

Original article

## Influences of Forest Type and Fragmentation by a Road on Beetle Communities in the Gwangneung Forest, South Korea

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**Abstract** The effects of forest type and fragmentation of forests by a road on the beetle community were investigated in the Gwangneung Forest, South Korea. Beetles were collected monthly using pitfall traps and by sweeping at 16 sites (eight in coniferous forests and eight in deciduous forests) for one year from April 1993 to April 1994, excluding winter. A total of 17,616 beetles belonging to 271 species from 39 families were collected. Among them, *Synuchus cycloderus* was the dominant species, with 14,060 individuals accounting for 80% of the total population. The influence of forest type (coniferous and deciduous) or sampling region (fragmented by a road) on species richness (number of species) was observed. We found that species richness was substantially different depending on the sampling method and taxa used. Beetles collected using pitfall traps responded more sensitively to habitat types than those collected by sweeping. Four dominant families differently responded to forest fragmentation and forest types. Carabidae was influenced by forest fragmentation, whereas Staphylinidae and Curculionidae were influenced by forest types. Chrysomelidae was not influenced.

**Key words:** Coleoptera, forest, habitat fragmentation, forest beetles

### INTRODUCTION

Beetles are the most diverse taxa, with an estimated 300,000~450,000 species (Nielsen and Mound, 1999). They are very important insects that play a crucial role in maintaining the ecosystem and have various ecological roles (Bouchard *et al.*, 2017). Therefore, many studies have been conducted on the diversity of beetles and the influence of

environmental factors on beetle communities. However, owing to the large number of beetle species, studies on all beetles are rare, and are usually conducted on specific taxa that serve as potential indicators such as Carabidae (Rainio and Niemelä, 2003), Scarabaeidae (Spector, 2006), and Staphylinidae (Pohl *et al.*, 2007) for environmental changes. Studies with selected taxa can induce biased responses to environmental changes because some taxa have unique ecological niches, resulting in a biased response to the environment. Several studies have focused on the usefulness of higher taxa as a surrogate for species richness (Ricotta *et al.*, 2002; Báldi, 2003; Kwon *et al.*, 2016; Lee *et al.*, 2020), although there is

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**Table 1.** Characteristics of study sites in Gwangneung.

Sampling site	Region	Dominant trees*	Forest type	Altitude (m)	Orientation	Slope (°)	Crown density
JH3	Jukyupsan	Qs	Nature	220	East	<5	Moderate
JM1	Jukyupsan	Qs	Nature	200	East	<5	Moderate
JC3	Jukyupsan	Pk	Planted	180	East	>10	Moderate
JC4	Jukyupsan	Pb	Planted	140	East	>10	Opened
JC1	Jukyupsan	Pd*	Nature	360	West	>10	Moderate
JH1	Jukyupsan	Qa	Planted	280	East	>10	Opened
JC2	Jukyupsan	Pk	Planted	160	West	<5	Closed
JH2	Jukyupsan	Qs	Nature	160	West	<5	Moderate
SH4	Soribong	Qs	Nature	80	South	<5	Moderate
SCI	Soribong	Pk	Planted	140	East	<5	Moderate
SC2	Soribong	Pb	Planted	320	West	>10	Closed
SH3	Soribong	Qs	Nature	260	East	<5	Moderate
SH2	Soribong	Qs	Nature	260	East	<5	Moderate
SC4	Soribong	Pk	Planted	140	West	<5	Moderate
SC3	Soribong	Pk	Planted	350	West	>10	Moderate
SHI	Soribong	Qm	Nature	440	West	>10	Moderate

\*Tree species, Qs: *Quercus serrata*, Qa: *Quercus acutissima*, Qm: *Quercus mongolica*, Pk: *Pinus koraiensis*, Pb: *Pinus banksiana*, Pd: *Pinus densifora*

an opposite view (Rosser and Eggleton, 2012). It appears that the whole fauna of the order beetles is more likely to show the influence of the environment than the specific taxa (de Oliveira *et al.*, 2020).

Forests in Korea are mainly deciduous, such as oaks and coniferous, such as red pine, Korean pine, and Rigida pine (KFS, 2021). Generally, the diversity of insects in deciduous forests is higher than that in coniferous forests because of the higher diversity of understory vegetation in deciduous forests. However, few studies have investigated this hypothesis. In Korea, 63% of the land is covered by forests, a large proportion of which is fragmented by roads and urbanization. Although forest fragmentation caused by roads has a remarkable influence on beetle diversity, few studies have been conducted in South Korea, especially on carabid beetles (Do and Joo, 2013; Jung *et al.*, 2018).

The questions in this study are as follows: 1) Are the beetles that live in deciduous and coniferous forests different? 2) Are there more beetle species living in deciduous forests? 3) Are the beetles living in forests fragmented by roads any different? 4) Does forest fragmentation by roads and different forest types impact the entire Coleoptera and low-level taxa?

## MATERIALS AND METHODS

### 1. Field sampling

This study was conducted in the Gwangneung Forest, an old forest preserved as a tomb forest of King Sejo of the Joseon dynasty. As a result, a wide variety of plants, animals, and insects live here (KNA, 2021). Field sampling was conducted monthly at 16 sampling sites from April 1993 to April 1994, excluding the winter (Table 1). The Gwangneung Forest was divided by a road into two regions: Soribong and Jukyupsan, each of which had eight sampling sites (four in the deciduous forest and four in the coniferous forest). Details of the sampling sites have been reported by Kwon (1995).

The beetles were collected using pitfall traps and sweeping at each sampling time. In the sweeping sampling, 33 sweeps were repeated three times at each site using an insect net (diameter 40 cm). In the pitfall sampling, five cellophane cups (7 mm in mouthpart diameter, 7 mm in height) were set up on the ground at 1~1.5 m intervals, and 20% formalin was used as a preservative in the pitfall traps. The collected samples were preserved in 70% ethyl alcohol for identification. After splitting the specimens based

on morphological groups, three or four specimens in each group were dried to be identified at the species or genus level. Species that could not be identified were classified as the morphological species. The specimens are currently preserved in the Insect Specimen Room of the National Institute of Forest Science, Korea.

## 2. Data analysis

The differences in beetle communities were analyzed using different sampling methods at different taxonomic levels. Nonmetric multidimensional scaling (NMDS) was conducted to reveal the differences in beetle communities among sampling sites and to determine the relationship between beetle communities and environmental factors. NMDS was analyzed using “envfit” in “vegan” package (Oksanen *et al.*, 2020) in R (R Core Team, 2020). Species richness was considered in all samples, sampling methods, and the four selected families (Carabidae, Staphylinidae, Chrysomeridae, and Curculionidae). These were compared between forest types (deciduous forests and coniferous forests) and sampling regions separated by roads (Jukyupsan and Soribong) using a regression model with categorical variables (forest type and sampling region). Species richness of the four families was used for samples collected with both pitfall traps and sweeping. A t-test was conducted to compare the differences in species richness between forest types, as well as between sampling regions. Statistical analyses were conducted with the ‘stat’ package in R (R Core Team, 2020). Using the collected data, Kwon (1996) reported the diversity and abundance of Carabidae and found that habitat fragmentation by roads did not influence the distribution of carabid beetles.

## RESULTS AND DISCUSSION

### 1. Beetle assemblages

From the field survey, 271 taxa from 39 families with 17,616 beetles were collected (Table 2). Among them, 45 taxa (16%) were identified at the family level, 97 (35%) at the genus level, and 105 species (38%) were identified at the species level. The number of individuals collected with the two different sampling methods was very different because of the differences in habitats and feeding habits of

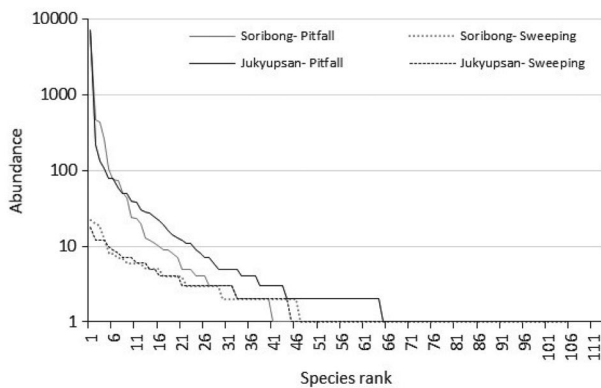
**Table 2.** Number of species and individuals in each family collected using two different sampling methods in Gwangneung in 1993~1994.

Family	Sweeping		Pitfall trap		Total	
	N*	SR**	N	SR	N	SR
Aderidae	2	2	0	0	2	2
Anthicidae	2	1	0	0	2	1
Apionidae	10	1	0	0	10	1
Attelabidae	10	4	1	1	11	5
Biphylidae	1	1	0	0	1	1
Bruchidae	1	1	0	0	1	1
Buprestidae	2	1	1	1	3	2
Cantharidae	18	3	0	0	18	3
Carabidae	8	5	15610	27	15618	32
Cephaloidea	0	0	2	1	2	1
Cerambycidae	5	4	7	3	12	7
Chrysomelidae	164	37	27	6	191	43
Cleridae	3	1	0	0	3	1
Coccinellidae	25	6	194	2	219	8
Curculionidae	185	35	315	21	500	56
Dermestidae	1	1	0	0	1	1
Dryophthoridae	0	0	3	1	3	1
Elateridae	2	1	8	5	10	6
Endomychidae	1	1	6	2	7	3
Eucnemidae	2	2	0	0	2	2
Histeridae	0	0	3	2	3	2
Leiodidae	0	0	1	1	1	1
Lucanidae	0	0	4	1	4	1
Lycidae	1	1	0	0	1	1
Melandryidae	2	1	0	0	2	1
Melolonthidae	2	2	22	4	24	6
Melyridae	1	1	0	0	1	1
Mordellidae	25	9	3	3	28	12
Nitidulidae	24	8	30	5	54	13
Phalacridae	0	0	1	1	1	1
Ptilodactylidae	1	1	0	0	1	1
Rutelidae	17	3	8	4	25	7
Scarabaeidae	0	0	40	3	40	3
Scolytidae	1	1	6	2	7	3
Silphidae	0	0	102	3	102	3
Silvanidae	2	1	304	1	306	2
Staphylinidae	12	11	290	35	302	46
Tenebrionidae	1	1	57	4	58	5
Undetermined	24	20	15	9	39	29
SUM	555	167	17060	148	17615	271

\* N: number of individuals, \*\* SR: number of species.

each taxon. The species collected using sweeping showed higher diversity than those collected by pitfall traps (Table 2, Fig. 1). Beetles belonging to Carabidae and Staphylinidae which forage on surfaces were collected mainly with pitfall traps, whereas beetles feeding on vegetation such as Chrysomelidae and Curculionidae were collected mainly by sweeping (Table 2).

*Synuchus cycloderus* was the dominant species, with



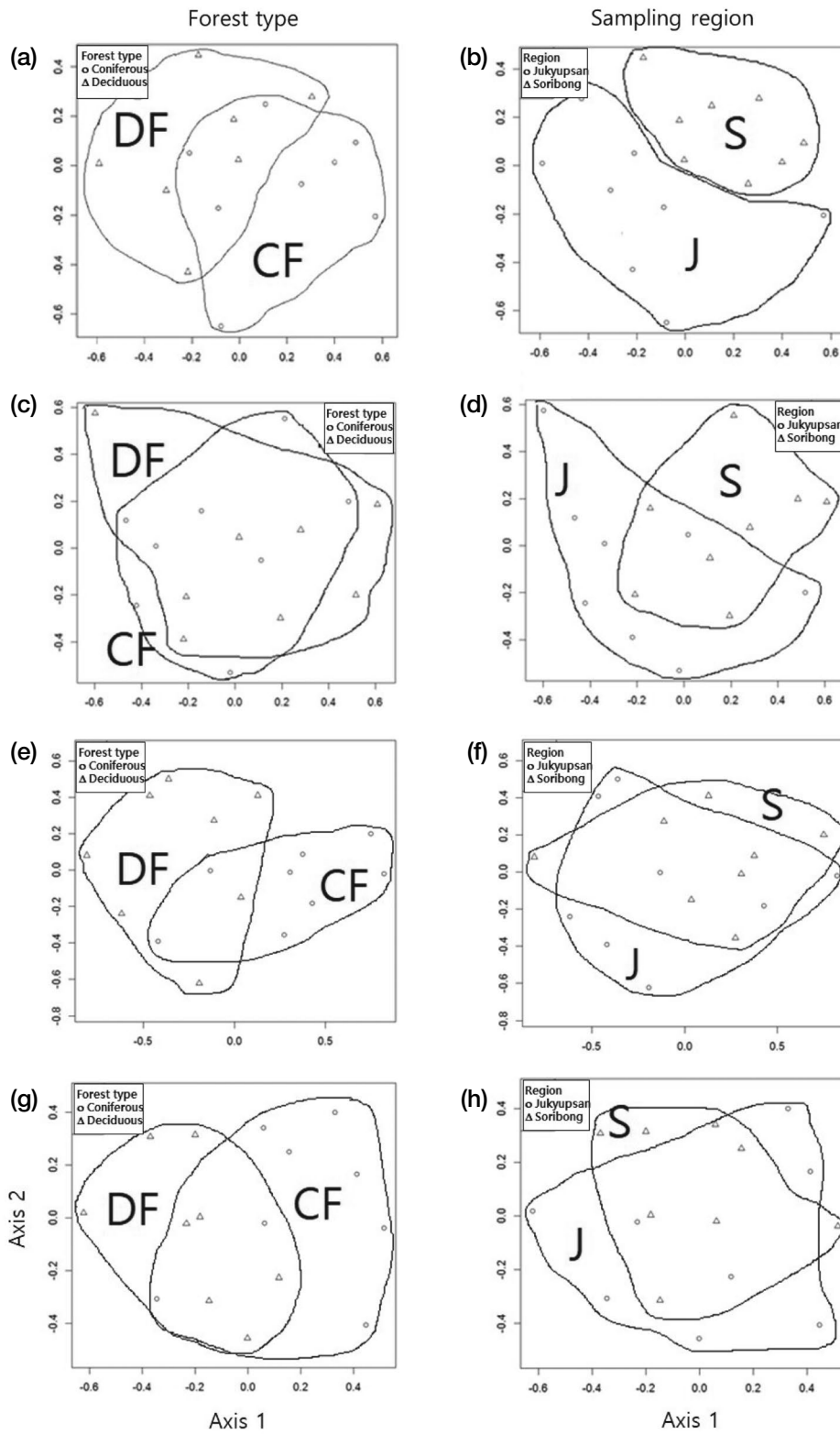
**Fig. 1.** Species rank abundance at two different study regions with two different sampling methods.

14,060 individuals accounting for 80% of the total population (Table 3). However, this species was collected only with pitfall traps, indicating that it mainly forages on the ground. Other abundant species (1% or more), including *Chlaenius naeviger*, *Eucarabus sternbergi*, *Harpalus* sp. 1, *Anatis halonis*, and *Psammoecus triguttatus* were also collected using pitfall traps. *Pseudocneorhinus* sp., *Enaptorrhinus granulatus*, and *Phyllolytus variabilis* of Curculionidae were the dominant species collected during sweeping. In contrast, only one individual was collected from 119 taxa, accounting for 44% of the total collected taxa. It is a common phenomenon that many species are rare.

It is necessary to clarify why *S. cycloderus* is extremely abundant in the Gwangneung Forest. Lee and Kwon (2013) argued that this dominance occurs as the resource monopoly by the dominant species intensifies in a stable environment, like in old forests. The population size of *S. cycloderus* is relatively smaller in mountains in other regions (Jung *et al.*, 2018, 2020) than in the present study. The difference could partly be due to the forest environment depending on forest type, soil properties, disturbance, etc. In fact, *S. cycloderus* is known to prefer dry forests (Fujita *et al.*, 2008; Jung *et*

**Table 3.** Ten most dominant species and their abundance at two different sampling regions using two different sampling methods.

Sampling method	Family	Species	Jukyupsan	Soribong	Total
Pitfall trap	Carabidae	<i>Synuchus cycloderus</i>	7094	6966	14060
	Carabidae	<i>Eucarabus sternbergi</i>	221	462	683
	Carabidae	<i>Harpalus</i> sp.1	38	429	467
	Carabidae	<i>Chlaenius naeviger</i>	79	106	185
	Carabidae	<i>Nebria coreica</i>	19	75	94
	Coccinellidae	<i>Anatis halonis</i>	133	52	185
	Curculionidae	<i>Asphalmus japonicus</i>	104	11	115
	Curculionidae	<i>Hylobius gebleri</i>	28	74	102
	Silphidae	<i>Nicrophorus quadripunctatus</i>	79	20	99
	Silvanidae	<i>Psammoecus triguttatus</i>	50	254	304
	Sweeping	Chrysomelidae	<i>Pyrhalta</i> sp.2		19
Chrysomelidae		<i>Pyrhalta</i> sp.1	6	12	18
Chrysomelidae		<i>Thlaspida</i> sp.	12	6	18
Chrysomelidae		<i>Demotina modesta</i>	12	1	13
Chrysomelidae		<i>Monolepta shirozui</i>	12		12
Curculionidae		<i>Pseudocneorhinus</i> sp.	8	20	28
Curculionidae		<i>Enaptorrhinus granulatus</i>	5	22	27
Curculionidae		<i>Phyllolytus variabilis</i>	18	7	25
Curculionidae		<i>Curculio</i> sp.3	10	5	15
Scarabaeidae		<i>Phyllopertha intermintia</i>	6	8	14



**Fig. 2.** NMDS ordination with beetle communities. Beetle assemblage collected using pitfall traps (a and b), assemblages of Carabidae (c and d), assemblages of Staphylinidae (e and f), and assemblages of Curculionidae (g and h). DF: deciduous forest, CF: coniferous forest, J: Jukyupsan, and S: Soribong. Sweeping and Chrysomelidae were not presented because factor analysis on the nonmetric multidimensional scaling displayed no statistical significance as shown in Table 4.

*al.*, 2018, 2020). However, limited species that are tolerant to disturbance can prevail in severely disturbed areas (Connell, 1978). Therefore, an intermediate disturbance hypothesis presenting high species richness with an intermediate disturbance has been proposed (Connell, 1978; Osman, 2015), although conflicting results have been reported (Fox, 2013).

NMDS showed differences in beetle community composition according to forest type, sampling region (habitat fragmentation), sampling methods, and among the four selected families (Fig. 2, Table 4). The beetle communities collected using pitfall traps were significantly different with respect to the forest type and between the two regions divided by a road (Fig. 2a, b, Table 4). However, the beetles collected by sweeping did not differ with respect to the forest types and regions (Table 4). Meanwhile, Carabidae was not different between forest types, but differed between the two regions in the NMDS ordination (Fig. 2c, d, Table 4). In contrast, Staphylinidae and Curculionidae were not different between the two regions, but differed between the two forest types (Fig. 2e-h, Table 4). Chrysomelidae was not different between the two forest types or between the two regions (Table 4). These results indicate that the dispersion capability of species may be crucial in understanding the species composition in two regions fragmented by roads. Unlike Staphylinidae, Curculionidae, and Chrysomelidae, many carabid beetle species that prefer forest environments cannot fly because their hindwings are generally reduced or lacking (Jung *et al.*, 2018).

In general, predatory insects such as Staphylinidae have a low dependence on plants, but leaf-feeders such as Chrysomelidae depend on plants living in forests. Therefore, it is highly likely that Chrysomelidae should respond to forest type, but Staphylinidae should not. This study showed opposite responses in both these families. However, Curculionidae, another plant feeder, responded significantly to forest type, but not to forest fragmentation. Carabidae responded significantly to forest fragmentation, but not to forest type. Thus, the response to the environment (type of forest, area cut off by roads) was very different among taxa. Therefore, using one specific family as an indicator to evaluate the entire fauna of Coleoptera may be problematic. In the data pooled from the two collection methods, pitfall traps showed a significant response to forest type and forest fragmentation, but sweeping showed no response. Beetles collected using pitfall

**Table 4.** Factor analysis on the nonmetric multidimensional scaling of beetle communities.

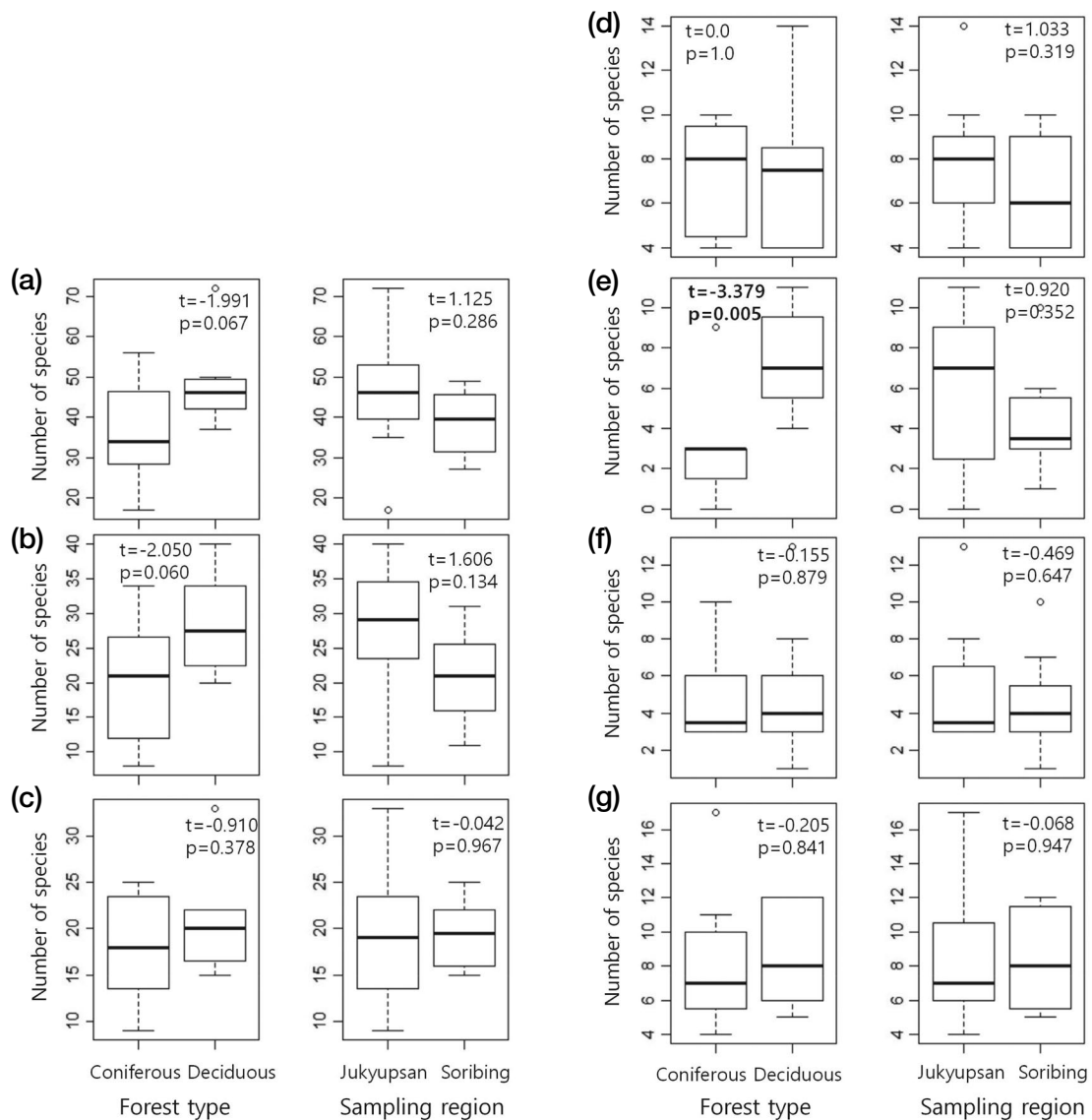
Species richness	Factor	R <sup>2</sup>	p
Species richness with pitfall trap	Region	0.295	0.004
	Forest	0.228	0.02
Species richness with sweeping	Region	0.044	0.543
	Forest	0.047	0.54
Species richness of Carabidae	Region	0.2	0.043
	Forest	0.028	0.662
Species richness of Staphylinidae	Region	0.048	0.508
	Forest	0.32	0.011
Species richness of Chrysomelidae	Region	0.055	0.44
	Forest	0.015	0.82
Species richness of Curculionidae	Region	0.065	0.387
	Forest	0.256	0.014

traps are mainly predators or decomposers, and those collected by sweeping are mainly plant feeders. Therefore, the latter are expected to respond to forest type, contrary to the former. However, this was not observed in the present study.

## 2. Diversity

The total of 271 taxa collected in this survey was relatively lower than those reported in other studies. For example, a total of 350 taxa were collected at seven sampling sites in the Wando Arboretum Forest, South Korea, in 2015 (Kwon *et al.*, 2018), and 310 taxa were identified at five sites in Gariwangsan Mountain in 2011 (Lee *et al.*, 2014). In the present study, 141 taxa with 17,060 individuals and 166 taxa with 556 individuals were collected using pitfall traps and a sweeping method, respectively. In contrast, Lee *et al.* (2014) collected more taxa using pitfall traps (110 taxa) than by the sweeping method (33 taxa) in Gariwangsan Mountain.

The effects of forest type or region on species richness were substantially different depending on the sampling method (Fig. 3a, Table 5). The total taxa richness was higher in Jukyupsan than in Soribong; although the difference was not statistically significant between regions ( $t = 1.125$ ,  $p = 0.286$ ) (Fig. 3a). Meanwhile, the total taxa richness was slightly different between deciduous and coniferous forests with low statistical significance ( $t = -1.991$ ,  $p = 0.067$ ). This is also supported by the results of previous studies. For example, Moon *et al.* (2018) reported that moth diver-



**Fig. 3.** Comparison of species richness according to forest type and sampling regions. (a) Total species richness of beetles collected using both pitfall trap and sweepings, (b) species richness with pitfall trap, (c) species richness with sweeping, and species richness of Carabidae (d), Staphilinidae (e), Chrysomelidae (f), and Curculionidae (g).

sity was higher in Mongolian oak forests than in Japanese larch forests, while Jung *et al.* (2020) reported that species richness of carabid beetle pine forests in Korea is generally lower than that in deciduous forests. However, in our study, species richness displayed higher variation in coniferous forests than in broad-leaved forests (Fig. 3a). This may be related to the degree of openness of canopy. In deciduous forests, this degree was usually constant, whereas in coniferous forests, there was a large difference between the sampling sites (Table 1). A high degree of canopy openness in-

duces a high diversity of substratum vegetation, resulting in a high diversity of insects (Moon *et al.*, 2018). In addition, some taxa, such as carabid beetles, are affected by forest fragmentation when there is a decrease in forest patch size (Jung *et al.*, 2018).

Species richness was different between the two forest types in samples collected using pitfall traps, although the difference was not statistically significant ( $t = -2.05$ ,  $p = 0.060$ ) (Fig. 3b). The difference was more clearly explained by the addition of forest types and regions in the ANOVA model

**Table 5.** Regression analysis with categorical variables on species richness with one or two factors (forest type and study region). F\_type + Region: regression with two variables, F\_type + Region + F\_type × Region: regression with two variables by considering interactions between two variables

Species richness	Categorical regression model	DF	F	<i>p</i>	Adjusted R <sup>2</sup>	AIC*
Total richness	F_type + Region + F_type × Region**	3, 12	1.95	0.175	0.16	129.5
	F_type + Region	2, 13	2.83	0.095	0.20	128.1
	F_type	1, 14	3.96	0.066	0.16	127.9
	Region	1, 14	1.27	0.280	0.02	130.5
Richness with pitfall trap	F_type + Region + F_type × Region	3, 12	2.68	0.094	0.25	116.5
	F_type + Region	2, 13	4.10	0.042	0.29	114.9
	F_type	1, 14	4.20	0.059	0.17	116.5
	Region	1, 14	2.58	0.131	0.10	118.0
Richness with sweeping	F_type + Region + F_type × Region	3, 12	0.37	0.777	-0.14	108.9
	F_type + Region	2, 13	0.39	0.688	-0.09	107.3
	F_type	1, 14	0.83	0.378	-0.01	105.3
	Region	1, 14	0.002	0.967	-0.07	106.2
Richness of Carabidae	F_type + Region + F_type × Region	3, 12	0.34	0.796	-0.15	87.2
	F_type + Region	2, 13	0.50	0.620	-0.07	85.4
	F_type	1, 14	<0.001	1.000	-0.07	84.6
	Region	1, 14	1.07	0.319	0.005	83.4
Richness of Staphylinidae	F_type + Region + F_type × Region	3, 12	4.34	0.027	0.40	81.5
	F_type + Region	2, 13	6.80	0.010	0.44	79.8
	F_type	1, 14	11.42	0.005	0.40	79.7
	Region	1, 14	0.92	0.352	-0.005	88.2
Richness of Chrysomelidae	F_type + Region + F_type × Region	3, 12	1.77	0.206	0.13	84.9
	F_type + Region	2, 13	0.11	0.894	-0.13	88.5
	F_type	1, 14	0.02	0.879	-0.07	86.7
	Region	1, 14	0.21	0.647	-0.05	86.5
Richness of Curculionidae	F_type + Region + F_type × Region	3, 12	0.08	0.970	-0.02	94.5
	F_type + Region	2, 13	0.02	0.979	-0.15	92.8
	F_type	1, 14	0.04	0.841	-0.09	90.8
	Region	1, 14	0.00	0.947	-0.07	90.8

\* AIC: Akaike's Information Criterion, \*\* F\_type: forest type, Region: sampling region.

( $F=4.1$ ,  $p=0.041$ ) (Table 5). However, no difference was observed between the sampling regions.

Species richness of Staphylinidae was significantly different between forest types, being plentiful in deciduous forests ( $t = -3.379$ ,  $p=0.005$ ) (Fig. 3e), which can be explained by considering both, forest types and sampling regions ( $F=6.80$ ,  $p=0.010$ ) (Table 5). However, no significant difference was detected between the sampling regions ( $F=0.92$ ,  $p=0.352$ ) (Fig. 3e). Meanwhile, species richness was not significantly different between the sam-

pling regions and forest types in the other three families, Carabidae, Chrysomelidae, and Curculionidae (Fig. 3d, f, g). In the case of vegetation foraging (plant feeder) insects, the dependence on plants was higher than that in predatory insects (Sobek *et al.*, 2009). Therefore, it was expected that there would be significant differences according to forest type. However, the present study does not support this hypothesis. Staphylinidae, a predator, is expected to be relatively independent of forest type, which was clearly not the case since this family showed a sensitive response to forest



types.

In conclusion, our study observed the influence of forest type and sampling region (fragmented by a road) on species richness. The differences were significant depending on the sampling method and taxa. Beetles collected using pitfall traps responded more sensitively to habitat type than those collected by sweeping. Four dominant families differently responded to forest fragmentation and forest types. Carabidae was influenced by forest fragmentation, whereas Staphylinidae and Curculionidae were influenced by forest types. Chrysomelidae was not influenced.

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**Author contribution statement** Conceptualization T.-S. Kwon, Y.-S. Park, Field survey and data collection: T.-S. Kwon, Data analysis and writing: T.-S. Kwon, J.-K. Jung, Y.-S. Park, Review and editing: T.-S. Kwon, J.-K. Jung, Y.-S. Park

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