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Original article

Prediction of abundance of beetles according to climate warming in South Korea

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A B S T R A C T

To identify the change in distribution of insects in climate warming, changes in abundance of beetles were predicted using data from 366 survey sites (forests) in South Korea. Abundance along temperature gradients showed patterns (linear or hump-shaped) of normal distribution for 18 candidate species. Mean abundance in temperature zones of these species was used to predict the change in abundance. Temperature change was based on climate scenario Representative Concentration Pathways (RCP) 4.5 and 8.5 and abundance of the two periods from 2011 to 2015 and 2056 to 2065 were predicted. Of the 18 species analyzed, six were predicted to increase in abundance and 12 were predicted to decrease. Using a high relationship between abundance change and temperature of collected sites, a qualitative prediction was conducted on non-candidate species with $\geq$ 1% occurrence. This prediction also shows that more beetle species in South Korea will decrease rather than increase as climate warms.

Introduction

Poleward shifts or upward shifts have been widely reported across various organisms throughout the 20th century (Parmesan et al 1999; Konvicka et al 2003; Hickling et al 2006; Kwon et al 2014a). Likewise, global warming is leaving a clear climate fingerprint in the biosphere (Parmesan and Yohe 2003; Walther et al 2002, 2005). However, due to the complex interaction between organisms and environmental factors (Thomas et al 2004) and the lack of data that can be used for predictions, there are many uncertainties to predict the biological reaction due to climate change. Studies on influences of climate change are concentrated in flagship taxonomic groups (i.e. butterflies, birds, fish, and trees) and thus there are few studies on most taxonomic groups. Therefore, sufficient data on biological changes of these neglected groups must be obtained to reliably predict the change of biosphere resulting from climate change (Hickling et al 2006).

Beetles are an insect group with the highest diversity in the world and have currently about 350,000 known species (Gullan and Cranston 2010). In the ecosystem, beetles play various roles such as predators, herbivores, detritivores, and fungivores, and they are also important food sources for birds, mammals, fish, amphibians, and reptiles. Moreover, beetles are also used as bioindicators that monitor various environmental disturbances such as forest management, clear-cutting, and forest fires (Kotze et al 2011). Changes in beetle distribution due to climate change are expected to have a great cascading effect on the terrestrial ecosystem because of its high diversity and various ecological functions. Despite this, there are few cases of using beetles in climate change studies, and there are no studies from a national perspective that reveal or predict distribution changes due to climate changes.

In South Korea, studies on prediction of changes in distribution due to climate warming have been conducted focusing on arthropods. Studies that predict changes of aquatic insect distribution and diversity using national investigations by the Ministry of Environment (Li et al 2013, 2014), and studies on ants (Kwon et al 2014c) and spiders (Kwon et al 2014b) have used the national survey data of the Korea Forest Research Institute. This study was carried out in order to identify how the abundance and distribution of beetles that live in the forests of South Korea will change according to climate warming using data of beetles collected in the data sets. It was presumed that the increase of temperature will be accorded with the climate change scenario Representative Concentration Pathways (RCP) 4.5 and 8.5.

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Materials and methods

Study site

The sampling of beetles was conducted at 366 forest sites (Kwon et al 2014b, 2014c). In order to select the study sites evenly, eight were randomly assigned in 0.5° longitude and 0.5° latitude grids. In this sampling design, a mean 8.3 study sites (standard deviation = 1.8, 6–13) were selected within a 0.5° grid. The study sites also include 12 mountains over 1100 m above sea level such as Seoraksan, Hwaaksan, Jirisan, Gyebangsan, Gariwangsan, Taebaeksan, Sobaeksan, Minjujisan, Deokyusan, Gayasan, Unmunsan, and Hallasan Mountains. The three highest mountains of South Korea (Hallasan, Jirisan, and Seoraksan) were included in the examination of high mountains. In these high mountains, four to seven study sites were selected at intervals of 200–300 m. Study sites were selected from healthy forests aged > 30 years and well-developed understory vegetation. However, because the tops of high mountains are grasslands with shrubs, these places were selected for the study sites.

Survey and identification of beetles

Surveys on beetles were carried out from 2006 to 2009 between mid-May to mid-September. The environmental factors of the survey site and the weather at the time of survey (period when traps were installed) were reported by Kwon et al (2013). Ten traps were installed in a line at 5-m intervals at each study site and were collected 10–15 days later. The traps were filled by one-third with automobile antifreeze liquid (polyethylene glycol, environmentally friendly) as a preservative. Because automobile antifreeze liquid does not have any effect in attracting beetles and because it has low evaporation rates and is suitable for the preservation of insect specimens, it is commonly used as a preservation liquid for pitfall traps (Greenslade and Greenslade 1971). For the trap container, a plastic container (diameter: 9.5 cm, depth: 6.5 cm) used as a soup container in outdoor lunch boxes available in the market was used. When collecting the traps, the liquids in the container were filtered out using a fine mesh and the remains including beetle bodies were placed in the container and the lid was closed, which was then taken to the laboratory and preserved with ethanol (100%). All specimens were dried and identified at the species level or morpho-species level. In the case of genera that were difficult to identify to the species level (i.e. *Synuchus* and *Eucarabus*), they were identified as a species group (spp.). C.M. Lee and Y.B. Cho identified Carabidae and Staphylinidae, respectively, and S.-S. Kim identified the remaining families.

Analysis and prediction

Environmental factors

Temperature (annual average temperature, highest temperature, lowest temperature), annual rainfall, sunlight, and vegetation index (Normalized Difference Vegetation Index, NDVI of May 2005) of the study sites were estimated using Geographic Information System (GIS) with the coordinates of the study sites. The temperature was estimated based on the digital climate map provided by the Korea Meteorological Administration and the National Center for Agro Meteorology (Yun et al 2013), and the average from 1971 to 2008 was used. The scale of the spatial resolution grid was 30 m.

Relationship between environmental factors and abundance

The relationship of the abundance (number of individuals per trap) of 24 common species with an occurrence (percent of collected sites) of ≥ 10% and the environmental factors of the study sites were analyzed using correlation analysis. Significance was determined at $p < 0.05$. In addition, stepwise multiple regression analysis was used to create the multiple regression models for the abundance of 18 candidate species that were projected for abundance change.

Prediction of temperature change

In 2012, based on the new climate change scenario to be used in the fifth report of the UN Intergovernmental Panel on Climate 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 1 km). In this study, the distribution map of average temperature of the RCP 4.5 and 8.5 scenarios (1 km resolution) distributed by the Korea Meteorological Administration were used to predict the abundance of beetles from 2011 to 2015 and 2056 to 2065 per grid (1 km^2).

Prediction of abundance

Generally, most species distribution models take into consideration various environmental factors, but factors that can actually be predicted due to climate change are temperature and precipitation, but precipitation has high variation according to time and space (Yun et al 2013), giving it low predictability compared to temperature. Accordingly, predictions have been made with the assumption that factors other than temperature do not change in the model including various environmental factors (i.e. ecological niche model). However, because other environmental factors will also change complexly together with climate change, such an assumption may be far from reality. Therefore, rather than the complex models that consider various factors aside from temperature, a simple model that takes into account only temperature would be more feasible and can reduce uncertainty from complexity of models. This is more so in the case of South Korea where the relationship of distribution of beetles and environmental factors is unknown. In this study, seven factors were used to create various multiple regression models, but their explanatory power was low at 0.8–15.2%, so it was judged that there would be limitations to make predictions with just these models (Table 1). Thus, in this study, the change of abundance was predicted as below using the average of abundance of each temperature zone.

When analyzing the correlation between the 24 species with ≥ 10% occurrence (with ≥ 37 collected study sites) and the environmental factors, the temperature (minimum and average) is more related with abundance compared to other environmental factors (Table 2, Figure 1), but this alone can explain only ∼2% of the variation in abundance (Figure 1). When comparing the average abundance along a gradient of temperature zones, a close relationship between abundance and temperature emerged (Figures 2 and 3) . In this study, the average temperature of the study sites were grouped into seven temperature zones of 3–7°C, 7–9°C, 9–11°C, 11–13°C, 13–15°C, 15–17°C, and 17–19°C to calculate the average and standard error of abundances at the occurred sites per temperature zone. When comparing the averages of abundance across temperature zones, it is assumed that species with linear or unimodal patterns (may be produced by normal distribution) have a high correlation with temperature. Results of analyses showed such a distribution pattern for 18 of 24 species. The average abundance in each temperature zone was used for prediction of abundance changes according to temperature changes (Table 3). Two periods from 2010 to 2015 and 2056 to 2065 were projected, and the distribution of temperature zones in the two periods was used to project abundance by substituting the average abundance of each temperature zone. This study was conducted only at forested sites so the analysis was applied only in the forests. Temperature zones of ≥ 15°C are not seen currently, so there are no data