Journal of Asia-Pacific Biodiversity 9 (2016) 116–137

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Journal of Asia-Pacific Biodiversity

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Original article

Prediction of abundance of arthropods according to climate change scenario RCP 4.5 and 8.5 in South Korea

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ARTICLE INFO

Article history:
Received 27 January 2016
Received in revised form
29 February 2016
Accepted 2 March 2016
Available online 10 March 2016

Keywords:
abundance
Arthropoda
climate change
Global warming
prediction
RCP 4.5 & 8.5
South Korea

ABSTRACT

Abundance and diversity of arthropods were projected according to climate warming in South Korea. The taxa highly linked with temperature were selected for the projection. The values of abundance and richness were estimated using the mean values of abundance and richness in each temperature range. Temperature changes were based on the RCP (Representative Concentration Pathway) 4.5 and RCP 8.5, and the abundance and richness during two periods (2011 -2015, 2056 -2065) were projected. From these projected results, change of other common taxa (> 1% occurrence) were qualitatively predicted (i.e., decrease or increase). The projections showed that 45 of a total of 73 taxa will increase, 6 will change a little and 24 will decrease: the number of taxa that were expected to increase was two times more than the number of taxa that were expected to decrease. However, the overall abundance and diversity of arthropods were expected to decline as the temperature rises.

Introduction

The distribution and phenology of living organisms are changing in response to climate change (Parmesan et al 1999; Konvicka et al 2003; Hickling et al 2006; Kwon et al 2014a). Interspecific interactions, biodiversity, and community structures are also changing due to the changes (Walther et al 2002). Climate change was suggested to be the major cause for the future decline in biodiversity, the most serious global crisis (Thomas et al 2004). It is necessary to identify various changes in organisms resulting from climate change in order to preserve biodiversity and sustainability of the biosphere. However, due to the complicated interaction between organisms and environmental factors and the lack of survey data that can be used in predictions, there is great uncertainty in predicting organisms' responses to climate change (Thomas et al 2004). Studies related to climate change have been mainly conducted on flagship taxa (e.g. butterflies, birds, fish, etc.; Parmesan et al 1999; Thomas and Lennon 1999), and only a few studies were conducted on the neglected taxa. Therefore, changes in the biosphere resulting from climate change can be predicted more accurately only when reliable data in the neglected taxa are sufficiently accumulated (Hickling et al 2006).

Arthropods are the most abundant and diverse animals in the terrestrial ecosystem, and the number of global arthropod species is reported to be 1,170,000 (Wikipedia 2016) and estimated to be 5,000,000–10,000,000, accounting for 80% of the total number of species on Earth (Ødegaard 2000). Arthropods play a critical role as herbivores, detritivores, and carnivores for nutrient cycles and energy flow in the terrestrial ecosystem. They are also extremely important in maintaining biodiversity as they are important food for larger animals such as birds, mammals, fish, amphibians, and reptiles. Arthropods are often used as bio-indicators to monitor various environmental changes. In the case of arthropods, studies conducted at higher taxonomic levels (family or order) are often used to assess biodiversity and identify the influences of various environmental disturbances such as invasive species, aerial pesticide spraying, forest fire, afforestation, and thinning (Cole et al 1992; Goldsbrough and Shine 2003; Kwon 2008; Kwon et al 2013b; Warren et al 1987; Yi and Moldenke 2005). In particular,

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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.2016.03.001
pISSN2287-884X eISSN2287-9544/

Table 1. Multiple regression models for the candidate arthropods.

Name	Korean name	Multiple regression model	R^2	p
No. of order	절지동물목수	$y = -7.821 + 4.430e\text{-}04*X_6$	0.1088	<0.001
Phalangida	장님거미목	$y = -3.647 + 1.205e\text{-}03*X_1$	0.0513	0.008184
Araneae	거미목	$y = -7.529 + 0.4373*X_3 - 0.2429*X_4$	0.1596	<0.001
Araneae richness	거미목 종수	$y = -0.3665 + 2.84* X_3 - 1.41* X_4 + 5.182e\text{-}04* X_6$	0.263	<0.001
Theridiidae	꼬마거미과	$y = -0.89 - 0.03024*X_5$	0.1257	<0.001
Linyphiidae	접시거미과	$y = -0.7257 - 0.05203*X_4$	0.1249	<0.001
Lycosidae	늑대거미과	$y = -1.154 + 0.0159*X_2 + 0.07653*X_3 + 2.954e\text{-}05*X_6$	0.1529	<0.001
Hahniidae	외줄거미과	$y = 0.3353 - 0.0233*X_4 - 0.02851*X_5$	0.0679	<0.001
Liocranidae	밭고랑거미과	$y = -0.8345 + 0.07634* X_3 - 0.03726* X_4$	0.1272	<0.001
Thomisidae	게거미과	$y = -0.6002 + 0.04315* X_3 - 0.01743* X_4 + 1.641* X_6$	0.0563	0.0039
Salticidae	깡충거미과	$y = -2.338 + 0.08901* X_3 + 2.918e\text{-}04* X_7$	0.1585	<0.001
Chilopoda	지네강	$y = 0.1139 - 0.04045* X_4$	0.0523	0.0071
Archaeognatha	돌좀목	$y = -6.571 + 0.4658* X_3 -0.292* X_4$	0.0756	<0.001
Blattariae	바퀴벌레목	$y = 0.4752 - 6.198e\text{-}05* X_6$	0.0772	<0.001
Gryllidae	귀뚜라미과	$y = -6.4140188 + 0.0017411*X_1$	0.0869	<0.001
Other Orthoptera	메뚜기목 기타	$y = 2.55 + 5.338e\text{-}04*X_1$	0.0231	0.2965
Homoptera	매미목	$y = -1.773 - 0.3075* X_3 +0.1169* X_4 + 0.2034* X_5 + 1.134e\text{-}04*X_6$	0.0672	<0.001
Coleoptera richness	딱정벌레목 종수	$y = -0.3133 - 1.482*X_4$	0.1861	<0.001
Staphylinidae	반날개과	$y = -0.1277 + 0.5676*X_5$	0.0621	0.00163
Melolonthidae	검정풍뎅이과	$y = 1.273 + 1.374e\text{-}04* X_1 - 0.03953* X_5 + 2.203e\text{-}05*X_6 - 6.951e\text{-}04* X_7$	0.1948	<0.001
Elateridae	방아벌레과	$y = -0.3809 + 9.217e\text{-}03* X_5$	0.0695	<0.001
Nitidulidae	밑빠진벌레과	$y = -0.7313 + 0.04029* X_5$	0.0636	0.0013
Tenebrionidae	거저리과	$y = -0.9784 - 0.03626* X_4$	0.0643	0.0012
Curculionidae	바구미과	$y = 0.4426 - 0.0711* X_3$	0.0583	0.0029
Formicidae	개미과	$y = -7.2774 + 0.01178* X_7$	0.0360	0.0892
Formicidae richness	개미과 종수	$y = -6.1904 + 0.00574* X_7$	0.0587	0.0047
Other Hymenoptera	벌목 기타	$y = -0.1855 - 0.1804* X_2 + 0.6623* X_5 + 5.059e\text{-}03*X_7$	0.0687	<0.001
Lepidoptera	나비목	$y = -0.2791 - 0.1003* X_4$	0.1570	<0.001

X_1 = precipitation; X_2 = insolation; X_3 = mean temperature; X_4 = minimum temperature; X_5 = maximum temperature; X_6 = Normalized Difference Vegetation Index; X_7 = altitude.

Kwon et al (2013b) demonstrated that the analysis at high taxonomic levels showed more robust results for changes in the ecosystem compared with that at low taxonomic levels. Despite such study results, no study has yet been done to assess the overall future changes in the high taxonomic levels of arthropods due to climate change on a national scale.

In South Korea, studies to predict changes in the distribution caused by climate warming have been conducted on the various

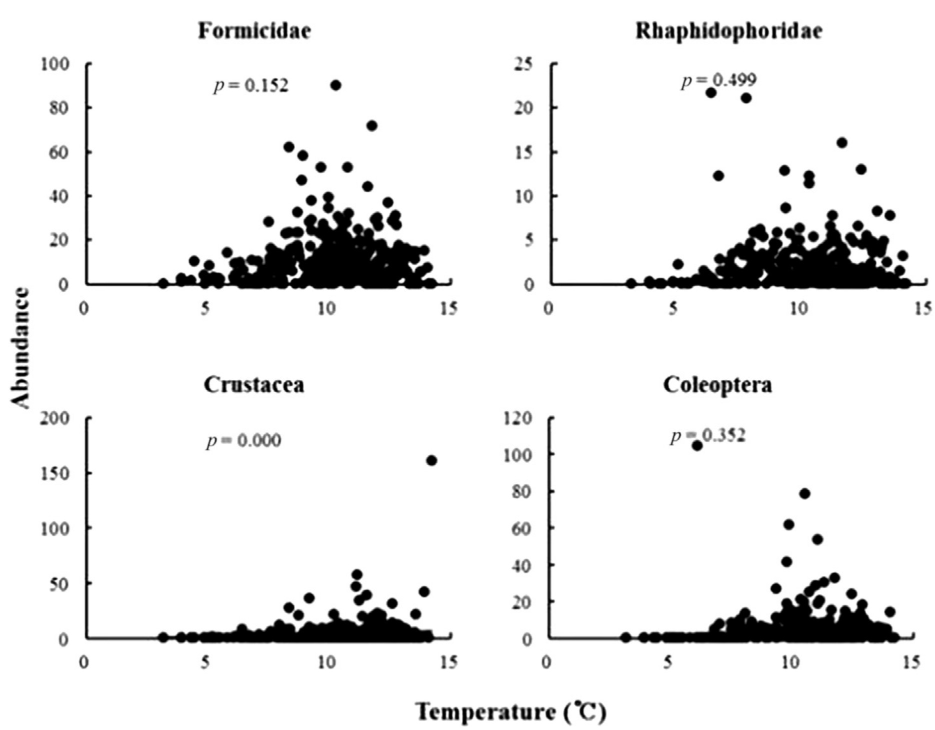


Figure 1. Abundance (number of individuals per trap) of four common arthropods across different temperatures.

arthropod groups: a projection of the distribution and diversity of aquatic insects using the Ministry of Environment's national survey data (Li et al 2013, 2014), and projections of distributional changes in ants (Kwon et al 2014c; Kwon and Lee 2015), spiders (Kwon et al 2014b), beetles (Kwon et al 2015), and flies (Lee et al 2015) using the data of the Korea Forest Research Institute, Seoul in South Korea. This study was performed to find the future changes in abundance and richness of arthropods due to the temperature increase at high taxonomic levels using the Korea Forest Research Institute data. The temperature increase was assumed to be in accordance with the two climate change scenarios [RCP 4.5 or RCP 8.5].

Materials and methods

Study site

The arthropods were sampled at 366 study sites (Kwon et al 2014b). About eight study sites were evenly selected in a grid of 0.5° longitude and 0.5° latitude. The study sites also included 12 high mountains with elevations of more than 1100 m: Mountain (Mt.) Halla, Mt. Seorak, Mt. Jiri, Mt. Hwaak, Mt. Gyebang, Mt. Gariwang, Mt. Taebaek, Mt. Sobaek, Mt. Minjuji, Mt. Deogyu, Mt. Gaya, and Mt. Unmun. Among them, Mt. Halla, Mt. Jiri, and Mt. Seorak are

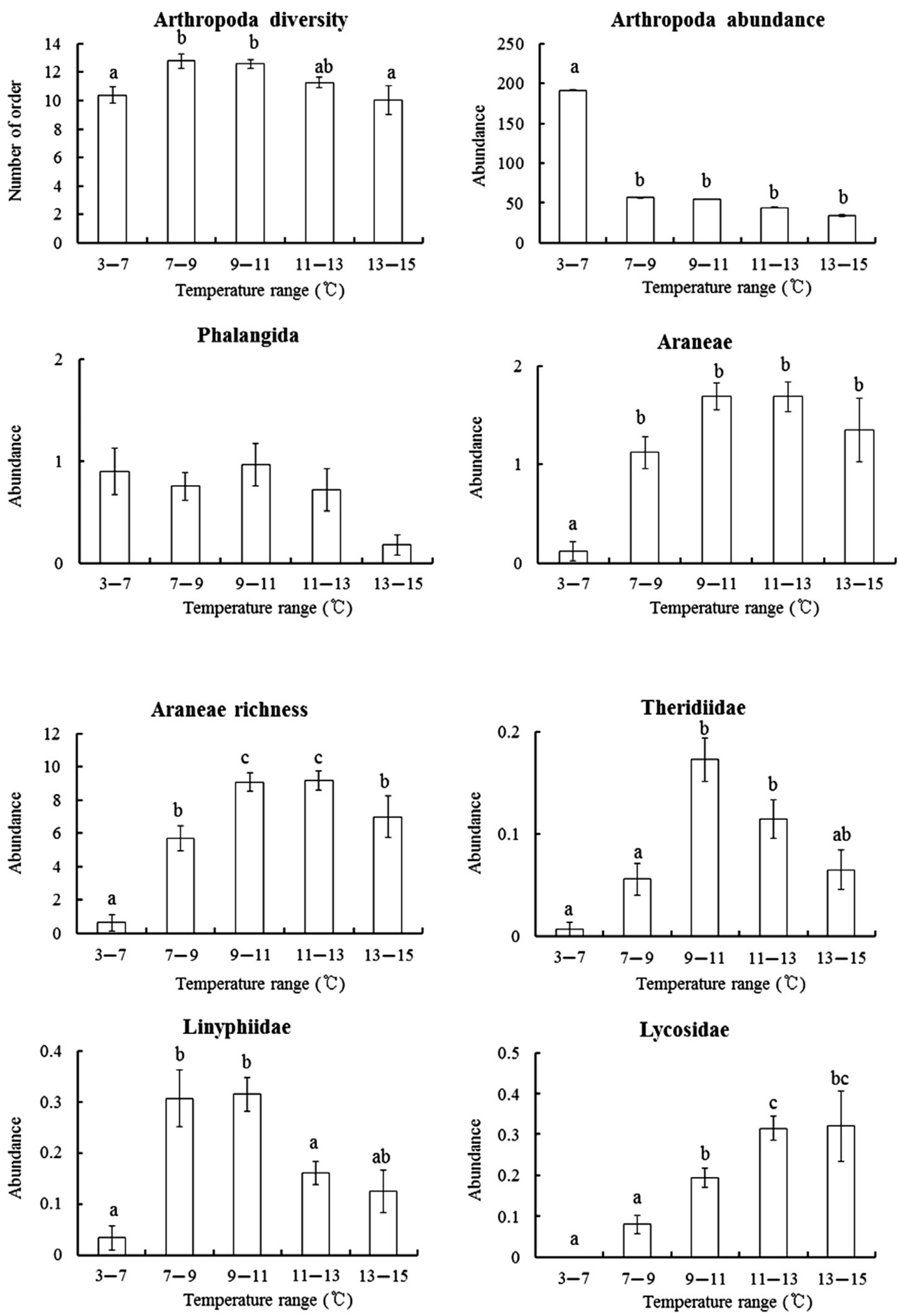
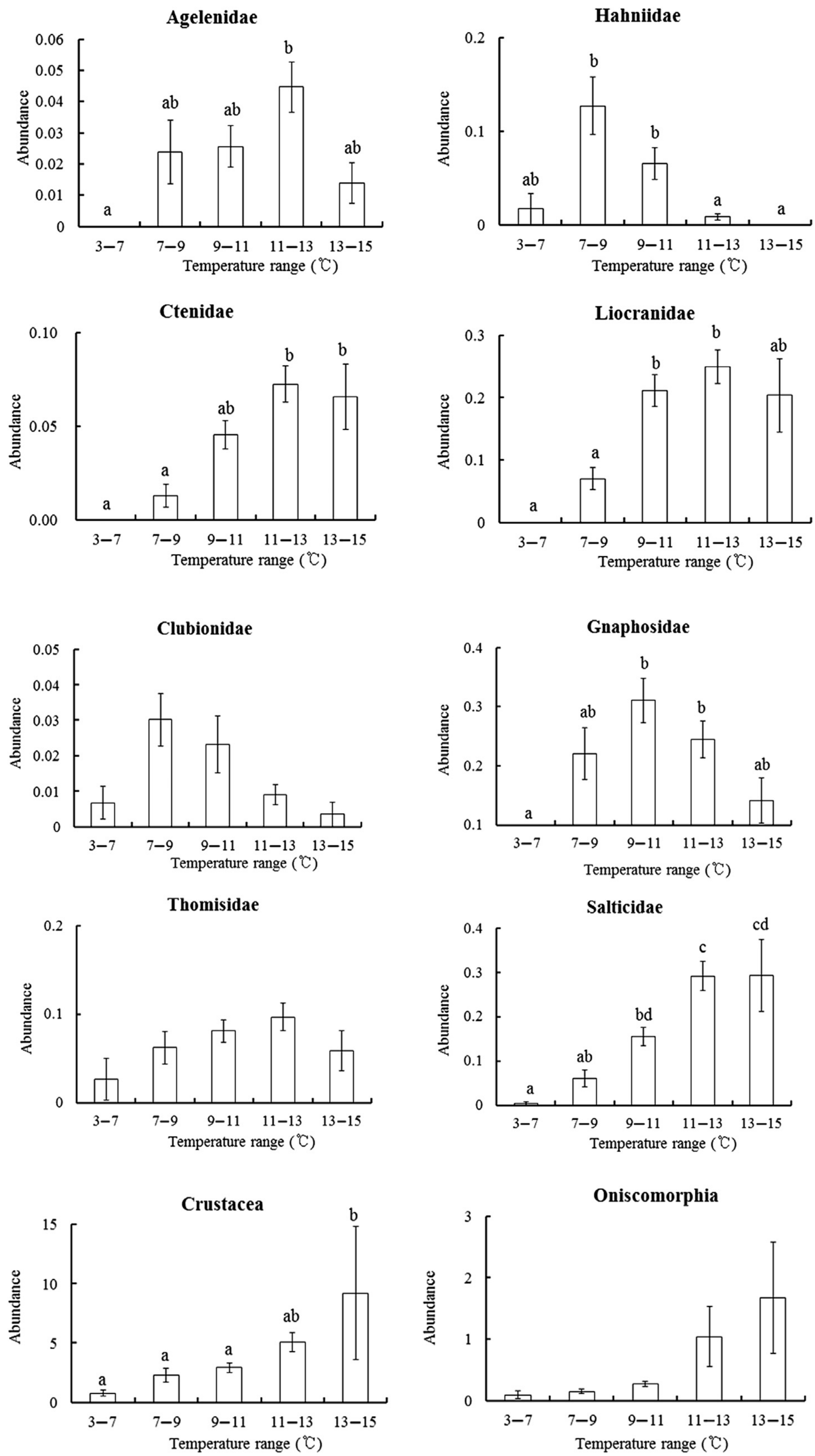


Figure 2. Abundance or richness of common (>10% occurrence) arthropods. Error bars mean one standard error. Different letters indicate a significant difference ($p < 0.05$) in Tukey multicomparison test after one-way analysis of variance.



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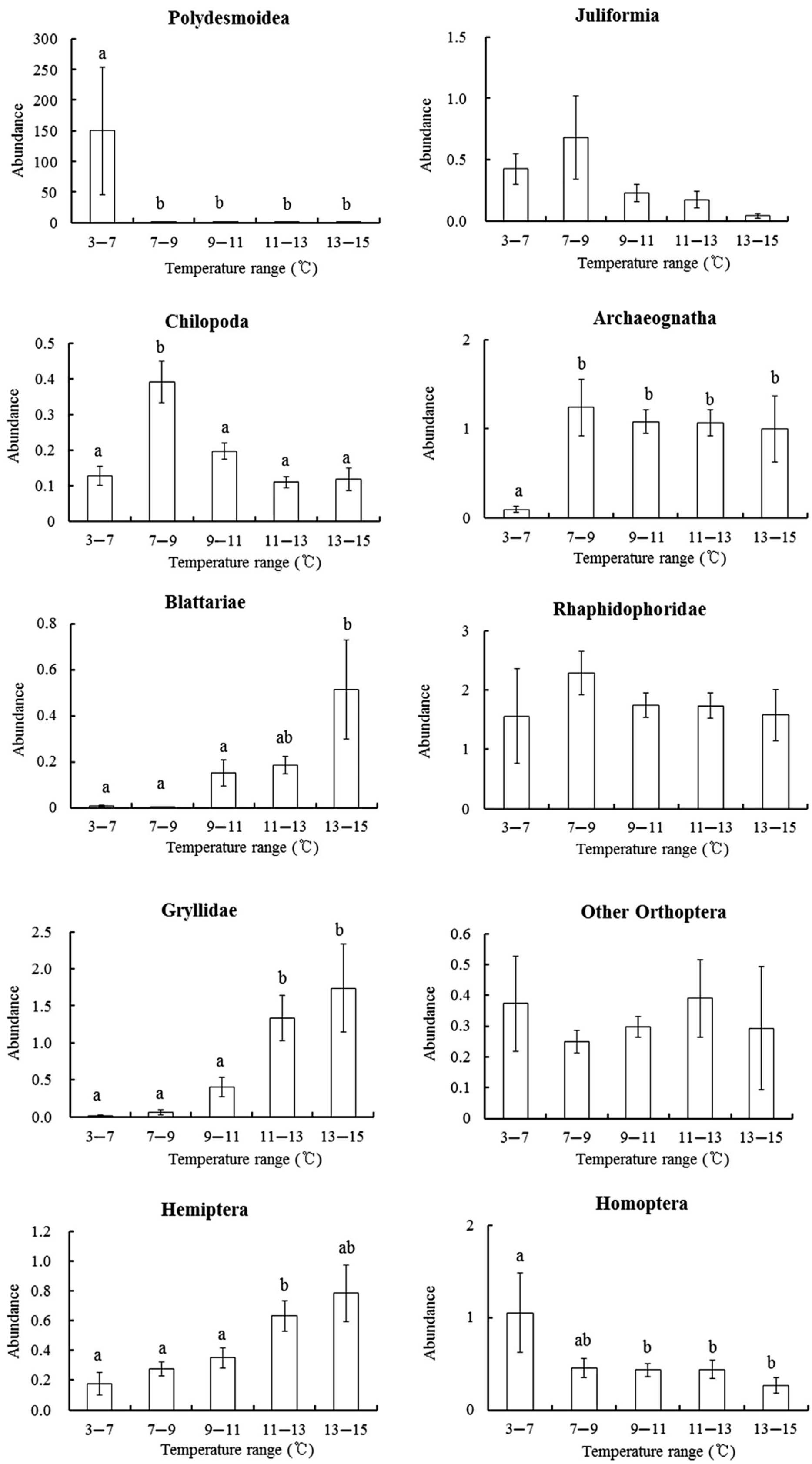

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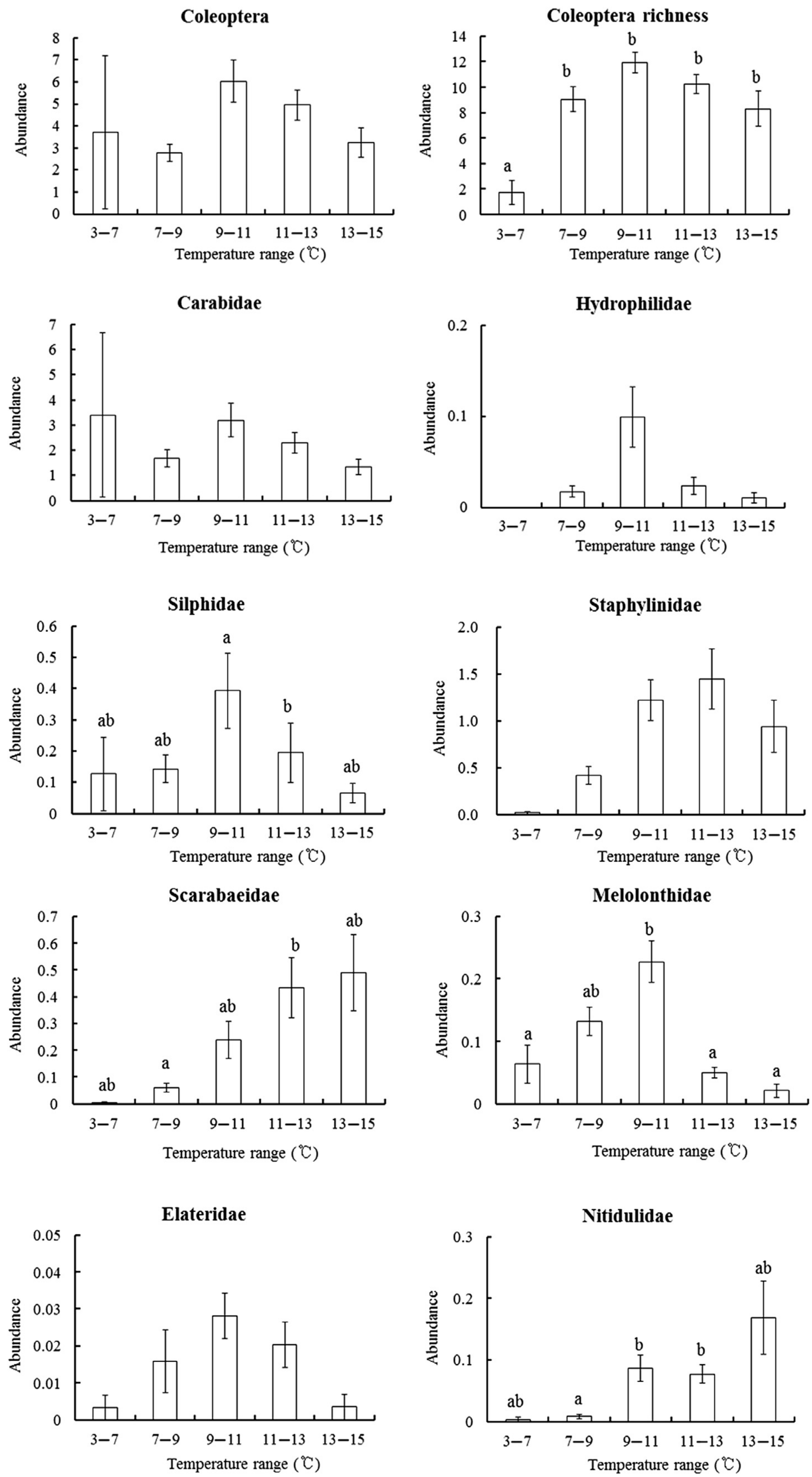

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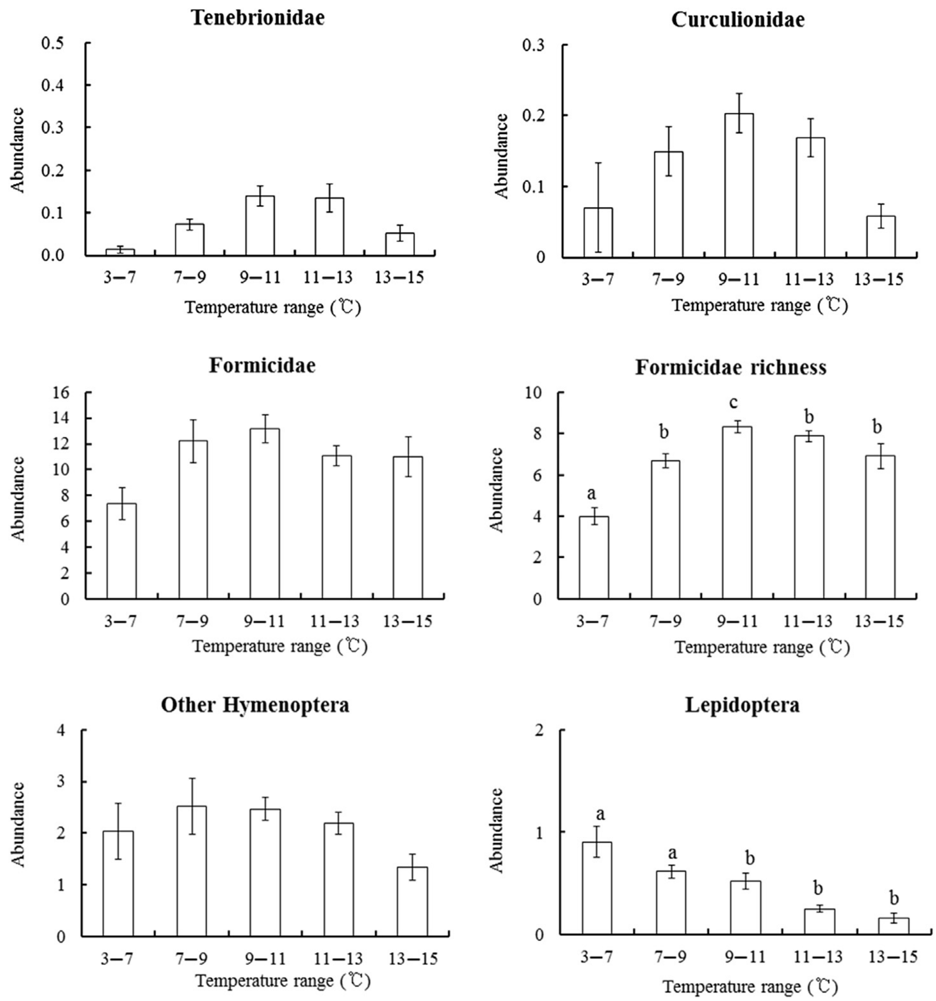


Figure 2. (*continued*)

the three highest mountains in South Korea. Four to seven sites in each mountain were selected in an interval of altitude 200–300 m. Forests with a tree age over 30 years and with well-developed understory vegetation were selected as study sites. However, at the top of the mountains, grasslands/shrub lands were chosen as study sites as the top areas were covered by such vegetation. The environmental factors of the study sites and the weather at the survey period (trap-locating period) in the study sites are reported in Kwon et al (2013a).

Arthropod sampling and identification

Arthropods were sampled for 4 years from 2006 to 2009 during mid-May to mid-September. Pitfall traps were used for the sampling of arthropods: 10 traps were lineally placed within a 5-m distance from each other at each site for 10–15 days. A third of each trap was filled with automobile antifreeze for specimen preservation (polyethylene glycol). Automobile antifreeze does not have an attraction effect and is widely used as a preservation solution for pitfall trapping because it is suitable for preserving insect specimens and its evaporation loss is low (Greenslade and Greenslade 1971). Plastic containers (diameter: 9.5 cm, depth: 6.5 cm) that are sold as soup containers in markets were used as trap containers. When collecting the traps, the fluid inside the traps were filtered with a fine mesh, and residues including arthropod bodies were put into containers, brought back to the laboratory, and kept with ethyl alcohol (100%) until an identification was conducted. The sampling was conducted once at each site. All specimens were identified at the order or family level. Ants, spiders, and beetles were identified at the species or morpho-species level.

Analysis and prediction

Environmental factors

Temperature (annual mean temperature, annual maximum temperature, annual minimum temperature), annual precipitation, insolation, and vegetation index (Normalized Difference Vegetation Index, NDVI of May 2005) were estimated based on the coordinates of the study sites using Geographic Information System (GIS). Temperatures were estimated based on the digital maps provided by the Korea Meteorological Administration (KMA) and the National Center for Agro Meteorology, and the mean values from 1971 to 2008 were used. The length of the spatial resolution grid is 30 m.

Table 2. Abundance (number of individuals) and richness (number of taxa) of candidate arthropods in seven temperature ranges. The values are mean values. Values in the 3–15°C temperature range are observed values, and those in the 15–19°C range were estimated with the Neighborhood Approximation method (Kown et al 2013a).

Name	Korean name	3–7°C	7–9°C	9–11°C	11–13°C	13–15°C	15–17°C	17–19°C
No. of order	절지동물목수	10.400	12.778	12.570	11.260	10.034	8.942	7.969
Abundance	절지동물개체수	191.653	56.690	54.934	44.499	34.586	26.882	20.893
Araneae	거미목	0.117	1.119	1.692	1.686	1.348	1.078	0.862
Araneae richness	거미목 종수	0.633	5.708	9.079	9.164	7	5.347	4.084
Theridiidae	꼬마거미과	0.007	0.055	0.172	0.115	0.064	0.036	0.020
Linyphiidae	접시거미과	0.033	0.306	0.315	0.161	0.124	0.096	0.074
Lycosidae	늑대거미과	0.000	0.079	0.193	0.315	0.321	0.327	0.333
Agelenidae	가게거미과	0.000	0.024	0.026	0.045	0.014	0.004	0.001
Hahniidae	외줄거미과	0.017	0.127	0.065	0.008	0.000	0.000	0.000
Ctenidae	너구리거미과	0.000	0.013	0.045	0.072	0.066	0.059	0.054
Liocranidae	밭고랑거미과	0.000	0.070	0.211	0.250	0.203	0.166	0.135
Clubionidae	염낭거미과	0.007	0.030	0.023	0.009	0.003	0.001	0.001
Gnaphosidae	수리거미과	0.013	0.221	0.311	0.245	0.141	0.082	0.047
Thomisidae	게거미과	0.027	0.062	0.081	0.097	0.059	0.036	0.022
Salticidae	깡충거미과	0.003	0.060	0.155	0.292	0.293	0.294	0.296
Crustacea	갑각강	0.750	2.305	2.911	5.047	9.197	16.757	30.534
Oniscomorphia	곰보노래기목	0.090	0.144	0.268	1.039	1.669	2.681	4.306
Juliformia	각시노래기목	0.423	0.679	0.225	0.173	0.041	0.010	0.002
Archaeognatha	돌좀목	0.090	1.238	1.079	1.064	1.000	0.940	0.883
Rhaphidophoridae	곱등이과	1.560	2.283	1.747	1.737	1.576	1.430	1.298
Gryllidae	귀뚜라미과	0.013	0.059	0.407	1.331	1.741	2.278	2.981
Hemiptera	노린재목	0.177	0.276	0.351	0.631	0.783	0.971	1.205
Homoptera	매미목	1.050	0.452	0.432	0.439	0.262	0.156	0.093
Coleoptera richness	딱정벌레 종수	1.733	9.046	11.906	10.25	8.286	6.698	5.414
Hydrophilidae	물땡땡이과	0.000	0.017	0.099	0.024	0.010	0.005	0.002
Silphidae	송장벌레과	0.127	0.143	0.393	0.194	0.066	0.022	0.007
Staphylinidae	반날개과	0.017	0.414	1.221	1.446	0.938	0.609	0.395
Scarabaeidae	소똥구리과	0.003	0.060	0.238	0.433	0.490	0.554	0.628
Melolonthidae	검정풍뎅이과	0.063	0.132	0.227	0.050	0.021	0.009	0.004
Elateridae	방아벌레과	0.003	0.016	0.028	0.020	0.003	0.001	0.000
Tenebrionidae	거저리과	0.013	0.073	0.139	0.135	0.052	0.020	0.008
Curculionidae	바구미과	0.070	0.149	0.203	0.169	0.059	0.020	0.007
Formicidae	개미과	7.367	12.206	13.172	11.106	10.992	10.879	10.767
Formicidae richness	개미과 종수	0.633	5.708	9.079	9.164	7	5.347	4.084
Other Hymenoptera	벌목 기타	2.033	2.514	2.466	2.190	1.341	0.822	0.503
Lepidoptera	나비목	0.903	0.614	0.517	0.246	0.155	0.098	0.062

A correlation between environmental elements and abundance

The relationship between taxa richness/abundance and the environmental factors was analyzed using a correlation analysis for common taxa (> 10% occurrence). Abundance is the number of individuals and richness is the number of taxa. Significance was determined based on $p < 0.05$. The multiple regression models for the abundance and the richness of the candidate taxa that were analyzed for the future changes was established using a stepwise multiple regression analysis.

Temperature change prediction

In 2012, the KMA developed and provided the detailed climate change scenarios for the Korean Peninsula (grid length 12.5 km) and South Korea (grid length 1 km) based on the new climate change scenario which was used in the fifth assessment report of the United Nations' International Panel on Climate Change (IPCC). In this study, the mean temperatures in 2011–2015 and 2056–2065 by each grid (1 km^2) were calculated using the mean temperature distribution maps of RCP 4.5 and RCP 8.5 provided by the KMA, and were used for the projection of abundance or richness of arthropods. This coarse scale may be a problem in representing the fine difference of temperature because the scale (1 km) covers 200–300 altitudinal ranges in mountains.

Prediction of abundance and diversity

In general, various factors are used for the species distribution model. However, when multiple regression models of candidate (bioindicator for climate warming) taxa were made with various factors, these models could only explain 2–26% of variations (Table 1). This is due to the high variations of arthropod abundance between the study sites (Figure 1) and the nonlinear characteristic (normal distribution) that the maximum level reaches around the optimal temperature range and, therefore, the patterns are bell-shaped rather than linear (Figure 2). If abundances were compared by the temperature ranges, a high relation was found between abundance and temperature (Figure 2). In this study, the mean temperatures at the study sites were classified into six temperature ranges, 3–7°C, 7–9°C, 9–11°C, 11–13°C, 13–15°C, 15–17°C, and 17–19°C, and the average and standard error of abundance of each taxon were calculated for each temperature range. If abundance (average values) exhibit a linear or bell-shaped abundance distribution pattern, it is very likely that the abundance is mainly determined by temperature. The 32 taxa of 92 examined taxa showed such distribution patterns. Abundance/richness of these candidate species was projected according to the temperature rise. Abundance was projected according to the temperature change using the mean value of abundance/richness of each temperature range (Table 2). The projections were carried out for two periods, 2010–2015 and 2056–2065. The projection was applied only to the polygons of forests

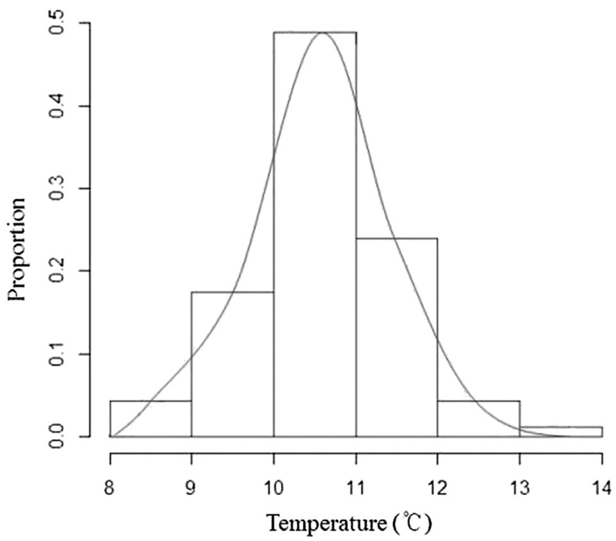


Figure 3. Histogram of temperature (annual mean) in occurred sites of arthropods. This pattern is the normal distribution (Shapiro–Wilk normality test, W = 0.9882, $p = 0.5821$). Data for this figure are provided in Table S1.

because the survey was performed in forests. As temperature barely goes over 15°C in South Korea, there is no data for the mean abundance value at the temperature range of 15–19°C. Therefore, the abundance of this temperature range was estimated using the neighborhood approximation method (Kwon et al 2014b). ArcGIS 10.1 (ESRI, Redlands, CA, USA) was used in all GIS related analyses.

Results

Temperature change according to the climate change scenarios RCP 4.5 and RCP 8.5

In the climate change scenarios RCP 4.5 and RCP 8.5, the mean temperature of South Korea will rise from 12.15°C to 13.3°C according to RCP 4.5, and from 11.17°C to 14.41°C according to RCP 8.5 (Kwon et al 2014b). The high temperature areas (above 15°C of annual mean temperatures), which have rarely been found so far, will increase by 19% of the total area and 43% after 50 years according to RCP 4.5 and RCP 8.5 respectively.

A correlation with environmental elements and a correlation between taxa

The occurrence of the arthropods collected and the temperatures of the occurred sites are shown in Table S1. The frequency of the annual mean temperature of the occurred sites of all the taxa is shown in Figure 3, which followed the normal distribution (Shapiro–Wilk normality test, W = 0.9882, $p = 0.5821$). The annual mean temperatures of taxa were most frequent (about 50%) at the range of 10–11°C. Considering that South Korea's annual mean temperature is 13.8°C (Lee et al 2011), this means that the optimal temperatures of most taxa are lower than the mean temperature of South Korea. The correlation between abundance/richness of common taxa (> 10% occurrence) and environmental factors is shown in Table 3. The factors that had most cases of significant correlations were temperature and altitude, and insolation had the least cases of significant correlations. Figure 4 shows the comparison of R^2 (coefficient of determination) values of the environmental factors in the correlations. Environment factors that had the highest value was the annual maximum temperature, and this factor was not different with other main factors such as altitude, annual mean temperature, and annual minimum temperature, but was significantly different with other minor factors such as precipitation, vegetation, and insolation. The correlations between taxa are shown in Table S2. Abundance of most taxa was significantly correlated with taxa richness (number of taxa), whereas only three of 36 studied cases was significantly correlated with abundance of total arthropods. Particularly, abundance of Polydesmoidea was very highly correlated with that of total arthropods (R = 0.97, $p < 0.001$), showing that the abundance of this taxa might be a powerful bio-indicator for the abundance of total arthropods. Meanwhile, the abundance of most taxa has a high possibility as an indicator for the richness of the entire arthropods.

A prediction of abundance and richness

Quantitative prediction

The results of predicting the abundance (number of individuals/trap) or richness (number of taxon/site) of 32 candidate taxa according to the climate change scenarios RCP 4.5 and RCP 8.5 are shown in Table 4. In the case of total arthropods, their richness and abundance were expected to decrease. Abundance was expected to decrease by 13% and 36% according to RCP 4.5 and RCP 8.5, respectively, whereas richness was expected to decrease by 5% (RCP 4.5) and 13% (RCP 8.5; Figures 5 and 6). Such predictions resulted from the pattern that abundance and richness increase at low temperature (Figure 2; Table 2). The richness of arthropods followed the bell-shaped pattern, which reaches a maximum at 7–9°C, while the abundance of arthropods reached the highest level at the low temperature range (3–7°C), and it was almost similar at the rest of the temperature ranges but tended to decline along with the rise in the temperature. The hot spot areas (red-colored area) with the highest arthropod abundance at present are alpine regions in Gangwon-do, but these areas were expected to decrease (RCP 4.5) or nearly disappear (RCP 8.5) after 50 years (Figures 5 and 6).

In the case of spiders, the abundance of total spiders was expected to decrease, and seven families are expected to decrease in abundance but four families are expected to increase (Table 4). The abundance of Coleoptera was not predicted quantitatively but was forecasted to increase according to a qualitative prediction (Table 5). Also, only Scarabaeidae among the families of Coleoptera was expected to increase, and the rest (Hydrophilidae, Silphidae, Staphylinidae, Melolonthidae, Elateridae, Tenebrionidae, and Curculionidae) were expected to decrease (Table 4; Figures 5 and 6). In the case of the rest of the taxa, it was forecasted that Crustacea, Oniscomorphia, Gryllidae, and Hemiptera will increase while Juliformia, Archaeognatha, Rhaphidophoridae, Homoptera, Formicidae, Hymenoptera (other), and Lepidoptera will decrease (Table 4 and Figures 5 and 6).

Qualitative prediction

For the taxa which were excluded from quantitative prediction as they had occurrence of 1–10% or above 10% but with a low relationship between abundance and temperature, three types of changes such as increase, no change, and decrease, in abundance/richness were qualitatively determined based on the quantitative prediction results. Figure 7 shows a correlation between the change rates (abundance/richness) of 36 candidate taxa and the average of the annual mean temperatures of the occurred sites. The values of temperatures were in a linear relationship with the abundance or richness change rate [100*(values in 2056–2065 − values in 2011–

Table 3. Correlation of abundance (number of individuals) and richness (number of taxa) with environmental factors in common (>10% occurrence) arthropods.

Name	Korean name	Environmental factors						
		Precipitation	Insolation	Mean temperature	Minimum temperature	Maximum temperature	Vegetation index	Altitude
No. of order	절지동물목수	−0.12*	−0.03	−0.07	−0.22‡	0.09	0.13*	−0.06
Abundance	절지동물개체수	0.04	0.00	−0.16†	−0.17†	−0.11*	0.10*	0.10*
Phalangida	장님거미목	0.16†	−0.04	−0.09	−0.05	−0.06	0.13*	0.08
Araneae	거미목	−0.27‡	0.03	0.23‡	0.00	0.34‡	−0.05	−0.32‡
Araneae richness	거미목 종수	−0.36‡	0.04	0.31‡	0.03	0.45‡	−0.09	−0.43‡
Theridiidae	꼬마거미과	−0.26‡	0.05	0.12*	−0.08	0.27‡	−0.09	−0.24‡
Linyphiidae	접시거미과	−0.17†	−0.09	−0.03	−0.22‡	0.14†	0.03	−0.13*
Lycosidae	늑대거미과	−0.19‡	0.09	0.34‡	0.20‡	0.34‡	−0.07	−0.33‡
Agelenidae	가게거미과	−0.04	0.00	0.08	0.03	0.12*	−0.04	−0.11*
Hahniidae	외줄거미과	−0.03	−0.06	−0.13*	−0.19‡	−0.09	0.15†	0.06
Ctenidae	너구리거미과	−0.14†	0.01	0.26‡	0.17†	0.26‡	−0.06	−0.26‡
Liocranidae	밭고랑거미과	−0.16†	0.06	0.28‡	0.11*	0.32‡	−0.14†	−0.32‡
Clubionidae	염낭거미과	−0.08	0.00	−0.06	−0.09	−0.02	0.10*	0.02
Gnaphosidae	수리거미과	−0.25‡	0.00	0.09	−0.09	0.21‡	−0.03	−0.19‡
Thomisidae	게거미과	−0.13*	0.03	0.10*	−0.01	0.14†	0.05	−0.12*
Salticidae	깡충거미과	−0.16†	0.10*	0.33‡	0.18‡	0.35‡	−0.10*	−0.30‡
Crustacea	갑각강	−0.01	0.01	0.17†	0.18‡	0.12*	−0.08	−0.13*
Oniscomorphia	곰보노래기목	−0.05	0.02	0.12*	0.10*	0.09	−0.08	−0.11*
Polydesmoidea	띠노래기목	0.05	0.00	−0.14†	−0.12*	−0.11*	0.09	0.10*
Juliformia	각시노래기목	0.12*	−0.02	−0.13*	−0.05	−0.15†	0.15†	0.16†
Chilopoda	지네강	0.01	−0.01	−0.15†	−0.21‡	−0.08	0.07	0.08
Archaeognatha	돌좀목	−0.11*	−0.01	0.09	−0.06	0.18‡	0.02	−0.17†
Blattariae	바퀴벌레목	−0.05	−0.07	0.19‡	0.16†	0.20‡	−0.20‡	−0.20‡
Rhaphidophoridae	곱등이과	0.06	0.07	−0.04	−0.04	−0.02	0.07	0.05
Gryllidae	귀뚜라미과	0.02	−0.05	0.23‡	0.19‡	0.22‡	−0.13*	−0.21‡
Other Orthoptera	메뚜기목 기타	0.09	0.02	0.02	0.03	0.03	−0.04	0.00
Hemiptera	노린재목	−0.12*	0.05	0.23‡	0.14†	0.24‡	−0.12*	−0.22‡
Homoptera	매미목	0.02	0.08	−0.16†	−0.13*	−0.10*	0.16†	0.14†
Coleoptera	딱정벌레목	−0.11*	0.00	0.05	−0.04	0.12*	−0.01	−0.09
Coleoptera richness	딱정벌레목 종수	−0.29‡	−0.05	0.20‡	−0.04	0.35‡	−0.02	−0.34‡
Carabidae	딱정벌레과	−0.07	0.00	−0.02	−0.07	0.02	0.02	0.00
Hydrophilidae	물땡땡이과	−0.05	0.00	0.02	−0.04	0.05	−0.03	−0.03
Silphidae	송장벌레과	−0.05	0.00	−0.01	−0.09	0.08	0.04	−0.07
Staphylinidae	반날개과	−0.11*	0.00	0.14†	0.04	0.22‡	−0.09	−0.17†
Scarabaeidae	소똥구리과	0.00	−0.02	0.20‡	0.19‡	0.15†	−0.08	−0.15†
Melolonthidae	검정풍뎅이과	−0.10*	−0.05	−0.10*	−0.26‡	0.07	0.12*	−0.12*
Elateridae	방아벌레과	−0.12*	−0.02	0.04	−0.10*	0.16†	0.02	−0.12*
Nitidulidae	밑빠진벌레과	−0.10*	0.04	0.18‡	0.12*	0.22‡	−0.14†	−0.18‡
Tenebrionidae	거저리과	−0.11*	−0.05	0.09	−0.06	0.17†	0.01	−0.16†
Curculionidae	바구미과	−0.19‡	−0.03	0.04	−0.06	0.15†	−0.06	−0.15†
Formicidae	개미과	0.07	0.07	−0.11*	−0.05	−0.13*	0.03	0.16†
Formicidae richness	개미과 종수	0.07	0.06	−0.11*	−0.05	−0.13*	0.03	0.16†
Other Hymenoptera	벌목 기타	0.08	−0.09	−0.09	−0.10*	−0.03	0.07	0.09
Lepidoptera	나비목	0.12*	0.04	−0.34‡	−0.36‡	−0.25‡	0.23‡	0.25‡

Significance
* $p < 0.05$.
† $p < 0.01$.
‡ $p < 0.001$.

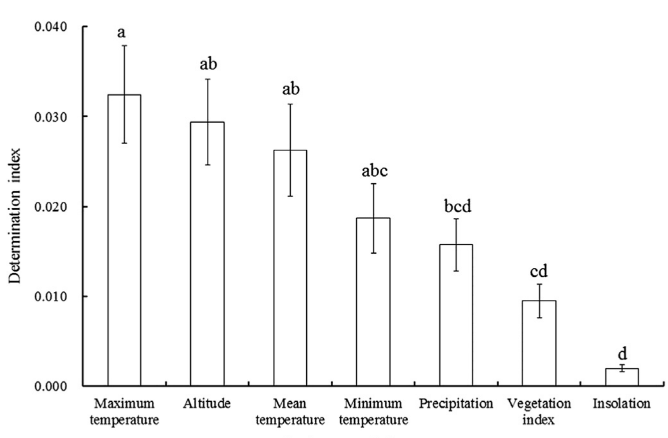


Figure 4. The determination index (R^2) of environmental factors on abundance or richness of the most common 39 arthropods. Data for this figure are provided in Table 3. Error bars indicate one standard error. Different letters on bars indicate a significant difference between cases in Tukey multicomparison test after an analysis of one-way analysis of variance, $F_{6,\ 266} = 8.0192$, $p < 0.001$.

2015)/ values in 2011–2015]. In the two regression models shown in Figure 7, the change rate becomes 0 when the temperature is 10.8°C in RCP 4.5 and 10.64°C in RCP 8.5. Accordingly, it was judged that there is a little change in abundance/richness when the values of temperature fall in the range of 10.64–10.8°C (no change), increases when the values are higher than 10.8°C, and decreases when the values are lower than 10.64°C. This qualitative prediction expected that 23 taxa will increase, 15 taxa will decrease, and six taxa will change a little (Table 5).

Discussion

The abundance and richness of the entire arthropods are expected to decrease, but the prediction results varied among taxa. In the quantitative or qualitative predictions, it was forecasted that among a total of 73 taxa, 45 will increase, six will show a little change, and 24 will decrease: the number of taxa that were expected to increase was two times more than the number of taxa that were expected to decrease. These results are in contrast with that of ants, spiders, and beetles, which were analyzed at the

Table 4. Change of abundance (number of individuals) and richness (number of taxa) of candidate (bio-indicator for climate warming) arthropods according to climate scenarios *Representative Concentration Pathway* (RCP) 4.5 and RCP 8.5.

Name	Korean name	RCP 4.5			RCP 8.5		
		2011–2015	2056–2065	Change (%)	2011–2015	2056–2065	Change (%)
No. of order	절지동물목수	11.360	10.774	−5.2	11.723	10.185	−13.1
Abundance	절지동물개체수	47.382	41.153	−13.1	56.768	36.247	−36.1
Araneae	거미목	1.525	1.462	−4.1	1.478	1.362	−7.8
Araneae richness	거미목 종수	8.143	7.734	−5.0	7.904	7.107	−10.1
Theridiidae	꼬마거미과	0.108	0.093	−14.4	0.112	0.075	−33.4
Linyphiidae	접시거미과	0.199	0.168	−15.5	0.220	0.140	−36.5
Lycosidae	늑대거미과	0.263	0.291	10.6	0.224	0.309	38.1
Agelenidae	가게거미과	0.030	0.025	−17.5	0.030	0.019	−38.0
Hahniidae	외줄거미과	0.030	0.017	−43.2	0.044	0.008	−81.9
Ctenidae	너구리거미과	0.058	0.062	7.2	0.050	0.064	27.4
Liocranidae	밭고랑거미과	0.209	0.209	0.1	0.191	0.201	4.9
Clubionidae	염낭거미과	0.013	0.009	−30.9	0.016	0.005	−65.4
Gnaphosidae	수리거미과	0.227	0.195	−14.4	0.238	0.159	−33.2
Thomisidae	게거미과	0.079	0.072	−9.5	0.079	0.062	−21.4
Salticidae	깡충거미과	0.235	0.262	11.5	0.198	0.280	41.5
Crustacea	갑각강	5.438	7.583	39.4	4.161	10.065	141.9
Oniscomorphia	곰보노래기목	0.944	1.321	40.0	0.676	1.720	154.3
Juliformia	각시노래기목	0.199	0.131	−34.1	0.268	0.081	−69.8
Archaeognatha	돌좀목	1.052	1.031	−2.0	1.035	1.003	−3.0
Rhaphidophoridae	곱등이과	1.741	1.660	−4.6	1.798	1.586	−11.8
Gryllidae	귀뚜라미과	1.096	1.408	28.4	0.819	1.698	107.2
Hemiptera	노린재목	0.569	0.672	18.0	0.481	0.770	60.2
Homoptera	매미목	0.400	0.340	−14.9	0.455	0.284	−37.6
Coleoptera richness	딱정벌레목 종수	9.893	9.273	−6.3	9.895	8.505	−14.1
Hydrophilidae	물땡땡이과	0.037	0.028	−25.9	0.043	0.018	−58.4
Silphidae	송장벌레과	0.203	0.154	−23.9	0.230	0.106	−54.0
Staphylinidae	반날개과	1.147	1.080	−5.9	1.085	0.964	−11.2
Scarabaeidae	소똥구리과	0.364	0.425	16.7	0.297	0.474	59.4
Melolonthidae	검정풍뎅이과	0.092	0.064	−29.9	0.115	0.040	−64.9
Elateridae	방아벌레과	0.017	0.012	−26.7	0.019	0.008	−57.5
Tenebrionidae	거저리과	0.107	0.088	−17.6	0.111	0.067	−39.7
Curculionidae	바구미과	0.145	0.114	−21.2	0.160	0.083	−47.8
Formicidae	개미과	11.612	11.381	−2.0	11.690	11.156	−4.6
Formicidae richness	개미과 종수	7.563	7.315	−3.3	7.513	6.973	−7.2
Other Hymenoptera	벌목 기타	2.056	1.762	−14.3	2.229	1.464	−34.3
Lepidoptera	나비목	0.328	0.251	−23.4	0.414	0.190	−54.1

species level, and that of flies, which were analyzed at the family level, in which more species or much more families were predicted to decrease than increase (Kwon et al 2014c; Kwon and Lee 2015; Kwon et al 2014b; Kwon et al 2015; Lee et al 2015). Lee et al (2015) assumed that the reason for the decline is that there are more northern species than southern species due to the peninsula effect of South Korea. However, it is generally thought that in the temperate regions, the number and diversity of arthropods are expected to increase as temperature increases due to the decrease of coldness, the main limit factor for insect survival in temperate regions (Dunn et al 2010). Deutch et al (2008) forecasted that the fitness of insects will generally increase in temperate regions with a rise in the temperature.

However, the various changes of the taxa may be related with the evolutionary origin of each taxon or regional topographic features (Kwon 2014). In general, taxa that have evolved in warmer regions than South Korea (warm-adapted taxa or southern taxa) will increase along with the increase in the temperature but those evolved in colder regions (cold-adapted taxa or northern taxa) will decrease. However, because Korea is a peninsula, the number of southern species might decrease due to local extinction resulting from isolation from a main population, resulting in more northern species than southern species. The case is opposite to the case of nonpeninsula inlands in the northern Hemisphere where southern species may be more diverse than northern species. However, in the warm-adapted taxa that are originated from the tropics or subtropics and only distributed across warm temperate regions, it is inevitable for them to be dominated by southern species in South Korea and they will increase along with the rise in the temperature. The taxa (e.g. Blattariae, Gryllidae, Scarabaeidae, and Crustacea) that are predicted to increase in this study are likely to be the case. However, in the taxa that occur widely across hot and cold areas, more species tend to decrease due to the dominance of northern species over southern species as noted above. This is the case for ants, spiders, beetles, and flies that more species are expected to decrease in abundance rather than to increase in warming climate. Also, in the taxa (e.g. aphids) that originate from temperate regions, there will be more decreasing species than increasing species (Kwon et al 2014d). However, as the distribution of organisms is affected by various factors besides temperature, including food, competition, predation, and disturbance, more studies are needed on this regard (Gilman et al 2010).

The fact that the responses of population to temperature increase vary across various taxa indicates that the community structure of arthropods will change considerably by climate change. For instance, among the taxa that are the litter feeders, Crustacea and Oniscomorphia will increase but Juliformia and Archaeognatha will decrease, indicating the rapid turnover of taxa in the

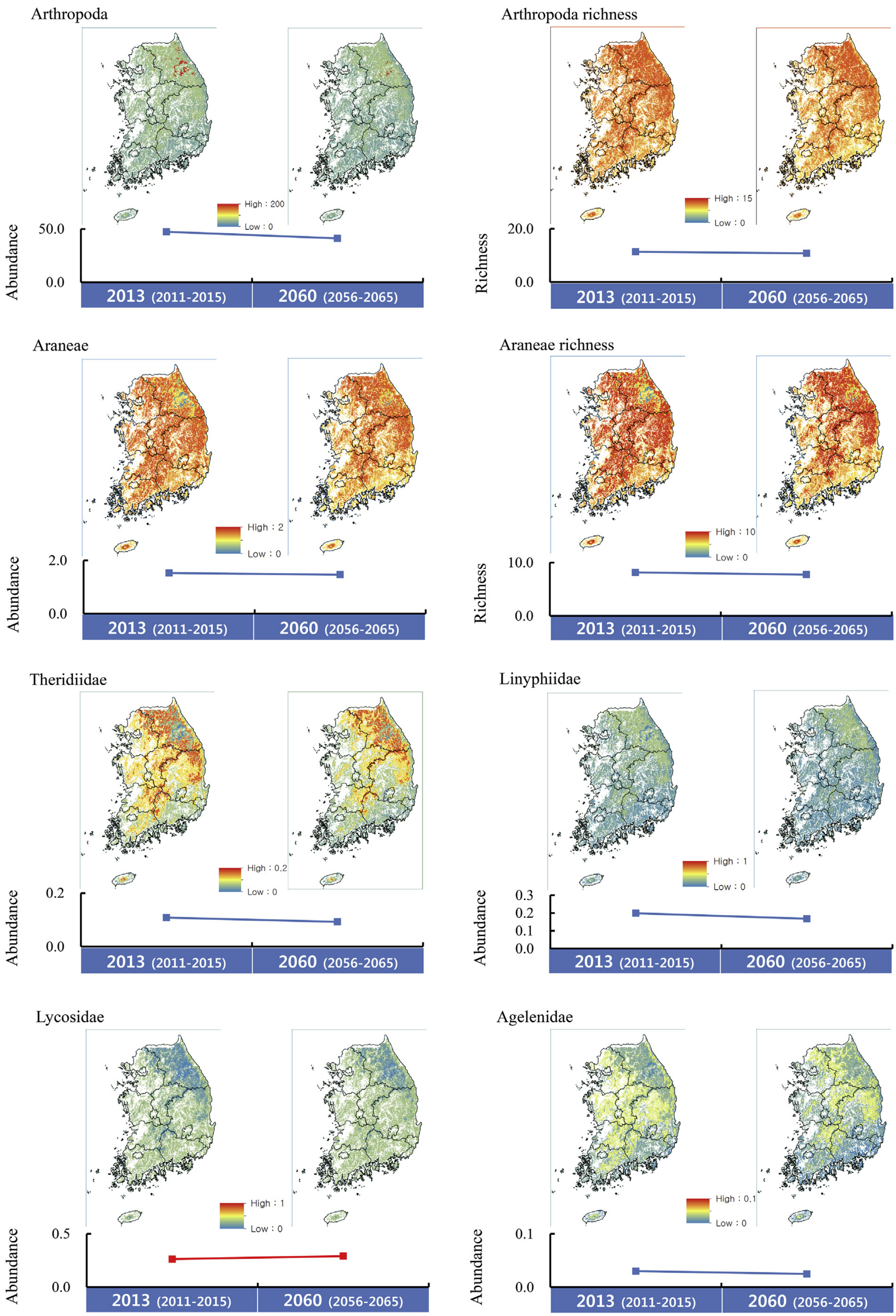


Figure 5. Change in abundance (number of individuals) and richness (number of taxa) of candidate (bio-indicator for climate change) arthropods according to climate scenario RCP 4.5.

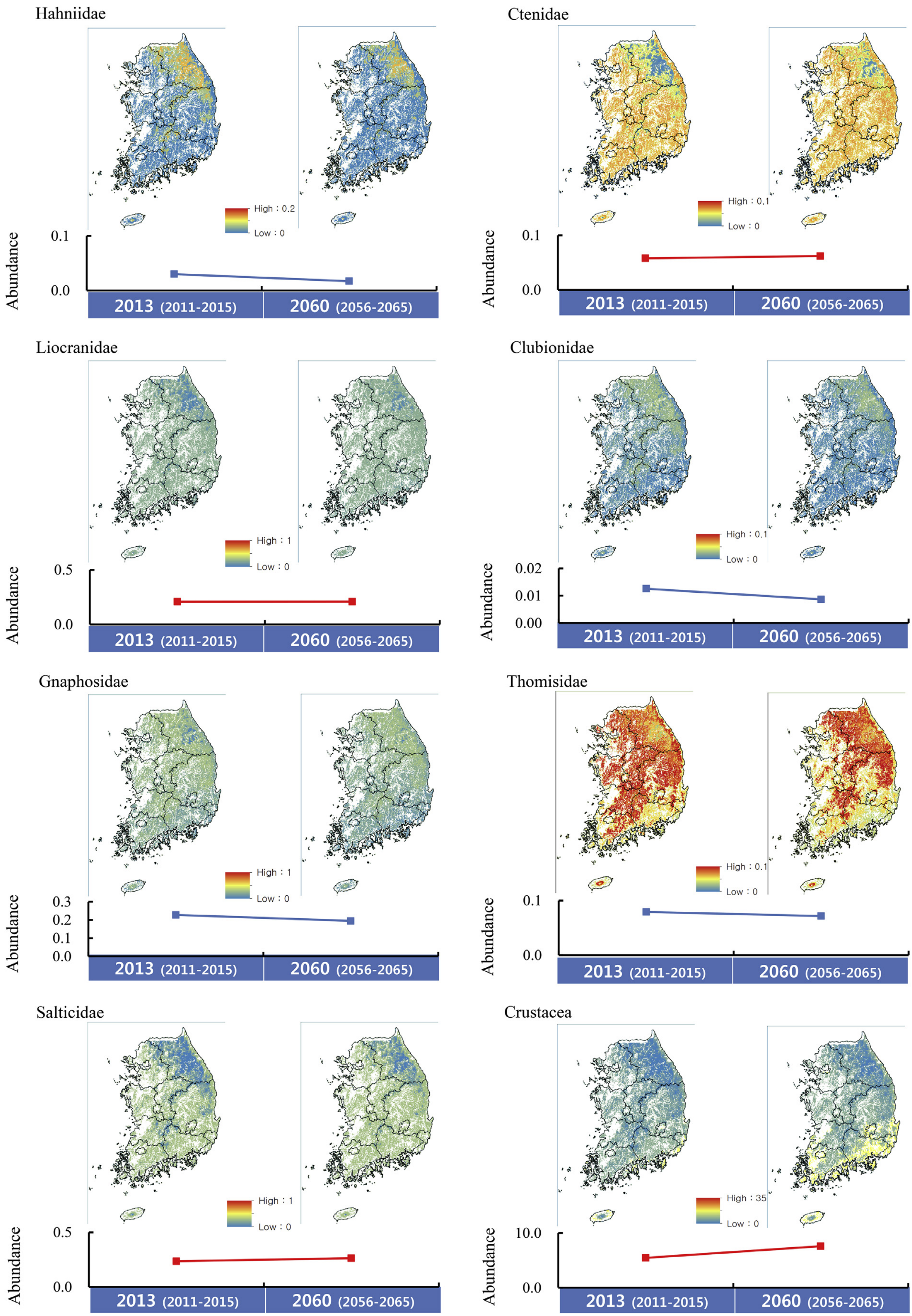
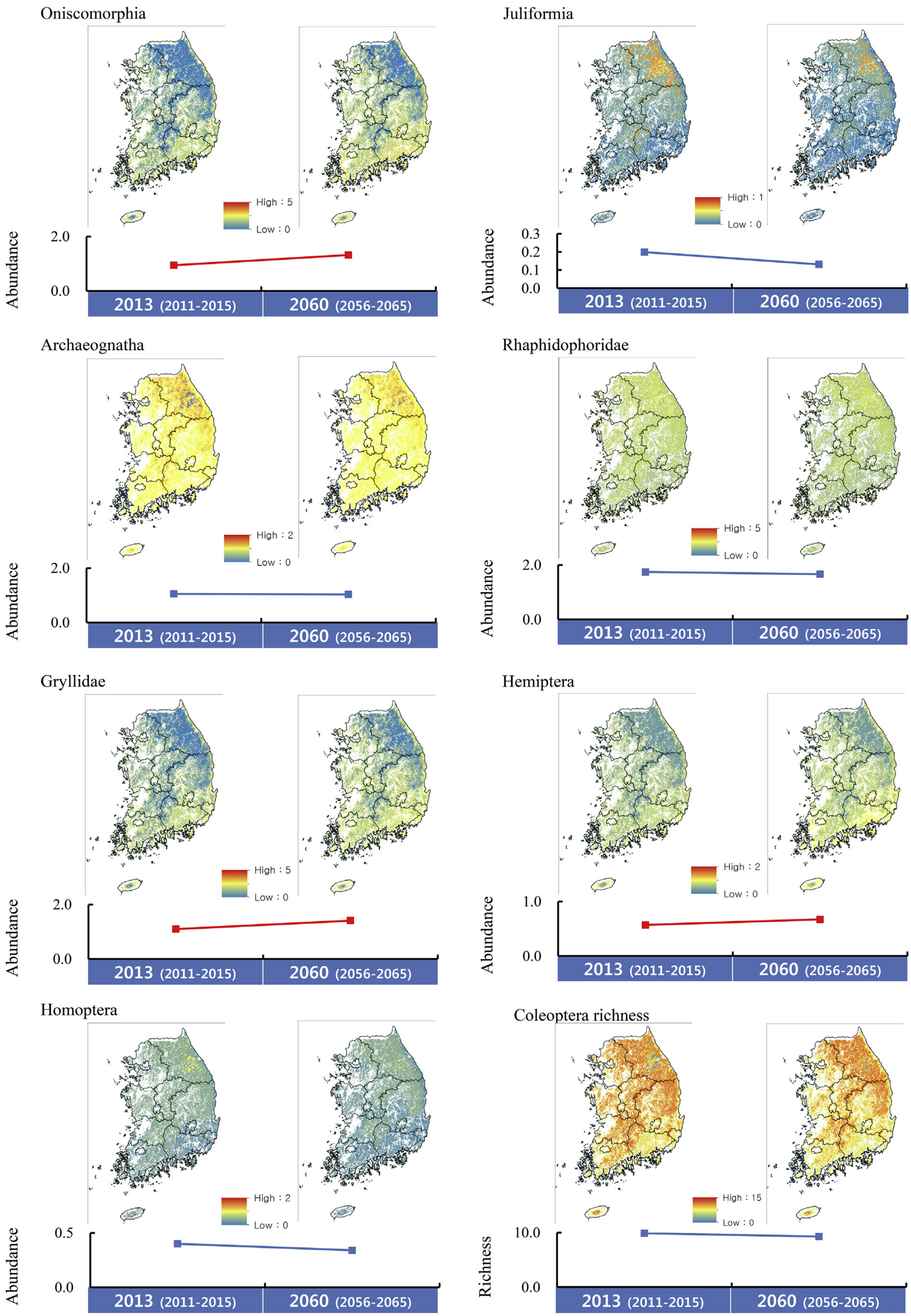


Figure 5. (*continued*)



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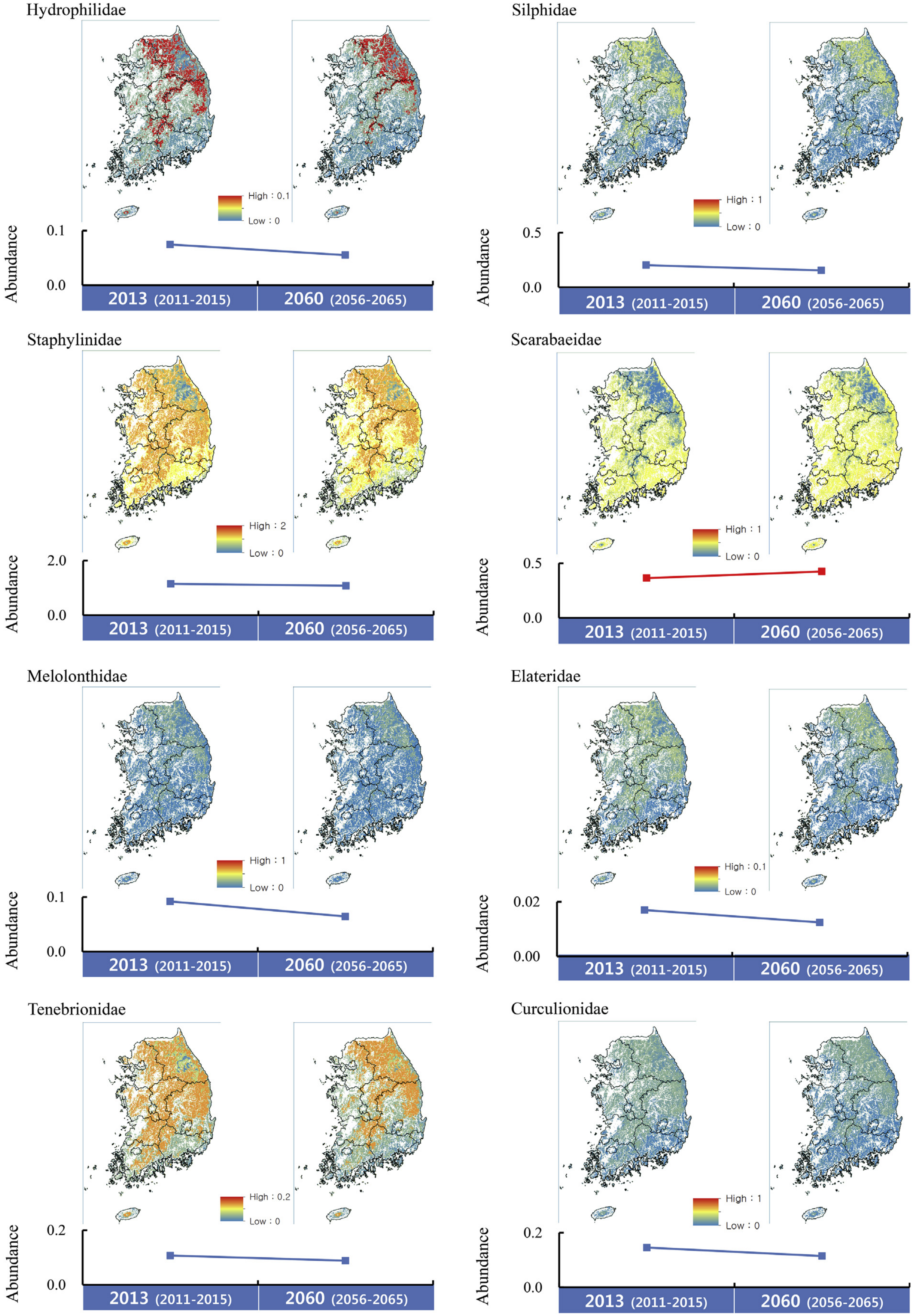

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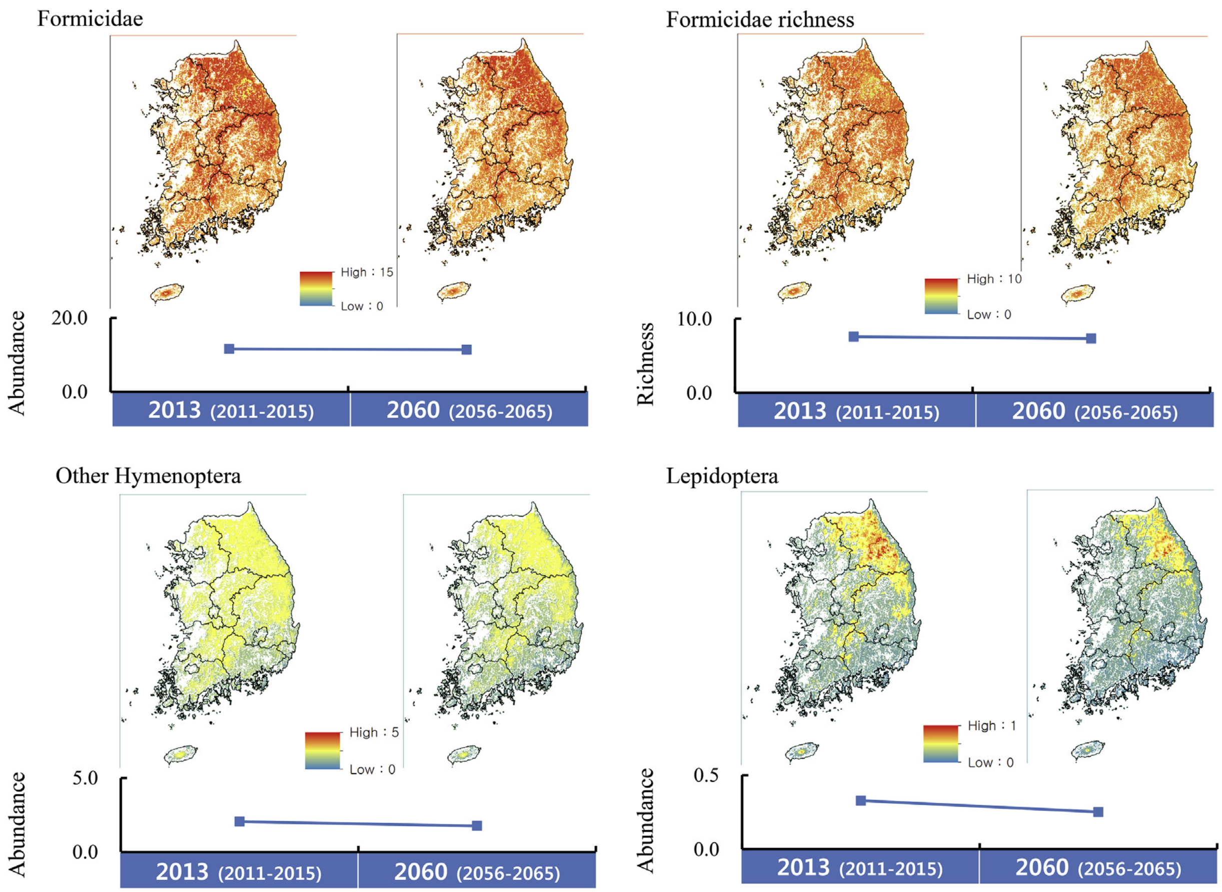


Figure 5. (*continued*)

detritivorous functional guild. The density of Juliformia is much higher in alpine regions at present, but it will decrease greatly if temperature increases and because Crustacea or Oniscomorphia, which will substitute for this taxon, will not be able to settle completely in high mountains in 50 years, the ecological services provided by Juliformia may be blanked temporarily in the highlands. Spiders (Araneae), of which all species are predators, also include families that will increase and families that will decrease, and, therefore, a radical change is expected in their community structure as temperature increases. Although the most distinctive property of the ecosystem is the nonstop change and the nonstop adaptation (Jørgensen and Fath 2011), the following-up adaptation will not be possible if the changes resulting from climate change are rapid.

As this study was conducted at a family or order level, its value may be questionable for the perspective of population ecologists, who places emphasis on studies at a species level. There are many arthropod groups including insects that are not properly studied for their taxonomy. Therefore, many studies on arthropod communities have been conducted with morphospecies or higher taxa (order, family, etc.), and results of such studies have been published in the major ecological journals (e.g. Cole et al 1992; Goldsbrough and Shine 2003), indicating that the high taxa level studies are recognized as the standardized study methods in the arthropod community ecology. The high taxa level projections of arthropods might contribute significantly for the whole picture of the climate warming related ecological change. Although a lot of studies that predict changes in organisms due to climate change have been conducted, no studies have been done on arthropods except those carried out in South Korea (Kwon et al 2014c; Kwon and Lee 2015; Kwon et al 2014b; Kwon et al 2015; Lee et al 2015; Li et al 2013; Li et al 2014). Because predictions using a species distribution model are mostly based on literature data or specimens in museums, they use information on occurrence (1, presence; 0, absence) rather than abundance. However, unlike other studies, this study made quantitative predictions (changes in abundance and richness) using the quantitative data (the number of individuals, the number of taxa), which were investigated using the standardized method according to the preplanned sampling design. In general, temperature and precipitation are dealt as important factors in the climate envelope models (Thuiller 2004), but this study considered only temperature because the spatial variation in precipitation in South Korea is not as great as other regions (e.g. United States, Australia). Neither grasslands nor deserts occur in Korea's natural conditions. The aim of this study cannot be fully achieved by simply making predictions. It is necessary to verify whether the predictions made in this study are accurate through an additional investigation, which provides helpful information for identifying the mechanism of the arthropod changes caused by the climate warming.

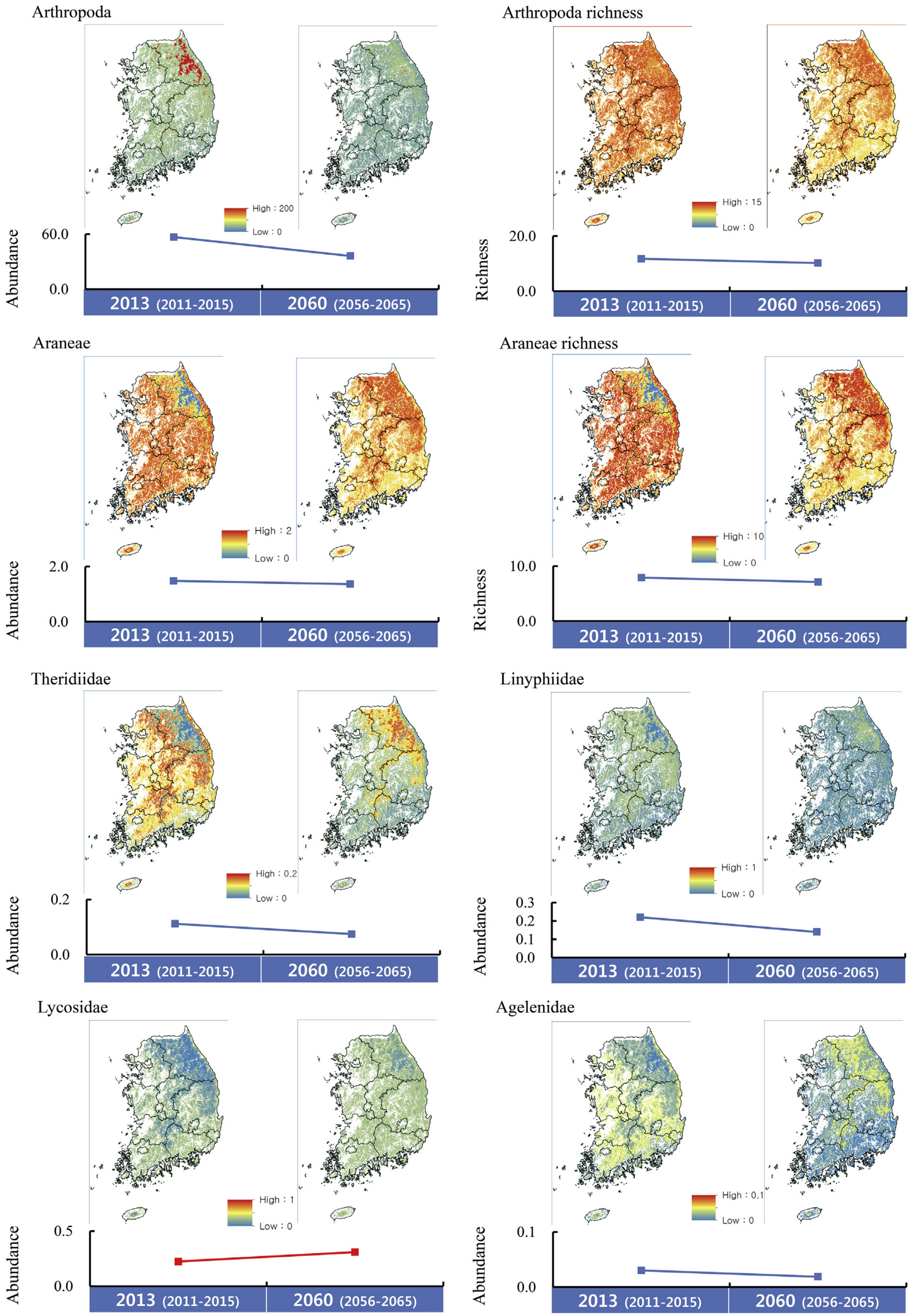
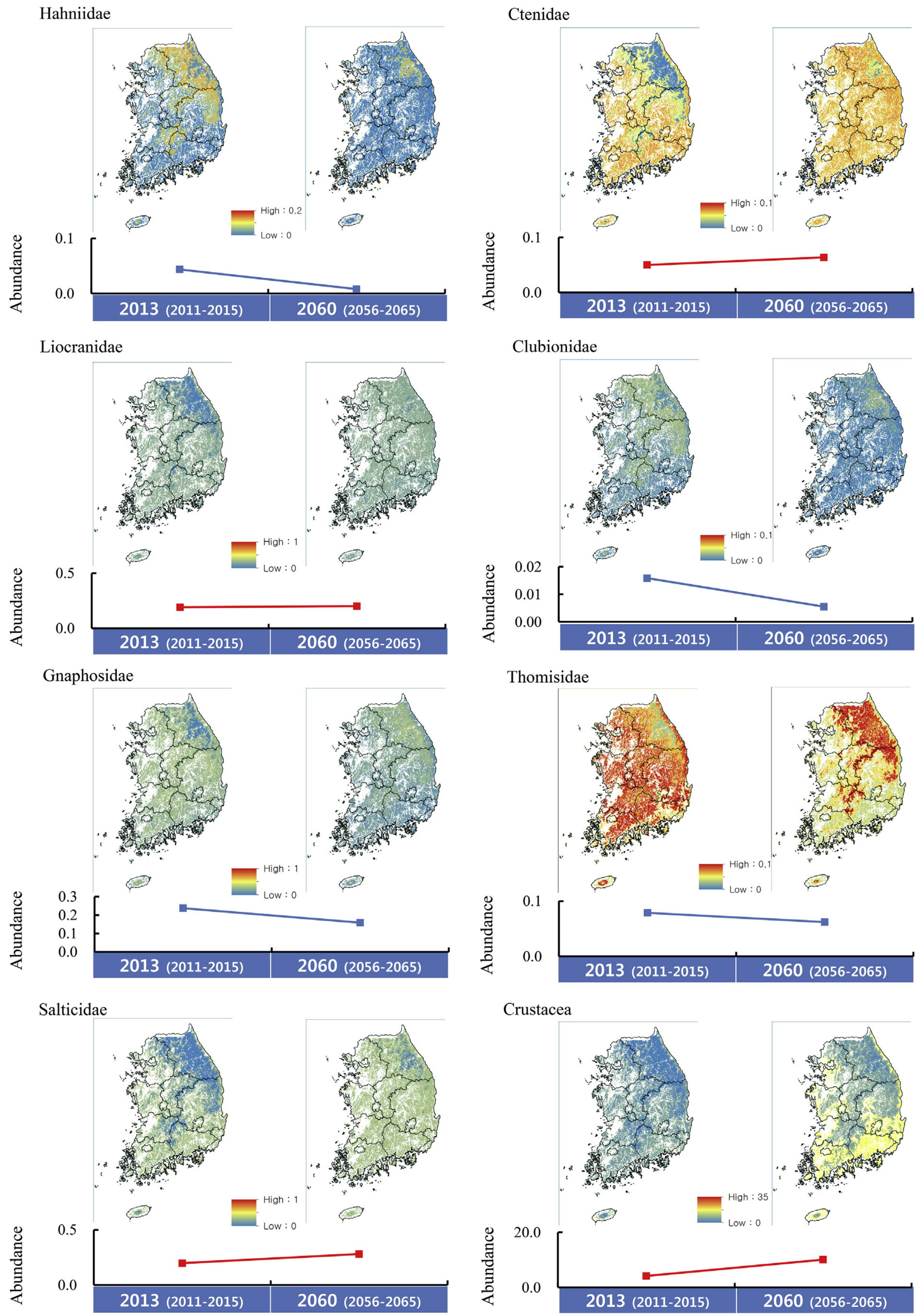


Figure 6. Change in abundance (number of individuals) and richness (number of taxa) of candidate (bio-indicator for climate change) arthropods according to climate scenario RCP 8.5.



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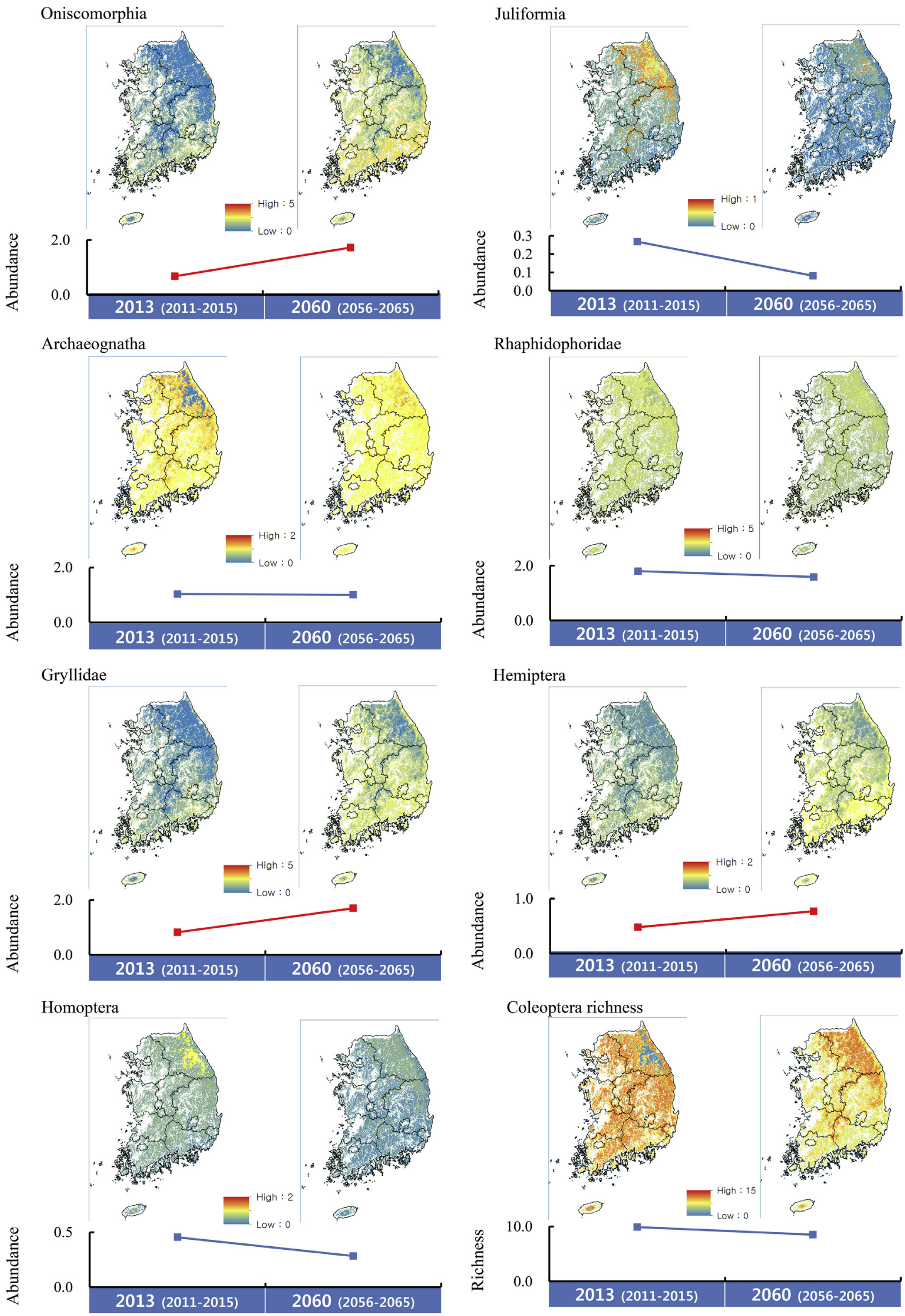

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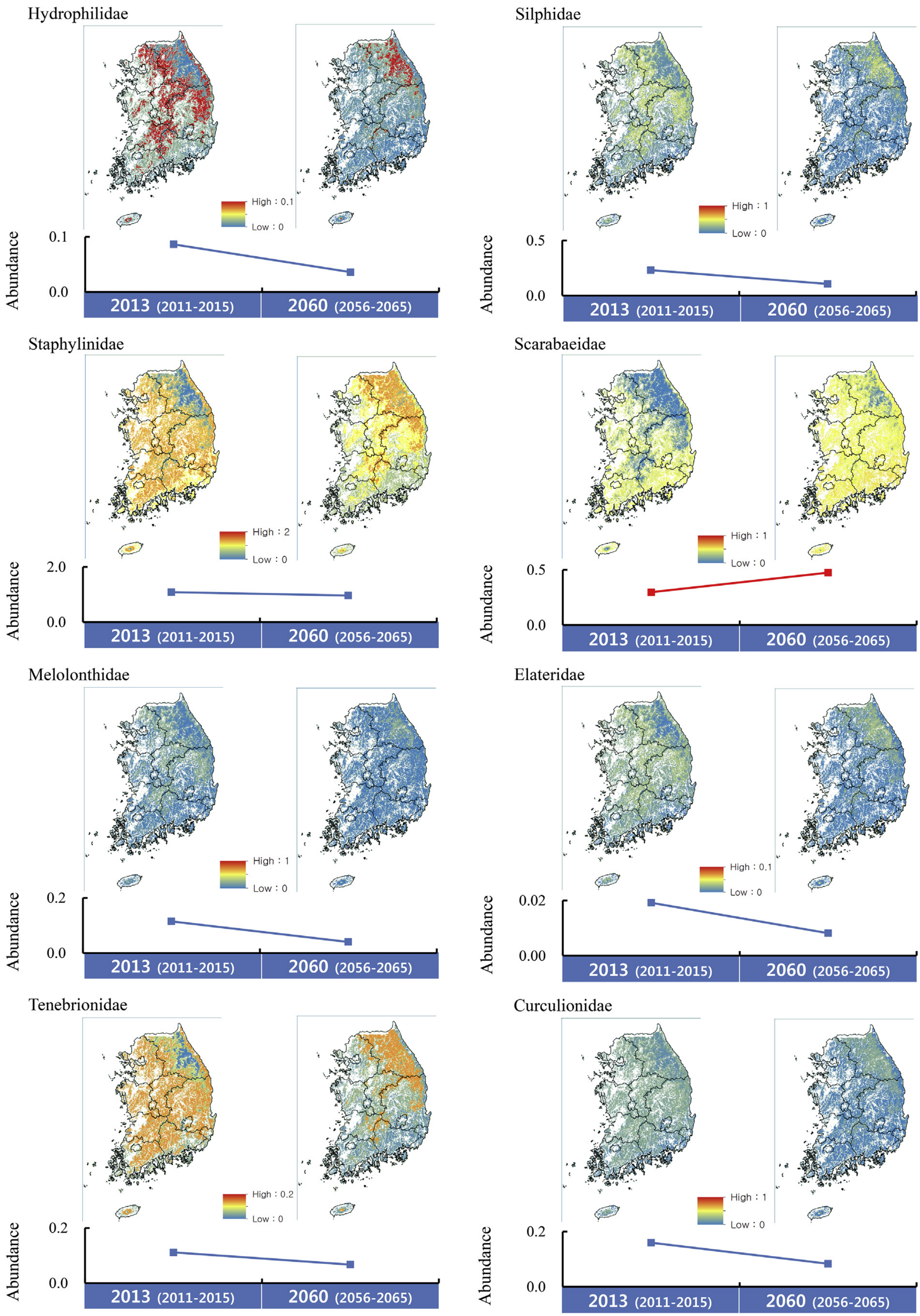

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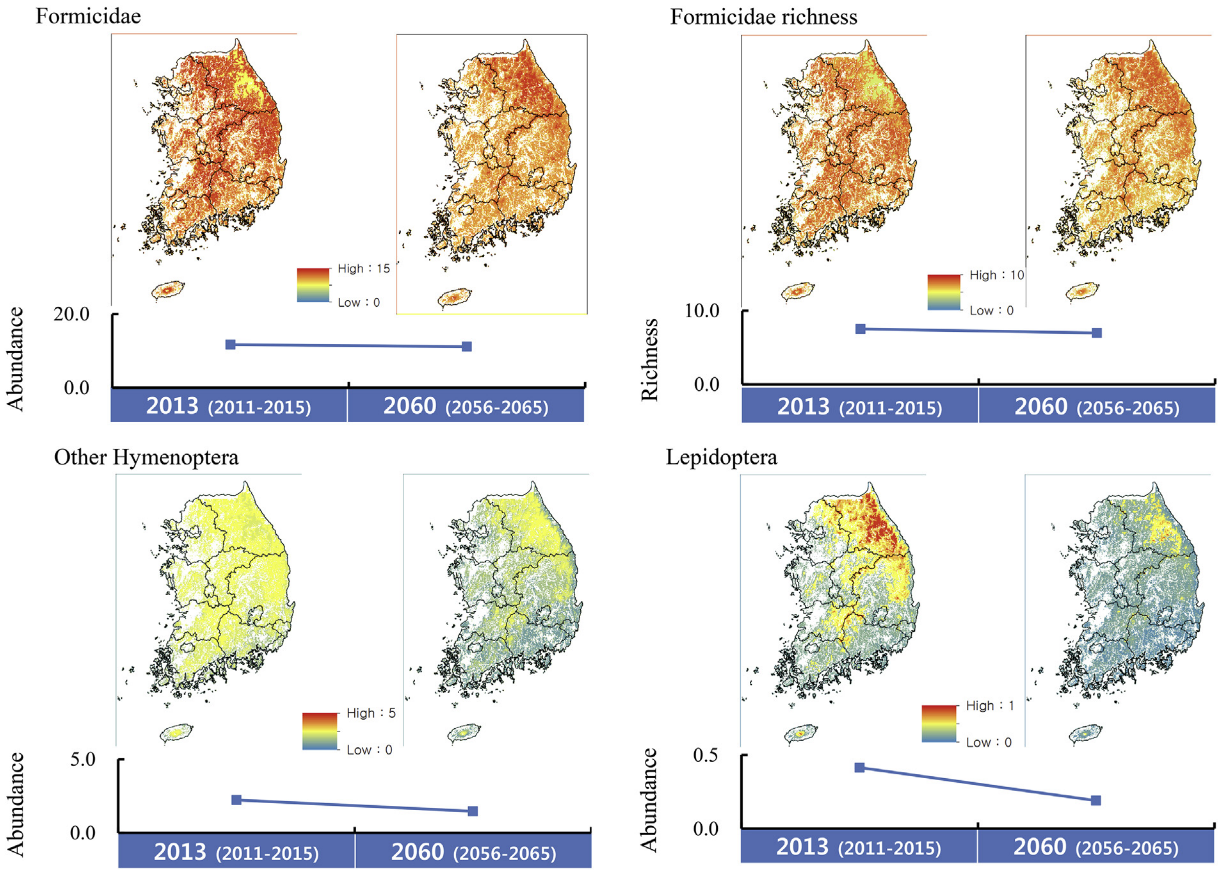

Figure 6. (*continued*).

Table 5. Qualitative prediction of abundance (number of individuals) and richness (number of taxa) for common arthropods (>1% occurrence) except the 36 candidate arthropod taxa in Table 4.

Name	Korean name	Change
Mimetidae	해방거미과	Increase
Segestriidae	공주거미과	Increase
Aphodiidae	똥풍뎅이과	Increase
Mordellidae	꽃벼룩과	Increase
Trogidae	송장풍뎅이과	Increase
Nesticidae	굴아기거미과	Increase
Blattariae	바퀴벌레목	Increase
Tetragnathidae	갈거미과	Increase
Corinnidae	코리나거미과	Increase
Rutelidae	풍뎅이과	Increase
Dermestidae	수시렁이과	Increase
Nitidulidae	밑빠진벌레과	Increase
Philodromidae	새우게거미과	Increase
Rhynchophoridae	왕바구미과	Increase
Leiodidae	알버섯벌레과	Increase
Oonopidae	알거미과	Increase
Lucanidae	사슴벌레과	Increase
Lycidae	홍반디과	Increase
Scolytidae	나무좀과	Increase
Geotrupidae	금풍뎅이과	Increase
Cetoniidae	꽃무지과	Increase
Chrysomelidae	잎벌레과	Increase
Pisauridae	닷거미과	Increase
Anapidae	도토리거미과	Stable
Araneidae	왕거미과	Stable
Dictynidae	잎거미과	Stable
Cryptophagidae	곡식쑤시기과	Stable
Oedemeridae	하늘소붙이과	Stable
Carabidae	딱정벌레과	Stable
Coleoptera	딱정벌레목	Decrease
Sparassidae	농발거미과	Decrease
Cerambycidae	하늘소과	Decrease
Histeridae	풍뎅이붙이과	Decrease
Melandryidae	긴썩덩벌레과	Decrease
Cantharidae	병대벌레과	Decrease
Endomychidae	무당벌레붙이과	Decrease
Lagriidae	잎벌레붙이과	Decrease
Chilopoda	지네강	Decrease
Other Orthoptera	메뚜기목 기타	Decrease
Phalangida	장님거미목	Decrease
Polydesmoidea	띠노래기목	Decrease
Cybaeidae	굴뚝거미과	Decrease
Zoridae	오소리거미과	Decrease
Amaurobiidae	비탈거미과	Decrease

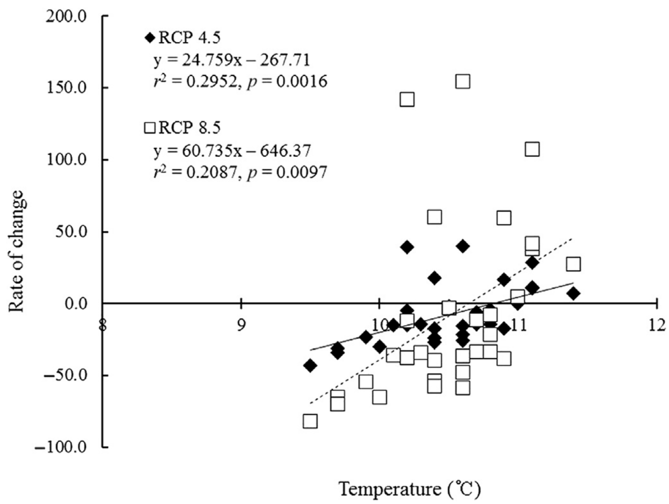

Figure 7. Average of annual mean temperature at the occurred sites and the rate of change in abundance or richness in the candidate arthropods. The values of the rate of change in abundance are provided in Table 4 and data of temperature are provided in Table S1.

Acknowledgments

This study was carried out as a part of research project of the Korea Forest Research Institute (project number 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 at http://dx.doi.org/10.1016/j.japb.2016.03.001.

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