Journal of Asia-Pacific Biodiversity 8 (2015) 152–157

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Journal of Asia-Pacific Biodiversity

journal homepage: http://www.elsevier.com/locate/japb

Journal of Asia-Pacific Biodiversity

Original article

Ant assemblages along the Baekdudaegan Mountain Range in South Korea: Human roads and temperature niche

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ARTICLE INFO

Article history:
Received 16 March 2015
Received in revised form
1 May 2015
Accepted 4 May 2015
Available online 9 May 2015

Keywords:
ant
Baekdudaegan
conservation
roads
temperature niche

ABSTRACT

The Baekdudaegan is a Korean main mountain range that passes through the Korean Peninsula, and Korean people consider it to be the main ecological axis of the Korean Peninsula. Many motor roads cross the Baekdudaegan, and the Baekdudaegan trail is popular among hikers. The present study investigated the ants of Baekdudaegan using pitfall traps in two separate surveys (2006–2008 and 2009) with different sampling designs at six uphill passes to identify the impacts of motor roads and trails. There was no influence from motor roads found (distance from the road and forest fragmentation by road). In the case of trails, however, the further the ants were located from the trails, the less population tended to be observed. The composition of ant species was determined by the temperature niche of ants. When the ants went further south, cold-adapted species declined, while warm-adapted species increased. In this study, a total of 28 species were collected, which is not higher compared with species richness in other areas.

Introduction

The Baekdudaegan is a mountain range that continuously runs through from Byeongsabong (2744 m) of Baekdusan to Cheonghwangbong of Jirisan (1915 m), and its length is about 1400 km (Kang and Kwak 1999). Korean people traditionally consider the Baekdudaegan as the spine of the Korean peninsula, and from this fabled perspective they widely accepted a logic that the Baekdudaegan is the main ecological axis of the Korean Peninsula. This is because a spine is a main structure for maintaining life of vertebrates. Based on such a traditional idea, the Korean government has been pursuing various policies and research projects to preserve the Baekdudaegan (Kim et al 2010). As the Baekdudaegan has become a symbol of nature conservation in South Korea, Baekdudaegan trails that pass through the southern area of the Baekdudaegan in South Korea have become popular. The Baekdudaegan is a geographical barrier that passes diagonally through the western part and the eastern part of South Korea, so there were already passenger roads across the Baekdudaegan from the past, and some of these roads have become motor roads today. These hill-passing motor roads cut through forests around the ridge of the Baekdudaegan and fragment forests. Furthermore, it is likely that the Baekdudaegan trails have various influences on the forests. The trails do not have vegetation and litter layers on the ground, so they have different conditions from surrounding areas. Although there are many studies about the impacts of motor roads on ecosystems (Fabrig and Rytwinski 2009), there are few studies on the impacts of hiking trails.

In order to identify the impact of motor roads and hiking trails on the ecosystem of the Baekdudaegan, studies were conducted on ants. Since ants are directly influenced by various environmental changes due to their sedentary habit, they are used frequently as bio-indicator organisms to monitor influences of environmental changes (Agosti et al 2000). In South Korea, the distribution of ants is mainly determined by temperature, but disturbance is also important to determine ant community structures (Kwon et al 2014a, 2014b). The objective of this study was to evaluate the impact of disturbance by roads and trails and the impact of temperature on ant assemblages. In the case of motor roads, it is expected that ant communities are different at both sides of the forest separated by roadways. In the case of trails, it was expected that there would be differences in ant species composition and abundance from adjacent areas and further areas from trails. As regards temperature, from north to south, there will be a change in the composition of cold-adapted species (CAS) and warm-adapted

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Peer review under responsibility of National Science Museum of Korea (NSMK) and Korea National Arboretum (KNA).

http://dx.doi.org/10.1016/j.japb.2015.05.001

species (WAS); towards the south the former will be decreased and the latter will be increased. In order to verify these predictions, studies were carried out in six uphill passes along the Baekdudaegan.

Materials and methods

Ant survey

Surveys on ants were carried out in six uphill passes of the Baekdudaegan (Figure 1 and Table S1). Two separate surveys were carried out in the passes. In the first survey, pitfall traps were set up as shown in Figure 1B to test the influence of roads and trails. Three forested sites on both sides of the road were selected at 10 m, 50 m, and 100 m away from the road and three pitfall traps (diameter 9.5 cm, depth 6.5 cm) were installed every 2 m at 1 m, 6 m, and 11 m away from the trail, and then collected 10 days later. This distance from the road is not a straight distance, but is on the trail. The survey was conducted in July and was performed at the two passes every year from 2006 to 2008 [Sabdangryeong (SD) and Hwabangjae (HB) in 2006, Jeosuryeong (JS) and Ihwaryeong (IH) in 2007, and Uduryeong (UD) and Yuksipreong (YS) in 2008]. The second survey was aimed to test only the impact of the motor road. Ten pitfall traps were set up every 10 m, 50 m, 100 m, 200 m, and 300 m away from motor roads at both sides of the forests (Figure 1C). Pitfall traps were linearly installed every 5 m from the trail to the interior forest. This survey was carried out in six uphill passes in July 2009. Ants were identified using the Korean ant key of Kwon et al (2012).

Data analysis

The generalized linear model (GLM) was used to test the influences of roads and trails on ant communities. Dependent variables were the number of species, the number of total individuals, and the numbers of four different species [*Lasius* spp. (*jap.*+*al.*), *Pheidole fervida*, *Myrmica kotokui*, and *Nylanderia flavipes*]. The occurrences (percent of occurred sites) of the four species were more than 30%. Independent variables were two linear variables (the distance from motor roads and the distance from trails), and two categorical variables are fragmentation and location (i.e., 6 uphill passes). Here, fragmentation refers to dividing the forest into the northward side and the southward side by the road. It is very likely that there is high reliability if the GLM results of the first survey and second survey are coincident, so the detailed data of each case are listed in Figures S1–10. Nonmetric Multidimensional Scaling (NMS) was used for comparison of the ant assemblages among the locations. Multi-Response Permutation Procedures (MRPP) analysis was used with the second survey data to test whether ant communities are influenced by fragmentation. Neumann-Keuls multiple range test was used for multiple comparisons among groups. NMS and MRPP analyses were conducted using PC-ORD version 6.0

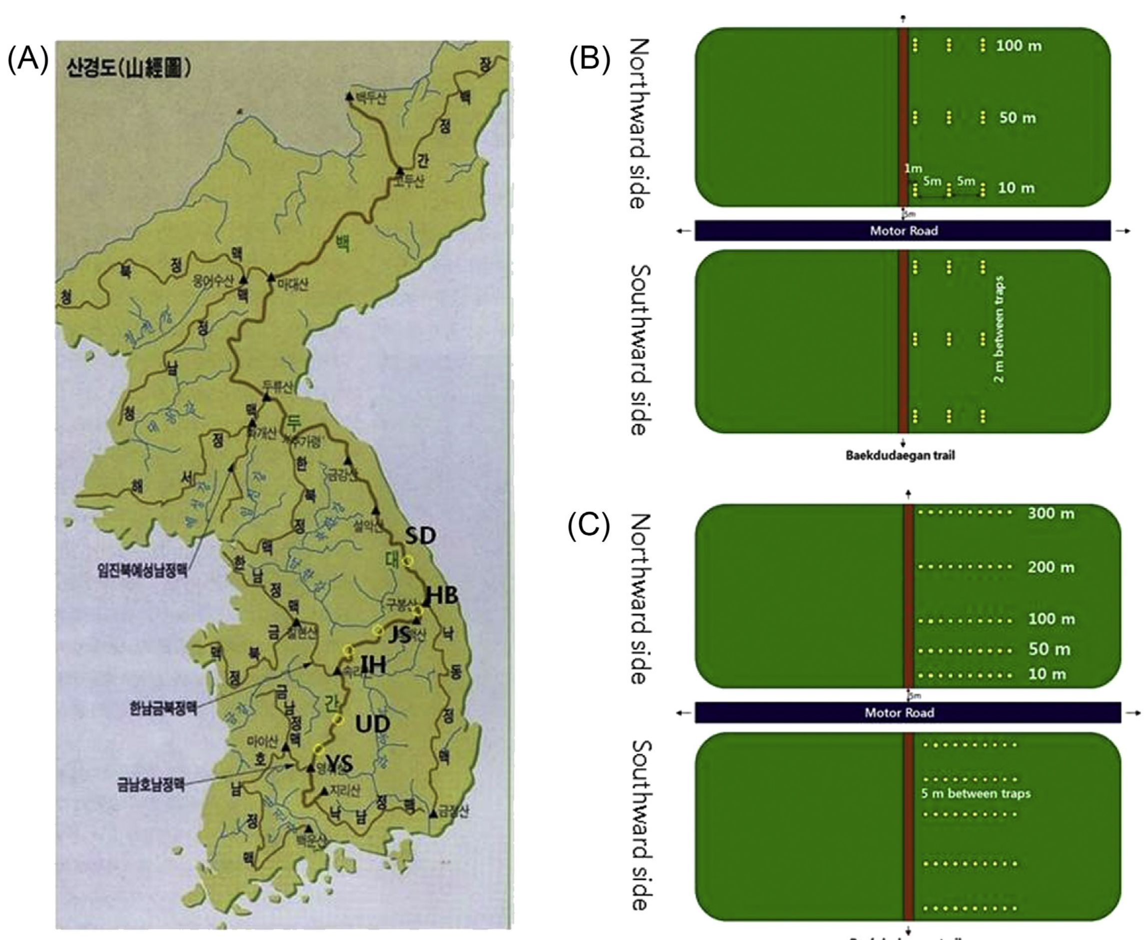

Figure 1. A, Map of the study locations; B, sampling designs of the first survey (2006–2008); C, sampling designs of the second survey (2009). HB = Hwabangjae, IH = Ihwaryeong, JS, Jeosuryeong, SD = Sabdangryeong, UD = Uduryeong, YS = Yuksipreong.

(MjM Software, Gleneden Beach, OR, USA), while GLM and other analyses were conducted using STATISTICA version 8.0 (Statsoft, Inc., Tulsa, OK, USA).

Results and discussion

Through two surveys, a total of 28 ant species were collected (Table 1). On the NMS ordination, communities were aligned along one axis (Axis 1), and their arrangement in the ordinal space was almost consistent with their position in the map (Figures 1 and 2). The stress value of Axis 1 was 9.725. Comparing the NMS score and optimum temperature of each ant species, it showed a significant positive correlation (Figure 3). Species with higher NMS scores are CAS and species with lower scores are WAS. Figure 4 shows this finding. Compared with low temperature locations such as SD, HB, and JS (7.3–8.1°C annual average temperature of locations), high temperature locations such as IH, UD, and YS (9–9.3°C) have more species and more individuals of WAS but less species and less individuals of CAS (Figures 4 and 5 and Tables S1–2). In particular, proportions of CAS were highest in HB with the lowest temperature (Figure 4).

GLM results on influences of roads, trails, fragmentation, and location are shown in Table 2. Although there was significant impact in part by the motor road, there were no consistent results in the two surveys, so the reliability is doubtful. In the MRPP analysis used to test whether the ant assemblages on either sides of the road are significantly different, results were not significant in all of the six locations ($p > 0.05$). With regards to trail impact, it was investigated only in the first survey making it difficult to guarantee its reliability, but significant impact was found in the number of total individuals and the number of *Nylanderia flavipes* ($p < 0.05$). Comparing the number of individuals according to the distance from the trail, the further the distance is, the higher the tendency is for fewer individuals (Figures S11 and S12). However, significant impact of location was found to be the same in the two surveys in the cases of the number of species and the number of *Pheidole fervida*, *Nylandera flavipes,* and *Myrmica kotokui*. In the case of the number of species, the difference by location was found to be very different in the two surveys (Figures S1 and S2). Meanwhile, in the case of the number of individuals for the three dominant species, the results were similar for the two surveys. *P. fervida* shows higher numbers in the central area (Figures S3 and S4), but *N. flavipes* shows higher numbers in southern locations (Figures S5 and S6), while *M. kotokui* was collected only in SD and HB of the northernmost areas (Figures S7 and S8). The impact of fragmentation can be verified from the interaction of location and fragmentation, and only the number of species showed significance being consistent in the two surveys. However, when reviewing the data, the number of species on both sides separated by roads varies by location in the first and second surveys, so it is difficult to judge this as the effect of fragmentation (Figures S9 and S10).

Higher numbers of ants were found towards the trail, however more evidence is needed to prove its generality but it is still worth noticing. The Baekdudaegan trails go along the ridges, so there are many cases in which both sides around the trails go towards the valley. Therefore, there is a high possibility that the further away from the trail, the more humid it is which can in turn impact the number of ants. Ants rarely make colonies on the trail so there is a possibility that places near trails will have relatively lower competition among ant species. Also, road kills by hikers may increase the mortality of ants, but at the same time killed ants are foods for other ants. Therefore, it is likely that the impact of trails is

Table 1. Number of ants collected along the Baekdudaegan trail.*

Species	Ab	SD		HB		JS		IH		UD		YS	
		2006	2009	2006	2009	2007	2009	2007	2009	2008	2009	2008	2009
Aphaenogaster japonica	Aj	14	17	0	3	1	4	26	43	8	0	0	1
Camponotus atrox	Ca	34	12	9	7	4	20	1	0	2	4	0	0
Camponotus japonicus	Cj	0	0	0	0	0	0	0	23	0	1	0	0
Camponotus kiusuensis	Ck	0	0	0	0	0	0	2	0	0	0	0	0
Camponotus nipponensis	Cn	0	0	0	0	0	0	0	0	0	0	1	5
Crematogaster osakensis	Co	0	0	0	0	0	0	0	1	0	0	0	1
Crematogaster teranishii	Ct	0	0	0	0	1	0	0	0	0	0	0	0
Cryptone sauteri	Cs	0	0	0	0	0	0	2	2	1	0	0	0
Dolichoderus sibiricus	Ds	0	0	0	0	0	0	0	0	0	0	0	1
Formica japonica	Fj	0	0	4	4	4	2	0	0	29	33	5	9
Formica yessensis	Fy	0	0	0	0	0	0	0	1	0	1	296	239
Lasius meridionalis	Lm	0	0	0	0	0	0	0	0	0	0	3	0
Lasius spp. (jap+al.)	Lja	5	8	30	16	8	39	1	31	84	84	49	63
Myrmecina nipponica	Mn	0	3	0	0	0	0	0	4	1	1	0	0
Myrmica carinata	Mc	0	0	3	0	0	78	0	0	13	12	47	20
Myrmica kotokui	Mk	237	176	144	343	12	0	0	0	0	0	0	0
Nylanderia flavipes	Nf	127	87	35	56	96	179	179	190	263	171	454	478
Pachycondyla javana	Paj	0	0	0	0	0	0	5	20	40	59	30	92
Pheidole fervida	Pf	67	33	200	76	142	250	141	237	310	190	42	79
Ponera japonica	Pj	2	0	1	0	0	0	1	0	3	1	4	0
Ponera scabra	Ps	0	0	0	0	0	0	0	14	0	0	0	6
Pristomyrmex pungens	Pp	0	0	0	0	0	0	0	1	0	0	11	0
Stenamma owstoni	So	2	4	7	27	0	9	0	1	0	0	0	0
Strumigenys lewisi	Sl	0	0	0	0	0	0	3	10	0	0	3	4
Technomyrmex gibbosus	Tg	0	0	0	0	0	0	0	1	0	0	0	0
Temnothorax nassonovi	Tn	8	1	5	0	0	0	0	0	0	0	0	0
Tetramorium caespitum	Tc	5	0	0	0	0	0	0	70	0	0	30	8
Vollenhovia emeryi	Ve	0	0	0	0	0	0	4	3	2	1	0	0
Number of species		11		11		10		20		14		17	
Number of individuals		842		970		849		1017		1314		1981	

* Six locations and sampling designs for the collection of ants are shown in Figure 1. Sampling methods and periods are shown in the text. The locations are shown in Figure 1. HB = Hwabangjae, IH = Ihwaryeong, JS, Jeosuryeong, SD = Sabdangryeong, UD = Uduryeong, YS = Yuksipreong.

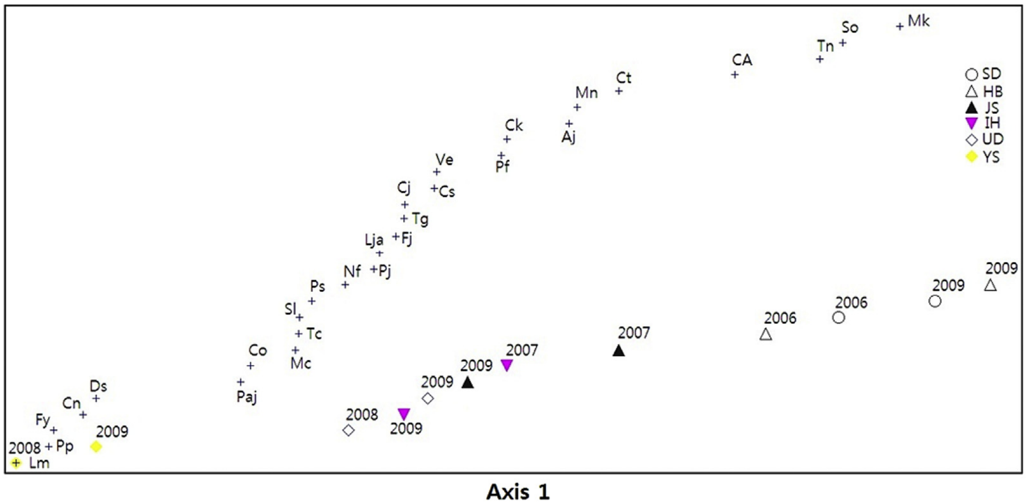

Figure 2. Ordination of ant assemblages and ant species using Nonmetric Multidimensional Scaling. Data of the second survey was used for the ordination. Numbers indicate year and study locations are shown in Figure 1. Full names of ant species are shown in Table 1. The study locations are shown in Figure 1. HB = Hwabangjae, IH = Ihwaryeong, JS, Jeosuryeong, SD = Sabdangryeong, UD = Uduryeong, YS = Yuksipreong.

complex, so further research is necessary. Why do impacts resulting from the motor road not appear? According to the study results in Gwangneung, it was found that ant assemblages can rapidly change due to changes in the tree crown layer such as withering of tree branches (Kwon et al 2014b). However, the survey sites were typical forests so it is difficult to expect changes in the ant communities due to changes in the tree crown layer. The survey sites were mostly dark and moist, and had well developed litter layers. Therefore, it is difficult for disturbance preferred species to live in such conditions, and therefore it is difficult to expect changes in species structures due to the distance from the motor roads. Also, most of the ant species that live in Korean forests form new colonies after mating flights (Kwon et al 2011, 2012) so the population is not influenced by the fragmentation of the forest due to a road.

Although influences of roads and trails were not significant or vague, the influence of temperature on ant fauna was obvious. According to the studies on patterns of ant diversity, it was reported that temperature was the dominant factor in the Northern Hemisphere temperate regions (Sanders et al 2007; Kaspari et al 2003), and this is the same in the case of Korea (Kwon et al 2014b). Kwon and Lee (2015) inferred that when the distribution of ants is determined by climatic factors, there will be many instances in which the preferred climate conditions are similar between species and there will be more positive correlations for inter-species

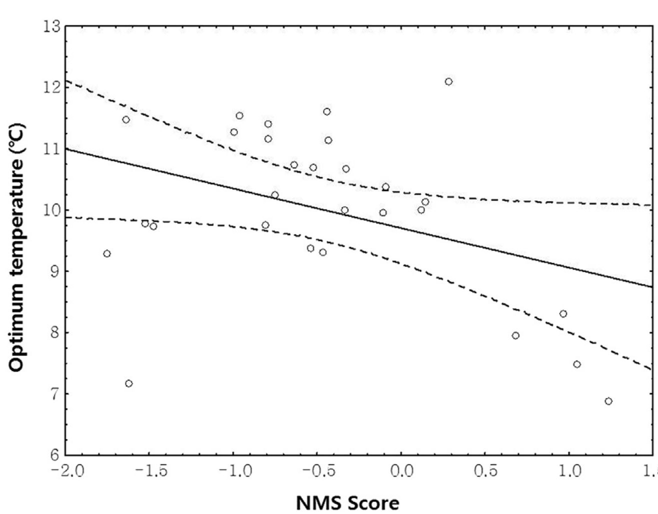

Figure 3. Optimum temperature and NMS (Nonmetric Multidimensional Scaling) score of ant species. Broken lines indicate 95% confidence values expected from the regression model.

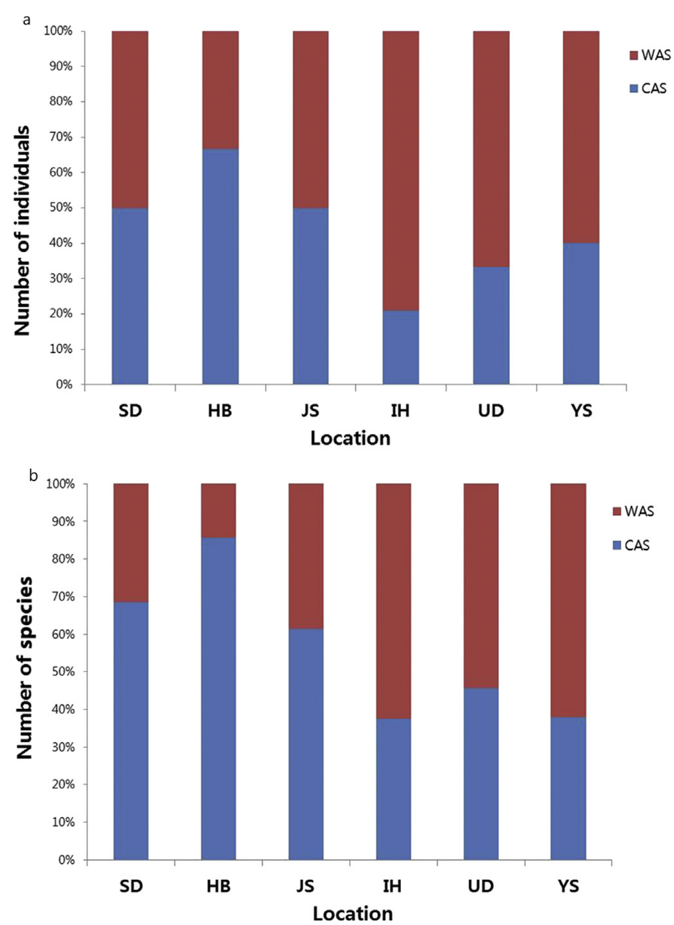

Figure 4. Proportion of warm-adapted species (WAS) and cold-adapted species (CAS): number of individuals. Grouping of WAS and CAS for Korean ant species are shown in Table S2, and the six study locations are shown in Figure 1. HB = Hwabangjae, IH = Ihwaryeong, JS, Jeosuryeong, SD = Sabdangryeong, UD = Uduryeong, YS = Yuksipreong.

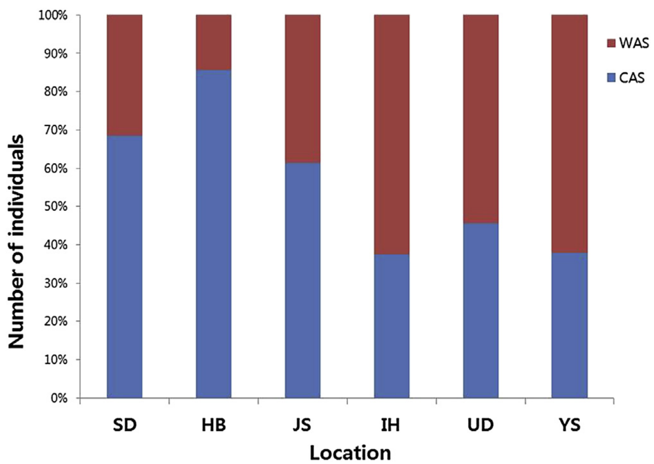

Figure 5. Proportion of warm-adapted species (WAS) and cold-adapted species (CAS): number of species. Grouping of WAS and CAS for Korean ant species are shown in Table S2, and the six study locations are shown in Figure 1. HB = Hwabangjae, IH = Ihwaryeong, JS, Jeosuryeong, SD = Sabdangryeong, UD = Uduryeong, YS = Yuksipreong.

correlation, and that if competition among species determines distribution, it will interfere with the habitation of other species, and there will be more negative correlations. Upon analyzing nationwide data, there were more than two fold positive correlations than negative correlations. The Baekdudaegan is the main mountain range of Korea, and therefore it may play preservation functions that promote the diversity of ants due to the rugged terrain features that increase diversity of habitats. A total of 28 species were found in this study which is similar to the 29 species found in the Gwangneung forest (~1000 ha; Kwon 2014). Twenty-eight species were found in the Hongneung Forest (41 ha) which is surrounded by downtown Seoul (Kwon et al 2011). This is lower than the 33 species found in the burned forests and pine forests in the eastern coastal region (12 sites in 4 locations for 8 years; Kwon et al 2013). It cannot be simply compared due to the different survey methods and scales used, but it is evident that ant diversity of the Baekdudaegan is not higher than that of other regions. Furthermore, there were no rare species or special species with high preservation value.

Table 2. Results from the generalized linear model to test the influence of local disturbances on the richness and abundance of ants.*

Year	Item	Environmental factors				
		Motor road	Trail	L	F	L × F
2006~2008	No of species	ns	ns	§	ns	‡
	No of individuals	§	§	†	ns	§
	Lasius spp. (jap.+al)	ns	ns	§	ns	§
	Pheidole fervida	ns	ns	§	ns	§
	Nylanderia flavipes	ns	†	§	ns	§
	Myrmica kotokui	†	ns	§	‡	ns
2009	No of species	ns		§	ns	§
	No of individuals	ns		ns	ns	ns
	Lasius spp. (jap.+al)	ns		ns	ns	ns
	Pheidole fervida	§		§	ns	ns
	Nylanderia flavipes	ns		§	ns	ns
	Myrmica kotokui	ns		§	ns	ns

* Factors of local disturbance are as follows: motor road indicates distance (m) from motor road, and trail indicates distance (m) from trail. Location means six study locations in Figure 1, and fragmentation means two sides (northward side and southward side, Figure 1) that are isolated by motor road. Underlined measures are consistent results between the first survey (2006–2008) and the second survey (2009).
† $p < 0.05$.
‡ $p < 0.01$.
§ $p < 0.001$.
F = fragmentation; L = location; ns = not significant.

Thus, the ants collected in this survey were composed of species easily found in other regions as well. However, it was slightly peculiar that *Myrmica kurokii* was not collected. This species is the most common species together with *M. kotokui* that has been always found in high altitudes exceeding 1000 m in South Korea (Kwon et al 2014a). The temperature range for this species is 3.9–10.6°C and the optimum temperature (abundance weighted) is 6.4°C (Table S1). Hence, the temperature conditions in SD (8.1°C) and HB (7.3°C) are slightly higher than the optimal temperature, but it is still within the habitable range, so the reason for its absence is questionable. Therefore, additional research is necessary to examine its absence in SD and HB. Unlike *M. kotokui*, *M. carinata* (3rd most common *Myrmica* species in South Korea) is more abundant in southern areas of JS, UD, and YS than in SD and HB. The optimal temperature for this species is 9.8°C which is similar to the temperature of UD and YS (Table S1). Unlike *M. kotokui* and *M. kurokii*, this species prefers mid-level altitudes and its optimal altitude is 475 m (Table S2). It is a common species in the north eastern coastal region of South Korea (Kwon et al 2013).

The Baekdudaegan is important not only symbolically, but also ecologically. As the Baekdudaegan blocks incoming winds, the eastern and western parts of the Baekdudaegan have clearly different climates. The reason why wet spells appear on one side (Yeongdong or Yeongseo region) of the Baekdudaegan and dry spells appear on the other side is due to the rainfall interception effect by the Baekdudaegan (Kim and Hong 1996). The side in which dry or wet spells occur depends on the wind direction. The climatic diversity and geological diversity created by the Baekdudaegan plays a definitive role in increasing the biodiversity of the Korean Peninsula. Compared with England, which has similar areas to the Korean Peninsula, it has approximately four times more butterfly species (Kim et al 2012). Although plants are diverse and unique in the Baekdudaegan (Cho et al 2005), the case is not the same with ants. The reason is that ants mainly live as scavengers or predators, thus having a wider range for selecting food (Hölldobler and Wilson 1990). Also, it is because their habitats can be easily discovered in forested area such as soils, fallen leaves, dead trees, cracks between stones, dead twigs, bark gaps, spaces within branches, and empty acorns. Various types of forest development occur around the Baekdudaegan and such damage acts as the biggest threat for preserving biodiversity (Kim et al 2010). Currently, the Baekdudaegan Arboretum is under construction and will take charge of preserving the plants living in the Baekdudaegan and will carry out research on the ecosystem. In order to preserve the various living organisms of the Baekdudaegan, it is necessary to conduct multidisciplinary research and to conserve its natural terrain from further development.

Acknowledgments

This study was conducted under the support of the Korea Forest Research Institute (Project FE 0100-2009-01, Effect of climate change on forest ecosystem and adaptation of forest ecosystem).

Appendix A. Supplementary data

Supplementary data related to this article can be found online at http://dx.doi.org/10.1016/j.japb.2015.05.001.

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