도시계획학 석사학위논문

Spider (Arachnida; Araneae) Community and Guild Structure in Green Roofs and Adjacent Ground-level Green Areas in Seoul

서울 옥상 녹지와 주변 지면 녹지에 서식하는 거미군집(거미강; 거미목)과 기능군 구조

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환경계획학과 환경관리전공

송 준 용

Abstracts

Spider (Arachnida; Araneae) Community and Guild Structure in Green Roofs and Adjacent Ground-level Green Areas in Seoul

Junyong Song
Depertment of Environmental Planning/ Environmental management
The Graduate School of Environmental Studies
Seoul National University

Green roofs are emerging as potential habitats for biodiversity within urban environment. However, studies on biodiversity on green roofs, its ecological functions and the difference to those of other urban habitats at ground-level are limited to certain geographic range. Spiders (Arachnida; araneae) are frequently studied taxa in understanding urban habitats for their importance in providing ecological functions and representing higher trophic structure. In this regard, this study assesses the spider communities on urban green roofs and ground-level habitats and examines what environmental factors influences spider community composition. Spider communities were compared at species and predatory guild level, in order to assess whether spider communities of two different habitat types provide different ecological functions.

Spider community was surveyed using pitfall traps on 12 intensive green roofs of *gu* (district) office buildings and 12 adjacent ground-level habitats in Seoul, South Korea. Age, area, height, plant structure and surrounding landuses within 300m radius were surveyed as environmental variables. Spider communities were grouped into two groups by hierarchical cluster analysis. Non-metric multi-dimensional scaling was used to visualize compositional difference of spider communities and environmental variables explaining the composition. Analysis of similarities and similarity percentages analysis was performed to examine the significance of difference in spider community compositions.

The results revealed that araneae community of each habitat type was significantly different, although some communities of green roof sites and ground-level sites were similar in composition. The compositional difference was explained by shrub and soil cover, and height of habitats, while landscape variables did not explain the compositional difference of spider communities. Difference in guild structure by habitat types suggest the functions of spider communities in each habitat could be different. Thus, perception of green roofs should not just be a surplus of green areas in urban environment, but a provision of distinct ecological communities, which is critical in terms of ecosystem services and biodiversity conservation.

Keywords: Urban ecology, Green roofs, spider community composition, guild structure, Analysis of similarities, Non-metric multi-dimensional scaling

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Ⅰ Introduction

Previous biodiversity conservation effort focused on lands with low human population apart from urban areas (Kareiva and Marvier 2003; Myers 1990; Miller and Hobbs 2002). However, urban regions provide great opportunities to tackle these conservation and sustainability issues (Grimm et al. 2008; Groffman et al. 2014). Recently, it is revealed that there is a distinct urban arthropod community compared to non-urban habitats that possibly contributes to gamma biodiversity at a broad scale (Sattler et al. 2011). Urban green roofs as novel ecosystems have strong potential for urban biodiversity conservation by converting existing space to new habitats (Schindler et al. 2011). Especially, green roofs can host diverse arthropod fauna in urban environment (Jones 2002; Kadas 2006; Colla et al. 2009; Tonietto et al. 2011; Braaker et al. 2014; Ksiazek, et al. 2014; Williams et al. 2014; MacIvor and Ksiazek, 2015). Arthropods found on green roofs are indicative of the essential roles they play in diverse ecological processes as followings: 1) substrate stabilization; 2) pest control; 3) pollination; 4) food web enhancement; 5) decomposition and 6) providing opportunities for ecological education for general public (MacIvor and Lundholm, 2011; Choi 2015; MacIvor and Ksiazek 2015).

However, it is still controversial whether green roofs actually contribute significantly to urban biodiversity conservation possibly due to lack of empirical data (Williams et al. 2014). Roles of green roofs are acknowledged and implemented only in some parts of the world. For example, local government of Basel, Switzerland now requires green roofs on every new building with flat roofs to maximize habitat value for local flora and fauna (Brenneisen 2006). Hundreds of species have been found on various green roof types globally (Jones 2002; Kadas 2006; Colla et al. 2009; Coffman and Waite 2011; Madre et al. 2013; Ksiazek et al. 2014). In London, even nationally rare invertebrate species were found on vegetated roofs (Kadas 2006). On the other hand, MacIvor and Lundholm (2011) found the insect species composition of green roofs did not differ from that of adjacent ground-level habitats. Also, only generalist species are known to be supported by green roofs with poor amount of documented research (Williams et al. 2014). The ability of different green roofs to host various biodiversity has been appreciated merely for a few years. Furthermore, the habitat value of green roofs for arthropods has been studied only in certain regions of the globe (MacIvor and Lundholm, 2011), just as other urban ecological studies (Mckinney 2008). This trend may have generated biased conclusion in urban ecological dynamics.

Developing a comprehensive understanding of the interactions between built environment and the urban biodiversity is an important task (Pataki 2015). Beyond understanding and appreciating green roofs per se as one type of habitat, it is necessary to compare the green roofs and other ground-level habitats directly in order to assess and understand the green roofs as urban habitats. However, ecological understanding on green roofs as a conservation strategy is still in its infancy. There are only few empirical studies (Kadas 2006; Schrader and Boning 2006; Colla et al. 2009; MacIvor and Lundholm 2011; Tonietto et al. 2011; Braaker et al. 2014) directly comparing arthropod diversity between green roofs and other urban habitats on ground-level. MacIvor and Lundholm

(2011) revealed that arthropods of green roofs and ground-level sites did not differ. On the other hand, Braaker et al. (2014) found arthropod communities get influenced differently according to the habitat connectivity and functional traits of taxa. Arthropod groups with low mobility (carabids and spiders) were mainly shaped by local environmental variables rather than habitat connectivity (Braaker et al. 2014). Considering the fact that these studies are biased geographically, previous patterns could not be generalized worldwide. Another research conducted in Switzerland emphasizes environmental control and stochasticity as major factors shaping the community compositions of urban taxa (Sattler et al. 2010*a*). Thus, previously revealed patterns can be extremely contrasting or different in regions with higher degree of urbanization.

In most ecological communities, spiders are the most abundant and dominant components of the arthropod predatory guild (Wise 1995; Nyffeler 2000). They are the key controlling agent in terrestrial ecosystems (Riechert and Lockley 1984; Nyffeler and Benz 1987; Marc et al. 1999). Spiders also might reflect changes in trophic structure in human-altered ecosystems (Shochat et al. 2004). These characteristics make spiders a good indicator group for comparing biodiversity of various environments including cities (Marc et al. 1999; Cardoso et al. 2004; Sattler et al. 2014). Thus, ground-dwelling spider diversity and community composition will be used as proxy for arthropod community diversity in this study.

In this study, spider community composition is examined and compared between green roofs and ground-level sites to improve understanding of dynamics of green roof habitats and their distinctive roles in urban ecosystem.

Specific goals are: 1) to examine if a distinct green roof community exists; 2) to explain how local environmental variables and landscape configuration build spider community composition in urban environment. Research hypotheses are the followings: 1) spider community of green roofs will be more diverse and abundant than that of ground-level habitats; 2) spider community of each habitat type will differ in both species and guild composition; 3) local environmental variables will have significant influence on arthropod community composition among different variables. The results of this study will be discussed in the perspective of urban biodiversity conservation and potential use of intensive green roofs as urban conservation site.

Ⅱ Materials and Methods

1. Study sites

The study was conducted on green roofs of twelve *gu* (district) office buildings and twelve ground-level sites near each of corresponding roof in Seoul, the capital city of South Korea (Figure 1). Seoul is the most urbanized and compact city in South Korea with an area of 605.25 km^2 and 10.2 million residents as of 2016 (Seoul Metropolitan Government 2016). Seoul has a temperate climate where mean annual temperature is 12.8℃ with the highest recorded summer temperature of 36.7℃ in 2012 and the lowest recorded winter temperature of -18.6℃ in 2001 for the last 20 years. The mean annual precipitation is 1,496.4 mm with concentrated rainfall during the summer (Korea Meteorological Administration 2016). Green roof technology has been greatly promoted in Seoul by Seoul Metropolitan City since 2002 in order to provide green areas for urban residents, to mediate urban heat-island effect and to improve urban air quality, energy efficiency and urban biodiversity. Most of the green roofs constructed in Seoul are intensive roofs, meaning their primary purpose is providing recreational space and aesthetic value to users in such exceptionally urbanized environment. Although the number of public and private green roofs is continuously growing in Seoul, but few empirical research tests the interactions between the urban biodiversity with local biodiversity and ground habitats (Choi 2015).

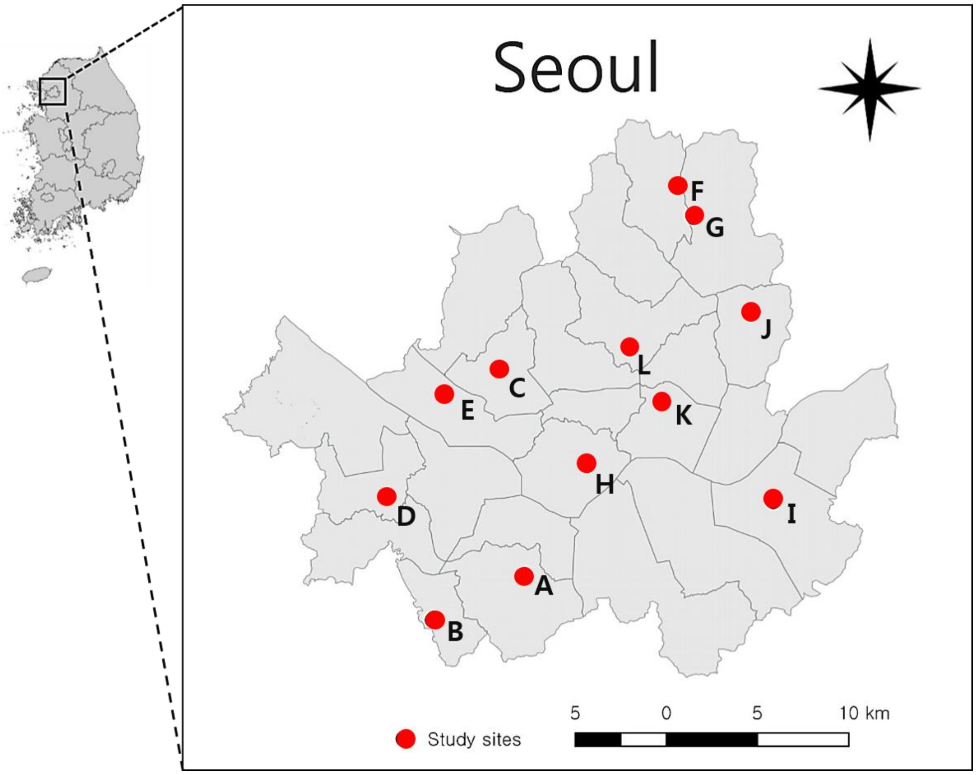


Figure 1. Location of twelve green roofs and corresponding ground-level sites in Seoul (12 pairs of green roof sites and ground-level sites). Red dots represent a pair of roof and ground-level habitats of *gu*s as follows: Gwanak-*gu* (A); Geumchun-*gu* (B); Seodaemun-*gu* (C); Yangcheon-*gu* (D); Mapo-*gu* (E); Dobong-*gu* (F); Nowon-*gu* (G); Yongsan-*gu* (H); Songpa-*gu* (I); Jungnang-*gu* (J); Seongdong-*gu* (K); Seongbuk-*gu* (L).

Green roofs on *gu* office buildings are geographically widely distributed across the city. Generally, green roofs can be categorized into extensive and intensive roof according to their purposes, components and maintenance regimes (Table 1.) (Kadas 2006; Köhler 2006; Oberndorfer et al. 2007). All of the green roofs selected in this study were intensive green roofs (Table 1), which are the representative form of urban green roofs in Seoul. Access to each green roof site during the study period was another important determinant of study site selection. Each ground-level habitat was the best possible analogue within 50 m from each green roof site in terms of size and vegetation type (modified from MacIvor and Lundholm 2011). The only exception was ground-level site of Jungnang-*gu*. The only vegetated site within 50 m radii around the district office building was a grassland of Bongsudae park. Both roof sites and ground sites were managed by local administrative institutions.

Table 1. Classification of green roofs (compliled from Kadas 2006; Köhler 2006; Oberndorfer et al. 2007)

Characteristic	**Extensive roof**	**Intensive roof**
Purpose	Functional: storm-water retention, thermal insulation, fireproofing and etc.	Functional and aesthetic
Substrate depth	Shallow (< 20cm)	Deep (> 20cm)
Plant community	Restricted to low-growing shallow rooted plants and mosses tolerant to harsh roof environment	Rarely restricted other than to those imposed by substrate depth, climate, building height, and water supply
Maintenance	Little or no maintenance required	Frequent maintenance required as regular gardens
Accessibility	Functional rather than accessible	Accessible: bylaw considerations

2. Spider sampling

Pitfall-trapping was the primary sampling technique in this study. It is one of the oldest, most frequently used method for ground-dwelling arthropods including spiders, but require cautions for proper sample collection (Uetz and Unzicker 1975; Woodcock 2005). A pitfall trap consisted of a 14 oz. transparent plastic beverage cup (98 mm wide, 110 mm deep), filled with 40% ethylene glycol for killing, and a plastic cover prevented the traps from being flooded by rain (Figure 2). At each green roof and corresponding ground-level habitat, six traps were planted randomly, with their rims flush with the surface. Minimum distance between each trap was 5 m (where not possible, 3 m) in order to prevent possible influence of close pitfall trap placement on catches (Ward et al. 2001). Pitfall traps were emptied and reset biweekly from the 26th of September to the 25th of November, 2016. Collected samples were moved into 70% ethyl alcohol for preservation and identified to species level.

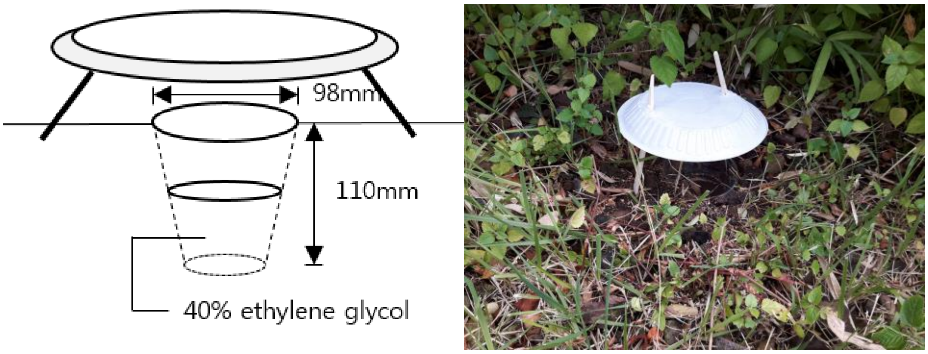


Figure 2. Design of a pitfall trap and installed trap

3. Environmental variables

Urban ecosystem is a unique setting, where ecological ‘rules’ often contradict those in natural ecosystem (Shochat et al. 2006). Human activities are primary driving force of fundamental ecological patterns and processes in both natural and urban environment at multiple spatial scales (Shochat et al. 2006). In this study, two sets of environmental variables were measured related to ecological processes at local and landscape levels which possibly affect spider community composition. The first variable set is composed of four local variables predicted to affect niche processes of spider community: 1) vegetation structural diversity; 3) building height; 4) habitat size; and 5) habitat age (Schindler et al. 2011; Madre et al. 2013; Braaker et al. 2014). Vegetation structure has been defined as one of the primary factors affecting urban arthropod community composition, especially spiders (Madre et al. 2013; McIntyre et al. 2001). Coverage of each vegetation structure (i.e. herb, shrub, tree, and soil) was measured using six 3×3 m^2 quadrats around each randomly distributed pitfall trap in each site (modified from McIntyre et al. 2001). Boundaries of each site was set as waypoints and track and altitude above sea level was measured by GPS device (Garmin 60CSx, Olathe, KS, USA). Areas were calculated by GIS software (QGIS 2.10.1, Pisa). The second variable set comprises the proportion of eleven landuse types: residential; industrial; commercial; recreational; traffic; public; broad-leaved forest; mixed forest; grassland; water and etc. Landuse cover was extracted from a digitized map of Seoul (Ministry of Environment 2013) and processed in ArcGIS 10.1 (Esri, Redlands, CA, USA). Percentage cover of each landuse type within 300 m range from edges of each site was calculated. Different landuse types within that range have significantly explained spider community composition on green roofs (Braaker et al. 2014).

4. Data Analyses

Before statistical analysis, singletons, species occurring in only one single study site during the study period, were removed in order to exclude an influence of stochastic species occurrences (Sattler et al. 2011; Braaker et al. 2014). Spider community compositions of green roofs and ground-level sites were explored using Non-metric multi-dimensional scaling (NMDS). NMDS can be used to examine patterns in a multivariate data (Anderson et al. 2011). NMDS is unconstrained by environmental variables and the ordination of sites is determined only by species composition. Thus, the environmental variables were fitted to the ordination using *envfit* function of the Vegan package in R (Oksanen et al. 2009). Significant difference in community composition was examined by Analysis of similarities (ANOSIM). Statistical significance was tested by 9999 random permutations. Also, Similarity percentages (SIMPER) analysis was used to identify species and guilds determining the observed community differences. To assess similarities (β diversity) between and within habitat types, hierarchical cluster analysis using the Ward’s minimum variance clustering method is performed (Ward 1963; Legendre and Legendre 1998) and visualized into a dendrogram. Statistical difference in environmental variables between roof sites and ground-level sites were tested by ANOVA. All statistical analyses were performed using R version 3.2.3 (R Development Core Team 2015) using functions of the Vegan library (Oksanen et al. 2009).

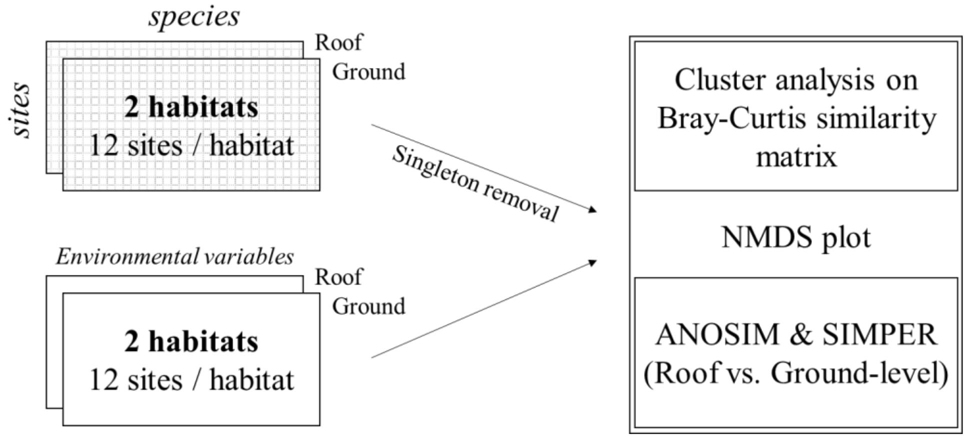


Figure 3. Overview on the data used and performed analyses (see Data Analysis for details).

Ⅲ Result

1. Spider community composition

In total, 833 specimens of 49 spider species belonging to 18 families were sampled from all sites (Table 2). After singleton removal, 815 individuals of 31 species were used in statistical analyses. Dominant species of all sampled spider were represented for the sake of record (Table 3). Dominant species are defined as representing more than 1% of total specimens in collected assemblage (Samu and Szinetár 2002). Abundance of spiders on green roofs were higher than that of ground-level sites, but not statistically significant. Diversity indices of each habitat type also did not differ significantly (Figure 4). However, community composition of spider differed significantly according to two habitat types (Figure 6). Two main clusters were identified respectively corresponding to similarity of community composition by hierarchical cluster analysis (Figure 5).

Table 2. Brief summary of sampled spider community in each habitat type

	Roof	**Ground-level**	**Total**
Species richness	38	31	49
Number of family	17	11	18
Abundance	508	325	833

Table 3. List of dominant spider species found in urban green roof sites and adjacent ground-level habitats

Family	**Species**	**Distribution** (Yoo et al. 2015)
Agelenidae	*Iwogumoa songminjae*	Russia, China, Korea
	Pireneitega spinivulva	Russia, China, Korea, Japan
Gnaphosidae	*Micaria divess*	Palearctic
	Zeltotes tortuosus	Korea, Japan
Hahniidae	*Hahnia corticicola*	Russia, China, Korea, Taiwan, Japan
Linyphiidae	*Erigone* sp.	Holarctic
Lycosidae	*Pardosa astrigera*	Russia, China, Korea, Taiwan, Japan
	Arctosa sp.	Russia, Korea, Japan
	Pardosa laura	Russia, China, Korea, Taiwan, Japan
	Piratula procurvus	China, Korea, Japan
Minmetidae	*Mimetus* sp.	China, Korea, Japan
Phrurolithidae	*Orthobula crucifera*	China, Korea, Japan
Salticidae	*Pseudeuophrys iwatensis*	Russia, China, Korea, Japan
Thomisidae	*Xysticus saganus*	Russia, China, Korea, Japan
	Ozyptila nongae	Russia, China, Korea, Japan

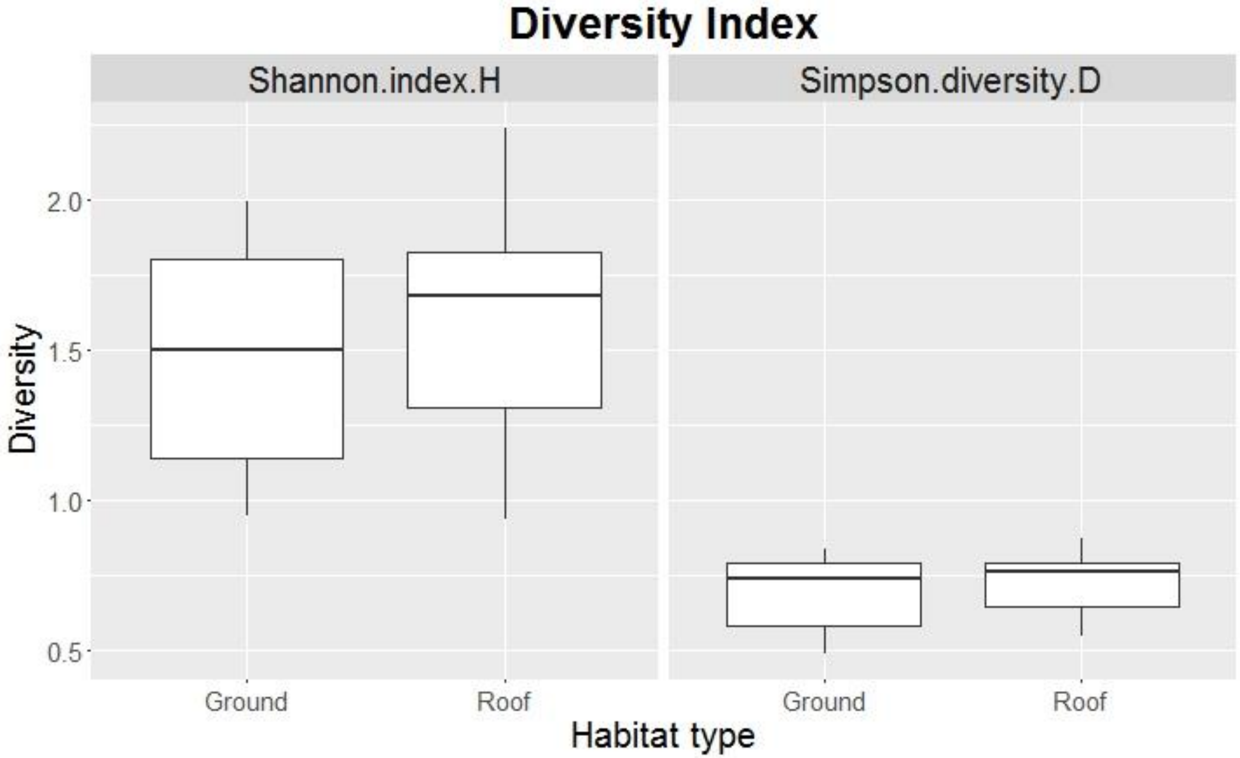


Figure 4. Comparison of Shannon diversity index (H') and Simpson diversity index (D) of spider community from two habitat types.

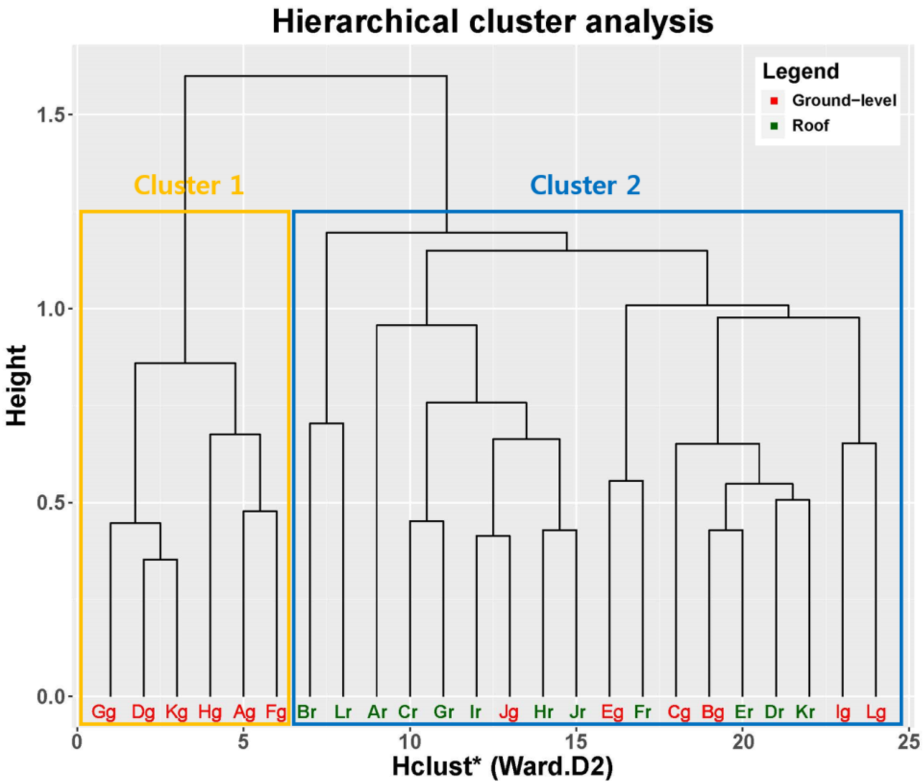


Figure 5. Dendrogram of the hierarchical cluster analysis based on Bray-Curtis dissimilarity. All sites were grouped into two main clusters**.**

2. Environmental variables

Local environmental variables such as areas, altitude, and percentage covers of four vegetation structure for roof sites and ground-level sites are summarized in Table 4. ANOVA confirmed no significant difference in all local environmental variables between roof sites and ground-level sites. However, shrub cover was slightly higher in roof sites. Also, height difference between roof sites and ground-level sites was 30 m in average. Landuse variables within 300 m range did not differ statistically, simply because roof sites and corresponding ground-level sites are nearby. Land use variables within 300 m range also was not correlated with spider community composition by each *gu*.

Table 4. Local environmental variables (Mean ± Standard deviation) of green roofs and ground-level sites (For details and landuse variables, see Appendix 2).

Environmental variables	**Roof sites**	**Ground-level sites**	**Total**
Age (years)	7.7 ± 2.3	13.6 ± 9.1	10.6 ± 7.1
Area (m^2)	535.9 ± 545.9	1407.6 ± 3210.3	971.7 ± 2295.6
Altitude above sea level (m)	79.9 ± 35.3	49.9 ± 38.1	64.9 ± 39.1
% Herb	54. 9± 23.6	55.3 ± 26.4	55.1 ± 24.5
% Shrub	26.1 ± 19.4	17.2 ± 9.9	21.6 ± 15.8
% Tree	7.2 ± 6.3	13.1 ± 11.4	10.1 ± 9.5
% Soil	16.9 ± 17.7	29.3 ± 21.5	23.1 ± 20.3

3. Community composition and environmental variables

Environmental variables were fitted into NMDS ordination plot of species –site matrix based on Bray-Curtis dissimilarity (Figure 6). Altitude and percentage cover of shrub and soil significantly explained the community composition of habitats. Higher soil cover explained spider community of ground-level sites, while higher shrub cover and higher altitude explained spider community of green roof sites. Result of ANOSIM proved spider species community of green roof sites and ground-level sites differ significantly (R = 0.36, P = 0.001). Guild composition of both sites also differed significantly (R = 0.273, P = 0.003). SIMPER analyses revealed four species that contributed more than 50% of species compositional difference and two predatory guilds contributed more than 50% of guild compositional difference (Table 5). Average dissimilarity of spider community between two habitat types was 80.63% at species level and 60.82% at functional (guild) level. Spider community structure of different urban habitat types was further explored in discussion section (Figure 9 and 10). Ambush hunters and ground hunters were respectively more abundant in green roof sites, while sheet-web building spiders were more abundant in ground-level sites. Other hunters 1, space-web building spiders and specialists showed no difference in mean abundance possibly due to uneven distribution through sites.

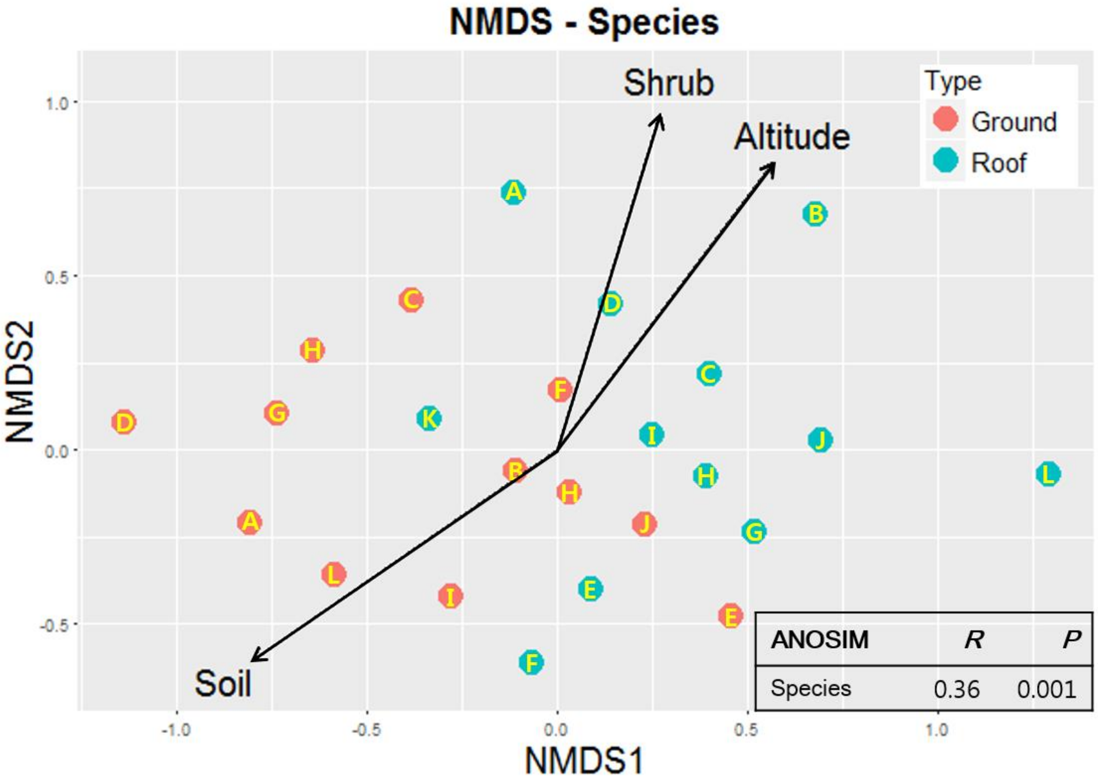


Figure 6. Ordination plot for NMDS analysis of studied sites run on singleton removed spider species-per-site data. Environmental variables correlated with 24 sites are displayed in arrows.

Table 5. SIMPER analysis of differences in (a) species (average dissimilarity = 80.63%), and (b) guild (average dissimilarity = 60.82%) composition of spider communities between two urban habitat types in Seoul.

		Roof	**Ground-level**	
	Family	**Mean abundance**	**Mean abundance**	**Cumulative contribution (%)**
(a) Species				
Xysticus saganus	Thmosidae	14.67	3.92	22.11
Iwogumoa songminjae	Agelenidae	0.67	8.25	38.25
Pardosa astrigera	Lycosidae	4.42	3.83	49.73
Ozyptila nongae	Thomisidae	3.83	2.00	58.45
(b) Predatory guild				
Ambush hunter		18.5	5.92	36.63
Ground hunter		15.5	8.58	70.73

4. Guild classification

Different ecological functions of spiders can be defined by ecological guilds of spider species. Species with same hunting mode (i.e. species that displays same predatory habits and exploit similar environmental resources) can be grouped into a same guild. Guild classification of sampled species were based on the recent worldwide spider guild classification (Cardoso et al. 2011) (Figure 6). Guild classification allows whether spider communities of each habitat type play different roles in terms of urban ecology. Variation in guild structure was examined (Figure 7) and difference was directly compared (Figure 8).

Table 6. Guild classification of sampled spiders based on Cardoso et al. (2011)

Predatory guild	**Family**	**Species**
Ambush hunters	Thomisidae	*Xysticus saganus*
		Ozyptila nongae
Ground hunters	Dictynidae	*Cicurina japonica*
	Gnaphosidae	*Micaria dives*
		Zeltotes tortuosus
		Gnaphosa kompirensis
		Drassodes serratidens
		Odontodrassus hondoensis
		Drassyllus truncatus
	Lycosidae	*Pardosa hedini*
		Pardosa astrigera

Predatory guild	Family	Species
Ground hunters (continued)		Arctosa sp.
		Pardosa laura
		Piratula procurvus
		Trochosa ruricola
		Arctosa kwangreungensis
		Lycosa suzukii
	Oonopidae	*Gamasomorpha cataphracta*
	Phrurolithidae	*Orthobula crucifera*
		Phrurolithus pennatus
Other hunters 1	Linyphiidae	*Agyneta rurestris*
		Erigone sp.
		Erigone prominens
		Bathyphantes gracilis
		Doenitzius pruvus
		Syedra oii
		Microneta viaria
	Philodromidae	*Thanatus nipponicus*
	Salticidae	*Euophrys kataokai*
		Bristowia heterospinosa
		Evarcha sp.
		Sitticus fasciger
		Pseudeuophrys iwatensis
		Heliophanus ussuricus
		Carrhotus xanthogramma
Other hunters 2	Clubionidae	*Clubiona* sp.
Sensing web	Atypidae	*Calommata signata*
	Oecobiidae	*Uroctea compactilis*
Sheet web	Agelenidae	*Iwogumoa songminjae*
		Agelena limbata

Predatory guild	Family	Species
Sheet web (continued)		*Pireneitega spinivulva*
	Hahniidae	*Hahnia corticicola*
Space web	Pholcidae	*Pholcus crypticolens*
		Pholcus sp.
	Theridiidae	*Steatoda triangulosa*
		Stemmops nipponicus
		Parasteatoda angulithorax
	Titanoecidae	*Nurscia albofasciata*
Specialists	Mimetidae	*Mimetus* sp.

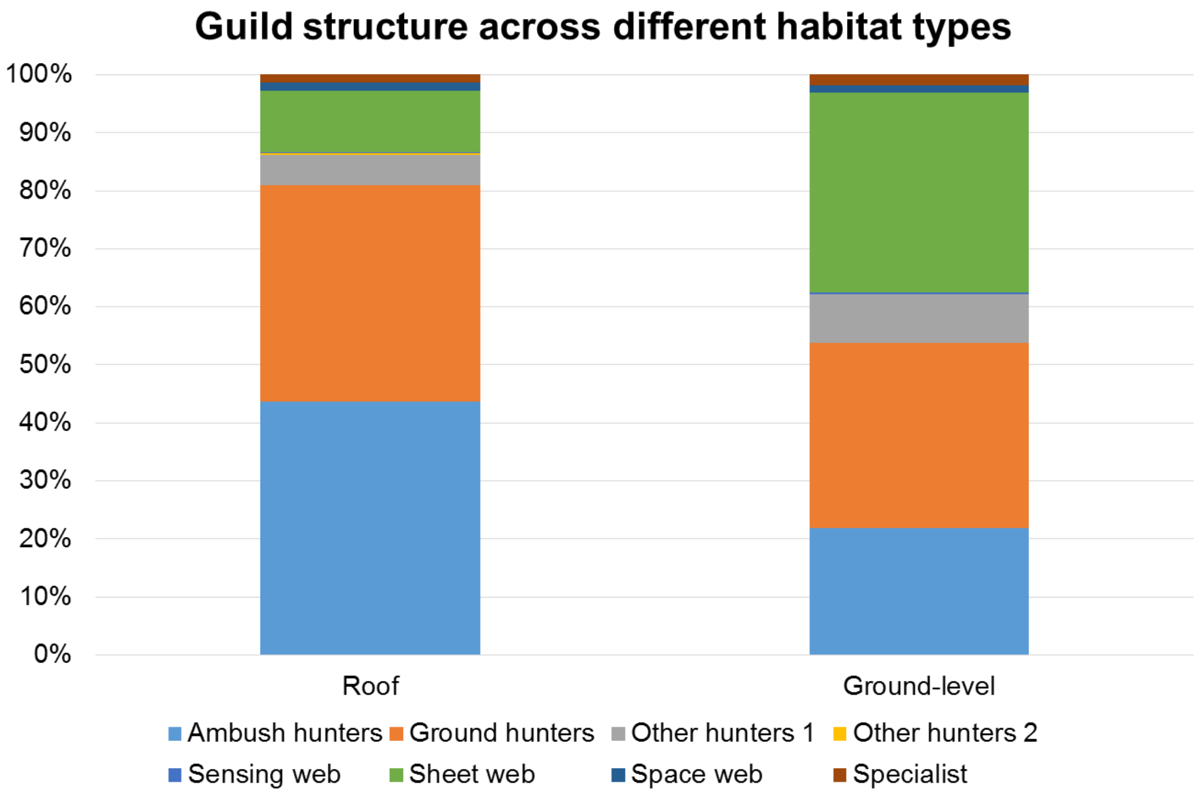


Figure 7. Predatory guild structure (i.e. hunting mode) by different habitat types.

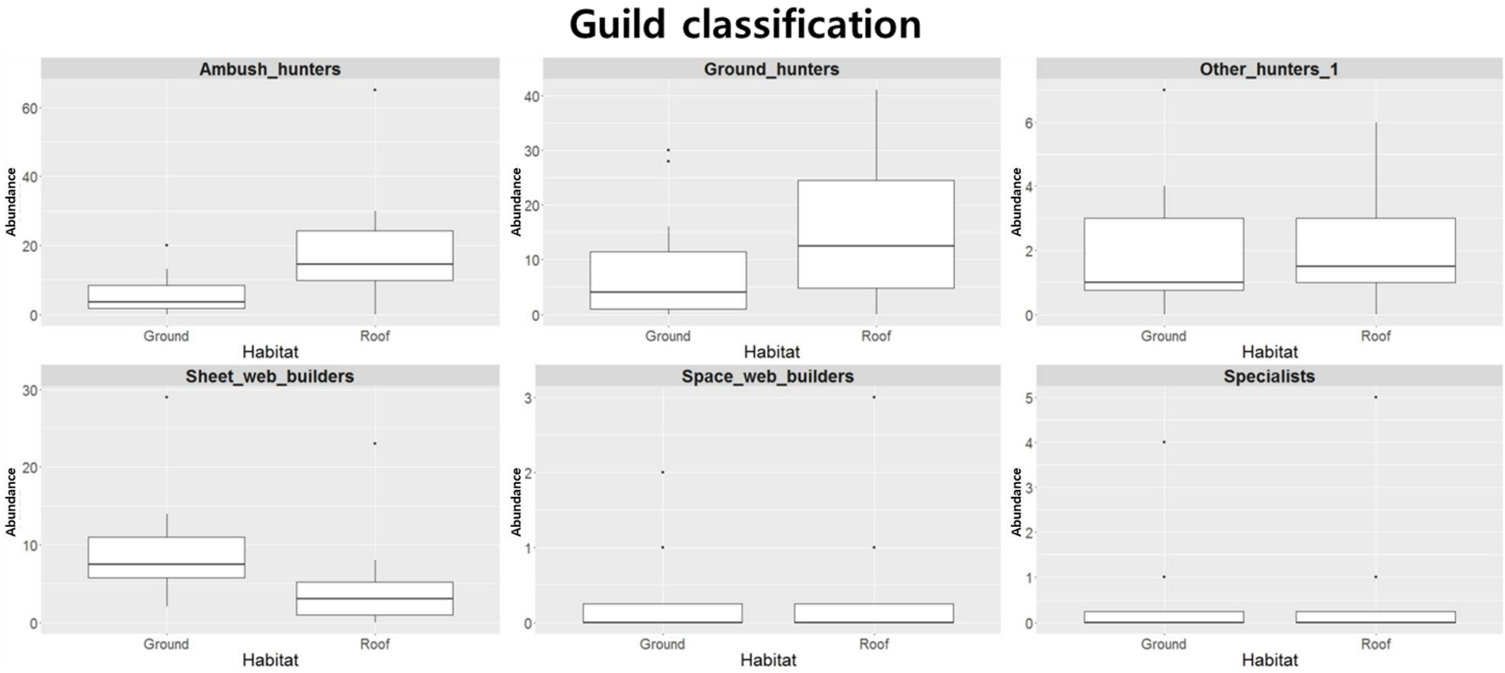


Figure 8. Direct comparison of predatory guilds (i.e. hunting modes) by different habitats.

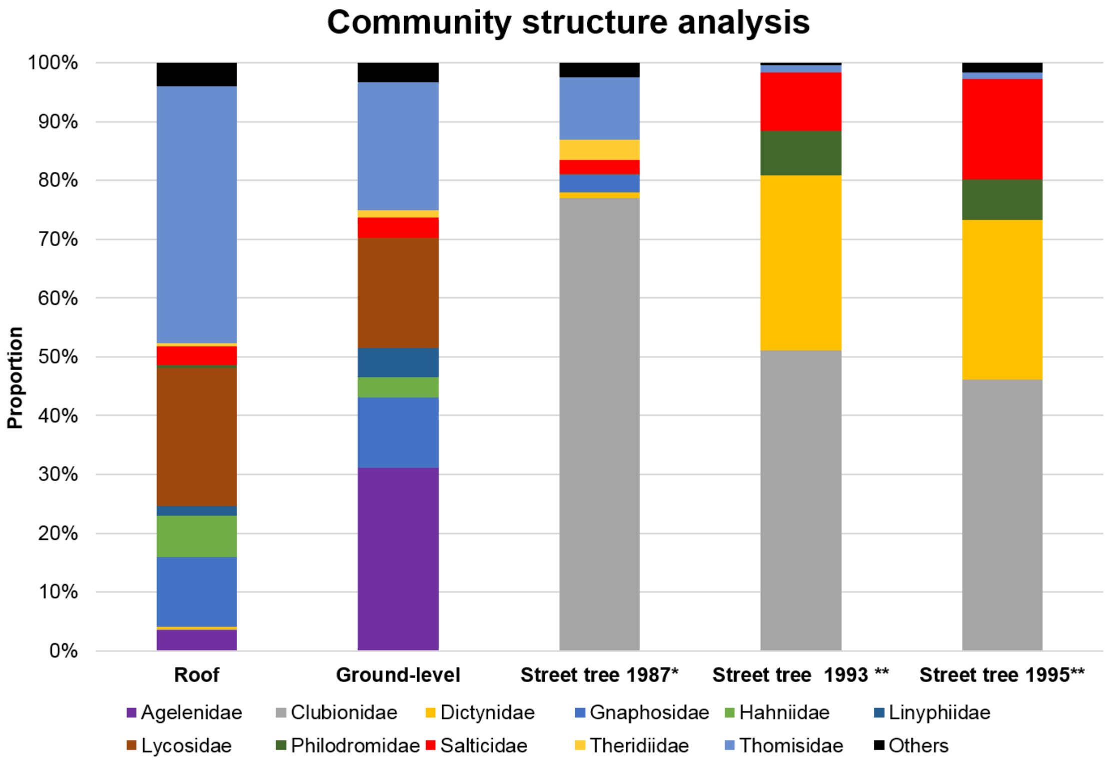
Ⅳ **Discussion**

1. Spider community structure in urban habitats

The present study is an inventory of spiders is one of the few studies on spider communities in Seoul. Only two previous studies have surveyed urban spider communities in Seoul (Lee et al. 1988; Kim and Kim 1995). Both studies examined community structure of straw bands (used by numerous arthropods for overwintering) of street trees. Direct comparison of community structure is not possible as both survey periods and methods are different to those used in this study (Table 7). Also, sampling result represented in Lee et al. (1988) and Kim and Kim (1995), may not fully represent the spider community of street trees, as sampling methods are unusual in any other places in the world. However, overall compositional difference of spider community is noticeable, which can be explained as there are major users of each habitat are different (Table 7). In further studies, spider community compositions of various habitat types in urban context could be made with consistent sampling methods and effort. Also, all dominant species found in studied sites are known to have wide distribution in Northeast Asia (Table 3). This study may be used in assessing endangered or rare species accompanied by long-term monitoring of spider community in Seoul.

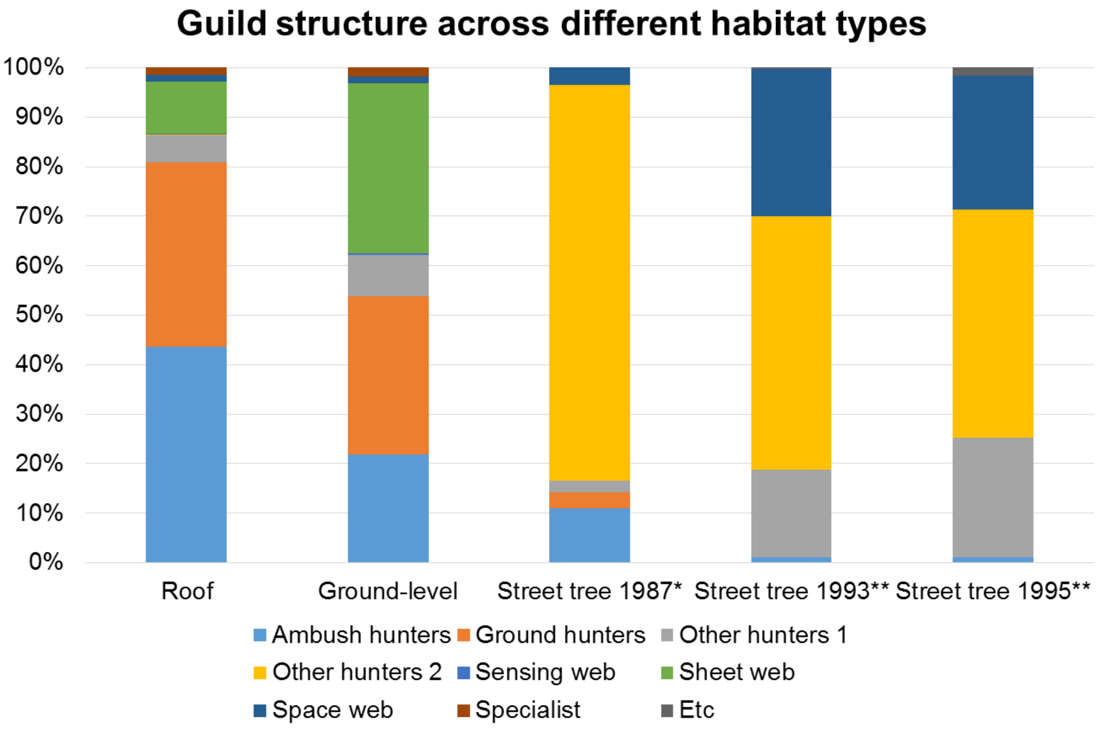
Table 7. Family proportion of urban spider community in Seoul

Family	**Roof (%)**	**Ground-level (%)**	**Street tree (%)** (Lee et al. 1988)	**Street tree (%)** (Kim and Kim 1995)	
Survey period	Sep – Nov 2016	Sep – Nov 2016	Dec 1987	Mar 1993	Mar 1995
Agelenidae	**3.5**	**31.1**	0.0	0.0	0.0
Atypidae	0.0	0.3	0.0	0.0	0.0
Clubionidae	0.2	0.0	**77.0**	**51.1**	**46.1**
Dictynidae	0.4	0.0	0.9	**29.7**	**27.1**
Gnaphosidae	**11.8**	**12.0**	**3.1**	0.0	0.0
Hahniidae	**7.1**	**3.4**	0.0	0.0	0.0
Linyphiidae	**1.6**	**4.9**	0.0	0.0	0.0
Lycosidae	**23.4**	**18.8**	0.1	0.0	0.0
Mimetidae	1.4	1.8	0.0	0.0	0.0
Oecobiidae	0.2	0.0	0.0	0.0	0.0
Oonopidae	0.2	0.0	0.0	0.0	0.0
Philodromidae	0.6	0.0	0.0	7.6	6.9
Pholcidae	0.4	0.0	0.0	0.0	0.0
Phrurolithidae	1.4	1.2	0.0	0.0	0.0
Salticidae	**3.1**	**3.4**	**2.4**	**10.0**	**17.1**
Theridiidae	0.6	1.2	**3.4**	0.0	0.0
Thomisidae	**43.7**	**21.8**	**10.6**	**1.2**	**1.2**
Titanoecidae	0.4	0.0	0.0	0.0	0.0
Araneidae	0.0	0.0	0.4	0.0	0.0
Others	0.0	0.0	2.1	0.4	1.6
Total	100	100	100	100	100



* (Lee et al. 1988), ** (Kim and Kim 1995)

Figure 9. Community structure analysis based on previous studies and this study. Minor families were grouped as ‘Others’.



* (Lee et al. 1988), ** (Kim & Kim 1995)

Figure 10. Predatory guild structure of different habitat types studied in previous studies and this study. Note that minor families were not specified in previous studies thus predatory guild could not be identified.

2. Community composition and environmental variables

Similar value of diversity indices indicate both roof and ground-level sites both support similarly diverse spider communities (Figure 4). This result rejected the first research hypothesis in this research as spider community roof habitat was not biologically more diverse or more abundant than that of ground-level habitat. No significant difference in arthropod species richness and abundance between roof and ground-level habitat has been previously reported (MacIvor and Lundholm 2011; Muller et al. 2014). However, this does not necessarily mean roof habitats and ground-level habitats are identical or substitutable in terms of biodiversity conservation. Conservation significance evaluation is desirable when species composition is taken account (Bolger et al. 2000). Furthermore, functional diversity, rather than species richness, can be utilized when explaining ecosystem function, thus should be considered when assessing biodiversity and its habitat (Cadotte et al. 2011).

MRPP revealed that spider community composition of each habitat type is significantly different (Figure 6). Also, compositional difference of all studied sites was revealed by hierarchical cluster analysis, which resulted in two main groups according to community composition of each site (Figure 5). Cluster 1 consists of six ground-level sites indicating spider community structure is similar within the group. Ground-level habitat of Jungnang-*gu* was one of exceptional components among cluster 2. This could be explained by exceptional size and establishment age of the ground-level habitat of Jungnang-

gu (Appendix 2). Similarly, compositional change in spider community to habitat size has been found in urban heath and woodland in Sydney (Gibb and Hochuli 2002). Also, the sites of Jungnang-*gu* were surrounded by mixed-forest covering a large area, which could have caused introduction of species from surrounding forest species to the open habitat site. Four roof sites and five ground-level sites were similar in community composition within cluster 2. However, this compositional similarity of different types of habitats was not clearly explained by environmental variables measured in this study. Other than measured local environmental variables, spiders are also known to be sensitive to vegetation height, soil moisture content and litter content by controlling microhabitat (Uetz 1979; Pétillon et al. 2008; Štokmane and Spuņģis 2016). In addition, consideration of other potential variables such as direct human disturbance, management regime and etc. is suggested in further research (Sattler et al. 2010*b*; Muller et al. 2014).

Three local environmental variables (shrub cover, soil cover, and site altitude) best explained the spider community compositions of all sites (Figure 6). Similar to what Horvath et al. (2015) found, local environmental variables better explained the spider communities than landscape variables did. Although vegetation structure of each habitat type did not differ significantly, coverage of shrub and bare ground significantly explained the community composition of all sites. Difference of shrub cover and proportion of bare ground between two habitat types could be explained by better condition of green roofs in terms of vegetation growth. Green roofs tend to be managed by building managers and get regular water supply, which is an important factor in determining habitat quality (Muller et al. 2014). On the other hand, ground-level habitats tend to receive less amount of sunlight because of surrounding buildings, especially in compact urban environment (Pearlmutter et al. 1999). Coverage of shrub was slightly higher in roof sites in general (Table 4). Vegetation structure is a crucial determinant in community composition of various taxa in numerous ecosystems (Schlinkert et al. 2015), including green roofs (Madre et al. 2013). Especially, spider community is closely related to vegetation structure (Hatley and Macmahon 1980; Greenstone 1984; DÖbel et al. 1990; Gunnarsson 1990; Pétillon et al. 2008). Soil cover is negatively related to species richness in general (Oxbrough et al. 2005). However, no such trend was revealed in this study as species richness was similar in both habitat types. Soil cover was mildly higher in ground-level sites, which might have been caused by higher disturbance on the site or less desirable environment for plant growth. Community composition of ground-level habitats can be characterized by the number of sheet-web builders similar to what Alaruikka et al. (2002) found in urban habitats. These sheet-web builders are only active at the ground-level under disturbance or in poor web sites in order to move their webs (Leclerc 1991). Behavioral response of ecological communities to disturbance or environmental change is common in urban ecosystems (Shochat et al. 2006; Kralj-Fiser and Schneider 2012). Thus, additional sampling methods (i.e. beating or hand collecting) are suggested in later research for more precise inspection of spider community.

Landscape variables poorly explained the spider community composition. Despite surrounding land cover and habitat connectivity is known as important factor affecting community composition, appropriate spatial scale needs to be determined (Jackson and Fahrig 2012). In urban ecosystem, a wide range of spatial scale (from less than 10 m to 300 m) has been proved to have significant explanation power depending on studied taxa and habitat type (Braaker et al. 2014; Sattler et al. 2010*a*). Spiders are often classified as 'low mobility' as they are wingless and expected to respond to small scale of environmental effects than other highly mobile taxa (Ö ckinger et al. 2009). Despite some groups of spiders have long distance dispersal strategies (i.e. ballooning), spider community composition may be determined by local environmental variables (Bell et al. 2005). In recent studies, however, importance of stochastic factors such as dispersal and habitat connectivity in structuring spider assemblages have been emphasized (Braaker et al. 2014; Rodriguez-Artigas et al. 2016). Impact of dispersal activities and habitat connectivity was not tested in this study, but it could provide supplementary indications for explaining different community compositions in urban habitats (Bonte et al. 2003; Braaker et al. 2014).

3. Guild composition of spider communities

Although a number of studies have assessed biodiversity on green roofs and related ecosystem functions (Colla et al. 2009; MacIvor and Lundholm 2011; Schindler et al. 2011; Madre et al. 2013), they lack consideration of diversity within higher trophic levels despite its importance (Duffy 2002). Predator functional trait (i.e. hunting mode) is intimately related to carnivore effects on ecosystem function in multiple trophic levels by altering suppression on herbivores (Schmitz 2008*b*; Belgrad and Griffen 2016). Ecosystem properties and levels of ecosystem functions could be altered by changes in identity and dominance of functional groups (Schmitz 2009; Wesner 2012). Thus, functional groups (or predatory guilds) of sampled species were examined based on various hunting modes (Table 6). Guild structure analysis and direct comparison revealed mild variation in sheet-web builders, ambush hunters and ground hunters (Figure 8). Impact of predators with different hunting mode has been experimentally presented (Schmitz 2008*a*). Dominance of ambush hunters slightly increased plant pseices diversity and reduced ANPP and N mineralization. On the other hand, active hunters such as ground hunters changed plant dominance and reduced plant species diversity. Eventually, it increased aboveground net primary production (ANPP) and N mineralization. Such empirical result could be unlikely in natural or urban ecosystems, but it clearly shows how difference in predator guild structure could affect multiple trophic levels by cascading effects. Disparity of predatory guild structure in green roof and ground-level habiats was not conspicuous in this research. However, this approach is highly encouraged in further researches, especially in assessing ecological functions of various urban ecosystems.

Ⅴ Conclusion

Habitat provision of green roofs and other urban green areas have drawn great attention by urban ecologists for the recent. However, few studies have examined the difference between biological communities of green roofs and ground-level habitat in the context of biodiversity conservation, despite of its importance. Predator communities can be directly related to ecological functions such as herbivore control and structuring plant communities. Araneae community of green roofs and adjacent ground-level habitats located in twelve different *gu* of Seoul were analyzed. Various environmental variables possibly affecting spider community, such as vegetation structure, height, habitat size, establishment age and surrounding landuse types were also surveyed.

Species richness of spider communities on urban green roofs and adjacent ground-level habitat did not differ significantly, but diversity and abundance was generally higher in roof sites. However, compositional difference was detected between the two habitats. Hierarchical cluster analysis grouped studied sites into two clusters according to similarity of spider community composition. Cluster 1 was composed of only ground-level sites and cluster 2 was mostly roof sites, while there were some ground-level sites similar with roof sites in terms of community composition. Among local and landscape environmental variables, coverage of soil and shrub and height of study site significantly explained the community compositions of spiders. Behavioral responses of some taxa to habitat quality or disturbance could have affected overall community composition. Consideration of management and disturbance is challenging, but it would deliver more precise explanation of dynamics of urban biodiversity. Also, classic community structure was analyzed and compared with previous literature. Spider guild composition differed significantly as well, suggesting different ecological functions exist by different habitat types. It is critical that perception of green roofs should not just be a surplus of green areas in urban environment, but a provision of distinct ecological communities, which is profoundly connected to ecosystem services and biodiversity conservation. In conclusion, long term empirical research on compositional change of predator groups in various urban ecosystems is suggested in order to fully understand the interaction between urban biodiversity and ecological functions.

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Ⅶ Appendices

A1. Sample data used in this study

		Roof sites												Ground-level sites											
Species	**Family**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**
Agelena limbata	Agelenidae	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Iwogumoa songminjae	Agelenidae	1	0	0	0	0	0	0	0	0	0	7	0	14	4	3	11	0	10	7	26	5	6	11	2
Pireneitega spinivulva	Agelenidae	6	0	0	0	0	0	0	0	0	1	0	3	0	0	0	0	0	0	0	1	0	0	0	0
Calommata signata	Atypidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Clubiona sp.	Clubionidae	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cicurina japonica	Dictynidae	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Drassodes serratidens	Gnaphosidae	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Drassyllus truncatus	Gnaphosidae	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0
Gnaphosa kompirensis	Gnaphosidae	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	2	0	0
Micaria dives	Gnaphosidae	0	1	1	1	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	1	2	0
Odontodrassus hondoensis	Gnaphosidae	0	0	0	0	0	0	1	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Zeltotes tortuosus	Gnaphosidae	0	1	4	0	0	0	6	2	18	12	0	0	0	0	0	0	4	1	0	1	0	22	0	0
Hahnia corticicola	Hahniidae	16	1	5	3	0	1	0	3	6	0	1	0	0	2	5	0	2	0	0	2	0	0	0	0
Agyneta rurestris	Linyphiidae	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bathyphantes gracilis	Linyphiidae	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Doenitzius pruvus	Linyphiidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Erigone prominens	Linyphiidae	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Erigone sp.	Linyphiidae	0	0	1	0	1	1	0	0	1	0	0	0	0	0	0	0	1	0	0	2	7	1	0	1
Microneta viaria	Linyphiidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Syedra oii	Linyphiidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Arctosa kwangreungensis	Lycosidae	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Arctosa sp.	Lycosidae	0	2	6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lycosa suzukii	Lycosidae	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pardosa astrigera	Lycosidae	0	4	8	6	2	0	15	1	8	4	0	5	0	4	0	0	1	13	0	23	2	3	0	0
Pardosa hedini	Lycosidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	2	0	0	0
Pardosa laura	Lycosidae	37	0	2	0	0	0	1	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0
Piratula procurvus	Lycosidae	0	6	0	1	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Trochosa ruricola	Lycosidae	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0

Mimetus sp.	Mimetidae	0	0	0	5	1	0	0	0	1	0	0	0	0	1	0	0	0	1	0	4	0	0	0	0
Uroctea compactilis	Oecobiidae	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Gamasomorpha cataphracta	Oonopidae	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Thanatus nipponicus	Philodromidae	1	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pholcus crypticolens	Pholcidae	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
pholcus sp.	Pholcidae	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Orthobula crucifera	Phrurolithidae	0	0	1	0	0	0	1	5	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0
Phrurolithus pennatus	Phrurolithidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Bristowia heterospinosa	Salticidae	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Carrhotus xanthogramma	Salticidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Euophrys kataokai	Salticidae	0	0	0	0	0	0	0	0	0	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0
Evarcha sp.	Salticidae	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Heliophanus ussuricus	Salticidae	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pseudeuophrys iwatensis	Salticidae	1	0	0	4	0	0	0	0	0	0	3	0	0	0	3	0	0	2	1	0	0	0	1	0
Sitticus fasciger	Salticidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0
Parasteatoda angulithorax	Theridiidae	2	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Steatoda triangulosa	Theridiidae	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Stemmops nipponicus	Theridiidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
Ozyptila nongae	Thomisidae	0	0	2	0	2	10	3	1	19	3	6	0	10	2	0	0	1	7	1	2	0	1	0	0
Xysticus saganus	Thomisidae	65	0	4	15	11	4	8	23	11	22	13	0	0	5	4	0	1	1	0	18	3	12	2	1
Nurscia albofasciata	Titanoecidae	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Total		**135**	**19**	**37**	**37**	**17**	**20**	**38**	**37**	**67**	**58**	**34**	**9**	**27**	**19**	**16**	**19**	**16**	**40**	**11**	**87**	**19**	**50**	**16**	**5**

A2. Detail profile of each study site

	Roof												Ground											
Variables	**Ar**	**Br**	**Cr**	**Dr**	**Er**	**Fr**	**Gr**	**Hr**	**Ir**	**Jr**	**Kr**	**Lr**	**Ag**	**Bg**	**Cg**	**Dg**	**Eg**	**Fg**	**Gg**	**Hg**	**Ig**	**Jg**	**Kg**	**Lg**
Local																								
Age (years)	10	9	8	7	6	3	7	7	6	8	12	9	10	9	13	25	10	14	7	7	9	38	12	9
Area (m^2)	314	520	564	327	525	1094	371	367	495	2818	296	494	320	1535	435	308	306	656	267	1117	1278	14590	438	103
Altitude (a.m.s.l)	85	55	75	18	175	157	43	10	41	25	69	51	71	38	91	49	58	24	82	62	63	45	106	65
Height (m)	30	57	18	33	16	18	33	42	34	20	18	41	0	0	0	0	0	0	0	0	0	0	0	0
% Herb	37	29	90	69	19	68	73	39	40	84	73	38	32	66	48	26	87	25	43	98	38	98	55	48
% Shrub	60	59	8	26	12	4	28	23	41	5	13	34	33	23	19	12	11	20	11	30	28	2	11	6
% Tree	17	1	0	0	11	12	3	14	8	0	6	14	27	3	0	11	15	12	17	7	10	0	40	15
% Soil	0	9	0	6	63	28	3	26	22	12	9	25	37	8	35	57	2	55	43	0	39	0	28	48
Landuse*(%)																								
Residential	42	31	25	53	29	21	4	64	14	41	28	33	45	25	26	53	29	23	9	61	18	29	25	33
Industrial	0	4	0	0	10	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0
Commercial	22	6	11	0	14	18	32	8	8	3	18	25	21	4	11	0	16	20	34	8	11	1	21	25
Recreational	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Traffic	18	19	22	20	22	24	31	21	30	11	19	21	20	21	22	20	21	26	27	20	30	8	22	21
Public	3	19	9	18	12	7	15	0	19	10	33	17	3	16	9	17	12	7	13	0	19	8	32	17
Broad-leaved forest	12	0	21	0	3	0	0	0	0	0	0	0	8	0	21	0	5	0	0	0	0	0	0	0
Mixed forest	0	0	0	0	0	0	0	0	0	26	0	0	0	0	0	0	0	0	0	2	0	47	0	0
Grassland	0	4	6	9	5	17	10	6	8	6	0	2	0	8	5	10	4	12	10	8	7	4	0	1
Water	2	9	2	0	10	2	1	0	14	3	2	2	2	10	2	0	10	2	1	0	11	2	0	2
Etc.	0	8	3	0	4	10	7	0	7	0	0	2	0	12	4	0	4	10	6	0	5	0	0	2

* Landuse variables are within 300 radius from each site.

국문초록

옥상녹지는 도시환경에서 생물다양성 보존을 위한 잠재 서식지로 주목을 받고있다. 하지만 기존 옥상녹지의 생물다양성과 다양한 생물들의 기능, 또 다른 지면의 도심서식지와의 비교에 대한 연구들은 매우 한정된 장소에서만 이루어졌다. 거미목은 도심서식지에서 중요한 생태기능을 제공함과 동시에 다른 영양단계를 반영하는 중요한 분류군이다. 이에 따라 본 연구는 옥상녹지와 그 주변 지면녹지의 거미군집의 구조를 파악하고, 어떤 환경 변수들이 거미군집 조성에 영향을 미치는지 살펴본다. 거미군집은 각 서식지 종류에 따라 거미군집이 다른 생태기능을 제공하는지 보기위해 종과 포식기능군의 단계에서 비교되었다.

거미군집은 서울시 25 개 구 중 옥상녹지를 갖고있는 12 개 구의 구청사 건물과 그 주변 지면녹지에서 함정트랩을 이용해 채집되었다. 지역적 환경변수로 서식지의 낡기, 면적, 지면으로부터의 높이, 식물구조 다양성이 측정되었고, 경관규모에서의 환경변수로 300m 반경의 면적 내의 토지이용도를 살펴보았다. 거미군집은 위계군집분석(hierarchical cluster analysis)을 통해 2 개의 그룹으로 분류되었고, 군집구성은 비계량형다차원척도법(Non-metric multi-dimensional scaling)을 통해 시각화 하였다. 서식지 종류에 따른 군집의 유사성을 살펴보기 위해 유사도분석(Analysis of similarities, ANOSIM)과

유사도비율분석(Similarity percentages analysis, SIMPER)가 수행되었다.

옥상녹지와 주변 지면녹지의 거미군집은 종과 포식기능군 단계에서 모두 유의한 차이를 나타냈다. 비슷한 조성을 보이는 옥상녹지와 지면녹지도 있었지만, 군집의 조성은 서식지의 높이와 관목의 면적비율, 토양의 면적비율 세가지 지역적 환경변수에 의해 유의하게 설명되었다. 서식지 종류별 포식기능군의 유의한 차이는 도시환경에서 두 서식지 간 생태적 기능의 차이로 해석될 수 있다. 이러한 차이는 옥상녹지가 기존 도시환경에서 지면녹지와 동일한 서식지의 추가가 아니라 새로운 서식지 면적의 증가 개념으로 받아들여야 한다는 데 의의가 있다. 본 연구는 또한 기존에 미흡했던 서울시 도심서식지의 거미목의 인벤토리를 제공한다.

주요어: 도시 생태, 옥상녹지, 거미 군집 조성, 기능군 구조, 유사도분석, 비계량형다차원척도법

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