed throughout both the former and current habitats. Within the former habitats, *Synuchus cycloderus* (10.70% per total collected individual in all former habitats) and *Damaster jankowskii* (10.56%) were dominant. In contrast, within the current habitats, *Am. chalcites* (32.98% per total collected individual in all current habitats), *Am. macronota* (19.30%), *A. punctatipennis* (14.89%), and *Anisodactylus signatus* (14.44%) were dominant.

Carabid richness, abundance, diversity index, and dominance index were significantly different between former and current habitats. In addition, former habitats had a significantly higher richness, abundance, and diversity index than the current habitats (Figure 2). The dominance index was significantly higher in the current habitat than in the former habitat. Within the former and current habitats, the difference in carabid diversity of each habitat was also significant (Table 2). In particular, within current habitats, carabid abundance in parks from the forest, agricultural land, urban stream riparian area, and residential area as green space were significantly higher than in residential areas and industrial areas of the current habitat ($F = 6.97$, $p = 0.005$). The dominance index of parks was significantly lower than that of the industrial area ($F = 3.684$, $p = 0.043$). However, the difference between the park and residential area and the dominance index were not significantly different ($p = 0.744$). Species richness ($F = 2.955$, $p = 0.074$), diversity index ($F = 2.698$, $p = 0.091$), and evenness index ($F = 1.736$, $p = 0.201$) were not significantly different between the park, residential, and industrial areas.

Table 1. Carabid beetles in different land-use types in the new town.

Name	Abbrev	HP	FA	F	A	RI	R	RA	RF	PF	PR	PA	PRI	IA	RR
Amara chalcites	Ach	O	A	34	42	26	16	18	31	8	42	33	41	20	24
Amara congrua	Aco	O	A		16	33	18	8	22		33	16	23	3	22
Amara macronota	Ama	E	A	26	15	32				82		2	14		
Anisodactylus punctatipennis	Apu	O	A	55	10	8	54	9	5	63	9		4	4	1
Anisodactylus signatus	Asi	O	A		27	32							2		
Carabus sternbergi	Cst	F	N	44						2					
Chlaenius micans	Cmi	F	A		34	9	6	4				12			
Chlaenius naeviger	Can	E	A		14						9				
Chlaenius pallipes	Cpa	O	A	12	43		3	4	9	27					
Chlaenius virgulifer	Cvi	E	A		21										
Damaster jankowskii	Dja	F	N	25											
Dolichus halensis	Dha	O	N		91	65							7		
Harpalus capito	Hca	O	A	4	57	16		8					7		
Harpalus sinicus	His	O	A		42			3							
Nebria chinensis	Nch	O	A		8	28									
Pheropsophus javanus	Pja	O	N		92	24									
Pheropsophus jessoensis	Pje	O	N		71	36									
Synuchus cycloderus	Scy	F	A	158						23					
Synuchus melantho	Sme	F	A	86						4					
Synuchus nitidus	Sni	F	A	32	12										
No. of species				10	16	11	5	7	4	7	3	5	7	3	3
No. of individuals				476	595	309	97	54	67	209	84	72	98	27	47

Abbreviations: HP: Habitat preference; FA: Flight ability; F: Forest; A: Agricultural land; RI: Riparian area; R: Residential area; RA: Residential area from agricultural land; RF: Residential area from forest; PF: Park from forest; PR: Park from residential area; PA: Park from agricultural land; PRI: Park from riparian area; IA: Industrial land from agricultural land; RR: Redevelopment area from residential area.

Table 2. ANOVA showing differences in carabid richness and abundance along with types (former or current habitat types) and among habitat types within types.

| Parameter	Source of Variation	df	MS	F	P
Richness	Types	1	256.889	12.506	<0.001
	Habitat types (Types)	10	20.542	33.614	<0.001
	Error	24	0.611		
Abundance	Types	1	73,216.889	13.571	0.004
	Habitat types (Types)	10	5395.208	32.334	<0.001
	Error	24	166.861		
Diversity index	Types	1	4.794	9.479	0.012
	Habitat types (Types)	10	0.506	9.933	<0.001
	Error	24	0.051		
Dominance index	Types	1	0.278	6.003	0.034
	Habitat types (Types)	10	0.046	4.296	0.002
	Error	24	0.011		
Evenness index	Types	1	0.022	1.771	0.213
	Habitat types (Types)	10	0.012	0.702	0.712
	Error	24	0.017		
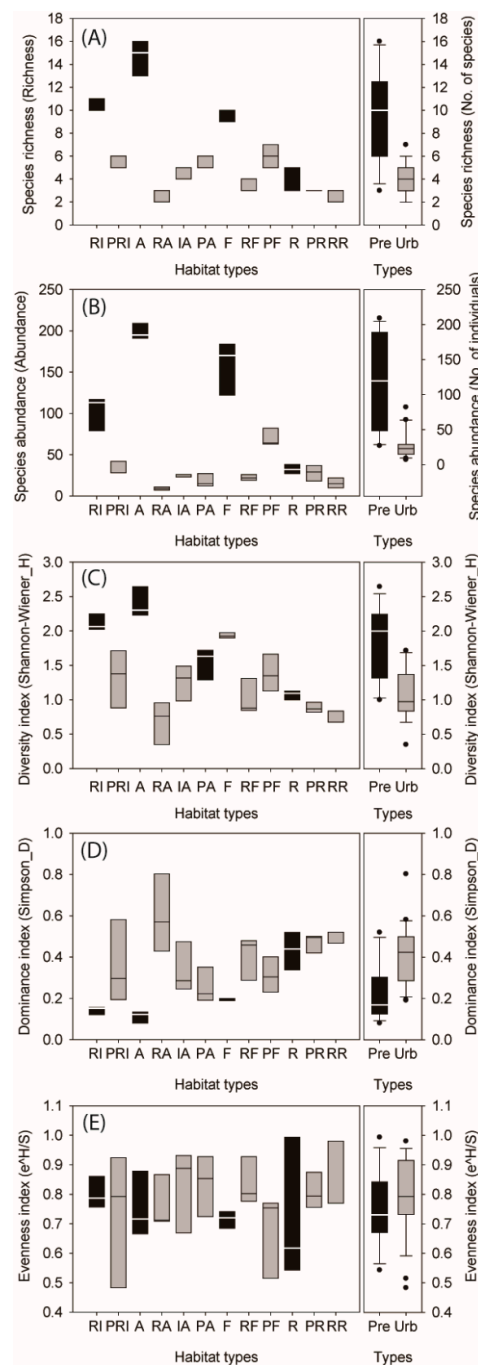
Figure 2. Average species richness (**A**), abundance (**B**), diversity index (**C**), dominance index (**D**), and evenness index (**E**) of each land-use types including former (black plots) and current (gray plot) land-use types; RI: Riparian area, R: Residential area, RA: Residential area from agricultural land, RF: Residential area from forest, PF: Park from forest, PR: Park from residential area, PA: Park from agricultural land, PRI: Park from riparian area, IA: Industrial land from agricultural land, RR: Redevelopment area from residential area, For: Former habitats, Cur: Current habitats.

3.2. Change of Carabid Assemblage in Urban Habitats

The TWINSPAN cluster analysis classified the 12 habitats into five groups (Figure 3). Former habitats were classified into different groups characterized by typical carabid species in each former land-use type, such as *D. jankowskii*, *Pheropsophus javanus*, and *Chlaenius pallipes*. Almost all current habitats were classified into the same group as the common carabid species. Only parks

modified from forests were classified into different groups with other current habitats by the forest carabid species (*Synuchus cycloderus*).
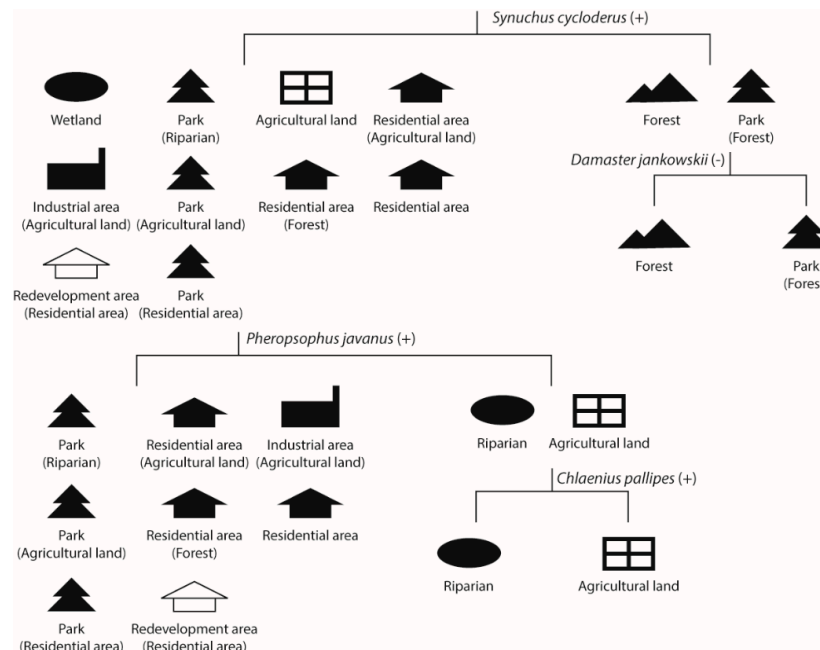

Figure 3. Two way indicator species analysis (TWINSPAN) classification of former and current land-use types. Indicator species are shown along the branches. Habitat types in the brackets are indicated as the former habitat types.

The former and current habitats identified by the TWINSPAN classification were clearly ordered along the first axis of the DCA ordination (Figure 4). The first axis (eigenvalue = 0.64) was representative of former or current habitats. The former habitats are found at the end of the axis. Comparatively, the current habitats were found at the center of the axis. *Synuchus cycloderus* ($r = 0.72$), *D. jankowskii* ($r = 0.66$), and *Carabus sternbergi* ($r = 0.66$), which represent the forest habitat, were positively correlated with axis 1. *Pheropsophus javanus* ($r = -0.53$) and *Dolichus halensis* ($r = -0.52$) that were characteristic for open habitats, such as agricultural land and wetlands, were negatively correlated with axis 1.
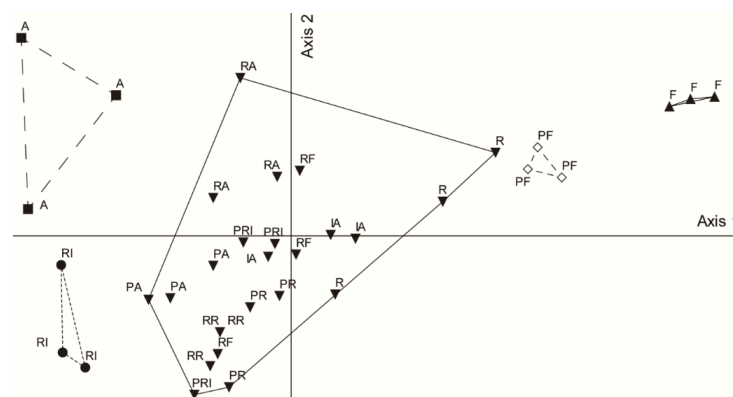

Figure 4. Detrended correspondence analysis (DCA) ordination showing former and current land-use types in new town and groups classified by TWINSPAN; RI: Riparian area, R: Residential area, RA: Residential area from agricultural land, RF: Residential area from forest, PF: Park from forest, PR: Park from residential area, PA: Park from agricultural land, PRI: Park from riparian area, IA: Industrial land from agricultural land, RR: Redevelopment area from residential area.

Carabid richness (F = 13.423, p = 0.002) and abundance (F = 21.576, p < 0.001) in different habitat preferences (i.e., forest, eurytopic, and open land species) showed significant relations with the habitat types (i.e., former or current habitat) (Table 3). Significant relations were observed between the richness (F = 4.11, p = 0.043) and abundance (F = 7.314, p = 0.009) of carabid species with flight capabilities and types (i.e., former or current habitat).

Table 3. Interaction between carabid beetles' types (former or current habitat types) by the generalized linear model.

	df	Deviance	Ratio	P
Richness				
Habitat preference	2	0.980	0.490	0.613
Flight ability	1	0.045	0.045	0.832
Types	1	13.423	13.423	<0.001
Habitat preference × Types	2	1.433	0.717	0.488
Flight ability × Types	1	4.110	4.110	0.043
Residual	52	51.342		
Total	7	93.459		
Abundance				
Habitat preference	2	2.912	1.456	0.243
Flight ability	1	2.684	2.684	0.107
Types	1	21.576	21.576	<0.001
Habitat preference × Types	2	3.333	1.666	0.199
Flight ability × Types	1	7.314	7.314	0.009
Residual	52	2022.295		
Total	7	73.478		

4. Discussion

The carabid diversity displayed by the abundance, richness, and diversity indices significantly decreased after urban development, while the dominance index was higher in the current habitats than in former ones. In disturbed habitats, the overall diversity usually decreases, and some generalist species become dominant [24,25].

Amara species as generalist carabid species were dominant in the current habitat of the new city. In many urban studies, *Amara* species were dominant in parks, industrial land, and brownfields, with strong preferences for disturbed and unstable habitats [26,27]. Seed-eaters are associated with disturbed ground and early successional stages although the disturbed ground does not support the biodiversity in the urbanized area. These species with full wings may be introduced temporarily to the disturbed ground [28]. In this study, carabid richness and abundance with flight capabilities were significantly higher than those of flightless species among the current habitats. For these species, the loss of a former habitat meant the creation of a suitable habitat, as recent urban development would consequently increase early successional habitats [26]. These species with a high abundance in the current habitats may be due to the fact that they offer favorable conditions for their survival in the initial stage of urban development. Therefore, these generalist carabid species would be dispersed to other urban habitats and dominate as the basis species with an increasing open habitat and decreasing forest stand for the specialist species over time and during urban expansion [29–31].

In contrast, the specialist carabid species in the forest and agricultural land among the former habitats, such as *S. cycloduerus*, *D. jankowskii*, and *P. javanus* were greatly affected by the loss of the former habitat. The existence of these species depended on the former habitat. The habitat loss greatly affects the habitat specialists that are more strongly related to changes in the habitat area and type. If the current habitats in new cities, especially green spaces, can provide sufficient sources, including large areas and the necessary food to the specialist carabid beetles, they might survive in the current habitat [32,33]. However, current habitats, including green spaces in new cities, may not be used as substitutes for former habitats. Carabid species may be continuously decreased since disturbances in

the remnant habitat may frequently create unfavorable conditions for carabid beetles [33]. In many studies on the urban habitat, the mean body size of the carabid assemblage decreased with the increasing urban intensity [34–36]. These results may be explained by the loss of specialist species by the initial urban development. Large carabid beetles may have already disappeared by converting undeveloped land into cities and towns. Remnant carabid species are affected by food competition and agonistic interactions among species in reduced quantities of the available habitat, which increase their stress level, compromise immunocompetence, and thereby lower their development in mobility [37,38].

Consequently, most carabid beetles were already lost during development. Urban habitats in new cities, including green spaces, represent simple and homogeneous habitats, although the development was designed and planned to enhance biodiversity [39]. To mitigate and avoid further destruction of former habitats in preparation for urban habitats, the present design and planning practice for green spaces needs to be revised to secure biodiversity. In this study, the park-modified forest had a relatively higher carabid diversity, and the carabid assemblage was also similar to the forest as the former habitat. The effect of the park construction in the fragmented forest is less than the habitat loss [40,41]. Some authors suggested that when breeding habitats cover more than 20% of the landscape, survival is virtually ensured no matter how fragmented the habitat is [42,43]. However, expanding the habitat size in the urbanized areas by connecting them with near-by alternative habitats, such as green infrastructure, may contribute to maintaining the biodiversity in the urbanized area.

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