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Original article

Prediction of abundance of forest spiders according to climate warming in South Korea

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ABSTRACT

Distribution of spiders will be changed as climate warms. Abundance of spider species was predicted nationwide in South Korea. Abundance of spiders was projected using temperature species distribution model based on a nationwide data (366 forest sites) according to climate change scenario RCP 4.5 and 8.5. The model predicts that 9 out of 17 species will increase in abundance while 8 species will decrease. Based on this finding, a qualitative prediction (increase or decrease) was conducted on the species with more than 1% occurrence: 68 species are expected to decrease, 9 to increase, and 8 to change a little. In pooled estimation, 76 species (75%) are expected to decrease, 18 species (18%) to increase, and by 8 species (8%) to have little change. The projection indicates that majority of spider species will decrease, but minority of species will increase as climate warms, suggesting great increase of remained species in lowlands.

Introduction

It has been confirmed in a variety of biota in the 20th century that the distribution of living creatures increasingly directs to the polar area or moves to higher altitude (Hickling et al., 2006, Konvicka et al., 2003, Parmesan et al., 1999). Although some uncertainty exists due to the complicated interaction between the members of living creatures in ecosystem, global warming is leaving distinct climate fingerprints in the biosphere (Parmesan and Yohe, 2003, Walther et al., 2002, Walther et al., 2005). Intergovernmental Panel on Climate Change ("IPCC" 2007) reported that as the mean temperature on earth increases by 1.5–2.5 °C compared to that during 1980 through 1999, about 20-30% of plant and animal species are likely to become extinct. Thomas et al. (2004) warned that the year of 2050 would witness 15–37% of the current species would become endangered. However, there are some researchers who pose a question of such a massive reduction in biodiversity (i.e. Botkin et al., 2007, Bradshaw and Holzapfel, 2006, He and Hubbell, 2011). As such, due to the complicated interaction between living creatures and environmental factors (Thomas et al., 2004) and a lack of data available for prediction, there are lots of uncertainties to predict the response of living creatures attributing to climate change. The studies on climate change have focused on flagship taxa (i.e. butterfly, bird, fish, etc.) while most of taxa have yet to be subject to study. In this respect, we could predict more precisely the change in biota caused by climate change only when the reliable data would be accumulated in relation to biological changes in those taxa that have experienced a lack of studies (Hickling et al., 2006).

Spiders are an animal that has evolved 0.4 billion years ago, 44,540 species of which are known to be distributed around the world (Platnick, 2000) and 726 species of which have been reported in Korea (Kim and Kim, 2010). Many people regard a spider as a kind of insects; systematology says spiders are completely different from insects. Insects have a variety of feeding habits while spiders show the same feeding habit as a predator. Spiders mostly eat insects; the feeding habit of which causes them to play an important role in ecosystem as a natural enemy to control the density of harmful insects generating in forests and farmlands. Spiders are largely divided into two by life type: those which spin a web (web spider) and those which do not spin a web (wandering spider) (Uetz, 1977). Webs are various including 7 other kinds such as orb web. Wandering spiders not spinning a web wander or hide in grass field or forest without a certain residing place and catch a prey, which account for about a half of Arachnida (Namkung, 2001). The results examining forest fire areas say that after a forest fire, web spiders decrease in population while wandering spiders rather increase in population (Lee et al., 2012).

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Spiders are used as a biological indicator to watch any environmental change because they are highly diverse, large in population, and significantly function in terrestrial ecosystems (Jung et al., 2008, Mgobozi et al., 2008). The studies on spiders inhabiting Korea were concentrated largely on taxonomic research and biota survey of spiders while ecological researches are relatively poor (i.e. Jung et al., 2008, Lee and Lee, 1990, Lee et al., 2012). Spiders inhabiting Korea were arranged by Namkung (2001); however, there is still a lack of studies that analyze the distribution status of spiders nationwide in a quantitative method. Even though some researchers recently conduct the studies on the effect of climate change on spiders (Brandon et al., 2009, Crouch and Lubin, 2000, Davies et al., 2011, Lensing and Wise, 2006, Saupe et al., 2011), there are few studies to predict the change in distribution of spiders in accordance with climate change. This study was aimed to project the abundance and the distribution of spiders inhabiting the domestic forests in Korea according to climate change. Using data of the spiders collected from a total of 366 study sites in the forests nationwide, we predicted the prospective changes in accordance with the climate change scenarios (RCP 4.5 and 8.5) by a temperature species distribution model using the value of abundance in each temperature band.

Materials and methods

Study site

Spider surveys were conducted at 366 study sites (Figure 1). In order to select study sites as impartially as possible, 8 study sites

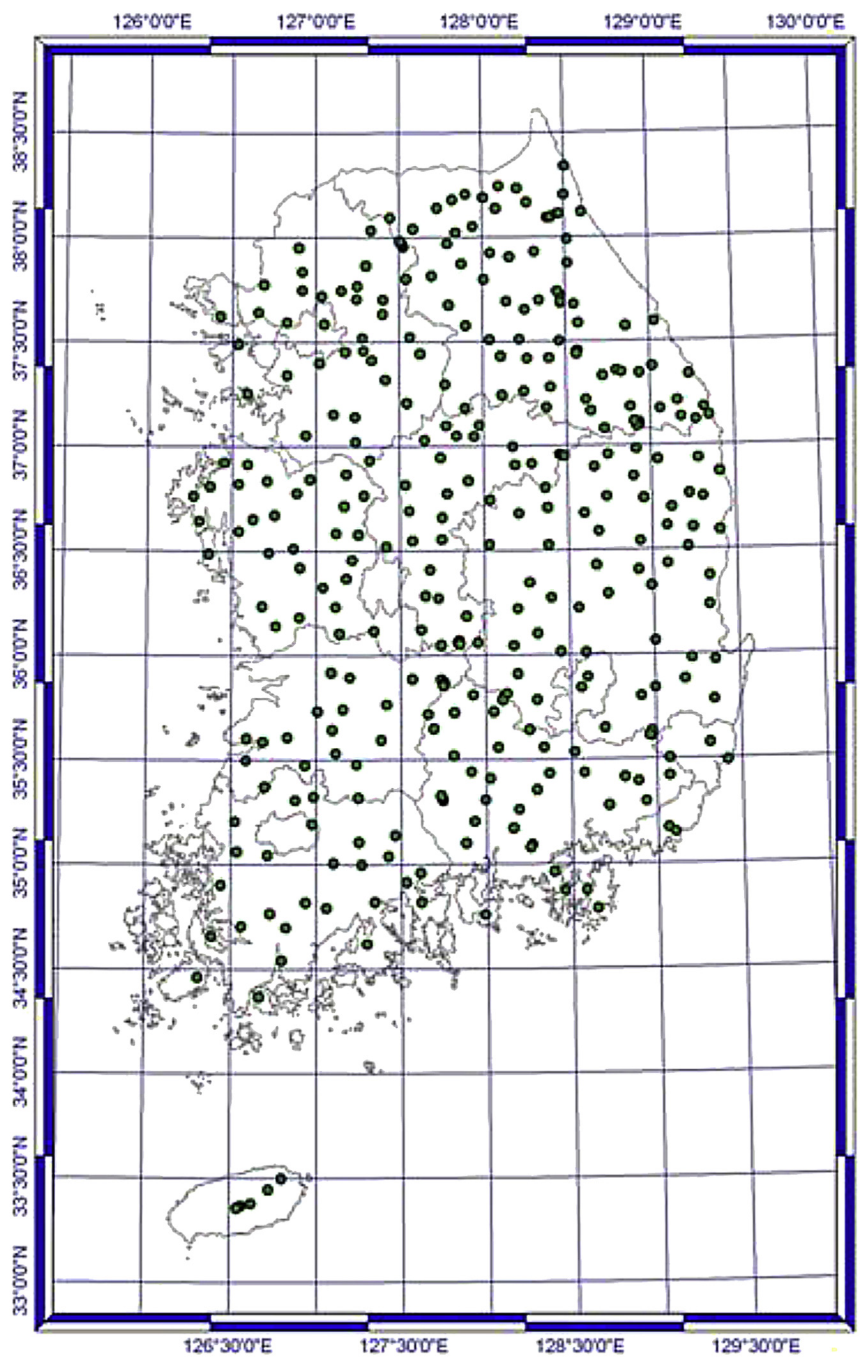


Figure 1. Study sites for the survey of forest spiders in South Korea.

Table 1
Species distribution model by multiple regression model for the 17 candidate spider species. 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).

Species	Korean name	Multiple regression model	R^2	*P*
Pirata yaginumai	방울늑대거미	$y = -1.922567 + 0.31465{*}X_3 - 0.11254{*}X_4 - 0.07989{*}X_5 + 0.00031{*}X_7 - 0.0002{*}X_6$	0.22	0.0000
Itatsida praticola	족제비거미	$y = -1.0351 + 0.19825{*}X_3 - 0.07865{*}X_4 - 0.06287{*}X_5 + 0.00014{*}X_1$	0.14	0.0000
Sernokorba pallidipatellis	석줄톱니매거미	$y = -1.52354 - 0.06448{*}X_4 + 0.13882{*}X_3 + 0.00022{*}X_7$	0.13	0.0000
Nippononeta cheunghensis	청하꼬마접시거미	$y = -0.298279 + 0.059378{*}X_4 + 0.098224{*}X_3 - 0.042547{*}X_5 + 0.000095{*}X_1$	0.12	0.0000
Stemmops nipponicus	먹눈꼬마거미	$y = -0.699992 - 0.029514{*}X_4 + 0.000016{*}X_6$	0.12	0.0000
Anahita fauna	너구리거미	$y = -0.836097 - 0.000184{*}X_7 + 0.095706{*}X_3 - 0.036412{*}X_4$	0.09	0.0000
Xysticus ephippiatus	대륙게거미	$y = -1.56221 + 0.18431{*}X_3 - 0.00028{*}X_7 - 0.0646{*}X_4 + 0.00010{*}X_1 - 0.03583{*}X_5 - 0.00001{*}X_6$	0.21	0.0000
Harmochirus insulanus	산표깡충거미	$y = -1.922567 + 0.31465{*}X_3 - 0.11254{*}X_4 - 0.07989{*}X_5 + 0.00031{*}X_7 - 0.0002{*}X_6$	0.22	0.0000
Orthobula crucifera	십자삼지거미	$y = -0.193785 + 0.006547{*}X_5 - 0.00503{*}X_2$	0.10	0.0000
Phintella cavaleriei	멋쟁이눈깡충거미	$y = -0.400873 - 0.000032{*}X_1 + 0.000095{*}X_7 - 0.027468{*}X_3$	0.10	0.0000
Diplocephaloides saganus	흰배애접시거미	$y = -0.005162 - 0.000081{*}X_7 + 0.00821{*}X_4 - 0.000053{*}X_1$	0.09	0.0000
Harmochirus pullus	반고리깡충거미	$y = -0.467958 - 0.063797{*}X_3 - 0.024772{*}X_4 - 0.000078{*}X_7 - 0.000008{*}X_6 - 0.014667{*}X_4 - 0.00003{*}X_1$	0.14	0.0000
Doenitzius purvus	땅접시거미	$y = -0.178526 - 0.000023{*}X_1 + 0.007681{*}X5 - 0.00005{*}X_7$	0.05	0.0000
Neoantistea quelpartensis	제주외줄거미	$y = -0.332385 - 0.030688{*}X_4 + 0.000018{*}X_6 - 0.000154{*}X_7 - 0.040605{*}X_5 + 0.053595{*}X_3$	0.09	0.0000
Evarcha albaria	흰눈썹깡충거미	$y = -0.284223 - 0.011042{*}X_5 + 0.000063{*}X_7 - 0.000006{*}X_6$	0.07	0.0000
Zelotes asiaticus	아시아염라거미	$y = -0.389359 + 0.054697{*}X_3 + 0.020883{*}X_4$	0.06	0.0011
Gnaphosa kompirensis	넓적니거미	$y = 0.291163 - 0.006885{*}X_5 - 0.000085{*}X_7 - 0.009597{*}X_6$	0.08	0.0000
Arctosa kwangreungensis	광릉논늑대거미	$y = 0.152723 - 0.000064{*}X_7 - 0.037205{*}X_3 - 0.01351{*}X_4 - 0.012876{*}X_5$	0.06	0.0008
Drassyllus biglobus	쌍방울참매거미	$y = 0.018929 - 0.003761{*}X_4$	0.03	0.0132

were arbitrarily arranged within the lattice (0.5 × 0.5 degrees of latitude and longitude). The currently selected sites were on average 8.3 study sites designated within the lattice (SD = 1.8; maximum value: 13; minimum value: 6), among which also include higher mountains more than 1100 m above sea level such as Hallasan, Seolaksan, Jirisan, Gyebangsan, Gariwangsan, Taebaeksan, Sobaeksan, Minjujisan, Deokyusan, Gayasan, and Unmunsan Mountains. Across those high mountains were selected and surveyed 4–7 study sites in each mountain at an interval of 200–300 m of altitude: the study sites are largely health forests more than 30 years old and with understory vegetation well developed. The top areas of those mountains that are formed in grassland and/or bushes were included in study sites. A survey was also conducted in the Jeju island; however, a mistake in the course of identification caused irrevocably to omit the results obtained on the island.

Survey and identification of spiders

Spider surveys were conducted using a pitfall trap. 10 pitfall traps were installed in a line at an interval of 5 m at each survey site and then collected 10–15 days later. Each trap was a third filled with automotive antifreeze (polyethylene glycol, eco-friendly) as preservative solution. Since automotive antifreeze has no attractive effect, less evaporates, and is fit for conserving insect specimen, it is being much used as preservative solution (Greenslade and Greenslade, 1971). A plastic container (diameter: 9.5 cm; depth: 6.5 cm) that is used to contain soup when going on a picnic was used for trap container. This container has a lid, easy to collect and conserve a sample. When collecting a pitfall trap, the liquid contained in the container was finely filtered and the residue including spider body was put into the container on which was then placed a

Table 2
Correlation between abundance (no of individuals per trap) and environmental factors in common (>10% occurrence) spider species. Significance, *: $P < 0.05$, **: $P < 0.01$, $P < 0.001$.

Species	Korean name	Environmental factor						
		Precipitation	Insolation	Mean temperature	Minimum temperature	Maximum temperature	Vegetation index	Altitude
Pirata yaginumai	방울늑대거미	−0.15**	0.08	0.37***	0.25***	0.33***	−0.20***	−0.31***
Itatsida praticola	족제비거미	−0.09	0.01	0.28***	0.15**	0.27***	−0.13*	−0.28***
Sernokorba pallidipatellis	석줄톱니매거미	−0.24***	0.06	0.13*	-0.06	0.23***	−0.02	−0.20***
Nippononeta cheunghensis	청하꼬마접시거미	−0.13*	−0.05	0.00	−0.18***	0.13*	−0.06	−0.14**
Stemmops nipponicus	먹눈꼬마거미	−0.25***	0.05	0.12*	−0.08	0.24***	−0.18***	−0.22***
Anahita fauna	너구리거미	−0.14**	0.02	0.26***	0.17**	0.26***	−0.10	−0.26***
Xysticus ephippiatus	대륙게거미	−0.13*	0.08	0.16**	0.06	0.17**	−0.11*	−0.14**
Harmochirus insulanus	산표깡충거미	−0.02	0.09	0.32***	0.25***	0.25***	−0.15**	−0.21***
Orthobula crucifera	십자삼지거미	−0.17**	0.13*	0.23***	0.08	0.26***	−0.19***	−0.23***
Phintella cavaleriei	멋쟁이눈깡충거미	−0.19***	0.12*	0.21***	0.11*	0.22***	−0.10	−0.19***
Diplocephaloides saganus	흰배애접시거미	−0.09	−0.07	0.05	−0.08	0.16**	−0.14**	−0.17**
Harmochirus pullus	반고리깡충거미	−0.09	0.10	0.24***	0.13*	0.23***	−0.19***	−0.20***
Doenitzius purvus	땅접시거미	−0.17**	0.06	0.10	−0.02	0.16**	−0.05	−0.13*
Phrurolithus pennatus	살깃도사거미	−0.11*	0.08	0.04	−0.08	0.13*	−0.08	−0.13*
Neoantistea quelpartensis	제주외줄거미	−0.03	−0.08	−0.13*	−0.20***	−0.07	0.16**	0.04
Evarcha albaria	흰눈썹깡충거미	−0.11*	0.07	0.20***	0.09	0.22***	−0.19***	−0.18**
Zelotes asiaticus	아시아염라거미	−0.05	0.00	0.18**	0.10*	0.16**	−0.10	−0.15**
Gnaphosa kompirensis	넓적니거미	−0.07	−0.09	−0.16**	−0.24***	−0.06	0.01	0.03
Synagelides agoriformis	어리개미거미	−0.07	0.00	0.04	−0.06	0.11*	0.04	−0.10
Arctosa kwangreungensis	광릉논늑대거미	−0.12*	0.03	0.11*	0.05	0.16**	−0.07	−0.16**
Drassyllus biglobus	쌍방울참매거미	−0.09	−0.05	−0.09	−0.14**	−0.02	0.05	0.00

lid; which was taken into a laboratory to conserve in alcohol (80%) until identification. Spider surveys were conducted from every mid-May to mid-September for 4 years between 2006 through 2009. Meteorological data were obtained from the nearest weather stations to survey sites for recording weather condition during sampling (Korea Meteorological Administration 2006–2009), which is available in Kwon et al. (2013). The identification work was conducted by late Dr Kim Byung-Woo (passed away in 2012 as a research scientist in the Korea National Park Research Institute). Data of survey sites and spider species collected is shown in Kwon et al. (2013).

Analysis and prediction

Environmental factors

Using GIS technique based on the coordinates of study sites, the temperature (annual average temperature, annual highest temperature, and annual lowest temperature), annual precipitation, daily value of solar radiation, and vegetation index (Normalized Difference Vegetation Index, NDVI as of May 2005) were determined. Temperature was estimated in reference to the digital map provided by the Korea Meteorological Administration and the National Institute of Agriculture & Forestry Meteorological Research (Yun et al., 2013), which used the mean value from 1971 to 2008. The length of lattice in spatial resolution was 30 m.

Relationship between environmental factors and abundance

The correlation between the abundance (number of individuals) of 21 species that appeared more than 10% in frequency and the environmental factors of collection sites was analyzed using the correlation analysis. Significance was determined in reference to $p < 0.05$. Stepwise multiple regression analysis was used to make a multiple regression model for the abundance of each species.

Prediction of temperature change

In 2012, the Korea Meteorological Administration (KMA) developed and provided the scenario of specific climate change of the Korean peninsula (lattice length: 12.5 km) including South Korea (lattice length: 1 km) which would be used in the fifth IPCC assessment report. This study used the distribution map of average temperature in the scenarios of RCP 4.5 and 8.5 provided by KMA (resolution of 1 km) to obtain the average temperature during 2011 through 2015 and during 2056 through 2065 in each lattice (1 km^2) which was used to predict distribution pattern of abundance.

Prediction of abundance

In general, species distribution model (SDM) mostly considers a variety of environmental factors; however, the factors available to predict climate change on an actual basis include temperature and precipitation: precipitation has higher variability in season (Yun et al., 2013), substantially lower predictability compared to temperature. Hence, the models including a variety of environmental factors (i.e. niche model) usually predict assuming that the other factors other than temperature do not change (MY Shin, personal communication). However, since the environmental factors other than temperature will change with complicated connection with temperature change, such assumption does not reflect reality. Therefore, rather than a complex model considering a variety of factors that is not possible to predict, a simple model only considering temperature would be regarded more reasonably realistic for a more robust prediction of climate-driven biological change. This is more the case particularly in South Korea where the relationship between the distribution of arthropods including spiders and insects and the environmental factors is little known. This study made a variety of multiple regression models using 7 factors; however, each of which had less power of explanation just ranging 3–22%; thus, we judged it not appropriate to predict using such models (Table 1). Accordingly, this study predicted the change in abundance in the following methods using the mean value of abundance in each temperature band.

The correlation analysis between 21 species that appeared 10% or more in occurrence (i.e., the number of study sites where the

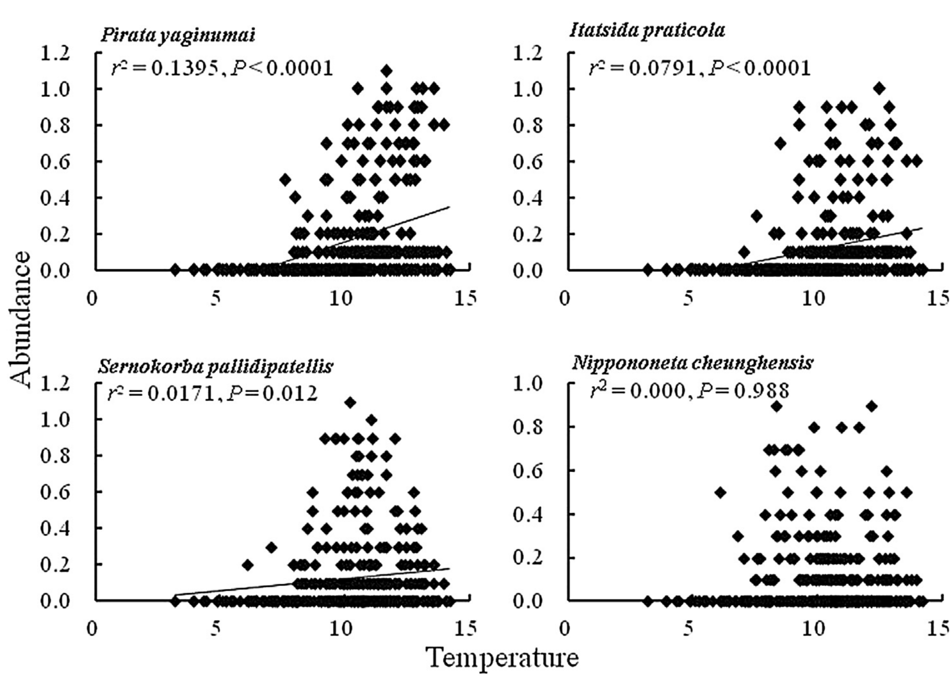


Figure 2. Temperature (annual mean) and abundance (number of individuals per trap) of the most common spider species.

species were collected is more than 37) and the environmental factors revealed that average temperature is highly correlated with abundance compared to the other environmental factors (Table 2), which explains only 4% of the variation of abundance (Table 2, Figure 6). This is because of high variability of abundance between study sites (Figure 2). However, comparing the mean value of abundance in each temperature band showed higher relevance between abundance and temperature (Figure 3). This study divided the average temperature of study sites into 6 bands: 3∼7°C, 7∼9°C, 9∼11°C, 11∼13°C, 13∼15°C, and 15∼17°C; then calculated mean value of abundance and SE of each species in those bands, respectively. When comparing the mean values of abundance by temperature band, the species that are distributed in linear or bell figure (normal distribution) were assumed to have high relevance with temperature. The analysis results revealed that 17 out of 21 species had such a distribution pattern highly depending on temperature change. Using the mean value of abundance in each temperature band (Table 3), the distribution change of each species was predicted in connection with temperature change. The periods of years predicted were two: during 2010 through 2015 and during 2056 through 2065; grasping the prospective distribution by temperature band during each period and reflecting the mean value of abundance in temperature band, the distribution pattern of abundance for each species was projected into two periods. Since

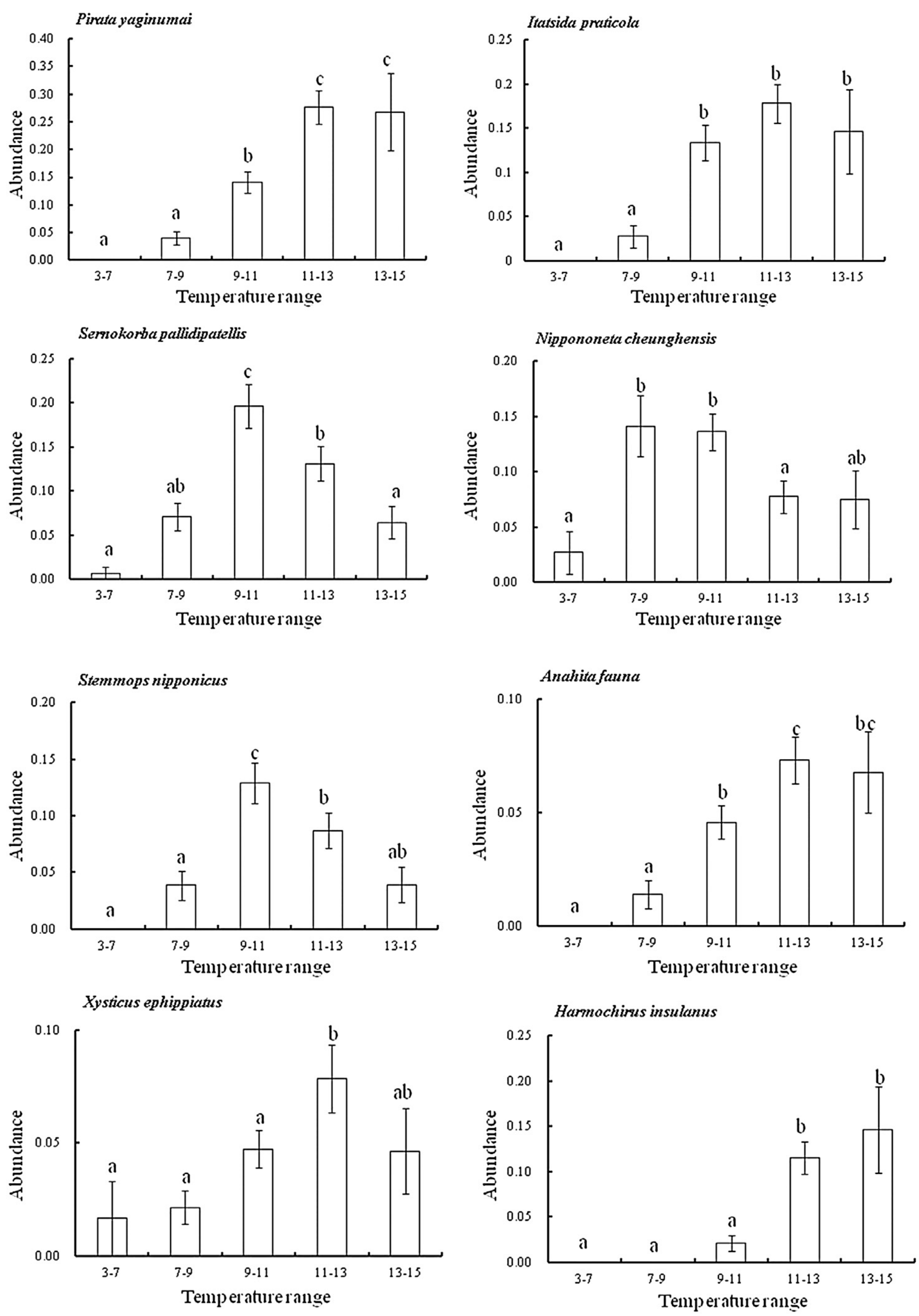


Figure 3. Abundance (number of individuals per trap) in most common (>10% occurrence) 21 spider species. Error bars mean one SE. Different letters indicate significant difference ($p < 0.05$) in Fisher LSD multi-comparison test after one-way ANOVA.

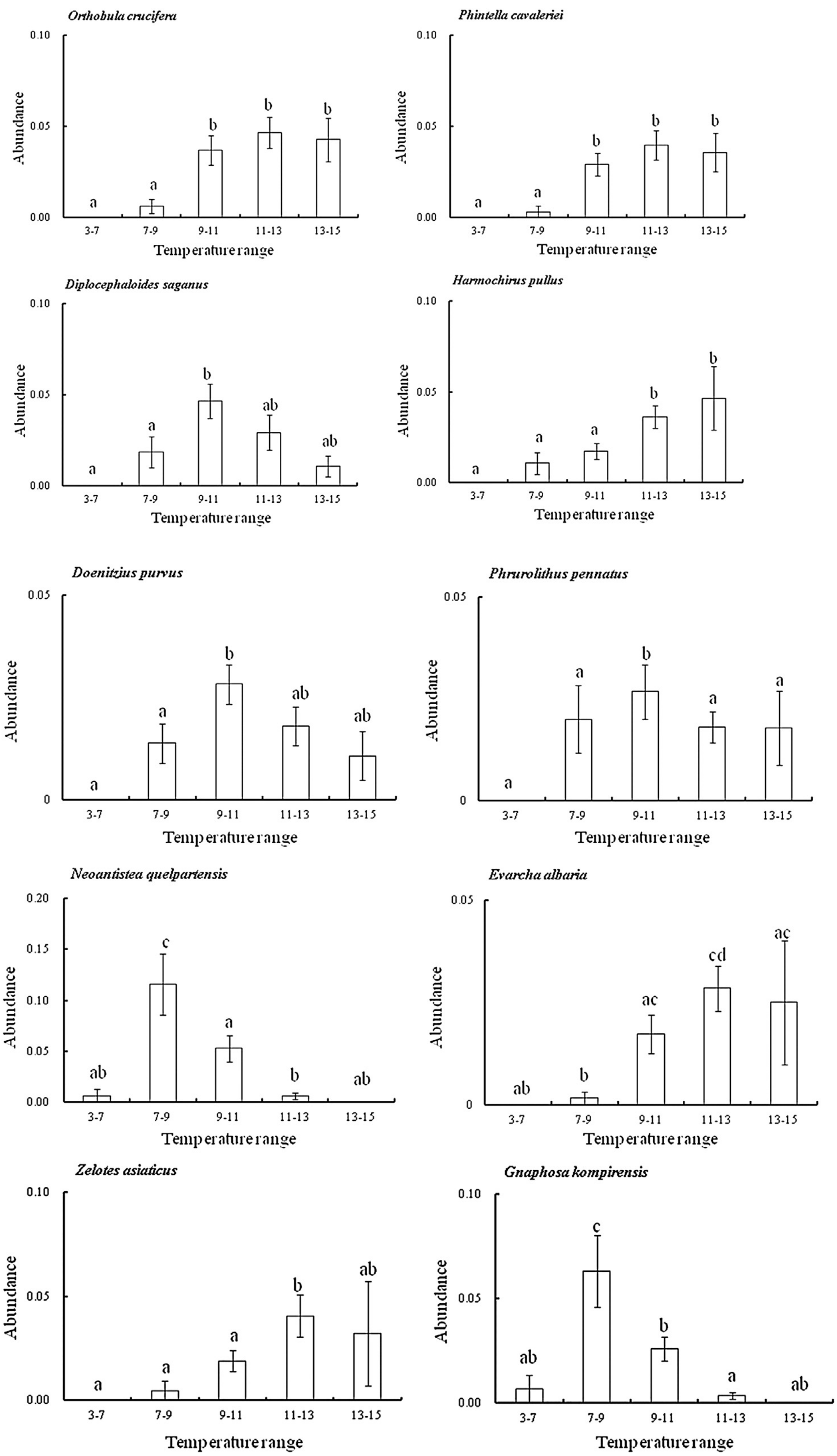


Figure 3. (continued).

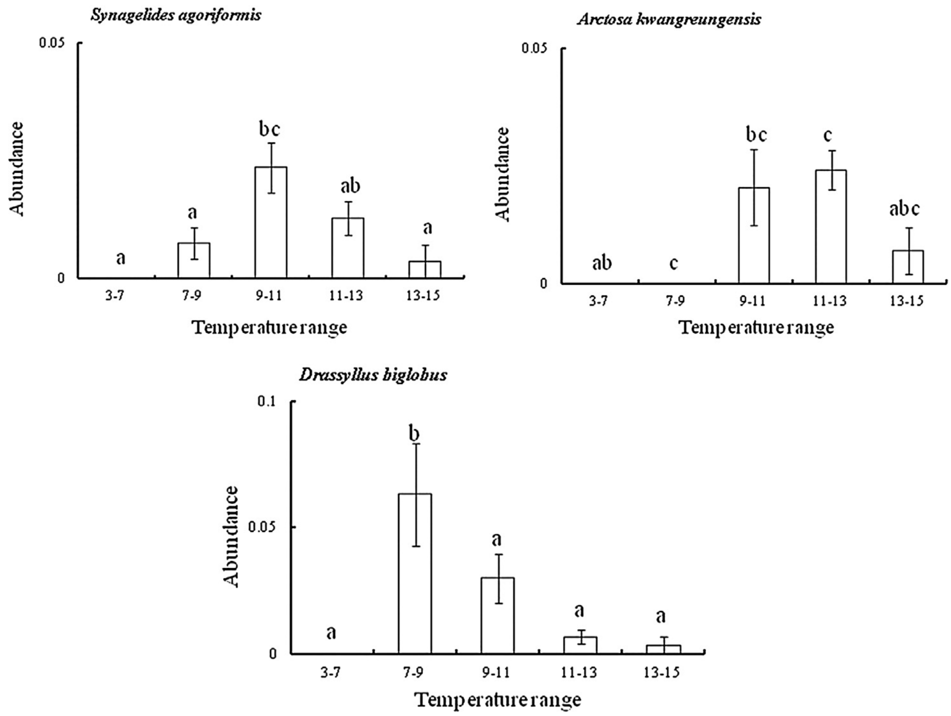


Figure 3. (*continued*).

the surveys were only conducted in forests, the analysis applied to forests. The temperature band more than 15°C rarely appeared as of now so that there is no data on the mean value of abundance. Thus, the abundance in this temperature band was estimated in the way described in Box 1. All GIS-related analyses was carried out using ArcGIS 10.1.

Results and discussion

Abundance of spiders and environmental factors

Appendix 1 shows the occurrence of 230 species collected from 366 survey sites in forests nationwide and the temperature of each collection site. The frequency in average temperature for all species that appeared at survey sites followed the normal distribution as shown in Figure 4 (Kolmogorov-Smirnov test, $D = 0.074$, $p = 0.2$). Table 2 shows the correlation between the abundance of 21 species of spiders collected commonly that appeared 10% or more in occurrence and the environmental factors. Figure 6 shows the comparison of r^2 (determination coefficient) value of environmental factors with abundance of such species. The environmental factors that most affect the distribution of spiders include highest temperature, average temperature, and altitude, indicating no significant difference between those 3 major environmental factors. The similarity of the influence of altitude to average temperature was due to the high correlation between those two environmental factors. Lowest temperature, precipitation, vegetation index, and solar radiation indicated relatively lower value of determination

Table 3
Abundance (no of individuals per trap) in eight temperature bands used for prediction of spider abundance. Abundance in 3–15°C is observed values, and that in 15–19 °C is estimated by the Neighborhood Approximation Method (Box 1).

Species	Korean name	Temperature range						
		3–7	7–9	9–11	11–13	13–15	15–17	17–19
Pirata yaginumai	방울늑대거미	0.000	0.040	0.141	0.277	0.268	0.259	0.251
Itatsida praticola	족제비거미	0.000	0.028	0.134	0.178	0.146	0.120	0.098
Sernokorba pallidipatellis	석줄톱니매거미	0.007	0.071	0.196	0.131	0.064	0.031	0.015
Nippononeta cheunghensis	청하꼬마접시거미	0.027	0.142	0.136	0.078	0.075	0.072	0.069
Stemmops nipponicus	먹눈꼬마거미	0.000	0.038	0.129	0.087	0.039	0.017	0.008
Anahita fauna	너구리거미	0.000	0.014	0.046	0.073	0.068	0.063	0.059
Xysticus ephippiatus	대륙게거미	0.017	0.022	0.047	0.078	0.046	0.027	0.016
Harmochirus insulanus	산표깡충거미	0.000	0.000	0.021	0.116	0.146	0.184	0.231
Orthobula crucifera	십자삼지거미	0.000	0.006	0.037	0.047	0.043	0.039	0.036
Phintella cavaleriei	멋쟁이눈깡충거미	0.000	0.003	0.029	0.040	0.036	0.032	0.029
Diplocephaloides saganus	흰배애접시거미	0.000	0.018	0.046	0.029	0.011	0.004	0.002
Harmochirus pullus	반고리깡충거미	0.000	0.011	0.017	0.036	0.046	0.059	0.075
Doenitzius purvus	땅접시거미	0.000	0.014	0.028	0.018	0.011	0.007	0.004
Evarcha albaria	흰눈썹깡충거미	0.000	0.002	0.017	0.028	0.025	0.022	0.020
Zelotes asiaticus	아시아염라거미	0.000	0.005	0.019	0.041	0.032	0.025	0.019
Gnaphosa kompirensis	넓적니거미	0.007	0.063	0.026	0.003	0.000	0.000	0.000
Synagelides agoriformis	어리개미거미	0.000	0.008	0.024	0.013	0.004	0.001	0.000

Box 1
Estimation of abundance in high temperature bands (>15°C) using Neighborhood Approximation Method

1. Background

Currently, Korea has its average temperature between 3 °C and 15 °C. The annual average temperature in study sites were divided into 6 temperature bands at an interval of approximately 3 °C: 3–7°C, 7–9°C, 9–11°C, 11–13°C, and 13–15°C. Among those bands, the study sites belonging to 3–5 °C and 5–7 °C band were far less so that those two bands were unified into one band (Figure 4). Currently, the study sties falling over the temperature band more than 15 °C are much less; according to the climate change scenario, however, 50 years later we will see far more temperature bands of 15–17 °C (Appendices 2 and 3). Therefore, it is important to accurately approximate the abundance in temperature zones more than 15 °C in order to raise accuracy of prediction. As a result of using the second order or third order of polynomial regressions that had been used for ants (Kwon et al., 2011), the second order polynomial regression tends to overestimate abundance while the third order one tends to underestimate abundance (Figure 5), demanding a new prediction method.

2. Assumption

Abundance of species is likely to be highest in the optimal temperature scope; if temperature is lower or higher than the scope, abundance gradually (non-linearly) reduces generating a bell-shaped distribution pattern in the entire temperature scope (normal distribution). However, the data obtained in this study were not collected from those entire temperature scopes so that it is difficult to estimate the abundance of the temperature band not observed in this study based on such data on assumption of normal distribution or using a simple statistical model. This study assumed that a change at a certain point would be the most similar to the change in the nearest point (based on the gradual change occurring in a normal distribution) and accordingly that the change rate steadily would remain, the subsequent values were approximated (Neighborhood Approximation Method).

3. Example for estimation of abundance

When a species indicates its abundance of 0.5 in the 11–13 °C temperature band and 0.3 in 13–15 °C, the abundance in the 15–17 °C band is estimated D = 0.3*(0.3/0.5) = 0.18 while the abundance in the 17–19 °C band is estimated D = 0.18*(0.18/0.3) = 0.108. However, the farther distant from the reference observation value (17–19 °C temperature band) the temperature band is, the larger the error is. Fortunately, the temperature bands higher than 17 °C rarely appears so that this approximation method would be a realistic way to raise predictability.

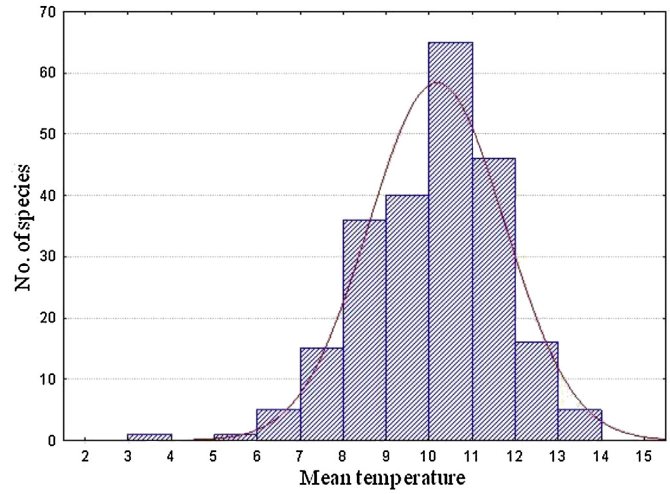


Figure 4. Histogram of temperatures (annual mean) in occurred sites of spider species. This pattern is not significantly different from the normal distribution (Kolmogorov-Smirnov test, D = 0.074, p = 0.2). Data for this figure is provided in Appendix 1. Species richness is no of species.

coefficients. Table 1 shows the multiple regression models of 17 candidate species; because the distribution model of each species was mostly very significant ($p < 0.05 \sim p < 0.0001$) but the power of explanation for the variation in abundance was relatively lower ($r^2 = 0.03 \sim 0.22$), the models were not regarded as an appropriate means to predict spider distribution.

Change of temperature according to climate scenario RCP 4.5 and 8.5

Appendices 2 and 3 shows the temperature change in accordance with the climate change scenarios RCP 4.5 and 8.5. RCP 4.5 says the average temperature in Korea will increase from 12.15 °C to 13.3 °C 50 years later while RCP 8.5 predicts that the average temperature in Korea will increase from 11.17 °C to 14.41 °C. The higher temperature of 15°C or more – little appearing in the present – is predicted to far increase by 19% in RCP 4.5 and 43% in RCP 8.5 in 50 years later.

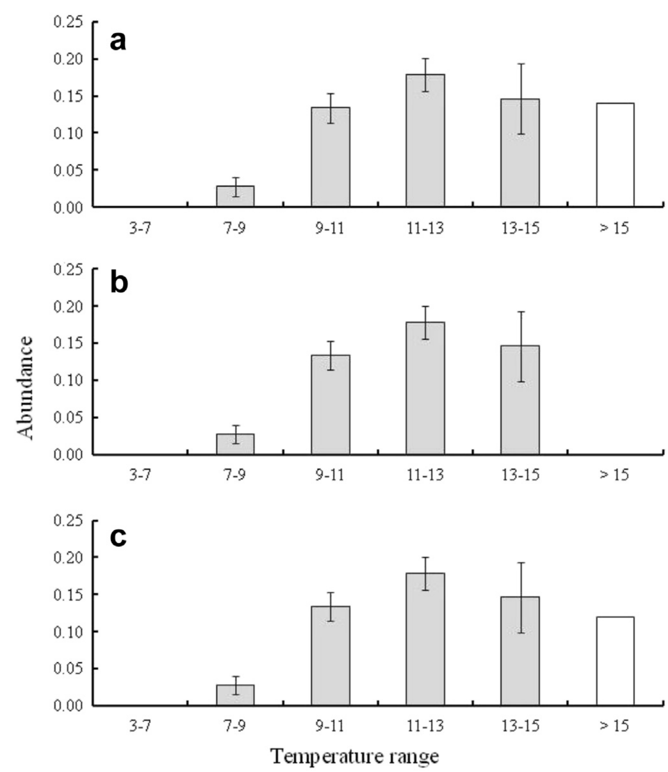


Figure 5. Abundance (no of individuals per trap) in six temperature bands in *Itatsida practicola*. Dark bars are observed values, and open bars in high temperature band (>15°C) are predicted values using quadratic (two-dimensional) polynomial regression model (a), three-dimensional polynomial regression model (b), and Neighborhood Approximation Estimation (Box 1) (c). Error bars indicate one SE. Equations for a and b are as follows; a) $y = -0.0129x^2 + 0.1219x - 0.1263$ ($R^2 = 0.893$, $P = 0.041$), b): $y = -0.0129x^3 + 0.1034x^2 - 0.1831x + 0.0908$ ($R^2 = 0.991$, $P = 0.041$)

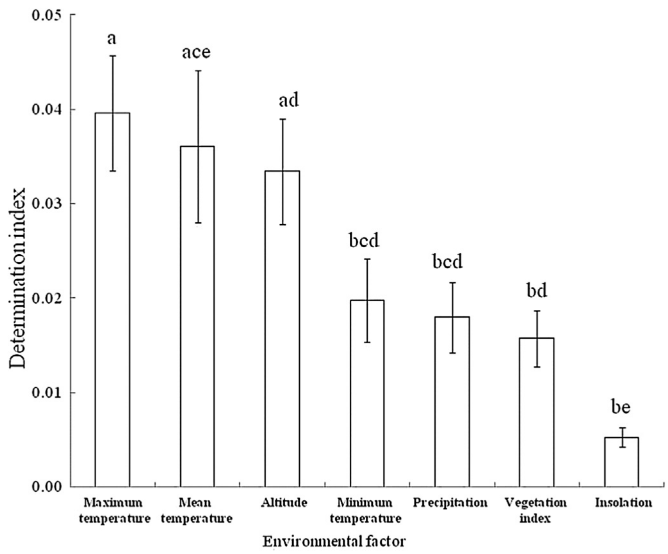


Figure 6. Determination index (R^2) of environmental factors on abundance of the most common 21 spider species. Data for this figure is provided in Table 2. Error bars indicate one SE. Different letters on bars indicate significant difference between cases in Fisher LSD multiple-comparison test after an analysis of one way ANOVA, $F_{6, 140} = 6.2726$, $P < 0.001$.

Prediction of abundance in each spider species

Quantitative prediction of abundance

Among 21 species that appeared more than 10% in occurrence, the results from predicting nationwide average of abundance of the candidate 17 species according to the climate change scenarios RCP 4.5 and 8.5 are shown in Table 4; among which, 9 species were predicted to increase their abundance while the remaining 8 species were predicted to have their abundance decreased. Descriptions on projections of abundance were arranged in descending order of occurrence.

Pirata yaginumai

This species was reported to inhabit mostly fields and grass land in Korea (Im, 1996, Namkung, 2001) and also reported to inhabit ginseng farmland (Im, 1996). It was reported to live mostly in humid habitats (e.g. lakeside, ponds, swampy meadows, etc.) in Russia (Omelko et al., 2011). Although it was reported a rare species in the Jeju island (Namkung et al., 2002), however, judging from the report on the spiders in Juwangsan Mountain– inland area – saying that this species was commonly collected in forests and surrounding green fields (Kim, 2010), this species is likely to inhabit forests as well as meadows. This species appeared the most common in this study (occurred at 51.6% sites). It is distributed in Japan, China, and Russia, regarded as a northern species; however, the projection shows that as temperature rises, this species increase in abundance and distribution (Table 4 and Figures 7 and 8). It is currently distributed more abundantly in areas other than high altitudes, but is predicted to increase gradually in such high altitudes. This species is abundantly distributed in most areas other than uplands and the average temperature of collection sites is between 7.6 and 14.1°C (mean = 11.2°C) (Appendix 1). According RCP 4.5, as 50 years elapse, its abundance is predicted to increase by 1.4% while RCP 8.5 predicted that it would increase by 7.5% (Table 4). This species shows high density in areas other than high mountains in Gangwon-do; however, it is predicted to be more abundant in high mountains but to be decreased in southern parts where it has a high abundance at present (RCP 8.5) (Figure 8).

Itatsida praticola

This species is a wandering spider often observed in the layers of litters, and under stone and dead trees in forests (Namkung, 2001). Im (1996) took notes of this species often found on grass roots and also in mulberry farmlands and reported its adult stage between May and June and between September and November. Yaginuma (1986) reported that it wandered on ground and was observed between grasses. It is distributed in China and Japan (Im, 1996, Namkung, 2001). Domestically, this species occurred secondly frequently (46.7%) following *Pirata yaginumai* and mostly inhabits forests; unlike *Pirata yaginumai* which is common inland but rare in the Jeju island, it is relatively common in this island (Namkung et al., 2002). The temperature range of this species is between 7.1 and 13.9°C (mean: 11.3°C) (Appendix 1): 50 years later, its abundance is likely to increase by about 3.5% (RCP 4.5) and by about 16.4% (RCP 8.5). In present, this species is denser in relatively lowland but predicted to become denser in upland other than those lowlands 50 years later (Figures 7 and 8). However, abundance of this species is expected to be still low in high mountains of Gangwon-do even in 50 years later.

Table 4
Change of abundance of the 17 candidate spider species according to climate scenario RCP 4.5 and 8.5.

Species	Korean name	RCP 4.5			RCP 8.5		
		2011～2015	2056～2065	Change (%)	2011～2015	2056～2065	Change (%)
Pirata yaginumai	방울늑대거미	0.214	0.217	1.4	0.182	0.196	7.7
Itatsida praticola	족제비거미	0.144	0.149	3.5	0.128	0.149	16.4
Anahita fauna	너구리거미	0.059	0.065	10.2	0.051	0.069	35.3
Harmochirus insulanus	산표깡충거미	0.089	0.108	21.3	0.065	0.12	84.6
Orthobula crucifera	십자삼지거미	0.039	0.042	7.7	0.035	0.044	25.7
Phintella cavaleriei	멋쟁이눈깡충거미	0.033	0.035	6.1	0.028	0.037	32.1
Sibianor pullus	반고리깡충거미	0.032	0.038	18.8	0.025	0.045	80.0
Evarcha albaria	흰눈썹깡충거미	0.022	0.025	13.6	0.019	0.027	42.1
Zelotes asiaticus	아시아염라거미	0.03	0.033	10.0	0.025	0.035	40.0
Sernokorba pallidipatellis	석줄톱니매거미	0.121	0.098	−19.0	0.128	0.069	−46.1
Nippononeta cheunghensis	청하꼬마접시거미	0.095	0.078	−17.9	0.102	0.058	−43.1
Stemmops nipponicus	먹눈꼬마거미	0.079	0.063	−20.3	0.083	0.044	−47.0
Xysticus ephippiatus	대륙게거미	0.057	0.055	−3.5	0.053	0.052	−1.9
Diplocephaloides saganus	흰배애접시거미	0.027	0.021	−22.2	0.029	0.014	−51.7
Doenitzius purvus	땅접시거미	0.018	0.015	−16.7	0.019	0.01	−47.4
Gnaphosa kompirensis	넓적니거미	0.013	0.007	−46.2	0.019	0.003	−84.2
Synagelides agoriformis	어리개미거미	0.013	0.01	−23.1	0.014	0.006	−57.1

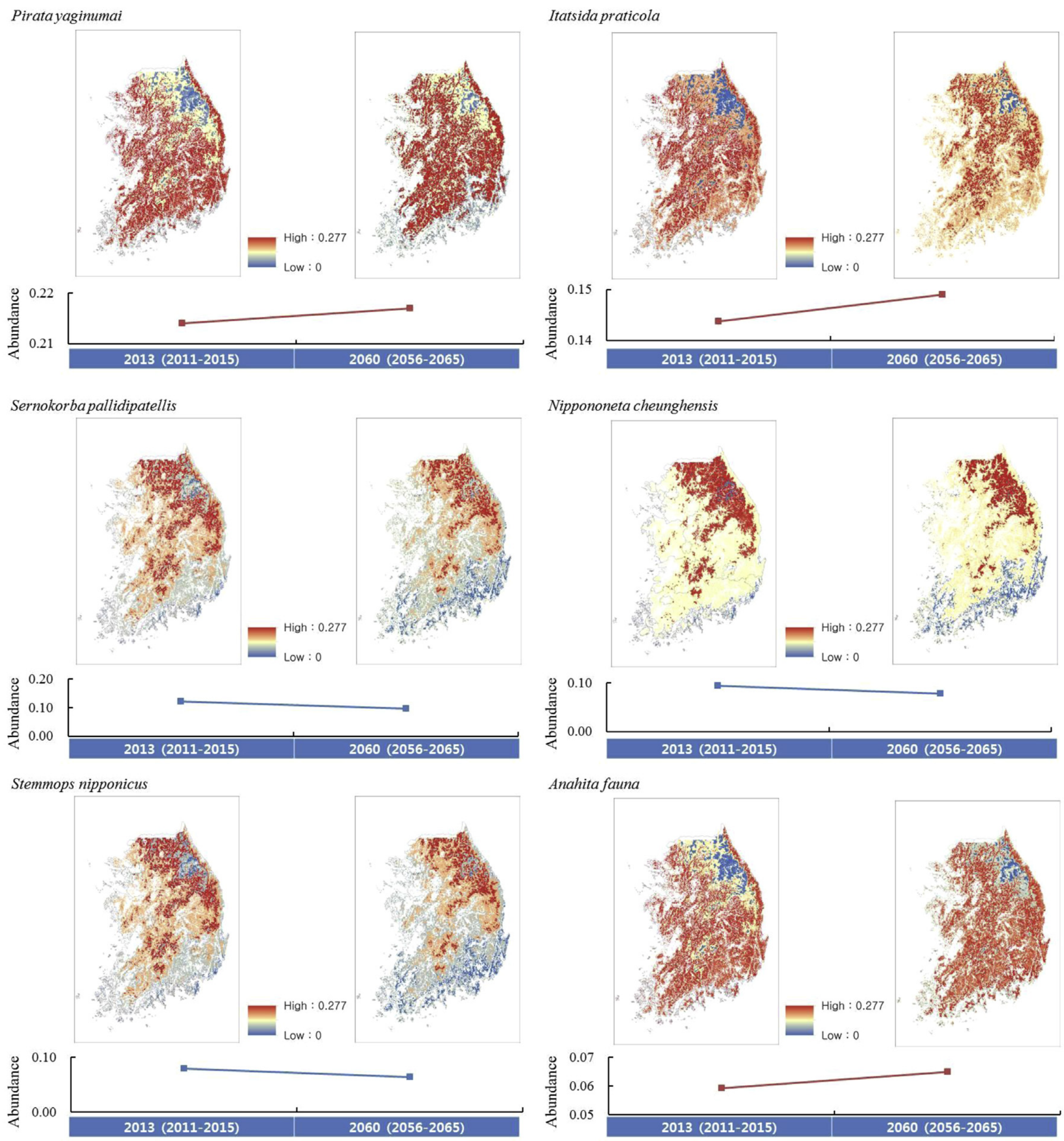


Figure 7. Charge in abundance of spiders according to climate scenario RCP 4.5.

Sernokorba pallidipatellis

This species wanders at the foot of a mountain, on ground surface of forest paths, or in the layers of litters, and also hides in tree trunks or under stone (Namkung, 2001). It is distributed in Japan and China (Namkung, 2001). However, this species was reported in 2009 to inhabit Lazo Nature Preservation District in Maritime, Russia (Marusik, 2009). This species was found as a dominant species in a variety of green fields in Paltan-myeon, Hwaseong-si, Gyeonggi-do (Jung et al., 2008) and also observed in vineyard in Cheonan-si (Kim et al., 2002). It wanders on grasslands and lives in bushes (Marusik, 2009). Thus, like both dominant species described above, it is a generalist species that inhabits in a variety of green fields including grassland and that widely uses ground surface and bushes. It is distributed in the Jeju island but not common there (Namkung et al., 2002). The average temperature of collection sites ranges between 6.1 and 13.9°C (mean = 10.8 °C) (Appendix 1). Currently, it tends to be distributed more abundantly in highlands than in lowlands, which is expected to be strengthen in future (Figures 7 and 8). The abundance in 50 years is predicted to reduce by about 19% (RCP 4.5) or by about 46% (RCP 8.5) compared to the current status (Table 4).

Nippononeta cheunghensis

This is a common species appearing 40.4% of the survey sites (Appendix 1); however, not recorded in the Korea's illustrated spider books (Im, 1996, Namkung, 2001) or in the Japan's illustrated spider book (Yaginuma, 1986) nor appeared in the spiders biota and population surveys conducted in Juwangsan Mountain (Kim, 2010), Jeju (Namkung et al., 2002), Cheonan, Chungcheongnam-do (Kim et al., 2002), Namyangju, Gyeonggi-do (Lee and Lee, 1990), and Hwaseong, Gyeonggi-do (Jung et al., 2008). Hence, this species is

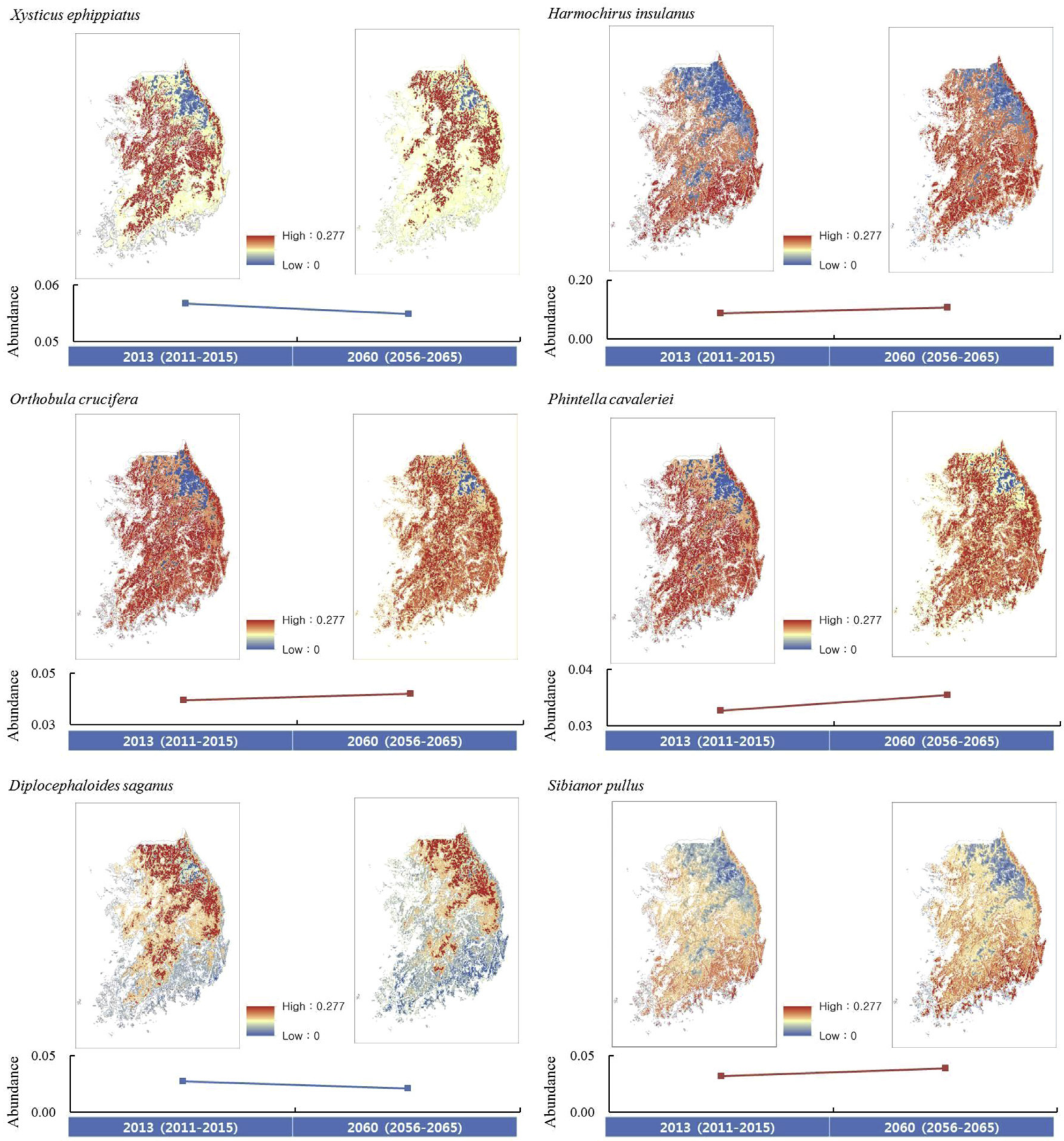


Figure 7. (*continued*).

likely to be recently renamed. It is distributed in areas where the temperature scope is between 6.1 and 10.4°C (mean = 10.4°C), similar to that of *Sernokorba pallidipatellis* (Appendix 1). Therefore, those two species have the similar distribution pattern in the present and future; however, this species tends to show more distinction of abundance between uplands and lowlands compared to *Sernokorba pallidipatellis*– that is to say, less abundance in lowlands but more abundance in uplands, and further the rising temperature is likely to more strengthen such trend as it is distributed more upwards (Figures 7 and 8). The change in its abundance is predicted to decrease by 17.9% in RCP 4.5 and by 43.1% in RCP 8.5.

Stemmops nipponicus

This species inhabits the layer of litters or dead trees spinning an irregular web, most of them wander on fallen leaves and are also found in caves (Namkung, 2001). It is distributed in China and Japan. Its adult stage is throughout the year. It is also observed in mulberry and ginseng farmlands (Im, 1996). It lives in the Jeju island (Namkung et al., 2002). This species was one of the dominant species found in a variety of green fields around rice paddies in Paltan-myeon, Hwaseong, Gyeonggi-do (Jung et al., 2008). Its degree of decrease in abundance is similar to that of *Sernokorba pallidipatellis* and it is predicted to decrease by 20.3% in RCP 4.5 and by 46.1% in RCP 8.5 (Table 4). Currently, it is distributed in areas where the temperature scope is between 7.6 and 14.1°C (mean = 10.8°C), the same as that of *Pirata yaginumai* but somewhat lower average temperature (Appendix 1). For this reason, this species is predicted to decrease in abundance unlike *Pirata yaginumai* (reduce by 20.3% in RCP 4.5; reduce by 47 % in RCP 8.5; Table 4). It shows higher abundance in higher mountains and rising temperature causes its movement to uplands, predicted to become more abundant in higher mountains in Gangwon-do in 50 years later (Figures 7 and 8).

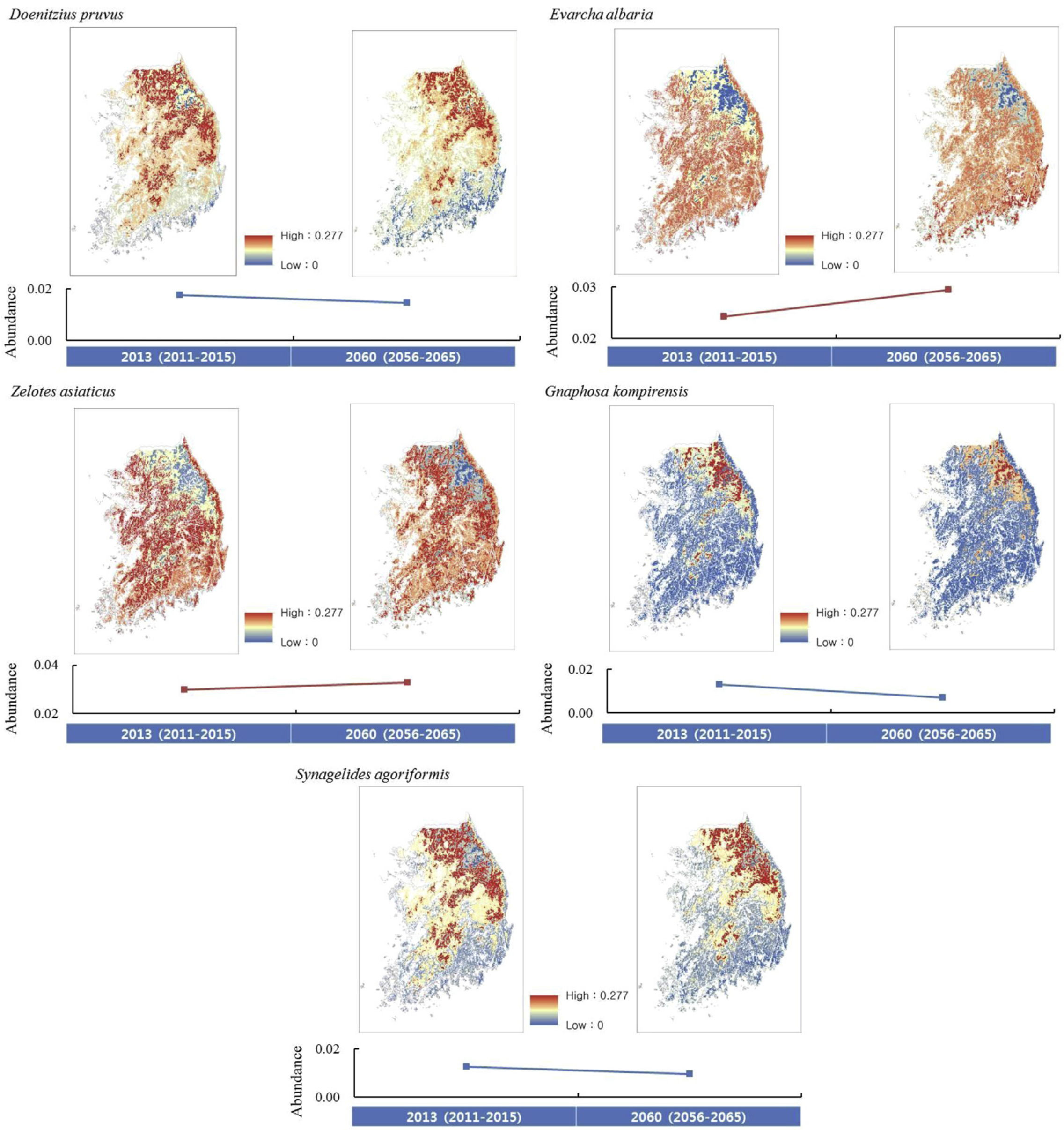


Figure 7. (*continued*).

Anahita fauna

This species wanders on ground surface, under stone, and in the litters in forests, mountains and fields, and grasslands (Im, 1996, Namkung, 2001). It produces a disc-shaped egg pouch on a leave which is protected by a mother spider (Namkung, 2001). It is distributed in Japan, China, Taiwan, and Russia (Im, 1996, Namkung, 2001) and is also found in Singapore (Zhang and Song, 2002). It reaches adult stage between May and July and domestically shows a wide distribution nationwide ranging from the Jeju Island to Sokrisan Mt. and Seolaksan Mt. (Im, 1996). This study confirmed that this species is distributed nationwide (Appendix 1). It appeared as a dominant species in a variety of green fields around rice paddies in Paltan-myeon, Hwaseong, Gyeonggi-do (Jung et al., 2008). The chromosome configuration and the sex-determining chromosome for a Taiwanese population were reported by Chen (1999). This species is distributed in areas where the temperature scope is between 8.0 and 14.1°C (mean = 11.4°C) (Appendix 1), showing relatively even abundance in the regions other than those at higher altitude. Rising temperature is predicted to cause its increase in abundance by 10.2% in RCP 4.5 or by 35.3% in RCP 8.5. It shows less change in distribution of abundance compared to other species; however, it is predicted to become more abundant in the regions at higher altitude (Figures 7 and 8).

Xysticus ephippiatus

This species is often observed in forests and grasslands and appears between May and September. It is distributed in Japan, China, Mongolia, and Russia (Namkung, 2001). It is often found in farmlands (mulberry, dong quai and bean/sesame farms, and cultivated upland, arable lands, and tea plantation) and confirmed to exist in the provinces of Gyeonggi, Gangwon, Chungcheong, and Gyeongsang (Im, 1996). It is commonly collected in the Jeju island

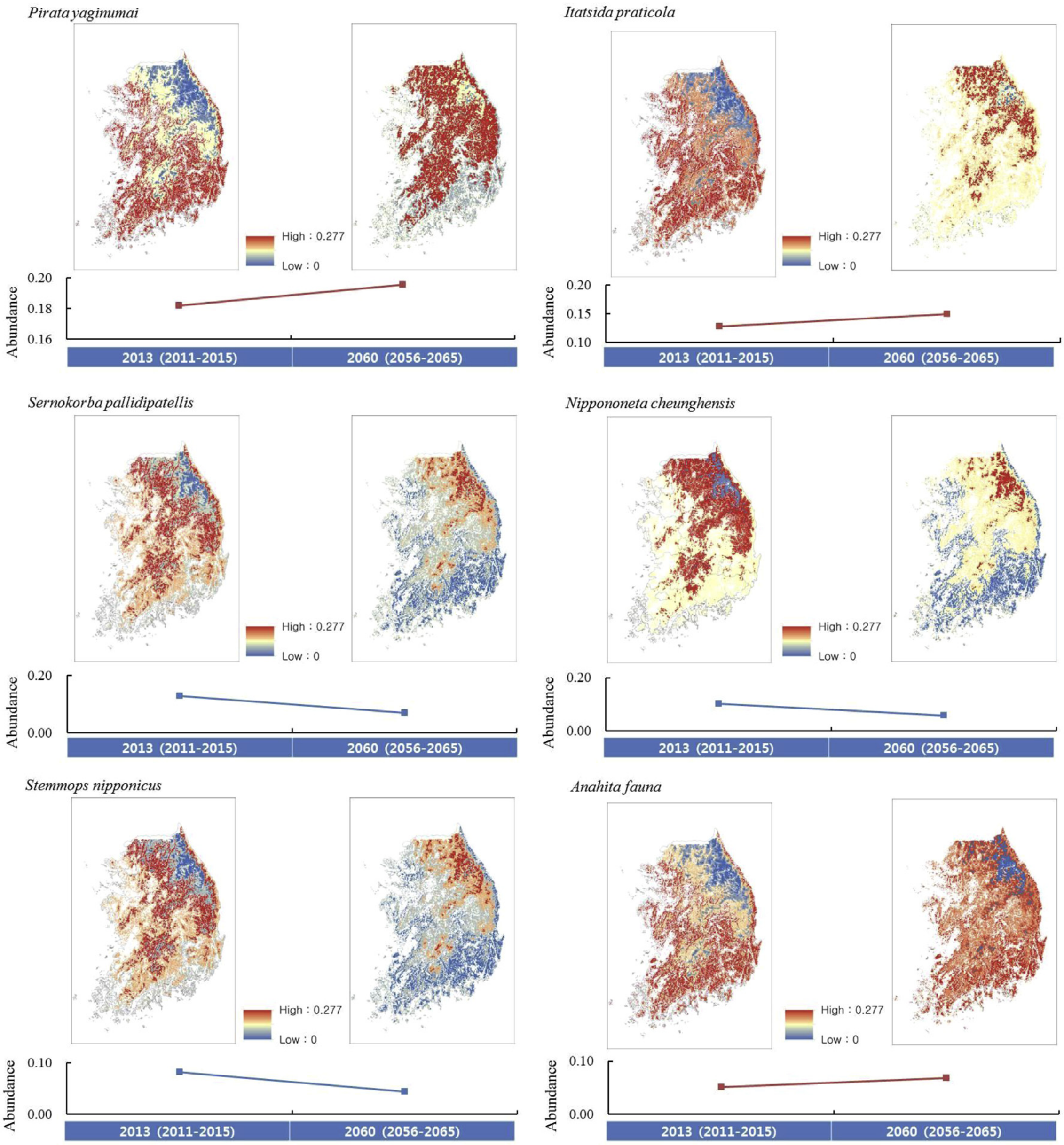
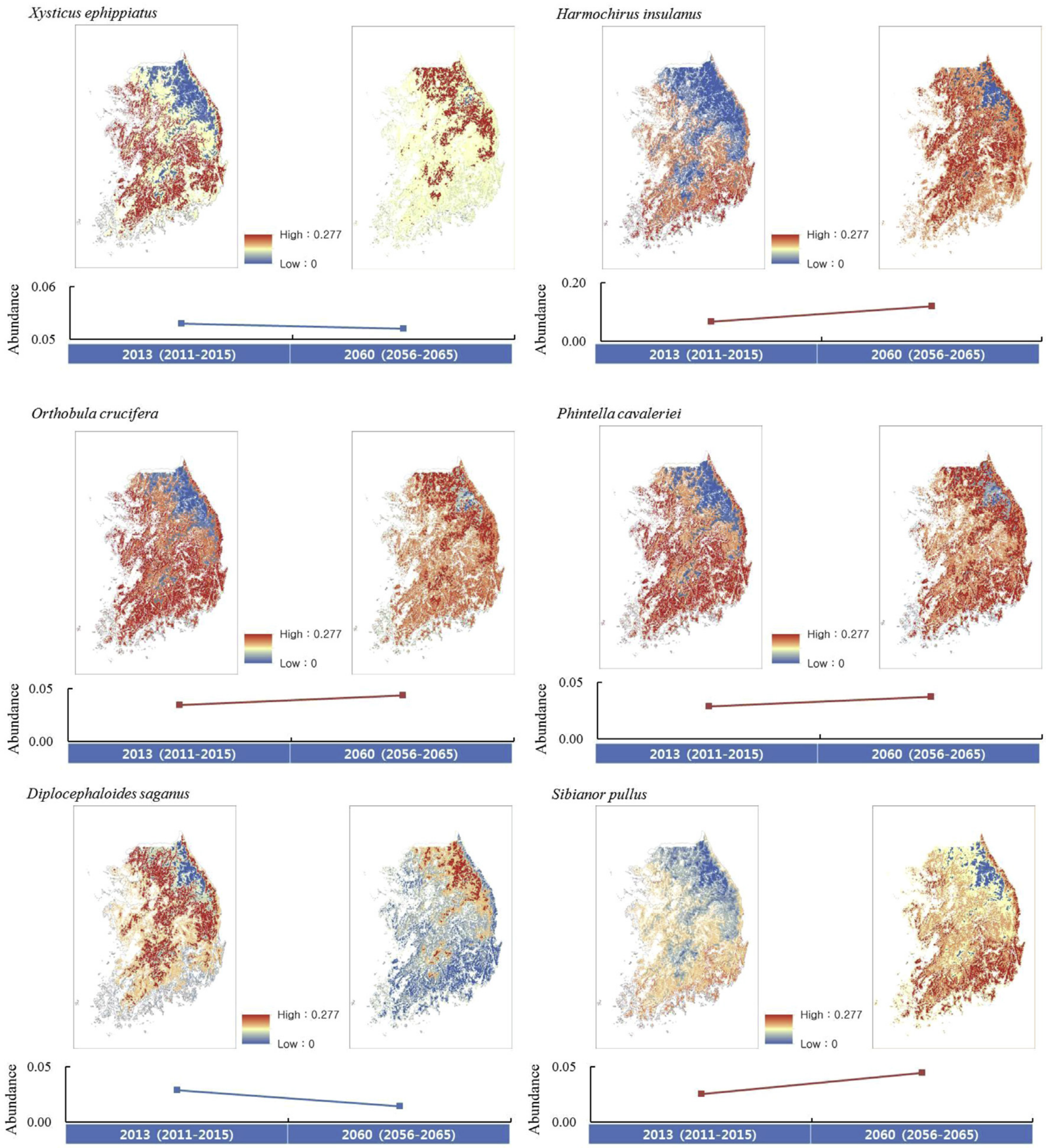


Figure 8. Charge in abundance of spiders according to climate scenario RCP 8.5.

(Namkung et al., 2002) and has a record to be collected in Juwangsan Mt. (Kim, 2010). It reaches adult stage between June and July (Im, 1996). Jung et al. (2008) revealed in his survey in green fields in Hwaseong, Gyeonggi-do that this species was a dominant one. It is distributed in areas where the temperature scope is between 6.1 and 13.6°C (mean = 11.0°C) (Appendix 1). It is currently predicted that the species will become highly abundant in most regions other than in higher mountains but rising temperature is likely to move its distribution upwards, predicted to have more abundant at higher altitude but less abundant at lower altitude (Figures 7 and 8). Its abundance is predicted to decrease by 3.5% in RCP 4.5 and by 1.9% in RCP 8.5 (Table 4). In contrast to other species that are predicted to more decrease in RCP 8.5 than in RCP 4.5, this species indicates more decrease in RCP 4.5. However, the degree of decrease is relatively lower than other species.

Harmochirus insulanus

This species wanders on tree leaves or grass leaves in mountains and fields, making a pouch-shaped nest under litters to overwinter (Namkung, 2001). Im (1996) also reported that this species does predatory activities in the layer of vegetation. However, judging from its common collection in a pitfall trap during this study, it was indicated that the species forages in vegetation as well as on ground. It reaches adult stage between June and September (Im, 1996) and is distributed in Japan, China, India, and Australia while being reported to be domestically distributed nationwide (Namkung, 2001). It has the closest relationship with *Harmochirus luculentus* (Logunov and Aoryhon, 2000). It is distributed mostly in areas where the temperature scope is between 9.8 and 14.1°C (mean = 12.0°C), predicted to become more abundant in future (Appendix 1). It is predicted that its abundance will increase due to rising temperature: by



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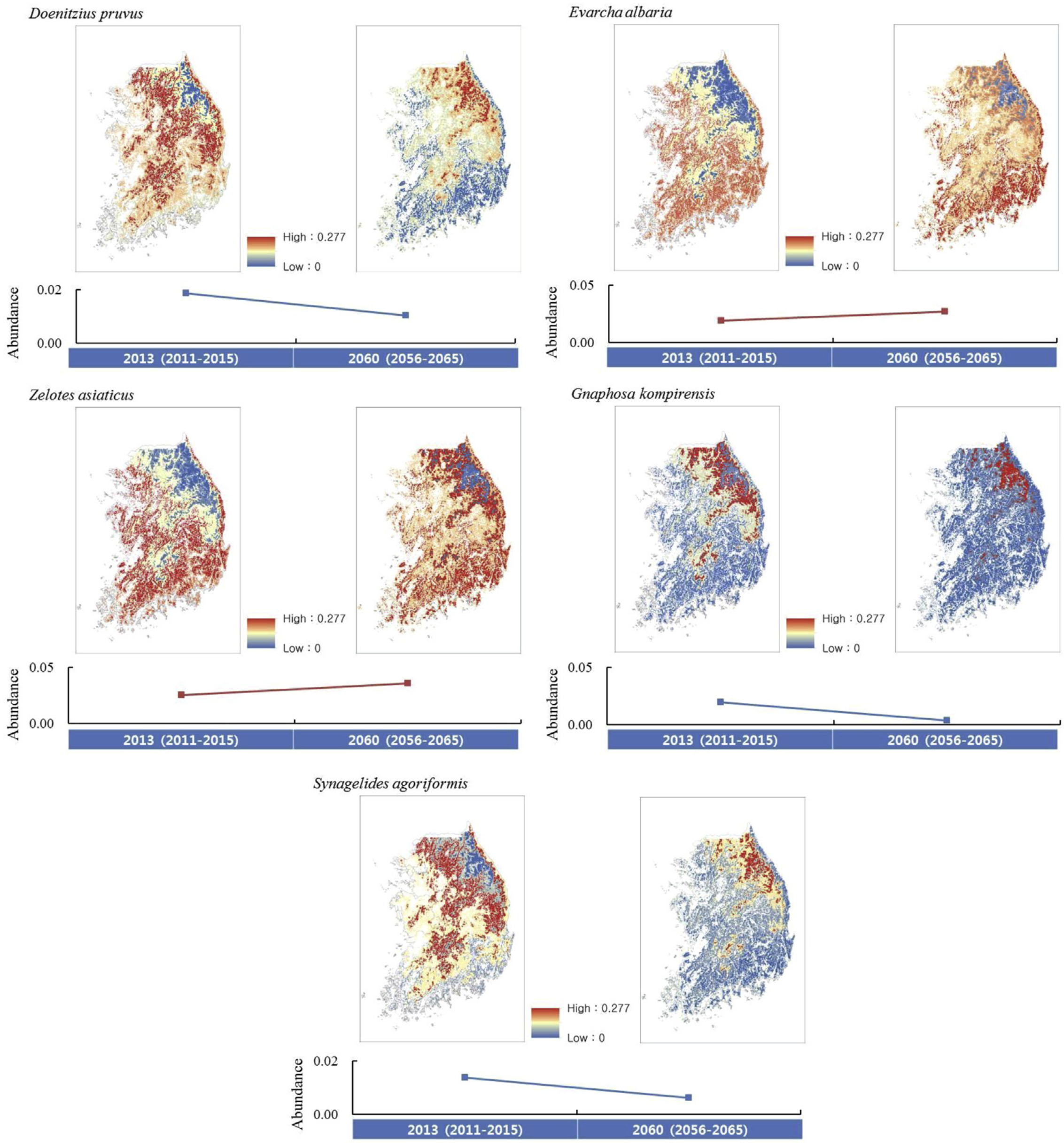
21.3% in RCP 4.5 and by 84.6% in RCP 8.5 (Table 4). This species is usually distributed currently in lowlands and is unlikely to move upwards due to rising temperature unlike other species so that it is expected to rarely occur at high altitudes even in 50 years later (Figures 7 and 8).

Orthobula crucifera

This species inhabits the litters or soils in forests wandering on ground (Im, 1996). It is domestically distributed in Suwon, Palgongsan Mt., and the Jeju island while distributing in Japan and China (Im, 1996, Namkung, 2001). This species appeared as a dominant spider in a variety of green fields around rice paddies in Hwaseong, Gyeonggi-do (Jung et al., 2008). Hence, it is determined to be a species that uses as a habitat, both forests and grasslands. It reaches adult stage between May and July and between September and November (Im, 1996) and is distributed in areas where the temperature scope is between 7.6 and 14.1°C (mean = 11.5°C), predicted to become more abundant (Appendix 1). The abundance is predicted to increase by 7.7% in RCP 4.5 and by 25.7% in RCP 8.5 (Table 4). This species is evenly distributed in most regions other than high altitudes, predicted to expand its distribution scope to uplands as temperature rises (Figures 7 and 8).

Phintella cavaleriei

This species inhabits mountains, plains, and farms and rice paddies, and jumps up on plant leaves to hunt a prey (Namkung, 2001). It is distributed in Korea and China (Namkung, 2001). There is no record on its distribution in the Jeju island and Japan overseas (Namkung et al., 2002, Yaginuma, 1986). There is a record that this species have been collected in Juwangsan Mt. (Kim, 2010) and it was often collected in rice paddies and surrounding green fields



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in Hwaseong, Gyeonggi-do, particularly more notable in forests than in open green fields (grassland on streamside and rice paddy ridges) (Jung et al., 2008), which suggests that this species usually inhabits forests rather than grasslands. In this study, its occurrence was 18% and it was distributed in areas where the temperature scope was between 8.5 and 14.1°C (mean = 11.5°C) (Appendix 1). Thus, it is predicted to become more abundant as climate warms. Its nationwide average of abundance was predicted to increase by 6.1% in RCP 4.5 and 32.1% in RCP 8.5 (Table 4). This species rarely occurs at highest altitudes at present; however, is evenly and abundantly distributed in the other areas. This species will move upwards in 50 years later, but remain to be in low abundance at very high altitudes and thus its distribution pattern of abundance will not be greatly changed. It is predicted to be widely distributed across the country (Figures 7 and 8).

Diplocephaloides saganus

This species reportedly appears during three periods: between April and May, between July and August, and between October and November; and is distributed in Japan (Namkung, 2001). It was reported to live mostly in open green fields (grasslands, streamside, and forest path sides); however, it is likely that it is regarded as a species that uses as a habitat, both forests and open green fields as this species occurred commonly in forests in the present study. It was not recorded in the Jeju island (Namkung et al., 2002) but was recorded in Mts. Juwangsan, Samaksan, and Jirisan (Im, 1996, Kim, 2010). This species appeared 16.1% in occurrence and its temperature scope of collection sites was between 8.2 and 13.2°C (mean = 10.7°C) (Appendix 1). Its abundance is predicted to decrease due to rising temperature: by 22.2% in RCP 4.5 and by 51.7% in RCP 8.5 (Table 4). Rising temperature will cause upward

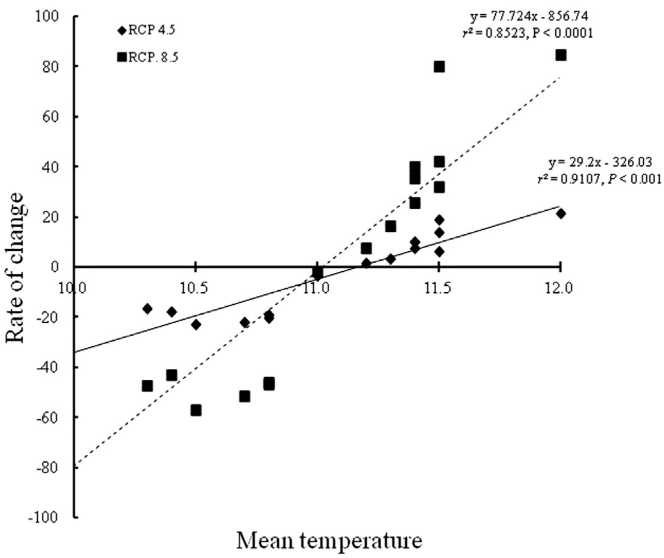


Figure 9. Average of annual mean temperature at the occurred sites and the rate of change in abundance in the 17 candidate spider species of which abundance was quantitatively predicted according to the climate scenario of RCP 4.5 (diamonds) and 8.5 (rectangles). The values for the rate of change in abundance are provided in Table 5.

movements and its distribution scopes will be narrowed. In 50 years later, its abundance will be higher at higher altitudes (Figures 7 and 8).

Sibianor pullus

This species wanders on ground of plains or green fields, and over litters in forests, being observed foraging all year round in southern regions. It is distributed in Japan, China, and Russias (Namkung, 2001). Its adults are observed between June and September (Im, 1996). It was not recorded in the Jeju island (Namkung, 2001) while it was recorded in farmlands in Geosan, Chungcheongbuk-do (ginseng farmland, cultivated upland) (Im, 1996). The surveys conducted in green fields around rice paddies in Hwaseong, Gyeonggi-do collected a few individuals only on rice paddy ridges (Jung et al., 2008). These results revealed that this species inhabits mostly open green fields and is likely a rare species; however, in this study it occurred at 16.1% of total sites, becoming the top 5.2% abundant species among a total of 230 species (Appendix 1). This finding indicated that the previous spider surveys were mostly conducted in green fields other than in forests by a qualitative collection method so that the results a bit differed from the actual distribution. This species is distributed in areas where the temperature scope is between 7.6 and 13.6°C (mean = 11.5°C) (Appendix 1). It is predicted to become increasingly more abundant due to rising temperature (18.8% increase in RCP 4.5; 80% increase in RCP 8.5) (Table 4). However, the species is expected to experience less altitudinal change in abundance compared to other species, and accordingly, is not abundant at high altitudes even in 50 years later (Figures 7 and 8).

Doenitzius pruvus

This is a species spinning a sheet-shaped web nearer to ground, often appearing between May and September and distributing in Japan, China, and Russia (Namkung, 2001). Domestically, it is recorded in the Jeju island and Mt. Juwangsan (Kim, 2010, Namkung et al., 2002), and was observed in higher population in forests than in other green fields in the surveys conducted in a variety of green fields around rice paddies in Hwaseong, Gyeonggi-do (Jung et al., 2008), suggesting it mainly inhabits forests. In this study this species occurred at 15.6% of total sites and the temperature scope of collection sites was between 5.4 and 12.9°C (mean = 10.3°C) (Appendix 1). It was predicted to become less abundant due to rising temperature. Scenario RCP 4.5 estimated the abundance to decrease by about 16.7% while RCP 8.5 estimated the decrease in abundance by about 47.4% (Table 4). It is widely distributed in most areas other than higher altitudes; however the population will move to higher altitudes as temperature increases in 50 years later so that its scope of distribution is predicted to be gradually narrowed (Figures 7 and 8).

Evarcha albaria

This species is distributed nationwide, often observed in forests and grasslands, and around private houses; appears between May and September and makes a nest by rolling up herb leaves around July for spawning (Namkung, 2001). It inhabits meadows or forests, foraging on branches and leaves, and seems to be abundant and reaches adult stage between June and July (Im, 1996). It is distributed in Japan, China, Mongolia, and Russia (Namkung, 2001). It is commonly distributed in the Jeju island (Namkung et al., 2002) and also recorded in Mt. Juwangsan (Kim, 2010). In the surveys on the green fields around rice paddies in Hwaseong, Gyeonggi-do, this species was collected at a similar level both in forests and open green fields (Jung et al., 2008). Thus, this species is determined to use as a habitat, both forests and open green fields. In this study, this species occurred at 12.8% of total sites and its temperature scope of collection sites was between 7.6 and 13.6°C (mean = 11.5°C) (Appendix 1), and thus was predicted to become more abundant due to rising temperature (by 13.5% in RCP 4.5; 42.1% in RCP 8.5; Table 4). The change in its abundance of this species is much different compared with other species. RCP 4.5 did not lead to much change in abundance while RCP 8.5 led to the increase in abundance in southern areas (Gyeongsangnam-do and Jeollanam-do) but the decrease in abundance in middle inland areas (provinces of Chungcheong, Gyeongsangbuk-do, and Jeollabuk-do, etc.) (Figures 7 and 8). Both scenarios predicted that the species would not expand its distribution to higher altitude in 50 years later.

Zelotes asiaticus

This species wanders over the litters or on ground surface, and often appears between April and September. It is distributed in Japan, China, and Taiwan, indicating a sort of southern species (Namkung, 2001). It reaches adult stage between September and October: it is estimated that it hatches out in summer and passes winter in immaturity and then becomes an adult next autumn. It is domestically distributed in Geumjeongsan, Ungilsan Bonghwa, Sokrisan, Juwangsan mountains, Hwaseong, Dopyeong, Suwon, Chungju, Geomundo Island, and the Jeju Island (Im, 1996, Jung et al., 2008, Kim, 2010, Namkung, 2001). The surveys on green fields around rice paddies in Hwaseong, Gyeonggi-do, this species were collected much more in forests than open green fields (Jung et al., 2008) suggesting that it more often uses forests as an habitat. In this study, this species occurred 12% of total sites and the temperature scope of collection sites was between 8.7 and 13.2°C (mean = 11.4°C) (Appendix 1). This species is predicted to become increasingly abundant due to rising temperature by 10% in RCP 4.5 and 40% in RCP 8.5 (Table 4). Abundance become homogenous in 50 years later in RCP 4.5 like *Evarcha albaria,* whereas abundant and less abundant (provinces of Gyeonggi, Chungcheong, and Gyeongsangnam-do) regions become clearly divided in RCP 8.5 (Figures 7 and 8). Both two scenarios indicate that this species moves its distribution to higher altitudes but is

Table 5
Qualitative prediction of abundance for common spider species (>1% occurrence) except the 17 candidate species in Table 4.

Family	Kor. Family	Species	Korean name	Change
Agelenidae	가게거미과	*Coelotes songminjae*	민자가게거미	Decreased
		Agelena limbata	들풀거미	Decreased
Thomisidae	게거미과	*Xysticus concretus*	쌍지게거미	Decreased
		Tmarus koreanus	한국범게거미	Decreased
		Diaea subdola	각시꽃게거미	Decreased
		Bassaniana decorata	나무껍질게거미	Decreased
Cybaeidae	굴뚝거미과	*Cybaeus triangulus*	삼각굴뚝거미	Decreased
		Cybaeus mosanensis	모산굴뚝거미	Decreased
Salticidae	깡충거미과	*Phintella linea*	안경깡충거미	Decreased
		Helicius yaginumai	골풀무깡충거미	Decreased
		Yaginumaella medvedevi	흰줄깡충거미	Decreased
		Euophrys kataokai	검정이마번개깡충거미	Decreased
		Bristowia heterospinosa	꼬마금오깡충거미	Decreased
		Asianellus festivus	산길깡충거미	Decreased
		Neon reticulatus	네온깡충거미	Decreased
		Marpissa milleri	왕깡충거미	Decreased
		Pseudeuophrys erratica	검은머리번개깡충거미	Decreased
Theridiidae	꼬마거미과	*Achaearanea angulithorax*	종꼬마거미	Decreased
		Achaearanea japonica	점박이꼬마거미	Decreased
		Dipoena castrata	검정미진거미	Decreased
		Dipoena mustelina	게꼬마거미	Decreased
		Robertus naejangensis	내장꼬마거미	Decreased
		Theridion longipalpum	긴수염꼬마거미	Decreased
		Theridion subpallens	회색꼬마거미	Decreased
		Episinus nubilus	민마름모거미	Decreased
Lycosidae	늑대거미과	*Alopecosa virgata*	채찍늑대거미	Decreased
		Pardosa lugubris	흰표늑대거미	Decreased
		Arctosa ipsa	흰털논늑대거미	Decreased
		Pardosa laura	가시늑대거미	Decreased
		Pardosa brevivulva	뫼가시늑대거미	Decreased
Pisauridae	닷거미과	*Pisaura lama*	아기늪서성거미	Decreased
Anapidae	도토리거미과	*Comaroma maculosa*	갑옷도토리거미	Decreased
Liocranidae	밭고랑거미과	*Phrurolithus palgongensis*	팔공도사거미	Decreased
		Phrurolithus sinicus	꼬마도사거미	Decreased
		Phrurolithus coreanus	고려도사거미	Decreased
		Phrurolithus pennatus	살깃도사거미	Decreased
Amaurobiidae	비탈거미과	*Ambanus euini*	입가게거미	Decreased
		Alloclubionoides jaegeri	자네르어리비탈거미	Decreased
		Ambanus kayasanensis	가야산가게거미	Decreased
		Ambanus lunatus	속리가게거미	Decreased
		Ambanus kimi	용기가게거미	Decreased
Philodromidae	새우게거미과	*Thanatus miniaceus*	중국창게거미	Decreased
		Philodromus subaureolus	갈새우게거미	Decreased
Gnaphosidae	수리거미과	*Drassyllus shaanxiensis*	중국참매거미	Decreased
		Drassyllus biglobus	쌍방울참매거미	Decreased
		Gnaphosa potanini	포타닌넓적니거미	Decreased
		Drassodes serratidens	톱수리거미	Decreased
Clubionidae	염낭거미과	*Clubiona rostrata*	부리염낭거미	Decreased
Zoridae	오소리거미과	*Zora nemoralis*	수풀오소리거미	Decreased
Araneidae	왕거미과	*Neoscona scylla*	지이어리왕거미	Decreased
Hahniidae	외줄거미과	*Hahnia corticicola*	외줄거미	Decreased
		Neoantistea quelpartensis	제주외줄거미	Decreased
Dictynidae	잎거미과	*Cicurina japonica*	두더지거미	Decreased
Linyphiidae	접시거미과	*Solenysa geumoensis*	개미시늉거미	Decreased
		Nippononeta projecta	뿔꼬마접시거미	Decreased
		Cresmatoneta nipponensis	개미접시거미	Decreased
		Eldonia kayaensis	가야접시거미	Decreased
		Neriene albolimbata	살촉접시거미	Decreased
		Neriene clathrata	십자접시거미	Decreased
		Lepthyphantes nasus	코접시거미	Decreased
		Gnathonarium gibberum	흑왕갈애접시거미	Decreased
		Nippononeta ungulata	발톱꼬마접시거미	Decreased
		Gonatium japonicum	왜가시다리접시거미	Decreased
		Neriene oidedicata	고무래접시거미	Decreased
		Walckenaeria lurida	황코뿔애접시거미	Decreased
		Walckenaeria coreana	가산코뿔접시거미	Decreased
		Arcuphantes scitulus	까막나사접시거미	Decreased
Corinnidae	코리나거미과	*Trachelas japonicus*	일본괭이거미	Decreased
Agelenidae	가게거미과	*Alloclubionoides cochlea*	달팽이어리비탈거미	Stable
Thomisidae	게거미과	*Xysticus saganus*	멍게거미	Stable
		Oxytate striatipes	줄연두게거미	Stable
		Ozyptila nongae	논개곤봉게거미	Stable

(continued on next page)

Table 5 (*continued*)

Family	Kor. Family	Species	Korean name	Change
Salticidae	깡충거미과	*Telamonia vlijmi*	검은날개무늬깡충거미	Stable
		Marpissa pulla	사층깡충거미	Stable
Linyphiidae	접시거미과	*Paikiniana vulgaris*	쌍코뿔애접시거미	Stable
		Hylyphantes graminicola	흑갈풀애접시거미	Stable
Tetragnathidae	갈거미과	*Leucauge celebesiana*	꼬마백금거미	Increased
Segestriidae	공주거미과	*Ariadna lateralis*	공주거미	Increased
Nesticidae	굴아기거미과	*Nesticella brevipes*	꼬마굴아기거미	Increased
Salticidae	깡충거미과	*Plexippoides regius*	왕어리두줄깡충거미	Increased
		Myrmarachne inermichelis	각시개미거미	Increased
Lycosidae	늑대거미과	*Arctosa kwangreungensis*	광릉논늑대거미	Increased
Amaurobiidae	비탈거미과	*Alloclubionoides coreanus*	광릉새염낭거미	Increased
Gnaphosidae	수리거미과	*Cladothela oculinotata*	흑갈갈래꼭지거미	Increased
Araneidae	왕거미과	*Chorizopes nipponicus*	머리왕거미	Increased

unlikely expanded to the highest altitudes in Kwangwondo where climate is most cool.

Gnaphosa kompirensis

This species is observed under stone, over litters, inside a cave, and in mountains and fields; and usually appear between May and September, widely distributing in Japan, China, Vietnam, and Russia (Namkung, 2001). Adult spiders occur between June and July and this species are found in a variety of farmlands (growing mulberry, ginseng, dong quai, bean, sesame, and other arable lands) largely in Suwon, Hongcheon, Yangyang, Pocheon, Goesan, Chunyang, Mungyeong, and Daejin (Im, 1996). It is also distributed in the Jeju island (Namkung et al., 2002) and also found in Mt. Juwangsan (Kim, 2010). The survey on the green fields around rice paddies in Hwaseong, Gyeonggi-do revealed the population was denser in forests than in open green fields (Jung et al., 2008). Thus, this species can be said to be a forest spider. The result from the survey conducted on ground and vegetation in pine tree forest in Namyangju, Gyeonggi-do revealed that the species was not collected from crown but from ground surface (Lee and Lee, 1990), suggesting that it is forage mostly on ground surface. It occurred 11.7% of total sites with the temperature scope between 6.1 and 12.8 °C (average 9.5 °C) (Appendix 1). This species was predicted to decrease greatest among 17 candidate species (RCP 4.5 reduced by 46.2% and RCP 8.5 by 84.2%) (Table 4). It is estimated that the species is currently distributed most in high altitudes. RCP 4.5 projects slightly changed range but RCP 8.5 project the greatly retracted range that is restricted in Kwangwondo (Figures 7 and 8).

Synagelides agoriformis

This species wanders over litters in forests, and overwinters in a nest under a stone or inside cave, the bark of a tree trunk (Namkung, 2001). It occurs between May and October, distributing in Japan, China, and Russia (Namkung, 2001) overseas, and also domestically distributing in the Jeju island, Mt. Juwangsan, and Hwaseong, Gyeonggi-do (Jung et al., 2008, Kim, 2010, Namkung et al., 2002). The surveys conducted 38 times on the green fields around rice paddies in Hwaseong, Gyeonggi-do for 4 years collected only 2 individuals from the green field along rice paddy ridges (Jung et al., 2008). However, this species occurred in this study at 11.5% of total sites with temperature scope between 8.2 and 13.1°C (average 10.5°C) (Appendix 1). Rising temperature is expected to decrease the abundance: RCP 4.5 by 23.1% and RCP 8.5 by 57.1% (Table 4). The current distribution is most abundant in the high altitude in the east northern region but few appearing in highest altitudes there. The distribution is projected to move upwards 50 years later with most abundant in highest altitudes, likely to decrease abundance in low to mid altitudes in other regions with much more reduction in RCP 8.5 (Figures 7 and 8).

Qualitative prediction of abundance

The non-candidate species with more than 1% occurrence were qualitatively determined into three categories: increase, no change, and decrease in abundance. Figure 9 shows the relation between the change rate of abundance of the candidate species and the average of temperatures of occurred sites. The mean value of annual average temperature in collection sites of species was a linear relation with the change rate of abundance (100*(abundance in 2056–2065 − abundance in 2011–2015)/ abundance in 2011–2015). Accordingly, RCP 4.5 had the change rate of 0 at 11.17 °C while RCP 8.5 had 0 at 11 °C on the regression equation in Figure 9. Therefore, it was determined assuming that: when the mean value of the average temperature in distribution site lies between 11 and 11.17 °C, abundance does not change (no change); when the value lies above the range, abundance increases; and when the value lies below the range, abundance decreases. It was predicted that: 9 out of a total of 85 species would have the increase in abundance, which would be followed by 68 species likely to have the decrease in abundance and subsequently 8 species likely to have little change in abundance (Table 5).

Conclusion

This study simply took the change in temperature in account when predicting the abundance of spiders, not considering the competition between species. Thus, as most species increase, a few species likely to increase in population would occupy the habitat of the disappearing species, likely to increase much more than expected. Therefore, many species decrease in population while some of species likely become far more abundant, predicted to lower diversity nationwide. Spiders have the same feeding habit as a predator; however, they show a variety of activity time, habitat, and behavior characteristics in each species, suggesting much more difference in their preferential preys by species. Accordingly, the rapid change in spiders due to rising temperature is suggested to substantially influence the other prey organisms (particularly, insects) or the predatory arthropod (ants, carabid beetles) in a competitive relation with them. Higher mountains are predicted to witness the increase in population and further the diversity of species because lowland species tend to move upward.

Appendix 1. Occurrence (number of occurred sites) and temperatures of occurred sites of spider species which had been collected from a national survey at 366 forest sites in South Korea from 2006 to 2009. Species are listed according to an order of occurrence.

Species	Korean name	Occurrence		Temperature		
		Site	%	Minimum	Maximum	Average
Pirata yaginumai	방울늑대거미	189	51.6	7.6	14.1	11.2
Itatsida praticola	족제비거미	171	46.7	7.1	13.9	11.3
Sernokorba pallidipatellis	석줄톱니매거미	163	44.5	6.1	13.9	10.8
Nippononeta cheunghensis	청하꼬마접시거미	148	40.4	6.1	13.9	10.4
Stemmops nipponicus	먹눈꼬마거미	124	33.9	7.6	14.1	10.8
Anahita fauna	너구리거미	113	30.9	8.0	14.1	11.4
Xysticus ephippiatus	대륙게거미	93	25.4	6.1	13.6	11.0
Harmochirus insulanus	산표깡충거미	83	22.7	9.8	14.1	12.0
Orthobula crucifera	십자삼지거미	75	20.5	7.6	14.1	11.4
Phintella cavaleriei	멋쟁이눈깡충거미	66	18.0	8.5	14.1	11.5
Diplocephaloides saganus	흰배애접시거미	59	16.1	8.2	13.2	10.7
Harmochirus pullus	반고리깡충거미	59	16.1	7.6	13.6	11.5
Doenitzius pruvus	땅접시거미	57	15.6	5.4	12.9	10.3
Phrurolithus pennatus	살깃도사거미	53	14.5	5.1	14.1	10.5
Neoantistea quelpartensis	제주외줄거미	51	13.9	5.5	13.1	9.9
Evarcha albaria	흰눈썹깡충거미	47	12.8	7.6	13.6	11.5
Zelotes asiaticus	아시아염라거미	44	12.0	8.7	13.2	11.4
Gnaphosa kompirensis	넓적니거미	43	11.7	6.1	12.8	9.5
Synagelides agoriformis	어리개미거미	42	11.5	8.2	13.1	10.5
Arctosa kwangreungensis	광릉논늑대거미	40	10.9	9.7	13.4	11.6
Drassyllus biglobus	쌍방울참매거미	37	10.1	5.4	13.0	9.1
Pardosa brevivulva	뫼가시늑대거미	35	9.6	5.4	13.7	10.2
Asianellus festivus	산길깡충거미	34	9.3	3.9	13.2	10.1
Clubiona rostrata	부리염낭거미	33	9.0	4.9	13.7	9.3
Gnaphosa potanini	포타닌넓적니거미	31	8.5	5.4	12.9	10.3
Cladothela oculinotata	흑갈갈래꼭지거미	26	7.1	5.1	14.1	11.3
Eldonia kayaensis	가야접시거미	24	6.6	6.5	13.7	8.9
Solenysa geumoensis	개미시늉거미	21	5.7	5.1	13.1	9.2
Zora nemoralis	수풀오소리거미	21	5.7	3.9	12.5	8.8
Lepthyphantes nasus	코접시거미	19	5.2	6.8	11.9	9.5
Ariadna lateralis	공주거미	18	4.9	10.3	13.1	12.2
Dipoena mustelina	게꼬마거미	17	4.6	5.4	12.7	10.1
Ambanus kayasanensis	가야산가게거미	16	4.4	6.2	12.8	10.3
Episinus nubilus	민마름모거미	16	4.4	7.3	13.8	10.8
Philodromus subaureolus	갈새우게거미	16	4.4	6.5	14.1	10.9
Phintella linea	안경깡충거미	16	4.4	7.6	14.1	10.5
Comaroma maculosa	갑옷도토리거미	15	4.1	7.2	13.1	10.7
Pseudeuophrys erraica	검은머리번개깡충거미	15	4.1	7.2	12.9	10.9
Xysticus concretus	쌍지게거미	15	4.1	5.5	13.1	8.8
Alloclubionoides cochlea	달팽이어리비탈거미	14	3.8	8.0	10.5	11.0
Coelotes songminjae	민자가게거미	14	3.8	9.4	12.1	10.7
Phrurolithus coreanus	고려도사거미	14	3.8	5.4	13.2	10.2
Drassodes serratidens	톱수리거미	13	3.6	6.8	13.1	10.6
Cybaeus mosanensis	모산굴뚝거미	12	3.3	7.1	12.0	9.7
Hahnia corticicola	외줄거미	12	3.3	5.5	12.0	8.4
Ambanus lunatus	속리가게거미	11	3.0	9.2	11.7	10.6
Arcuphantes scitulus	까막나사접시거미	11	3.0	8.4	12.0	9.9
Neon reticulatus	네온깡충거미	11	3.0	7.1	12.2	10.6
Theridion longipalpum	긴수염꼬마거미	11	3.0	5.4	14.1	10.4
Alloclubionoides jaegeri	자네르어리비탈거미	10	2.7	6.1	11.6	8.7
Oxytate striatipes	줄연두게거미	10	2.7	9.3	12.6	11.1
Pardosa laura	가시늑대거미	10	2.7	3.9	12.3	9.6
Xysticus saganus	멍게거미	10	2.7	8.2	13.8	11.1
Achaearanea angulithorax	종꼬마거미	9	2.5	5.5	12.6	9.3
Cresmatoneta nipponensis	개미접시거미	9	2.5	5.1	12.2	8.7
Euophrys kataokai	검정이마번개깡충거미	9	2.5	5.4	11.8	9.5
Leucauge celebesiana	꼬마백금거미	9	2.5	6.2	13.1	11.3
Robertus naejangensis	내장꼬마거미	9	2.5	8.0	11.9	10.2
Thanatus miniaceus	중국창게거미	9	2.5	7.2	12.4	10.5
Walckenaeria coreana	가산코뿔접시거미	9	2.5	7.9	12.8	10.5
Gonatium japonicum	왜가시다리접시거미	8	2.2	6.8	13.7	10.0
Helicius yaginumai	골풀무깡충거미	8	2.2	10.0	11.7	10.9
Neriene clathrata	십자접시거미	8	2.2	5.5	13.7	9.3
Neriene oidedicata	고무래접시거미	8	2.2	6.2	13.1	10.9
Nesticella brevipes	꼬마굴아기거미	8	2.2	7.6	12.7	11.2
Phrurolithus sinicus	꼬마도사거미	8	2.2	6.8	12.8	8.9
Pisaura lama	아기늪서성거미	8	2.2	7.2	12.4	10.5
Telamonia vlijmi	검은날개무늬깡충거미	7	1.9	8.1	14.1	11.1
Bristowia heterospinosa	꼬마금호깡충거미	6	1.6	5.1	12.7	10.0
Drassyllus shaanxiensis	중국참매거미	6	1.6	7.1	12.3	8.9
Hylyphantes graminicola	흑갈풀애접시거미	6	1.6	8.3	12.4	11.1
Marpissa pulla	사층깡충거미	6	1.6	8.5	14.1	11.0
Neoscona scylla	지이어리왕거미	6	1.6	6.2	12.9	10.7

(*continued on next page*)

(*continued*)

Species	Korean name	Occurrence		Temperature		
		Site	%	Minimum	Maximum	Average
Ozyptila nongae	논개곤봉게거미	6	1.6	9.3	12.2	11.1
Phrurolithus palgongensis	팔공도사거미	6	1.6	6.5	10.2	8.4
Yaginumaella medvedevi	흰줄깡충거미	6	1.6	5.5	10.4	8.2
Achaearanea japonica	점박이꼬마거미	5	1.4	8.7	13.1	10.3
Agelena limbata	들풀거미	5	1.4	8.7	10.8	10.8
Alopecosa virgata	채찍늑대거미	5	1.4	8.2	11.3	9.9
Ambanus euini	입가게거미	5	1.4	7.1	9.0	8.0
Ambanus kimi	용기가게거미	5	1.4	9.2	12.8	10.7
Diaea subdola	각시꽃게거미	5	1.4	8.7	11.8	10.0
Marpissa milleri	왕깡충거미	5	1.4	8.9	12.1	10.9
Trachelas japonicus	일본괭이거미	5	1.4	5.4	13.1	8.4
Alloclubionoides coreanus	광릉새염낭거미	4	1.1	11.6	12.2	12.8
Arctosa ipsa	흰털논늑대거미	4	1.1	7.1	10.5	8.5
Bassaniana decorata	나무껍질게거미	4	1.1	8.6	12.3	10.8
Chorizopes nipponicus	머리왕거미	4	1.1	11.1	13.2	12.3
Cicurina japonica	두더지거미	4	1.1	6.8	13.1	10.1
Cybaeus triangulus	삼각굴뚝거미	4	1.1	8.0	9.6	8.7
Dipoena castrata	검정미진거미	4	1.1	7.9	11.1	9.3
Gnathonarium gibberum	흑왕갈애접시거미	4	1.1	8.2	10.7	9.6
Myrmarachne inermichelis	각시개미거미	4	1.1	10.3	13.5	12.2
Neriene albolimbata	살촉접시거미	4	1.1	6.5	10.7	9.1
Nippononeta projecta	뿔꼬마접시거미	4	1.1	6.7	10.2	8.0
Nippononeta ungulata	발톱꼬마접시거미	4	1.1	8.2	10.6	9.9
Paikiniana vulgaris	쌍코뿔애접시거미	4	1.1	8.7	12.6	11.1
Pardosa lugubris	흰표늑대거미	4	1.1	7.6	9.3	8.3
Plexippoides regius	왕어리두줄깡충거미	4	1.1	11.1	12.4	11.6
Theridion subpallens	회색꼬마거미	4	1.1	7.3	11.8	10.7
Tmarus koreanus	한국범게거미	4	1.1	8.8	10.2	9.6
Walckenaeria lurida	황코뿔애접시거미	4	1.1	6.8	12.0	9.6
Acusilas coccineus	잎왕거미	3	0.8	10.3	11.7	11.0
Arctosa stigmosa	논늑대거미	3	0.8	10.0	12.8	12.0
Arcuphantes pennatus	날개나사접시거미	3	0.8	9.3	10.5	9.8
Callobius koreanus	반도비탈거미	3	0.8	8.1	10.7	9.5
Clubiona kasanensis	가산염낭거미	3	0.8	7.9	10.1	8.7
Crustulina guttata	점박이사마귀꼬마거미	3	0.8	9.7	11.6	10.4
Diphya okumae	각시어리갈거미	3	0.8	7.9	11.5	9.8
Dipoena flavomarginatum	황줄미진거미	3	0.8	8.0	8.4	8.2
Drassyllus sanmenensis	삼문참매미거미	3	0.8	11.2	11.5	11.3
Haplodrassus montanus	산새매거미	3	0.8	7.1	11.4	8.7
Neriene emphana	대륙접시거미	3	0.8	8.9	12.5	10.5
Nurscia albofasciata	살깃자갈거미	3	0.8	9.3	9.6	9.4
Oia imadatei	낫애접시거미	3	0.8	8.3	11.1	9.8
Paikiniana mira	긴코뿔애접시거미	3	0.8	6.8	11.2	8.7
Phintella abnormis	갈색눈깡충거미	3	0.8	10.7	14.1	12.1
Poecilochroa coreana	한국솔개거미	3	0.8	7.9	12.8	9.7
Sergiolus hosiziro	흰별솔개거미	3	0.8	8.4	13.5	10.1
Sinopoda stellata	별거북이등거미	3	0.8	9.9	10.6	10.3
Tmarus rimosus	언청이범게거미	3	0.8	8.0	8.4	8.2
Walckenaeria antica	고풍쌍혹애접시거미	3	0.8	9.7	10.8	10.2
Agyneta rurestris	꼬마접시거미	2	0.5	7.1	12.5	9.8
Alloclubionoides quadrativulvus	모가게거미	2	0.5	11.3	12.7	12.0
Alopecosa albostriata	흰무늬늑대거미	2	0.5	7.6	10.0	8.8
Anyphaena pugil	팔공거미	2	0.5	9.4	11.9	10.7
Argiope minuta	꼬마호랑거미	2	0.5	12.5	13.7	13.1
Bathylinyphia major	가시접시거미	2	0.5	5.1	11.9	8.5
Callilepis schuszteri	쌍별도끼거미	2	0.5	9.2	10.1	9.6
Clubiona coreana	한국염낭거미	2	0.5	8.4	10.8	9.6
Clubiona diversa	천마염낭거미	2	0.5	8.5	11.3	9.9
Crispiphantes rhomboideus	마름모꼬마접시거미	2	0.5	6.8	10.1	8.4
Cyclosa sedeculata	넷혹먼지거미	2	0.5	8.4	11.8	10.1
Doenitzius peniculus	용접시거미	2	0.5	9.4	12.0	10.7
Dolomedes sulfureus	황닷거미	2	0.5	5.1	8.1	6.6
Ero japonica	뿔해방거미	2	0.5	9.8	12.8	11.3
Gnaphosa hastata	창넓적니거미	2	0.5	10.1	13.2	11.6
Gnathonarium dentatum	황갈애접시거미	2	0.5	8.4	8.7	8.5
Lathys dihamata	쌍갈퀴마른잎거미	2	0.5	5.1	9.4	7.2
Leucauge blanda	중백금거미	2	0.5	10.7	12.6	11.7
Lycosa coelestis	제주늑대거미	2	0.5	11.5	12.9	12.2
Micaria dives	소천영롱거미	2	0.5	12.4	13.1	12.7
Mimetus testaceus	큰해방거미	2	0.5	12.0	12.2	12.1
Neoscona punctigera	적갈어리왕거미	2	0.5	9.9	11.1	10.5
Opopaea syarakai		2	0.5	12.8	13.2	13.0
Pardosa hedini	중국늑대거미	2	0.5	9.6	12.6	11.1
Pisaura ancora	닻표늪서성거미	2	0.5	12.0	14.1	13.0
Ryojius japonicus		2	0.5	10.6	11.1	10.8
Siler cupreus	청띠깡충거미	2	0.5	11.1	13.2	12.1
Theridion lyricus	돈꼬마거미	2	0.5	7.8	9.1	8.4

(*continued*)

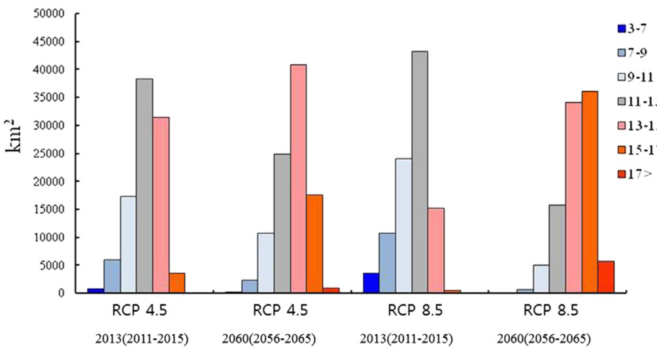
Species	Korean name	Occurrence		Temperature		
		Site	%	Minimum	Maximum	Average
Thymoites ulleungensis	울릉코보꼬마거미	2	0.5	7.9	8.7	8.3
Tibellus oblongus	두점가재거미	2	0.5	10.1	10.6	10.4
Trochosa ruricola	촌티늑대거미	2	0.5	8.7	12.8	10.8
Agroeca mongolica	몽골밭고랑거미	1	0.3	9.7	9.7	9.7
Alloclubionoides coreana	한국어리비탈거미	1	0.3	7.7	7.7	7.7
Alloclubionoides terdecimus	거제어리비탈거미	1	0.3	12.9	12.9	12.9
Alopecosa hokkaidebsis		1	0.3	10.5	10.5	10.5
Alopecosa pulverulenta	먼지늑대거미	1	0.3	9.0	9.0	9.0
Ambanus dimidiatus	팔공가게거미	1	0.3	10.0	10.0	10.0
Anelosimus crassipes	가시잎무늬꼬마거미	1	0.3	11.3	11.3	11.3
Araneus fuscocolorata	먹왕거미	1	0.3	7.7	7.7	7.7
Argiope bruennichi	긴호랑거미	1	0.3	11.9	11.9	11.9
Catrianeira shaxianensis	대륙나나니거미	1	0.3	9.8	9.8	9.8
Cheiracanthium taegense	대구어리염낭거미	1	0.3	12.8	12.8	12.8
Cheiracanthium uncinatum	갈퀴혹어리염낭거미	1	0.3	10.4	10.4	10.4
Chikuni albipes	삼각점꼬마거미	1	0.3	12.2	12.2	12.2
Clubiona jucunda	살깃염낭거미	1	0.3	9.4	9.4	9.4
Clubiona kimyoungkii	김염낭거미	1	0.3	7.7	7.7	7.7
Coleosoma octomaculatum	여덟점꼬마거미	1	0.3	8.5	8.5	8.5
Crispiphantes biseulsanensis	비슬산접시거미	1	0.3	6.8	6.8	6.8
Cyclosa kumadai	어리장은먼지거미	1	0.3	11.4	11.4	11.4
Cyclosa octotuberculata	여덟혹먼지거미	1	0.3	11.8	11.8	11.8
Cyclosa vallata	녹두먼지거미	1	0.3	7.9	7.9	7.9
Dipoena punctisparsa	서리미진거미	1	0.3	11.6	11.6	11.6
Dolomedes raptor	먹닷거미	1	0.3	11.6	11.6	11.6
Entelecara dabudongensis	다부동상투애접시거미	1	0.3	7.1	7.1	7.1
Eriophora sachalinensis	북왕거미	1	0.3	5.5	5.5	5.5
Floronia exornata	꽃접시거미	1	0.3	7.9	7.9	7.9
Gnaphosa kansuensis	감숙넓적거미	1	0.3	9.8	9.8	9.8
Haplodrassus kulczynskii	큰수염새매거미	1	0.3	7.9	7.9	7.9
Haplodrassus mayumiae		1	0.3	12.4	12.4	12.4
Hypsosinga sanguinea	산짜애왕거미	1	0.3	8.4	8.4	8.4
Ischnothyreus flagellichelis		1	0.3	3.9	3.9	3.9
Kishidaia albimaculata		1	0.3	7.8	7.8	7.8
Larinioides cornutus	기생왕거미	1	0.3	10.9	10.9	10.9
Lathys sexoculata	육눈이마른잎거미	1	0.3	7.9	7.9	7.9
Lepthyphantes latus	한라접시거미	1	0.3	11.5	11.5	11.5
Lycosa suzukii	땅늑대거미	1	0.3	12.0	12.0	12.0
Meioneta nigra	검정꼬마접시거미	1	0.3	10.8	10.8	10.8
Miagrammopes orientalis	손짓거미	1	0.3	10.6	10.6	10.6
Moneta caudifer	긴마름모거미	1	0.3	6.2	6.2	6.2
Myrmarachne formicaria	산개미거미	1	0.3	13.7	13.7	13.7
Myrmarachne japonica	불개미거미	1	0.3	11.5	11.5	11.5
Mysmenella jobi	깨알거미	1	0.3	8.4	8.4	8.4
Nematogmus sanguinolentus	앵도애접시거미	1	0.3	9.5	9.5	9.5
Neon minutus	부리네온깡충거미	1	0.3	8.4	8.4	8.4
Neoscona scylloides	연두어리왕거미	1	0.3	8.8	8.8	8.8
Nephila clavata	무당거미	1	0.3	13.2	13.2	13.2
Neriene longipedella	농발접시거미	1	0.3	8.1	8.1	8.1
Octonoba sinensis	중국응달거미	1	0.3	11.0	11.0	11.0
Orchestina sanguinea		1	0.3	10.7	10.7	10.7
Orchestina thoracica		1	0.3	8.1	8.1	8.1
Ozyptila nipponica	점곤봉게거미	1	0.3	12.0	12.0	12.0
Paracoelotes spinivulvus	한국깔때기거미	1	0.3	11.6	11.6	11.6
Parasteatoda culicivora	대륙꼬마거미	1	0.3	6.2	6.2	6.2
Pardosa astrigera	별늑대거미	1	0.3	9.5	9.5	9.5
Perenethis fascigera	번개닷거미	1	0.3	11.5	11.5	11.5
Philodromus rufus	북방새우게거미	1	0.3	11.1	11.1	11.1
Philodromus spinitarsis	나무결새우게거미	1	0.3	8.0	8.0	8.0
Phintella bifurcilinea	황줄깡충거미	1	0.3	11.5	11.5	11.5
Phlegra fasciata	배띠산길깡충거미	1	0.3	11.6	11.6	11.6
Pirata piratoides	공산늑대거미	1	0.3	10.9	10.9	10.9
Pirata procurvus	좀늑대거미	1	0.3	9.8	9.8	9.8
Plexippoides annulipedis	큰줄무늬깡충거미	1	0.3	10.9	10.9	10.9
Sinopoda pengi		1	0.3	11.8	11.8	11.8
Talavera trivittata	세줄번개깡충거미	1	0.3	13.2	13.2	13.2
Tetragnatha extensa	큰배갈거미	1	0.3	8.4	8.4	8.4
Theridion adamsoni	아담손꼬마거미	1	0.3	8.5	8.5	8.5
Theridion quadrimaculatus	월매꼬마거미	1	0.3	12.4	12.4	12.4
Theridion sterninotata	살별꼬마거미	1	0.3	8.0	8.0	8.0
Tibellus fengi		1	0.3	8.2	8.2	8.2
Tibellus tenellus	넉점가재거미	1	0.3	7.6	7.6	7.6
Tmarus orientalis	동방범게거미	1	0.3	10.2	10.2	10.2
Ummeliata angulituberis	모등줄애접시거미	1	0.3	6.5	6.5	6.5
Ummeliata feminea	흑등줄애접시거미	1	0.3	10.1	10.1	10.1
Ummeliata insecticeps	등줄가슴애접시거미	1	0.3	13.1	13.1	13.1

(*continued on next page*)

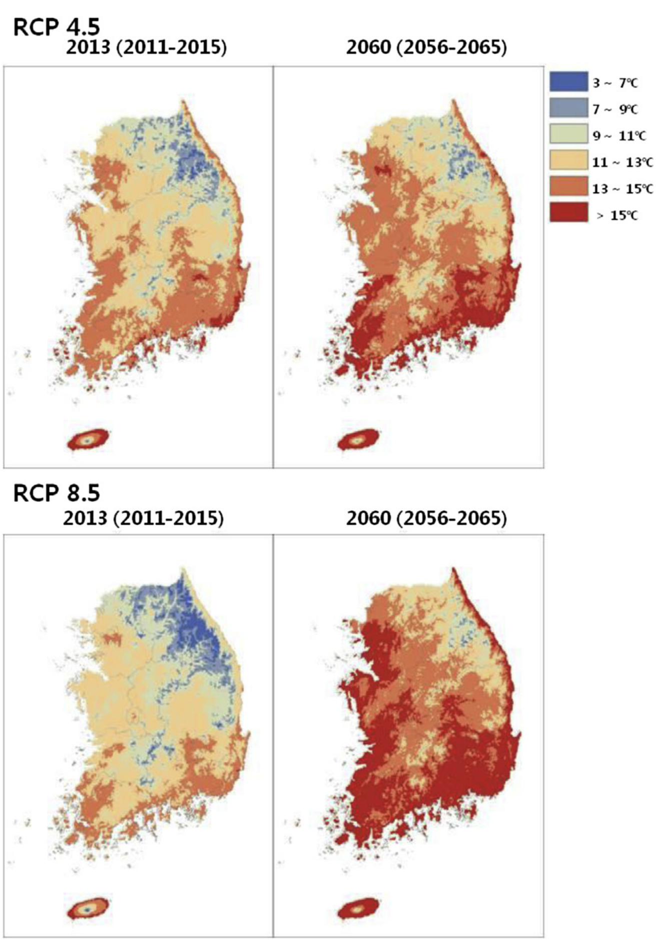
(*continued*)

Species	Korean name	Occurrence		Temperature		
		Site	%	Minimum	Maximum	Average
Walckenaeria nishikawai		1	0.3	10.8	10.8	10.8
Xysticus atrimaculatus	점게거미	1	0.3	11.6	11.6	11.6
Xysticus croceus	풀게거미	1	0.3	12.0	12.0	12.0
Zelotes kimwha	김화염라거미	1	0.3	11.1	11.1	11.1

Appendix 2. Change in temperature according to climate scenario RCP 4.5 and 8.5.



Appendix 3. Distribution of temperature according to climate scenario RCP 4.5 and 8.5.



References

Botkin DB, Saxe H, Araújo MB, et al. 2007. Forecasting the effects of global warming on biodiversity. *BioScience* 57:227–236.

Bradshaw WE, Holzapfel CM. 2006. Evolutionary response to rapid climate change. *Science* 312:1477–1478.

Brandon TB, Beckerman AP, Schmitz OJ. 2009. Climate warming strengthens indirect interactions in an old-field food web. *Ecology* 90:2346–2351.

Chen S-H. 1999. Cytological studies of six species of spiders from Taiwan (Araneae: Theridiidae, Psechridae, Uloboridae, Oxyopidae, and Ctenidae). *Zoological Studies* 38:423–434.

Crouch TE, Lubin Y. 2000. Effects of climate and prey availability on foraging in a social spider, *Stegodyphusmimosarum* (Araneae, Eresidae). *Journal of Arachnology* 28:158–168.

Davies KF, Melbourne BA, McClenahan JL, Tuff T. 2011. Statistical models for monitoring and predicting effects of climate change and invasion on the free-living insects and a spider from sub-Antarctic Heard Island. *Polar Biology* 34: 119–125.

Greenslade P, Greenslade PJM. 1971. The use of baits and preservatives in pitfall traps. *Journal of Australian Entomological Society* 10:253–260.

He F, Hubbell SP. 2011. Species-area relationships always overestimate extinction rates from habitat loss. *Nature* 473:368–371.

Hickling R, Roy DB, Hill JK, et al. 2006. The distributions of wide range of taxonomic groups are expanding polewards. *Global Ecology and Biogeography* 12:450–455.

Im MS. 1996. *The spiders of Korea*. Seoul: Jigu Publishing Co.. p. 249.

IPCC. 2007. Climate change 2007: impacts adaptation and vulnerability. In: Parry ML, Canziani O, Palutikof J, et al., editors. *Contribution of working group II to the fourth assessment report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press.

Jung MP, Kim ST, Kim H, et al. 2008. Biodiversity and community structure of ground-dwelling spiders in four different field margin types of agricultural landscapes in Korea. *Applied Soil Ecology* 38:185–195.

Kim BW, Kim JP. 2010. A check list of Korean spiders. *Korean Arachnology* 26:121–165.

Kim BW. 2010. A preliminary note on spider fauna of Mt. Juwangsan National Park in Korea. *Journal of National Park Research* 1:141–149.

Kim ST, Uhm KB, Lee JH, et al. 2002. Spiders in a grape vineyard in Korea. *Journal of Asia-Pacific Entomology* 5:181–184.

Konvicka M, Maradova M, Benes J, et al. 2003. Uphill shifts in distribution of butterflies in the Czech Republic effects of changing climate detected on a regional scale. *Global Ecology and Biogeography* 12:403–410.

Korea Meteorological Administration. 2006–2009. *Annual and monthly reports on meteorological observations*. Available at: http://www.kma.go.kr/weather/main.jsp [Date accessed: 10 November 2013].

Kwon T-S, Kim S-S, Lee CM, et al. 2011. *Prediction of distribution and abundance of ants based on climate change of A1B climate scenario*. Research Note 417. Korea Forest Research Institute. Seoul: Nanuri Pub. Co..

Kwon T-S, Lee CM, Kim BW, et al. 2013. *Prediction of distribution and abundance of forest spiders according to climate scenario RCP 4.5 and 8.5*. Research Note 528. Seoul: Korea Forest Research Institute. p. 383.

Lee CM, Kwon TS, Park YK, Kim BW. 2012. Influences of disturbance intensity on community structure, species richness and abundance of arthropod predators (Araneae, Carabidae, Staphylinidae, and Formicidae) in burned-pine forest. *Journal of Korean Forestry Society* 101:488–500.

Lee GH, Lee HP. 1990. Guild structure and seasonal occurrences of spider communities in pine plantation habitat. *Korean Journal of Ecology* 13:149–163.

Lensing JR, Wise DH. 2006. Predicted climate change alters the indirect effect of predators on an ecosystem process. *Proceedings of the National Academy of Sciences* 103:15502–15505.

Logunov DV, Aoryhon AB. 2000. A redefinition of the genera Bianor Peckham & Peckham, 1885 and Harmochirus Simon, 1885, with the establishment of a new genus Sibianorgen.n. (Aranei: Salticidae). *Arthropoda Selecta* 9:221–286.

Marusik YM. 2009. A check-list of spiders (Aranei) from the LazoReserrve, Maritime Province, Russia. *Arthropoda Selecta* 18:95–109.

Mgobozi MP, Somers MJ, Dippenaar-Schoeman AS. 2008. Spider responses to alien invasion: the effect of short- and long-term Chromolaena odorata invasion and management. *Journal of Applied Ecology* 45:1189–1197.

Namkung J, Im MS, Kim ST, et al. 2002. Spider fauna of Jeju Island in Korea. *Journal of Asia-Pacific Entomology* 5:55–74.

Namkung J. 2001. *The spiders of Korea*. Seoul: Kyohak Publishing Co., Ltd.. p. 647.

Omelko MM, Marusik YM, Koponen S. 2011. A survey of the east Palearctic Lycosidae (Arenei). 8. The genera Pirata Sundevall, 1983 and Piratula Roewer, 1960 in the Russian Far East. *Arthropoda Selecta* 20:195–232.

Parmesan C, Yohe G. 2003. A globally coherent fingerprint of climate change impacts across natural systems. *Nature* 421:37–42.
Parmesan C, Phyholm N, Stefanescus C, et al. 1999. Poleward shifts in geographical ranges of butterfly species associated with regional warming. *Nature* 399:579–583.
Platnick NI. 2000. *The world spider catalog, version 14.5*. Available at: [Date accessed: 10 January 2014] http://research.amnh.org/iz/spiders/catalog/.
Saupe EE, Papes M, Selden PA, Vetter RS. 2011. Tracking a medically important spider: climate change, ecological niche modeling, and the brown recluse (*Loxosceles recluse*). *Plos One* 6:1–10.
Thomas CD, Cameron A, Green RE, et al. 2004. Extinction risk from climate change. *Nature* 427:145–148.
Uetz GW. 1977. Coexistence in a guild of wandering spiders. *Journal of Animal Ecology* 46:531–541.
Walther GR, Berger S, Sykes MT. 2005. An ecological 'footprint' of climate change. *Proceedings of the Royal Society B: Biological Sciences* 272:1427–1432.
Walther GR, Post E, Convey P, et al. 2002. Ecological responses to recent climate change. *Nature* 416:389–395.
Yaginuma T. 1986. *Spider of Japan in color*. Japan: Hoikusha Publishing Co.. p. 305.
Yun JI, Kim JH, Kim SO, et al. 2013. *Development of digital climate map of Korean forest and prediction of forest climate*. Research Report 13–19. Korea Forest Research Institute. Seoul: Korean Disabled Culture Pub. Co.
Zhang JX, Song DX. 2002. A checklist of spiders from Singapore (Arachnida: Araneae). *Raffles Bulletin of Zoology* 50:359–388.