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Distributional patterns of ground beetles (Coleoptera: Carabidae) in fragmented forest landscape

단편화된 산림 경관에서 지표성 딱정벌레류

(딱정벌레목: 딱정벌레과)의 분포 패턴

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(Coleoptera: Carabidae) in fragmented forest landscape

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Abstract

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Understanding the pattern of biodiversity is central to conservation biology. The overall aim of this study was to determine the diversity pattern of ground beetles living in temperate forest and adjacent habitats to establish strategies for biodiversity conservation in Korea.

First, assemblage structure and distributional patterns of ground beetles were investigated across forest–farmland transect from two different agro-forested landscapes in Korea. Nine and five sites were selected from Hwaseong (a fragmented landscape) in 2011 and 2012, respectively. Eight sites were selected from Hoengseong (a relatively well-protected landscape) in 2012. Ground beetles were collected by pitfall traps. Species richness in the forest edge of Hwaseong was similar to that

in the forest interior. Forest edge species richness in Hoengseong was intermediate. The richness level was between that of the forest interior and that of the surrounding. Non-metric multidimensional scaling based on combined data of Hwaseong and Hoengseong revealed that species composition of ground beetles in the forest edge was similar to that in the forest interior, although some open-habitat species were observed at forest edges. Three characteristic groups (forest specialist, edge associated species, and open-habitat species) of ground beetle species were detected by Indicator Value analysis. In this study, ground beetles showed different response to forest edges in the two agro-forested landscapes, suggesting that edge effect on biota could be influenced by landscape structure.

Second, ground beetles were collected in agro-forested landscape to compare their species richness between conifer plantations and regenerating forests in forest ages throughout Korea. How different functional groups (habitat type, wing morph, and body size) responded to forest type, forest age, patch size, elevation, and geographic location were also determined. A total of 34 species were identified from 3,156 collected ground beetles. Individual-based rarefaction curves showed greater species richness in regenerating forests, especially in 40 to 50 years old forests compared to that in conifer plantations. Stepwise multiple

regression analysis and multivariate regression tree showed that patch size and elevation were major predictors of species richness and/or abundance of forest specialists, brachypterous species, as well as large- and medium-sized species. A multivariate regression tree indicated that patch size and elevation were major predictors of assemblage structure. These results suggest that maintaining forest areas may be essential to preserve ground beetle assemblages in agricultural landscapes regardless of forest types.

Finally, community structure of ground beetles among different forest patch sizes according to different forest types at central Korea were compared. In addition, how different functional groups (habitat type, wing morph, and body size) and species responded to patch size, habitat, and geographical variables were determined. A total of 50 species were identified from 17,845 ground beetles in 27 study sites. Individual-based rarefaction curves indicated that higher species richness was found in continuous forests than in forest patches regardless of forest types. Positive relationships were found between forest patch size and species richness of each functional group associated with forest habitat. When all patch size, geographical, and habitat variables were considered simultaneously in multiple regressions, patch size, longitude, latitude,

elevation, organic matter, and litter depth were significant predictors of the abundance and species richness of forest specialists, brachypterous, dimorphic, and large-bodied species. Although longitude in multivariate regression tree was the best predictor for 27 study sites, elevation and patch size were also important for further analyses of subgroups. In summary, decreasing patch size is a major factor in the loss of biodiversity for ground beetles. Medium-sized patches regardless of forest types are more suitable for biodiversity conservation than small-sized patches.

Key words: Edge effect, Agro-forest landscape, Patch size, Forest type, Carabid

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List of contents

VI

VIII

List of tables

x

List of figures

XIV

List of Appendices

Chapter 1.

General Introduction

Biodiversity occurs in all aspects of life, including genes, species, communities, and ecosystems (Gaston, 1996). In animals, insects is the most diverse group with significant functional roles. They are pollinators, decomposers, herbivors, and predators. Thus, conservation of insects has a major role in the preservation of diverse ecological processes that life ultimately depends on (Samways *et al.,* 2010). However, human alteration to the global environment has triggered sixth major extinction events in the history of life, causing widespread changes to the global distribution of organisms (Chapin III *et al.,* 2000). Insect biodiversity is also threatened by environmental changes. In particular, agricultural modification, urbanization, habitat management that affects the structural simplification of habitats, and removal of indigenous vegetation have led to changes of insect communities in terms of abundance, distribution, and species composition.

Therefore, the objective of this study was to determine the diversity pattern of ground beetle assemblages living in temperate forest and adjacent habitats to provide information and strategy for biodiversity conservation. In this thesis, literatures regarding the loss of biodiversity and the emergence of contemporary conservation biology were reviewed in Chapter 2. Simultaneously, the current state of forest environment in Korea was briefly reviewed. The history of community ecology on ground beetles

was also reviewed to understandt the effect of habitat fragmentation (e.g., land-use change and habitat fragmentation).

The community ecology of ground beetles was studied in the following three research chapters (Fig. 1): 1) Habitat fragmentation and edge effect; 2) Effect of forest types on ground beetles throughout Korea; 3) Effect of habitat fragmentation (i.e., patch size) and management regime (i.e., forest type).

First, the edge effect on ground beetles in agro-forested landscape was studied (Chapter 3, Fig. 1a). In Korea, natural grasslands have been decreased. They only account for approximately 0.4 % of the total land area of Korea. Approximately 20% of land is used for agriculture (Ministry of Land, Transport and Maritime Affairs, 2014). This land-use change is still in progress to maximize the availability of land because mountain and forest areas cover approximately 64% of the total land of the nation. Assessment on the biodiversity under the impact of habitat modification by humans might be the first step to establish a future plan for biodiversity conservation in agro-forest landscapes using ground beetle assemblages. Determining habitat type of ground beetle species may allow functional group analysis on environmental change. Therefore, the assemblage structure and distributional patterns of ground beetles across forest–farm

transect from two different agro-forest landscapes in Korea were examined.

In Chapter 4, the effect of forest type and age on ground beetle assemblages was studied (Fig. 1b). In Korea, forest adjacent to human-dominated landscape is generally composed of young secondary forests, including regenerating forest and conifer plantation. Therefore, the community structures of ground beetles in regenerating forest and conifer plantation were compared to determine if there was any difference in beetle diversity regarding forest types. In addition, how different species and functional groups would respond to geographic variables were determined.

In Chapter 5, the effect of forest type and patch size on ground beetle assemblages was studied (Fig. 1c). Habitat fragmentation (i.e., decreases in patch size) is a reason behind the increase in edge habitat. It is an important factor responsible for the loss of insect biodiversity and species extinction due to decreasing core habitat. In addition, conifer trees such as Japanese red pine and Korean pine are the most abundant species throughout Korea. Therefore, the community structures of ground beetles in different patch sizes considering forest types were compared to determine if there was any difference in beetle diversity with regard to

patch sizes. In addition, how different species and functional groups would

respond to patch size, geographic, and habitat variables was studied.
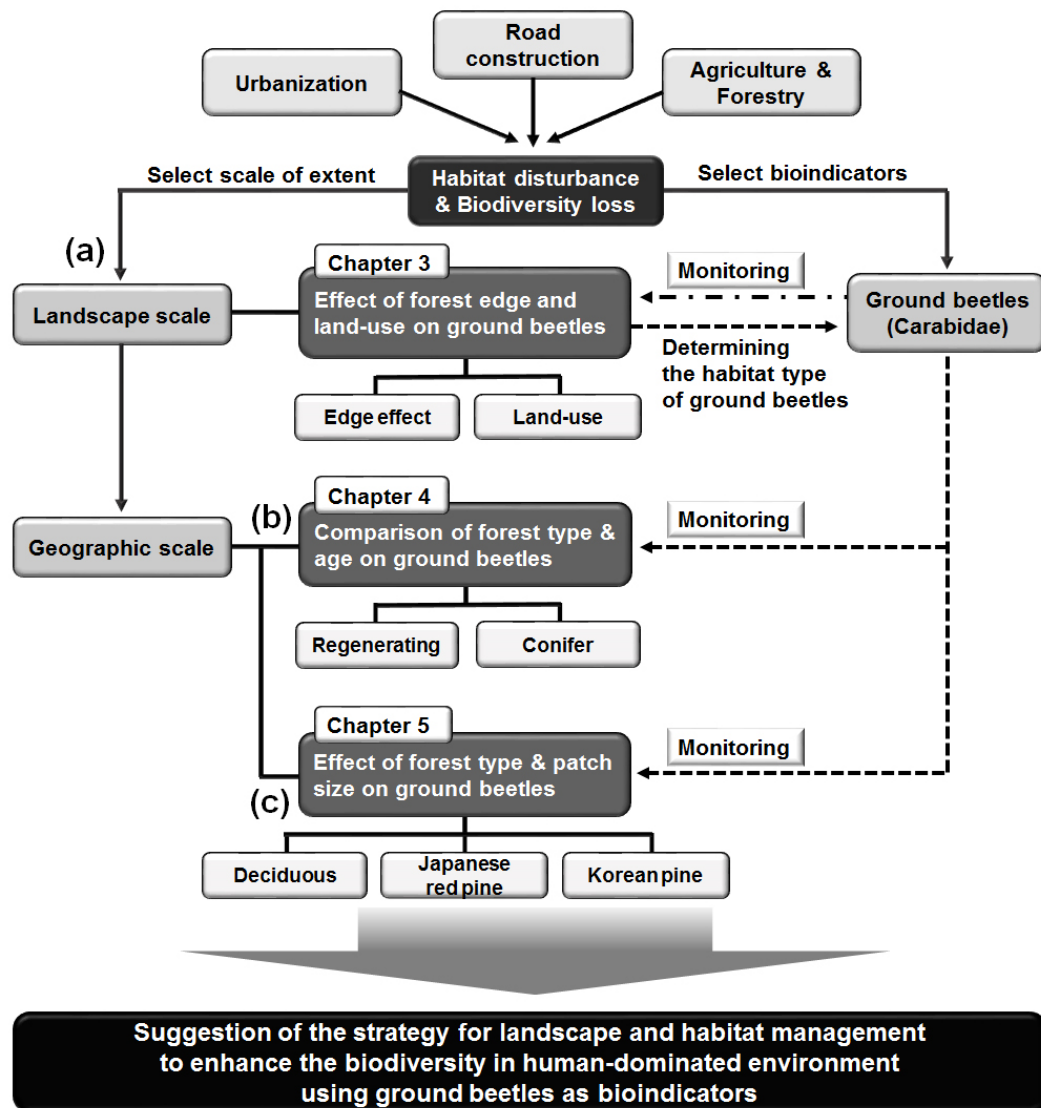
Fig. 1. Flow chart for the organization of this thesis. This thesis was consisted of three main parts: (a) Effect of forest edge and land-use on ground beetles (Chapter 3); (b) Comparison of ground beetles between regenerating forest and conifer plantation (Chapter 4); and (c) Effect of forest type and patch size on ground beetles (Chapter 5).

Chapter 2.

Literature review

2.1. Habitat fragmentation and conservation biology

Human disturbance is the most significant factor that causes the change of terrestrial ecosystems. There is a clear evidence of recent trend in the loss of green space caused by planned and unplanned urbanization (IPCC, 2012). Habitat fragmentation is generally referred as breaking a whole into smaller pieces while controlling for changes in the amount, which is a particular spatial process of land conversion (Collinge, 2009). The nature of land-use change in recent decades has not only resulted in a dramatic decrease in total forest cover, but also resulted in increasingly skewed size-distribution of forest remnants (Didham *et al.,* 1996) with increased ratio of forest edges (Laurance, 2008) (Fig. 2.1). In particular, increases of forest edge may reduce habitat qualities of forest interior environments due to changes in microhabitat variables (e.g., temperature, soil humidity, light intensity, seed dispersal pattern, and so on) (Laurance, 2008) that are defined by edge effects (the effect of artificially created edges on biota). Identifying key effects of land conversion and edge effect on biodiversity in terrestrial ecosystems is an urgent issue for biodiversity conservation.

On the other hand, differences in species distribution at geographical scales are natural because various environmental variables strongly related to geographic location can affect species distribution (MacArthur,

11

1984). For this reason, another approach is needed for biodiversity conservation at a larger scale, such as conservation biogeography. Conservation biogeography is a subset of conservation biology. With focus on pattern and process at coarser scales of analysis (Ladle and Whittaker, 2011), it is also applicable to biodiversity conservation. Conservation biology is focused on large field (Fig. 2.2), but conservation biogeography is focused on bridging ecology and biogeography (e.g., theory of island-biogeography, single large or several small reserves, habitat corridors, and metapopulation theory) at local-landscape scale applicable for mapping and modelling biogeographic patterns or the distribution and explanation of geographical patterns in diversity (Whittaker *et al.,* 2005). These study fields are too difficult to be investigated or explained. However, biogeographical thinking and analysis are important for biodiversity conservation.
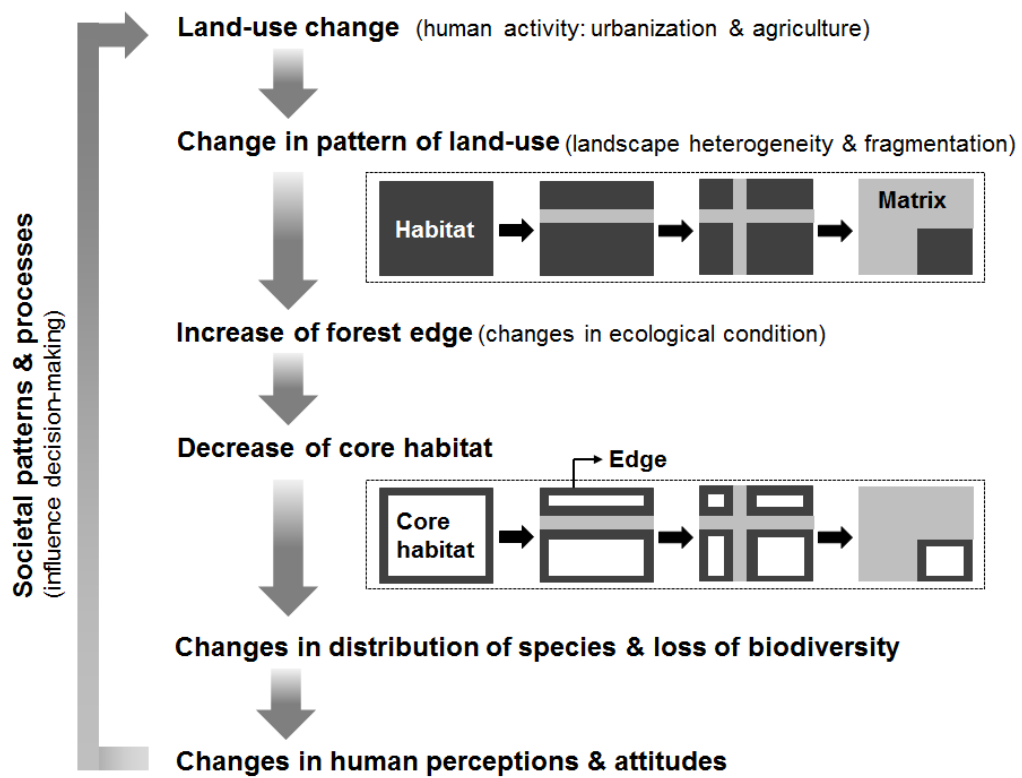
Fig. 2.1. Conceptual scheme for integrating ecological and social systems from human dominated environments in this study (see Samways *et al*., 2010).

Chronology of emergence of conservation biology

c. 1800 AD
Biogeography

c. 1900 AD
Wildlife conservation

c. 1950 AD
Nature conservation

c. 1980 AD
Conservation biology

Population scale
Minimum Viable Population (MVP),
Genetic Attrition,
Behavioral Ecology

Landscape scale
Equilibrium Theory of Island-Biogeography (ETIB),
Single Large Or Several Smalls (SLOSS),
Metapopulation

Geographic scale
Centers of Richness & Endemism,
Biogeographic Regions

c. 2000 AD
Conservation biogeography

Fig. 2.2. Approximate chronology of the emergence of conservation biology. Re-drawn from Ladle and Whittaker (2011).

2.2. Characteristic of forest in Korea

Prior to investigate the effect of forest edge and fragmentation on biodiversity, the characteristic of forest in Korea was reviewed. The Korean peninsula lies in the east of the temperate forest zone with distinct seasonal variation in temperature and precipitation. Forest forms the base of the Korean Peninsula with "Baekdudaegan", the important habitats for conservation and enhancement of biodiversity since they cover approximately 64% of the total land of the nation.

However, most primeval forests in Korea were devastated. Their growing stocks also decreased precipitously to 5.6 m^3/ha in 1952 (Lee, 2012) due to colonial exploitation policy under Japanese colonial era (1910–1945) and the overuse of forest resources by starved inhabitant after the Korean War (1950–1953) (Fig. 2.3a). Since the 1970s, a forest policy in Korea was enacted to prevent destructive logging, over-harvesting, forest fires, and illegal entry into forests with a compulsory reforestation regulation (Woo and Choi, 2009). For reforestation, natural coniferous trees (e.g., Japanese red pine and Korean pine) and exotic ones (e.g., Pitch pine and Black locust) were planted in urban and agricultural landscapes as well as high mountains (Fig. 2.3b, c), while deciduous trees were regenerated in high mountains generally (Fig. 2.3d).

Fig. 2.3. Photos of forest landscape in Korea showing devastated forest landscape during Korean War (a) (Retrieved from http://global.britannica.com/ EBchecked/media/71892/US-troops-advance-past-a-stream-of-retreating-civilians -in); reforestation in forest (b) and urban landscape (c) on annual tree planting day; and   current status (d) of forest landscape in Korea.

Consequently, young regenerating deciduous and mixed forests are approximately 30–50-years-old. Conifer forest (both plantation and regenerating) are abundantly distributed throughout Korea (Fig. 2.4a, b). Growing stocks of Korean forests were remarkably increased to 126 m^3/ha in 2010 (Fig. 2.4c) (Lee, 2012). Recently, the 5th national forest plan during 2008 to 2017, based on foundations and frameworks established under the 4th plan during 1998 to 2007, has been designed to further expand the implementation of sustainable forest management to maximize forest functions (Kim, 2007).

Although reforestation has been successful in Korea, the biodiversity in Korea is facing a serious threat, because approximately 12,000 ha of forests is lost every year due to habitat loss and fragmentation (Ministry of Environment, 2012) (Fig. 2.4c). For this reason, identifying the key effect of habitat loss and fragmentation caused by land conversion on biodiversity is important. To assess the effect of habitat fragmentation, ground beetle assemblages were selected as bioindicator because the identification of whole biota is impossible.
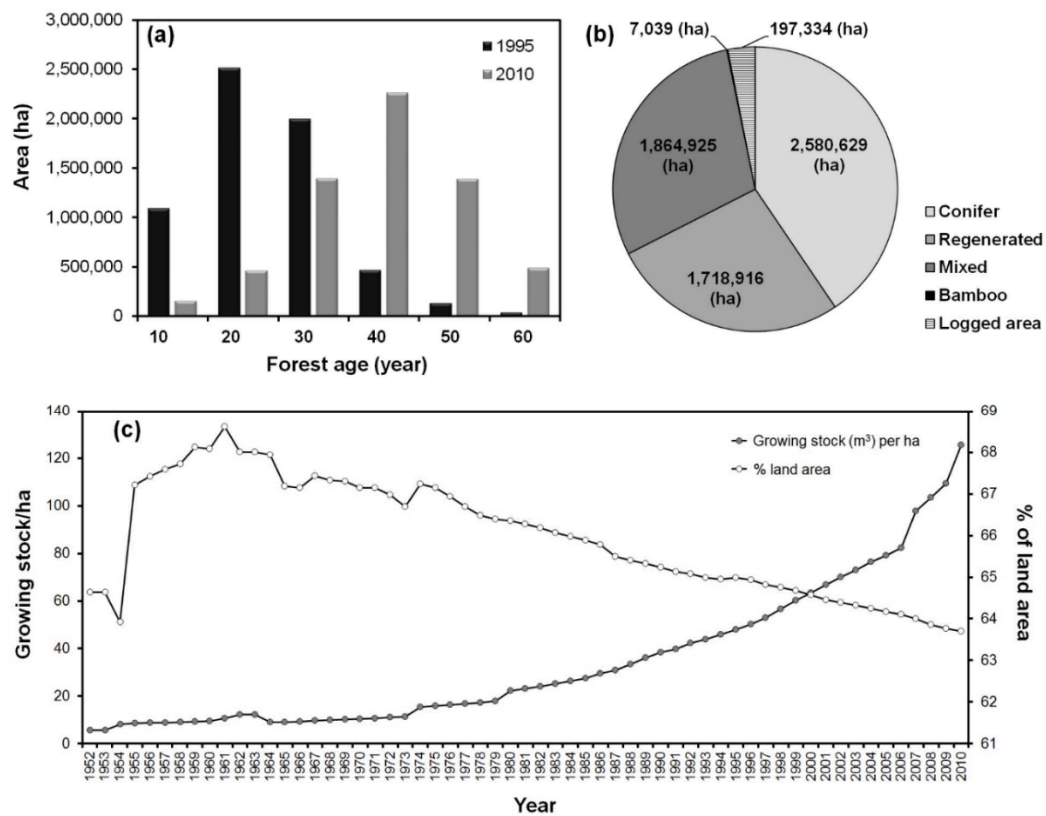
Fig. 2.4. Successional change of forest age (a), their current composition in 2010 (b), and change of growing stock (m^3) per hectare and percentage of forest area from 1952 to 2010 in Korea (c). Data cited from Korea Forest Service (http://www.forest.go.kr).

2.3. Concept of bioindicators and potential of ground beetles

Bioindicator or biodiversity indicator is generally used in most ecological studies. Bioindicator provides a short-cut in monitoring programs (Ferris and Humphrey, 1999) and detecting changes in the environment (Rainio and Niemelä, 2003). There are several international and national initiatives to develop criteria and bioindicator in classifying the sustainability of forests (e.g., McGeoch, 1998; Lindenmayer *et al.,* 2006; Samways *et al.,* 2010). Samways *et al.* (2010) have summarized the term of bioindicator as follows:

(1) Bioindicator readily reflects the abiotic or biotic state of an environment;

(2) Bioindicator represents the impact of environmental change on a habitat, community or ecosystem;

(3) Bioindicator is indicative of the diversity of a subset of taxa or wholesale diversity within an area.

Insects are generally used as bioindicators due to their diversity, large biomass, their functional roles, and their immediate response to environmental change (Samways *et al.,* 2010). Among many insect families, ground beetles or carabids (Coleoptera: Carabidae) are the best studied taxa (Lövei and Sunderland, 1996) because they can sensitively respond to many anthropogenic disturbances. Therefore, they are suitable

for environmental monitoring (Rainio and Niemelä, 2003). Ground beetles are also diverse, ecologically well known, and abundant in most ecosystems. Therefore, they have been investigated in numerous topics of ecology, evolution, and conservation research programs (Lövei and Sunderland, 1996). In addition, many species of them have highly specific habitat preference, such as forest specialist and open-habitat species (Thiele, 1977). In particular, large-bodied and poorly dispersing (i.e., flightless) ground beetle species with lower reproductive rate may be more vulnerable to disturbances than small-bodied generalist species with good flight ability (Kotze and O'Hara, 2003; Rainio and Niemelä, 2003). Koivula (2011) has evaluated the indicator potential of ground beetles (Fig. 2.5) and found that ground beetles appear to be useful model organisms and possible indicators because they can be easily collected in sufficiently large numbers for statistical analyses in addition to their characteristics mentioned above.
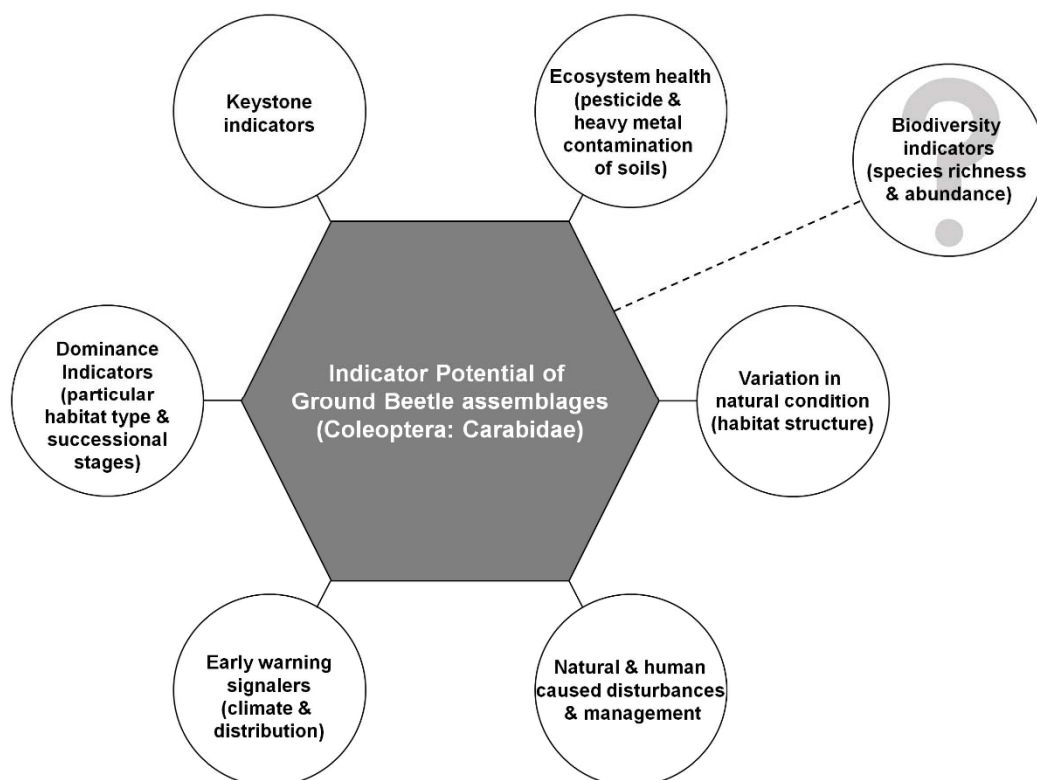
Fig. 2.5. Indicator potential of ground beetles. Modified from Koivula (2011).

2.4. Historical review of studies on ground beetles in Korea

Internationally, 4,892 publications on ground beetles or carabids published between 1932 and 2015 were found in SCOPUS database (http://www.scopus.com). A total of 65 studies focused on the biodiversity and community ecology of arthropods that dealing with ground beetles were found in Korean environments, including forest, island, urban-rural landscape, and wetland (Fig. 2.6a, Appendix S2.1). Although many studies were focused on biodiversity (i.e., fauna=species list), some studies compared diversity (e.g., species richness, Shannon's index, Simpson's dominance and diversity, and Evenness) among study sites and investigated relationships between environmental characteristics and community structure based on multivariate analyses (e.g., dendrogram, ordination, regression tree, and so on). Recently, estimated species richness (e.g., rarefaction curves, Chao I, Chao II, and Jackknife) and ecological trait analysis (e.g., habitat type, wing morph, body size, and feeding habits) have been investigated to understand the patterns of biodiversity (Fig. 2.6b).

Many previous studies using ground beetles were conducted on agricultural and urban landscape in other regions due to the important role of ground beetles in agricultural habitats as predator and as prey for birds

and animals (Holland, 2002). However, few studies have been conducted in Korea on inventory study in levee (Choi *et al.,* 2004) or the community structure according to land-use differences (Do *et al.,* 2011, 2012a, b; Kang *et al.,* 2009), i.e., studies that investigate the community structure of ground beetles among land-uses and the effect of landscape structure on species richness and abundance in agricultural landscape. Compared to agricultural landscape, the biodiversity and community structure of ground beetles in urban landscape are poorly studied with only a few available data (Park, 2010; Jung *et al.,* 2012b; Do *et al.*, 2014a, b). Their studies provided basic information for the management of biodiversity in agricultural and urban landscapes using ground beetles, although their ecological roles in those ecosystems should be clarified in further studies.

Many studies on ground beetle assemblages in Korea have been focused on forest habitats (Kim and Lee, 1992; Lee and Lee, 1995; Kim and Choi, 1995; Kwon, 1996; Kwon and Byun, 1996; Park *et al.,* 1996, 1997, 2003; Nam, 1997; Lee *et al.,* 1998, 2005, 2010; Chang and Kim, 2000; Kim and Kim, 2000; Kubota *et al.,* 2001; Choi and Moon, 2002; Kwon and Park, 2005; Yeon *et al.,* 2005; Lee, 2011; Jung *et al.,* 2011a, b, 2012a, b, 2013, 2014, 2015; Kwon *et al.,* 2010, 2011; Do and Joo, 2013; Kang *et al.,* 2013) (Fig. 2.7a). Of these studies, many researchers investigated the

inventory and diversity in a particular region or national parks (Kim and Choi, 1995; Kwon, 1996; Kwon and Byun, 1996; Lee *et al.,* 1998, 2010; Nam, 1997; Choi and Moon, 2002; Jung *et al.,* 2011b; Lee, 2011) (Fig. 2.7b), whereas others examined the relationships between ground beetles and forest environmental characteristics, as well as the effect of forest management on beetles (Lee and Lee, 1995; Chang and Kim, 2000; Kubota *et al.,* 2001; Kwon and Park, 2005; Lee *et al.,* 2005; Jung *et al.,* 2011a, 2013, 2014, 2015; Kwon *et al.,* 2010, 2011; Lee *et al.,* 2012; Kang *et al.,* 2013) (Fig. 2.7c). The change of community structure and diversity of ground beetles across altitudinal gradient has also been investigated (Park *et al.,* 1997, 2003; Kim and Kim, 2000; Yeon *et al.,* 2005; Jung *et al.,* 2012a). At population level, there are a few studies on seasonal activities of some ground beetle species (Kim and Lee, 1992; Park *et al.,* 1996).

As mentioned above, studies on insect communities in Korea compared to other regions has been limited to some study subjects such as biodiversity, although insects have a lot of advantages when assessing various environmental changes. Some researchers have only recently begun to focus on the importance of ground beetles for assessing environmental state and habitat management. For example, Jung *et al.* (2014) have investigated ground beetle assemblages throughout the

Korean Peninsula (see Chapter 4 of this thesis) and showed that forest patch size and elevation are the most important factors in the presence of ground beetles (see chapter 4 in this thesis). Do *et al.* (2014a, b) have studied the ecological importance of green infrastructure (e.g., park, landfill, unmanaged grassland, brownfield, garden, roadside, forest park) and assessed those habitat's value for the community structure of ground beetles, which revealed the potential of multi-functional habitat in enhancing biodiversity in urbanized areas.
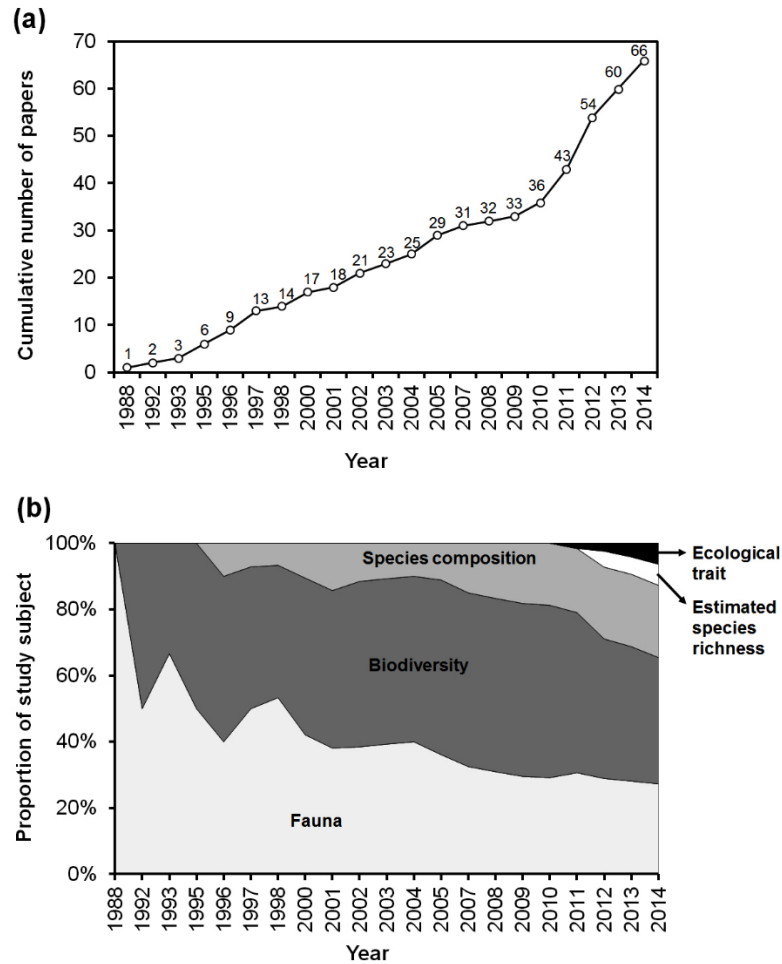
Fig. 2.6. Cumulative number of articles on community studies on ground beetles and related taxa (a) and study subjects proportion (b) from 1988 to 2014 in Korea. In fauna studies, species listed in papers were used. Biodiversity studies were consisted of several diversity indices (e.g., species richness, Shannon's diversity, Evenness, and Simpson's diversity). Multivariate analyses (e.g., cluster analysis and ordination) were conducted to understand species composition between study sites. To estimate species richness, some estimation tools were used to compare biodiversity between study sites, such as rarefaction curves and Chao. Finally, ecological trait analysis was conducted to clearly illustrate ecological patterns.
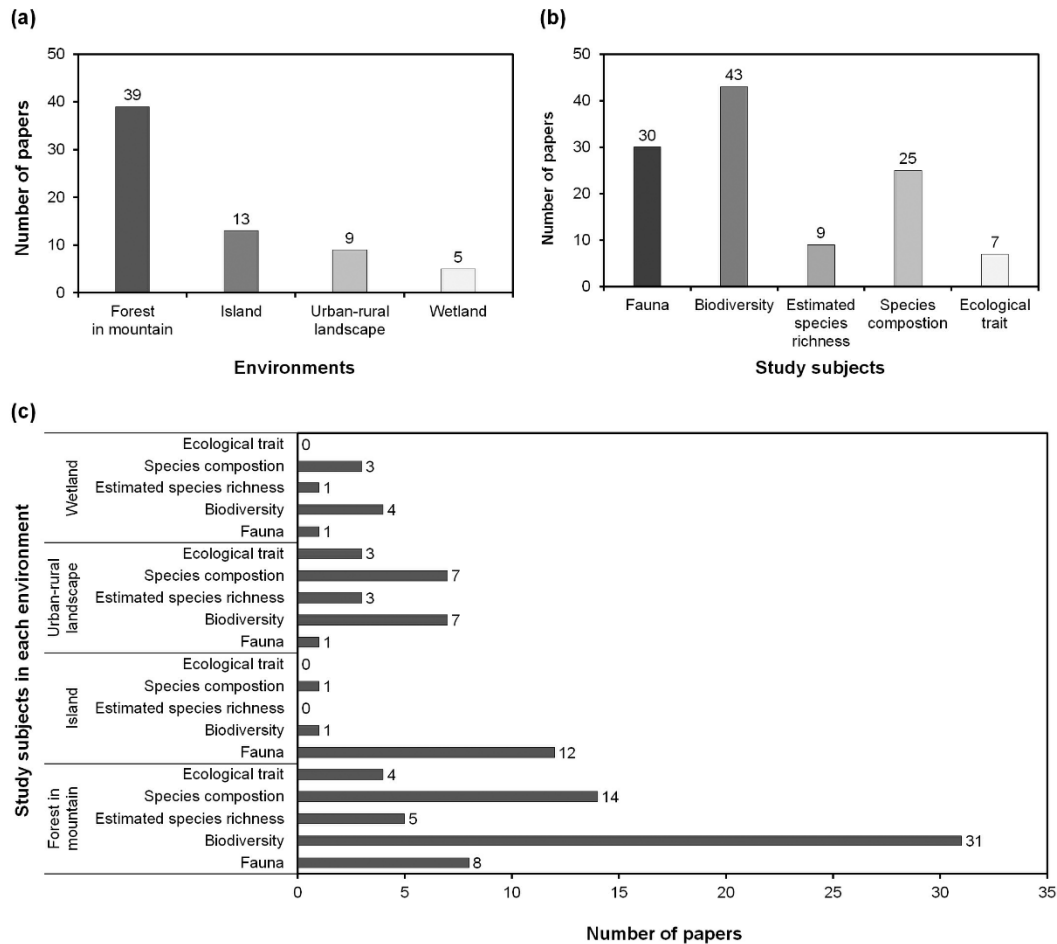
Fig. 2.7.　Historical review of papers in Korea focused on ecological studies on ground beetle assemblages. Description about each plot was followed: (a) four major environments (forest in mountain, island, urban-rural landscape and wetland); (b) five study subjects; (c) combined (a) with (b). See Fig. 2.6 on the detailed explanations for study subjects. The numbers in the histogram were redundantly counted in each research paper (e.g., Jung et al. (2015) have 3 study subjects: biodiversity, estimated species richness, and species composition).

Chapter 3.

Effects of forest–farm edge and landscape structure on ground beetles (Coleoptera: Carabidae) in Korea

Abstract

In fragmented landscapes, ecological processes may be significantly influenced by edge effect, but there are little available for the edge effect across forest–farmland edges. We investigated the patterns of species richness, abundance, and species composition of ground beetles across the forest–farm edge in two different agro-forested landscapes in Korea. Nine and five sites were selected from Hwaseong, a fragmented landscape, in 2011 and 2012, respectively, while eight sites were selected from Hoengseong, a relatively well-protected landscape, in 2012. Ground beetles were collected by pitfall traps. Species richness of the forest edge in Hwaseong was similar with the forest interior, while forest edge species richness in Hoengseong was intermediate, at a level between the forest interior and surrounding. Non-metric multidimensional scaling based on the combined data of Hwaseong and Hoengseong also showed that the species composition of ground beetles in the forest edge was more similar to the forest interior, although some open-habitat species occurred at the forest edges. Three characteristic groups (forest specialist, edge associated species, and open-habitat species) of ground beetle species were detected by Indicator Value analysis. In our study, ground beetle assemblages showed a different response to the forest edges in two

agro-forested landscapes suggesting that the edge effect on biota can be influenced by landscape structure. To increase biodiversity, therefore, reductions should be made in excessive use of forest edges and surroundings for agro-forested purposes so as to retain natural habitats provide corridors.

3.1. Introduction

Habitat fragmentation is frequently caused by human activities such as agriculture, rural development, and urbanization, with forest edges becoming more abundant in human-dominated areas. In fragmented habitats, habitat structure and microclimate are negatively affected by edge creation (see Harper et al. 2005; Laurance 2008), and thus species composition may change. Therefore, understanding of the edge effect in fragmented environments is important for biodiversity conservation. Indeed, the negative effects of edge creation for habitat specialist species have become more apparent (Harper et al. 2005). For example, habitat fragmentation is often a severe factor for several bird species becoming threatened (Watson et al. 2004), and large-scale edge effects can lead to the local extinction of beetle species that are restricted to habitat interiors (Ewers and Didham 2008).

In Korea, forests and adjacent native habitats have been more excessively used by humans. During the Korean War and earlier, most primary forests were devastated, resulting in growing stocks of 5.6 m^3/ha in 1952, after which forests were regenerated through extensive reforestation, with growing stocks now at 126 m^3/ha in 2010 (Lee 2012). However, whilst reforestation has been successful, rapid industrialization has prompted a

loss of biodiversity by the modification of land-use of natural habitats (i.e., forest and grassland) to agricultural and urban environments. From the 1970s to 1990s, for example, natural grasslands in Korea decreased to occupy about 0.4 % of the nation, with about 20% being used for agriculture (Ministry of Land, Transport and Maritime Affairs 2014). This land-use change to maximize the land availability is still in progress because mountains and forests cover approximately 64% of the nation. As a result, many natural habitats like grasslands and forests have been modified to arable lands, artificial grasslands, and built-up areas. For these reasons, disturbances by human activity, such as urbanization and agriculture, are major events in the biodiversity loss of Korea (Ministry of Environment 2012), and it has become important to examine the effect of human activities on biodiversity at forest edge for planning conservation and management of biodiversity.

In this study, the spatial pattern and the species richness of ground beetles were investigated along the forest–farm edge in two different agro-forested landscapes, because ground beetles were selected because they are useful model organisms and possible indicators of environmental change (Rainio and Niemelä 2003). Ground beetles are favorable subjects for comparative ecological studies using pitfall traps. In addition, ground

beetles are a diverse group, both taxonomically and ecologically well known, and they reflect environmental conditions well (Thiele 1977; Lövei and Sunderland 1996; Rainio and Niemelä 2003). There are many previous studies investigated the species richness and composition of ground beetles in forest edge (Kotze and Samways 1999; Heliölä et al. 2001; Magura et al. 2001; Molnár et al. 2001; Magura 2002; Koivula et al. 2004; Yu et al. 2007; Ewers and Didham 2008; Roume et al. 2011; Tóthmérész et al. 2014; Lacasella et al. 2015; Ohwaki et al. 2015), but most of these studies were conducted in forest–clearcuts or forest–grasslands except for the study by Koivula et al. (2004) and Ohwaki et al. (2015) who studied the forest–farmland edge in a agro-forested landscape. In Korea, there are several studies investigated the effects of land-uses (Kang et al. 2009; Do et al. 2011, 2012a, 2012b; Jung et al. 2012) on ground beetles since 2000s, but these studies did not study the patterns in abundance and species richness of ground beetles along forest–farmland edges.

Therefore, we investigated the patterns of species richness, abundance, and species composition of ground beetles across the forest–farm edge in two different agro-forested landscapes, a fragmented and developing landscape and a relatively well-protected landscape. In

addition, we examined the habitat preferences of each ground beetle species for further ecological study based on their distributional patterns.

3.2. Materials and Methods

3.2.1. Study area

This study was conducted at two sites, Hwaseong and Heongseong, in Korea. Hwaseong located in the western part of Korea is highly heterogeneous and is composed of fragmented landscapes (Fig. 1a). Approximately 36.9% (25,344.9 ha) of the land area is forest, while 36.1% (24,854.7 ha) and 14.4% (9,913.0 ha) are farmlands (rice fields, uplands, and orchards) and urban areas (built-up areas, roads, and railways), respectively (Hwaseong Statistical Year Book 2010). In addition, forests and farmlands have consistently decreased due to the increase of built-up areas and roads (Hwaseong Statistical Year Book, http://www.hscity.go.kr).

Hoengseong, located in the eastern part of Korea, is a well preserved agro-forested landscape compared to Hwaseong (Fig. 1c). Approximately 77.0% (76,806.1 ha) of the land area is forest, while 15.2% (15,196.6 ha) and 1.3% (1,286.1 ha) are farmlands (rice fields, uplands, and orchards) and built-up areas, respectively (Hoengseong Statistical Year Book, http://www.hsg.go.kr).

3.2.2. Sampling

For ground beetle collection, pitfall traps were used. Pitfall trapping is a standard sampling method for comparing the abundance or community structure of ground beetles (Niemelä 1996; Koivula et al. 2003). The plastic pitfall traps (300 ml volume, 75 mm diameter, and 120 mm depth) were un-baited, containing preservatives (150 ml, 95% ethyl-alcohol:95% ethylene-glycol=1:1) as killing-preserving solution. A plastic roof was placed 3 cm above each trap to prevent the inflow of rainfall and litter.

In Hwaseong, nine and five forests were selected in 2011 and 2012, respectively, and their edges and surroundings were also studied (Fig. 3.1a, Table 3.1). Seven study sites in the forested side were conifer forests dominated by *Pinus densiflora* Siebold et Zucc. and *Pinus rigida* Mill., while others were mixed forests dominated by oaks (*Quercus acutissima* Carruthers), Japanese chestnut (*Castanea crenata* Siebold & Zucc.), and *Pinus* species. Patch sizes of all forests (mixed or *Pinus* forests) ranged from 4.6 ha to 518.5 ha except for site M1 (1548.4 ha), but all these forests were regenerating forests or plantations (30–50-year-old). The surroundings were generally human-managed areas, such as arable lands, levees in rice fields, and turf in a cemetery area.

The minimum diameter of small patches in Hwaseong was about 40

m, with the shape of small patches being highly thinned or reduced. For this reason, true forest edge-interior distance in Hwaseong was 20 m, and the total length of a gradient across the forest surrounding to interior is 40 m. Therefore, we divided it into three separate zones according to their distance from the forest edge: 3 traps at the edge (1 m inward from the boundary of the forest), 3 traps in the forest interior (20 m inward from the boundary of the forest), and 3 traps in the forest surrounding (20 m outward from the boundary of the forest) (Fig. 3.1b). Therefore, 9 pitfall traps were placed in each study site and a total of 126 pitfall traps were used in 14 study sites in Hwaseong. Pitfall traps were replaced every month from early June to early October in 2011 and late June to late October in 2012.

In Hoengseong, there are also secondary forests (40-year-old) (Table 3.1). Four study sites (PF1, PF2, PQF1, and PQF2) were dominated by conifer tree species (*P. densiflora*), but the forest edge at PQF1 and PQF2 was mixed with oaks (*Quercus* spp.). The four sites (LQF1, LQF2, QF1, and QF2) were mixed forests dominated by oaks, but two transects at LQF1 and LQF2 were mixed with *Larix kaempferi* Carriere and oaks.

Unlike the forest in Hwaseong, the forest in Hoengseong is continuously interconnected and the landscapes are well preserved in general (Fig. 3.1c). For this reason, a set of two pitfall traps were installed

along the transect (Fig. 3.1d). Each transect started in the forest interior 80 m away from the forest edge, which is the boundary between the forest and farmland, and they extended 80 m into the surrounding habitats (+80 m, +40 m, +20 m, +1 m, -20 m, -40 m, -80 m). Surrounding habitats were composed of arable land, levee in rice fields, unmanaged area, turf in a cemetery area, and a riverbank. Eight transects were set at least 300 m away from each other to provide adequate statistical independence for pitfall samples. Therefore, 14 pitfall traps were placed in each study site, with a total of 112 pitfall traps used in Hoengseong. Pitfall traps were replaced every month from early May to early October in 2012.

Forest information (forest patch sizes, dominant conifer trees, and forest ages) in two study landscapes was confirmed by the forest geographic information service system in Korea (Korea Forest Service, http://www.forest.go.kr/newkfsweb).

Collected ground beetles were brought to the laboratory and dried, mounted, and identified to species level under a dissecting microscope (×63). Identification was performed according to Habu (1967, 1973, 1978, 1987), Kwon and Lee (1984), and Park and Paik (2001), and nomenclature was confirmed according to the lists of Korean Carabidae by Park and Paik (2001) and Park (2004).

Table 3.1. Description of environment in each study site.

Forest types	Site code	Year	Dominant tree in forest interior [a]	Dominant tree in forest edge	Surrounding habitat [b]	Elevation at edge (m)	Patch size (ha)	Forest age	Direction [c]
Hwaseong									
Pine	P1	2012	*Pinus densiflora*	*Pinus densiflora*	Turf	49	147.7	40	Southern
	P2	2011	*Pinus densiflora*	*Pinus densiflora*	Turf	61	179.9	40	Southern
	P3	2011	*Pinus densiflora*	*Pinus densiflora*	Arable	28	17.4	30	Northern
	P4	2012	*Pinus densiflora*	*Pinus densiflora*	Turf	31	10.0	40	Southern
	P5	2011	*Pinus densiflora*	*Pinus densiflora*	Arable	23	7.9	40	Southern
	P6	2011	*Pinus rigida*	*Pinus rigida*	Arable	49	74.9	30	Southern
	P7	2011	*Pinus rigida*	*Pinus rigida*	Turf	101	67.6	30	Southern
Mixed	M1	2012	*Quercus acutissima*	*Quercus acutissima*	Levee	46	1548.4	40	Northern
	M2	2012	*Castanea crenata*	*Castanea crenata*	Levee	62	518.5	50	Southern
	M3	2012	*Castanea crenata*	*Castanea crenata*	Arable	58	441.3	50	Northern
	M4	2011	*Castanea crenata*	*Castanea crenata*	Levee	31	11.2	50	Northern
	M5	2011	*Castanea crenata*	*Castanea crenata*	Levee	30	6.7	30	Northern
	M6	2011	*Quercus acutissima*	*Quercus acutissima*	Arable	29	5.3	30	Northern
	M7	2011	*Castanea crenata*	*Castanea crenata*	Levee	23	4.6	30	Northern

Table 3.1. *Continued*.

Hoengseong

Pine	PF1	2012	*Pinus densiflora*	*Pinus densiflora*	Arable, River bank	142	3877.6	40	Southern
	PF2	2012	*Pinus densiflora*	*Pinus densiflora*	Arable, River bank	132	3877.6	40	Southern
Mixed	PQF1	2012	*Pinus densiflora*	*Pinus-Quercus* mixed	Arable, River bank	148	777.8	40	Southern
	PQF2	2012	*Pinus densiflora*	*Pinus-Quercus* mixed	Arable, River bank	132	777.8	40	Southern
	LQF1	2012	*Larix-Quercus* mixed	*Larix leptolepsis*	Natural grass, Arable	189	1421.8	40	Northern
	LQF2	2012	*Larix-Quercus* mixed	*Quercus* spp.	Natural grass, Levee	176	1421.8	40	Northern
Oak	QF1	2012	*Quercus* spp.	*Quercus* spp.	Arable, Levee	153	785.2	40	Northern
	QF2	2012	*Quercus* spp.	*Quercus* spp.	Natural grass, Levee	167	1421.8	40	Southern

[a] Dominant tree in forest interior in Hoengseong included forest interior only (+80 m ~ +20m)

[b] Surrounding habitat is a sampling site of forest exterior neighboring forest edge

[c] Direction is classified as follows: northern, forest edge facing from North-West to North-East; southern, forest edge facing from South-West to South-East

42
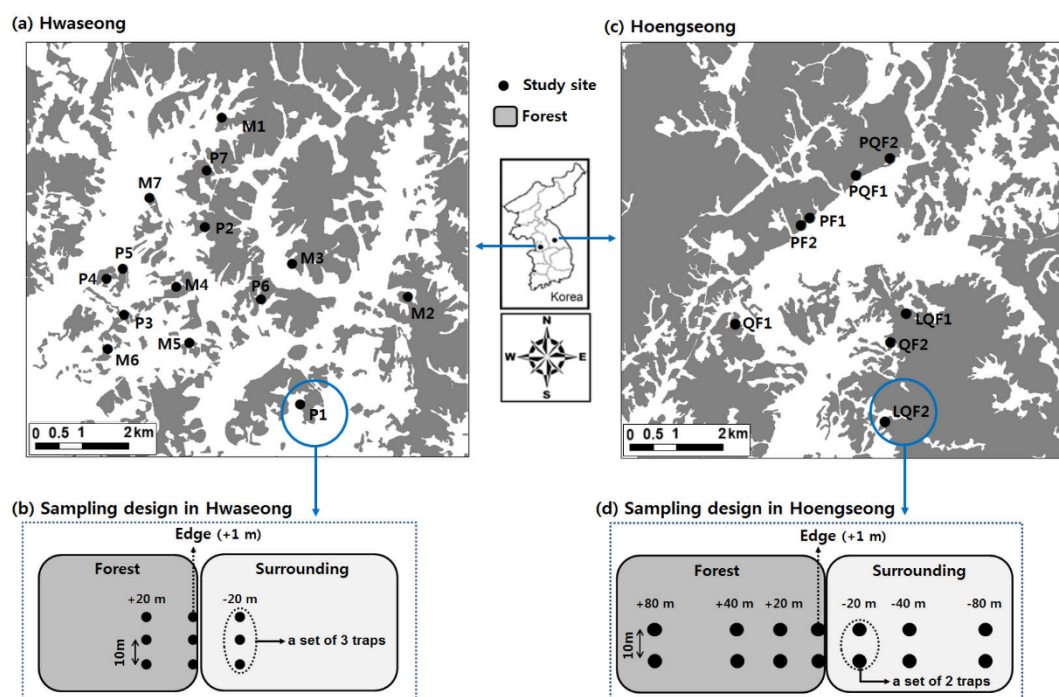
Fig. 3.1. Locations of 14 and 8 collection sites in Hwaseong (a) and Hoengseong (b), respectively, and sampling designs for ground beetle collection in Hwaseong (c) and Hoengseong (d). Abbreviations of sampling sites are given in Table 1.

3.2.3. Data analysis

The species richness was measured based on the total number of species collected during the sampling period, and abundance was measured based on the total number of individuals collected in a set of traps for each study site. We conducted linear regression analysis to investigate the relationship between the species richness of ground beetles and area of forest stand. In addition, we conducted two-way ANOVA (GLM procedure) to explore effects of forest type, direction (i.e., orientation of the edge), and distance from edge on ground beetle abundance and species richness. Because the ground beetle catches may be influenced by orientation of the edge (Ries et al. 2004), we classified the edges to northern (i.e., forest edge facing from North-West to North-East) and southern (i.e., forest edge facing from South-West to South-East) (Koivula et al. 2004). The data of abundance and species richness analyzed with linear regression and two-way ANOVA were log (n+1) transformed to normalization. In addition, the species richness of ground beetles was estimated with individual-based rarefaction curves for each habitat type. We pooled the data (abundance and species richness) of collected ground beetles according to habitat types (forest interior, edge, and surrounding) in each study landscape, and then estimated species richness was compared among the habitat types.

Rarefaction curves are based on random re-sampling of the pool of captured individuals, and are used to estimate expected richness at lower sample size (Gotelli and Colwell 2001). Rarefaction methods allow for meaningful standardization and comparison of datasets (Gotelli and Colwell 2001).

To summarize and compare species composition among different habitat types and distance to edge based on square-root transformed data, a similarity matrix of Bray-Curtis similarity values was created (Clarke and Warwick 2001). Similarities among study sites of both Hwaseong and Hoengseong were graphically represented by non-metric multidimensional scaling (NMDS) ordination. NMDS was chosen because it performs well with ecological data that do not meet the assumption of normality (McCune and Grace 2002), and thus it is the most generally effective ordination and classification method for ecological community data (Jongman et al. 1995; McCune and Grace 2002). In NMDS, stress represents distortion between real data point positions in a graphical representation. Lower stress represents less distortion from the real data point positions and is thus associated with a graph that more accurately represents dissimilarities in species composition.

The Indicator Value (IndVal) approach was employed in order to find indicator species that characterize the habitats (Dufrêne and Legendre 1997). The flexible IndVal was independent of other species' relative abundance, and there was no need to use pseudo-species. The IndVal is at maximum (100%) when all individuals of a species are found in a single group of sites and when the species occurs in all sites for that group. Therefore, abundance and occurrence stability indexes for species were determined to be important and were included for analysis. Furthermore, it is possible to assess the statistical significance of the species indicator values using a Monte Carlo permutation test (Legendre and Legendre 1998; McGeoch and Chown 1998).

Linear regression, two-way ANOVA with Tukey's *post hoc test*, rarefaction curves, and NMDS based on Bray-Curtis similarity and IndVal were conducted using R Project for Statistical Computing (http://www. r-project.org/).

3.3. Results

3.3.1. Community structure of ground beetles

In Hwaseong during 2011 and 2012, a total of 5276 ground beetles belonging to 42 species were collected from 14 study sites (2125 individuals of 18 species in forest interior, 2208 individuals of 15 species in forest edge, and 943 individuals of 38 species in forest surroundings) (Appendix 3.1). Four species (*Chlaenius naeviger* Morawitz, *Synuchus arcuaticollis* Motschulsky, *Synuchus cycloderus* (Bates), and *Synuchus nitidus* (Motschulsky)) accounted for more than 81.3% of individuals.

In Hoengseong in 2012, a total of 3741 ground beetles belonging to 61 species were collected from 8 study sites (2160 individuals of 21 species in the forest interior, 810 individuals of 25 species in forest edge, and 771 individuals of 52 species in forest surroundings) (Appendix 3.2). Seven species (*C. naeviger*, *Coptolabrus jankowskii jankowskii* (Oberthur), *Coptolabrus smaragdinus branickii* Taczanowski, *Pheropsophus jessoensis* Morawitz, *S. arcuaticollis*, *S. cycloderus*, and *S. nitidus*) accounted for more than 80.7% of individuals.

The patch size of the forest stand correlated with the species richness of total (linear regression; $F_{1, 20}$=6.84, r^2=0.25, P=0.017) and forest specialist ground beetles ($F_{1, 20}$=11.48, r^2=0.36, P=0.003) based on pooled data of Hwaseong and Hoengseong. However, the species richness of open-habitat species and abundance of all groups did not correlated with the patch size.

Among the forest type, direction, and distance to edge, the distance to edge was most significant factor for the abundance and species richness of ground beetles (Table 3.2). The abundance of total and forest specialists of both Hwaseong and Hoengseong was significantly higher in the forest interior and edge sites than in the farmland sites, while that of open habitat species was higher in the farmland sites. Similar patterns were found in the species richness of forest specialists and open-habitat species. However, the forest type and direction were insignificant for the species richness and abundance of forest specialists.

Individual-based rarefaction curves for all species from Hwaseong (Fig. 3.2a) and Hoengseong (Fig. 3.2b) showed that species richness was generally higher in the surrounding habitat than in the forest interior or edge. The species richness of the forest edge in Hwaseong was similar to the forest interior (Fig. 3.2a), while forest edge species richness was

intermediary between that of the forest interior and surroundings in Hoengseong (Fig. 3.2b).

The combined data from Hwaseong and Hoengseong was used for NMDS based on the Bray-Curtis similarity measure, and showed that the species composition of ground beetles in the forest edge was more similar with that in the forest interior (Fig. 3.3). However, some difference between Hwaseong and Hoengseong was found by axis 2 not only in the forest interior (ANOSIM, Global R=0.237, P=0.001) and edge (Global R=0.378, P=0.002) but also in the surrounding (Global R=0.118, P=0.024) (Fig. 3.3a). According to the habitat types, the species composition of ground beetles was not separated by forest types (i.e., pine dominated, oak dominated, and mixed forest) and surrounding habitat types (i.e., arable, levee, turf, river bank, and unmanaged area) (Fig. 3.3b). This was found by cluster analysis based on Bray-Curtis similarity for both agro-forested landscapes in Hwaseong and Hoengseong (Figs. 3.4).
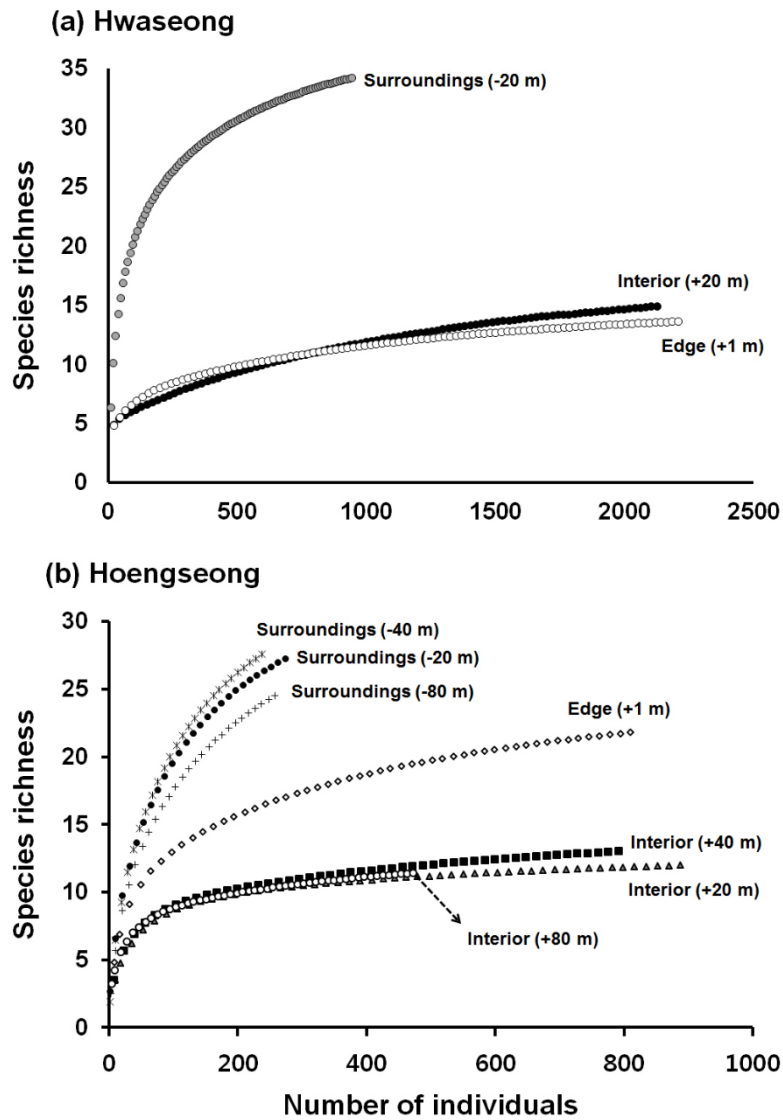
Fig. 3.2. Individual-based rarefaction curves based on ground beetle catches of the forest interior (+80 ~ +20 m), edge (+1 m), and surrounding (-20 ~ -80 m) in Hwaseong (a) and Hoengseong (b). Data points indicate average species numbers estimated for the given number of individuals.

50

Table 3.2. Two-way ANOVA results for abundance and species richness of total ground beetles and two habitat-association groups.

Group/source	Hwaseong				Hoengseong			
	df	F	P	Tukey's test	df	F	P	Tukey's test
Abundance								
Total								
Forest type	1	2.88	0.099		2	3.79	0.035	Mixed ≥ Oak ≥ Pine
Direction	1	0.84	0.366		1	0.00	0.973	
Distance	2	5.74	0.007	(+20, +1) > -20	6	5.69	0.001	+20 > (+1, +40) ≥ +80 ≥ -20 ≥ -80 ≥ -40
Forest type *direction	1	2.01	0.166		1	5.25	0.030	
Forest type *distance	2	2.91	0.069		12	0.70	0.742	
Direction*distance	2	0.79	0.464		6	0.51	0.793	
Forest specialists								
Forest type	1	0.03	0.858		2	1.95	0.162	
Direction	1	3.88	0.058		1	0.15	0.698	
Distance	2	51.26	<0.001	(+20, +1) > -20	6	37.79	<0.001	(+80...+1) > (-20...-80)
Forest type *direction	1	8.79	0.006		1	5.45	0.027	
Forest type *distance	2	2.84	0.073		12	0.97	0.502	
Direction*distance	2	0.53	0.593		6	0.95	0.480	
Open-habitat species								
Forest type	1	1.93	0.175		2	5.25	0.012	Mixed ≥ Pine ≥ Oak
Direction	1	4.33	0.045	Northern > Southern	1	0.08	0.781	
Distance	2	8.36	0.001	(+20, +1) < -20	6	5.08	0.001	+80 ≤ (+40, +20) ≤ (+1...-80)
Forest type *direction	1	0.05	0.830		1	0.97	0.332	
Forest type *distance	2	0.31	0.735		12	0.36	0.966	
Direction*distance	2	2.40	0.107		6	0.45	0.840	

Table 3.2. *Continued*.

Species richness								
Total								
Forest type	1	9.83	0.004	Mixed > Pine	2	2.77	0.081	
Direction	1	2.76	0.106		1	0.06	0.811	
Distance	2	10.97	0.000	(+20, +1) < -20	6	2.05	0.093	
Forest type *direction	1	0.76	0.389		1	1.31	0.263	
Forest type *distance	2	3.92	0.030		12	0.80	0.646	
Direction*distance	2	1.38	0.266		6	0.31	0.925	
Forest specialists								
Forest type	1	0.50	0.485		2	0.24	0.786	
Direction	1	0.42	0.521		1	0.03	0.861	
Distance	2	27.55	<0.001	(+20, +1) > -20	6	29.11	<0.001	(+80...+1) > -20 > (-40, -80)
Forest type *direction	1	5.37	0.027		1	0.00	0.985	
Forest type *distance	2	0.42	0.660		12	0.58	0.836	
Direction*distance	2	1.49	0.241		6	2.21	0.073	
Open-habitat species								
Forest type	1	5.92	0.021	Mixed > Pine	2	3.89	0.033	Mixed ≥ Pine ≥ Oak
Direction	1	6.96	0.013	Northern > Southern	1	0.04	0.836	
Distance	2	34.35	<0.001	(+20, +1) < -20	6	21.20	<0.001	(+80...+20) < (+1...-80)
Forest type *direction	1	0.10	0.756		1	1.13	0.297	
Forest type *distance	2	2.78	0.077		12	1.24	0.306	
Direction*distance	2	2.17	0.130		6	0.16	0.986	

52
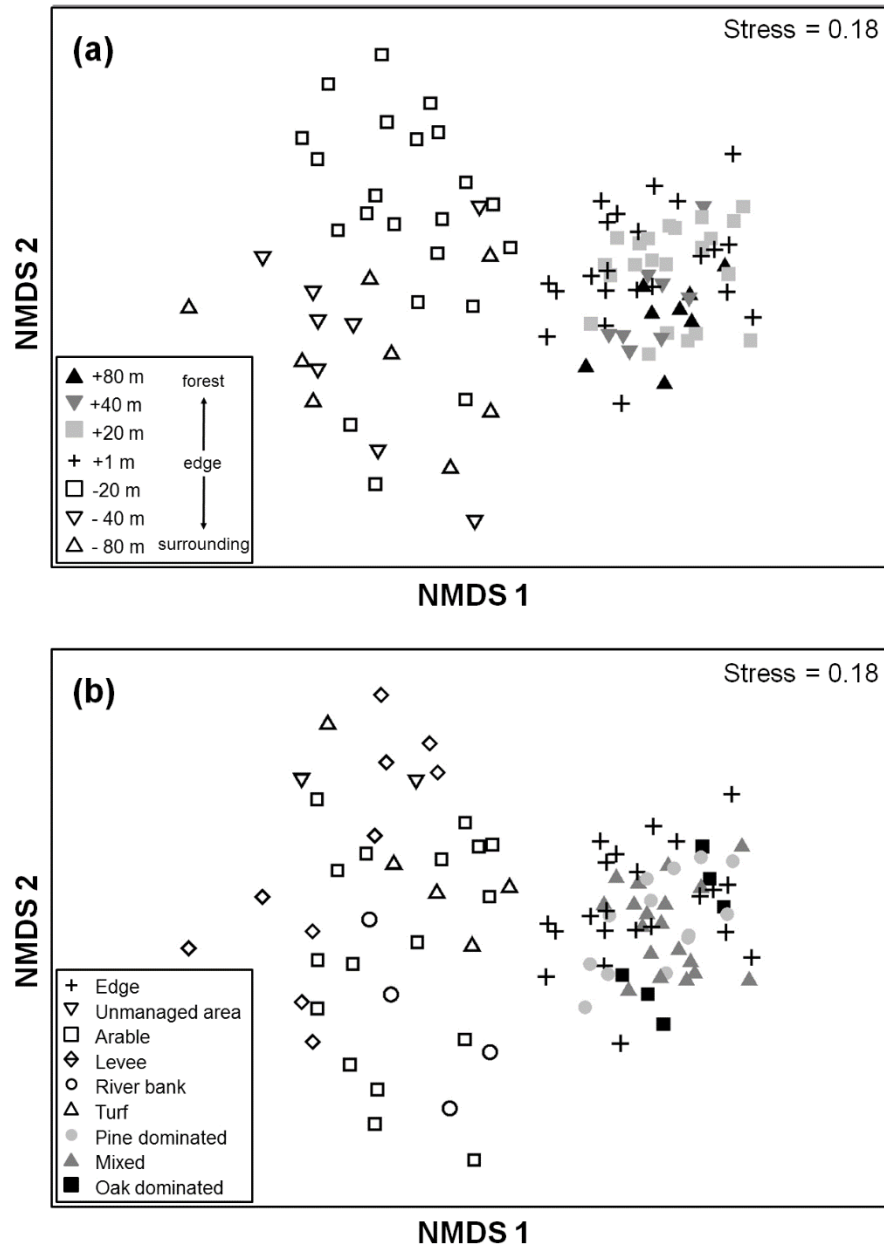
Fig. 3.3. Non-metric multidimensional scaling using Bray–Curtis similarity based on square-root transformed data of ground beetle assemblages of both Hwaseong and Hoengseong according to the distances from forest edge (a) and the habitat types (b).

53
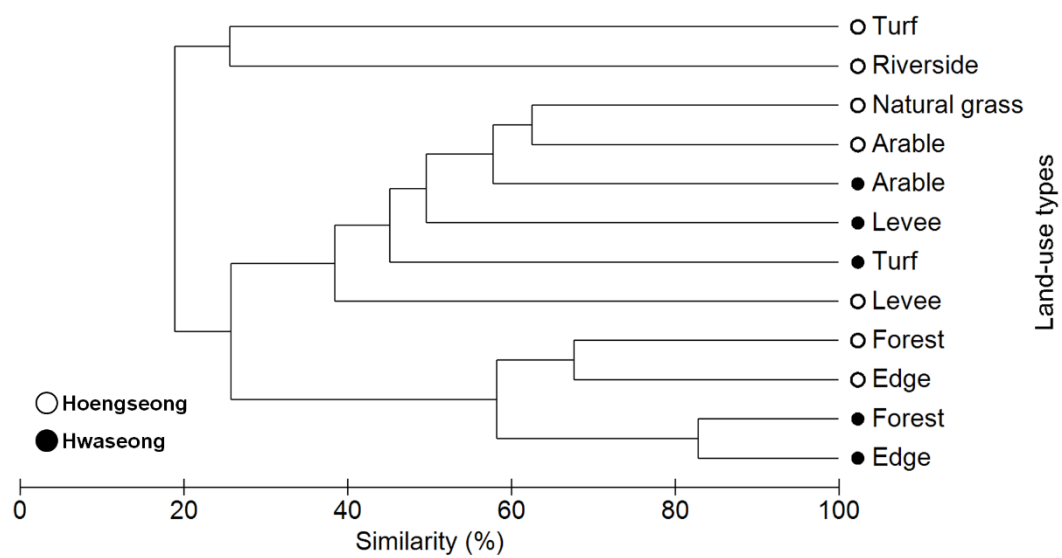
Fig. 3.4. Group averaging cluster analysis using Bray–Curtis similarity based on square-root transformed data of ground beetle assemblages according to the land-uses in Hwaseong and Hoengseong.

3.3.2. Indicator species analysis

Three characteristic groups of ground beetle species were detected by IndVal (Table 3.3): edge associated species (e.g., *Harpalus niigatanus* Schauberger), most abundant in the forest edge and surroundings (Fig. 3.5); open-habitat species (e.g., *Dolichus halensis halensis* (Schaller)*, H. tridens* Morawitz*, H. eous* Tschitschérine*, H. sinicus sinicus* Hope*, Chlaenius variicornis* Morawitz*, C. micans* (Fabricius)*, Nebria chinensis chinensis* Bates and so on), most abundant in open-habitats such as grassland, arable, and levees (Fig. 3.6); and forest specialist (e.g., *S. nitidus, S. cycloderus, S. arcuaticollis, C. jankkowskii jankkowskii,* and *Calosoma cyanescens* Motschulsky), numerous in most forest interior and edge areas (Fig. 3.7). Although some species such as *C. naeviger* and *P. jessoensis* were not included in these groups by IndVal, they were abundant in the forest edge as well as forest interior or surroundings (Fig. 3.5a, c). In addition, *C. smaragdinus branickii* was mainly caught from forests in Hoengseong, but this species was mostly collected from surrounding habitats in Hwaseong (Fig. 3.7c).

Table 3.3. Two-way indicator table showing the ground beetle species indicator value for the habitat clustering hierarchy from two different agro-forest landscape, and number of individuals of ground beetles by each habitat type.

Habitat	Indicator value	P	Number of individuals (Hw, Hwaseong; Ho, Hoengseong)					
			Forest interior		Forest edge		Surrounding	
			Hw	Ho	Hw	Ho	Hw	Ho
Forest interior and edge								
Synuchus nitidus	0.978	0.001	1,055	548	266	961	5	19
Synuchus cycloderus	0.976	0.001	563	482	132	408	1	
Synuchus arcuaticollis	0.902	0.001	175	723	20	423	35	11
Coptolabrus jankkowskii jankkowskii	0.532	0.200	63		35		8	
Calosoma cyanescens	0.493	0.046	51		48		1	
Calosoma maximowiczi	0.399	ns	15		13			
Forest edge and surrounding								
Harpalus niigatanus	0.5	0.031			25		36	11
Surrounding								
Dolichus halensis halensis	0.935	0.001			8	2	91	172
Harpalus tridens	0.902	0.001	1	2	4		87	65
Harpalus eous	0.660	0.001				1	3	43
Harpalus sinicus sinicus	0.623	0.001			4		56	28
Chlaenius variicornis	0.544	0.020	1	2	2	1	31	31
Chlaenius micans	0.522	0.003					6	103
Harpalus sp.1	0.522	0.002					5	1
Nebria chinensis chinensis	0.481	0.030	1	1	1		5	7
Chlaenius biomaculatus	0.474	0.043		1		24		25
Chlaenius costiger	0.474	0.067		2		3	2	13
Amara congrua	0.449	0.037	1				8	
Pheropsophus javanus	0.441	0.038			1		2	8
Amara simplicidens	0.426	0.024					3	2
Anisodactylus punctatipennis	0.426	0.033					105	3
Chlaenius pallipes	0.426	0.024					1	7
Harpalus tinctulus	0.426	0.028					4	1
Curtonotus giganteus	0.376	ns			2		9	2
Harpalus chalcentus	0.369	ns					5	1
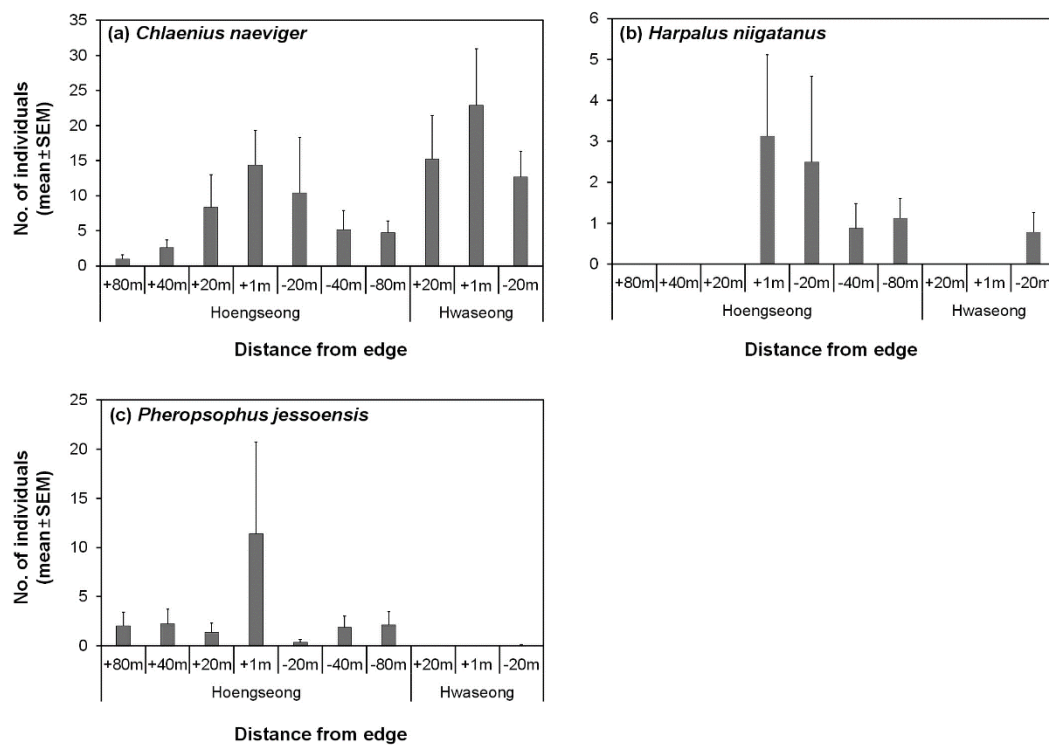
Fig. 3.5. Spatial distribution of 3 abundant edge associated species along forest (+80 ~ +20 m)–edge (+1 m)–farm (-20 ~ -80 m) gradients in Hoengseong and Hwaseong.
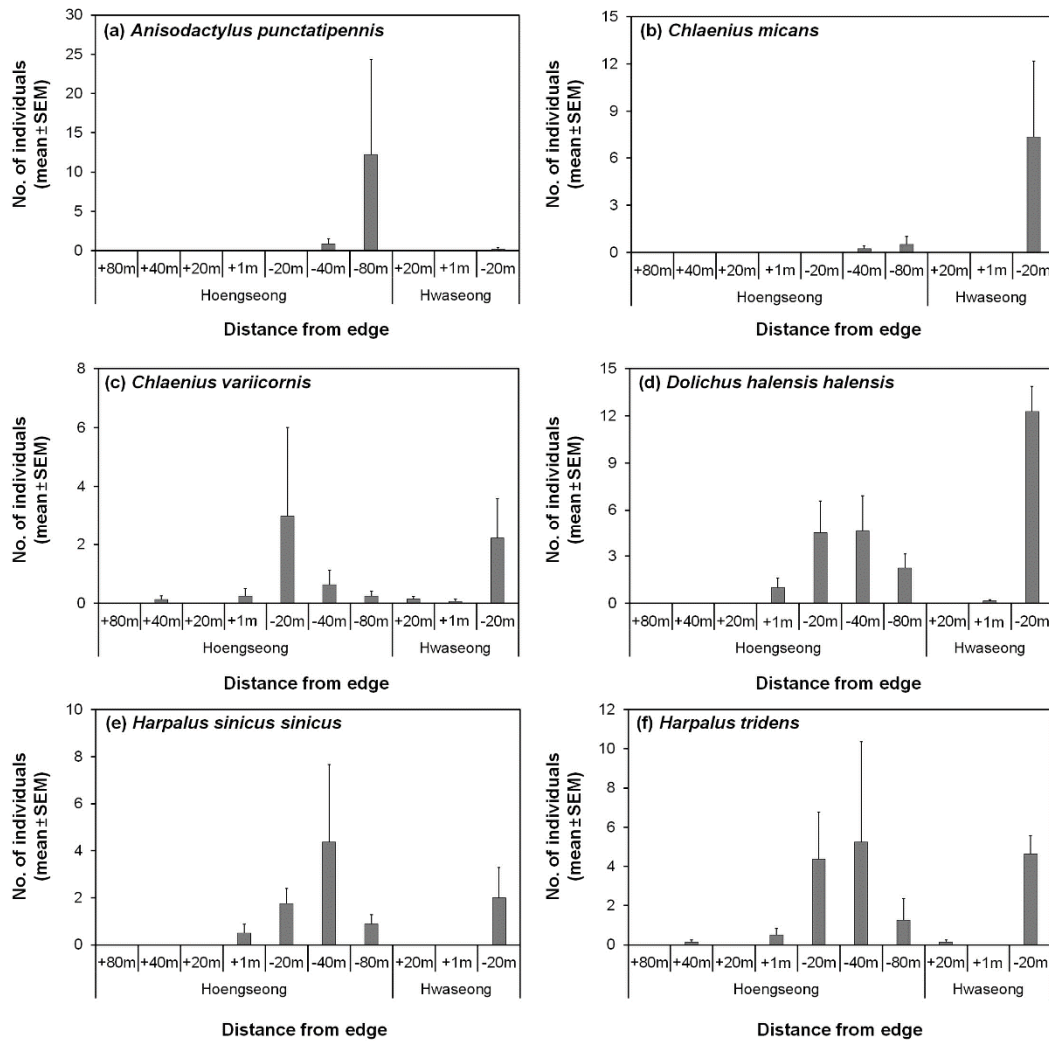
Fig. 3.6. Spatial distribution of 6 abundant open-habitat species along forest (+80 ~ +20 m)–edge (+1 m)–farm (-20 ~ -80 m) gradients in Hoengseong and Hwaseong.

58
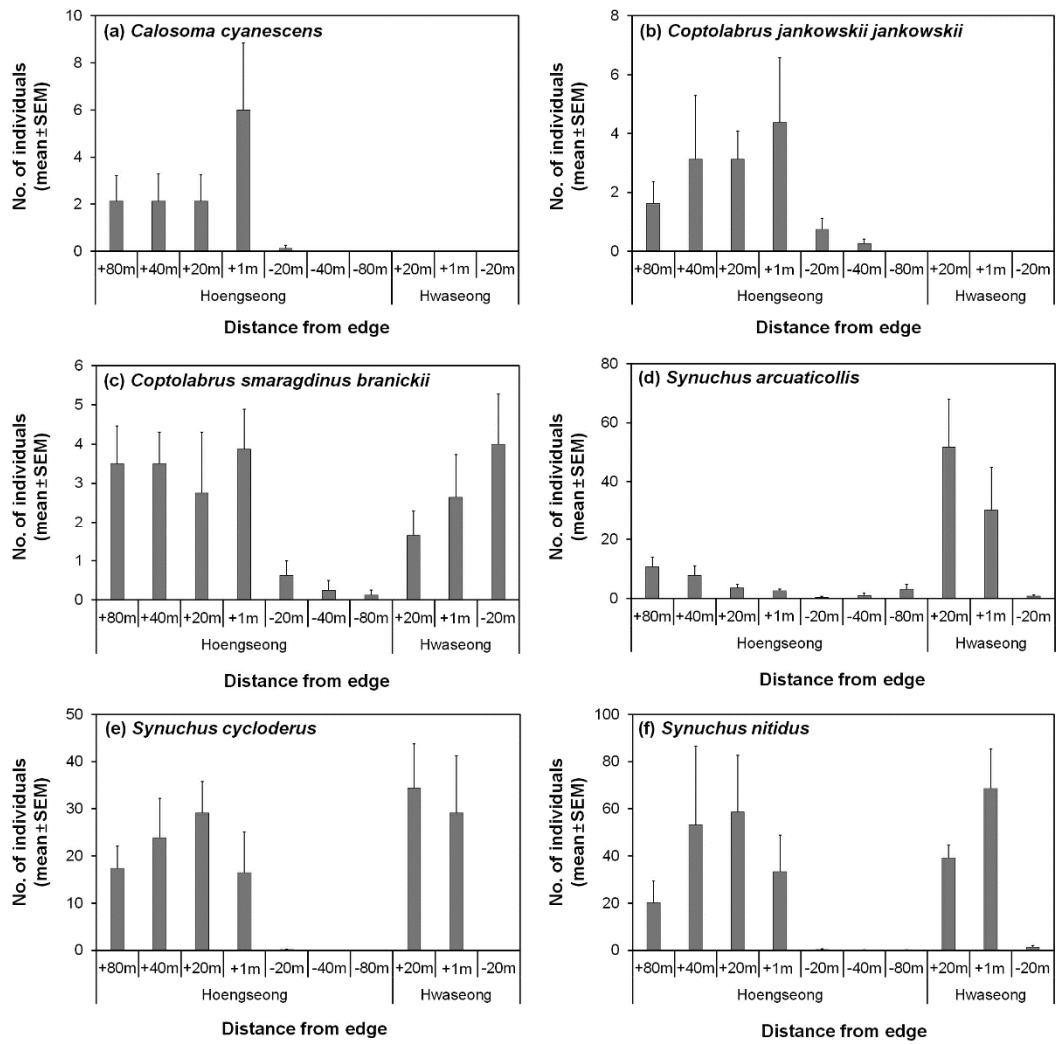
Fig. 3.7. Spatial distribution of 6 abundant forest specialists along forest (+80 ~ +20 m)–edge (+1 m)–farm (-20 ~ -80 m) gradients in Hoengseong and Hwaseong.

3.4. Discussion

We examined species richness and composition of ground beetles in terms of the edge effect along forest–farmland transects, with patterns of species richness found to be different between the two agro-forested landscapes. Our results indicate that ground beetle assemblages, including species richness, species composition, and species distribution, were primarily influenced by forest edge and landscape structure. When comparing ground beetle assemblages between two agro-forest landscapes, total species richness of both open-habitat species and forest specialists was higher in Hoengseong, a relatively well-preserved landscape, than in Hwaseong. In addition, the species composition of Hwaseong and Hoengseong differed not only in the forest interior and forest edge but also in the non-forest area. Although the two studied landscapes are far apart from each other, the difference in proportion of forest, arable, and urbanized area in each landscape may be significant factors affecting ground beetle assemblages at forest edges. The difference pattern of species richness at the forest edge between Hwaseong and Hoengseong may be caused by the heterogeneity of the vegetation and differences in the management regime of open-habitats (Roume et al. 2011). On the other hand, our study sites are not too small to conserve the biodiversity in

60

agro-forested landscape, i.e. area of the smallest patch in our study was 4.6 ha in fact. However, the combined effects of short history forestry and habitat fragmentation may be important factor to understand the biodiversity in Korean forest. In fact, the forests in Korea have been more excessively used by humans during the Korean War and earlier, although forests were regenerated through extensive reforestation successfully.

For ground beetles, higher species richness has generally been found in forest edges and surroundings than in interiors (Segers and Bosmans 1982; Niemelä et al. 1988, 1992; Niemelä and Halme 1992; Halme and Niemela 1993; Bedford and Usher 1994; Levesque and Levesque 1994; Magura 2002; Tóthmérész et al. 2014; Lacasella et al. 2015; Ohwaki et al. 2015). In particular, Magura (2002) found higher abundance and species richness in forest edges than in forest interiors, suggesting that management of forest edges is important for ground beetles, especially forest specialists. However, the pattern of species distribution across the forest–farmland edge in a fragmented landscape appears to be inconsistent with those of the natural forest edges and clear-cut edges. There are little available for the edge effect across forest–farmland edges produced by Koivula et al. (2004) and Ohwaki et al. (2015). In our study, species richness at the forest edge was different

between two agro-forest landscapes. In Hoengseong, a relatively well-preserved landscape, estimated species richness of the forest edge was at an intermediate level between that in the forest interior and surroundings mainly due to many open-habitat species being caught in Hoengseong, while no difference was found between the forest edge and interior in Hwaseong, a fragmented and developing landscape. This difference may be natural in that it could be caused by different degrees of habitat fragmentation and urbanization. In fact, habitats in Hoengseong appear to be more stable than those in Hwaseong in terms of forest connectivity and lower rate of urbanization. Although the forests studied in both regions were in fact similar in terms of the forest type and age, the forests in Hoengseong were generally interconnected continuously whereas Hwaseong is a highly fragmented and developed landscape. These differences in the habitat stability of the forested side and landscape structure may have produced the different patterns of species richness and composition of ground beetles in the forest edges in our two studied landscapes. In general, forest specialist ground beetles are generally influenced by the patch size and forest management regime (Magura et al. 2010; Do and Joo 2013; Jung et al. 2014), while open-habitat species are generally affected by the land-use (Vanbergen et al. 2005). Similarly,

Barbosa and Marquet (2002), Ewers et al. (2007) and Soga et al. (2013) found synergistic interaction of patch size and distance to edge to be an important determinant of beetle community structure. In our study, decreases of the forest area can negatively affect forest specialists, while open-habitat species can acquire the opportunity to expand their distributional range may resulted in different diversity patterns between Hwaseong and Hoengseong. However, measurement and prediction of the interaction of area and edge on biota is very difficult work, because many potential mechanisms are responsible for habitat fragmentation (Ries et al. 2004).

In both Hwaseong and Hoengseong, the species composition of ground beetles was very similar between the forest edge and interior compared to that of the surrounding habitats. This result agrees with several studies that conducted in forest–farmland edge (e.g., Koivula et al. 2004; Ohwaki et al. 2015) and forest–grassland edge (e.g., Tóthmérész et al. 2014; Lacasella et al. 2015). However, Ohwaki et al. (2015) pointed out that diversity peaks and species composition in forest–meadow edge was changed according to seasonal change in the distribution of open-habitat species for overwintering. Unlike open-habitat species, the dispersal of many forest-associated ground beetles in a heavily fragmented landscape

may be restricted to within the forest. This is because canopy cover is known as a major determining factor in the spatial distribution of ground beetles (Koivula et al. 2004; Vanbergen et al. 2005). Although several forest specialists (e.g. *Calosoma* spp., *Coptolabrus* spp., and *Synuchus* spp.) in our study were sometimes collected in surrounding habitats, their distribution was mostly restricted to the forest. This is caused by differences of soil properties and habitat characteristics induced by human activity, and may act as a barrier (Koivula et al. 2004). Therefore, it can be suspected that large or continuous forests in agro-forested landscapes may not play a role as a source habitat for other populations in patches, especially flightless beetles. For this reason, it can be assumed that forest specialist ground beetles may not act as predators in agroecosystem. Thus in order to minimize the adverse effects of farmlands on ground beetle dispersal and predation, the forest edge in agro-forested landscape should be protected by the expansion of the field margin with the aim of facilitating the provision of more diverse microhabitats. These works may has some advantages to enhance biodiversity not only for ground beetles, but also for many endangered or threatened arthropods. However, further study is needed to clarify the potential role of forest patches in fragmented landscapes, not only for ground beetles, but also other arthropods.

At species level analysis, we examined habitat affinity of several Korean ground beetle species, and found some interesting distributional patterns. For example, although *C. naeviger* has been reported as an open-habitat species in several previous studies (Ishitani et al. 2003; Jung et al. 2012, 2014), this species was caught mainly from the forest edge and neighboring sites in both forest and non-forest areas. Thus, it is more plausible that *C. naeviger* is an edge-associated species. On the other hand, *P. jessoensis* was found to be related to open-habitat according to some studies (ElSayed and Nakamura 2010; Jung et al. 2012, 2014), but this species was collected from the forest interior and edge of PQF1 and PQF2 sites in Hoengseong. In fact, *P. jessoensis* is known to be a hydrophilic beetle (Lake Biwa Museum, http://www.lbm.go.jp/) and has generally been found in moist forests at other monitoring sites (unpublished data). Thus, *P. jessoensis* appears to be an edge- and moist forest-associated species. Finally, the spatial distribution of *C. smaragdinus branickii,* known as a forest specialist and a very large species in Korea, is more interesting. *C. smaragdinus branickii* was abundant at the forest interior and edge in Hoengseong, but this species was more abundantly collected from the forest edge and surrounding habitat in Hwaseong. In addition, adults of *C. smaragdinus branickii* in Hwaseong moved freely

across the edge and its neighboring habitats, but their larvae were generally restricted to the forest area (data not shown). For these reasons, we suggest that *C. smaragdinus branickii* can actively move from forest to open-habitats to find prey, such as snails, which may help agriculture through the dispersal of predatory forest species into agricultural fields (Roume et al. 2011). This characteristic of *C. smaragdinus branickii* may also allow for colonization in the forest patches of agro-forested landscape unlike another similar large forest specialist, *C. jankowskii jankowskii*.

Many forest-associated species, in terms of their abundance and richness, may not be affected by forest edges since their species composition was similar between forest edges and interiors. Unlike many forest-associated species, edge-preferring species (e.g., *Chlaenius naeviger* and *Pheropsophus jessoensis*) were found at 40 m into the forest interior in our study, indicating these species could penetrate into the forest interior significantly. This result was similar with that found by Molnár et al. (2001). Although more varied and detailed studies on the edge effect are needed to evaluate ground beetles as well as other taxa, the habitat affinity of each ground beetle species examined by this study will be useful validating the results of further basic ecological and experimental studies. In addition, further study is needed to clarify the edge effect on biota as well

as ground beetles, since the forest specialists in our study may not be true forest species in Korea, that are restricted to the inner forest core habitat. For example, Ewers and Didham (2008) studied edge effects for beetle communities in natural reserves at the kilometer-scale, and they concluded that isolated nature reserves of at least 11,500–14,000 ha in area would have to be preserved to retain core habitat for forest-interior beetle assemblages.

Chapter 4.

A comparison of diversity and species composition of ground beetles (Coleoptera: Carabidae) between conifer plantations and regenerating forests in Korea

Abstract

Ground beetles were collected by pitfall trapping to compare their species richness between conifer plantations (14 sites) and regenerating forests (14 sites) and among forest ages and to examine how different functional groups responded to forest type, forest age, patch size, elevation, and geographic location in terms of abundance and richness. Ground beetles were collected from middle August to late October, 2008. A total of 34 species were identified from 3,156 collected ground beetles. Individual-based rarefaction curves showed greater species richness in regenerating forests, especially in 40–50-year-old forests, than in conifer plantations. Stepwise multiple regression analysis showed that patch size and elevation were major predictors of species richness and/or abundance of forest specialists, brachypterous species, and large- and medium-sized species. A multivariate regression tree indicated that patch size and elevation were major predictors of assemblage structure. Although my results suggest that maintaining forest areas adjacent to agricultural landscapes may be essential to preserve ground beetle assemblages irrespective of forest types, further study is necessary to clarify the effects of habitat quality and amount on ground beetles in forests.

Keywords: Biodiversity; Conservation; Carabids; Forest types; MRT

4.1. Introduction

Conserving biodiversity in forests has become a key issue in national and international forest policy and management because forests support numerous species in many taxonomic groups including birds, invertebrates, and microbes (Lindenmayer *et al.,* 2006). In particular, rapid changes in landscapes due to urbanization, agriculture, and road construction have caused forest loss and fragmentation, threatening forest biodiversity worldwide (Brockerhoff *et al.,* 2008). Because of this problem, many studies have focused on the relationship between biodiversity and forest remnants (e.g., Gibbs and Stanton, 2001; Niemelä *et al.,* 2002; Magura *et al.,* 2010).

In Korea, forests are important for conserving and enhancing biodiversity because they cover approximately 64% of the nation (Lee, 2012). During the Korean War and earlier, most primary forests in Korea were devastated, and growing stocks declined precipitously to 5.6 m^3/ha in 1952 (Lee, 2012). Since the 1970s, a forest policy in Korea was enacted to prevent destructive logging, over-harvesting, forest fires, and illegal entry into forests and to require reforestation by logging operators (Woo and Choi, 2009). During reforestation periods, coniferous trees (e.g., *Pinus* spp. and *Larix* spp.) were planted in urbanized areas or agricultural landscapes,

while deciduous trees (e.g., *Quercus* spp., *Robinia pseudoacacia* L.) were regenerating or planted in mountainous areas. Consequently, growing stocks of Korean forests have increased to 126 m^3/ha in 2010 (Lee, 2012).

Although reforestation in Korea was successful, several coniferous tree species, such as *Pinus densiflora* Sieb. et Zucc., *Pinus koraiensis* Sieb. et Zucc., *Larix kaempferi* (Lamb.), and exotic *Pinus rigida* Mill., are now dominant, covering approximately 40% of the Korean Peninsula (Lee, 2012). Although these plantations may negatively affect the biodiversity of vegetation, birds, and beetles, some findings indicate that biodiversity in plantations may be similar to that in semi-natural forests (Carnus *et al.,* 2006; Brockerhoff *et al.,* 2008). In general, plantations and regenerating forests are potentially important for biodiversity in Korea, because about 82% of all forest area in Korea comprises 30–50-year-old trees (Korea Forest Service, 2014). Because of this short history of forest regeneration, the impacts of forest management are poorly known in Korea. Hence, investigation of the current biodiversity and community structure in these forests is highly valuable.

Ground beetles (Coleoptera: Carabidae) respond sensitively to many anthropogenic disturbances and are therefore suitable for environmental monitoring (Rainio and Niemelä, 2003). They are diverse, ecologically well

known, and abundant in most ecosystems (Lövei and Sunderland, 1996). In addition, many species show highly specific habitat preferences (Thiele, 1977) and often poor dispersal ability (Schuldt and Assmann, 2009). In particular, large-bodied and poorly-dispersing ground beetles may be more vulnerable to disturbances than small, generalist species that fly well (Rainio and Niemelä, 2003). Therefore, analyses of habitat type, wing morph, and body size of ground beetles, in addition to their assemblage structure, would provide useful diagnostic information on forest health.

In this study, I compared the species richness of ground beetles between conifer plantations and regenerating forests and among forest ages and examined how different ground beetle functional groups responded to forest type, forest age, patch size, elevation, and geographic location in terms of abundance and richness.

4.2. Materials and Methods

4.2.1. Study area

Twenty-eight sites encompassing 14 conifer plantations and 14 regenerating forests were selected to investigate the community structures of ground beetles throughout the country (Fig. 4.1). The study sites are described in Table 4.1. Latitudes and longitudes of the study sites were 34°34′–37°58′ and were 126°39′–129°27′, respectively. Elevations were 3–320 m. Conifer plantations in my study sites were generally monocultures of *P. densiflora*, *P. koraiensis*, *L. kaempferi*, or *P. rigida*. *Pinus densiflora*, *L. kaempfer*, and *P. koraiensis* are the most abundant trees on the Korean Peninsula. *Pinus rigida* is also common, but this tree is primarily planted in urban and agricultural landscapes. In contrast, regenerating forests were composed of oaks (*Quercus* spp.), *R. pseudoacacia*, and conifers (*P. densiflora*, *P. koraiensis*, *P. rigida*, and *L. kaempferi*). *Pinus rigida* and *R. pseudoacacia* are exotic species used to re-green denuded lands. Twelve study sites comprising conifer plantations were located at a lower elevation (< 100 m), while many regenerating forests were at higher elevations (Table 4.1). The 28 sites were grouped into three forest-age categories: 30-year-old (6 sites), 40-year-old (12 sites), and 50-year-old

75

(10 sites) forests. Forest types and forest ages in each site were confirmed

using a forest geographic information system (GIS) database (FGIS, 2012).

Table 4.1. Site descriptions of the 28 study sites.

Forest type	Location [a]		Code	Dominant tree species in sampling site [b]	Location		Elevation (m)	Patch size (ha)	Forest age
					Latitude	Longitude			
Conifer plantation	GG	Gapyeong-gun	GGG	Korean pine	37° 51′	127° 30′	91	88.3	30
		Icheon-si	GGI	pitch pine	37° 15′	127° 26′	82	80.1	40
		Samcheok-si	GWS	pine	37° 14′	129° 20′	24	16.2	30
	CB	Jecheon-si	CBJ	Japanese larch	37° 07′	128° 10′	239	91.0	50
	CN	Dangjin-gun	CND	pitch pine	36° 57′	126° 46′	4	2.4	40
		Janghang-eup	CNJ	pine	36° 00′	126° 40′	10	27.2	40
	JB	Buan-gun	JBB	pine	35° 43′	126° 39′	10	24.0	50
		Jeongeup-si	JBJ	pine	35° 36′	126° 48′	46	11.2	50
	JN	Haenam-gun	JNHn	pine	34° 34′	126° 39′	51	5.5	30
		Suncheon-si	JNS	pine	34° 51′	127° 26′	5	45.0	40
	GB	Gyeongju-si	GBG	pine	35° 47′	129° 16′	70	1.8	40
		Uiseong-gun	GBUs	pine	36° 26′	128° 43′	152	16.5	30
		Uljin-gun	GBUj	pine	36° 43′	129° 27′	9	669.4	50
	GN	Gimhae-si	GNGh	pine	35° 17′	128° 43′	29	140.4	50
Regenerating native forest	S	Gwanak-gu	SG	oak, pitch pine	37° 27′	126° 57′	193	> 1000.0	50
	U	Ulju-gun	UL	oak, pine, pitch pine	35° 25′	129° 19′	43	281.6	40
	GG	Bupyeong-si	GGB	oak, pine, pitch pine	37° 27′	126° 43′	74	39.1	30
		Hwaseong-si	GGH	oak, pine, pitch pine	37° 06′	126° 48′	12	4.3	40
		Pocheon-si	GGP	oak, Korean pine, pitch pine	37° 58′	127° 17′	257	> 1000.0	50

77

Table 4.1. *Continued.*

	Uiwang-si	GGU	oak, pitch pine	37° 20′	126° 59′	93	13.6	40
GW	Inje-gun	GWI	oak, Korean pine, Japanese larch	37° 57′	128° 07′	320	> 1000.0	50
	Pyeongchang-gun	GWP	oak, Japanese larch, pine	37° 22′	128° 23′	307	158.3	40
CB	Okcheon-gun	CBO	oak, pine, pitch pine	36° 18′	127° 45′	108	153.7	40
JB	Namwon-si	JBN	oak, pine	35° 32′	127° 21′	131	13.7	50
JN	Gwangyang-si	JNG	oak, pine	34° 55′	127° 42′	3	2.2	30
	Hwasun-gun	JNHs	oak, pine, pitch pine	35° 04′	127° 10′	192	> 1000.0	50
GB	Chilgok-gun	GBC	oak, Korean pine, pine	36° 03′	128° 32′	196	338.3	40
GN	Goseong-gun	GNGo	oak, pine, pitch pine	35° 06′	128° 19′	194	237.7	40

[a] Location: CB, Chungcheongbuk-do; CN, Chungcheongnam-do; GG, Gyeonggi-do; GB, Gyeongsangbuk-do; GN, Gyeongsangnam-do; GW, Gangwon-do; JB, Jeollabuk-do; JN, Jeollanam-do; S, Seoul; U, Ulsan

[b] Dominant tree: pine, *Pinus densiflora*; Korean pine, *Pinus koraiensis*; pitch pine, *Pinus rigida*; Japanese larch, *Larix leptolepsis*; oak*, Quercus* spp.

78
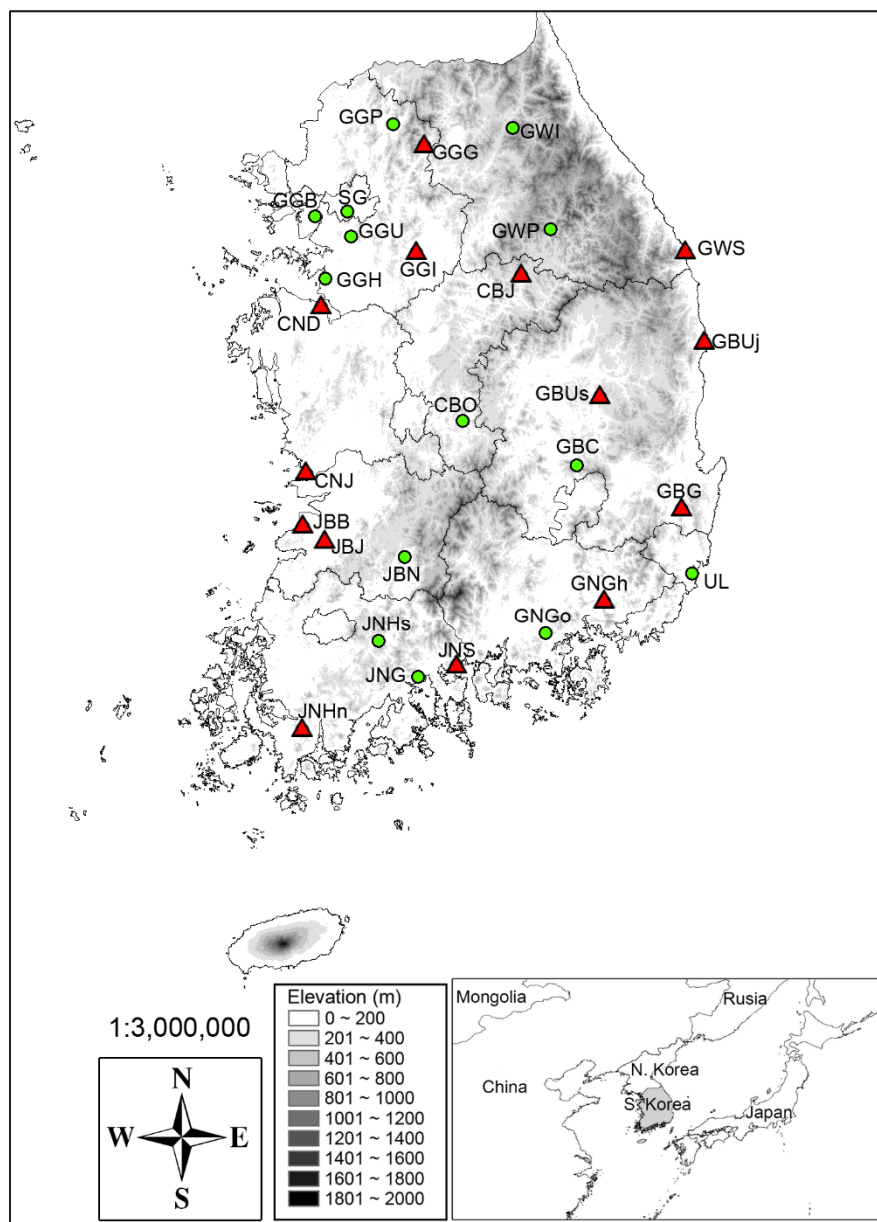
Fig. 4.1. Locations of 28 collection sites in South Korea. Abbreviations of sampling sites are given in Table 1 (triangles, conifer plantations; circles, regenerating forests).

4.2.2. Sampling

Ground beetles were collected from middle August to late October in 2008. Pitfall traps were placed approximately 30 m inside the edge of the study sites, and three traps were buried 10 m apart along a line transect in each site. Pitfall trapping is a standard sampling method for comparing the abundance or community structure of ground beetles (Niemelä, 1996; Koivula *et al.,* 2003). The traps were plastic bottles (500 mL, 10.5 cm diameter, 8 cm deep) with lids having six holes (2 cm diameter each) to prevent the catch of small mammals and herpetofauna. A plastic rain-cover was placed 3 cm above each trap. Traps were filled with preservative (300 mL 1:1 95% ethyl-alcohol:95% ethylene-glycol) and replaced every month.

The collected beetles were identified to species level using a dissecting microscope (63×, Olympus SZ61), according to Habu (1967, 1973, 1978, 1987), Kwon and Lee (1984), and Park and Paik (2001). Nomenclature follows Park and Paik (2001) and Park (2004). Voucher specimens were deposited at the Insect Ecology Laboratory, Entomology Program, Seoul National University, Korea. Habitat type of each identified species was determined according to Jung *et al.* (2011a,b, 2012a,b). The wing morph of each individual was determined by dissecting specimens.

Body sizes were measured using digital calipers (Sanling Group, Ltd., Zhejiang, China; 0.01 mm accuracy) and, for analysis, the species were grouped into three classes based on mean size: small (5–14.99 mm), medium (15–24.99 mm), and large (25–40 mm). To measure body size, 1–200 individuals (depending on availability) were randomly selected from all of the samples of each species.

4.2.3. Data analysis

I conducted ANOVA to explore the similarity of environmental variables between conifer plantations and regenerating forests. Species richness was measured based on the total number of species collected during the sampling period, and abundance was measured based on the total number of individuals collected in the three traps for each study site. To compare species richness by forest type and forest age, I estimated the species richness using rarefaction curves. This technique is based on random re-sampling of the pool of collected individuals and is used to estimate expected species richness at lower sample sizes (Gotelli and Colwell, 2001). Rarefaction curves allow for meaningful standardization and comparison of datasets (Gotelli and Colwell, 2001).

Stepwise multiple linear regression was used to test the relative importance of independent environmental variables (patch size, elevation, latitude, and longitude) in explaining the abundance and richness of different ground beetle functional groups. In addition, I further conducted stepwise multiple linear regression analyses for species that were selected based on their abundance (>30 individuals) and occupancy (present in ≥ 8 sites). Data on ground beetle assemblages were transformed by log (N+1) for normalization.

I further analyzed the assemblage-level responses to the four environmental variables by subjecting log-transformed data to multivariate regression tree analysis (MRT) based on Bray–Curtis pair-wise similarities between sample sites and included all species. I ran the MRT at least 50 times until I got the lowest cross-validated relative error (CV error). MRT analyzes community data but makes no assumptions about the form of relationships between species and their environment (De'ath, 2002). MRT identifies groups of sites defined by environmental variables and can potentially account for non-linearities (De'ath, 2002). Results are usually presented as a tree of dichotomies. Each dichotomy is chosen to minimize the dissimilarity of sample sites within each branch. I did the final tree selection by detecting the tree size (number of 'end' branches) with the lowest CV error followed by the 1-SE rule of Breiman *et al.* (1998). The CV error better estimates the predictive accuracy of the resulting model and it varies from 0 for a perfect predictor of community structure to close to 1 for a poor predictor (De'ath, 2002).

The species richness estimate calculated by Species Diversity and Richness v3.0 software (Henderson and Seaby, 2002) was used to evaluate sample size adequacy and to compare species richness between forest types. Stepwise multiple regression, ANOVA, and MRT were

83

conducted using the statistical software package R (R Development Core

Team, 2010).

4.3. Results

4.3.1. Environmental variables

Patch size (conifer plantations, 87.07 ± 46.19 ha (mean ± SE); regenerating forests, 374.46 ± 87.07 ha, $F_{1,26}$ = 5.51, P = 0.027) and elevation (conifer plantations, 58.71 ± 17.90 m; regenerating forests, 151.64 ± 27.32 m, $F_{1,26}$ = 8.09, P = 0.009) were significantly different between conifer plantations and regenerating forests. In contrast, latitude and longitude did not differ significantly between the two forest types.

Patches of 40–50-year-old conifer plantations were generally larger and at higher elevation than those of 30-year-old conifer plantations but not significantly so. For regenerating forests, only patch size differed significantly among age classes (30-year-old forests, 20.65 ± 18.45 ha; 40-year-old forests, 169.64 ± 48.23 ha; 50-year-old forests, 802.74 ± 197.26 ha, $F_{2, 11}$ = 9.17, P = 0.005).

4.3.2. Community structure of ground beetles

A total of 34 species belonging to 19 genera in nine subfamilies were identified among 3,156 collected ground beetles (Appendix S4.1, S4.2). In conifer plantations, 18 species were identified from 712 ground beetles; in regenerating forests, 31 species were identified from 2,444 beetles. Three species, *Synuchus nitidus* (Motschulsky), *Synuchus cycloderus* (Bates), and *Synuchus* sp.1, were commonly abundant, and *Coptolabrus jankowskii* Oberthur and *Harpalus tridens* Morawitz were abundant only in some study sites. The dominant species at most sites were *S. nitidus* (1,122 individuals, 35.6% of all beetles) and *S. cycloderus* (998, 31.6%), which had the broadest distributions, irrespective of forest type.

Individual-based rarefaction curves indicated that higher species richness was found in regenerating forests than in conifer plantations (28.81 ± 1.50 and 21.99 ± 0.10, respectively) (Fig. 4.2a). In particular, species richness was generally higher in regenerating forests than conifer plantations except in 30-year-old regenerating forests (Fig. 4.2b).

Stepwise multiple regression also showed that patch size and elevation were significant predictor variables of the abundance and species richness of some functional groups, such as brachypterous and large-bodied species (Table 4.2). For forest specialists, species richness

was affected by patch size and elevation. In contrast, open-habitat, macropterous, and small-bodied species were not influenced by patch size and elevation, although latitude was a significant predictor for the abundance and species richness of open-habitat species. Because three *Synuchus* species (*S. nitidus*, *S. cycloderus*, and *Synuchus* sp.1) were predominant in the most study sites, additional analyses were conducted by excluding them to check whether or not the results were solely caused by these abundant species. The general trend was similar, although patch size and elevation were the predictors for forest specialist abundance (y ~ patch size + elevation, adjusted r^2 = 0.49, $F_{4, 23}$ = 7.57, P < 0.001). At the species level, *C. jankowskii* was positively associated with increasing patch size and elevation, while *Chlaenius naeviger* Morawitz was negatively associated with increasing latitude. Other abundant species did not show significant relationships with these environmental variables.

The MRT analysis consistently produced a three-node tree with patch size, elevation, and latitude being the best predictors of ground beetle assemblages, together explaining 29.3% of the variation in the data (Fig. 4.3). However, the CV error of 1.25 (SE = 0.163) was relatively high, indicating poor predictive value of the model.
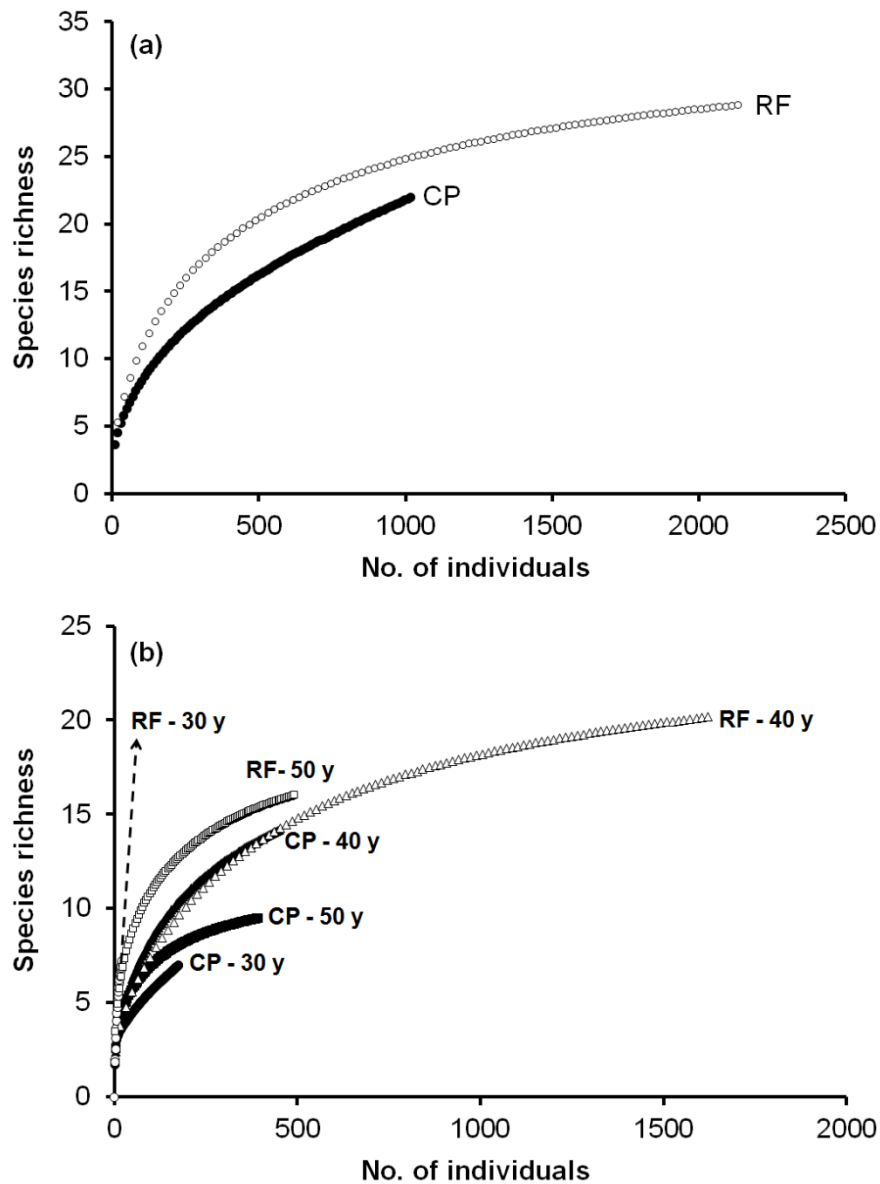
Fig. 4.2. Individual-based rarefaction curves for ground-beetle catches in conifer plantations (CP) and regenerating forests (RF) (a) and in forest age classes (30 y, 30 years old; 40 y, 40 years old; 50 y, 50 years old) (b). Data points indicate average species numbers computed for the given number of individuals.

Table 4.2. Relationship between ground beetle assemblages (log-transformed abundance and species richness) and selected independent variables as determined by stepwise multiple regression. Superscript asterisks indicate the significance of a P-value (*<0.05, **<0.01, ***<0.001). Table includes the parameter (β, relative importance of the predictor) for each variable in the models as well as the significance level and adjusted r^2 for the overall models. Hyphen in final model indicates that any variables were not entered in regression models.

Dependent variables	Parameter (β) of independent variables				Statistics			
	patch size	elevation	latitude	longitude	Adj. r^2	$F_{4, 23}$	P	Final model
Abundance								
Total	0.0005				-0.04	0.73	0.579	y ~ patch size
Forest specialists	0.0006				-0.02	0.85	0.509	y ~ patch size
Open-habitat species			-0.1800*		0.16	2.30	0.090	y ~ latitude
Brachypterous species	0.0008**	0.0025*			0.53	8.47	< 0.001	y ~ patch size + elevation
Macropterous species					-0.10	0.38	0.822	−
Large-bodied species	0.0007*	0.0021*			0.42	5.81	0.002	y ~ patch size + elevation
Medium-bodied species	0.0003		-0.0934		0.21	2.76	0.052	y ~ patch size + latitude
Small-bodied species			0.1701		0.09	1.63	0.201	y ~ latitude
Species richness								
Total		0.0010**	-0.0487		0.28	6.30	0.006	y ~ elevation + latitude
Forest specialists	0.0002	0.0008**			0.46	6.82	< 0.001	y ~ patch size + elevation
Open-habitat species			-0.1011*		0.12	1.96	0.135	y ~ latitude
Brachypterous species	0.0003*	0.0015**			0.51	8.10	< 0.001	y ~ patch size + elevation
Macropterous species					-0.01	0.95	0.453	−
Large-bodied species	0.0002	0.0011*			0.40	5.45	0.003	y ~ patch size + elevation
Medium-bodied species		0.0004	-0.0596		0.03	1.20	0.336	y ~ elevation + latitude
Small-bodied species		0.0004			0.02	0.89	0.488	y ~ elevation

Table 4.2. *Continued.*

Abundant species	patch size	elevation	latitude	longitude				model
Chlaenius naeviger			-0.1212*		0.08	1.61	0.206	y ~ latitude
Coptolabrus jankowskii	0.0004***	0.0013*			0.64	12.8	< 0.001	y ~ patch size + elevation
Coptolabrus smaragdinus					-0.06	0.63	0.644	−
Harpalus tridens			-0.1120	0.0917	0.04	1.30	0.300	y ~ latitude + longitude
Synuchus cycloderus		0.0025			-0.07	0.53	0.714	y ~ elevation
Synuchus nitidus			0.2547	0.2296	0.07	1.52	0.230	y ~ latitude + longitude
Synuchus sp.1	-0.0002			-0.1997	0.07	1.48	0.241	y ~ patch size + longitude

Patch size < 62.55 ha   Patch size ≥ 62.55 ha

(28)

Elevation ≥ 217.5 m   Elevation < 217.5 m

(14)

(14)

GBG (1.8 ha)
CND (2.4 ha)
JNHn (5.53 ha)
JBJ (11.2 ha)
GWS (16.2 ha)
GBUs (16.5 ha)
JBB (24.0 ha)
CNJ (27.2 ha)
JNS (45.0 ha)

JNG (2.2 ha)
GGH (4.3 ha)
GGU (13.6 ha)
JBN (13.7 ha)
GGB (39.1 ha)

Latitude ≥ 35° 64′   Latitude < 35° 64′

(4)

(10)

CBJ (239 m)

GWI (320 m)
GWP (307 m)
GGP (257 m)

(6)

(4)

CBUj (36° 43′)
GGI (37° 15′)
GGG (37° 51′)

GBC (36° 03′)
CBO (36° 18′)
SG (37° 27′)

GNGh (35° 17′)

JNHs (35° 04′)
GNGo (35° 06′)
UL (35° 25′)
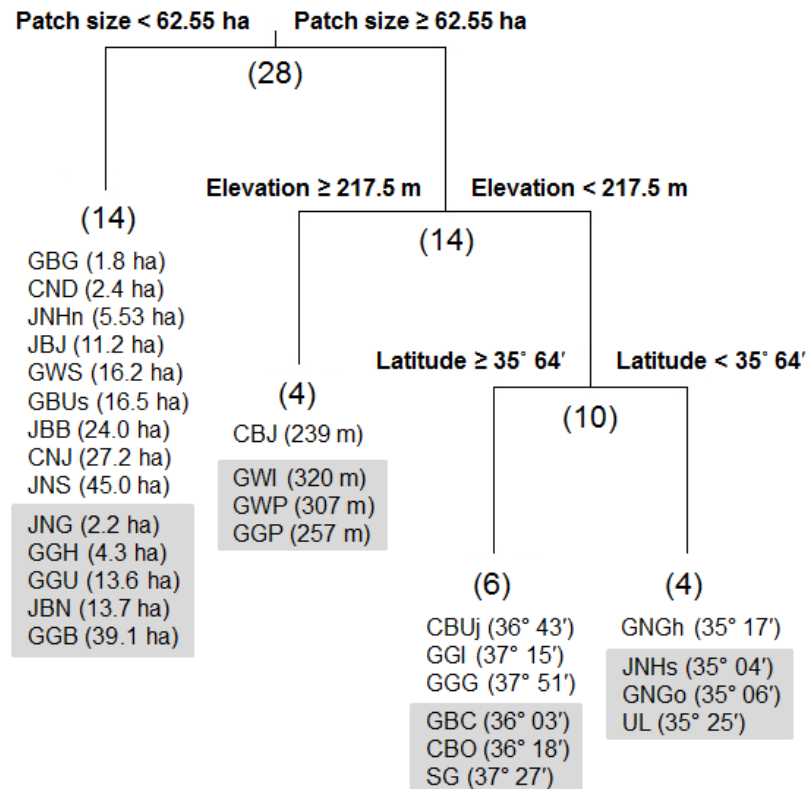
Fig. 4.3. Multivariate regression tree for ground beetle catches in my study of conifer plantations and regenerating forests. Bray-Curtis similarity was used for splitting based on log-transformed data. Numbers of site are shown in parentheses. Site codes (see Fig. 1) are shown under each column plot: shaded site codes indicate regenerating forests, and unshaded codes represent conifer plantations.

4.4. Discussion

My results indicated that ground beetle assemblages, including species richness, abundance, and species composition, were primarily influenced by patch size and elevation, although the rarefaction standardized richness estimates were generally higher in regenerating forests than in conifer plantations. Many studies have reported reduced abundance and species richness of ground beetles in coniferous forests compared to mixed and deciduous forests (Butterfield and Benitez-Malvido, 1992; Butterfield *et al.,* 1995; Fahy and Gormally, 1998; Jukes *et al.,* 2001; Kubota *et al.,* 2001; Yu *et al.,* 2006), although some of these studies (Jukes *et al.,* 2001; Kubota *et al.,* 2001; Yu *et al.,* 2006) compared forest types of different successional phases. On the other hand, other studies (Niemelä *et al.,* 1993; Lee and Lee, 1995; Koivula *et al.,* 2002; Oxbrough *et al.,* 2012) have found greater or equal beetle abundance and species richness in coniferous forests than in natural or mixed forests. These differences among studies may be in part due to different tree species at each study site (Yu *et al.,* 2006). In addition, several environmental variables, such as elevation, geographic location, and habitat complexity (e.g., amount of dead wood, number of tree species, canopy cover, and leaf-litter depth), may also be more important factors affecting the distribution of ground beetles (Koivula *et al.,* 2002; Fuller *et al.,*

2008; Oxbrough *et al.,* 2012).

Differences in ground beetle assemblages between forest types or management regimes have been widely examined but only rarely at national or larger spatial scales (but see Kotze and O'Hara, 2003). Oxbrough *et al.* (2012) showed that species richness and assemblage composition of ground beetles in Ireland were similar in mixed plantations and monocultures of coniferous trees and suggested that several environmental variables, including location, stand structure, vegetation, litter, and soil, may be more important factors than forest type. Although I did not conduct a pairwise comparison, my results also indicate that the species composition of ground beetle assemblages may not necessarily differ between forest types. Unfortunately, my study periods concentrated on late summer and autumn, so I probably missed many spring breeders, such as *Calosoma* spp., while autumn breeders, such as *Synuchus* spp. were abundantly collected in most sampling sites. In particular, *Calosoma* spp., a specialist on lepidopteran larvae, generally inhabit broad-leaved forests and may be underestimated in regenerating forests in my study. Nonetheless, based on my data, I hypothesize that the ground beetle assemblages appear to be similar between regenerating forests and conifer plantations.

Unlike species composition, estimated species richness was higher in regenerating forests than in conifer plantations and was higher in 40–50-year-old forests than in 30-year-old forests. There are some potential factors affecting ground beetle species richness in forests, such as patch size, elevation, and forest age and type. The study sites were different in size and elevation. Regenerating forests were generally larger and located at the higher elevation than conifer plantations. My results indicate that forest patch size and elevation are most important variables in determining species richness and abundance of forest specialists, brachypterous, and large-bodied species, and some abundant species such as *C. jankowskii* (Table 4.2). Forest specialists, brachypterous and/or large-bodied species were generally more frequently collected in 40–50-year-old forests (Appendix S4.1, S4.2), supporting Riley and Browne (2011). For these reasons, higher species richness might be observed in regenerating forests, particularly 40–50-year-old forests. Thus, these differences in environmental characteristics among study sites may mask the relationships between ground beetle assemblage structure, forest type, and forest age. Hence further studies are needed to clarify the effects of patch size, elevation, and forest age and type on ground beetles. These studies should sample throughout the growing season.

In Korea, planted or regenerating forests are generally found throughout the nation, while primary forests are restricted to protected and higher mountainous areas, particularly national parks. Many studies in Korea have reported greater diversity of brachypterous and/or large-bodied ground beetles in deciduous forests in protected mountain forests (Lee and Lee, 1995; Kubota *et al.,* 2001; Jung *et al.,* 2011a, b, 2012a). In my study, large- and medium-sized species, such as *Aulonocarabus* spp., *C. jankowskii*, and *Eucarabus* spp., were frequently collected at sites within larger patches of mountainous area. In contrast, low abundance and species richness of forest specialists were found in small fragments of both coniferous and mixed forests, although some forest specialists, such as *S. cycloderus*, *S. nitidus*, and *Synuchus* sp.1 were still abundant at those sites.

In general, large-bodied species suffer greater declines during environmental change than smaller ones, possibly because of their lower reproductive and dispersal powers (Kotze and O'Hara, 2003). In Korea, urbanization and habitat fragmentation have occurred at a high rate, especially in lowlands, and some ground beetles, such as brachypterous and/or large-bodied species, may not have been able to re-establish viable populations in small forest patches after habitat fragmentation. Koivula and

Vermeulen (2005) explored the effect of roads on ground beetles, and they suggested that the tendency of forest specialists to avoid open habitat makes crossings of paved highway lanes unlikely. Unlike large-bodied species, some small-bodied forest specialists, such as *S. cycloderus*, *S. nitidus*, and *Synuchus* sp.1, were generally dominant and abundant at many sites in my study. That these forest specialists were less influenced by patch size is not surprising (see also Fujita *et al.,* 2008).

Overall, ground beetles in forests can be influenced by patch size and elevation, in addition to forest type and forest age. Therefore, although retaining broadleaved stands in conifer plantations is essential to conserve populations of forest specialists (Fuller *et al.,* 2008), preserving a large extent of forest is more important for biodiversity conservation within a fragmented landscape (Niemelä *et al.,* 2002; Koivula and Vermeulen, 2005; Magura *et al.,* 2010). In addition, there is evidence on the importance of natural old-growth deciduous forest for ground beetles (Yu *et al.,* 2006, 2010; Koivula, 2012).

Acknowledgement

Chapter 5.

Effects of patch size and forest type on ground beetles (Coleoptera: Carabidae) in Korea

Abstract

To identify the major effects of human disturbance on terrestrial ecosystems is a major issue in the contemporary conservation biology. This study was conducted to compare the community structure of ground beetles among different forest patch sizes according to the different forest types, such as deciduous, Korean pine, and Japanese red pine forests. In addition, I examined how different functional groups and species responded to patch size, and habitat and geographical variables. I sampled ground beetles in 9 continuous forests and 18 patches. Ground beetles were collected using 5 pitfall traps in each site, and replaced every month during May to October in 2013. Individual-based rarefaction curves indicated that higher species richness was found in continuous forests than forest patches irrespective of the forest types. Positive relationships were found between forest patch size and species richness of each functional group associated with forest habitat. When all patch size, geographical, and habitat variables were considered simultaneously for multiple regressions, patch size, longitude, latitude, elevation, organic matter and litter depth were generally selected as significant predictor variables of the abundance and species richness of forest specialists, brachypterous, dimorphic, and large-bodied species, but in MRT longitude was only

selected as a best predictor for 27 study sites. In conclusion, decreasing patch size is a major factor to loss of biodiversity for ground beetles, and medium-sized patches irrespective of forest types are needed to better conserve biodiversity than small-sized patches. Therefore, protecting as large as old-growth forests is critical for conserving and enhancing biodiversity.

5.1. Introduction

To identify major effects of the habitat fragmentation, caused by human activities, on terrestrial ecosystems is important to establish habitat management strategy, because habitat fragmentation is an important process to the loss of biodiversity and the species extinction (see Fahrig, 2003). Because smaller fragments contain a higher proportion of edge habitat than larger ones, changes of microclimate and plant community structures in small fragments may reduce the habitat quality in a core area (see Collinge, 2009; Laurance, 2008).

Since Pickett *et al.* (1997) proposed that the land-use gradient could serve as a model system for the study of biotic community responses to human disturbance, the island biogeography theory has been of enormous impacts on conservation biology using ground beetles (Coleoptera: Carabidae) (Halme and Niemelä, 1993; Burke and Goulet, 1998; Alaruikka *et al.,* 2002; Ishitani *et al.,* 2003; Venn *et al.,* 2003; Magura *et al.,* 2004, 2008a, b, c; Deichsel, 2006; Lövei *et al.,* 2006; Elek and Lövei, 2007; Fujita *et al.,* 2008; Gaublomme *et al.,* 2008; Tóthmérész *et al.,* 2011), which respond sensitively to many anthropogenic disturbances and are therefore suitable for environmental monitoring (Rainio and Niemelä, 2003). For ground beetles, it has been reported that overall abundance and species

richness were not negatively affected by patch size in several studies (Alaruikka *et al.,* 2002; Deichsel, 2006; Elek and Lövei, 2007; Fujita *et al.,* 2008), because many open-habitat species may gain dominance in small patches. On the other hand, many studies represented that abundance and species richness of habitat specialists were significantly declined in smaller (Halme and Niemelä, 1993; Alaruikka *et al.,* 2002; Ishitani *et al.,* 2003; Venn *et al.,* 2003; Magura *et al.,* 2004, 2008a, b, c; Lövei *et al.,* 2006; Elek and Lövei, 2007; Fujita *et al.,* 2008; Gaublomme *et al.,* 2008; Tóthmérész *et al.,* 2011) and more isolated patches (Burke and Goulet, 1998; Deichsel, 2006).

In Korea, patch size is also known to be the most important variable to determine community structure of ground beetles (Jung *et al.,* 2014). Although most natural forests in Korea were devastated during the Japanese occupation (1910–1945) and the Korean War (1950–1953), reforestation has been largely successful since then, due to effective large-scale restoration programs (Lee and Miller-Rushing, 2014). However, habitat loss and fragmentation have been accelerated by the rapid expansion of urban areas and road constructions resulting in a substantial loss of biodiversity (Lee and Miller-Rushing, 2014). In addition, forest types, especially in regenerating forests and plantations are generally different

across the geographic location, because forest management strategies in Korea have been differently applied according to plant characteristics and their preferred environment (Lee, 2012). Hence, patch size and forest types should be considered as important habitat components to conserve biodiversity in Korea.

The main objective of my study was to compare the community structure of ground beetles among different patch sizes considering forest types to find if there are differences in beetle diversity with regard to patch sizes. I expected that deciduous patches have a high potential to preserve biodiversity than coniferous forest patches, because in Korea species richness of ground beetles in plantations was generally lower than regenerating forests (Jung *et al.,* 2014). In addition, I examined how different species and functional groups respond to patch size, and habitat and geographical variables.

5.2. Materials and Methods

5.2.1. Study area

To investigate the community structure of ground beetles in central Korea (longitude, 126° 54' 49"–127° 49' 20" E; latitude, 37° 22' 54"–37° 58' 43" N), 27 sites encompassing 9 deciduous forests in Seoul, 3 deciduous and 6 Korean pine forests in Gapyeong, and 3 deciduous and 6 Japanese red pine forests in Chuncheon were selected (Fig. 4.1, Table 4.1). In my study area, deciduous and mixed forests are dominant in the urban landscape of Seoul (47.2% in deciduous and 30.9% in mixed forests), while conifer forests of Japanese red pine (*Pinus densiflora* Sieb. et Zucc.) and Korean pine (*Pinus koraiensis* Sieb. et Zucc.) are dominant in the urban landscape of Gapyeong (48.1%) and Chuncheon (36.1%), respectively (Korea Forest Service, http://forest.go.kr). For these reasons, forest patches in Seoul, Gapyeong, and Chuncheon in my study are generally composed of deciduous, Korean pine, and Japanese red pine, respectively (FGIS, 2013). Although Seoul, Gapyeong, and Chuncheon are rather different in their landscape structures and city sizes, forest patches in the study sites could be categorized by three size classes; continuous forest (> 1000 ha), medium-sized patch (12.8–51.2 ha), and small-sized patch (1.1–9.6 ha)

(Appendix S4.1). Therefore, 27 study sites were categorized as 9 deciduous forests in continuous mountains (hereafter abbreviated to continuous forest), 9 medium patches (3 deciduous, 3 Korean pine, and 3 Japanese red pine forests), and 9 small patches (3 deciduous, 3 Korean pine, and 3 Japanese red pine forests).

Nine continuous forests in Seoul (3 continuous forests), Gapyeong (3 continuous forests), and Chuncheon (3 continuous forests), were regenerating forests, dominated by several deciduous tree species, such as Mongolian oak (*Quercus mongolica* Fisch. ex Ledeb.), Oriental chestnut oak (*Quercus aliena* Bl.), Konara oak (*Quercus serrata* Thunb.), Sawtooth oak (*Quercus acutissima* Carruth.), and Japanese chestnut (*Castanea crenata* S.et Z.). In medium and small patches in Seoul, Mongolian oak was a dominant tree species, but Sargent's cherry (*Prunus sargentii* Rehd.) and Black locust (*Robinia pseudoacacia* L.) were also occasionally found in some patches. Whereas, Korean pine and Japanese red pine were dominant in all forest patches of Gapyeong and Chuncheon.

Mean diameter at breast height (dbh, 1.3 m) of the dominant tree layer ranged between 13.5 and 27.7 cm, and the number of stems ≥ 10 cm in dbh ranged between 23 and 103 per study plot (20 m^2). In some small- and medium-sized patches, urban inhabitants are frequently visited

compared with the continuous forests, and thus more disturbances could

occur in those areas.
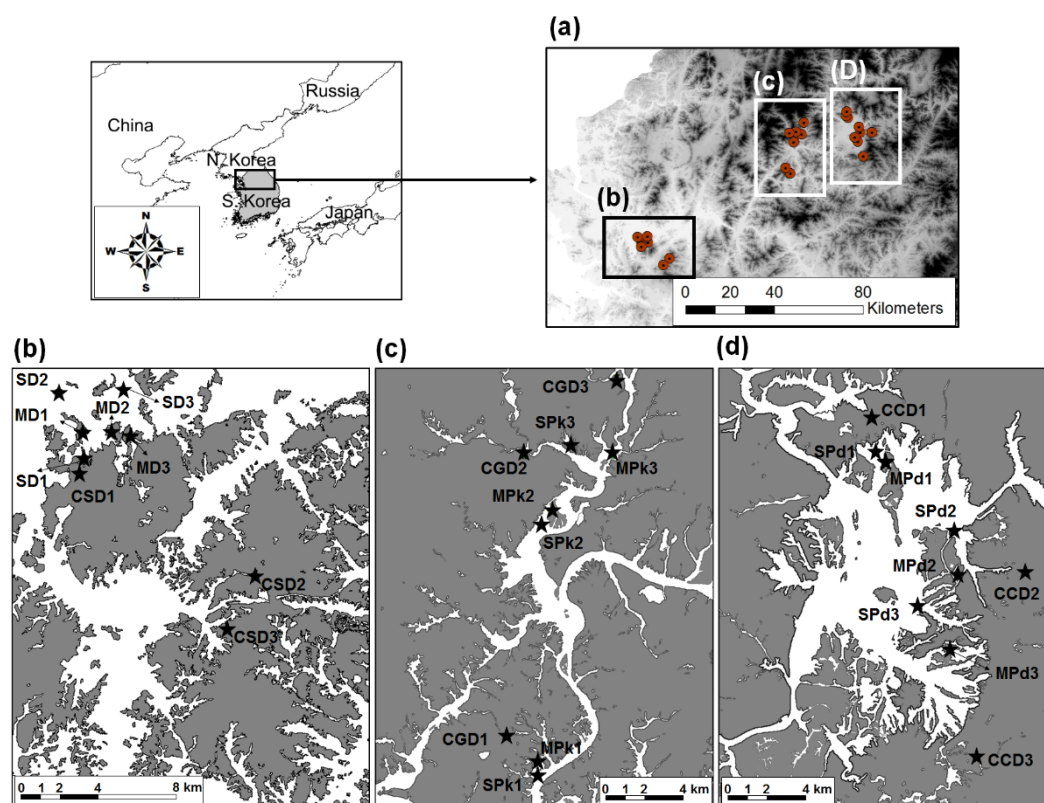
Fig. 5.1. Locations of 27 collection sites in central Korea (a). Nine deciduous forests in Seoul (b) and 3 deciduous and 6 Korean pine forests in in Gapyeong (c), and 3 deciduous and 6 Japanese red pine forests in Chuncheon (d) were selected. Abbreviations of site code and detailed information of study sites are given in Table 5.1. Asterisks indicate location of study site.

Table 5.1. Site description of the 27 study sites.

District	Treatment (patch size, ha)	Site code	Mountain	Forest type	Forest age
Seoul	Continuous forest (>1000)	CSD1	Mt. Gwanaksan	Deciduous	40
		CSD2	Mt. Cheonggyesan	Deciduous	40
		CSD3	Mt. Baekunsan	Deciduous	40
	Medium patch (10< <100)	MD1		Deciduous	40
		MD2		Deciduous	40
		MD3		Deciduous	40
	Small patch (<10)	SD1		Deciduous	40
		SD2		Deciduous	40
		SD3		Deciduous	40
Gapyeong	Continuous forest (>1000)	CGD1	Mt. Homyeongsan	Deciduous	40
		CGD2	Mt. Gunamusan	Deciduous	50
		CGD3	Mt. Sudeoksan	Deciduous	40
	Medium patch (10< <100)	MPk1		Korean pine	50
		MPk2		Korean pine	40
		MPk3		Korean pine	40
	Small patch (<10)	SPk1		Korean pine	50
		SPk2		Korean pine	40
		SPk3		Korean pine	40

Table 4.1. *Continued.*

Chuncheon	Continuous forest (>1000)	CCD1	Mt. Yonghwasan	Deciduous	50
		CCD2	Mt. Suribong	Deciduous	40
		CCD3	Mt. Daeryongsan	Deciduous	40
	Medium patch (10< <100)	MPd1		Japanese red pine	40
		MPd2		Japanese red pine	50
		MPd3		Japanese red pine	40
	Small patch (<10)	SPd1		Japanese red pine	40
		SPd2		Japanese red pine	50
		SPd3		Japanese red pine	40

5.2.2. Sampling

Pitfall trapping is a standard sampling method to compare the abundance or community structure of ground beetles (Niemelä, 1996; Koivula *et al.,* 2003). Five pitfall traps were placed in each study plot (20 m^2); four traps were in the corner and one trap was in the center of the plot. Each study plot was approximately 50–100 m from the nearest forest edge. I used a plastic cup as a pitfall trap (430 mL, 9 cm in diameter, 10 cm deep), and a plastic rain-cover was placed 3 cm above each trap to prevent inflow of rainwater and plant materials into the trap. Traps were filled with preservatives (200 mL, 95 % ethyl-alcohol:95 % ethylene-glycol = 1:1) and replaced every month during middle May to early November in 2013.

Beetles were identified to species level under a dissecting microscope (63×, Olympus SZ61), using available taxonomic literatures (Habu, 1967, 1973, 1978, 1987; Kwon and Lee, 1984; Park and Paik, 2001). I followed nomenclatures to consider current scientific names (Park and Paik, 2001; Park, 2004). Voucher specimens were deposited at the Insect Ecology Laboratory, Entomology Program, Seoul National University, Korea. Habitat type of each species was determined according to Jung *et al.* (2011a, b, 2012a, b, 2014) or followed general characteristics of genus if there were a lack of information on species. All specimens were

dissected to record wing dimorphism. To measure body size, 1–10 individuals (depending on availability) were randomly selected from all samples of each species. Body sizes were measured using a digital caliper (Sanling Group, Ltd., Zhejiang, China; 0.01 mm accuracy). The species were grouped into three classes based on mean size: small (5.0–14.9 mm), medium (15.0–24.9 mm), and large (25.0–40.0 mm) (Jung *et al.,* 2014).

Fourteen environmental variables under three categories (i.e., patch size, geographical, and habitat variables) were measured to explore whether any of these measurements could predict the abundance and species richness of ground beetle assemblages (Appendix S4.1). Patch size in each study site was measured using aerial photographs. In geographical variables, longitude, latitude, and elevation were measured by Global Positioning System (Garmin International Inc., Olathe, Kansas; Garmin GPSMAP 60CSX Portable Navigator). In habitat variables, I measured organic matter (percent of C and N), depth and cover of leaf litter layer, canopy cover, number of trees, soil humidity, and pH in each study plot. To determine forest type, numbers of each tree species were counted and transformed to the percentage value.

3.2.3. Data analysis

I conducted ANOVA to explore the similarity of environmental variables based on log- or arcsine-transformed data among patch size classes in each district. ANOVA was also applied to compare species richness and abundance of ground beetles. Abundance was measured based on the total number of individuals collected in the five traps per each study site, and species richness was measured based on the total number of species in each site. In addition, abundance and species richness of different functional groups were compared using ANOVA test. Tukey's post hoc tests were conducted when ANOVA results were significant ($P < 0.05$)

To compare species richness by patch size with forest type, I estimated a species richness using non-parametric rarefaction curves. This technique is based on random re-sampling of the pool of collected individuals and is used to estimate expected species richness at the lowest sample sizes (Gotelli and Colwell, 2001). Rarefaction curves allow meaningful standardization and comparison of datasets (Gotelli and Colwell, 2001).

Simple linear regression was used to explore the relationship between patch size and species richness in different functional groups of ground beetles. In addition, stepwise multiple linear regression was

conducted to test the relative importance of all independent environmental variables in explaining the abundance and richness of different functional groups. At species level, I further conducted stepwise multiple linear regression analyses for abundant species that were selected based on their abundance (>50 individuals). Data on ground beetle assemblages were transformed by log (N + 1) for normalization.

To summarize and compare species composition among different habitats based on square-root transformed data, a similarity matrix of Bray-Curtis similarity values was created (Clarke and Warwick, 2001). Based on Bray-Curtis similarity, group averaging cluster analysis was performed for determining groups. For cluster analysis, data of ground beetle assemblages were pooled according to the patch size classes. I further analyzed the assemblage-level responses to the eleven environmental variables by subjecting untransformed data to multivariate regression tree analysis (MRT) based on Bray-Curtis similarities between sample sites. I ran the MRT at least 100 times until the lowest crossvalidated relative error (CV error) was found. MRT analyzes community data but makes no assumptions about the form of relationships between species and their environment (De'ath, 2002). MRT identifies groups of sites defined by environmental variables and can potentially

account for non-linearities (De'ath, 2002). Results are usually presented as a tree of dichotomies. Each dichotomy is chosen to minimize the dissimilarity of sample sites within each branch. I did the final tree selection by detecting the tree size (number of 'end' branches) with the lowest CV error followed by the 1-SE rule of Breiman *et al.* (1998). The CV error better estimates the predictive accuracy of the resulting model and it varies from 0 for a perfect predictor of community structure to close to 1 for a poor predictor (De'ath, 2002). Since the original MRT in which all 27 study sites were included suggested that longitude was the only predictor (error = 0.480, CV error = 0.585), I divided all sites into two groups based on longitude (i.e., 9 forests in Seoul and 18 forests in Gapyeong and Chuncheon), and further analyzed MRT to obtain informative results.

The Indicator Value (IndVal) approach was employed in order to find indicator species that characterize the habitats (Dufrêne and Legendre, 1997). The flexible IndVal was independent of other species' relative abundance, and there was no need to use pseudo-species. The IndVal is at maximum (100%) when all individuals of a species are found in a single group of sites and when the species occurs in all sites for that group. Therefore, abundance and occurrence stability indexes for species were determined to be important and were included for analysis. Furthermore, it

114

is possible to assess the statistical significance of the species indicator values using a Monte Carlo permutation test (Legendre and Legendre, 1998; McGeoch and Chown 1998).

Statistical software R version 3.0.2 (R Development Core Team, 2013) was used to compute ANOVA, individual-based rarefaction curves, stepwise multiple regression, cluster analysis, MRT, and IndVal.

5.3. Results

5.3.1. Environmental variables among patch sizes

Patch size was significantly different among patch size classes irrespective of districts (Table 4.2). In Seoul, latitude was significantly different among patch sizes but other variables were not different. In both Gapyeong and Chuncheon, elevation, soil humidity, and pH were significantly higher in continuous forests than conifer patches, but in Gapyeong organic matters (i.e., percent of C and N) were higher only in continuous forests compared to Korean pine patches. Although leaf litter depth and its cover, canopy cover, and number of trees in smaller fragments were similar to those of continuous forests, soil humidity, pH, and organic matters were relatively lower in smaller patches than in continuous forests (Table 5.2, Appendix S4.1). For forest types, percent of deciduous tree species in Seoul was not different among patch size classes, but in Gapyeong and Chuncheon it was significantly higher in continuous forest than small- and medium-sized patches of both Korean pine and Japanese red pine.

116

Table 5.2. ANOVA showing differences in patch size, geographical and habitat variables (log- or arcsine-transformed data) among patch sizes (C, deciduous forest in continuous mountain; M, medium-sized patch; S, small-sized patch). In Seoul, all patches and continuous forests were deciduous forests; in Gapyeong and Chuncheon, continuous forests were deciduous forests, while medium- and small-sized patches of Gapyeong and Chuncheon were Korean pines and Japanese red pines, respectively.

Dependent variables	Statistics in study districts								
	Seoul			Gapyeong			Chuncheon		
	$F_{2,6}$	P	Tukey test	$F_{2,6}$	P	Tukey test	$F_{2,6}$	P	Tukey test
Patch size	157.39	<0.001	S<M<C	190.88	<0.001	S<M<C	46.67	<0.001	S<M<C
Geographical									
Longitude	2.38	0.173		0.14	0.870		0.45	0.657	
Latitude	7.02	0.027	C≤M≤S	0.13	0.884		0.13	0.880	
Elevation	2.33	0.179		10.42	0.011	(S=M)<C	33.43	<0.001	(S=M)<C
Habitat									
Organic matter (C)	2.32	0.179		9.41	0.014	(S=M)<C	0.89	0.457	
Organic matter (N)	1.53	0.291		8.45	0.018	(S=M)<C	2.51	0.161	
Litter depth	2.34	0.177		1.01	0.420		0.26	0.778	
Leaf cover	2.92	0.130		2.94	0.129		2.97	0.127	
Canopy cover	0.28	0.767		2.11	0.202		4.13	0.074	
Soil humidity	1.27	0.346		17.72	0.003	(S=M)<C	10.68	0.011	(S=M)<C
No. of trees	0.09	0.915		0.95	0.439		1.80	0.245	
pH	0.13	0.880		15.88	0.004	(S=M)<C	7.89	0.021	M≤S≤C
D	3.90	0.082		26.30	0.001	(S=M)<C	144.80	<0.001	(S=M)<C
Pk	.	.		11.92	0.008	C<(S=M)	.	.	
Pd	3.64	0.092		3.37	0.105		36.19	<0.001	C<M<S

5.3.2. Species richness and abundance of ground beetles

A total of 50 species were identified from 17,845 ground beetles in 27 study sites. At district level, 25 species were identified from 5,549 ground beetles in Seoul (Appendix S5.2); 31 species were identified from 5,537 beetles in Gapyeong (Appendix S5.3); 37 species were identified from 6,759 beetles in Chuncheon (Appendix S5.4). *Synuchus cycloderus* (Bates) (8,728 individuals, 48.9% of all beetles) was most abundant in study sites, while *Synuchus arcuaticollis* Motschulsky (3,181 individuals, 17.8%) and *Synuchus nitidus* (Motschulsky) (1,808 individuals, 10.1%) were generally abundant in medium- and small-sized patches, respectively.

Individual-based rarefaction curves indicated that higher species richness was generally found in continuous forests and medium-sized patches (Fig. 5.2a). This pattern was more clearly shown when considered forest specialists, and the lowest species richness of forest specialists was found in small-sized patches (Fig. 5.2b). At district level, similar patterns were found in ANOVA test for species richness and abundance of functional groups, especially in forest specialists, brachypterous, dimorphic, and large- and medium-bodied species (Table 5.3).
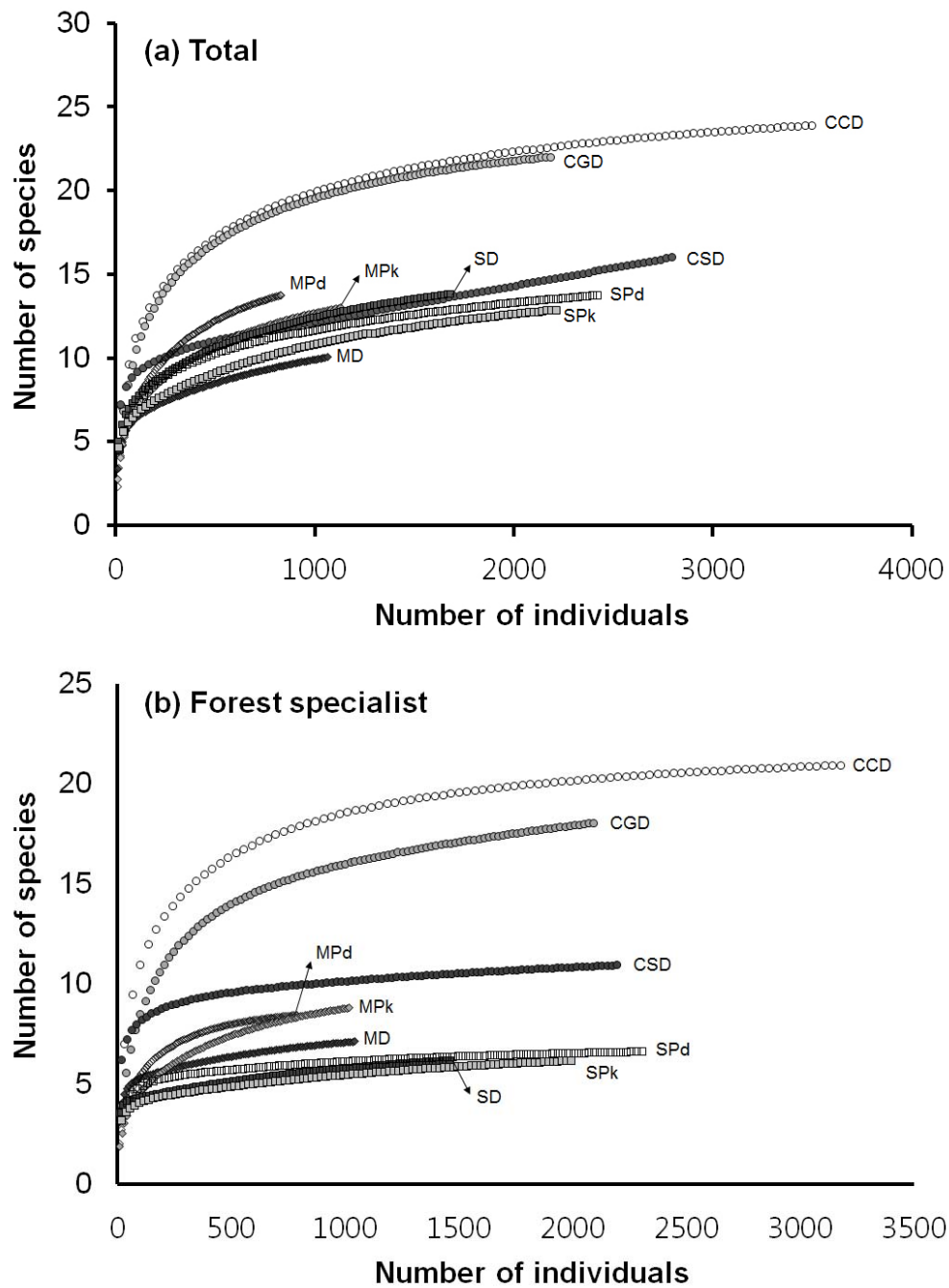
Fig. 5.2. Individual-based rarefaction curves for whole ground beetle assemblages (a) and forest specialist (b). Abbreviations of study sites are given in Table 5.1.

Table 5.3. ANOVA showing differences in abundance and species richness of functional group of ground beetles among patch sizes (C, deciduous forest in continuous mountain; M, medium-sized patch; S, small-sized patch). Data were log-transformed to apply parametric test assumptions.

Dependent variables	Statistics in study districts								
	Seoul			Gapyeong			Chuncheon		
	$F_{2,6}$	P	Tukey test	$F_{2,6}$	P	Tukey test	$F_{2,6}$	P	Tukey test
Abundance									
Total	0.66	0.549		1.52	0.293		8.23	0.019	M≤S≤C
Forest specialist	0.37	0.704		1.40	0.318		7.60	0.023	M≤S≤C
Open-habitat	1.45	0.306		0.55	0.603		8.54	0.018	C≤M≤S
Brachypterous	4.83	0.056		8.34	0.019	(S=M)<C	14.89	0.005	(S=M)<C
Dimorphic	4.13	0.075		99.09	<0.001	(S=M)<C	196.94	<0.001	(S=M)<C
Macropterous	0.03	0.966		1.09	0.394		5.94	0.038	
Lage-bodied	4.29	0.070		21.20	0.002	(S=M)<C	4.31	0.069	
Medium-bodied	1.29	0.342		0.33	0.733		14.31	0.005	(S=M)<C
Small-bodied	0.02	0.977		1.11	0.389		5.95	0.038	C≤M≤S
Species richness									
Total	4.33	0.069		6.03	0.037	M≤S≤C	9.39	0.014	(S=M)<C
Forest specialist	8.85	0.016	(S=M)<C	9.56	0.034	(S=M)<C	19.98	0.002	(S=M)<C
Open-habitat	1.08	0.398		1.14	0.381		3.06	0.121	
Brachypterous	6.42	0.032	S≤M≤C	12.47	0.007	(S=M)<C	21.49	0.002	(S=M)<C
Dimorphic	∞	<0.001	(S=M)<C	∞	<0.001	(S=M)<C	∞	<0.001	(S=M)<C
Macropterous	1.39	0.320		1.60	0.278		3.29	0.109	
Lage-bodied	6.58	0.031	S≤M≤C	9.55	0.014	S≤M≤C	3.23	0.112	
Medium-bodied	0.56	0.597		2.17	0.195		4.53	0.063	
Small-bodied	1.50	0.296		7.14	0.026	M≤S≤C	0.44	0.663	

5.3.3. Response of ground beetles on environmental variables

Most functional groups of ground beetles showed positive relationships between patch size and species richness except for species associated with open-habitat (Fig. 5.3c) and macropterous beetles (Fig. 5.3f). Total species richness showed a positive relationship between patch size explaining 43.9% of the total variation (Fig. 5.3a). Species richness of forest specialists showed a strong positive correlation with patch size explaining 63.4% of the total variation (Fig. 5.3b). Similarly, species richness of brachypterous, dimorphic, large-, and medium-bodied species showed positive correlation with patch size ($r^2 = 0.671$, $r^2 = 0.853$, $r^2 = 0.605$, and $r^2 = 0.177$, respectively) (Fig. 5.3d, e, g, h). Open-habitat and macropterous species showed weak negative correlations with patch size ($r^2 = 0.124$ and $r^2 = 0.232$, respectively) (Fig. 5.3c, f).

When all patch size, geographical, and habitat variables were considered simultaneously in multiple regressions, patch size, longitude, latitude, elevation, organic matters (percent of C and N), and litter depth were generally selected as significant predictor variables that determine the abundance and species richness of some functional groups, especially forest specialists, brachypterous, dimorphic, and large-bodied species (Table 5.4).

121

At the species level, only four large-bodied species (i.e., *Aulonocarabus koreanus koreanus* Reitter, *Coptolabrus jankowskii jankowskii* Oberthur, *Coptolabrus smaragdinus branickii* Taczanowski, and *Eucarabus sternbergi sternbergi* Roeschke) were collected from these continuous forests (Appendix S4.2). However, more species (i.e., *Aulonocarabus seishinensis seishinensis* Lapouge, *Aulonocarabus semiopacus* Reitter, *Leptinocarabus wulffiusi opacipennis* Reitter, *Pterostichus orientalis orientalis* Motschulsky, *Pterostichus vicinus* Park and Kwon, and *Pterostichus woongbii* Park and Kwon) were collected in other continuous forests in Gapyeong (Appendix S5.3) and Chuncheon (Appendix S5.4). And these species were also associated with several geographical (longitude and latitude) and habitat variables (organic matter, leaf cover, pH, and percent of deciduous and Korean pine tree) than patch size (Table 5.5).

For 9 forests in Seoul as the first subgroup, the MRT analysis consistently produced a two-node tree with pH and longitude being the best predictors of ground beetle assemblages, together explaining 69.2% of the variation in the data (Fig. 5.4a). For 18 forests in Gapyeong and Chuncheon as second subgroup, the MRT analysis consistently produced a two-node tree with elevation and patch size being the best predictors of

ground beetle assemblages, together explaining 52.1% of the variation in the data (Fig. 5.4b). The CV error value in the first and second subgroups were 1.440 (SE=0.479) and 0.955 (SE=0.152), respectively, which were relatively higher indicating poor predictive power of the model for my dataset.

Species composition of ground beetles based on square root-transformed data in deciduous forests was generally similar from each other, whereas those in two conifer forest patches were more different compared to deciduous forests (Fig. 5.5a). When incident data was used, however, species composition of ground beetles in continuous forests was more similar than medium- and small-sized patches of all forest types (Fig. 5.5b). At district level, species composition of ground beetles in continuous forests was significantly different compared to medium- and small-sized patches except for S_D1 and M_D1 in Seoul (Appendix S5.5)
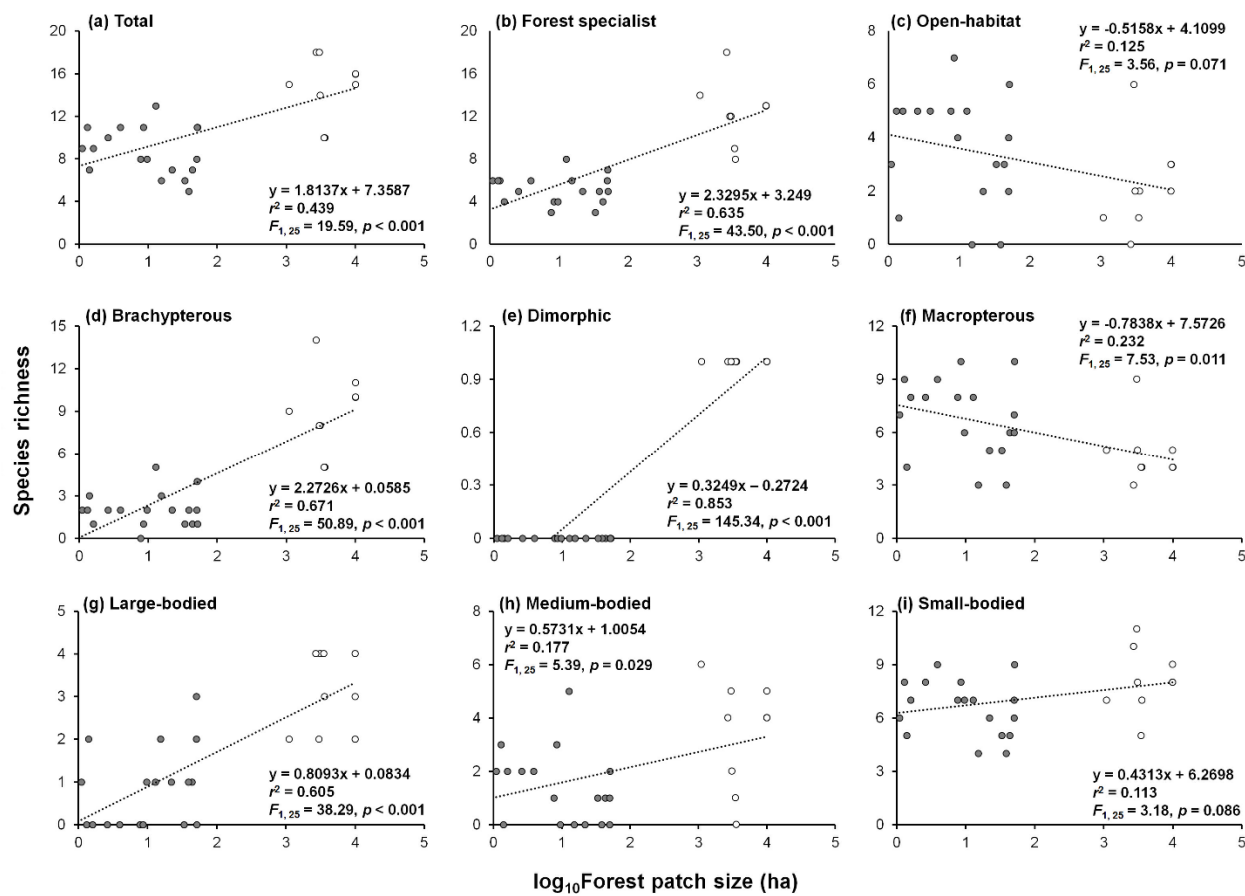
Fig. 5.3. Relationship between forest patch size (log10 ha) and species richness of ground beetle functional groups for 18 forest patches (grey circles) and 9 continuous forest sites (open circles).

Table 5.4. Relationship between ground beetle assemblages (log-transformed abundance and species richness) and selected independent variables (log- or arcsine-transformed data) as determined by stepwise multiple regression.

Dependent variables	Parameter (beta) of independent variables														Statistics		
	Intercept	Longitude	Latitude	Patch size	Elevation	C	N	Leaf litter depth	Leaf cover	Soil humidity	pH	D	Pk	Pd	adj. r^2	$F_{14,\ 12}$	P
Abundance																	
Total															0.055	1.11	0.434
Forest specialists															0.320	1.87	0.141
Open-habitat															0.354	2.02	0.115
Brachypterous	60.98		-146.00		1.39		57.38	2.45							0.574	3.50	0.018
Dimorphic	36.48		83.16	0.11		*-31.38	218.79	0.81	-0.66	*3.28		0.30			0.888	15.72	<0.001
Macropterous															0.038	1.07	0.456
Large bodied	-367.47	400.04	-297.53			43.68	-315.91	*4.05	-2.18	5.33					0.672	4.80	0.005
Medium bodied															-0.057	0.90	0.579
Small bodied															0.227	1.55	0.228
Species richness																	
Total															0.301	1.80	0.157
Forest specialists	-113.49	80.22	-35.11	0.03	0.18	-5.21	45.18	0.40		0.73			-0.11	-0.11	0.784	7.75	<0.001
Open-habitat															-0.360	0.51	0.886
Brachypterous	-187.92	159.47	*-94.97	0.05	0.43		89.52	*0.95				2.20			0.847	11.29	<0.001
Dimorphic	122.82		20.55	**0.06	*0.25	-7.00	45.18	0.26	*-0.32	0.54			0.05	0.07	0.876	14.11	<0.001
Macropterous															-0.065	0.89	0.590
Large bodied	-142.79		-82.05	0.07				*1.10	-0.36						0.573	3.50	0.018
Medium bodied															0.251	1.62	0.203
Small bodied															-0.076	0.87	0.604

Superscript asterisks indicate the significance of a *P* value (* <0.05, ** <0.01). The table includes the parameter (beta, relative importance of the predictor) for each variable in the models as well as the significance level and adj. r^2 for the overall models.

Table 5.5. Relationship between log-transformed number of individuals in 16 abundant species (>50 individuals) and selected independent variables (log- or arcsine-transformed data) as determined by stepwise multiple regression. Species names are marked with 4+4 letter abbreviations, e.g., *Aulonocarabus koreanus* = Aulo kore.

Dependent variables	Parameter (beta) of independent variables															Statistics		
	Intercept	Longitude	Latitude	Patch size	Elevation	C	N	Litter depth	Leaf cover	Canopy cover	Soil humidity	pH	D	Pk	Pd	adj. r^2	$F_{14,\,12}$	P
Aulo kore																0.270	1.69	0.185
Aulo seis	-341.82		90.33		-1.08		181.42	0.96	-0.62	-0.89		5.37	0.47			0.641	4.32	0.008
Aulo semi	***-1428.00	**701.90		-0.17		-17.95			-0.70	1.34	*4.46	**-13.26	*0.88	0.52		0.785	7.77	<0.001
Chla naev																0.436	2.43	0.065
Copt jank	-328.65	283.12	-162.57					***4.92	**-3.13		3.62	-12.58	0.39	0.78		0.761	6.91	<0.001
Copt smar																-0.074	0.87	0.601
Euca ster	757.20	-449.94		0.21	1.80	*-65.54	380.54	1.43				-8.28				0.650	4.45	0.007
Lept wulf	*-537.80	*318.10	-85.86						-85.58		*3.23	3.42	0.22	0.19		0.843	10.99	<0.001
Pher jess																0.288	1.75	0.168
Synu arcu																0.231	1.56	0.224
Synu croc	**-1139.00	**649.70	-145.30	-806.10					-1.12				*0.89	5.92		0.616	3.98	0.011
Synu cycl	-80.96				*1.75			1.35	-1.07			6.62	-0.27			0.618	4.01	0.010
Synu mela	-22.69		54.74	*0.14		-25.54	174.15	0.67	-0.50		*3.14		0.28			0.892	16.36	<0.001
Synu niti																0.021	1.04	0.479
Synu sp.1																0.229	1.55	0.226
Tric lept	278.01	-144.45		0.11			292.57	-0.45		-0.53		4.19	**-0.99	**-0.82	*-0.75	0.753	6.66	0.001

Superscript asterisks indicate the significance of a *P* value (* <0.05, ** <0.01, *** <0.001). The table includes the parameter (beta, relative importance of the predictor) for each variable in the models as well as the significance level and adj. r^2 for the overall models.

(a) Seoul

(9)

pH < 5.15 | pH ≥ 5.15

Longitude < 127 | Longitude ≥ 127

(3)

CSD1
MD1
SD1

(4)

MD2
MD3
SD3
SD2

(2)

CSD2
CSD3

(b) Gapyeong & Chuncheon

(18)

Elevation < 288 | Elevation ≥ 288

Patch size < 6.756 | Patch size ≥ 6.756

(4)

CGD1
CCD1
CCD2
CCD3

(5)

SPk1
SPk2
SPk3
SPd1
SPd3

(9)

CGD2
CGD3
MPk1
MPk2
MPk3
MPd1
MPd2
MPd3
SPd2

Error: 0.308 CV Error: 1.440 SE: 0.479   Error: 0.479 CV Error: 0.955 SE: 0.152
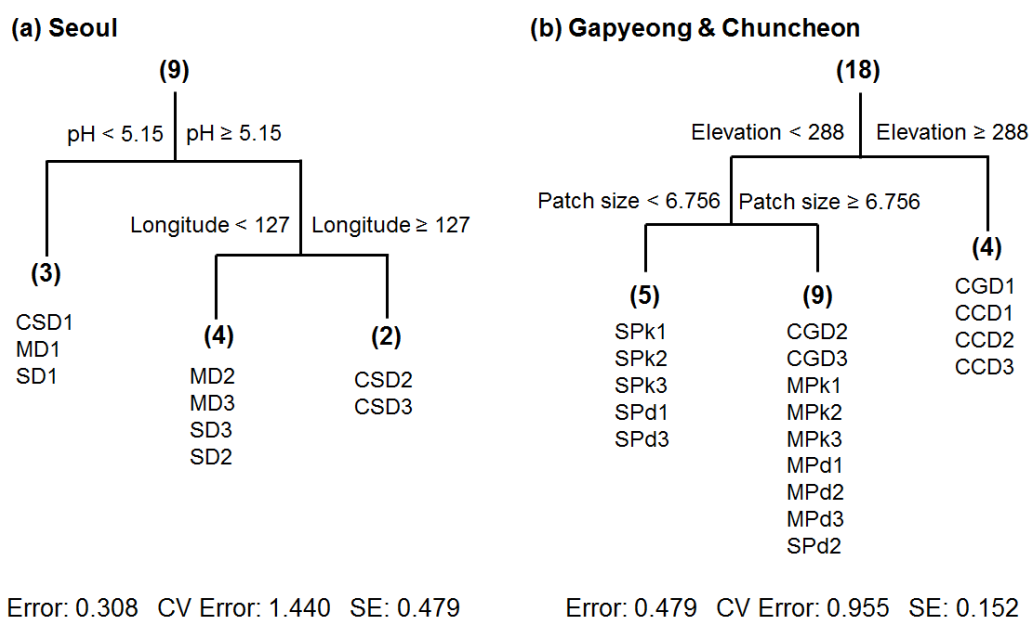
Fig. 5.4. Multivariate regression tree for ground beetle catches collected in 9 forests of Seoul (a) and 18 forests of Gapyeong and Chuncheon (b). Bray-Curtis pair-wise similarity between sites was used for splitting based on un-transformed data. Numbers of site are shown in parentheses and site code of study sites in each district are given in Table 5.1.
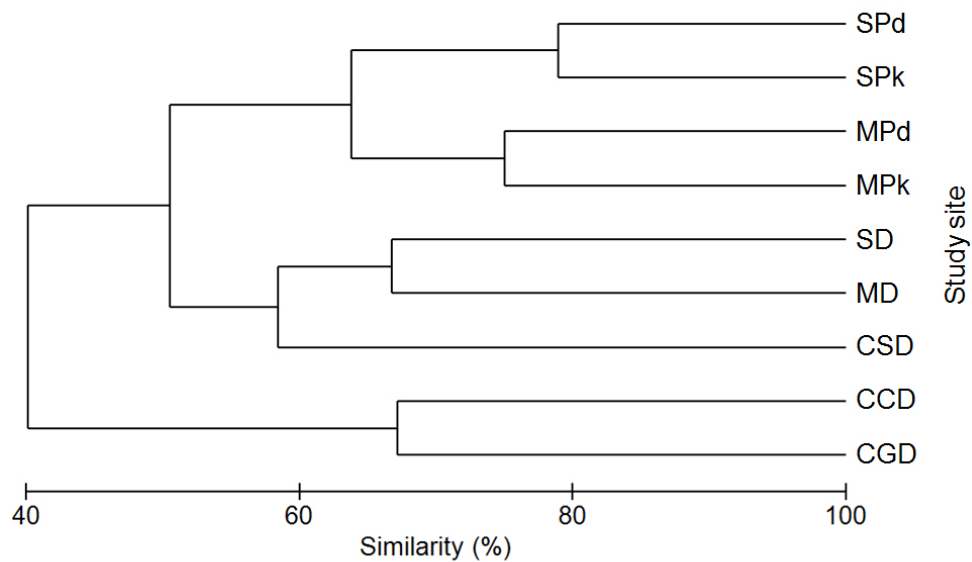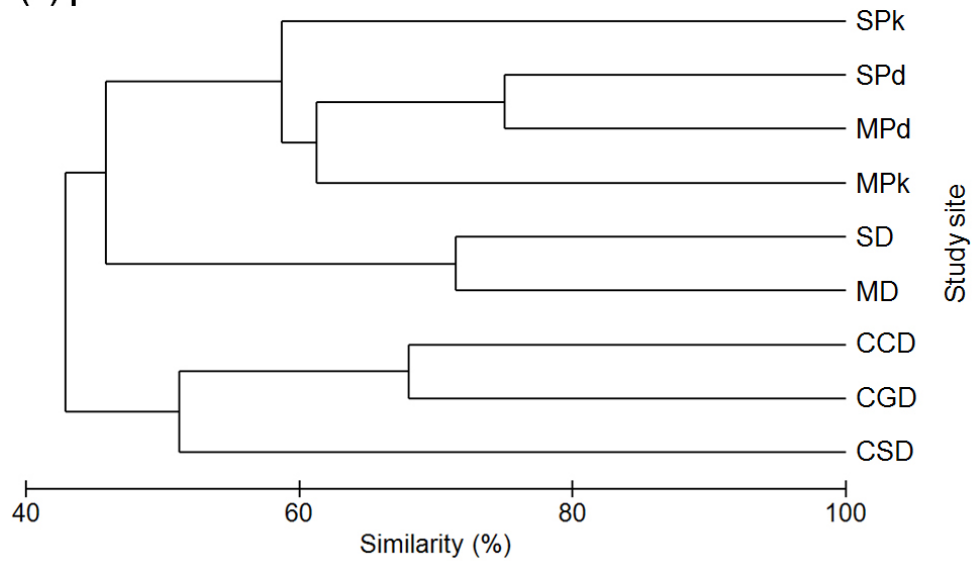
Fig. 5.5. Group averaging cluster analysis using Bray-Curtis similarity based on transformed data of ground beetle assemblages by square root (a) and presence/absence (b). Site codes for study sites are given in Table 5.

5.3.4. Indicator species analysis

Three characteristic groups of ground beetle species were detected by IndVal in terms of patch sizes (Table 5.6): 1) *Synuchus melantho* (Bates)*, E. sternbergi sternbergi, C. jankowskii jankowskii*, and *L. wulffiusi opacipennis* were numerously collected in most continuous deciduous forests; 2) *Chlaenius costiger* Chaudoir was most abundant in the small-sized patches; and 3) *Chlaenius naeviger* Morawitz was most abundant in medium- and small-sized patches.

According to forest types, three characteristic groups of ground beetle species were detected (Table 5.7): 1) *E. sternbergi sternbergi, C. jankowskii jankowskii*, and *S. melantho* were numerously collected in most continuous deciduous forests; 2) *C. smaragdinus branickii, Chlenius micans* (Fabricius), and *Nebria coreica* Solsky were most abundant in the Japanese red pine forest; and 3) *C. naeviger, Chlaenius pictus* Chaudoir*, Nebria chinensis chinensis* Bates, and *Trigonognatha coreana* (Tschitschérine)were most abundant in the Korean pine and Japanese red pine forests.

Table 5.6. Two-way indicator table showing the ground beetle species indicator value for the habitat clustering hierarchy according to the patch sizes, and number of individuals of ground beetle species by patch sizes and their probability in observation.

Patch size classes	Indicator value	P-value	Number of individuals (no. of observation sites / no. of sampling sites)		
			Continuous forest	Medium-sized	Small-sized
Continuous forests					
Synuchus melantho	1.000	0.001	128 (9/9)	0 (0/9)	0 (0/9)
Eucarabus sternbergi sternbergi	0.995	0.001	303 (9/9)	2 (1/9)	1 (1/9)
Coptolabrus jankowskii jankowskii	0.887	0.002	427 (9/9)	36 (4/9)	80 (1/9)
Leptinocarabus wulffiusi opacipennis	0.805	0.001	67 (6/9)	2 (1/9)	0 (0/9)
Pristosia vigil	0.797	0.004	20 (6/9)	1 (1/9)	0 (0/9)
Aulonocarabus seishinensis seishinensis	0.745	0.004	61 (5/9)	0 (0/9)	0 (0/9)
Aulonocarabus koreanus koreanus	0.667	0.034	104 (4/9)	0 (0/9)	0 (0/9)
Dolichus coreicus	0.667	0.023	34 (4/9)	0 (0/9)	0 (0/9)
Trichotichnus sp.1	0.667	0.020	53 (4/9)	0 (0/9)	0 (0/9)
Aulonocarabus semiopacus	0.655	0.028	115 (4/9)	4 (1/9)	0 (0/9)
Pterostichus solskyi	0.650	0.013	19 (4/9)	0 (0/9)	1 (1/9)
Pterostichus woongbii	0.634	0.033	19 (4/9)	2 (1/9)	0 (0/9)
Synuchus crocatus	0.577	0.083	59 (3/9)	0 (0/9)	0 (0/9)
Small-sized patches					
Chlaenius costiger	0.667	0.020	0 (0/9)	0 (0/9)	17 (4/9)
Medium- and small-sized patches					
Chlaenius naeviger	0.877	0.011	36 (3/9)	95 (7/9)	330 (8/9)

Table 5.7. Two-way indicator table showing the ground beetle species indicator value for the habitat clustering hierarchy according to the forest types, and number of individuals of ground beetle species by forest types and their probability in observation.

Forest types	Indicator value	P-value	Number of individuals (no. of observation sites/no. of sampling sites)		
			Deciduous forest	Japanese red pine	Korean pine
Deciduous forest					
Eucarabus sternbergi sternbergi	0.856	0.005	306 (11/15)	0 (0/6)	0 (0/6)
Coptolabrus jankowskii jankowskii	0.847	0.003	538 (11/15)	2 (1/6)	3 (2/6)
Synuchus melantho	0.775	0.005	128 (9/15)	0 (0/6)	0 (0/6)
Japanese red pine patches					
Coptolabrus smaragdinus branickii	0.759	0.030	17 (6/15)	50 (4/6)	1 (1/6)
Chlenius micans	0.632	0.043	0 (0/15)	4 (3/6)	1 (1/6)
Nebria coreica	0.577	0.081	0 (0/15)	7 (2/6)	0 (0/6)
Korean pine & Japanese red pine patches					
Chlaenius naeviger	0.844	0.082	192(7/15)	109 (6/6)	160 (5/6)
Chlaenius pictus	0.803	0.013	2 (2/15)	15 (3/6)	9 (5/6)
Nebria chinensis chinensis	0.633	0.135	2 (2/15)	16 (3/6)	4 (2/6)
Trigonognatha coreana	0.633	0.061	1 (1/15)	7 (3/6)	3 (2/6)

5.4. Discussion

5.4.1. Area effect

Although species composition of ground beetles was different by geographic location according to MRT analysis, change of species richness of many functional groups (e.g., forest specialists, brachypterous, dimorphic, and large-bodied species) showed positive relationships along the increasing patch sizes. In addition, based on rarefaction curves for forest specialists (Fig. 5.2b), medium-sized patches (12.8-51.2 ha) were higher species richness than small-sized patches (<9.6 ha). Similarly, species composition in patch size above 6.756 ha was different than that of smaller patches (Fig. 5.4b). From two different analyses, decreasing patch size is a major factor to loss of biodiversity for ground beetles, and medium-sized patches are needed to better conserve ground beetle assemblages. Nonetheless, species composition in medium-sized patches were still different compared to continuous forests. In fact, many forest specialists (e.g., *Aulonocarabus* spp., *Eucarabus* spp., *Pterostichus* spp., and brachypterous or dimorphic *Synuchus* spp.) were not collected in medium-sized patches generally. Therefore, I can assume that many forest patches located in a human-dominated area in Korea may not have core

habitat to support ground beetle diversity. In fact, many forest specialists may be more vulnerable to habitat disturbances, because brachypterous and large-bodied species associated with forest habitats have lower dispersal capability and reproduction rate in general (Kotze and O'Hara, 2003). In other words, to conserve ground beetles, especially large-bodied and brachypterous species, it may need preservation of larger undisturbed area than I expected (12.8-51.2 ha in my study). However, a minimum forest patch size to conserve biodiversity should be clarified more in further studies, because it may vary depending on geographic location, habitat structure, or stand ages (Lövei *et al.,* 2006).

Unlike forest associated species, species richness and abundance of small-bodied and macropterous species increased in smaller patches. These results similar with several studies (Alaruikka *et al.,* 2002; Deichsel, 2006; Elek and Lövei, 2007; Fujita *et al.,* 2008). However, relationships between patch size and species richness of ground beetles may not be simple. Changes in species composition along patch size are thought to be the result of combinations of changes in environmental variables. For example, a higher proportion of edge habitats can be easily found in smaller fragments than larger ones, and forest biota changes as patch size

decreases because of a combined effect of an increased edge and a reduced core habitat within a fragment (Collinge, 2009; Laurance, 2008).

5.4.2. Effect of forest type

I also tested effect of forest types, such as deciduous, Korean pine, and Japanese red pine forests, on ground beetles. Because Japanese red pine and Korean pine are indigenous trees in Korea and are occupied higher proportion of total forest area since successful reforestation (Korean Forest Service, 2014), it was necessary to consider these conifer forests and young regenerating forests simultaneously. As a result, the species composition of ground beetles in small- and medium-sized patches irrespective of forest types were significantly different compared to the nearest continuous forest, although habitat conditions in terms of leaf litter depth and its cover, and canopy cover were similar between patches and continuous forests (Table 5.3). In fact, differences in species composition of ground beetles between continuous forests and forest fragments were found in many studies (Halme and Niemelä, 1993; Burke and Goulet, 1998; Alaruikka *et al.,* 2002; Ishitani *et al.,* 2003; Venn *et al.,* 2003; Magura *et al.,* 2004, 2008a, b, c; Deichsel, 2006; Lövei *et al.,* 2006; Elek and Lövei, 2007; Fujita *et al.,* 2008; Gaublomme *et al.,* 2008; Tóthmérész *et al.,* 2011). For this reason, protecting as large as old-growth forests is critical for conserving and enhancing biodiversity in boreal (Koivula, 2012) and temperate forests (Yu *et al.,* 2010).

Between patches, I expected that deciduous forest patches have a potential for higher species richness than coniferous forest patches, because species richness of ground beetles in conifer plantations was generally lower than regenerating forests in Korea (Jung *et al.,* 2014) and UK (Fuller *et al.,* 2008). However, there were no differences in species richness of ground beetles among different forest types (Fig. 5.2b). The difference from Jung *et al.* (2014) is probably due to differences of mean patch size between forest types. In Jung *et al.* (2014), mean patch size of conifer plantations (87.07 ha) was smaller than regenerating forests (374.46 ha), which may produce different results. On the other hand, the species composition of ground beetles based on presence/absence data in the deciduous patches showed more similar with conifer patches (i.e., small- and medium-sized patches). This result can be explained by biotic homogenization means that the process by which the genetic, taxonomic or functional similarities of regional biotas increase over time (Ladle and Whittaker, 2011).

At species level, on the other hand, some forest specialists showed interesting distributional patterns. In particular, *C. smaragdinus branickii* is very large species in Korea, which species was mostly collected in Japanese red pine forests (Table 5.7). From this finding and my other

studies (see chapter 3), *C. smaragdinus branickii* has been adapted to Japanese red pine forests, especially surrounded by arable lands or grasslands, rather than deciduous and Korean pine forests. Therefore, Japanese red pine forests may have a priority for the biodiversity conservation, although many other large-bodied species were not collected in conifer forest patches even in deciduous patches.

5.4.3. Effect of environmental variables

In my study, a decreasing habitat quality caused by fragmentation may affect the abundance and species richness of some forest specialists. For example in Seoul, some large-bodied forest specialists (*C. jankowskii jankowskii*, and *Eucarabus sternbergi sternbergi* Roeschke) were collected in some fragments of deciduous forests (i.e., SD1 and MD1 sites), and their species compositions were also more similar to the nearest continuous forest (i.e., CSD1 site). Fragmentation history and lower trampling intensity may be possible reasons to understand higher similarity among these three sites. In fact, SD1 and MD1 sites were fragmented from the nearest continuous forest (i.e., Mt. Gwanaksan) at 1980s (Seoul Metropolitan Government, http://www.seoul.go.kr). In addition, SD1 site is not used as recreation places like urban parks compared to other fragments, which may indicate that there aren't any trampling effect. Although there are no available data for the trampling intensity in my study, the trampling effect on distribution of ground beetles is generally known for Europe and Canada (Kotze *et al.,* 2012). Because a rapid development of urban areas for several decades in Korea resulted in the loss of native habitats, urban inhabitants in those areas have a small proportion of green spaces for their well-being (Korea Forest Service, http://forest.go.kr). For this reason, forest

patches in urban area are generally used as recreational places. Among my study landscapes, Seoul and Chuncheon are a megacity and a medium-sized local city, respectively, but patterns of use of urban forests, especially small patches located in urban centers in my study, are similar as recreational areas. Therefore, there are some possibilities of trampling effect on ground beetle assemblages, especially forest specialists associated with moist forest habitats, in urban forests (see Lehvävirta *et al.,* 2006; Kotze *et al.,* 2012), but further study may be needed to clarify this.

In addition, organic matters in small patches may be another factor to determine species composition of ground beetles. The primary source for the formation of soil organic matters is decaying plant material (Melillo *et al.,* 1989), which is generally less found in small patches (Niemelä *et al.,* 2002). In fact, organic matters in some small-sized deciduous patches were lower than other similar sized patches (Appendix S5.1). This difference may affect the possibility of distribution and colonization of forest specialists associated with forest habitats, which more impacted on large-bodied forest specialists in smaller patches in particular. In fact, ground beetle biomass is related to organic matters, which may support the persistence of large-bodied species (Blake *et al.,* 1994).

5.4.4. Ground beetles at geographic scale

Differences in species distribution at geographical scale are natural, because different organisms interact with various environmental variables that are strongly related to different geographic locations (MacArthur, 1984). Although several environmental variables such as elevation, patch size, pH, and latitude were selected as predictors for ground beetles through MRT analysis (Fig. 5.4), longitude was the only selected predictor for 27 forest sites in my initial analysis. In fact, compared to continuous forests in Gapyeong and Chuncheon, three continuous forests in Seoul showed lower diversity of brachypterous and medium- and large-bodied species as well as forest specialists. These differences may be found from geographical characteristics in Korea. In Korea, there are several mountain ranges, and all continuous forests in Gapyeong and Chuncheon were originated from the Taebaek mountain range. Unlike these continuous forests, continuous forests in Seoul have been disconnected by Han River and human inhabited areas for a long time. Consequently, geographic location may be a fundamental determinant factor affecting the distribution of ground beetle species in central Korea, and this result similar to western Palaearctic regions (Schuldt and Assmann, 2009). Therefore, geographic

location should be considered as an important factor to test effects of patch

size or forest type on biota.

Chapter 6.

Conclusion

6.1. General conclusion

Study of ground beetles has been conducted on a variety of topics for a long time in the world, because they are diverse, ecologically well known, and abundant in most ecosystems. For these reasons, ground beetles have been used as bioindicator groups in the area of the ecology, evolution, and conservation biology. Nonetheless, according to the historical review of this taxon in Korea (see chapter 2), whole insects sometimes including ground beetles were studied not only for the biodiversity study in native reserves (e.g. national parks) but also for the assessment of environmental change. However, monitoring of whole biota is inefficient and difficult in general. Therefore, several issues in the area of ecology and conservation biology using ground beetles were studied in this thesis, and following measures for for biodiversity conservation are suggested: 1) landscape management for biodiversity conservation; 2) forest habitat management for biodiversity conservation.

6.1.1. Landscape management to enhance biodiversity

To examine the edge effect on distributional patterns and community structure of ground beetles, I conducted two different agro-forest landscapes (chapter 3). Ground beetles (species richness and composition) showed different response to the forest edges in two agro-forested landscapes suggesting that ground beetles could respond differently to the forest edge according to the landscape structure. Although forest edges in large forested areas have the potential role of providing temporary refuge and overwintering sites for the dispersal and re-colonization of ground beetles (Magura *et al*., 2001; Molnár *et al*., 2001; Magura, 2002; Yu *et al*., 2007; Roume *et al.,* 2011; Ohwaki *et al.,* 2015), agro-forested landscape combined with short forest history may hinder dispersal and re-colonization of forest specialists (Koivula *et al*., 2004). Therefore, for biodiversity conservation, it is important to retain natural habitats and provide corridors by reducing excessive use of forest edges and surroundings for agro-forested purposes. On the other hand, due to the reduction of natural habitats in agro-forested landscapes, roadside, riverside, and farmland can be used as alternative corridors for biodiversity conservation. In this regard, future research should also be conducted on the dispersal capacity of other taxa in agro-forested landscapes.

6.1.2. Forest habitat management to enhance biodiversity

Forests are species-rich ecosystems supporting various taxa worldwide (Lindenmayer, 1999). In Korea, mountainous forests form the basis of the Korean Peninsula, which are important for conservation and enhancement of biodiversity since the forests cover approximately 64% of the nation. However, several conifer trees and 30–50-year old forests covers approximately 40 % and 82 % of total forest area, respectively (Korea Forest Service, http://forest.go.kr). In Korea, for these reasons, the assessment of biodiversity in young regenerating and conifer forests should be tested to the establishment of strategy on biodiversity conservation.

To investigate the effect of patch sizes on ground beetles, therefore, I selected several forest type, such as young regenerating forests, Japanese red pine, and Korean pine. As a result, retaining forest areas adjacent to agricultural landscapes may be essential to preserve ground beetle assemblages, although geographical distributions of each species in my study are different according to habitat variables depending on geographical location (see chapter 4, 5). In particular, for biodiversity conservation in temperate forest regions at least in Korea, medium-sized patches (i.e., 12.8–51.2 ha in my studies) may have a better conservation

priority than small-sized patches (i.e., <9.6 ha) irrespective of forest types, although those patches still have less potential capacity for the biodiversity of ground beetles compared to continuous forests.

From these findings, forest associated species, especially forest specialist, will be disappeared due to reducing patch size, while forest generalists and open-habitat species (edge preferring and open-habitat specialist) may be take an opportunity to get dominance in small patches (Fig. 7). In particular, of forest specialists large-bodied and brachypterous ground beetle species were more affected by habitat fragmentation than small-bodied and macropterous species. To reduce biodiversity loss caused by habitat fragmentation, therefore, the following measures are recommended: 1) the habitat fragmentation should be minimized, because many environmental variables may be changed in accordance with decrease of patch size, which indicates that core habitat may be simultaneously disappeared from the patch; 2) if there are undisturbed or less disturbed habitat, especially old growth forest, in the forest patch, these habitats should be preserved as core habitat (Koivula, 2012; Yu *et al*., 2010); and 3) increase of habitat quality may help to enhance biodiversity, because various functional groups of beetles are strongly associated with their feeding habits and habitat components (Lassau *et al*., 2005).
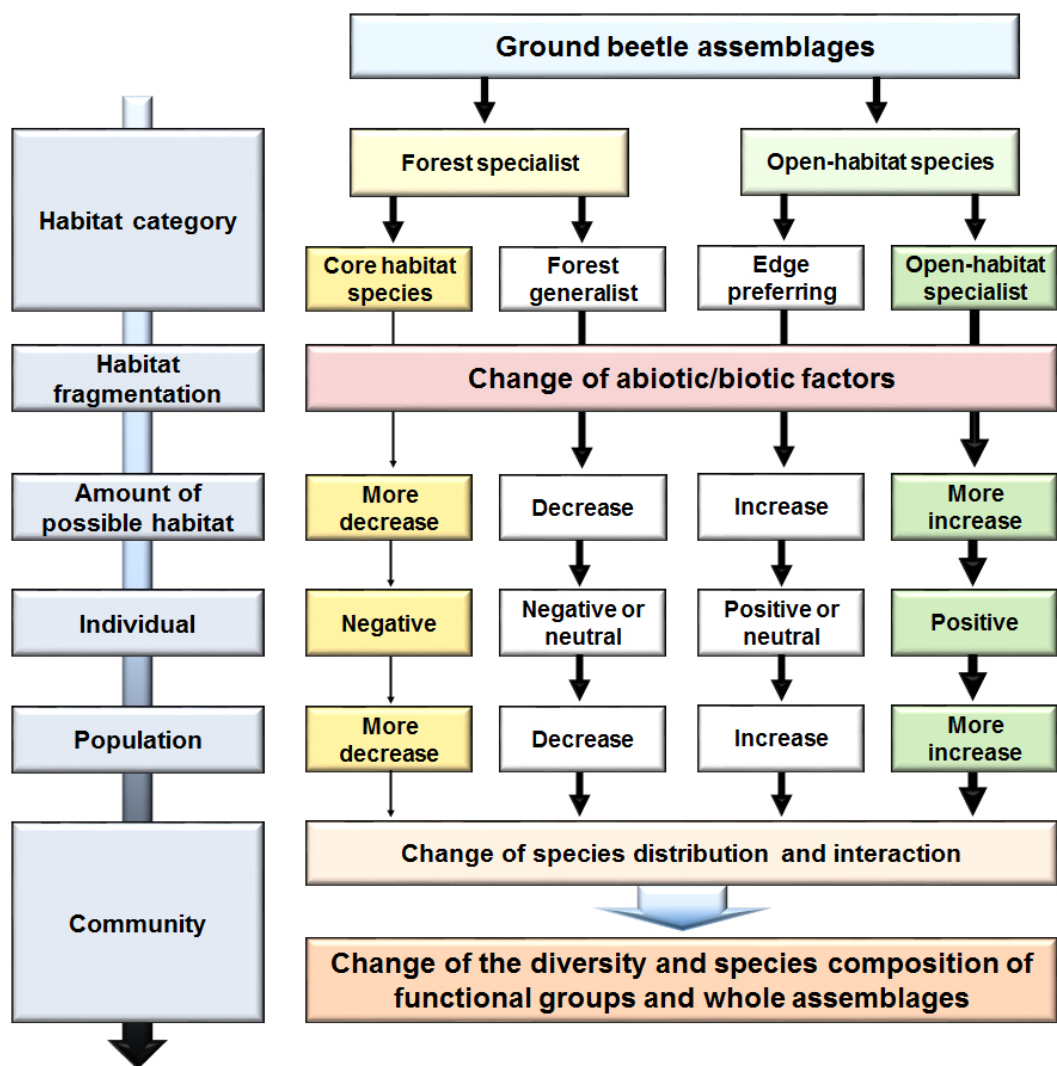
Fig. 6. Response of species expected according to their habitat type about reducing of forest area.

6.2. Further studies

I hope that the result in my thesis would provide a useful information to establish a basis on the conservation biology in Korea, but ground beetles should be cautiously applied for environmental monitoring and conservation biology (Rainio and Niemelä, 2003; Koivula, 2011). Therefore, I suggest several further studies for the development of strategy and framework on the biodiversity conservation using ground beetles as bioindicators.

6.2.1. Indicator value of ground beetles

Although general habitat type of ground beetles is well known for subfamily or genus level, determining a habitat type for many species are still incomplete. For this reason, more studies are needed to investigate the biological and ecological studies for ground beetles in Korea. Taxonomic study to identify ground beetles to the species level is a first step to understand the relationship between species and habitat characteristics. Thereafter, the morphological character (body size and wing morph), functional feeding character (herbivorous, omnivorous and predacious), habitat fidelity (habitat specialist and generalist) in each species should be

150

examined. A series of these processes may allow to acquire valuable ecological data for the functional analysis, which may help to understand of the ecological process. But assessment of indicator capability of ground beetles about other taxa, rare and threatened species and environmental conditions may be an essential prerequisite (Koivula, 2011).

6.2.2. Response of ground beetles on environmental changes

For forest management, edge effect along a deciduous forest–conifer plantation transect should be examined, because conifer plantations, occupied a large extent of forest in Korea, may have a different role of the enhancing biodiversity. Effect of landscape heterogeneity on forest biota is another approach to evaluating the human impact on biodiversity. For example Vanbergen *et al.* (2005) studied ground beetle assemblages along a gradient of land-use composed of six 1 km^2 quadrats with an increasing proportion of agricultural land reflecting fragmentation intensity. Evaluation of efficiency of the habitat corridors between habitat and other habitat will also provide a meaningful information for landscape management, which can promote the biodiversity in both habitats (see Collinge, 1998). At species level, the spatial distribution models of rare and threatened species through detailed grid-type sampling may help to decide specific habitat

preservation (e.g., Matern *et al.*, 2007; Müller and Brandl, 2009; Work *et al.*, 2011).

6.2.3. Development of sampling protocols

To assess indicator capacity of ground beetles, the framework of sampling protocols for ground beetles should be established in priori. In fact, I tried to develop the sampling protocols collecting coleopterans (Jeong *et al*., 2005) and ground beetles in terms of trap placement, trap types, and trap exposure time (unpublished data). However, there are still some difficult problems to investigate ground beetles in Korea as follows: 1) Previous developed sampling methods to collect ground beetles should be tested in other natural reserves. For example, further studies should test variety trap arrangements in larger preserved area such as the Seolaksan National park and the Jirisan National park and determine the efficient sampling methods considering the environmental characteristics in a study area; 2) Because pitfall trapping is most attractive sampling method to study ground dwelling arthropods including ground beetles, standardization of the sampling method (e.g., number of sites and traps, sampling period, and trap size and type) collecting ground beetles for further comprehensive statistical analysis is needed. In addition, biodiversity monitoring will

provide more accurate information for the assessment of habitat quality if the monitoring program includes not only ground beetles but also many other ground-dwelling arthropods, such as spiders, ants, and staphylinids.

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Appendices

Appendix S2.1. List of papers for community ecology using insects, coleopterans, ground beetles in Korea.

Reference	Taxa [a]	Environment				Study subject [b]				
		Forest	Urban and rural landscape	Island	Wetland	Fauna	Diversity	Estimated species richness	Species compostion	Ecological trait
Paik (1988)	Carabidae			◎		◎				
Kim and Lee (1992)	Carabidae	◎					◎			
Paik and Kwon (1993)	Carabidae			◎		◎				
Yahiro (1995)	Carabidae			◎		◎				
Kim and Choi (1995)	Insecta	◎					◎			
Lee and Lee (1995)	Carabidae	◎					◎			
Kwon (1996)	Carabidae	◎					◎		◎	
Kwon and Byun (1996)	Insecta	◎				◎				
Park et al. (1996)	Carabidae	◎					◎			
Paik (1997)	Carabidae			◎		◎				
Paik (1997)	Carabidae			◎		◎				
Nam (1997)	Insecta	◎				◎				
Park et al. (1997)	Carabidae	◎					◎			
Lee et al. (1998)	Insecta	◎				◎				
Chang and Kim (2000)	Carabidae	◎					◎		◎	
Kim and Kim (2000)	Coleoptera	◎					◎			
Park and An (2000)	Coleoptera	◎					◎			

Appendix S2.1. *Continued.*

Kubota et al. (2001)	Carabidae	◎					◎		◎	
Do and Moon (2002)	Carabidae				◎		◎			
Choi and Moon (2002)	Insecta	◎					◎			
Do et al. (2002)	Insecta	◎					◎			
Paik and Jung (2003)	Carabidae			◎		◎				
Park et al. (2003)	Carabidae	◎					◎			
Choi et al. (2004)	Insecta		◎				◎			
Paik and Jung (2004)	Carabidae			◎		◎				
Kwon and Park (2005)	Coleoptera	◎					◎			
Yeon et al. (2005)	Carabidae	◎					◎			
Lee et al. (2005)	Coleoptera	◎					◎			
Jeong et al. (2005)	Coleoptera	◎					◎		◎	
Do et al. (2007)	Carabidae				◎		◎		◎	
Do et al. (2007)	Carabidae				◎		◎		◎	
Jeon et al. (2008)	Carabidae			◎			◎		◎	
Kang et al. (2009)	Carabidae		◎				◎		◎	
Park (2010)	Insecta		◎			◎				
Lee et al. (2010)	Carabidae	◎					◎			
Kwon et al. (2010)	Insecta	◎					◎		◎	
Do et al. (2011)	Carabidae		◎				◎		◎	
Jung et al. (2011)	Carabidae	◎					◎			

174

Appendix S2.1. *Continued.*

Jung et al. (2011)	Carabidae	◎					◎		◎	
Kwon et al. (2011)	Coleoptera	◎					◎		◎	◎
Lee (2011)	Coleoptera	◎					◎			
Park and Park (2011)	Insecta	◎				◎				
Park and Park (2011)	Insecta	◎				◎				
Do et al. (2012)	Carabidae		◎					◎	◎	
Do et al. (2012)	Carabidae		◎				◎	◎	◎	
Jung et al. (2012)	Carabidae		◎				◎		◎	◎
Lim et al. (2012)	Insecta			◎		◎				
Oh et al. (2012)	Insecta			◎		◎				
Do et al. (2012)	Carabidae				◎	◎		◎		
Ahn and Park (2012)	Insecta				◎		◎		◎	
Hong et al. (2012)	Insecta	◎				◎				
Jung and Oh (2012)	Insecta	◎				◎				
Lee et al. (2012)	Insecta	◎					◎		◎	
Jung et al. (2012)	Carabidae	◎					◎	◎	◎	
Lim et al. (2013)	Insecta			◎		◎				
Oh et al. (2013)	Coleoptera			◎		◎				
Kang et al. (2013)	Carabidae	◎					◎			
Lee and Kwon (2013)	Insecta	◎					◎	◎	◎	◎
Jung et al. (2013)	Carabidae	◎					◎		◎	
Do et al. (2014a)	Carabidae		◎				◎		◎	◎

Appendix S2.1. *Continued.*

Do et al. (2014b)	Carabidae		◎				◎	◎	◎	◎
Jeon et al. (2014)	Insecta	◎				◎				
Lee et al. (2014)	Coleoptera	◎					◎	◎	◎	◎
Park et al. (2014)	Insecta			◎		◎				
Jung et al. (2014)	Carabidae	◎					◎	◎	◎	◎
Jung et al. (2015)	Carabidae	◎					◎	◎	◎	

[a] For taxa, researchers studied Insecta or Coleoptera including Carabidae.
[b] In fauna studies, there were species list in papers only. Diversity studies were consisted of several diversity indices (e.g., species richness, Shannon's diversity, Evenness, and Simpson's diversity). For understanding of species composition between study sites multivariate analyses (e.g., cluster analysis and ordination) were conducted. In estimated species richness, some estimation tools were used to compare biodiversity between study sites, such as rarefaction curves and Chao. Finally, ecological trait analysis was conducted to illustrate ecological patterns clearly.

Appendix S3.1. List of ground beetles at 14 forest fragments in Hwaseong, Korea.

Trap location	Species	Ecological groups			Study sites (surrounding of study sites[d])													
		Habitat type[a]	wing morph[b]	feeding habit[c]	M1 (L)	M2 (L)	M3 (A)	M4 (L)	M5 (L)	M6 (A)	M7 (L)	P1 (T)	P2 (T)	P3 (A)	P4 (T)	P5 (A)	P6 (A)	P7 (T)
Interior	*Chlaenius biomaculatus*	O	M	C				1										
	Chlaenius costiger	O	M	C							1					1		
	Chlaenius naeviger	E	M	C				36	3	26	81		8	22		2	1	34
	Chlaenius pictus	O	M	C													1	
	Chlaenius variicornis	O	M	C					1					1				
	Coptolabrus smaragdinus branickii	F	B	C	2						1		1					4
	Cosmodiscus platynotus	F	M	C					1									
	Cymindis daimio	O	D	C			2											
	Harpalus discrepans	O	M	O												2		
	Harpalus tridens	O	M	O						1							1	
	Nebria chinensis	O	M	C									1					
	Nebria coreica	O	M	C						1								
	Oxycentrus argutoroides	O	M	C						1								
	Poecilus nitidicollis	O	M	C												2		
	Synuchus arcuaticollis	F	M	C	12	2	54	6	36	32		42	26	6	186	184	69	68
	Synuchus cycloderus	F	M	C	26		24	3	127	26	21	6	54	6	36	44	84	25
	Synuchus nitidus	F	M	C	46	22	44	19	32	53	23	32	33	16	40	99	40	49
	Synuchus orbicollis	F	B	C	18		110		2								2	1

Appendix S3.1. *Continued.*

Habitat	Species																	
Edge	*Chlaenius biomaculatus*	O	M	C					15		8				1				
	Chlaenius costiger	O	M	C							1		2						
	Chlaenius naeviger	E	M	C				83	64	22	76				21	18	4	33
	Chlaenius variicornis	O	M	C							1								
	Coptolabrus smaragdinus branickii	F	B	C			2				8		5				1	9
	Cosmodiscus platynotus	F	M	C					1		1								
	Cymindis daimio	O	D	C			2	1											
	Dolichus halensis	O	M	C					1	1									
	Harpalus discrepans	O	M	O					1	1									
	Harpalus eous	O	M	O							1								
	Oxycentrus argutoroides	O	M	C					1		1								
	Synuchus arcuaticollis	F	M	C	4	20	26	3	30	50	1	16	48	5		211	2	7
	Synuchus cycloderus	F	M	C	22	16		11	177	15	33	2	30	4	6	58	29	5
	Synuchus nitidus	F	M	C	120	162	12	162	102	115	13	22	42	9	24	150	15	13
	Synuchus orbicollis	F	B	C	4		24	1			1							
Surrounding	*Amara congrua*	O	M	O					1	1								
	Amara simplicidens	O	M	O	2													
	Anisodactylus punctatipennis	O	M	O					3									
	Anisodactylus signatus	O	M	O					7					1				
	Chlaenius biomaculatus	O	M	C		2			12	2	4			2		2	1	
	Chlaenius costiger	O	M	C		2			2	1	3					5		
	Chlaenius inops	O	M	C		2												

Appendix S3.1. *Continued.*

Species																	
Chlaenius micans	O	M	C	4	58			40								1	
Chlaenius naeviger	E	M	C	4		10	3	14	14	3		2	9	16	46	30	27
Chlaenius pallipes	O	M	C				2	2	3								
Chlaenius pictus	O	M	C	2			2										
Chlaenius prostenus	O	M	C		62												
Chlaenius variicornis	O	M	C		4		1	6		1						19	
Coptolabrus smaragdinus branickii	F	B	C	4	4			8	1	5			10			5	10
Curtonotus giganteus	O	M	O	2													
Cymindis daimio	O	D	C								1					1	
Dolichus halensis	O	M	C	16	20	6	12	20	11	23	10	4	16	10	6	11	7
Harpalus chalcentus	O	M	O													1	
Harpalus eous	O	M	O			2		1	1	1	23	2	2			11	
Harpalus jureceki	O	M	O						1	1							
Harpalus niigatanus	O	M	O			6			2							3	
Harpalus sinicus	O	M	O	2	16	10											
Harpalus tinctulus	O	M	O						1								
Harpalus tridens	O	M	O	6	4	14	5	5	2	3	4	1	3	2	2	10	4
Harpalus sp.1	O	M	O						1								
Harpalus sp.2	O	M	O								1						
Lachnocrepis prolixus	O	M	C			2											
Lachnolebia cribricollis	O	M	C				1	1									

Appendix S3.1. *Continued.*

	a	b	c														
Nebria chinensis	O	M	C	2	4				1								
Nebria coreica	O	M	C	12								1					
Patrobus flavipes	O	M	C	30		2											
Pheropsophus javanus	O	M	C			4						2	2				
Pheropsophus jessoensis	O	M	C					1									
Pterostichus microcephalus	O	M	C											1			
Oxycentrus argutoroides	O	M	C					1									
Synuchus arcuaticollis	F	M	C				1			3					4		2	1
Synuchus nitidus	F	M	C					2								4	7	6
Synuchus orbicollis	F	B	C	18								2	10				

[a] Habitat type: E, edge preferring species; F, forest species; O, open-habitat species

[b] Wing morph: M, macropterous; B, brachypterous; D, dimorphic

[c] Feeding habit: O, omnivorous; C, Carnivorous

[d] Surrounding of study sites: L, levee in rice fields; A, arable land; T, turf in cemetery area

Appendix S3.2. List of ground beetles at 8 transects in Hoengseong, Korea.

Trap location	Species	Ecological guilds			Study sites (surrounding of study sites[d])							
		Habitat type[a]	wing morph[b]	feeding habit[c]	PF1 (A, R)	PF2 (A, R)	PQF1 (A, R)	PQF2 (A, R)	LQF1 (N, A)	LQF2 (N, L)	QF1 (A, L)	QF2 (N, L)
Interior	*Amara congrua*	O	M	O			1					
	Calosoma cyanescens	F	M	C	1		4	10	3	3	7	23
	Calosoma maximowiczi	F	M	C				2			8	5
	Chlaenius naeviger	E	M	C	1	47	1	1	12	19	15	
	Chlaenius pictus	O	M	C						2		
	Chlaenius variicornis	O	M	C								1
	Coptolabrus jankowskii jankowskii	F	B	C	11	2	8	2	8	1	31	
	Coptolabrus smaragdinus branickii	F	B	C	4	9	7	8	23	14	7	6
	Cymindis daimio	O	D	C				1				
	Elaphrus sp.1	O	M				1					
	Harpalus discrepans	O	M	O					1	1	1	1
	Harpalus tridens	O	M	O								1
	Lioptera erotyloides	F	M		1							
	Nebria chinensis	O	M	C	1							
	Perigona nigriceps	O	M	C		1						
	Pheropsophus jessoensis	O	M	C			19	26				
	Planetes puncticeps	F	M	C	1			1				
	Synuchus arcuaticcollis	F	M	C	46		15	34	14	21	5	40
	Synuchus cycloderus	F	M	C	73	29	78	27	123	73	13	147

Appendix S3.2. *Continued.*

	Synuchus nitidus	F	M	C	21	19	42	54	207	92	52	568
	Trigonognatha coreana	F	M	C							3	
Edge	*Calosoma cyanescens*	F	M	C			18	17			11	2
	Calosoma maximowiczi	F	M	C			4	4			3	2
	Chlaenius naeviger	E	M	C	5	7	1	21	43	16	20	2
	Chlaenius variicornis	O	M	C					2			
	Coptolabrus jankowskii jankowskii	F	B	C	6	1	2	2	4	1	19	
	Coptolabrus smaragdinus branickii	F	B	C	1	1	1	2	7	7	6	6
	Curtonotus giganteus	O	M	O	1					1		
	Cymindis daimio	O	D	C			1		1			
	Dolichus halensis	O	M	C		5			1	1	1	
	Galerita orientalis	F	M	C					1			
	Harpalus corporosus	O	M	O		1						
	Harpalus discrepans	O	M	O					1		1	1
	Harpalus niigatanus	O	M	O		16			6	3		
	Harpalus sinicus	O	M	O					3		1	
	Harpalus tridens	O	M	O						2	2	
	Nebria chinensis	O	M	C					1			
	Nebria coreica	O	M	C						2		
	Pheropsophus javanus	O	M	C				1				
	Pheropsophus jessoensis	O	M	C	1			14	76			
	Pterostichus microcephalus	O	M	C					1			

Appendix S3.2. *Continued.*

	Species											
	Pterostichus solskyi	F	B	C					1			
	Synuchus arcuaticcollis	F	M	C	3	1	1	4	5	1		5
	Synuchus cycloderus	F	M	C	17	8	3	3	75	4	17	5
	Synuchus nitidus	F	M	C	4	8	5	10	131	7	45	56
	Trigonognatha coreana	F	M	C							1	
Surrounding	*Amara congrua*	O	M	O				1	1	2	1	3
	Amara simplicidens	O	M	O	1			1		1		
	Anisodactylus punctatipennis	O	M	O				102	1			2
	Leptinocarabus wulffiusi opacipennis	F	B	C	1							
	Calosoma cyanescens	F	M	C								1
	Chlaenius costiger	O	M	C			1		1			
	Chlaenius micans	O	M	C		1		5				
	Chlaenius naeviger	E	M	C	16	2	21	11	101	1	4	6
	Chlaenius pallipes	O	M	C					1			
	Chlaenius pictus	O	M	C			1			4		
	Chlaenius variicornis	O	M	C	1				29	1		
	Coptolabrus jankowskii	F	B	C			1	1	2		4	
	Coptolabrus smaragdinus	F	B	C				1	3	1		3
	Curtonotus giganteus	O	M	O		2	4		3			
	Curtonotus hiogoensis	O	M	O					1			
	Curtonotus macronotus	O	M	O							1	1
	Demetrias marginicollis	O	M	C	1							

Appendix S3.2. *Continued.*

Species											
Dicranoncus femoralis	O	M	C		2						
Diplocheila zeelandica	O	M	C		1				2		
Dolichus halensis	O	M	C	3	13	1	24	29	11		10
Harpalus bungii	O	M	O	1							
Harpalus chalcentus	O	M	O						1		4
Harpalus discrepans	O	M	O		1		11		1		1
Harpalus eous	O	M	O		1				2		
Harpalus griseus	O	M	O					1			
Harpalus niigatanus	O	M	O		19		7		7	1	2
Harpalus sinicus	O	M	O		7		6	2	30	8	3
Harpalus sp.1	O	M	O	1		1	1		1		1
Harpalus tinctulus	O	M	O			1	1				2
Harpalus tridens	O	M	O	3		2	1	58	1	22	
Harpalus tsushimanus	O	M	O						1		1
Harpalus vicarius	O	M	O					5			
Hemicarabus tuberculosus	O	B	C	1							
Lachnocrepis prolixus	O	M	C							1	
Lesticus magnus	O	M	C	1							2
Nebria chinensis	O	M	C	1		1			1	2	
Nebria coreica	O	M	C								1
Odacantha aegrota	O	M	C	1	1						

Appendix S3.2. *Continued.*

Species	a	b	c							
Partobus flavipes	O	M	C					1		
Pentagonica daimiella	O	M	C				1			
Pheropsophus javanus	O	M	C			1		1		
Pheropsophus jessoensis	O	M	C			19	4	11	1	
Planetes puncticeps	F	M	C	1						
Platymetopus flavilabris	O	M	O							1
Poecilus coerulescens	O	M	C					1		
Pterostichus microcephalus	O	M	C			1	1			
Pterostichus sp.1		M						1		
Scarites terricola	O	M	C					1		
Synuchus arcuaticcollis	F	M	C	4	3		6	21		1
Synuchus cycloderus	F	M	C							1
Synuchus nitidus	F	M	C			1	1	2		1
Tachyura gradata	O	M	C					2		

[a] Habitat type: E, edge preferring species; F, forest species; O, open-habitat species

[b] Wing morph: M, macropterous; B, brachypterous; D, dimorphic

[c] Feeding habit: O, omnivorous; C, Carnivorous

[d] Surrounding of study sites: L, levee in rice fields; A, arable land; T, turf in cemetery area

Appendix S4.1. List of ground beetles with number of individuals caught per site per species in 14 coniferous forests.

Subfamily	Species	Mean body size (mm)	Body size class [a]	Habitat types [b]	Wing morph [c]	Locations in three forest age													
						30 years				40 years					50 years				
						GGG	GWS	JNHn	GBUs	GGI	CND	CNJ	JNS	GBG	CBJ	JBB	JBJ	GBUj	GNGh
Carabinae	*Aulonocarabus koreanus*	28.6	L	F	Br					4									
	Coptolabrus jankowskii	35.1	L	F	Br											3			1
	Coptolabrus smaragdinus	36.6	L	F	Br					1			3	1		3		1	17
Nebriinae	*Nebria chinensis*	14.5	S	O	Ma					1					4		1		
Pterostichinae	*Pterostichus microcephalus*	9.9	S	O	Ma									1					
	Synuchus cycloderus	13.1	S	F	Ma	39	14	4		18		24	3	1	7		56	3	1
	Synuchus nitidus	14.8	S	F	Ma	10	30		25	123	7	14		3	7		8	104	16
	Synuchus sp.1	9.6	S	F	Ma	34		6	8	186	4	18	4	6		130	16	6	
	Trigonognatha coreana	19.4	M	F	Ma					1									
Harpalinae	*Harpalus roninus*	15.9	M	O	Ma						1								
	Harpalus tridens	11.6	S	O	Ma				1		3	3		1			1		4
Zabrinae	*Amara simplicidens*	8.1	S	O	Ma	1													
	Curtonotus giganteus	18.8	M	O	Ma														1
	Curtonotus macronotus	11.8	M	O	Ma									1					
Callistinae	*Chlaenius costiger*	23.6	M	O	Ma					1								1	
	Chlaenius naeviger	14.0	S	O	Ma				3	3	1	7							
	Chlaenius pictus	14.1	S	O	Ma					1						1			

Licininae	*Diplocheila zeelandica*	20.5	M	O	Ma			1	
Lebiinae	*Planets puncticeps*	12.1	S	F	Ma	1	2		1
	Cymindis daimio	8.7	S	F	Ma	1			
Brachininae	*Pheropsophus jessoensis*	15.5	M	O	Ma		1		

Abbreviation of locations are: GGG, Gapyeong-gun; GGI, Icheon-si; GWS, Samcheok-si; CBJ, Jecheon-si; CND, Dangjin-gun; CNJ, Janghang-eup; JBB, Buan-gun; JBJ, Jeongeup-si; JNHn, Haenam-gun; JNS, Suncheon-si; GBG, Gyeongju-si; GBUs, Uiseong-gun; GBUj, Uljin-gun; GNGh, Gimhae-si.

[a] Body size class: S < 15 mm; 15 mm ≤ M < 25 mm, 25 mm ≤ L

[b] Habitat types: F, forest specialists; O, open-habitat species

[c] Wing morph: Br, brachypterous species; Ma, macropterous species

Appendix S4.2. List of ground beetles with number of individuals caught per site per species in 14 regenerating forests.

Subfamily	Species	Mean body size (mm)	Body size class[a]	Habitat type[b]	Wing morph[c]	30 years		40 years							50 years				
						GGB	JNG	UL	GGH	GGU	GWP	CBO	GBC	GNGo	SG	GGP	JBN	JNHs	GWI
Carabinae	*Aulonocarabus koreanus koreanus*	28.6	L	F	Br					2			3					1	1
	Aulonocarabus semiopacus	26.3	L	F	Br						4								15
	Coptolabrus jankowskii jankowskii	35.1	L	F	Br				3			1		2		18		45	6
	Coptolabrus smaragdinus branickii	36.6	L	F	Br						1			1	1	1			
	Eucarabus cartereti cartereti	24.4	M	F	Br														9
	Eucarabus sternbergi sternbergi	24.5	M	F	Br								2		3				
	Leptinocarabus wulffiusi opacipenniss	19.9	M	F	Br														12
Nebriinae	*Leistus niger niger*	11.6	S	F	Ma						1								
	Nebria chinensis chinensis	14.5	S	O	Ma		1	2			4		2			1	1	1	
Pterostichinae	*Dolichus halensis halensis*	16.9	M	O	Ma			5						3					
	Pristosia vigil	14.3	S	F	Br								9						
	Pterostichus ishikawai	24.3	M	F	Br						1								
	Pterostichus microcephalus	9.9	S	O	Ma									2					
	Pterostichus sp.1	18.7	M	F	Br													1	
	Pterostichus sp.2	20.9	M	F	Br									2					
	Synuchus cycloderus	13.1	S	F	Ma		1	48		6		99	436	89	21	16	53		59
	Synuchus nitidus	14.8	S	F	Ma	1	5	29	126	8	1	239	283		4	8	10	41	20
	Synuchus sp.1	9.6	S	F	Ma	1		10	82	14	2	2	24	17	110	1	7	1	19
	Synuchus sp.2	10.2	S	F	Br														37
	Trigonognatha coreana	19.4	M	F	Ma									1					

Appendix S4.2. *Continued.*

Subfamily	Species	(mm)	[a]	[b]	[c]	SG	GGB	GGH	GGP	GGU	GWI	GWP	CBO	JBN	JNHs	GBC	GNGo
Harpalinae	*Harpalus tridens*	11.6	S	O	Ma		1	23		2	1			12			1
Zabrinae	*Amara simplicidens*	8.1	S	O	Ma			1									
Callistinae	*Chlaenius costiger*	23.6	M	O	Ma		2										
	Chlaenius naeviger	14.0	S	O	Ma	1	4	2						6		2	1
	Chlaenius pictus	14.1	S	O	Ma												
Licininae	*Diplocheila zeelandica*	20.5	M	O	Ma						1						1
Lebiinae	*Cymindis collaris*	8.4	S	F	Ma								3				
	Cymindis daimio	8.7	S	F	Ma										1		
	Planets puncticeps	12.1	S	F	Ma	2						1					
Brachininae	*Brachinus scotomedes*	15.2	M	O	Ma		2										
	Pheropsophus jessoensis	15.5	M	O	Ma							1		3		2	

Abbreviation of locations are: SG, Gwanak-gu; UL, Ulju-gun; GGB, Bupyeong-si; GGH, Hwaseong-si; GGP, Pocheon-si; GGU, Uiwang-si; GWI, Inje-gun; GWP, Pyeongchang-gun; CBO, Okcheon-gun; JBN, Namwon-si; JNG, Gwangyang-si; JNHs, Hwasun-gun; GBC, Chilgok-gun; GNGo, Goseong-gun.

[a] Body size class: S < 15 mm; 15 mm ≤ M < 25 mm, 25 mm ≤ L

[b] Habitat types: F, forest specialists; O, open-habitat species

[c] Wing morph: Br, brachypterous species; Ma, macropterous species

189

Appendix S5.1. Summary of patch sizes, geographical variables, and mean habitat variables in each study site. Each habitat variables were measured from a study quadrat (20 m^2).

Site code	Patch size (ha)	Geographical variables			Habitat variables							
		Latitude	Longitude	Elevation (m)	Organic matter (%)		Litter depth (cm)	Leaf cover (%)	Canopy cover (%)	Soil humidity (%)	Soil pH	No. of tress
					C	N						
CSD1	3600.0	37.453	126.927	231	5.65	0.42	3.90	85.73	94.38	18.48	4.96	55
CSD2	3100.0	37.409	127.037	274	5.02	0.41	5.00	98.33	83.48	30.99	5.19	29
CSD3	3500.0	37.382	127.012	131	5.58	0.37	3.40	98.60	89.18	24.26	5.25	37
MD1	43.4	37.472	126.928	78	6.33	0.42	3.90	96.40	92.40	24.99	4.97	38
MD2	50.3	37.473	126.944	134	4.70	0.33	2.80	97.60	89.18	20.45	5.26	39
MD3	38.5	37.471	126.955	112	5.38	0.44	2.00	90.33	93.20	19.68	5.25	49
SD1	1.4	37.459	126.930	123	4.65	0.31	3.90	86.27	89.65	17.79	5.12	47
SD2	7.7	37.491	126.914	49	3.61	0.25	1.10	81.00	93.50	18.80	5.27	42
SD3	8.5	37.493	126.952	124	5.03	0.42	1.40	87.90	88.41	21.14	5.18	36
CGD1	3000.0	37.760	127.489	387	4.89	0.34	5.20	97.87	93.37	32.19	6.36	48
CGD2	>10000.0	37.895	127.504	295	7.76	0.75	3.70	96.93	92.78	39.86	6.24	35
CGD3	>10000.0	37.936	127.561	208	6.54	0.54	5.62	95.00	92.28	33.73	6.40	19
MPk1	12.8	37.742	127.504	124	3.30	0.21	4.40	99.60	87.90	24.91	6.08	47
MPk2	33.5	37.866	127.522	136	3.45	0.19	3.00	99.20	76.81	22.47	5.90	25
MPk3	15.3	37.892	127.552	151	3.51	0.19	4.50	96.33	91.67	16.96	6.03	53
SPk1	1.3	37.739	127.508	75	2.92	0.16	4.40	98.53	85.14	18.64	6.11	64
SPk2	1.6	37.859	127.519	98	3.15	0.16	4.10	99.27	87.82	21.57	6.08	32
SPk3	2.6	37.900	127.529	144	4.43	0.24	3.20	99.73	91.54	20.48	6.12	66

Appendix S5.1. *Continued.*

CCD1	1100.0	37.979	127.727	297	5.41	0.47	4.50	96.07	90.14	37.03	5.88	31
CCD2	2700.0	37.897	127.824	485	4.87	0.39	4.30	95.07	89.96	34.58	5.98	39
CCD3	>10000.0	37.807	127.792	371	5.35	0.38	2.80	84.33	91.40	30.22	6.01	42
MPd1	51.2	37.954	127.732	145	4.61	0.27	3.10	95.67	83.64	15.83	5.08	23
MPd2	50.5	37.898	127.780	198	4.75	0.27	5.60	98.67	91.01	24.30	5.49	62
MPd3	22.0	37.862	127.771	136	3.37	0.18	4.72	99.00	83.97	15.39	5.61	66
SPd1	1.1	37.963	127.725	142	4.50	0.26	4.20	98.20	71.72	26.43	5.65	18
SPd2	9.6	37.920	127.776	133	5.92	0.47	3.60	96.47	87.77	19.13	5.52	34
SPd3	3.9	37.879	127.758	118	3.25	0.18	4.34	98.47	72.81	17.95	5.58	25

Appendix S5.2. List of ground beetles with number of individuals caught per site per species in 3 deciduous deciduous forests in continuous mountains and 6 deciduous patches in Seoul.

Subfamily	Scientific name	Habitat type[a]	wing morph[b]	Body size class[c]	Continuous			Medium			Small		
					CSD1	CSD2	CSD3	MD1	MD2	MD3	SD1	SD2	SD3
Brachininae	*Pheropsophus jessoensis*	O	M	M		14	583						55
Callistinae	*Chlaenius costiger*	O	M	M								13	2
	Chlaenius naeviger	O	M	S				6	11		135		4
	Chlaenius pictus	O	M	S	1								
Carabinae	*Aulonocarabus koreanus koreanus*	F	B	L		25	71						
	Calosoma maximowiczi	F	M	L					1				
	Coptolabrus jankowskii jankowskii	F	B	L	138	112	50	31			80		
	Coptolabrus smaragdinus branickii	F	B	L		4	2		1				
	Eucarabus sternbergi sternbergi	F	B	L	45	52	4				1		
Harpalinae	*Anisodactylus punctatipennis*	O	M	S				1				1	1
	Anisodactylus tricuspidatus	O	M	S								1	
	Harpalus discrepans	O	M	S					1			3	1
	Harpalus sinicus	O	M	S								1	
Lebiinae	*Cymindis daimio*	O	B	S	1								
Licininae	*Diplocheila zeelandica*	O	M	M				1					4
Pterostichinae	*Agonum* sp.1	F	B	S		1							
	Dolichus coreicus	F	B	M		1							
	Pristosia vigil	F	B	S		1							
	Pterostichus sp.1	F	B	S							1		

Appendix S5.2. *Continued.*

	Synuchus arcuaticollis	F	M	S	722	1	27	612	57	55	454	6	76
	Synuchus cycloderus	F	M	S	276	14	51	23	44	49	182	4	23
	Synuchus melantho	F	D	S	1	14	1						
	Synuchus nitidus	F	M	S	446	1	30	75	10	27	517	10	108
	Synuchus sp.1	F	B	S	54	18	31		44	12			2
Zabrinae	*Amara congrua*	O	M	S		1							1

[a] Habitat type: F, forest specialists; O, open-habitat species

[b] Wing morph: Br, brachypterous species; Ma, macropterous species

[c] Body size class: S < 15 mm; 15 mm ≤ M < 25 mm, 25 mm ≤ L

Appendix S5.3. List of ground beetles with number of individuals caught per site per species in 3 deciduous deciduous forests in continuous mountains and 6 Korean pine patches from Gapyeong.

Subfamily	Scientific name	Habitat type[a]	wing morph[b]	Body size class[c]	Continuous			Medium			Small		
					CGD1	CGD2	CGD3	MPk1	MPk2	MPk3	SPk1	SPk2	SPk3
Brachininae	*Brachinus scotomedes*	O	M	M				1			1		
	Pheropsophus jessoensis	O	M	M	1	1		47	15		70		20
Callistinae	*Chlaenius costiger*	O	M	M								1	1
	Chlaenius micans	O	M	M								1	
	Chlaenius naeviger	O	M	S	31		1	12	33		25	13	77
	Chlaenius ocreatus	O	M	S	3			1					
	Chlaenius pictus	O	M	S				2	2		1	2	2
Carabinae	*Aulonocarabus seishinensis seishinensis*	F	B	M		18	31						
	Aulonocarabus semiopacus	F	B	L			1						
	Coptolabrus jankowskii jankowskii	F	B	L	2	2	20	1		2			
	Coptolabrus smaragdinus branickii	F	B	L						1			
	Eucarabus sternbergi sternbergi	F	B	L	21	5	6						
	Leptinocarabus wulffiusi opacipennis	F	B	M	7	7	4	2					
Harpalinae	*Trichotichnus* sp.1	O	M	S	1	50	1						
Nebriinae	*Nebria chinensis chinensis*	O	M	S	1		1				1		3
Pterostichinae	*Dolichus coreicus*	F	B	M	3	2							
	Dolichus halensis halensis	O	M	M	1								
	Pristosia vigil	F	B	S	7	1	2	1					

Appendix S5.3. *Continued.*

Pterostichus microcephalus	O	M	S									1
Pterostichus orientalis orientalis	F	B	S		3							
Pterostichus solskyi	F	B	S		10	4						1
Pterostichus sp.2	F	B	M			1						
Pterostichus woongbii	F	B	M	1	4	3	2					
Synuchus arcuaticollis	F	M	S	8			9		2	130	123	133
Synuchus crocatus	F	B	S			2						
Synuchus cycloderus	F	M	S	1145	293	190	274	257	381	278	710	408
Synuchus melantho	F	D	S	9	14	25						
Synuchus nitidus	F	M	S	2	4			13	24	5	150	22
Synuchus sp.1	F	B	S	61	166	12	8	4	35	2	12	21
Synuchus sp.2	F	B	S	1						2		
Trigonognatha coreana	F	M	M				2			1		

[a] Habitat type: F, forest specialists; O, open-habitat species

[b] Wing morph: Br, brachypterous species; Ma, macropterous species

[c] Body size class: S < 15 mm; 15 mm ≤ M < 25 mm, 25 mm ≤ L

Appendix S5.4. List of ground beetles with number of individuals caught per site per species in 3 deciduous deciduous forests in continuous mountains and 6 Korean pine patches from Chuncheon.

Subfamily	Scientific name	Habitat type[a]	wing morph[b]	Body size class[c]	Continuous			Medium			Small		
					CCD1	CCD2	CCD3	MPd1	MPd2	MPd3	SPd1	SPd2	SPd3
Brachininae	*Brachinus scotomedes*	O	M	M				1					
Callistinae	*Chlaenius micans*	O	M	M					2	1			1
	Chlaenius naeviger	O	M	S			4	26	4	3	34	28	14
	Chlaenius nigricans	O	M	M							1		
	Chlaenius ocreatus	O	M	S				1					1
	Chlaenius pictus	O	M	S				1	1		1		13
Carabinae	*Aulonocarabus koreanus koreanus*	F	B	L		7	1						
	Aulonocarabus seishinensis seishinensis	F	B	M	1	9	2						
	Aulonocarabus semiopacus	F	B	L	63	24	27		4				
	Coptolabrus jankowskii jankowskii	F	B	L	20	59	24		2				
	Coptolabrus smaragdinus branickii	F	B	L			1	2		15	2	5	28
	Eucarabus sternbergi sternbergi	F	B	L	29	140	1						
	Leptinocarabus wulffiusi opacipennis	F	B	M	8	18	23						
Harpalinae	*Anisodactylus punctatipennis*	O	M	S								1	
	Anisodactylus tricuspidatus	O	M	S						1			
	Trichotichnus sp.1	O	M	S	1								
Lebiinae	*Cymindis collaris*	F	M	S		1							

Appendix S5.4. *Continued.*

Subfamily	Species	a	b	c	1	2	3	4	5	6	7	8	9
Nebriinae	*Leistus niger*	F	B	S		2							
	Nebria chinensis chinensis	O	M	S				1			3	12	
	Nebria coreica	O	M	S				1				6	
Pterostichinae	*Dolichus coreicus*	F	B	M		28							
	Pristosia vigil	F	B	S	5	4							
	Pterostichus orientalis orientalis	F	B	S		8							
	Pterostichus solskyi	F	B	S		2	3						
	Pterostichus sp.1	F	B	S									1
	Pterostichus subovatus	F	M	S	3								
	Pterostichus sulcitarsis	O	M	S						1			
	Pterostichus vicinus	F	B	M	17								
	Pterostichus woongbii	F	B	M	11								
	Synuchus arcuaticollis	F	M	S				2	1	2	7		754
	Synuchus crocatus	F	B	S		37	20						
	Synuchus cycloderus	F	M	S	1030	508	685	130	372	171	539	373	318
	Synuchus melantho	F	D	S	28	23	13						
	Synuchus nitidus	F	M	S	55	3	13	16	17	23	122	7	108
	Synuchus sp.1	F	B	S	475	30	33	7	18	3	12	1	30
	Trigonognatha coreana	F	M	M	1				4		1		2
Zabrinae	*Curtonotus macronotus*	O	M	S									1

[a] Habitat type: F, forest specialists; O, open-habitat species

[b] Wing morph: Br, brachypterous species; Ma, macropterous species

[c] Body size class: S < 15 mm; 15 mm ≤ M < 25 mm, 25 mm ≤ L
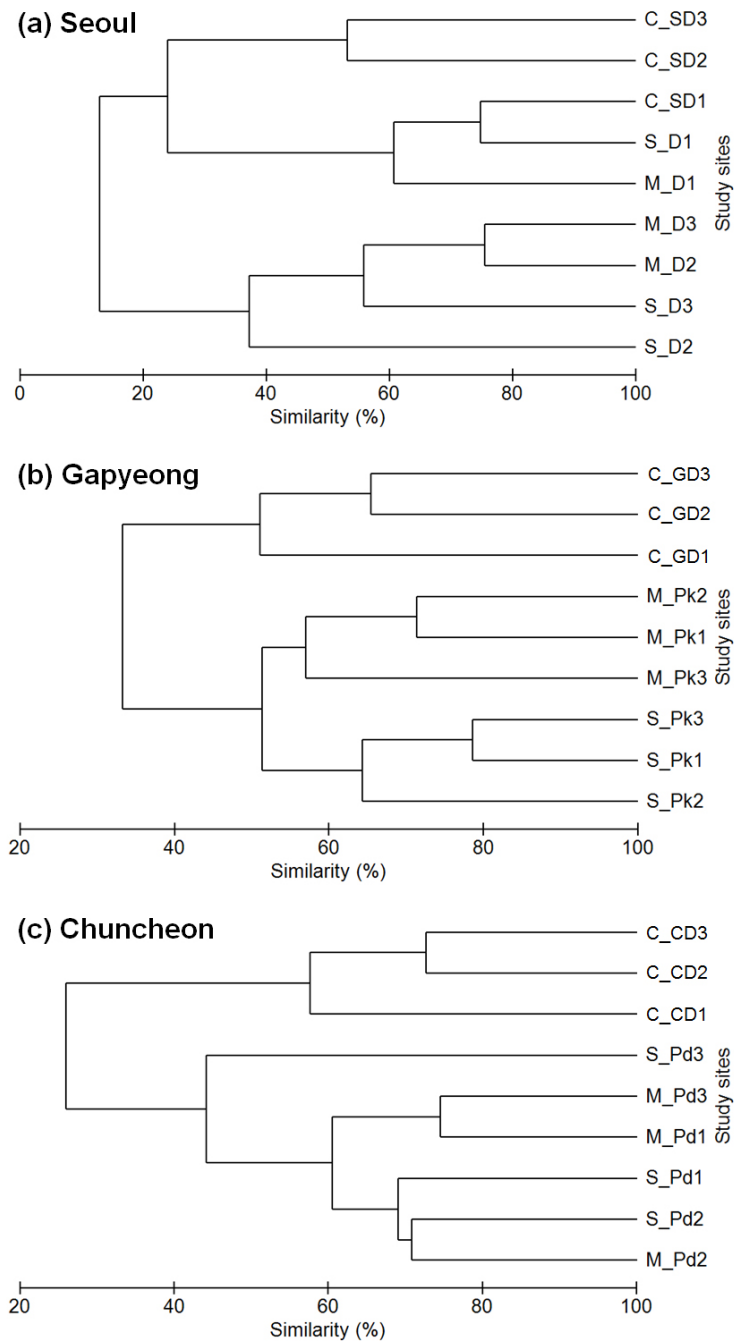
Appendix S5.5. Cluster analysis based on square root-transformed data of ground beetle assemblages using Bray-Curtis similarity in each district. Site codes for study sites in each district are given in Table 5.1.

198

국문 초록

단편화된 산림 경관에서 지표성 딱정벌레류
(딱정벌레목: 딱정벌레과)의 분포 패턴

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농생명공학부 곤충학전공

생물다양성의 양상을 이해하는 것은 보전생물학의 핵심이다. 따라서 본 연구는 한국의 생물다양성 보전 전략 수립을 위한 기초 정보 제공의 차원에서 한국의 온대림과 인접한 서식처에서의 지표성 딱정벌레류에 대한 다양성 양상을 연구하였다.

먼저, 한국의 농업-산림경관에서 숲으로부터 농경지로 이어지는 서식환경의 변화에 따른 지표성 딱정벌레류의 군집 구조와 분포의 변화를 연구하였고, 이를 통해 각 종의 서식처 선호성을 구별하고자 하였다. 그 결과, 화성시에서는 42 종 5276 개체를 채집하였고, 횡성군에서는 61 종 3741 개체를 채집하였다. 화성의 경우, 숲 가장자리의 종수가 숲 내부와 유사하였는데, 횡성에서는 숲 가장자리의 종수가 숲 내부와 숲 외부 환경의 중간에 위치하여 구분되었다. 비록 몇몇 외부환경을 선호하는 종이 숲 가장자리에서 채집되었지만, 다차원척도법(non-metric multi-dimensional scaling)에 의해서 숲 가장자리의 지표성 딱정벌레류의 종구성이 숲 외부보다는 숲 내부

환경에 보다 가까운 특성을 보였다. 채집된 지표성 딱정벌레류는 지표종분석(IndVal)에 의해 세 가지 유형의 서식처 선호성(산림 종, 숲 가장자리 선호 종 및 숲 외부 종)을 갖는 것으로 구분되었다. 요약하면, 지표성 딱정벌레류는 경관의 구조적인 특성에 따라 숲 가장자리에 반응하는 양상이 달라지는 것으로 판단된다.

한국 전지역에 걸쳐 자연갱신림과 조림지간 그리고 숲의 임령간에 지표성 딱정벌레류 종수와 군집구조를 연구하였다. 또한 각 기능군의 종수 및 개체수가 숲의 유형, 임령, 패치 크기, 고도 및 지리적 위치에 따라 어떻게 반응하는지를 살펴보았다. 총 34 종 3156 개체의 지표성 딱정벌레류를 채집하였고, 개체수 기반 종 추정 곡선(individual-based rarefaction curves)을 통해 종수를 추정하였다. 그 결과, 추정된 종수는 조림지보다 자연갱신림에서 높게 나타났으며, 특히 40~50 년된 숲에서 높았다. 다중회귀분석과 다변량 회귀 나무 분석(multivariate regression trees)을 통해 지표성 딱정벌레류의 군집(산림성 종, 대형 종 및 단시형 종)은 패치 크기나 고도에 의해 가장 많은 영향을 받는 것으로 나타났다. 본 결과를 통해 농업 경관에 위치한 산림의 경우, 숲의 유형에 관계없이 넓은 산림 면적을 보호하는 것이 지표성 딱정벌레류의 다양성 보전에 필수적인 요소임을 알 수 있었다.

마지막으로 중부지방에서 보다 정밀한 연구를 통해 패치의 크기와 숲의 유형이 지표성 딱정벌레류의 군집 구조에 미치는 영향을 비교하였다. 또한 기능군 수준에서 패치 크기, 서식처 및 지리적 변수에 대해 어떻게 반응하는지를 분석하였다. 총 50 종 17,845 개체의 지표성 딱정벌레류를 채집하였고, 개체수 기반 종 추정 곡선을 통해 추정된 종수는 나무 수종별(활엽수림, 소나무림, 잣나무림) 패치들에 비해

200

연속적인 숲에서 가장 높게 나타났다. 숲을 선호하는 기능군의 종수는 패치 크기와 양의 상관관계를 보였으며, 모든 환경 변수를 포함한 다중회귀분석에서는 패치 크기를 비롯하여 경도, 위도, 고도, 유기물 및 낙엽층 두께가 산림 종, 단시형 종, 날개이형성 종 및 대형 종의 종수와 개체수에 영향을 주었다. 그러나 다변량 회귀 나무 분석에 의해서는 경도만이 27개 조사지점에 대한 주요 예측변수로 선택되었다. 요약하면, 패치 크기 감소는 지표성 딱정벌레류의 다양성 감소의 주요 원인이며, 중간 크기의 패치는 숲의 유형과는 관계없이 지표성 딱정벌레류의 다양성을 보전하는데 있어 작은 크기의 패치보다 유리한 것으로 판단된다.

주요어: 가장자리 효과, 농업-산림 경관, 패치 크기, 산림 유형, 딱정벌레과