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Original article

Prediction of abundance of ants due to climate warming in South Korea

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ABSTRACT

Among the 57 species of ants collected from 366 forest sites, 16 candidate species whose abundance has a close relation with temperature were selected to predict the changes in distribution and abundance according to the A1B climate change scenario. The results showed that, when the temperature rises, the abundance of 11 species is expected to decrease, whereas five species are expected to increase. Based on the qualitative estimation, the abundance of 10 species among the 31 species is predicted to increase, whereas that of 21 species is projected to decrease. The abundance of 32 species among 57 species was expected to decrease due to climate changes, whereas 15 species was expected to increase; the number of species expected to decrease was more than two times that of species that are expected to increase.

Introduction

As environmental changes due to climate warming have recently become known as serious problems, social demands for studies focusing on the influences of climate changes on the ecosystem have gradually increased (Choi and Choi, 2011). The first step for such climate change impact research is to select indicator species suitable for the research. For insects, research studies have been most actively conducted on butterflies. Although there were many attempts to study other insects such as beetles, significant results like those found in butterflies have not yet been produced. Ants are very likely to be an indicator species for monitoring environmental changes owing to their sedentary habit, long activity season, high diversity and density, and high relation with environmental factors. For these reasons, 31 researchers in six countries proposed a standard monitoring method to activate monitoring of ants (Agosti et al., 2000). There have been many studies that have used ants as an indicator species for various environmental changes (e.g. changes in habitats). Oddly enough, studies on the influence of climate changes with ants are rare: only results of research on changes in the distribution of harmful ants that emerged as a global challenge were reported.

Based on the present distribution of the Argentine ants, *Linepithema humile* Mayr, changes in their global distribution, which were caused by climate warming, were expected through ecological niche modeling (Roura-Pascual et al., 2004). The Argentine ants have not yet established a foothold in Southwestern Asia and in the seashores of Tropical Africa, but have the potential to expand to these regions. If climate warming continues to proceed, the distribution of Argentine ants will decrease in the tropical regions but could expand to high latitude regions. This species is currently not found in Korea, but it is suitable for their inhabitation. In the 2050s, the thermal environment of the Korean peninsula will no longer be favorable for their inhabitation, whereas conditions will be better for them in Manchuria. Fire ants (*Solenopsis invicta* Baren), which are native to South America, invaded the southern regions of the United States and are now rapidly expanding. Based on the temperature and rainfall in the habitats of the species in the United States, changes in their distribution by climate warming are globally expected, according to the CLIMEX model (Sutherst and Maywald, 2005).

Choi (1985) investigated the distribution of ants in Halla, Seolak, Sokri, Sobaek, and Wolak Mountains, and then reported the vertical

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distribution of ant species that inhabited specific altitudes. The results of this report were obtained using qualitative methods such as colony collection. To determine the vertical distribution of ants, quantitative investigation using the pitfall trap method was carried out at various altitudes (200 m, 400 m, 1300 m, 1600 m, and 1900 m) in Jeju Island in 2006, confirming the vertical distribution of ants. This vertical distribution of ants is a result of the specific thermal ranges because the temperature decreases by 0.5–0.6°C for every 100 m increase in altitude in the mountains. This phenomenon is also found in 12 high mountains in South Korea by Kwon et al., (2014), who proved that the thermal regimes mainly determine the distribution of ants.

Thus, it is possible to make the distribution model of ants with respect to temperature. Based on this, it is possible to expect changes in abundance and distribution of ants caused by climate changes. This study was performed to expect changes in the distribution of ants with respect to the temperature in Korea. A total of 366 sites, including 65 sites in 12 high mountains (with altitudes >1100 m), were selected for this survey. To exclude the effects of habitats on ants, only healthy forests were selected. The results of prediction obtained in this study will be useful later for a hypothesis to verify changes in the distribution of ants caused by climate changes.

Materials and methods

Survey sites

To uniformly select the 366 sites used in this study, eight sites were selected in a grid cell of latitude 0.5° and longitude 0.5° (mean ± SD, 8.3 ± 1.8; 6–13). The study sites include 12 high mountains (with altitude >1100 m)—Halasan, Seolaksan, Jirisan, Gyebangsan, Gariwangsan, Taebaeksan, Sobaeksan, Hwaksan, Minjujisan, Deokyusan, Gayasan, and Unmunsan Mountains. Among these mountains are three of the highest mountains (Halasan, Seolaksan, and Jirisan) in South Korea. In every mountain, four to seven survey sites were selected at every 200–300 m of the altitude. For our survey sites, we selected only healthy forests that were more than 30 years old and where understory vegetation has developed. Study sites on the summits of high mountains are located in shrublands.

Sampling methods

Ants were investigated with the pitfall trap method, in which 10 pitfall traps were installed in series at every 5 m and polyethylene glycol (environment-friendly antifreezing solution) was used as the preservation solution, filling one-third of the trap depth. Polyethylene glycol cannot attract ants and is popular as a preservation solution because the amount of evaporation is small and it is suitable for preservation of insect specimens (Greenslade and Greenslade, 1971). The investigation had been carried out from 2006 to 2009. Pitfall traps were set up for 10–15 days. Plastic containers (diameter 9.5 m, depth 6.5 m) were used. When pitfall traps were returned, the liquid in the container was filtered through a fine net; dead bodies of ants were again placed in the container with the cover closed; then, they were placed in alcohol (80%) for preservation until identification in the laboratory. Ants were investigated from mid-May to mid-September. In this period, it was reported that many ants were collected in pitfall traps owing to their active foraging (Kwon, 2010).

Identification of ants

Ants were identified with the classification key described by Kwon et al. (2012). Except for *Myrmica* and *Lasius* genera, ants were identified to the level of species and morphospecies. The *Myrmica* genus was divided into *Myrmica kotokui* and the rest (*Myrmica* spp.). Although *Lasius japonica* and *Lasius alienus* are the most common species in the *Lasius* genus, individuals with the intermediate shape of the two species were frequently found. Two species, therefore, were identified into *Lasius* spp. (*japonicus* + *alienus*) (Kwon et al., 2012). All ant specimens are deposited in the forest ecology laboratory of the Korea Forest Research Institute.

Estimation of abundance

Ants in pitfall traps call their family workers with attraction activities such as sound or pheromone (Hölldobler and Wilson, 1990); therefore, the number of collected ants depends on the attraction activities of a species. When there were ant colonies around pitfalls, very large numbers of ants were sometimes collected. For this reason, the number of ants is not adequate as an indicator for the abundance of ants. To exclude the effects of attraction activities, the frequency of collected traps was transformed to the percentage to be used as the abundance. The following is an equation to obtain the rate of abundance: abundance = 100 × (the number of collected traps)/(the number of returned traps). This index is equivalent with the probability that a species is collected when one pitfall trap is installed at a site.

Relationship between abundance and environmental factors

With the Geographic Information System (GIS) method based on the coordinates of the survey sites, temperature (yearly mean, the maximum, and the minimum temperature), yearly rainfall, solar radiation, and vegetation index (Normalized Difference Vegetation Index as of May in 2005) were estimated. The temperature was estimated from the digital maps (Yun, 2010) that were provided by the Korea Meteorological Administration and National Center for Agro Meteorology. Climatic data were the mean value from 1971 to 2008, which have been usually represented by the mean values for 30 years. The length of spatial resolution lattices was 30 m. The relation of environmental factors in habitats to the abundance of 20 common species (more than 10% of occurrence frequency, the number of sites more than 37) was analyzed with correlation analysis. Significance was determined with $p < 0.05$.

Prediction of abundance

Among the 57 species of ants that were collected at the 366 study sites in forests, the abundance of the 20 common species was analyzed in relation with the temperature. After the average temperature of study sites was classified into six temperature zones (3–7°C, 7–9°C, 9–11°C, 11–13°C, 13–15°C, and >15°C), the average value and standard error (SE) of the abundance were calculated for each temperature zone. After the average values of the abundance for temperature zones were compared, 16 species with linear or bell-shaped types (normal distribution), which were later called candidate species, were selected, and then change in abundance was projected with respect to temperature. It was projected under the assumption that the average abundance of each temperature zone did not change. The years in which change in the abundance rate was expected are 2011, 2020, 2060, and 2090. After the temperature zone in each year was selected, the average abundance of the zone was applied to obtain the distribution of the abundance of each species. The overall average abundance in each year was annually compared in each species (the lower graph in Figures 5–20). There are no data on average abundance in the temperature zone of higher than 15°C because ants are hardly found at this zone. According to the A1B climate scenario, the