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A Study on the Community of Xylophagous Beetles in Korean White Pine, *Pinus koraiensis*, Forests

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잣나무림에서 천공성 딱정벌레 군집에 관한 연구

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ABSTRACT: The community of xylophagous beetles belonging to Cerambycidae, Curculionidae and Scolytinae in Korean white pine, *Pinus koraiensis* Siebold & Zuccarini, forests was surveyed using Malaise traps in 2007. A total of 1,615 xylophagous beetles were collected, including 184 cerambycids from 15 species, 185 curculionids from 17 species, and 1,246 scolytid beetles from 6 species, of which the dominant species was the ambrosia beetle *Xyleborus mutilatus* Blandford. Ranked by order of population size, the wood-boring and bark beetle community in Korean white pine showed high dominance by one species of Scolytinae, suggesting the community had low biological diversity. Thinning in Korean white pine forests influenced on the abundance of bark and ambrosia beetles, whose populations in particular stands increased 1 year after thinning, and then decreased the following year.

Key words: Cerambycidae, Curculionidae, Scolytinae, Xylophagous beetles, *Pinus koraiensis*

초 록: 2007년에 잣나무림에서 하늘소과, 바구미과, 나무좀아과에 속하는 천공성 딱정벌레 군집을 말레이즈 트랩을 활용하여 조사하였다. 하늘소류 15종 184 개체, 바구미류 17종 185개체, 6종 1,246개체의 총 1,615개체 천공성 딱정벌레가 채집되었고 우점종은 왕녹나무좀이었다. 개체수에 따라 순위를 매겼을 때, 잣나무림에서 천공성 해충과 나무좀류 군집은 나무좀아과의 한 종에 의해 우점되어 생물다양성이 낮은 것으로 나타났다. 잣나무림에서 간벌은 나무좀과 암브로시아좀류의 풍부도에 영향을 미쳐 특정 임분에서의 개체군들은 간벌 1년 후 밀도가 증가했으나 그 후 감소하였다.

검색어: 하늘소과, 바구미과, 나무좀아과, 천공성 딱정벌레, *Pinus koraiensis*

Xylophagous beetles that bore into wood and reproduce in the inner bark on either living or dead trees are one of the most diverse groups in forests (Grove, 2002; Langor et al., 2008). They are an important source of biological diversity in forests, involved in nutrient cycling and energy flow both as consumers and decomposers (Coleman and Hendrix, 2000; Piñero et al., 2011). Among these beetles, the Cerambycidae and Curculionidae (among the weevils, especially the Scolytinae) are the most diverse and abundant groups (Creffield, 1991). Several bark and ambrosia beetles (Scolytinae) and other wood-boring Coleoptera can be one of the most serious threats to forest health because they can attack and reproduce in the living trees. Due to these behaviors, some species are well known as forest pests, such as *Dendroctonus ponderosa* Hopkins and *Dendroctonus frontalis* Zimmermann in North America (Chansler, 1967; Logan and Bentz, 1999; Evans et al., 2011), and *Ips typographus* (Linnaeus) in Europe (Wermelinger, 2004).

Korean white pine, *Pinus koraiensis* Siebold & Zuccarini, is native to Korea, with a distribution that extends into Russia. Usually its native distribution is ranged between 600 and 1,500 m elevation in Korea (Son et al., 2001). Korean white pine has

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been extensively planted throughout the country outside of native distribution during the last several decades because of the high economic value of its seeds and wood (Korea Forest Service, 1999). As trees were extensively planted in the 1960s and 1970s, many Korean white pine stands are now monocultures of mature trees, providing ideal conditions for outbreaks of wood-boring beetles, although serious outbreaks have not yet been reported in Korean pine forests. In addition, the Korean white pine is expected to be especially vulnerable to climate change as it generally favors cooler temperatures (Lee et al., 2009).

Disturbances which alter the surrounding environment can change the interactions among species in communities (Molles, 2008). In general, ecosystems with high species diversity resist disturbances better than ones with low biodiversity, and species diversity is positively correlated with habitat complexity (Doak et al., 1998). Accounting for 3.5% of forests worldwide, most forest plantations are monocultures (Maleque et al., 2009). While monocultures can be easy to manage for economic benefit, their low diversity makes them vulnerable to disturbances such as outbreaks of wood-boring insects and diseases (Shepherd, 1986; Smith, 1986). Korean white pine has been widely planted in monocultures in Korea, and the area of Korean white pine plantations is about 315,000 ha and comprised about 18% of total area of forestry plantations in Korea (Korea Forest Service, 2009).

Thinning is one of the potential anthropogenic disturbances although it reduces stand density and improves the growth rate of the remaining trees because of higher availability of resources such as light, soil water and nutrients (Nyland, 2002). After the thinning, various understory plants can occupy the area of thinning, resulting in increasing plant diversity and complexity in vegetation structure (Wilson and Puettmann, 2007). These environmental changes in the thinned forest affect abundance and diversity of insect communities (Warriner et al., 2002). Also, some studies have suggested that community structure, diversity, and abundance of insects can be changed in relation to the thinning history (Kwon et al., 2010; Taki et al., 2010). For example, Taki et al. (2010) reported that species richness and abundances of longhorn beetles in unthinned forest stands were significantly lower than those in forest stands 1 year after thinning while the significant differences were not observed 3 years after thinning.

We expected that diversity of xylophagous beetles would be low due to low tree diversity in the area of Korean white pine plantations. Diversity of the beetles can be an important indicator in assessing forest health and effects of forest management practices (Werner, 2002). Therefore, in this study, we surveyed the communities of xylophagous beetles in plantations of Korean white pine through periodical sampling. In addition, we elucidate the effect of thinning history on the structure of the xylophagous beetle fauna. Our survey provides basic data on the xylophagous beetle community in Korean white pine forests, information potentially useful for forest management.

Materials and methods

Study sites

The study was conducted in the Korean white pine plantations at four sites: (1) Gunpo-si (GP), (2) and (3) Cheongju-si (CJ1 and CJ2), and (4) Boeun-gun (BE) in Korea. The latitude and longitude of the GP, CJ1, CJ2 and BE site were N37°20’-E126°53’, N36°39’-E127°41’, N36°38’-E127°33’ and N36°33’-E127°39’, respectively. Altitudes of sampling areas ranged from 100 to 400 m (Table 1). The area of plantation forests in GP, CJ1, CJ2 and BE site were 0.27, 0.09, 0.80, and 2.93 ha, respectively. The average diameter at breast height (DBH) of trees ranged from 15 to 20 cm. Forests at CJ1 and CJ2 had not been thinned in the 5 years before sampling, while BE and GP had been thinned 1 and 2 years before sampling, respectively. In thinned stands, suppressed trees and dead branches were cut and the cut dead branches and logs were removed from the forests.

Annual mean precipitation was 1,325 mm in GP, 1,534 mm in CJ1 and CJ2, and 1,532 mm in BE. Annual mean temperature from January to December was 12.9 ℃ in GP, 13.7 ℃ in CJ1 and CJ2, and 11.7 ℃ in BE (Korea Meteorological Administration). The understory of study sites consisted of mostly covering shrubs such as *Rhododendron mucronulatum* Turzaninow, *Rhododendron schlippenbachii* Maximowicz, *Lespedeza bicolor* Turczaninow, and *Rosa multiflora* Thunberg, showing generally less than 10% land coverage except for BE that the coverage was 20-30%.

Table 1. Information on location of study areas, acronyms and characteristics of forests surveyed

Study site	Acronyms	Latitude/longitude	Altitude (m)	Mean DBH[a] (cm)	Years after thinning forest	Vegetation of understory	
						Coverage (%)	Dominant species
Gunpo	GP	N37°20'/E126°53'	100	15	2	<10	*Rhododendron mucronulatum*
Cheongju	CJ1	N36°39'/E127°41'	400	16	-[b]	<10	*Rhododendron mucronulatum*
Cheongju	CJ2	N36°38'/E127°33'	200	20	-[b]	<10	*Rhododendron mucronulatum*
Boeun	BE	N36°33'/E127°39'	300	20	1	20-30	*Rhododendron mucronulatum*

[a]indicates diameter at breast height
[b]Forests at CJ1 and CJ2 had not been thinned in the 5 years before sampling

Sampling and identification

Beetles were collected bi-weekly from April to October 2007 in a Malaise trap which was set up at the center of each forest stand. Trap catch bottles containing approximately 300 ml of 90% ethanol were replaced every two weeks, when samples containing specimens were collected. Xylophagous beetles in trap catches were taken to the laboratory in jars of ethanol, and were identified to species (Hong et al., 2011; Park et al., 2012), focusing just on species of Cerambycidae and Curculionidae (especially Scolytinae).

Statistical analyses

Prior to analyzing the data, we divided xylophagous into three groups; Cerambycidae, Curculionidae (excluding Scolytinae) and Scolytinae. Species diversity and evenness of beetles in three target groups were determined for each location using the Shannon diversity index (Begon et al., 1996) as follows: (1) diversity, $H = -\sum_{i=1}^{S} P_i \ln P_i$, where S is the total number of individuals and P_i is ratio of ith species, and (2) evenness, $J = H / \ln S$. The Shannon diversity indices of the sites were compared with Hutcheson's t test (Hutcheson, 1970). Also, rarefaction curves were used to compare total species richness among the forests. The method permits comparisons of the species richness among communities when the samples differ in total numbers of individuals. The expected number of species, $E(S_n)$ in a random sample of n individuals was estimated from a population of N total individuals distributed among S species (Hurlbert, 1971). For each sample, rarefaction algorithms generate expected species richness based on random subsamples of individuals for each abundance level.

Results

The total number of xylophagous beetles collected was 1,615, consisting of 184 cerambycids from 15 species, 185 curculionids (exclusive of scolytid beetles) from 17 species, and 1,246 bark or ambrosia beetles from 6 species (Table 2). Abundance was highest at CJ1 (654 individuals) and BE (654 individuals), followed by CJ2 (268 individuals), and lowest at GP (39 individuals) (Fig. 1A). The species richness between sites ranged from 11 (GP) to 28 (BE) species (Fig. 1B). The species diversity index was 1.0 in BE, 1.6 in CJ1, 1.8 in CJ2, and 1.8 in GP (Fig. 1C). The Hutcheson's t test showed significant difference between the indices of BE and CJ1 (t = 4.59; P < 0.0001), whereas difference between the indices of CJ1 and CJ2 (t = 1.86; P = 0.06), and GP and CJ2 was not significant (t = 0.34; P = 0.74). Species evenness ranged from 0.31 to 0.58 (Fig. 1D). Similarly, rarefaction curves indicate that at n = 30, expected species, $E(S_n)$ in GP was the most highest, followed by CJ2, CJ1 and BE (Fig. 2).

Monthly abundance for the three target groups showed different patterns. The number of cerambycid beetles peaked in May at GP and BE, and in June at CJ1 and CJ2. Peaks at BE and CJ1 were higher than those at GP and CJ2 (Fig. 3A). The

Table 2. List of wood-boring and bark beetle species collected in Korean white pine forests, April-October, 2007

Family	Species	Sites[a]	Month[b]
Cerambycidae	*Prionus insularis* Motschulsky	GP	July
	Pidonia (=*Omphalodera*) *puziloi* (Solsky)	GP, CJ1, BE	May - Jun
	Pidonia (=*Pidonia*) *amurensis* (Pic)	CJ1, CJ2	May - Jun
	Pidonia gibbicolis (Blessig)	CJ1, BE	May
	Pidonia (=*Pidonia*) *similis* (Kraatz)	CJ2, BE	Jun
	Corymbia succedanea Lewis	CJ1, BE	Aug
	Leptura arcuata Panzer	CJ1, CJ2, BE	Jun
	Pseudallosterna misella (Bates)	GP, CJ1, CJ2	May - Jun
	Leptoxenus ibidiiformis Bates	CJ1, BE	Jun
	Clytus melaenus Bates	CJ1, BE	May - Jun
	Rhaphuma gracilipes (Faldermann)	GP, CJ2	May - Jun
	Moechotypa diphysis (Pascoe)	CJ1, BE	Jun - Oct
	Nupserha marginella (Bates)	BE	Aug
	Acalolepta sejuncta (Bates)	BE	Aug
	Gaurotes ussuriensis Blessig	CJ	Jun
Curculionidae (exclusive of bark beetles)	*Cyrtepistomus castaneus* (Roelofs)	CJ1, CJ2	Aug - Sep
	Enaptorrhinus granulatus Pascoe	GP	Apr - Aug
	Pseudocneorhinus *adamsi* Roelofs	GP, CJ1, CJ2, BE	May - Sep
	Pseudocneorhinus minimus Roelofs	CJ2	Aug
	Hylobitelus haroldi (Faust)	CJ1, CJ2, BE	May - Oct
	Lissorhoptrus oryzophilus Kuschel	CJ2	Jun
	Deiradocranus setosus (Morimoto)	CJ1, BE	Jun
	Camptorhinus notabilis (Walker)	CJ2	Jun
	Caenocryptorrhynchus frontalis Morimoto	CJ1	Jul - Aug
	Shirahoshizo rufescens (Roelofs)	GP, CJ1, CJ2, BE	May - Oct
	Metialma cordata Marshall	CJ1, CJ2, BE	May - Jun
	Balanobius (*Balanobius*) *parvus* Kwon et Lee	GP	Apr - May
	Curculio dentipes (Roelofs)	CJ1	Aug
	Baris dispilota (Solsky)	CJ1	Aug
	Rhamphus pulicanus (Herbest)	CJ1	Jul
	Mecysolobus erro (Pascoe)	CJ2	Jun
	Egiona konoi Nakane	BE	Jun
Scolytinae	*Xyleborinus saxeseni* (Ratzeburg)	GP, CJ1, CJ2, BE	Apr - Aug
	Xylosandrus germanus (Blandford)	GP, CJ1, CJ2, BE	Jun - Sep
	Xyleborus adumbratus Blandford	CJ1, CJ2, BE	Jul - Sep
	Xyleborus apicalis Blandford	GP	Apr
	Xyleborus mutilatus Blandford	GP, CJ1, CJ2, BE	May - Aug
	Xyleborus rubricollis Eichhoff	CJ1, CJ2, BE	Jun - Sep

[a]GP: Gunpo-si, CJ1 and CJ2: Cheongju-si and BE: Boeun-gun
[b]indicates occurrence periods of each species

monthly abundance of curculionids (not including the Scolytinae) of GP and BE was highest in May, while at CJ1 numbers increased until June, and at CJ2 they increased until July and August (Fig. 3B). The abundance of bark or ambrosia beetles at all four sites also peaked in June (Fig. 3C). The rank order of cerambycids at GP and BE showed a steep slope, while it had a gradual slope at CJ1 and CJ2 (Fig. 4A). The rank order curve for curculionids (exclusive of Scolytinae) at GP showed a gradual slope, while that at BE had the steepest slope (Fig. 4B). The rank order of bark and ambrosia beetles showed a steep slope for all locations except GP (Fig. 4C). The rank orders of all xylophagous beetle species, pooled by location, showed that GP had the most gradual slope, followed by CJ2, CJ1, and BE (Fig. 4D).

The dominant species in GP was the cerambycid *Pidonia puziloi* Solsky, while the second most abundant species was weevil *Balanobius parvus* Kwon et Lee. Monthly abundance of *P. puziloi* and *E. granulatus* was highest in May (Fig. 5A). The dominant species in CJ1, CJ2, and BE was the ambrosia beetle *Xyleborus mutilatus* Blandford, whose monthly density was highest in June (Fig. 5B, C and D). The second most

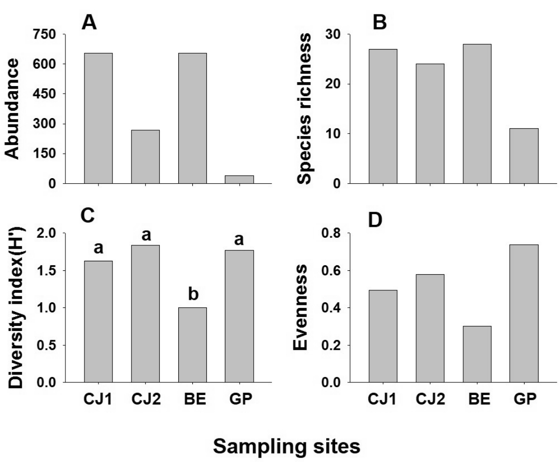

Fig. 1. Abundance (A), species richness (B), diversity index (C), and evenness (D) of total xylophagous beetles collected from Malaise traps in four sites (GP: Gunpo-si, CJ1 and CJ2: Cheongju-si and BE: Boeun-gun). Bars with different lower case letters indicate significant differences based on a Hutcheson's *t*- test at $P < 0.05$.

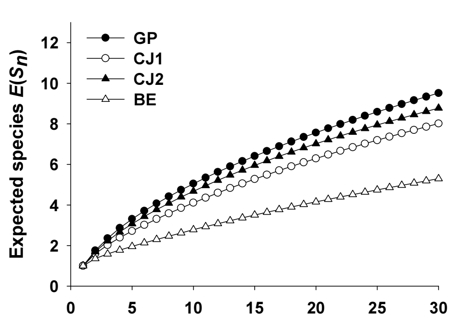

Fig. 2. Rarefaction curves for the four sites.

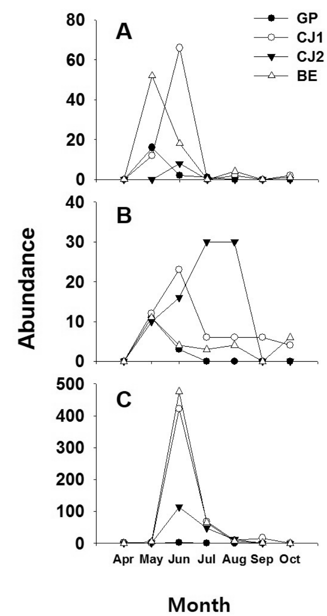

Fig. 3. Monthly changes in total abundance of species that belong to Cerambycidae (A), Curculionidae (exclusive of bark beetles) (B), and Scolytinae (C) in four sites from April to October in 2007 (GP: Gunpo-si, CJ1 and CJ2: Cheongju-si and BE: Boeun-gun).

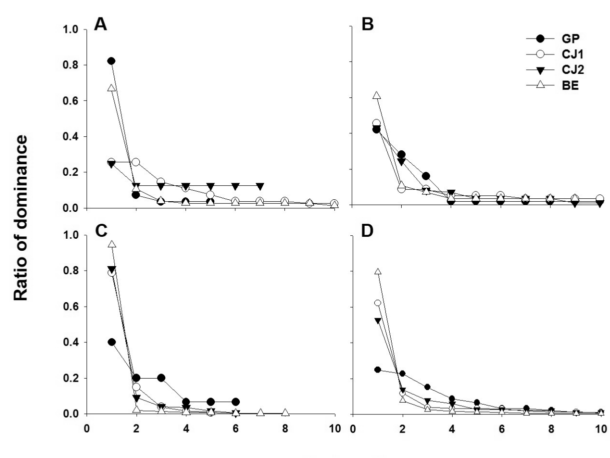

Fig. 4. Rank order of species belonging to Cerambycidae (A), Curculionidae (exclusive of bark beetles) (B), Scolytinae (C) and total number of Xylophagous beetles (D) in four sites (GP: Gunpo-si, CJ1 and CJ2: Cheongju-si and BE: Boeun-gun).

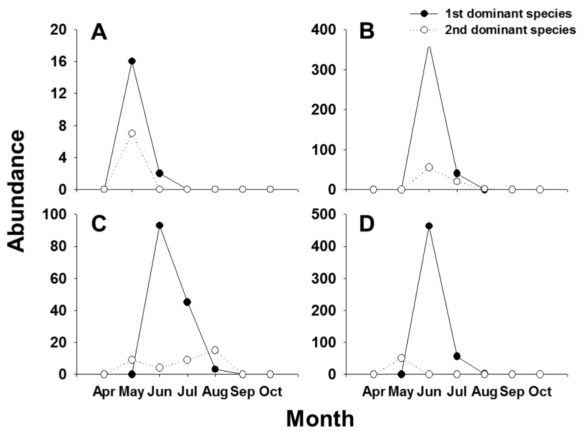

Fig. 5. Monthly changes in abundance of the dominant and second most abundant species in GP (A), CJ1 (B), CJ2 (C), and BE (D) from April to October 2007. The dominant species in CJ1, CJ2, and BE was Xyleborus mutilatus, and Pidonia puziloi in GP (GP: Gunpo-si, CJ1 and CJ2: Cheongju-si and BE: Boeun-gun).

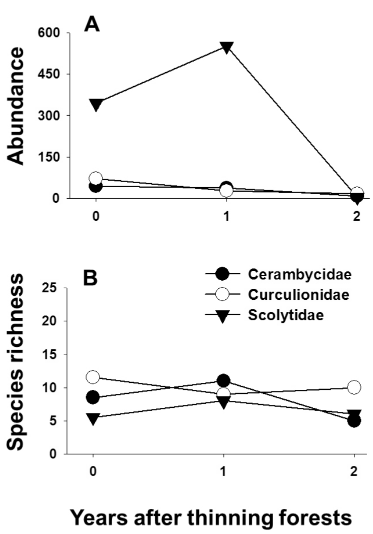

Fig. 6. Abundance (A) and species richness (B) belonging to the Cerambycidae, Curculionidae (exclusive of bark beetles), and Scolytinae in the years following thinning in Korean white pine forests.

abundant species in CJ1 was the ambrosia beetle *Xyleborinus saxeseni* Ratzebug, whose monthly density was highest in June (Fig. 5B). The weevil *Hylobitelus haroldi* Faust was the second most abundant species in CJ2, with two peaks, one in May and one in August (Fig. 5C). The peak of *P. puziloi*, the second most abundant species in BE, occurred in May (Fig. 5D). The total number (P_i) of *X. mutilatus* trapped was 1,068 (66% of the total), while the numbers of *P. puziloi*, *X. saxeseni* and *H. haroldi* trapped were 90 (6% of total captures), 77 (5%) and 37 (2%), respectively.

Based on pooling the data from the study sites, after thinning, the total abundance of trap catches of Cerambycidae and Curculionidae (excluding Scolytinae) decreased, while the abundance of bark and ambrosia beetles increased one year after thinning and then decreased in the second year after thinning (Fig. 6A). The species richness of Cerambycidae and Scolytinae increased one year after thinning and then decreased the second year after thinning, whereas that of Curculionidae (without the Scolytinae) followed the opposite pattern (Fig. 6B).

Discussion

In three of the four forest stands surveyed, the dominant group was the scolytid beetles (Scolytinae) and the dominant species was the ambrosia beetle *X. mutilatus*. The rank order of total xylophagous beetles showed a steep slope, suggesting that the communities consisted primarily of only one or two major xylophagous beetle species. It is well known that communities consisted of one or two highly dominant species is unstable (van Emden and Williams, 1974; Tilman, 1996; Sankaran and McNaughton, 1999). Therefore, our results suggest that xylophagous beetle communities in Korean white pine forest are potentially unstable due to highly dominancy of *X. mutilatus*. The ambrosia beetle is native to Korean without any outbreaks in Korea. This species invaded to North America in 1999 (Schiefer and Bright, 2004; Stone et al., 2007; Koch and Smith, 2008; Six et al., 2009) and is considered a threat to the health of forests there (Tang, 2000). The fact that recent climate change has altered the behavior of secondary ambrosia beetles from attacking only weakened or dead trees to attacking and killing vigorous trees (Kühnholz et al., 2001) suggested that *X. mutilatus* is potential risk to forest healthy even within its native distribution.

It is commonly known that coniferous forests generally have lower wood borer diversity than deciduous forests because conifers secrete chemical defense compounds against potential invaders (Franceschi et al., 2005; Keeling and Bohlmann, 2006). Our sites, rather than being natural forests, were monoculture plantations of Korean white pine trees artificially planted with a dense crown coverage (Korea Forest Service 1999) which lowers the habitat complexity that is fundamental to biological diversity (Johnson et al., 2003). Therefore, it was expected that biodiversity of our sites would be lower than that of natural mixed forest. Similarly, Lee et al. (2010) reported that species diversity of tree, arborescent and shrub layer the deciduous forest in Chukryongsan Recreational forest was higher than that of artificial *Pinus koraiensis*. The biodiversity index of the deciduous and artificial *Pinus koraiensis* forest were 1.3562 and 1.2091, respectively. Interestingly, among the four study sites, the biodiversity at GP where species richness was the lowest was the highest comparing to other sites. First, this results can be attributed that species richness per abundance was relatively high by comparison with other study sites. Also, it is supported by the rank of dominance curves (Fig. 4); each species belonging to the three groups in GP was equally abundant, each comprising 20% of the beetle community by contrast to over 50% of the individuals in other sites belonged to one species.

Among the three groups monitored in this study, bark and ambrosia beetles were the group most influenced by stand thinning. The abundance of bark and ambrosia (Scolytinae) beetles increased one year after thinning, and then decreased in the second year. This pattern explained by the increase in resources for wood-boring and Scolytinae beetles in the form of remaining freshly killed logs and branches resulting from thinning and branches of surrounding trees damaged by thinning process although the cut log and branches were removed from the forests. By the second year, these materials were mostly used up by bark or ambrosia beetles or too decayed for use as breeding sites, and therefore Scolytinae populations decreased (Hindmarch and Reid, 2001). Similarly, bark/ambrosia beetle populations including genus of *Dendroctonus*, *Dryocoetes*, *Ips*, *Orthotomicus*, *Scierus*, *Scolytus* and *Trypodendrum* often increase in the first year after thinning (Werner, 2002) although many wood borers are significantly reduced by thinning operations. In general, thinning has been viewed as a positive tool for managing biodiversity in forests (Smith, 1986; Hunter and Calhoun, 1995; Hartley, 2002; Nyland, 2002; Kim et al., 2003; Wilson and Puettmann, 2007; Brockerhoff et al., 2008; Igarashi and Kiyono, 2008). However, our results showed that thinning has the potential to induce increase in population size of bark beetles (Fig. 6A).

The monthly occurrence patterns of cerambycids showed peaks in spring. The adults of this family feed on flower pollen (Allison et al. 2004), suggesting that their abundance is related to the blooming of understory plants. Both sites which had previously been thinned showed earlier peaks of cerambycids than non-thinned sites. After thinning, gaps in the tree canopy create a range of light conditions, leading to earlier flower bloom (Andrés et al., 2009). Unlike bark/ambrosia beetles and longhorn beetles, which peaked before July, most curculionids (exclusive of Scolytinae) were found until September, likely because their food resources remained available until autumn. As most curculionids caught in traps were generalist herbivores, feeding on a variety of plant parts such as buds, leaves, stems, fruit and logs. The weevils (exclusive of Scolytinae) caught at CJ1 and CJ2 were mostly wood-boring weevils, such as *H. haroldi* and *Shirahoshizo rufescens* Roelofs, that damage pine trees (Lee and Lee, 2000). Their abundance was low in BE and they were rarely found in GP because dead or cut trees suitable for breeding were removed in the thinning process. The peak period for bark/ambrosia beetles was shorter than for Cerambycidae and other Curculionidae. The peak period of the dominant species in the Scolytinae, *X. mutilatus*, was very similar to that of trap catch of the Scolytinae as a whole because *X. mutilatus* accounted for over 86% of all Scolytinae caught. The peak period for *X. mutilatus* occurred mostly in June at all study sites, similar to the findings of Schiefer and Bright (2004) who reported that flight of this species occurred from June to August, peaking in June in Mississippi.

Our results showed that xylophagous beetle communities in Korean white pine forests were unstable, with low biological diversity and the dominancy of one or two wood-boring beetles. The most dominant species, *X. mutilatus,* can be considered a potential pest and, in the context of climate change, a threat to Korean white pine forest health. While information found in this study suggests some concerns relevant for the management xylophagous beetles in the Korean white pine forests, further study is needed to predict the potential for outbreaks of emerging pests such as *X. mutilatus*.

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