Article

Response of Ground Beetle (*Coleoptera: Carabidae*) Communities to Effect of Urbanization in Southern Osaka: An Analytical Approach Using GIS

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Abstract: Urbanization involves the profound alteration of original habitats and causes habitat loss and biodiversity decline. This study aims to clarify the response of ground beetle communities to the effect of urbanization in southern Osaka, Japan. In total, 2950 individuals from 53 species of ground beetle were collected in nine urban green areas. The categories of land use regarding the study sites were determined based on GIS data. The community index was not significantly different between areas. Urban areas and roads in land use mainly have a negative influence on ground beetles. Paddies, fields, parks and green spaces, and open space were positively correlated with species richness of forest species and large-sized species, and open space was positively correlated with species richness and the density of open land species. However, ground beetle communities in different areas of varying sizes did not group separately. These results suggest that changes in paddies, fields, parks and green spaces, forests, and open space associated with the expanding urban area and road greatly influenced species composition, and the community structure remained similar.

Keywords: ground beetle; urbanization; land use; urban green area; GIS

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1. Introduction

Urbanization drives global environmental changes and is one of the major anthropogenic activities that impacts biodiversity and ecosystem processes [1–3]. Currently, 55% of the global human population lives in urban areas, and this trend is expected to continue in the coming decades [4]. Urbanization has a significant impact on abiotic and biotic factors in nature and leads to substantial changes in natural habitats with profound effects on wildlife and their activity pattern, spatial distribution, phenology, productivity, and biotic interactions [5–7]. The diversity and community structure of wildlife will change significantly in urban habitats compared with rural ones [3,8–10].

Ground beetles are useful bio-indicators because they are sufficiently varied both taxonomically and ecologically, abundant, and sensitive to the anthropogenic effect [11,12]. Urbanization has a huge effect at various levels of the biological organization on ground beetles in urban habitats [13]. Ground beetles with large body sizes, predatory feeding habits, strict forest habitat requirements, and poor dispersal ability were most sensitive to urbanization [6]. Many studies have been conducted to clarify the relationships between ground beetle diversity and the effect of urbanization according to the urban–rural gradient [8,14,15].

There is a need for studies on the responses of ground beetle communities according to different areas and land use. To our knowledge, this is the first study to clarify the response of ground beetles to the effect of urbanization using the GIS method. This study was carried out in nine urban green areas in southern Osaka. We tested the following questions: (1) How does the ground beetle community respond according to the area and

land use? (2) Which species are more vulnerable to the effect of urbanization? (3) Which environmental factors influence positively, or negatively, the ground beetle community? Finally, we propose an alternative to improve ground beetle diversity in urban areas.

2. Materials and Methods

2.1. Study Sites

Osaka Prefecture is the second largest metropolitan area in Japan, and its area is about 1905 km² and the population is about 8.8 million as of April 2021. Osaka Prefecture is surrounded by Mt. Izumikatsuragi, Mt. Iwawaki, Mt. Kongo, Mt. Iwahashiyama, and Mt. Ikoma. Yodo River and Yamato River flow through Osaka. Many areas in Osaka are comprised of houses, apartments, and other buildings (Figure 1). However, Osaka Prefecture has remnant forests between mountain areas and flatland areas, and paddy fields in suburban areas. There are also large urban green areas, such as urban parks, urban forests, temples, shrines, university campuses, etc. Urban green areas have been fragmented by urban areas and separated from other surrounding natural areas. However, urban green areas play an important role in maintaining water and air quality, providing wildlife habitat, and supporting meta-populations of regional flora and fauna, as well as recreational areas for human wellbeing [2,16,17]. The urban green areas should be properly evaluated to maintain their ecological value in the urban ecosystem.

Figure 1. Map of study area.

We chose nine urban green areas in southern Osaka (Figure 2). Suzunomiya park (SU), Chayama park (CH), Niwasiro park (NI), and Kouzen park (KO) are surrounded by residential areas, apartment complexes, and roads. Izumigaokaryokuchi (IZ), Kurotoriyama park (KU), and Koumyouike park (KM) are partially connected to natural habitats. Takasago park (TA) and Umitonohureaihiroba (UM) are located in landfill areas. The detailed information of each site is included in Table 1. The nine urban green areas were classified into three groups based on size: small area (<5 ha), medium area (>5 ha and <15 ha), and large area (>15 ha).

Figure 2. Map of the study sites. SU: Suzunomiya park, CH: Chayama park, TA: Takasago park, IZ: Izumigaokaryokuchi, NI: Niwasiro park, KU: Kurotoriyama park, UM: Umitonohureaihiroba, KO: Kouzen park, KM: Koumyouike park.

2.2. Survey and Ground Beetle Identification

The survey was carried out 18 times from April to December 2007 using pitfall traps in nine urban green areas in southern Osaka. A plastic cup (diameter 7 cm, depth 10 cm) was used to make a trap without using any bait, and five holes were made to avoid rainwater. Ten traps were set 5 m apart in a straight line in the grassland area and another 10 traps in the forest area for 7 days at each site. As some traps were lost during the survey period, 346, 321, 357, 333, 297, 342, 345, 307, and 297 traps were collected from SU to KM, respectively. The ground beetle specimens were identified using taxonomic keys [18] to the level of species under a stereoscopic microscope.

2.3. Body Size and Habitat Type

The body size of ground beetles was grouped into three size classes: small (<10.0 mm), medium (11.0–20.0 mm), and large (>21.0 mm) based on Ueno et al. [18]. In terms of habitat type, the ground beetles were classified into two groups based on their location when collected. Forest species were mainly recorded in forests such as broadleaf forests, pine forests, urban forests, and secondary forests, whereas open land species were mainly recorded on riverbanks, paddy fields, urban green areas, and urban parks. If a species was recorded in more than one habitat, the habitat where the species was more frequent was used. Habitat type was determined based on Ueno et al. [18], Lee [19], and Lake Biwa Museum [20].

2.4. Land Use Analysis

The land use data were collected from a 1:5000 scale map published in 2001 by the Geospatial Information Authority of Japan. The patterns of the surrounding environment of survey routes in nine urban green areas were analyzed using GIS. There is no standard method or previous study that suggested an appropriate radius for considering the influence of urbanization on ground beetle communities. A 1 km radius in the urban green areas in southern Osaka included some natural habitats. A previous study suggested that a circle of 500 m radius was appropriate for considering the impact of urbanization on ground arthropods [21]. The land use was classified into ten categories: paddy, field, park and green space, forest, urban area, road, open space, river and pond, sea, and others.

Table 1. Summary of study sites.

Study Site	Acronym	Coordinates		Year	Area (ha)	Main Plants		Cho/Dai/Machi	City	Facility	Remark
		Latitude	Longitude			Subsite 1	Subsite 2				
Suzunomiya park	SU	34.5284	135.4804	1976	Small (1.4)	<i>Q. glauca</i> grove	Lawn area around deciduous trees such as <i>C. sinensis</i> var. <i>japonica</i> , and <i>Ligustrum japonicum</i>	Hatanishimachi	Sakai	Playground	Near to Hatadaimyou temple
Chayama park	CH	34.4889	135.5186	1982	Small (4.4)	<i>Q. glauca</i> grove	Lawn area near deciduous trees such as <i>L. tulipifera</i> and <i>Triadica sebifera</i>	Chayamadai	Sakai	Playground	Surrounded by residential areas
Takasago park	TA	34.5379	135.4063	1979	Small (4.8)	Around deciduous trees such as <i>Rhaphiolepis indica</i> var. <i>umbellata</i>	Grassland area where the majority of herbs were <i>Desmodium paniculatum</i> and <i>Hypochaeris radicata</i>		Takaishi	Baseball ground	landfill area
Izumigaokaryokuchi	IZ	34.5029	135.5304	1982	Medium (5.3)	Secondary forest where the majority of trees were <i>Q. serrata</i> and <i>Q. acutissima</i>	Grassland where the majority of herbs were <i>S. canadensis</i> var. <i>scabra</i> and <i>Juncus tenuis</i>	Ueno	Sakai		Connected to natural forests
Niwasiro park	NI	34.4742	135.4975	1982	Medium (6.9)	Around deciduous trees such as <i>Myrica rubra</i> and <i>Q. glauca</i>	Lawn area near deciduous trees such as <i>Albizia julibrissin</i> and <i>Ulmus parvifolia</i>	Niwasirodai	Sakai	Baseball ground	Surrounded by residential areas
Kurotoriyama park	KU	34.4866	135.4438	1960	Medium (7.2)	Around a secondary forest where the majority of trees were <i>Q. serrata</i> and <i>Q. acutissima</i>	Lawn area near a lake	Kurotoricho	Izumi	Playground	Partially surrounded by paddy fields and crop fields
Umitonohureaihiroba	UM	34.6027	135.4256	2000	Large (15.8)	Around a colony of <i>Pittosporum tobira</i>	Grassland area where the majority of herbs were <i>Trifolium repens</i> and <i>Digitaria ciliaris</i>	Chikkoyawatamachi	Sakai	Biotope	Landfill area near the mouth of Yamato River
Kouzen park	KO	34.5012	135.4965	1982	Large (17.4)	Around an <i>Acer buergerianum</i> grove	Grassland dominated by <i>Erigeron annuus</i> and near deciduous trees such as <i>Liriodendron tulipifera</i> and <i>L. japonicum</i>	Miyamadai	Sakai	Playground	Tajihayahime temple's private estate
Koumyouike park	KM	34.4610	135.4756	1987	Large (33.4)	Second forest where the majority of trees were <i>Q. serrata</i> and <i>Q. acutissima</i>	Grassland where the majority of herbs were <i>Artemisia indica</i> var. <i>maximowiczii</i> and <i>Pueraria lobata</i>	Kurotoricho	Izumi	Artificial lake	Partially connected to natural forests

2.5. Data Analysis

A one-way ANOVA was used to verify the differences in species richness and density of body size and habitat type, species diversity (H'), and species evenness (J') between different areas. The relationships between eight categories of land use and the ground beetles index were examined using Pearson's correlation analysis. Ground beetle communities were ordinated using non-metric multidimensional scaling (NMDS). Singleton species occurring on one site were excluded from NMDS ordination. NMDS ordination, species diversity, and species evenness were calculated using Vegan R package (ver. 2.5-6). All statistical analyses were performed using R 4.0.3 [22].

3. Results

A total of 2950 ground beetles representing 53 species were collected (Table 2). Species richness was the highest at UM (30 species) near the mouth of Yamato River and the lowest at TA (4 species) in the landfill area in Takaishi city. Density was the highest at IZ (59.76) and the lowest at TA (1.24). Species diversity and evenness broadly ranged from 1.12 to 2.80 and from 0.42 to 0.89, respectively. *Synuchus nitidus* was the most abundant species, with 951 individuals (32.2% of all individuals). *S. dulcigradus* (20.9%) and *Dolichus halensis* (10.1%) were also abundant. Three dominant species accounted for 63.3% of all individuals. When body size was considered, 30 medium-sized species, 16 small-sized species, and 7 large-sized species were found (Table 2). Species richness of small-sized species and medium-sized species was the highest at NI (8) and UM (19), respectively, but the lowest at TA (1 and 3, Figure 3). Species richness of large-sized species was the highest at KM (5). However, large-sized species were not found in SU, CH, TA, or NI. The density of small-sized species and medium-sized species was the highest at IZ (26.07 and 33.15) and the lowest at TA (0.28 and 0.56). The density of large-sized species was the highest at KU (2.22). In terms of habitat type, 13 forest species and 40 open land species were found. Species richness of forest species were the highest at IZ and KM (10) and the lowest at TA (1). Species richness and density of open land species were the highest at UM (28 and 25.80) and the lowest at TA (3 and 0.78).

Figure 3. Species richness and density (abundance per 20 traps) according to body size and habitat type of ground beetles in nine urban green areas. SU: Suzunomiya park, CH: Chayama park, TA: Takasago park, IZ: Izumigaokaryokuchi, NI: Niwasiro park, KU: Kurotoriyama park, UM: Umitonohureaihiroba, KO: Kouzen park, KM: Koumyouike park.

Table 2. Ground beetles collected using pitfall traps in nine urban green areas in southern Osaka.

Species	Small Area (<5 ha)			Medium Area (>5 ha and <15 ha)			Large Area (>15 ha)			Total	%	Body Size	Habitat Type
	SU	CH	TA	IZ	NI	KU	UM	KO	KM				
Carabidae													
<i>Campalita chinense</i>							0.16 (2)			2 (0.12)	0.1	L	O
<i>Carabus yaconinus</i>				0.18 (3)		1.99 (34)			0.94 (14)	51 (3.11)	1.7	L	F
<i>Leptocarabus kumagaii</i>									0.27 (4)	4 (0.27)	0.1	L	F
<i>Scarites terricola pacificus</i>		0.12 (2)			0.2 (3)		0.29 (5)	0.26 (4)		14 (0.88)	0.5	M	O
<i>Tachyura laetifica</i>					0.2 (3)					3 (0.2)	0.1	S	O
<i>Archipatrobus flavipes</i>	0.29 (5)			0.18 (3)		0.12 (2)	0.12 (2)			12 (0.7)	0.4	M	O
<i>Lesticus magnus</i>				0.12 (2)		0.06 (1)	0.46 (8)	0.13 (2)	0.27 (4)	17 (1.04)	0.6	L	O
<i>Trigonotoma lewisii</i>				0.06 (1)						1 (0.06)	0.0	M	F
<i>Pterostichus sulcicarsis</i>		0.62 (10)		0.18 (3)	0.13 (2)			2.67 (41)	0.2 (3)	59 (3.81)	2.0	S	O
<i>P. fortis</i>							0.64 (11)			11 (0.64)	0.4	M	O
<i>P. prolongatus</i>							0.17 (3)			3 (0.17)	0.1	M	O
<i>P. microcephalus</i>	0.06 (1)			0.06 (1)			0.06 (1)	0.13 (2)	0.07 (1)	6 (0.37)	0.2	S	O
<i>P. polygenus</i>					0.34 (5)				0.2 (3)	8 (0.54)	0.3	S	O
<i>Platynus magnus</i>				0.06 (1)						1 (0.06)	0.0	M	O
<i>P. chalcimus</i>					0.13 (2)					2 (0.13)	0.1	S	O
<i>Dolichus halensis</i>	2.66 (46)	0.19 (3)	0.34 (6)	0.9 (15)	0.67 (10)	0.35 (6)	7.65 (132)	4.95 (76)	0.27 (4)	298 (17.98)	10.1	M	O
<i>Synuchus nitidus</i>	7.8 (135)	3.8 (61)	0.06 (1)	26.07 (434)	15.08 (224)	2.87 (49)		2.8 (43)	0.27 (4)	951 (58.75)	32.2	M	F
<i>S. cycloderus</i>	0.29 (5)			1.68 (28)		0.23 (4)			0.07 (1)	38 (2.27)	1.3	M	F
<i>S. melantho</i>				0.54 (9)						9 (0.54)	0.3	M	F
<i>S. dulcigradus</i>	1.5 (26)	0.25 (4)		24.86 (414)	3.77 (56)	3.86 (66)	0.29 (5)	1.89 (29)	1.14 (17)	617 (37.57)	20.9	S	F
<i>S. arcuaticollis</i>				0.84 (14)	0.4 (6)	0.23 (4)			0.2 (3)	27 (1.68)	0.9	S	F
<i>Amara congrua</i>	1.5 (26)		0.28 (5)	0.12 (2)	0.34 (5)	0.29 (5)	0.64 (11)	1.17 (18)	0.2 (3)	75 (4.54)	2.5	S	O
<i>A. chalcites</i>	0.06 (1)				0.07 (1)					2 (0.13)	0.1	S	O
<i>A. nipponica</i>							0.12 (2)	0.07 (1)		3 (0.18)	0.1	S	O
<i>A. simplicidens</i>	0.12 (2)									2 (0.12)	0.1	S	O
<i>A. macronota</i>	0.06 (1)					0.06 (1)	0.12 (2)			4 (0.23)	0.1	M	O
<i>A. gigantea</i>							0.06 (1)			1 (0.06)	0.0	M	O
<i>Anisodactylus signatus</i>	0.12 (2)			0.06 (1)		0.53 (9)	0.06 (1)		0.07 (1)	14 (0.83)	0.5	M	O
<i>A. sadoensis</i>	0.06 (1)			0.18 (3)	0.07 (1)	0.06 (1)	0.17 (3)	0.52 (8)	0.07 (1)	18 (1.13)	0.6	M	O
<i>A. tricuspidatus</i>	0.12 (2)			1.38 (23)				0.2 (3)		28 (1.69)	0.9	M	F
<i>Harpalus capito</i>				0.06 (1)			0.12 (2)			3 (0.18)	0.1	L	O
<i>H. griseus</i>	0.23 (4)					1.17 (20)	4.29 (74)	0.72 (11)	0.07 (1)	110 (6.47)	3.7	M	O
<i>H. eous</i>		0.25 (4)		0.36 (6)		0.06 (1)	0.23 (4)	0.2 (3)	0.27 (4)	22 (1.36)	0.7	M	O
<i>H. tridens</i>	0.17 (3)			0.18 (3)		0.06 (1)		0.07 (1)	0.07 (1)	9 (0.54)	0.3	M	O
<i>H. sinicus</i>	0.75 (13)	0.06 (1)	0.17 (3)	0.36 (6)	0.2 (3)	0.88 (15)	2.55 (44)	5.8 (89)	0.13 (2)	176 (10.9)	6.0	M	O
<i>H. niigatanus</i>	1.1 (19)			0.24 (4)	0.07 (1)	0.29 (5)	0.17 (3)		0.4 (6)	38 (2.28)	1.3	M	O
<i>H. simplicidens</i>	0.23 (4)			0.06 (1)			0.06 (1)			6 (0.35)	0.2	M	O
<i>H. chalcensis</i>								0.39 (6)		6 (0.39)	0.2	M	O
<i>H. tinctulus</i>	2.89 (50)	0.19 (3)					0.29 (5)	1.24 (19)	0.07 (1)	78 (4.67)	2.6	S	O
<i>Platymetopus flavilabris</i>							0.06 (1)			1 (0.06)	0.0	S	O
<i>Stenolophus fulvicornis</i>	0.06 (1)					0.12 (2)				3 (0.17)	0.1	S	O
<i>S. quinquepustulatus</i>								0.07 (1)		1 (0.07)	0.0	S	O
<i>Haplochlaenius costiger</i>				0.18 (3)		0.12 (2)	0.06 (1)		0.2 (3)	9 (0.56)	0.3	L	F
<i>Chlaenius virgulifer</i>		0.12 (2)				0.29 (5)	0.17 (3)	0.33 (5)	0.07 (1)	16 (0.98)	0.5	M	O

Table 2. Cont.

Species	Small Area (<5 ha)			Medium Area (>5 ha and <15 ha)			Large Area (>15 ha)			Total	%	Body Size	Habitat Type
	SU	CH	TA	IZ	NI	KU	UM	KO	KM				
<i>C. variicornis</i>									0.13 (2)	2 (0.13)	0.1	M	O
<i>C. pallipes</i>							0.06 (1)			1 (0.06)	0.0	M	O
<i>C. micans</i>							0.35 (6)			6 (0.35)	0.2	M	O
<i>C. naeviger</i>						0.23 (4)			1.55 (23)	27 (1.78)	0.9	M	F
<i>C. posticalis</i>							0.23 (4)			4 (0.23)	0.1	M	O
<i>Aephmidius adelioides</i>	0.06 (1)						1.51 (26)			27 (1.57)	0.9	S	O
<i>Galerita orientalis</i>						0.06 (1)		0.07 (1)	0.2 (3)	5 (0.33)	0.2	L	F
Brachinidae													
<i>Brachinus scotomedes</i>				0.18 (3)		0.12 (2)			0.07 (1)	6 (0.36)	0.2	M	F
<i>Pheropsophus jessoensis</i>	0.12 (2)	0.12 (2)		0.66 (11)		0.06 (1)	5.04 (87)		0.67 (10)	113 (6.68)	3.8	M	O
Species richness	22	10	4	26	14	24	30	20	27	53			
Abundance	350	92	15	995	322	241	451	363	121	2950			
Density	20.23	5.73	0.84	59.76	21.68	14.09	26.14	23.65	8.15	20.00			
Species diversity (H')	2.06	1.31	1.24	1.40	1.12	2.31	2.26	2.24	2.80	2.43			
Species evenness (J')	0.67	0.57	0.89	0.43	0.42	0.73	0.66	0.75	0.85	0.62			

Density indicates abundance per 20 traps. The numbers in parentheses indicate abundance. See text for classification methods of body size and habitat type. Study sites: SU: Suzunomiya park, CH: Chyayama park, TA: Takasago park, IZ: Izumigaokaryokuchi, NI: Niwasiro park, KU: Kurotoriyama park, UM: Umitonohureaihiroba, KO: Kouzen park, KM: Koumyouike park. Body size, S: 1–10 mm, M: 11–20 mm, L: 21–50 mm. Habitat type, F: forest species, O: open land species.

$df = 2, r^2 = 0.32, p = 0.076).$

Figure 4. Non-metric multidimensional scaling (NMDS) ordination of ground beetle communities in nine urban green areas. Singleton species occurring at one site were excluded from the NMDS ordination. Solid line indicates communities in small area, dashed line indicates communities in medium area, and dotted line indicates communities in large area. SU: Suzunomiya park, CH: Chayama park, TA: Takasago park, IZ: Izumigaokaryokuchi, NI: Niwasiro park, KU: Kurotoriyama park, UM: Umitonohureaihiroba, KO: Kouzen park, KM: Koumyouike park.

Table 3. Species richness, density, body size, and habitat type of species richness and density, species diversity, and species evenness according to urban green area.

Community Index	Area			One-Way ANOVA	
	Small Area (<5 ha)	Medium Area (>5 ha and <15 ha)	Large Area (>15 ha)	$F_{2,6}$	p
Species richness					
All species	12.0 ± 5.29	21.3 ± 3.71	25.7 ± 2.96	2.90	0.132
Body size					
Small	4 ± 2.08	5.7 ± 1.20	7.0 ± 0.00	1.17	0.372
Medium	8.0 ± 3.21	13.0 ± 3.51	15.0 ± 2.31	1.39	0.319
Large	0.0	2.7 ± 1.33	3.7 ± 0.88	4.22	0.072
Habitat type					
Forest species	2.3 ± 0.88	7.3 ± 2.19	5.3 ± 2.40	1.68	0.264
Open land species	9.7 ± 4.41	14.0 ± 1.53	20.3 ± 3.84	2.36	0.175
Density					
All species	8.93 ± 5.82	31.85 ± 14.13	19.31 ± 5.63	1.49	0.299
Body size					
Small	2.53 ± 1.87	11.99 ± 7.04	4.09 ± 1.59	1.39	0.320
Medium	6.41 ± 3.97	18.94 ± 7.56	14.28 ± 5.36	1.19	0.368
Large	0.00	0.92 ± 0.67	0.94 ± 0.50	1.26	0.350
Habitat type					
Forest species	4.61 ± 2.80	28.31 ± 14.10	3.40 ± 1.53	2.83	0.136
Open land species	4.33 ± 3.11	3.53 ± 0.58	15.91 ± 6.66	2.65	0.150
Species diversity (H')	1.54 ± 0.26	1.61 ± 0.36	2.43 ± 0.18	3.21	0.113
Species evenness (J')	0.71 ± 0.09	0.53 ± 0.10	0.75 ± 0.05	1.95	0.223

Table 4. Area (ha) and percentage of land use categories within the range of 500 m from the edge of nine urban green areas.

Land Use Category			Paddy Field		Park and Green Space	Forest	Urban Area	Road	Open Space	River and Pond	Sea	Others	Total
Small area (<5 ha)	SU	ha	3.9	5.9	3.0	2.0	81.9	13.0	6.4	0.2	0.0	0.0	116.4
		%	3.4	5.1	2.6	1.8	70.4	11.2	5.5	0.2	0.0	0.0	100.0
	CH	ha	0.0	0.4	9.0	13.4	73.1	22.2	4.2	0.7	0.0	0.0	123.0
		%	0.0	0.4	7.3	10.9	59.4	18.0	3.4	0.6	0.0	0.0	100.0
	TA	ha	0.0	0.0	2.5	0.0	89.3	7.9	4.3	0.0	19.7	0.0	123.6
		%	0.0	0.0	2.0	0.0	72.3	6.4	3.5	0.0	15.9	0.0	100.0
Medium area (>5 ha and <15 ha)	IZ	ha	5.5	11.9	6.2	11.8	68.7	20.1	2.9	11.5	0.0	0.0	138.5
		%	4.0	8.6	4.5	8.5	49.6	14.5	2.1	8.3	0.0	0.0	100.0
	NI	ha	6.2	2.5	4.5	8.9	93.6	21.4	6.1	5.6	0.0	0.0	148.7
		%	4.2	1.7	3.0	6.0	62.9	14.4	4.1	3.7	0.0	0.0	100.0
	KU	ha	15.5	16.1	10.6	28.4	49.2	4.7	7.3	7.6	0.0	11.8	151.2
		%	10.3	10.6	7.0	18.8	32.5	3.1	4.8	5.0	0.0	7.8	100.0
Large area (>15 ha)	UM	ha	0.0	0.0	0.0	0.0	2.6	0.0	61.6	0.0	115.2	0.0	179.3
		%	0.0	0.0	0.0	0.0	1.4	0.0	34.3	0.0	64.2	0.0	100.0
	KO	ha	25.5	7.6	4.0	14.9	82.4	22.7	7.6	6.0	0.0	0.0	170.7
		%	15.0	4.4	2.4	8.7	48.3	13.3	4.4	3.5	0.0	0.0	100.0
	KM	ha	16.5	19.6	22.3	43.8	167.4	29.2	23.4	12.9	0.0	0.0	335.0
		%	4.9	5.8	6.7	13.1	50.0	8.7	7.0	3.9	0.0	0.0	100.0

Study sites; SU: Suzunomiya park, CH: Chayama park, TA: Takasago park, IZ: Izumigaokaryokuchi, NI: Niwasiro park, KU: Kurotoriyama park, UM: Umitonohureaihiroba, KO: Kouzen park, KM: Koumyouike park.

Table 5. Pearson's correlation coefficient between ground beetles index and land use category of nine urban green areas.

Community Index	Year	Area (ha)	Paddy	Field	Park and Green Space	Forest	Urban Area	Road	Open Space	River and Pond
Species richness										
All species	0.333	0.591 **	0.234	0.305	−0.288	0.022	−0.900 ***	−0.806 ***	0.702 ***	0.081
Body size										
Small	0.639 ***	0.379	0.017	−0.235	−0.700 ***	−0.490 *	−0.612 **	−0.476 *	0.707 ***	−0.321
Medium	0.287	0.527 **	0.215	0.349	−0.254	0.047	−0.891 ***	−0.796 ***	0.675 ***	0.125
Large	0.061	0.692 ***	0.369	0.515 *	0.085	0.374	−0.791 ***	−0.774 ***	0.479 *	0.265
Habitat type										
Forest species	−0.654 ***	0.172	0.641 ***	0.960 ***	0.700 ***	0.841 ***	−0.055	−0.077	−0.358	0.831 ***
Open land species	0.644 ***	0.562 **	−0.026	−0.089	−0.615 **	−0.342	−0.946 ***	−0.836 ***	0.913 ***	−0.274
Density										
All species	0.127	−0.476	−0.061	0.262	−0.306	−0.231	−0.127	0.175	0.040	0.568 **
Body size										
Small	−0.214	−0.630 ***	0.060	0.453 *	0.032	0.033	0.195	0.442 *	−0.336	0.783 ***
Medium	0.399	−0.362	−0.196	0.024	−0.567 **	−0.467 *	−0.310	0.008	0.307	0.306
Large	−0.336	0.694 ***	0.570 **	0.658 ***	0.492 *	0.721 ***	−0.493 **	−0.628 **	0.139	0.283
Habitat type										
Forest species	−0.327	−0.692 ***	0.031	0.467 *	0.181	0.123	0.353	0.570 **	−0.490 *	0.819 ***
Open land species	0.795 ***	0.471	−0.155	−0.413 *	−0.822 ***	−0.597 **	−0.841 ***	−0.742 ***	0.947 ***	−0.550 **
Species diversity (H')	0.146	0.902 ***	0.411 *	0.219	−0.020	0.256	−0.749 ***	−0.874 ***	0.580 **	−0.222
Species evenness (J')	0.144	0.901 ***	0.416 *	0.223	−0.020	0.258	−0.751 ***	−0.874 ***	0.579 **	−0.216

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

4. Discussion

Unexpectedly, species richness, density, body size, habitat type, species diversity, and species evenness did not differ between the different urban green areas. Furthermore, the community structure of ground beetles was similar in different areas. It seems that ground beetle communities formed by the effect of urbanization may become similar regardless of area. Ishitani et al. [23] showed that in urban habitats, large-sized forest specialists may completely disappear, whereas small-sized forest specialists and medium-sized habitat generalists were in higher abundance. Fragmentation and isolation as well as lower habitat quality of remnant urban habitat patches may cause generalist species to increase [13]. Lee and Ishii [24] studied riverbank, urban park, rice paddy, and coppice remnants in southern Osaka and showed that forest specialist, open-habitat specialist, large-sized, and endemic species have been reduced by urbanization. In our study, four large-sized forest species (*Carabus yaconinus*, *Leptocarabus kumagaii*, *Haplochlaenius costiger*, and *Galerita orientalis*) were recorded. Ishitani et al. [23] considered *C. yaconinus* and *H. costiger* as forest generalists. *L. kumagaii* and *G. orientalis* might be forest generalists based on collected records such as riverbanks, paddy fields, and urban green areas around forests in previous studies [20,24,25]. Among three dominant species, *Synuchus nitidus* and *Dolichus halensis* were considered forest generalist and habitat generalist, respectively [24]. This result seems to be consistent with previous studies.

Remnant forests may be one of the reasons why ground beetle assemblages were similar regardless of area. Although SU was the smallest area in this study, 22 ground beetle species were recorded, and this value was higher than the average (20 species). SU is located near Hatadaimyou temple where there are remnant forests dominated by evergreen oaks (*Quercus* species). Forests associated with shrines and temples are recognized as important components of urban green spaces and can potentially function as a key role in ecosystem conservation in urban areas [17]. Although urban forests have less species richness and abundance and different species composition and dominant species compared with rural forest, they can provide habitats for wildlife and potentially be used as stepping stones in the urban green space network [17,26]. Connectivity for ground beetles in urban areas will be another important factor. Both UM and TA are located in landfill areas. However, species richness in UM was the highest, whereas that in TA was the lowest. UM is located near the mouth of Yamato River, whereas TA is connected to inland with two bridges. Yamato River is a class A river in the Kansai region and flows from Nara and Osaka Prefectures to the Osaka Bay [25]. Lee and Ishii [25] reported that 53 ground beetles were found in various places such as gravelly riverbeds, sand lands, and grassy riverbanks in Yamato River. Among ground beetles found in UM, 86% species composition was the same as that found by Lee and Ishii [25]. In addition, this result showed that *Carabus yaconinus* was collected in IZ, KU, and KM, which are connected to natural habitats. Lee and Ishii [24] reported that *Carabus yaconinus* was not found in urban parks which are separated from natural forests in southern Osaka. Lee and Kwon [16] suggested that short-winged *Carabidae* species, poor dispersers, disappear in fragmented forests. These species may not be able to disperse through corridors or stepping stones. Our results suggest that remnant forests and connectivity will contribute to keeping ground beetle diversity in the urban area.

Although there is no significant relationship between ground beetle communities and area, community indices were positively or negatively correlated with area. Among them, ground beetle species richness, species diversity, and species evenness showed positive correlations with area. Urban area and road were negatively correlated with species richness of all species, small-sized species, medium-sized species, large-sized species, open land species, and density of large-sized species and open land species, and species diversity and species evenness. Koivula and Vermeulen [27] showed that carabid populations isolated by highways were significantly affected by patch size, and forest carabids rarely cross roads. Keller and Largidèr [28] reported that the isolation caused by major roads has a significant impact on the genetic structure of ground beetle populations.

Urbanization substantially influences all levels (species group, population, and community) of the biological organization of ground beetles living in urban green areas [13]. Our results were consistent with previous studies. However, there are no uniform patterns in year, field, park and green space, forest, or open space with community index. Future studies should increase the sample size to enhance the statistical rigor.

5. Conclusions

Our results suggest that there is no significant relationship between ground beetle communities and area. However, community indices were positively or negatively correlated with area. The changes in paddy, field, park and green space, forest, and open space associated with the increasing urban area and road greatly influenced species composition and the similar community structure remained. Remnant forests and connectivity were important factors to conserve ground beetle diversity in urban areas. The urban green space network will be essential for biodiversity conservation in an urban ecosystem. As cities expand, decision-makers should invest in preserving and restoring remnant habitats and their connectivity to the urban green space network.

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