Journal of Asia-Pacific Biodiversity 8 (2015) 49–65

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Journal of Asia-Pacific Biodiversity

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

Original article

Prediction of abundance of ants according to climate change scenarios RCP 4.5 and 8.5 in South Korea

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ARTICLE INFO

Article history:
Received 12 January 2015
Accepted 26 January 2015
Available online 4 February 2015

Keywords:
abundance
ant
RCP 4.5
RCP 8.5
South Korea

ABSTRACT

In order to identify change of ant distribution expected due to climate change in South Korea, data on ants collected from 344 forest sites were used to predict change of abundance of ant species. In distribution of abundance along temperature gradient, 16 species displayed the patterns expected from normal distribution. For these species, abundance in temperature zones was used to link with temperature changes and predict the abundance. Temperature changes were based on Representative Concentration Pathways (RCP) 4.5 and 8.5, and the national average and distribution of abundance during the two periods from 2011 to 2015 and from 2056 to 2065 were predicted. The rate of change of ant abundance and the average temperature of the collection sites showed a clearly positive relationship. Based on these results, qualitative prediction (increase or decrease) was conducted for species with $\geq 1\%$ occurrence. The results showed that eight species would increase and 29 decrease, so the number of the decrease-expected species is three times more than that of the increase-expected species.

Introduction

The air and ocean temperatures on the globe are rising, and the sea level is also rising (Li et al 2013). Over the past 100 years, the global temperature rose by 0.74°C and the Korean temperature increased by 1.5°C (IPCC 2007; Kwon 2003). According to the recently reported climate change scenario (RCP 8.5), it is predicted that in 100 years the minimum temperature of May in the Korean Peninsula would increase by approximately 6.1°C and precipitation would increase, causing a rise in the frequency of extreme climates (Yun et al 2013). Temperature is one of the most important factors that determine the distribution of living organisms. Thus, when temperature rises, the organisms would move toward more suitable thermal conditions. In the Northern Hemisphere where temperature gradually decreases from the equator to the pole, it is expected that living organisms would also shift their range northward. Such predictions have been ascertained in various animal groups such as butterflies, spiders, birds, and fish (Hickling et al 2006; Konvicka et al 2003; Parmesan et al 1999). In South Korea, southern butterfly species have been shifting their northern margins northward, and the speed of margin shifts is almost consistent with the speed of the rise in temperature (Kwon et al 2014c).

Studies that predict changes in distribution according to climate warming are being conducted for various taxonomic groups (Kwon et al 2014d,e; Li et al 2013, 2014; Martinez-Meyer 2005; Neilson et al 2005). Ants are abundant in almost all land ecosystems excluding the polar regions; they are also important constituents in the food web and energy flow in the terrestrial ecosystems as carnivores, detritivores, and herbivores, while playing a very important role for the spreading of plants as a disperser of seeds (Stiles 2000). Ants build their nests in the soil, and supply oxygen and nutrition to the soil to improve its productivity (Folgarait 1998). Moreover, ants determine the structure of communities as the top predators in the biotic community in the soil. The lycanid butterflies that include many rare species maintain a symbiosis with ants, so change of ant fauna can affect the butterfly community. Therefore, it is expected that changes in the distribution of ants would have various effects on the ecosystem, and therefore, predicting the changes of ant distribution is crucial for identifying ecological changes due to global warming. However, predictions on changes

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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.2015.01.003

of ant distribution are limited to harmful ant species that are spreading worldwide and damaging the ecosystem (Dunn et al 2010), and the only study on changes in ant distribution on a national scale was reported by Kwon et al (2014e).

As temperature projections are different according to the various climate scenarios, projections of distributional shifts are different between the climate change scenarios. The Korean standard climate change scenario was recently changed from A1B to RCP 8.5. A recent study (Kwon et al 2014e) predicted changes in abundance and distribution of Korean ants according to the A1B climate change scenario. In this study, the changes in abundance and distribution of Korean ants were identified according to the new climate change scenarios of RCP 4.5 and 8.5, and the projections in these scenarios were compared with those in A1B.

Materials and methods

Study site

Ant sampling was carried out at 366 forest sites (Kwon et al 2014e), but errors in data were discovered in some of the sites, so data only from 344 sites were used for analysis (Figure 1). In order to select the sampling sites evenly, approximately eight sites were randomly assigned within a grid of 0.5° longitude and 0.5° latitude. The sampling sites also included 12 high mountains, over 1100 m above sea level, such as Hallasan, Seoraksan, Jirisan, Hwaaksan, Gyebangsan, Gariwangsan, Taebaeksan, Sobaeksan, Minjujisan, Deokyusan, Gayasan, and Unmunsan mountains. The three highest mountains in South Korea, Hallasan, Jirisan, and Seoraksan mountains, were included in these high mountains, where four to seven sampling sites were selected with an elevational interval of every 200–300 m. Sampling sites were selected from healthy forests having trees $\geq$ 30 years old, and moderately or well-developed understory vegetation. However, as the summits of high mountains are grasslands with bushes and small trees, these areas were selected as sampling sites. Information on sampling sites was provided by Kwon et al (2012).

Survey and identification of ants

The survey on ants was carried out between mid-May and mid-September for 4 years from 2006 to 2009. The environmental factors of the sampling sites and the weather at the time of investigation (period of installing pitfall traps) were reported by Kwon et al (2014d). Pitfall traps were used for ant sampling. Ten pitfall traps were set 5 m apart in a straight line for each sampling site and collected 10–15 days later. Traps were filled one-third with an automobile antifreeze liquid (polyethylene glycol, environment friendly, SK energy, Super A) as a preservation solution. The automobile antifreeze liquid does not have any role in attracting ants, and it is commonly used as a preservation liquid as it has a low evaporation rate and is suitable for the preservation of insect specimens. A plastic container (diameter: 9.5 cm, depth: 6.5 cm) was used as the trap container. When collecting the traps, the liquids in the container were filtered out using a fine iron mesh, and the remains including ant bodies were placed in the container and the lid was closed, which was then taken to the laboratory and treated with alcohol (100%) for preservation until identification. All specimens were identified at species or morphospecies level. The identification key was provided by Kwon et al (2012).

Analysis and prediction

Environmental factors

Based on the coordinates of the sites, Geographic Information System (GIS) was used to estimate the survey sites' temperature (annual average temperature, maximum temperature, and minimum temperature), annual rainfall, insolation, and vegetation index (NDVI (Normalized Difference Vegetation Index) values in May 2005). The temperature was estimated based on the digital map provided by the

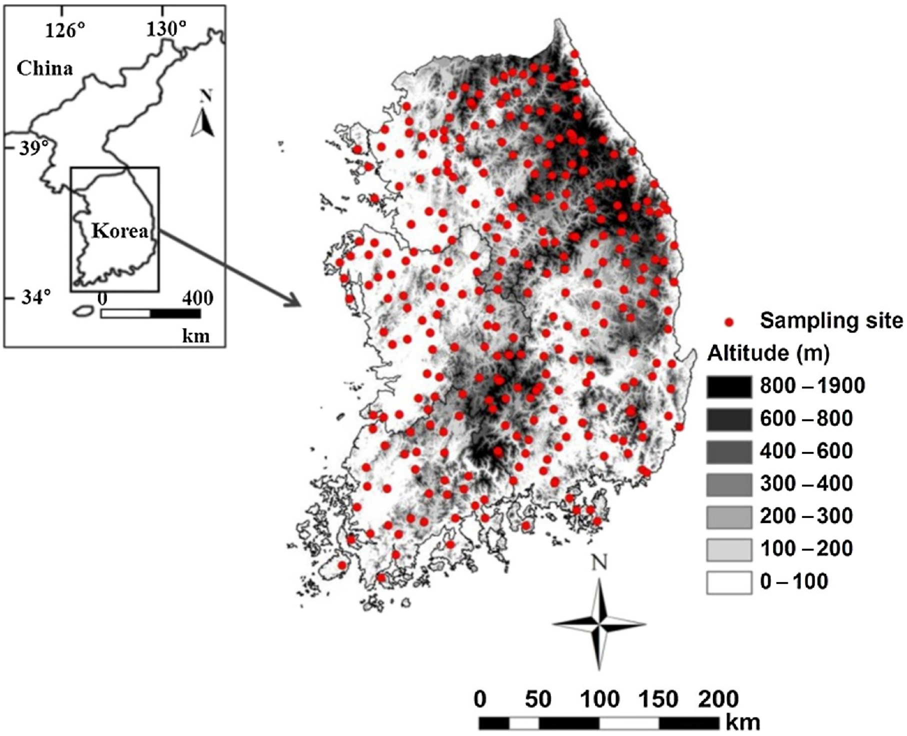


Figure 1. Distributions of sampling sites and patterns of digital elevations.

Korea Meteorological Administration and the National Center for Agro Meteorology (Yun et al 2013), and the average from 1971 to 2008 was used. The length of the spatial resolution grid was 30 m.

Relationship between environmental factors and abundance

The relationship between the abundance (proportion of collected traps, %) of 20 species with an occurrence of $\geq$ 10% and the environmental factors of the collection spots was analyzed using correlation analysis. Significance was determined at $p < 0.05$. Stepwise multiple regression analysis was used to create the multiple regression models for the abundance of candidate species.

Prediction of temperature change

The Korea Meteorological Administration developed and distributed a detailed climate change scenario for the Korean Peninsula (grid length of 12.5 km) as well as South Korea (grid length of 1 km) in 2012, based on the new climate change scenario to be used in the fifth evaluation report of the Intergovernmental Panel on Climate Change (Unites Nations). In this study, the average temperature distribution of the RCP 4.5 and 8.5 scenarios (1 km resolution) distributed by the Korea Meteorological Administration was used to predict the distribution of abundance from 2011 to 2015 and from 2056 to 2065 per grid (1 km^2).

Prediction of abundance

Generally, most species distribution models take into consideration various environmental factors. However, factors that can actually be predicted due to climate change are temperature and precipitation, but precipitation has great spatial and temporal variation (Yun et al 2013), giving it very low predictability compared to temperature. Accordingly, predictions are made with an assumption that factors other than temperature do not change in the model, including various environmental factors (i.e. ecological niche model). However, as other environmental factors would also change complicatedly together with climate change, such an assumption seems to be unrealistic. Therefore, rather than complex models that use various factors along with temperature, a simple model that only takes temperature into account would be more logically feasible and can be expected to reduce uncertainty due to the complexity of models. In this study, seven factors were used to create various multiple regression models, but their explanatory power was low at 4–44% (Table 1). Thus, in this study, the change of abundance was predicted using the average of abundance in temperature zones as follows.

When comparing the value of the determination index (R^2) using the correlation coefficient obtained through correlation analysis between abundance of the 20 species with an occurrence of $\geq$ 10% and environmental factors, the maximum and average of annual temperature were significantly higher compared to other environmental factors (minimum temperature, precipitation, vegetation index, and insolation; Kwon et al 2014e). However, the average temperature alone can explain only 10% of the variation of abundance (Kwon et al 2014e). This is due to the high variation of abundance among study sites (Figure 2) and the nonlinear relationship (i.e., unimodal tendency of abundance to be peak in optimal temperature zone) between temperature and abundance (Figure 3). When comparing the average of abundance in each temperature zone in order to find the patterns hidden in the high variation among the survey sites, a strong relationship between abundance and temperature emerged (Figure 3). In this study, the average temperature of the study sites was grouped into five temperature zones of 3–7°C, 7–9°C, 9–11°C, 11–13°C, and 13–15°C. to calculate the average and SE (standard error) of abundance in the temperature zones. When comparing the average abundance by temperature zone, it is likely that species with linear or unimodal (may be produced by normal distribution) patterns have a strong relationship with temperature. Analyses showed such distribution patterns along the temperature gradient for 16 of the 20 species (Figure 3). The abundance patterns of the four species that did not show such patterns are presented in Figure 4. The average abundance in each temperature zone was used for projection of abundance toward temperature changes (Table 2). The predicted years were the two periods from 2010 to 2015 and from 2056 to 2065, and the abundance in each temperature zone in two periods was estimated using values of the average abundance in Table 2. This study was conducted only on forested areas, so the analysis was applied only to the forests. Temperature zones of $\geq$ 15°C are not seen currently, so there are no data on the average abundance. Accordingly, abundance of these high-temperature zones was estimated using the 1–3 polynomial regression models (Figure 5). All GIS-related analyses were made using ArcGIS 10.1 (ESRI, Redlands, CA, USA).

Results and discussion

Change of temperature according to climate change scenarios RCP 4.5 and 8.5

When examining the change of temperature according to the climate change scenarios RCP 4.5 and 8.5 (Kwon et al 2014d), it is predicted that in 50 years' time, the average temperature of Korea will rise from 12.15°C to 13.3°C with RCP 4.5 and from 11.17°C to 14.41°C with RCP 8.5. The high-temperature zone of $>$ 15°C that does not appear in the current climate is expected to increase by 19% in RCP 4.5 and by 43% in RCP 8.5 in the next 50 years.

Abundance of ants and environmental factors

The occurrence of the 59 collected species and the temperature of the collection sites are shown in Appendix 1. Mean values of the annual average temperature of collection sites of the ant species

Table 1. Species distribution model by multiple regression model for the 10 candidate ant species.

Species	Korean name	Multiple regression model	R^2	p
Nylanderia flavipes	스미스개미	$y = -151.161 + 32.843{*}X_3 - 14.867{*}X_4 - 8.834{*}X_5$	0.305	0.000
Lasius spp. (*japonicus* + *alienus*)	고동털개미류	$y = 63.46211 - 0.02125{*}X_7$	0.053	0.0066
Aphaenogaster japonica	일본장다리개미	$y = -27.1487 + 0.0033{*}X_6$	0.044	0.022
Crematogaster osakensis	노랑꼬리치레개미	$y = -11.5264 - 0.0019{*}X_6$	0.086	0.000
Strumigenys lewisi	비늘개미	$y = -28.3645 + 6.5558{*}X_3 - 2.5367{*}X_4$	0.073	0.0003
Vollenhovia emeryi	에메리개미	$y = 36.11433 + 0.00186{*}X_6 - 0.01851{*}X_7$	0.098	0.000
Myrmica kotokui	코토쿠뿔개미	$y = 125.3537 - 3.7399{*}X_5$	0.437	0.0005
Camponotus atrox	홍가슴개미	$y = 37.57895 - 4.90579{*}X_3 - 2.20586{*}X_4 - 3.70723{*}X_5$	0.178	0.000
Pachycondyla chinensis	왕침개미	$y = 52.08856 - 7.81967{*}X_5 + 4.63113{*}X_4$	0.109	0.163
Myrmica kurokii	쿠로키뿔개미	$y = 112.0727 - 3.6620{*}X_5 - 0.0086{*}X_1$	0.377	0.000

Environmental factors: rainfall (X_1), insolation (X_2), mean temperature (X_3), minimum temperature (X_4), maximum temperature (X_5), NDVI (X_6), and altitude (X_7).

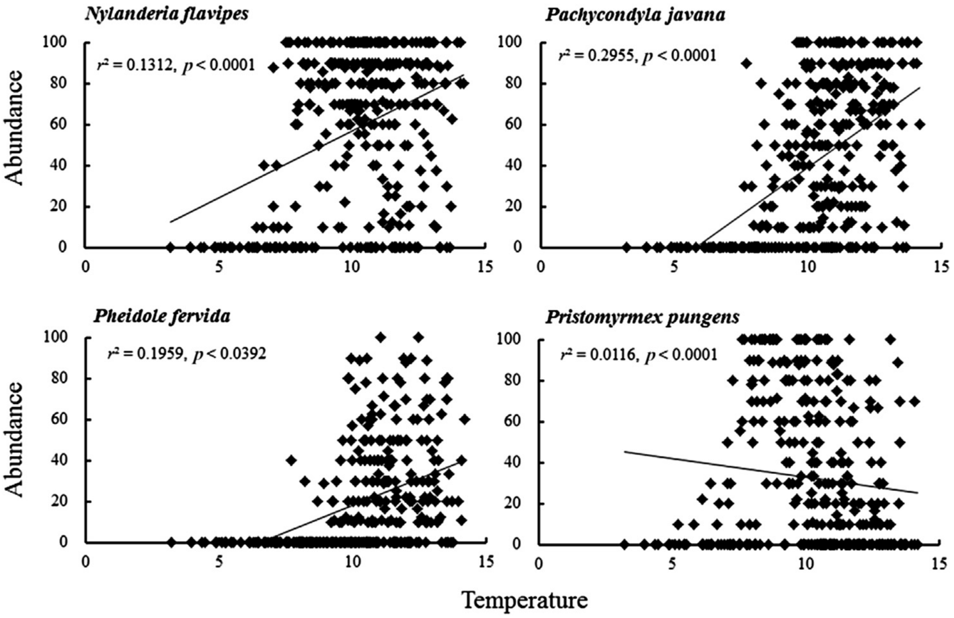


Figure 2. Temperature (annual mean) of collection sites and abundance (percent of collected traps) of the most common ant species.

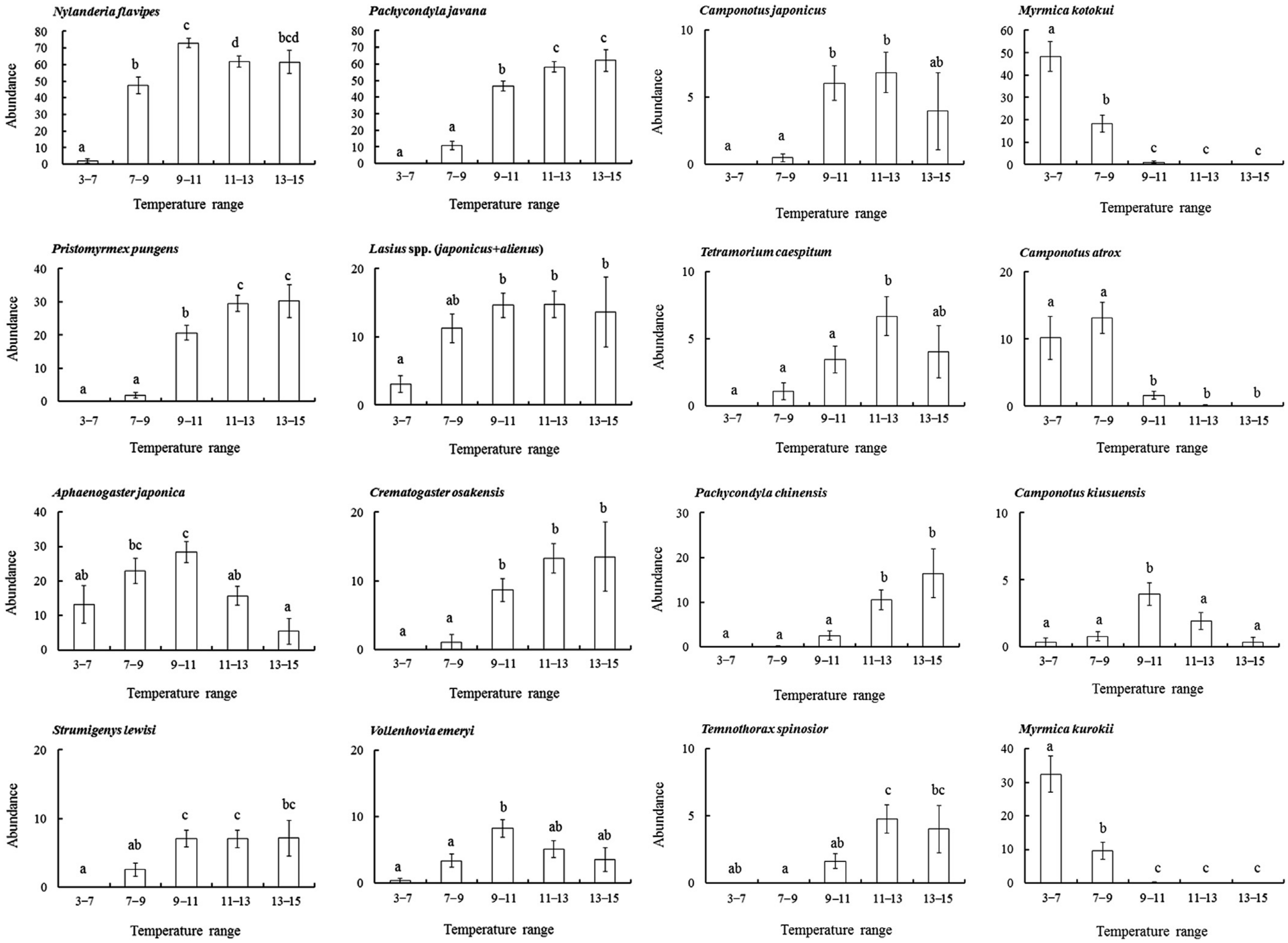


Figure 3. Abundance of 16 candidate ant species in five temperature bands. Abundance is percent of occurred traps in returned traps. Error bars mean one SE. Different letters indicate significant difference ($p < 0.05$) in Fisher LSD multicomparison test after one-way ANOVA. ANOVA = analysis of variance; LSD = Least Significant Difference; SE = Standard Error.

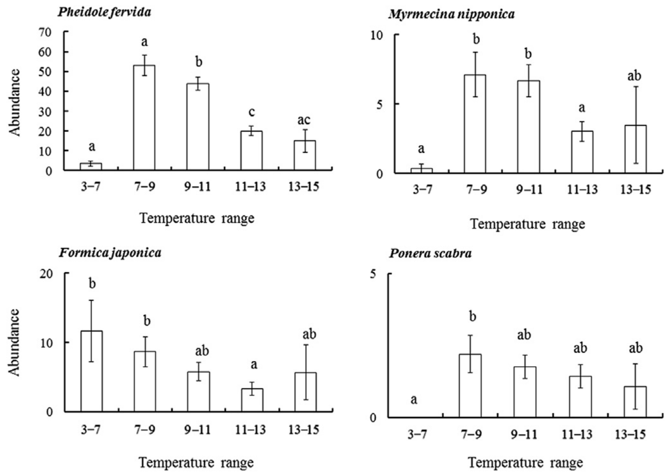


Figure 4. Abundance (number of individuals per trap) of four noncandidate common (>10% occurrence) ant species in five temperature bands. These species were not used for prediction of abundance, because their abundance patterns are irregular rather than continuous (linear or curved). *Formica japonica*, whose abundance pattern is continuous, is excluded because its abundance in the highest-temperature band (13–15°C) increased unexpectedly. Error bars mean one SE. Different letters indicate significant difference ($p < 0.05$) in Fisher LSD multicomparison test after one-way ANOVA. ANOVA = analysis of variance; LSD = Least Significant Difference; SE = Standard Error.

were most frequent in 10–12°C (Figure 6), and its occurrence was not significantly different from normal distribution (Kolmogorov–Smirnov test, $D = 0.083$, $p = 0.2$). As explained above, the environmental factors with the greatest impact on ant abundance were the maximum annual temperature and the average of annual temperatures (Kwon et al 2014e).

Prediction of abundance in ant species

Quantitative prediction of abundance

The abundance (national average of collection probability) of the 18 candidate species in two periods according to climate change scenarios RCP 4.5 and 8.5 is shown in Table 3. Among these, 10 species are expected to decrease in abundance, two are predicted to increase, and the remaining four have different predictions depending on the scenarios. The abundance and distribution change were described by species according to the order of occurrence (from highest to less).

Nylanderia flavipes

Nylanderia flavipes is the most common species in Korean forests, but also makes a colony in forest edges, shrub lands, grasslands, and even flowerpots of apartment (Kwon et al 2011). It is originally an East Asian endemic species found in Korea, Japan, and China, but it has recently been reported to occur in West Asia, North America, and Europe (Boer 2008; Collingwood et al 1997; Ellison et al 2012). *N. flavipes* forms a colony in soil, litter layer, and dead twigs of forests, and a colony is made up of dozens to hundreds of ants. This species is most subordinate in food competition of ants. It tends to search for food faster than other species, but when other species approach the food, it tends to give up the food rather than fight. This species showed the highest occurrence in this study and was collected in 78% of all sampling sites (Appendix 1). The temperature range was 6.4–14.2°C, and the mean of the average annual temperatures of the collection sites was 10.7°C (Appendix 1). Its abundance was predicted to decrease through all the climate change scenarios (RCP 4.5, −5.6%; RCP 8.5, −14.4%; A1B, −28.2%; Table 3). It is currently abundant in most forests excluding highlands, and the abundance is expected to be relatively low in coastal areas. However, it is forecasted that this species will also inhabit high altitudes in 50 years' time and low-density areas in lowland will be expanded (Figures 7 and 8).

Pachycondyla javana

Pachycondyla javana searches for food individually and is relatively indifferent to other species during foraging. This species showed the second highest occurrence, being collected in 69.4% of all sampling sites (Appendix 1). The temperature range was 7.6–14.2°C, and the mean of the average annual temperatures of collection sites was 11.1°C (Appendix 1). Its abundance was expected to increase through all climate change scenarios (RCP 4.5, +1.7%; RCP 8.5, +6.8%; A1B, +13.6%; Table 3). There were differences of the current distribution between scenarios, and for the nonoccurrence areas, compared to A1B (Kwon et al 2014e) and RCP 4.5, RCP 8.5 would have wider distribution in mountainous areas of Gangwon-do. In RCP 4.5, it was predicted that the species would not occur in very high altitudes. In RCP 4.5, the low-density areas in lowland will occur in the southern coastline, but in RCP 8.5, these areas will expand to Gyeongbuk (Figures 7 and 8).

Pristomyrmex pungens

Pristomyrmex pungens is a queenless ant, and movement of its colony was frequently observed in forest roads. An ant nest made

Table 2. Abundance (percent of occurred traps) in seven temperature bands used for prediction of ant abundance.

Species	Korean name	Temperature range (°C)						
		3–7	7–9	9–11	11–13	13–15	15–17	17–19
Nylanderia flavipes	스미스개미	2.0	47.5	72.9	61.9	61.5	25.1	0.0
Pachycondyla javana	일본침개미	0.0	10.8	46.5	58.2	62.2	22.6	0.0
Pristomyrmex pungens	그물등개미	0.0	1.8	20.7	29.5	30.2	1.4	0.0
Lasius spp. (*japonicus* + *alienus*)	고동털개미류	3.1	11.2	14.6	14.8	13.7	8.1	0.0
Aphaenogaster japonica	일본장다리개미	13.2	23.0	28.4	15.7	5.4	0.0	0.0
Crematogaster osakensis	노랑꼬리치레개미	0.0	1.1	8.6	13.3	13.5	1.5	0.0
Strumigenys lewisi	비늘개미	0.0	2.6	7.0	7.0	7.1	3.2	0.0
Vollenhovia emeryi	에메리개미	0.3	3.4	8.3	5.1	3.6	0.0	0.0
Camponotus japonicus	일본왕개미	0.0	0.5	6.1	6.9	4.0	2.0	0.0
Myrmica kotokui	코토쿠뿔개미	48.3	18.3	0.9	0.2	0.0	0.0	0.0
Tetramorium caespitum	주름개미	0.0	1.1	3.5	6.7	4.0	0.0	0.0
Camponotus atrox	홍가슴개미	10.1	13.1	1.6	0.1	0.0	0.0	0.0
Pachycondyla chinensis	왕침개미	0.0	0.2	2.5	10.5	16.4	18.9	23.2
Camponotus kiusuensis	갈색발왕개미	0.3	0.8	3.9	1.9	0.4	0.0	0.0
Temnothorax spinosior	긴호리가슴개미	0.0	0.0	1.6	4.8	4.0	0.0	0.0
Myrmica kurokii	쿠로키뿔개미	32.4	9.6	0.2	0.0	0.0	0.0	0.0

Abundance in 3–15°C is observed values (mean), and that in 15–19°C is estimated by polynomial regression models (Figure 5).

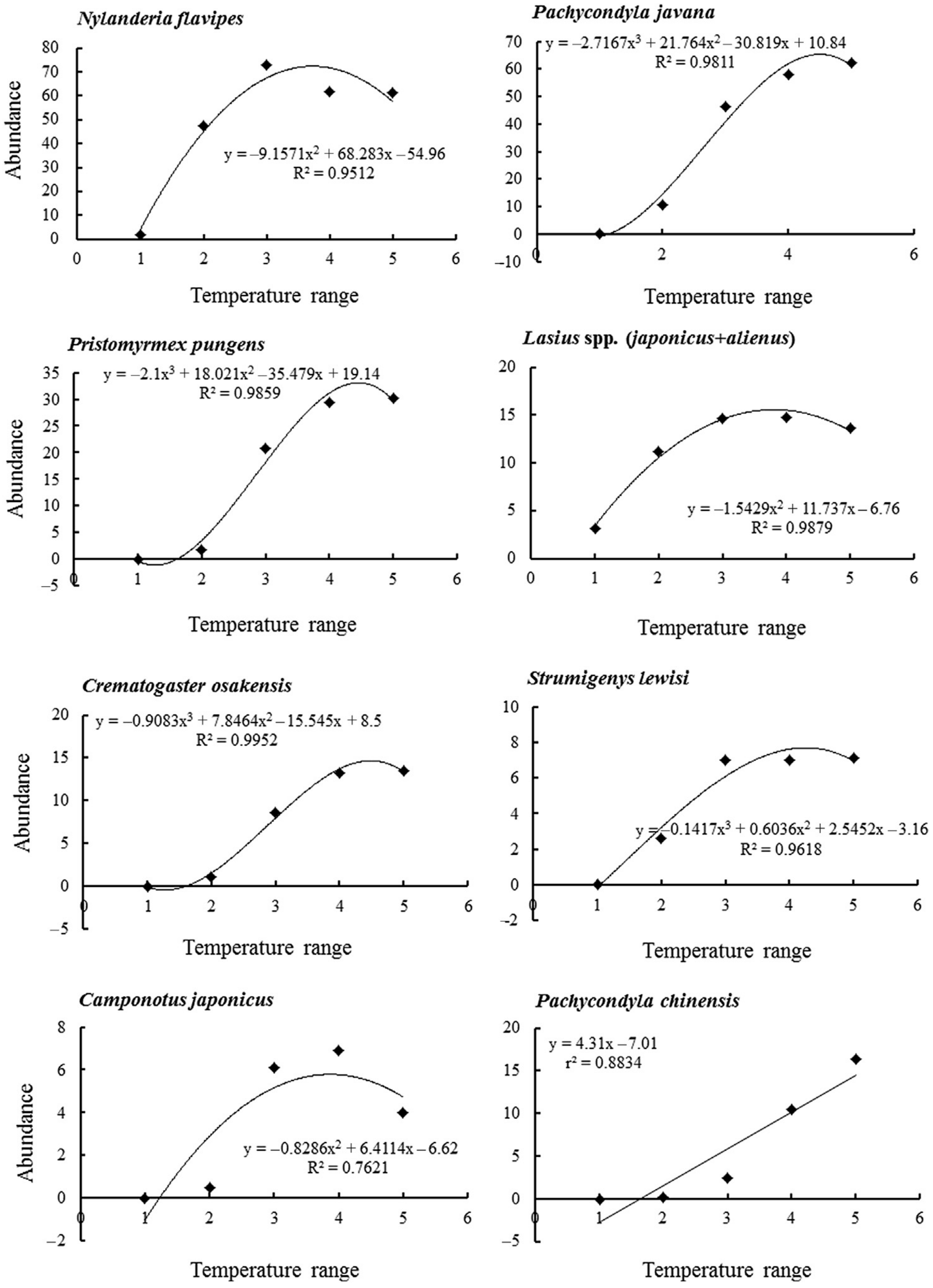


Figure 5. Polynomial regression models to estimate abundance of eight ant species in high-temperature zones (>15°C). Temperature zones—1: 3–7°C, 2: 7-9°C, 3: 9-11°C, 4: 11-13°C, 5: 13-15°C, and 6: >15°C.

with various plant materials between leaves of a shrub in a garden (approximately 1 m in height) has also been observed. *P. pungens* showed the fourth highest occurrence and was collected in 50% of all sampling sites (Appendix 1). The temperature range was 7.7–14.2°C, and the mean of the average annual temperatures of the collection sites was 11.4°C (Appendix 1). There were differences in change of abundance according to the climate change scenarios, and it was found that it will decrease in RCP 4.5 and 8.5 but increase in A1B (RCP 4.5, –1.5%; RCP 8.5, –3.5%; A1B, +31.4%; Table 3). It can be found nationwide in South Korea, but its occurrence was considerably lower in Gangwon-do (Kwon et al 2012, 2014e). It inhabits most forests excluding the alpine regions in South Korea, and its abundance is expected to be relatively lower in southern areas than in inland areas. However, as its range will shift upward in 50 years' time, there will be a turnover in abundance pattern that the southern areas where this species is currently abundant will become a nondistributed area (Figures 7 and 8).

Lasius spp. (japonica + alienus)

Lasius spp. (*japonica* + *alienus*) is abundantly found in forests, but it prefers open habitat such as grasslands and forest edges rather than forests (Kwon et al 2013). *Lasius* spp. (*japonica* + *alienus*) was the fifth highest in occurrence and were collected in 44.5% of all sampling sites (Appendix 1). The temperature range was 6.1–14.2°C, and the mean of the average annual temperatures of the collection sites was 10.4°C (Appendix 1). The optimum temperature of abundance was 10.8°C (Kwon 2014b). Its abundance was expected to decrease through all climate change scenarios (RCP

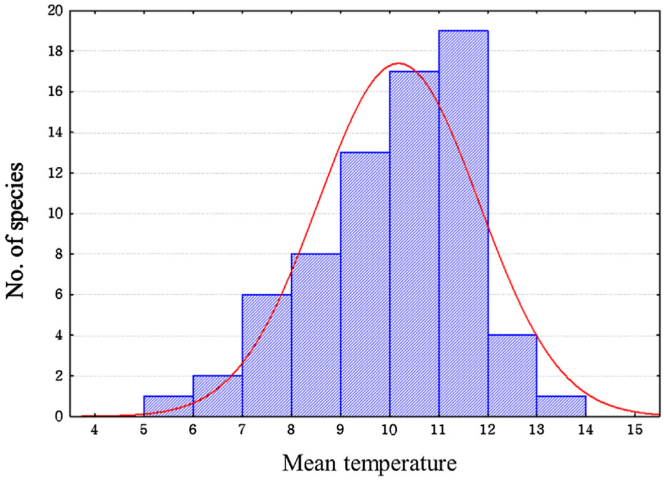


Figure 6. Histogram of temperatures (annual mean) of ant occurrence sites. This pattern is not significantly different from the normal distribution pattern (Kolmogorov–Smirnov test, $D = 0.083$, $p > 0.2$). Data for this figure are provided in Appendix 1.

4.5, −3.7%; RCP 8.5, −8.6%; A1B, −19.0%; Table 3). They are currently distributed nationwide (Kwon et al 2012) and abundant in most forests excluding the alpine regions. In 50 years' time, however, it is expected that they will inhabit high altitudes more abundantly than low altitudes. This will be more evident in RCP 8.5 (Figures 7 and 8).

Aphaenogaster japonica

Aphaenogaster japonica is a typical forest-dwelling ant species (Kwon et al 2011, 2013), and its density decreases when a forest is disturbed (Kwon et al 2014b). *A. japonica* is one of the dominant species in the food competition among ants in South Korea (Kwon, unpublished data). It was collected in 44.3% of all sampling sites (Appendix 1). The temperature distribution range was 6.1–13.5°C, and the mean of the average annual temperatures of the collection sites was 10.0°C (Appendix 1). The optimum temperature of abundance was 10.1°C (Kwon 2014b). Its abundance was predicted to decrease through all climate change scenarios (RCP 4.5, −26.7%; RCP 8.5, −59.6%; A1B, −78.6%; Table 3). Although it is currently distributed nationwide (Kwon et al 2012), in 50 years' time it is expected to be greatly declined in its distribution areas in the southern region (Figures 7 and 8).

Crematogaster osakensis

Crematogaster osakensis was collected in 26.5% of all sampling sites (Appendix 1). The temperature distribution range was 7.6–14.2°C, and the mean of the average annual temperatures of the collection sites was 11.5°C (Appendix 1). The optimum temperature of abundance was 11.6°C (Kwon 2014b). There were differences in the change of abundance between the climate change scenarios. In the RCP scenarios, little changes were expected, but in AIB, it was predicted to increase (RCP 4.5, −0.4%; RCP, 0.3%; A1B, +29.2%; Table 3). It distributes nationwide in South Korea; however, it was more frequently collected in Gyeongnam and Gyeonggi-do, while its occurrence in the Gangwon-do was lower (Kwon et al 2012). It is currently distributed with low density in most forests excluding the alpine regions of Gangwon-do, and its abundance shows decreasing patterns as altitude rises. However, after 50 years, *C. osakensis* is expected to dwell in such high altitudes, excluding the highest areas, and the distribution of abundance is also expected to become more homogenous. In RCP 8.5, it is expected that in the southern and western lowlands, there will be a large expansion of low-density or completely vanishing areas due to high temperatures (Figures 7 and 8).

Strumigenys lewisi

Strumigenys lewisi is a predator that preys on collembolan insects in litter layer or soil layer rather than on the surface (Kwon et al 2014b), and the species was collected in 24.6% of all samplings sites (Appendix 1). The temperature range was 7.7–14.2°C, and the mean of the average annual temperatures of the collection sites was 11°C (Appendix 1). The optimum temperature of abundance was 11.2°C (Kwon 2014b). There were differences by climate change scenarios, and decrease of abundance in RCP but increase in A1B are expected (RCP 4.5, −1.3%; RCP 8.5, −1.9%; A1B, +12.2%; Table 3). Although it is distributed nationwide in South Korea, it is rarely collected in the Chungnamdo and Jeollado (Kwon et al 2012). However, in the temperature distribution model, it was predicted that it would inhabit forests in most regions excluding the alpine regions of Gangwon-do. In RCP 8.5, it is forecasted that after 50 years, the species will also dwell in the highest altitudes, and its density will be declined greatly in the seaside areas (Figures 7 and 8).

Volenhovia emeryi

It is likely that *Volenhovia emeryi* is a predator that preys on mites in the litter layer or soil layer rather than on the surface, and

Table 3. Change of abundance of the 16 candidate ant species according to climate scenarios RCP 4.5 and 8.5, and A1B.

Species	RCP 4.5			RCP 8.5			A1B[a]		
	2011–2015	2056–2065	Change (%)	2011–2015	2056–2065	Change (%)	2011	2060	Change (%)
Nylanderia flavipes	61.7	58.2	−5.6	59.6	51.1	−14.4	67.2	48.2	−28.3
Pachycondyla javana	50.8	51.6	1.7	44.4	47.4	6.8	50.9	57.8	13.6
Pristomyrmex pungens	24.2	23.9	−1.5	20.9	20.2	−3.5	24.5	32.1	31.4
Lasius spp. (*japonicus* + *alienus*)	13.9	13.4	−3.7	13.4	12.3	−8.6	14.7	11.9	−19.0
Aphaenogaster japonica	16.6	12.2	−26.7	19.5	7.9	−59.5	21.0	4.5	−78.7
Crematogaster osakensis	10.8	10.7	−0.4	9.2	9.3	0.3	10.8	13.9	29.2
Strumigenys lewisi	6.5	6.4	−1.3	5.9	5.8	−1.9	6.9	7.7	12.2
Vollenhovia emeryi	5.2	4.3	−16.6	5.4	3.2	−41.2	6.2	2.3	−63.8
Camponotus japonicus	5.3	4.9	−8	5.0	4.1	−16.8	5.9	2.3	−60.3
Myrmica kotokui	2.6	1.0	−61	5.9	0.3	−94.5	4.0	0.1	−97.7
Tetramorium caespitum	4.6	4.2	−9.3	4.2	3.3	−21.5	4.8	2.2	−53.9
Camponotus atrox	1.7	0.8	−54.7	3.1	0.3	−91.1	2.4	0.1	−96.0
Pachycondyla chinensis	9.1	12.1	32.7	6.5	14.6	126.3	7.4	19.6	164.1
Camponotus kiusuensis	1.9	1.4	−26.4	2.1	0.9	−58.4	2.5	0.5	−81.6
Temnothorax spinosior	3.3	3.2	−1.2	2.7	2.7	0.1	3.2	1.9	−39.3
Myrmica kurokii	1.3	0.5	−64.7	3.4	0.1	−96.1	3.8	0.3	−91.2

[a] Data of A1B is from Kwon et al (2014e).

the species was collected in 23% of all sampling sites (Appendix 1). The temperature range was 4.9–14.2°C, and the mean of the average annual temperatures of collection sites was 10.5°C (Appendix 1). The optimum temperature of abundance was 10.7°C (Kwon 2014b). Decreased abundance was predicted through all climate change scenarios (RCP 4.5, −16.6%; RCP 8.5, −41.2%; A1B, −63.8%; Table 3). Although it is distributed nationwide in South Korea, its occurrence was lower in Gyeongnam and Jeonnam regions compared to the central regions in South Korea (Kwon et al 2012), and it was also ascertained by the current distribution using the temperature distribution model. It is predicted that as distribution shifts upward, the density in the southern lowlands will decrease (Figures 7 and 8). When *S. lewisi* and *V. emeryi*, which rarely dwell in the alpine regions of Gangwon-do, begin to inhabit these areas, it is expected to have a huge impact on the soil biotic communities.

Camponotus japonicus

Camponotus japonicus prefers open habitats such as grasslands and forest edges over forests (Kwon et al 2013, 2014b), and the species was collected in 18.3% of all sampling sites (Appendix 1). The temperature range was 8–13.6°C, and the mean of the average annual temperatures of collection sites was 11°C (Appendix 1). The optimum temperature of abundance was 11.2°C (Kwon 2014b). Decreased abundance was predicted through all climate change scenarios (RCP 4.5, −8.0%; RCP 8.5, −16.8%; A1B, −60.3%; Table 3). It was distributed nationwide in South Korea (Kwon et al 2012), and it appears to be of low density in most forests excluding the alpine regions. It is forecasted that with a rise in temperature, its habitat scope will rise to higher altitudes, and it will also show clear signs of decrease in the southern regions (Figures 7 and 8).

Myrmica kotokui

Myrmica kotokui is the most dominant species in the alpine regions, and in the national survey, it showed the 13th highest occurrence (15.8%; Appendix 1). However, in this study, when only the 12 high mountains of Korea were surveyed, its occurrence (number of collection sites) and abundance (number of individuals) were highest (Kwon et al 2014a). The temperature distribution range was 3.2–11.4°C, and the mean of the average annual temperatures of collection sites was 7.2°C (Appendix 1). The optimum temperature of abundance was 6.75°C (Kwon 2014b). A great decrease is expected in abundance through all climate change scenarios (RCP 4.5, −61.0%; RCP 8.5, −94.5%; A1B, −97.7%; Table 3). Currently, *M. kotokui* inhabits high altitudes with high abundance, but the abundance is expected to decline greatly (Figures 7 and 8). In RCP 8.5 and A1B, it is expected that the species will disappear almost from high altitudes by circa 2060, but in RCP 4.5, while the distribution areas will decrease heavily, it is expected to dwell in the areas with relatively high density (Figures 7 and 8; Kwon et al 2014e).

Tetramorium caespitum

Like *C. japonicus*, *Tetramorium caespitum* prefers open habitats, such as grasslands and forest edges, over forests (Kwon et al 2011, 2013), and the species was collected in 15% of all sampling sites (Appendix 1). The temperature distribution range was 7.6–13.6°C, and the mean of the average annual temperatures was 11.3°C (Appendix 1). Decreased abundance was predicted through all climate change scenarios (RCP 4.5, −9.3%; RCP 8.5, −21.5%; A1B, −53.9%; Table 3). It is distributed nationwide in South Korea, but its occurrence was higher in the eastern areas (Gangwon-do, Gyeongbuk, and Gyeongnam) than in the western areas (Gyeonggi-do, Chungnam, Jeonbuk, and Jeonnam; Kwon et al 2012). In A1B, after 50 years it will almost completely disappear from the central and southern regions where it currently exists in high abundance, and it is expected that it will spread its habitat range to the central northern alpine regions where it is rarely found at present (Kwon et al 2014e). In the RCP scenario, however, it will also decline in southern areas as it will migrate to higher altitudes, (Figures 7 and 8).

Camponotus atrox

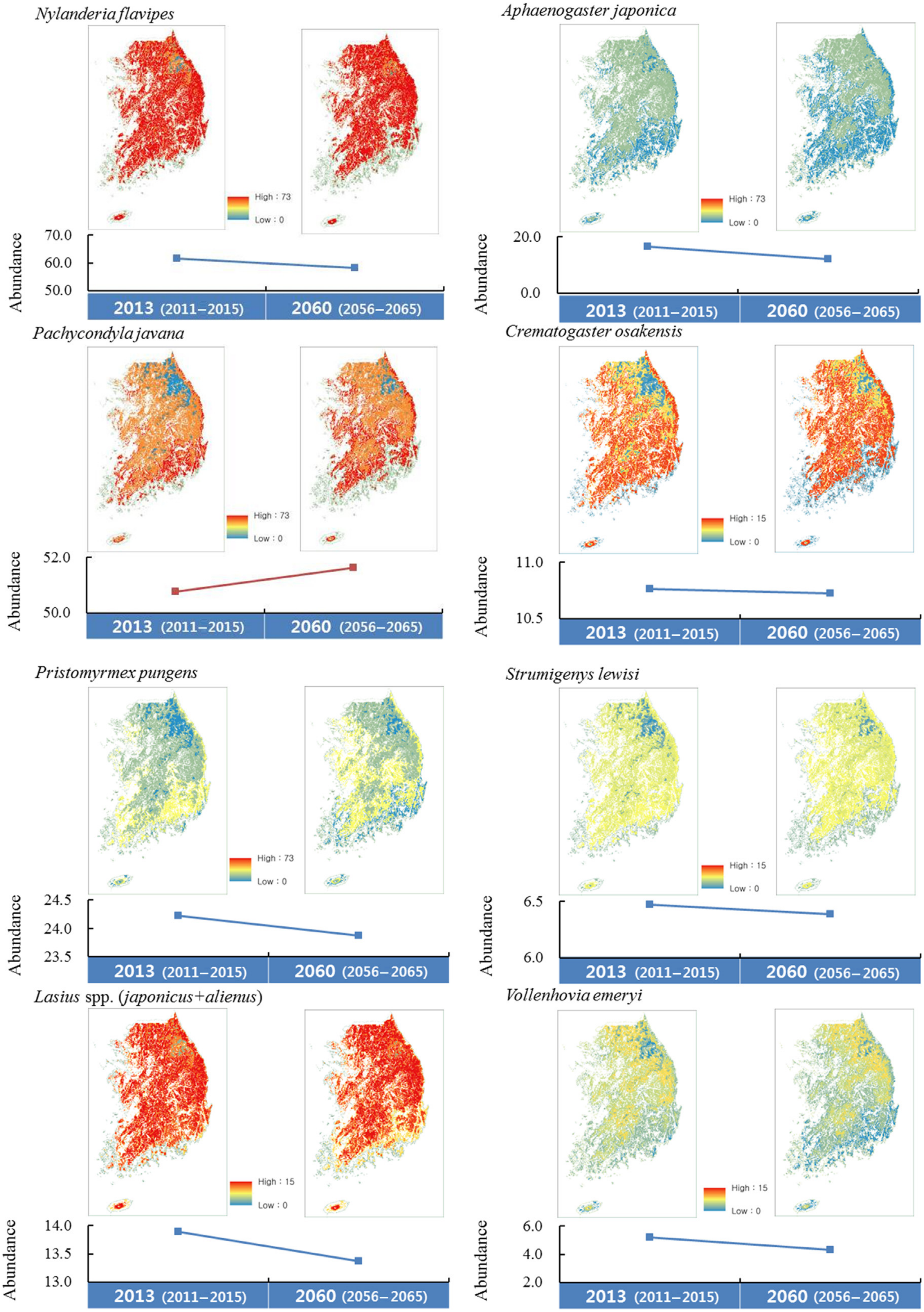
Like *M. kotokui* and *M. kurokii*, *Camponotus atrox* generally inhabits high altitudes (Kwon et al 2012, 2014a; Kwon 2014a) and the species was collected in 14.8% of all sampling areas (Appendix 1). The temperature distribution range was 5.5–11.4°C, and the mean of the average annual temperatures of collection sites was 8.1°C (Appendix 1). The optimum temperature of abundance was 8.04°C (Kwon 2014b). A large decline in abundance was predicted through all climate change scenarios (RCP 4.5, −54.7%; RCP 8.5, −91.1%; A1B, −96.0%; Table 3). It was mainly collected only in Gangwon-do (Kwon et al 2012), and it almost accorded with the prediction of the current distribution using the temperature distribution model (Figures 7 and 8). This shows that the extremely simple temperature distribution model developed in this study is useful for predicting the distribution of Korean ants. All three climate change scenarios predict that the distribution range would be considerably decreased (Figures 7 and 8; Kwon et al 2014e).

Pachycondyla chinensis

Three ant species under the genus *Pachycondyla* are found in Korea (Paek et al 2010), and unlike most Ponerinae species that are small in size and forage in the soil or litter layer, *P. chinensis* is relatively large and forage frequently over grounds, so it is captured easily by pitfall traps (Kwon et al 2012). *P. chinensis* was collected in 14.2% of all sampling sites (Appendix 1). The temperature range was 7.9–14.2°C, and the mean of the average annual temperatures of collection sites was 11.9°C (Appendix 1). The optimum temperature of abundance was 12.19°C (Kwon 2014b). Increased abundance is predicted through all climate change scenarios, and in RCP 8.5 and A1B, it is predicted that the species will greatly increase in abundance (RCP 4.5, +32.7%; RCP 8.5, +126.3%; A1B, +164.1%; Table 3). It is distributed nationwide in South Korea, but its occurrence in Gangwon and Gyeongbuk was very low (Kwon et al 2012). The distribution limited to the southern and western areas is expected to expand gradually; however, it is predicted that even after 50 years, it will not occur in high altitudes (Figures 7 and 8). This prediction is the same as that of A1B (Kwon et al 2014e).

Camponotus kiusuensis

As a large species, it is likely that *Camponotus kiusuensis* searches for food in the vegetation rather than on the ground. Although its distribution is nationwide in Korea, its occurrence was low in the southwestern areas of Chungnam, Jeollado, and Gyeongnam (Kwon et al 2012). In this study, *C. kiusuensis* was collected in 13.7% of all sampling sites (Appendix 1). The temperature range was 6.4–13.1°C, and the mean of the average annual temperatures of collection sites was 10.2°C (Appendix 1). The optimum temperature of abundance was 10.4°C (Kwon 2014b). Decreased abundance was predicted through all climate change scenarios (RCP 4.5, −26.4%; RCP 8.5, −58.4%; A1B, −81.6%; Table 3). It was collected in all areas excluding Chungnam (Kwon et al 2012), and the temperature distribution model predicts that it would be distributed in low density in all forests excluding high altitudes (Figures 7 and 8). In RCP 8.5, it is forecasted that its density will decrease in most areas when it will migrate to higher altitudes (Figures 7 and 8). In A1B, it is predicted to be distributed only in high altitudes (Kwon et al 2014e).



Nylanderia flavipes

Aphaenogaster japonica

Pachycondyla javana

Crematogaster osakensis

Pristomyrmex pungens

Strumigenys lewisi

Lasius spp. (*japonicus*+*alienus*)

Vollenhovia emeryi

Figure 7. Change of abundance in 16 candidate ant species according to climate scenario RCP 4.5. Abundance is percent of collected traps, which is equal to the probability of collection by a pitfall trap at a site.

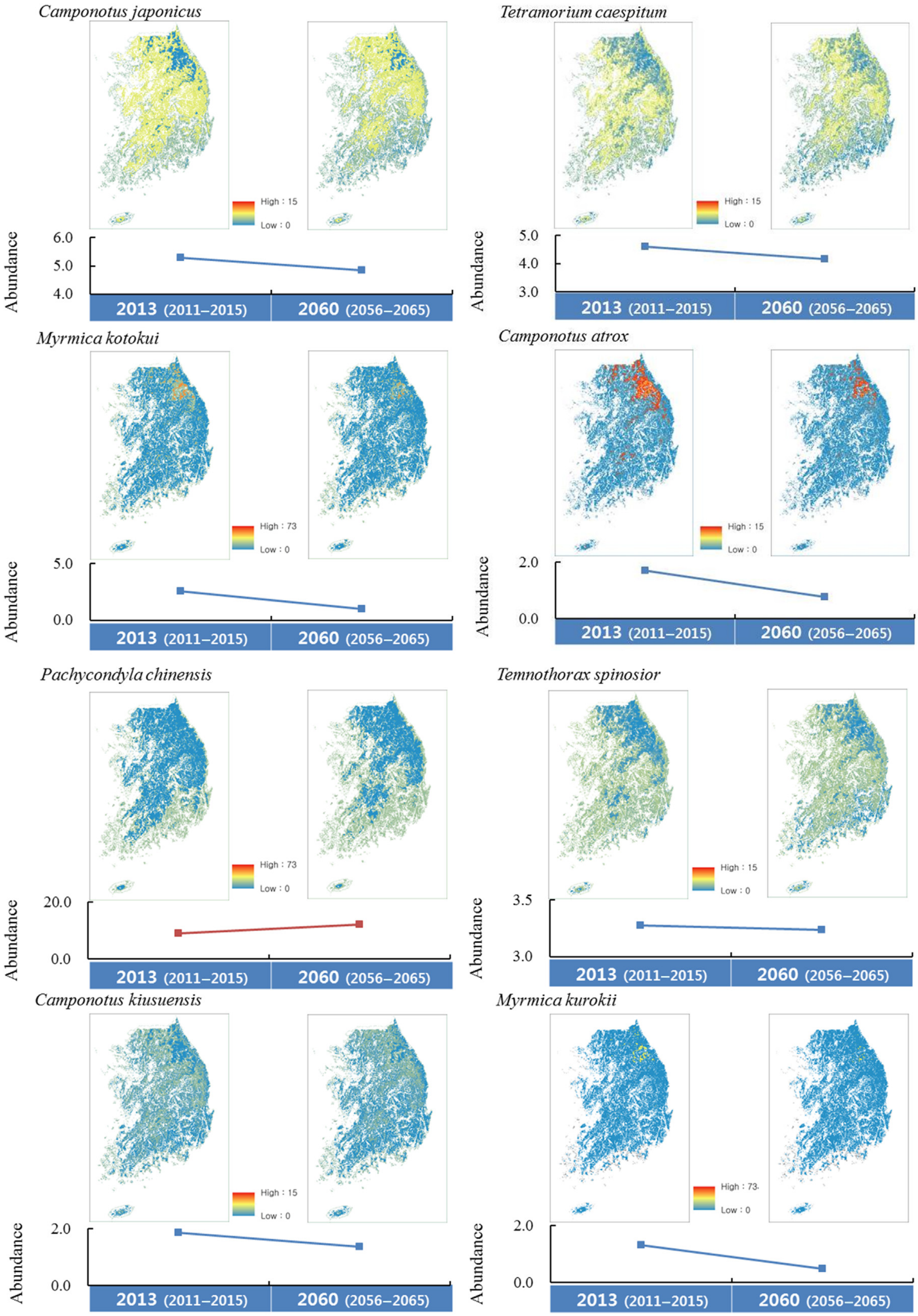


Figure 7. *(continued).*

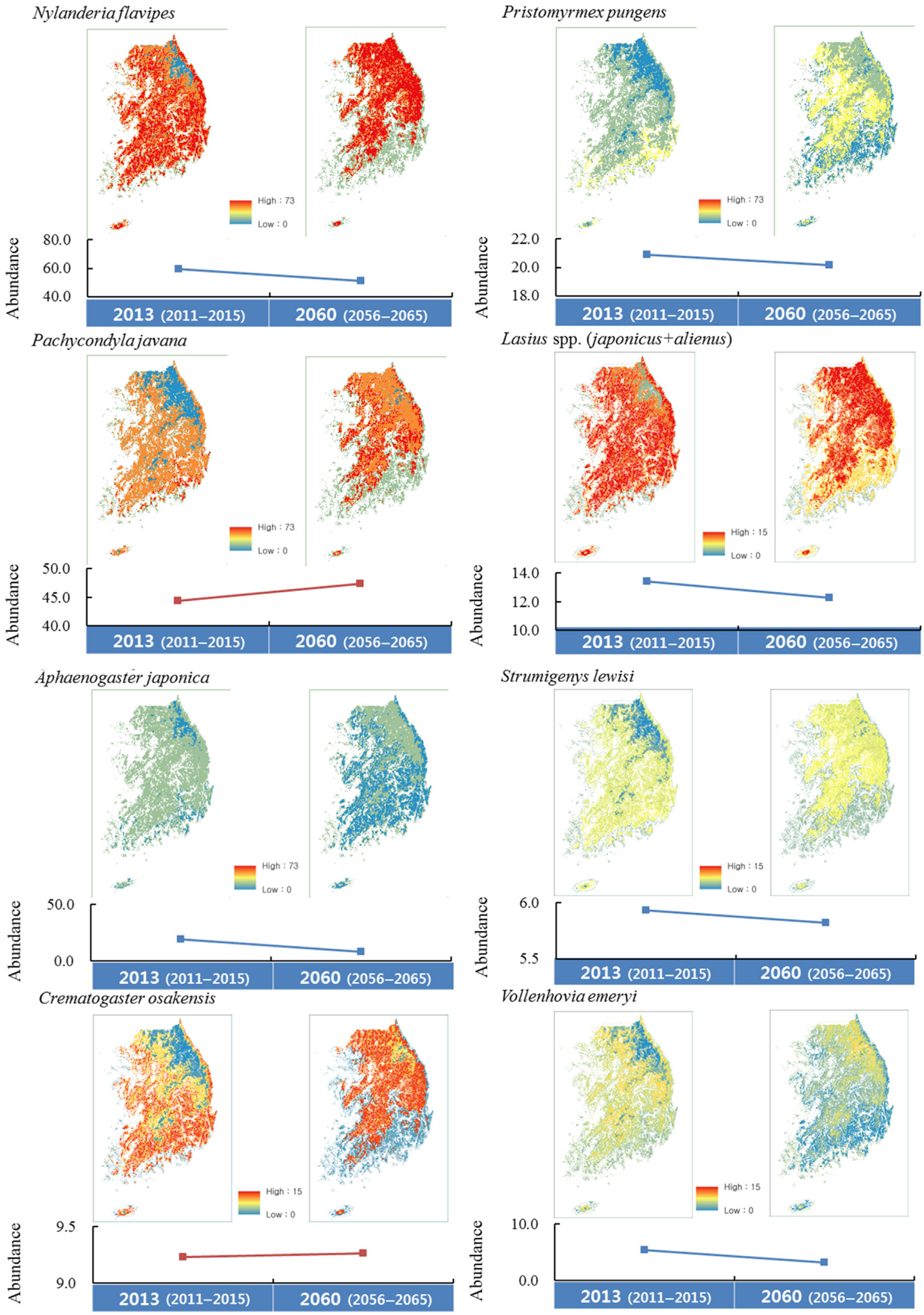


Figure 8. Change of abundance in 16 candidate ant species according to climate scenario RCP 8.5. Abundance is percent of collected traps, which is equal to the probability of collection by a pitfall trap at a site.

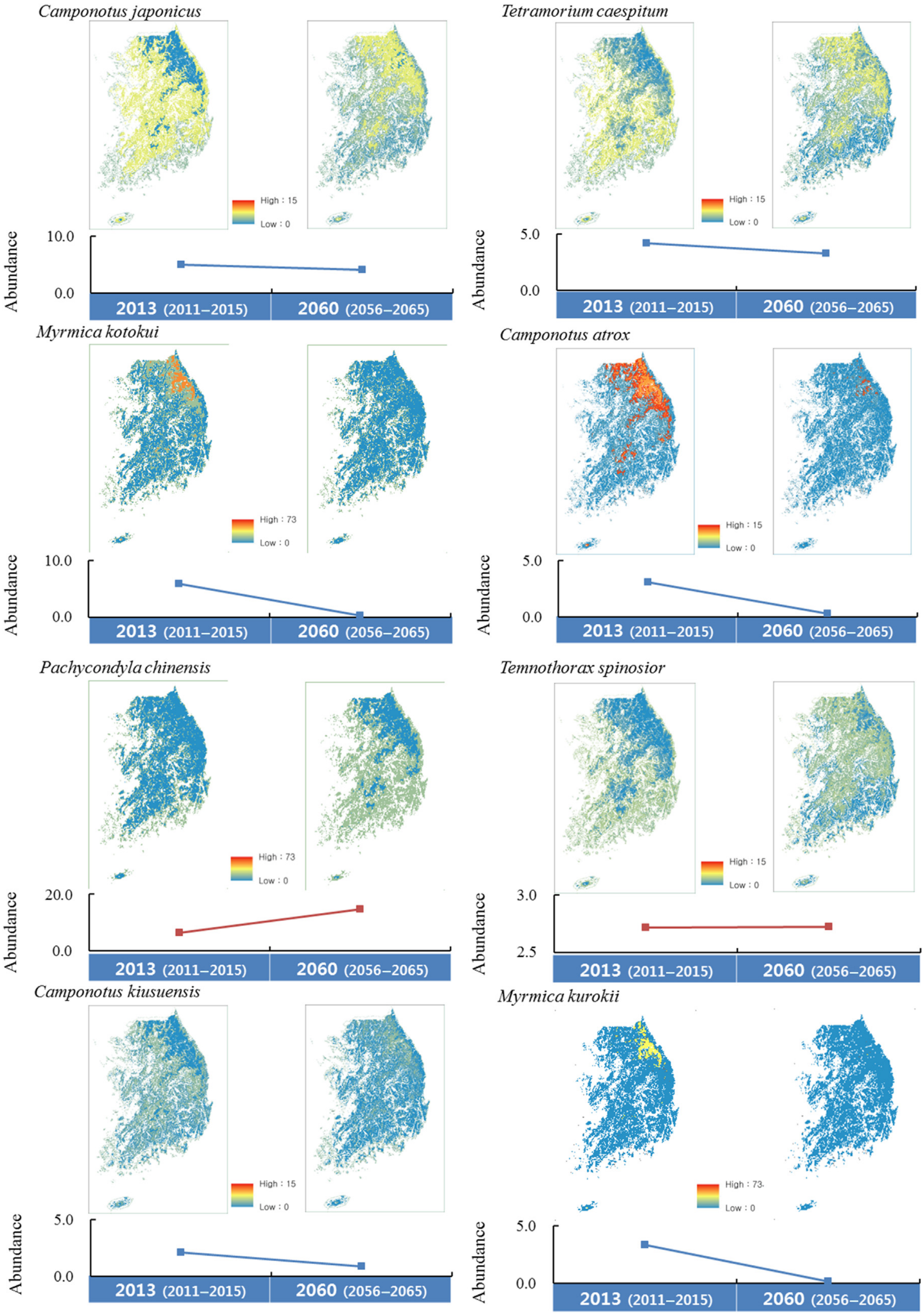


Figure 8. (*continued*).

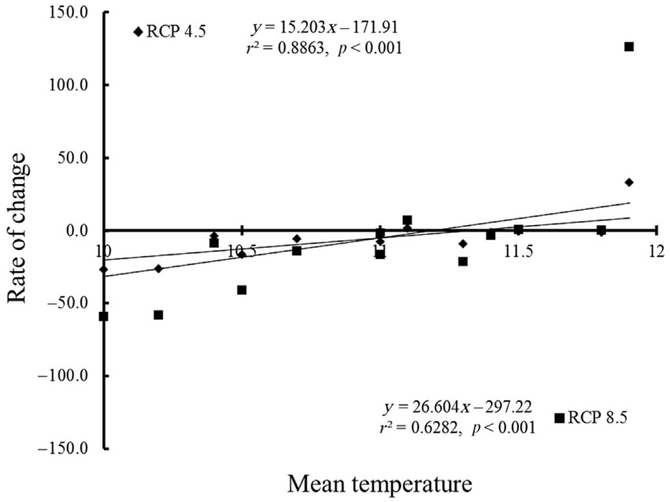


Figure 9. Average of the annual mean temperatures at the occurrence sites and the rate of change in abundance in the 16 candidate ant species for which abundance was quantitatively predicted according to the climate change scenario of RCP 4.5 (diamonds) and 8.5 (rectangles). The values for the rate of change in abundance are provided in Table 3.

Temnothorax spinosior

Temnothorax spinosior was collected mainly in the southwestern areas; in north eastern area, it was collected only at two sites in the provincial border of Gangwon-do and only in the southern area (near Pohang and Daegu) in Gyeongbuk (here it was identified as *Leptothorax* sp. 2; Kwon et al 2012). It was collected in 11.5% of all sampling sites (Appendix 1). The temperature range was 9.7–13.5°C, and the mean of the average annual temperatures of collection sites was 11.8°C (Appendix 1). The change in abundance was different between climate change scenarios; a slight decrease was predicted in RCP 4.5, little change in RCP 8.5, and moderate decrease in A1B (RCP 4.5, –1.2%; RCP 8.5, +0.1%; A1B, −39.3%; Table 3). Currently, *T. spinosior* inhabits most forests with low density excluding those at high altitudes; it is expected that the distribution range will be expanded when its distribution will shift to higher altitudes, and there will be places of disappearance in the southern region (Figures 7 and 8).

Myrmica kurokii

M. kurokii inhabits mostly high altitudes together with *M. kotokui*, but the species tends to show lower density and prefers higher altitudes (Kwon et al 2014a). In the national survey, it showed the 20th highest occurrence (15.8%; Appendix 1); however, when only 12 of the high mountains of Korea were surveyed, its occurrence and abundance were the second highest (Kwon et al 2014a). The temperature range was 3.2–10.6°C, and the mean of the average annual temperatures of collection sites was 6.6°C, which was the lowest temperature (Appendix 1). Largely decreased abundance was expected through all climate change scenarios (RCP 4.5, −64.7%; RCP 8.5, −96.1%; Table 3). It currently inhabits high altitudes with high abundance, but it is expected to nearly vanish after 50 years (Figures 7 and 8).

Qualitative prediction of abundance

For the species that were excluded from quantitative predictions due to the low relationship of abundance and temperature despite having occurrence of > 10% or of 1–10%, based on the quantitative prediction results, the abundance was predicted qualitatively with the three changes of increase, no change, or decrease. The relationship between the change rate of 16 candidate species and the average value of the annual mean temperatures of collection sites of these species is shown in Figure 9. The average of annual mean temperatures of collection sites had a linear relationship with the abundance change rate [100*(abundance in 2056–2065 – abundance in 2011–2015)/abundance in 2011–2015]. Therefore, based on the regression formula shown in Figure 9, the change rate becomes 0 at a temperature of 11.3°C in RCP 4.5 and 11.17°C in RCP 8.5. Thus, if the average value of temperature was between 11.17°C and 11.3°C, the abundance was determined to be not changed (no change); if the value was higher than the baseline, the abundance was determined to increase; and if the value was lower, the abundance was determined to decrease. Of the 23 species, six were determined to increase in abundance with the rise in temperature, 17 to decrease, and zero to be not changed (Table 4).

Table 4. Qualitative prediction of abundance for common ant species (>1% occurrence) except the 16 candidate species in Table 3.

Subfamily	Kor. subfamily	Species	Korean name	Change
Dolichoderinae	시베리아개미아과	*Dolichoderus sibiricus*	시베리아개미	Decrease
Formicinae	불개미아과	*Camponotus nipponensis*	털왕개미	Decrease
		Camponotus sp. 1		Decrease
		Formica japonica	곰개미	Decrease
		Lasius meridionalis	나도황개미	Decrease
		Lasius sp. (n.morisitai)		Decrease
		Lasius spathepus	민냄새개미	Decrease
		Polyrhachis lamellidens	가시개미	Decrease
Myrmicinae	두마디개미아과	*Crematogaster matsumurai*	마쓰무라꼬리치레개미	Decrease
		Mymica carinata	나도항아리뿔개미	Decrease
		Myrmecina nipponica	가시방패개미	Decrease
		Pheidole fervida	극동혹개미	Decrease
		Stenamma owstoni	오스톤개미	Decrease
		Temnothorax nassonovi	낫소노브호리가슴개미	Decrease
Ponerinae	침개미아과	*Cryptone sauteri*	장님침개미	Decrease
		Ponera japonica	침개미	Decrease
		Ponera scabra	거치른침개미	Decrease
Dolichoderinae	시베리아개미아과	*Technomyrmex gibbosus*	납작자루개미	Increase
Formicinae	불개미아과	*Camponotus* sp. 2		Increase
Myrmicinae	두마디개미아과	*Crematogaster brunea*	검정꼬리치레개미	Increase
		Crematogaster vagula	등굽은꼬리치레개미	Increase
		Solenopsis japonica	일본열마디개미	Increase
Ponerinae	침개미아과	*Proceratium itoi*	배굽은침개미	Increase

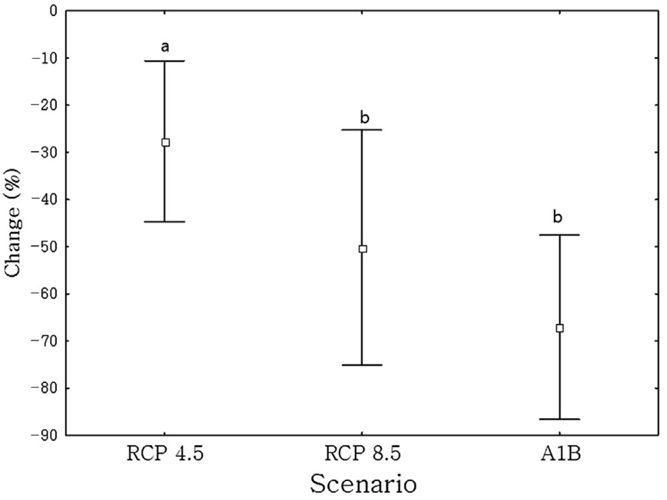


Figure 10. Average, with 95% confidence interval, of the abundance change rate (%) of the 10 decrease-expected ant species in three climate change scenarios. One-way ANOVA indicates the significant difference between groups ($F_{2,27} = 4.623$, $p < 0.05$). Different letters mean significant differences in Bonferroni multiple comparison test. ANOVA = analysis of variance.

Difference between climate change scenarios

When examining the temperature change according to climate change scenarios RCP 4.5 and 8.5 (Kwon et al 2014d), RCP 4.5 predicts that the average temperature of Korea will rise from 12.15°C to 13.3°C and RCP 8.5 predicts that the average temperature will rise from 11.17°C to 14.41°C. High temperatures > 15°C that rarely occur at present are expected to occur in 19% regions of the nation in RCP 4.5 and 43% in RCP 8.5 in 50 years' time. In A1B, the temperature in 2060 will rise by approximately 2.4°C compared to today (Li et al 2013), and high-temperature zones exceeding 15°C are expected to increase by approximately 53% (Kwon et al 2014e). The scale of the change of abundance increased in the order of RCP 4.5, RCP 8.5, and A1B (Figure 10). When comparing the rate of change of species expected to decrease in abundance, the average was −27.67 ± 7.54% (SE) in RCP 4.5, −50.21 ± 11.02% in RCP 8.5, and −67.05 ± 8.66% in A1B ($F_{2,27} = 4.623$, $p < 0.05$). In the case of species expected to increase, there were only a few species ($n = 2$), thus having no significance ($F_{2,3} = 0.426$, $p = 0.687$), but this trend appeared consistently (Table 3).

There were four species with different predictions between scenarios. These species show a small rate of change of < 4% in the RCP scenarios, and have relatively high average values of the annual mean temperatures of the collection sites. *P. pungens* and *S. lewisi* were predicted to decrease in the RCP scenarios and increase in the A1B scenario. *C. osakensis* was predicted to have slight changes in the RCP scenarios and an increase in the A1B scenario. By contrast, *T. spinosior* was predicted to have small changes in RCP but relatively large decreases in A1B. Korea is colder compared to the main distribution areas of these southern species, and as an intuitive judgment, these species are likely to increase in number than decrease with climate warming. While the binary predictions (increase or decrease) are consistent in case of most of the species (12 of 16 species are consistent), the differences in the remaining four species may be due to the difference of the target area of analysis (forest in RCP and all areas in A1B) and the size differences of cell grids used for temperature estimation (1 km^2 in RCP and 900 m^2 in A1B).

Ants in warming climate

Distribution of living organisms is determined by physiochemical factors such as temperature and biological factors such as competition (Krebs 1994). Since competition is a key factor that determines the structure of ant communities (Parr and Gibb 2010), it is expected that competition would have a great impact on the distribution change of ants according to climate change. In this study, however, influences of interactions between such species were not considered, and predictions were made on the presumption that the distribution of ants is determined by the single factor of temperature. This can be viewed to be the biggest limitation of this study. Realistically, however, it is difficult to create a

Table 5. Correlation between abundance of common (>10% occurrence) ant species.

	Nfl	Pja	Pfe	Ppu	Las	Aja	Cos	Sle	Mni	Vem	Fja	Cja	Mko	Tca	Cat	Pch	Cki	Psc	Tsp	Mku
Nfl	–																			
Pja	$\underline{0.50}$	–																		
Pfe	$\underline{0.35}$	0.08	–																	
Ppu	$\underline{0.39}$	$\underline{0.47}$	−0.06	–																
Las	$\underline{0.17}$	0.06	$\underline{0.18}$	$\underline{0.15}$	–															
Aja	−0.04	−0.02	−0.04	−0.03	0.00	–														
Cos	$\underline{0.26}$	$\underline{0.25}$	0.01	$\underline{0.35}$	$\underline{0.12}$	−0.03	–													
Sle	$\underline{0.31}$	$\underline{0.26}$	$\underline{0.15}$	$\underline{0.27}$	$\underline{0.17}$	0.05	$\underline{0.22}$	–												
Mni	$\underline{0.23}$	0.04	$\underline{0.23}$	0.08	$\underline{0.16}$	$\underline{0.24}$	$\underline{0.14}$	$\underline{0.14}$	–											
Vem	$\underline{0.23}$	$\underline{0.19}$	$\underline{0.2}$	$\underline{0.23}$	$\underline{0.11}$	$\underline{0.27}$	$\underline{0.15}$	$\underline{0.32}$	$\underline{0.31}$	–										
Fja	0.07	−0.05	$\underline{0.11}$	−0.08	$\underline{0.13}$	−0.02	−0.01	0.01	0.08	0.04	–									
Cja	$\underline{0.22}$	$\underline{0.26}$	−0.05	$\underline{0.19}$	$\underline{0.11}$	0.06	$\underline{0.19}$	$\underline{0.16}$	$\underline{0.11}$	0.03	0.07	–								
Mko	$-\underline{0.46}$	$-\underline{0.39}$	$-\underline{0.24}$	$-\underline{0.27}$	$-\underline{0.12}$	0.01	$-\underline{0.15}$	$-\underline{0.15}$	$-\underline{0.11}$	$-\underline{0.14}$	0.05	$-\underline{0.11}$	–							
Tca	$\underline{0.25}$	$\underline{0.21}$	$-\underline{0.11}$	$\underline{0.29}$	0.04	−0.09	$\underline{0.11}$	$\underline{0.11}$	−0.06	0.01	0.04	$\underline{0.17}$	$-\underline{0.11}$	–						
Cat	$-\underline{0.16}$	$-\underline{0.32}$	$\underline{0.12}$	$-\underline{0.24}$	−0.06	0.08	$-\underline{0.14}$	$-\underline{0.13}$	−0.02	−0.09	0.03	$-\underline{0.11}$	$\underline{0.26}$	$-\underline{0.11}$	–					
Pch	−0.04	$\underline{0.13}$	$-\underline{0.10}$	$\underline{0.22}$	0.01	−0.04	$\underline{0.12}$	0.02	−0.05	0.01	−0.09	−0.02	$-\underline{0.11}$	0.06	−0.10	–				
Cki	$\underline{0.16}$	$\underline{0.11}$	$\underline{0.15}$	0.02	0.02	$\underline{0.15}$	0.02	0.07	$\underline{0.13}$	$\underline{0.12}$	0.06	0.09	−0.09	−0.02	−0.07	0.00	–			
Psc	$\underline{0.14}$	−0.02	$\underline{0.13}$	−0.01	−0.04	$\underline{0.14}$	−0.01	0.03	$\underline{0.28}$	$\underline{0.17}$	0.05	0.00	−0.09	0.00	0.07	−0.06	$\underline{0.26}$	–		
Tsp	$\underline{0.21}$	$\underline{0.23}$	−0.05	$\underline{0.31}$	0.04	−0.07	$\underline{0.21}$	$\underline{0.16}$	−0.02	0.00	−0.03	0.04	$-\underline{0.11}$	$\underline{0.19}$	−0.10	$\underline{0.15}$	−0.02	−0.04	–	
Mku	$-\underline{0.43}$	$-\underline{0.33}$	$-\underline{0.20}$	$-\underline{0.22}$	$-\underline{0.15}$	0.03	$-\underline{0.13}$	$-\underline{0.13}$	−0.10	$-\underline{0.12}$	0.02	−0.10	$\underline{0.49}$	−0.10	$\underline{0.22}$	−0.09	−0.09	−0.06	−0.09	–

The underlined correlation coefficients are significant at $p < 0.05$.

Aja = *A. japonica*; Cat = *C. atrox*; Cja = *C. japonicas*; Cki = *C. kiusuensis*; Cos = *C. osakensis*; Fja = *F. japonica*; Las = *Lasius* spp. (*japonicus* + *alienus*); Mko = *M. kotokui*; Mku = *M. kurokii*; Mni = *M. nipponica*; Nfl = *N. flavipes*; Pch = *P. chinensis*; Pfe = *P. fervida*; Pja = *P. javana*; Ppu = *P. pungens*; Psc = *P. scabra*; Sle = *S. lewisi*; Tca = *T. caespitum*; Tsp = *T. spinosior*; Vem = *V. emeryi.*

prediction model (e.g., Bewick et al 2014) that takes into account competition factors in circumstances where the interaction among occurring species or the ecological characteristics are not clarified. Thus, even if a sophisticated model considering various factors is made, it would probably increase uncertainties for prediction due to complex interactions between factors, instead of improving the predictive accuracy compared to the temperature distribution model used in this study (Kwon et al 2014e). In the United States, it was reported that upon analyzing altitudinal distributions of two species of the genera *Aphaenogaster*, distribution shifted upward due to rising temperatures (Warren and Chick 2013). In the survey of investigating ants at Hallasan Mountain across altitudes, it was found that the distribution of *A. japonica* shifted to higher altitudes, while the abundance of ants of the genus *Myrmica*, which is the dominant species in high altitudes, tended to decrease in higher altitudes. Upon analysis of the diversity of ants across altitudes in the 12 high mountains of South Korea, the distribution of ants was mostly determined by temperature (Kwon 2014a; Kwon et al 2014a). Compared with the ant colonies at the Gwangneung forest 20 years ago, it was found to be consistent with the predictions due to temperature rise, and *M. kotokui*, which was the dominant species in high altitudes, was locally extinct (Kwon 2014b). In this study, this species is expected to be decreased.

If the distribution of ants is determined by physiochemical factors such as temperature, when correlation analysis is conducted using abundance of ant species, those species that prefer similar environments would have a positive correlation, and therefore, there would be more positive correlations than negative correlations. By contrast, if distribution is determined by interspecific competition than by abiotic factors, the species would interfere with the presence of other species, and therefore, there would be more negative correlations than positive correlations. In the event that the two factors act similarly or do not have any significant effects so that the correlation of the two types occurs randomly, the frequency of positive and negative correlations would become similar. A test to verify this prediction is provided in Table 5. In the correlation analysis using abundance for 20 species with occurrence of $> 10\%$ (Table 5), the number of positive correlations was 70, which is more than twice that of negative correlations (30) with a significant difference ($x^2 = 8.33$, df $= 1$, $p < 0.01$). This represents that distribution of Korean ants is mainly determined by abiotic factors such as temperature rather than by biotic factors such as interspecific competition.

From the quantitative and qualitative predictions on changes in abundance of Korean ants, six species were projected to increase in abundance with temperature rise and 17 species to decrease. Thus, the projections toward a decline of abundance are more than threefold than that toward an increase of abundance. Except this study and a study by Kwon et al (2014e), there are no studies that predicted the change of ant distribution on a regional or national scale, but Dunn et al (2010) predicted that the species diversity and abundance of ants in temperate regions are likely to increase upon global warming because the diversity and abundance of ant species and their ecological roles increase more in warmer regions. Deutch et al (2008) estimated a change of fitness based on the thermal range and optimum temperature for 38 insect species in the tropical and temperate regions. Since species in the temperate regions have a lower optimal temperature compared to the thermal conditions of their habitat, their fitness would rise with the increase of temperature. However, species in tropical regions live in habitats having temperatures near the optimum temperature; thus, their fitness would decrease if temperature rises. Although Deutch et al (2008) estimated fitness based on the maximum temperature, ranges of ants in the temperate forests are determined by coldness rather than by hotness (Kwon 2014a; Kwon et al 2014a; Warren and Chick 2013).

As noted above, the prediction obtained through this study is opposite to those of Dunn et al (2010) and Deutch et al (2008). In Korea, when analyzing the biogeography of butterflies, these insects are more of northern than of southern types (Kim and Seo 2012). The Korean peninsula is connected by land to the north, but it is separated by sea from other regions to the south. Therefore, more species come from the north than from the south, which is a biogeographical feature of a peninsula (Choi 2004). In the case of northern species that normally live in areas colder than Korea, when the temperature rises, they shift northward or upward, thus reducing the distribution area with a decrease of the national average of their abundance. Most species predicted to decrease in this study are such type of species. However, further studies are necessary to confirm which predictions are correct.

Appendix 1. Occurrence and temperature range of ant species that had been collected from a national survey conducted in 344 forest sites in South Korea from 2006 to 2009.

Species*	Korean name	Occurrence		Temperature		
		Site	%	Minimum	Maximum	Average
Nylanderia flavipes	스미스개미	287	78.4	6.4	14.2	10.7
Pachycondyla javana	일본침개미	254	69.4	7.6	14.2	11.1
Pheidole fervida	극동혹개미	215	58.7	5.2	14.1	10.5
Pristomyrmex pungens	그물등개미	182	49.7	7.7	14.2	11.4
Lasius spp. (*japonicus* + *alienus*)	고동털개미	163	44.5	6.1	14.2	10.4
Aphaenogaster japonica	일본장다리개미	162	44.3	6.1	13.5	10.0
Crematogaster osakensis	노랑꼬리치레개미	97	26.5	7.6	14.2	11.5
Strumigenys lewisi	비늘개미	90	24.6	7.7	14.2	11.0
Myrmecina nipponica	가시방패개미	86	23.5	4.3	13.6	10.1
Vollenhovia emeryi	에메리개미	84	23.0	4.9	14.2	10.5
Formica japonica	곰개미	80	21.9	3.2	13.6	9.6
Camponotus japonicus	일본왕개미	67	18.3	8.0	13.6	11.0
Myrmica kotokui	코토쿠뿔개미	58	15.8	3.2	11.4	7.2
Tetramorium caespitum	주름개미	55	15.0	7.6	13.6	11.3
Camponotus atrox	홍가슴개미	54	14.8	5.5	11.4	8.1
Pachycondyla chinensis	왕침개미	52	14.2	7.9	14.2	11.9

(*continued on next page*)

(*continued*)

Species[*]	Korean name	Occurrence		Temperature		
		Site	%	Minimum	Maximum	Average
Camponotus kiusuensis	갈색발왕개미	50	13.7	6.7	13.1	10.2
Ponera scabra	거치른침개미	43	11.7	7.1	13.5	10.2
Temnothorax spinosior	긴호리가슴개미	42	11.5	9.7	13.5	11.8
Myrmica kurokii	쿠로키뿔개미	38	10.4	3.2	10.6	6.6
Mymica carinata	나도항아리뿔개미	35	9.6	7.7	12.1	9.8
Lasius spathepus	민냄새개미	33	9.0	6.8	12.6	10.1
Cryptone sauteri	장님침개미	33	9.0	6.2	13.5	10.1
Crematogaster vagula	등굽은꼬리치레개미	27	7.4	8.8	13.1	11.4
Temnothorax nassonovi	낫소노브호리가슴개미	27	7.4	6.1	11.6	8.7
Stenamma owstoni	오스톤개미	24	6.6	4.0	10.6	7.7
Polyrhachis lamellidens	가시개미	23	6.3	7.7	12.8	10.6
Camponotus nipponensis	털왕개미	18	4.9	7.7	12.1	9.7
Crematogaster matsumurai	마쓰무라꼬리치레개미	17	4.6	9.7	12.7	11.1
Proceratium itoi	배굽은침개미	16	4.4	9.0	14.1	12.1
Camponotus sp. 1		15	4.1	7.6	13.5	10.8
Technomyrmex gibbosus	납작자루개미	14	3.8	8.1	14.1	11.4
Solenopsis japonica	일본열마디개미	12	3.3	9.6	14.1	11.6
Crematogaster brunea	검정꼬리치레개미	9	2.5	10.4	13.5	12.0
Dolichoderus sibiricus	시베리아개미	9	2.5	8.8	10.7	9.8
Lasius meridionalis	나도황개미	7	1.9	6.2	11.3	9.1
Camponotus sp. 2		7	1.9	10.0	13.5	12.1
Ponera japonica	침개미	6	1.6	7.6	11.8	9.5
Lasius sp. (n.morisitai)		4	1.1	10.1	11.1	10.6
Lasius teranishii	테라니시털개미	3	0.8	7.5	10.2	8.7
Technomyrmex albipes	흰발납작자루개미	3	0.8	11.4	12.6	11.9
Plagiolepis flavescens	노랑잘록개미	3	0.8	8.7	13.2	10.6
Lasius talpa	두더지털개미	2	0.5	12.0	12.6	12.3
Monomorium intrudens	배검은꼬마개미	2	0.5	12.5	14.2	13.3
Formica yessensis	불개미	2	0.5	6.9	8.6	7.8
Nylanderia sakurae	사쿠라개미	2	0.5	8.0	11.7	9.8
Dacatria templaris	등뿔개미	2	0.5	11.0	12.5	11.8
Pyramica japonica	톱니비늘개미	2	0.5	9.9	13.2	11.6
Plagiolepis pygmae	남색개미	1	0.3	12.0	12.0	12.0
Myrmecina flava	노란방패개미	1	0.3	10.6	10.6	10.6
Formica sanguinea	분개미	1	0.3	10.0	10.0	10.0
Hypoponera sauteri	사우터침개미	1	0.3	11.4	11.4	11.4
Messor aciculatus	짱구개미	1	0.3	9.6	9.6	9.6
Lasius hayashi	하야시털개미	1	0.3	7.9	7.9	7.9
Lasius flavus	황개미	1	0.3	12.0	12.0	12.0
Iridomyrmex sp. 1		1	0.3	9.2	9.2	9.2
Myrmica sp. (n. *rubra*)		1	0.3	8.9	8.9	8.9
Myrmica sp. 3		1	0.3	7.6	7.6	7.6
Myrmica sp. 4		1	0.3	6.5	6.5	6.5

[*] Species are listed according to their order of occurrence.

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