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Prediction of Changes in Habitat Distribution of the Alfalfa Weevil (*Hypera postica*) Using RCP Climate Change Scenarios

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RCP 기후변화 시나리오 따른 알팔파바구미(*Hypera postica*)의 서식지 분포 변화 예측

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ABSTRACT: Climate change can affect variables related to the life cycle of insects, including growth, development, survival, reproduction and distribution. As it encourages alien insects to rapidly spread and settle, climate change is regarded as one of the direct causes of decreased biodiversity because it disturbed ecosystems and reduces the population of native species. *Hypera postica* caused a great deal of damage in the southern provinces of Korea after it was first identified on Jeju lsland in the 1990s. In recent years, the number of individuals moving to estivation sites has concerned scientists due to the crop damage and national proliferation. In this study, we examine how climate change could affect inhabitation of *H. postica*. The MaxEnt model was applied to estimate potential distributions of *H. postica* using future climate change scenarios, namely, representative concentration pathway (RCP) 4.5 and RCP 8.5. As variables of the model, this study used six bio-climates (bio3, bio6, bio10, bio12, bio14, and bio16) in consideration of the ecological characteristics of 66 areas where inhabitation of *H. postica* was confirmed from 2015 to 2017, and in consideration of the interrelation between prediction variables. The fitness of the model was measured at a considered potentially useful level of 0.765 on average, and the warmest quarter has a high contribution rate of 60-70%. Prediction models (RCP 4.5 and RCP 8.5) results for the year 2050 and 2070 indicated that *H. postica* habitats are projected to expand across the Korean peninsula due to increasing temperatures.

Key words: Alien species, Potential habitat, Climate change, RCPs scenarios, MaxEnt

초 록: 기후변화는 곤충의 성장, 발육, 생존, 생식력, 분포범위 등 생활사의 변수들에 영향을 준다. 특히 외래곤충의 경우 생태계 정착 및 확산이 빨라지고 있으며, 생태계 교란, 토착종 감소 등 생물다양성을 감소시키는 직접적인 원인 중 하나이다. 알팔파바구미는 1990년대 제주도에서 처음 발견 후 남부지방에 대량 발생하여 농업해충으로 인식되었다. 최근 하면처로 이동하는 개체에 의한 밭작물의 피해와 여러 시군에서 서식이 확인되며 확산의 우려되고 있다. 본 연구에서는 기후변화가 알팔파바구미에 미치는 영향에 대해 파악하였다. 미래의 기후 시나리오 RCP 4.5와 RCP 8.5에서 알팔파바구미의 잠재적 분포를 추정하기 위해 MaxEnt 모델을 적용하였다. 모형의 변수는 2015~2017년까지 알팔파바구미의 서식이 확인된 66개 지점과 종의 생태특성 및 예측변수간 상관성을 고려한 6개(bio3, bio6, bio10, bio12, bio14, bio16)의 생물기후를 사용하였다. 예측된 모형의 적합도는 평균 0.765로 잠재력이 의미 있는 값이며, 최고 따뜻한 분기의 평균기온(bio10)이 60~70%로 높은 기여도를 나타냈다. 2050년과 2070년의 시나리오(RCP 4.5, RCP 8.5)에 대한 모형의 결과는 한반도 전역에서 알팔파바구미의 분포 변화를 보여 주었으며, 기온상승에 따른 전국적 확산이 예측되었다.

검색어: 외래생물, 잠재 서식지, 지구온난화, RCPs 시나리오, MaxEnt

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Increased activities in trade, transportation, travel, and tourism due to globalization are blamed for accelerating the introduction and spread of alien species; several alien species have settled in new environments and disrupted the local ecosystems (Bang et al., 2004). Invasive alien species (IAS) are animals or plants that naturally or artificially move from their original habitats to settle in other places, threatening the survival of native species (Secretariat of the Convention on Biological Diversity, 2010). As an environmental factor climate change accelerates the migration and spread of these alien species, and is a main cause of biodiversity degradation that can affect species geological distribution and abundance.

Climate change affects the survival of various species (Fleming and Candau, 1998), as their growth, reproduction, and survival are directly affected by temperature changes (Sutherst, 2000; Bale, 2002). A variety of changes are projected to occur in terms of their inhabitation patterns and ranges, as well as ecological status.

The alfalfa weevils (*H. postica*), belonging to the order Coleoptera and family Curculionidae, originated from Eurasia and are now widely distributed in North Africa, India, and southwestern (Cothran and Summers, 1972; Miller et al., 1972) and northeastern Asia (Baba, 1983; Morimoto, 1987). In South Korea, inhabitation of the species was first confirmed on Jeju Island in the 1990s, and it was confirmed that they were present in imported dry plants during a quarantine inspection between 2000 and 2001 (Hong and Kim, 2002). In 2005, a massive outbreak occurred in areas of roughage in Gyeongnam Province (Lee et al., 2012). *H. postica* winter as adults and become active when the temperature reaches 15℃ the next spring. They bore holes in the stems of leguminous plants and lay 1-40 yellow eggs. After a few weeks, the eggs hatch and larvae move to the growing point, eating fresh young leaves in an early state and then eating other leaves, flowers, and stems as they mature. Their main host plants are leguminous plants including alfalfa (*Medicago sativa*), chinese milkvetch (*Astragalus sinicus*), common vetch (*Vicia sativa*), and white clover (*Trifolium repens*)(Kim et al., 2003). Recently, it has been reported that in the southern provinces of South Korea, field crops have suffered severe damage caused by first generations of adult insects that move to their estivation sites in May and June (Bae et al., 2014). According to a field survey conducted by the National Institute of Ecology, *H. postica* were confirmed to inhabit 18 cities and counties across the country. In consideration of the inhabitable climate range and high reproduction of *H. postica* a possible economic loss due to its spread has generated much concern (Metcalf and Luckman, 1994), and therefore, it is necessary to develop an appropriate pest control and management system.

Understanding the ecological and geographical distribution of animal and plant species is vital in elucidating biodiversity patterns and their formation (Ferrier et al., 2002b; Rushton et al., 2004). In the present study, species distribution models (SDMs) were used to identify environmental requirements from either the absence or presence of known species. Based on the ecological status of the species, this method can predict presumptive and potential distribution of species' habitats by linking the covariance between variables related to the appearance and non-appearance of species. The results of the model have been used for decisions on conservation management policies and species control, as well as to explain ecological and biogeographical theories and phenomena (Akcakaya et al., 1995; Ferrier et al., 2002a; Keith et al., 2014; Pearce and Lindenmayer, 1998). In recent years, SDMs have been widely used by studies relating to potential habitat distribution and the spread of species due to climate change (Kwon et al., 2014; Park et al., 2016), as well as studies on the distribution of alien species and their hazards (Crossman et al., 2011; Gallien et al., 2012; Hill et al., 2016). Therefore, the present study provides the basic data by using the MaxEnt model was used for the prediction of their distribution by inferring their climatic environmental requirements from localities where are currently known to occur of *H. postica*.

Materials and Methods

Location data collection

Distribution data of *H. postica* were collected from 66 places where inhabitation was confirmed by a field test (Fig. 1). The field survey was conducted on riversides, in forest, in parks, and on arable land and farmland across the country in consideration of the ecological characteristics from March to June of 2015 to 2017. Inhabitations are indicated with

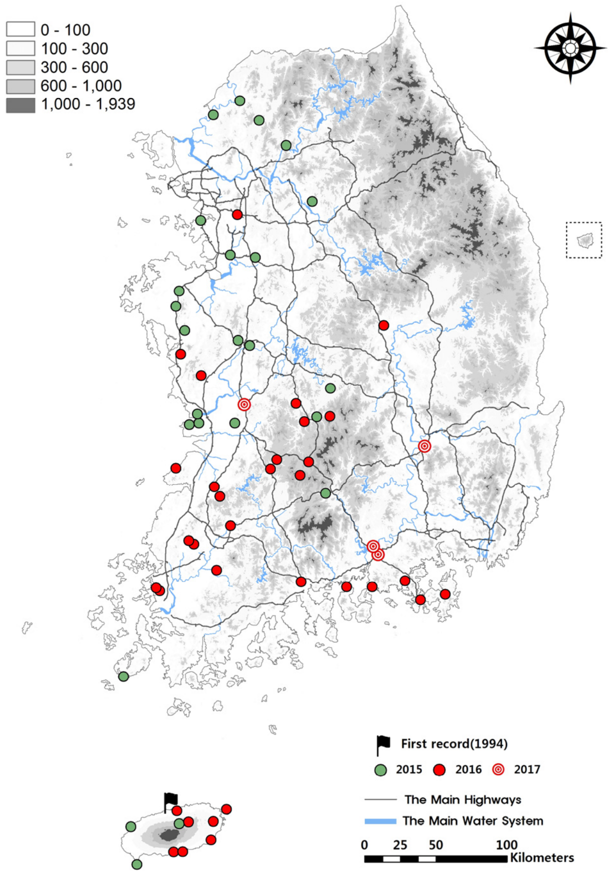

Fig. 1. Occurrence sites of alfalfa weevil (*H. postica*).

longitudes and altitudes, and are converted into a *.csv file format.

Environmental variables

Due to the fact that *H. postica* inhabits flat lands such as rice paddies and upland fields, as well as the edges of forests, this study excludes geographical variables and uses only climate variables as explanatory variables. In terms of climate variables, the study used past mean temperature data from the 1950s to 2000s provided by worldclim (http://www.worldclim.org) and future mean temperatures for the 2050s and 2070s predicted by HadGEM2-AO as bio-climatic data. Bio-climatic data provided by worldclim contain 19 kinds of climate data parameters based on temperature and precipitation, and is the most widely used database for biogeographic and bio-ecological studies (Nix, 1986; Hijmans et al., 2005; Kumar and Stohlgren, 2009).

These bio-variables reveal trends in the general climate, seasonality and extremity; they can offer significant biological insights when trying to identify species' ecological and physiological scopes. Given this, they can hold greater significance in the case of insects more sensitive to temperature changes than monthly data. Of the 19 variables, the final six variables (Table 1) were selected based on the correlation between major analysis results and variables considering the occurrence of multicollinearity, and on ecological characteristics of target species. This study used ArcGIS 10.2 to convert data into the final file format (*.asc).

This study applies RCP scenarios from the 5th IPCC Report and divides them into analyses of the year 2050 (2041-2060) and the year 2070 (2061-2080). Representative concentration pathway (RCP) scenarios are those offered by the IPCC, and suggest a total of four pathways that depending on the policy execution level. Scenarios are consistent descriptions of future situations and are mainly used for the evaluation of adaptation to climate change impact and vulnerability. This study compares the effects of habit distribution by alien species in both RCP 4.5, in which greenhouse emission reduction policies may have been substantially realized, and RCP 8.5, in which greenhouse emissions continue to increase at the current pace in absence of reduction policies.

Table 1. Environmental variables considered for the distribution models among the biological climate provided by worldclim

Climate variables	Description
Bio3	Isothermality (bio2/bio7)(*100)
Bio6	Min temperature of coldest month (℃)
Bio10	Mean temperature of warmest quarter (℃)
Bio12	Annual precipitation (mm)
Bio14	Precipitation of driest month (mm)
Bio18	Precipitation of warmest quarter (mm)

Model selection

To identify potential inhabitation spread of *H. postica* due to climate change, this study used an algorithm with the MaxEnt model (version 3.3.3k)(Phillips et al., 2006). As the MaxEnt model enables a prediction based on appearance information of the species, it is widely used in various disciplines including environment, ecology, and geology due to its usability, statistical excellence, and ease of interpretation (Phillips et al., 2006; Seo et al., 2008; Flanklin, 2009). The model determines the maximum entropy distribution and assesses the odds of existence of the species based on appearance records and randomly created background points, and uses the normalization of parametric variables to control overfitting. Continuous and categorical variables can be used as environmental variables, and distribution probability is a continuous set of numbers from 0 to 1, used to evaluate the fitness of a form.

In this study, the *k*-fold cross-validation resampling method was repeatedly conducted 10 times to increase the statistical reliability of the MaxEnt model (Thuiller, 2003; Merow et al., 2013). The appropriateness of inhabitation which is the output of the MaxEnt model, is expressed with a set of continuous numbers from 0 to 1. In the case of possible inhabitation areas, spatial range classification is based on the threshold point where the appearance predictability (sensitivity) coincides with the non-appearance predictability (specificity).

Accuracy evaluation

Prediction accuracy of the model was evaluated by using the area under curve (AUC) of the receiver operating characteristic (ROC) that was frequently used for assessment of species distribution models (Hanley and McNeil, 1983). The ROC curve is a graph revealing sensitivity and specificity simultaneously, and the AUC value is an independent measure of the threshold value for a model's ability to distinguish non-appearance or background from appearance. An AUC value of 0.9-1 means a very high performance, 0.7-0.9 means a reasonable performance, and close to 0.5 is considered to have a low performance (Thuiller, 2003; Peterson et al., 2011).

In terms of the main variables of the model, their relative significance was measured through variable contribution and jackknife tests. The analysis of variable contributions shows the predictive contribution percentage each variable contributes to the model, while the jackknife tests identify the most important variables by running a test for each variable in isolation and comparing it to all of the variables (Dowling, 2015). The response curves of the variables were used to determine a relationship between bio-climatic variables and the appearance probability of target species.

Results

Model verification and major variables

Verification of the model was evaluated by using the AUC of the ROC curve. At the current temperature, the AUC was recorded at 0.770, with the standard deviation estimated at 0.057. In future climate models, similar values were measured, as the AUC values were respectively estimated at 0.766, 0.770, and 0.753 (Table 2).

The contribution level of the variables showed the effect of individual independent variables on the MaxEnt model prediction. In the current climate, the warmest quarter's mean temperature (bio10) and the coldest quarter's mean temperature (bio6) were the most powerful predictive factors, and their contribution levels were measured at 64.3% and 24.6%, respectively (Table 3). As for the jackknife test results, a higher gradient value was measured when only one variable, either bio10 or bio6, was used (Fig. 2). As for the curve for individual responses to different biological variables, the distribution probability of *H. postica* gradually increased with

Table 2. Results of area under the receiver operating characteristic curve and standard deviation

	Current	2050		2070	
		PCP 4.5	PCP 8.5	PCP 4.5	PCP 8.5
AUC	0.770	0.766	0.766	0.770	0.753
Standard deviation	0.057	0.078	0.094	0.089	0.068

Table 3. Relative contribution of different bioclimatic variables to the MaxEnt model for *H. postica* (%)

Classification	Current	2050		2070	
		PCP 4.5	PCP 8.5	PCP 4.5	PCP 8.5
Bio10	64.3	58.3	64.2	63.2	63.0
Bio6	24.6	27.1	23.6	23.9	21.1
Bio3	3.4	3.8	3.4	3.2	4.8
Bio14	3.3	2.9	2.8	3.0	4.8
Bio18	2.8	3.1	2.9	4.0	3.3
Bio12	1.6	4.7	3.1	2.7	4.8

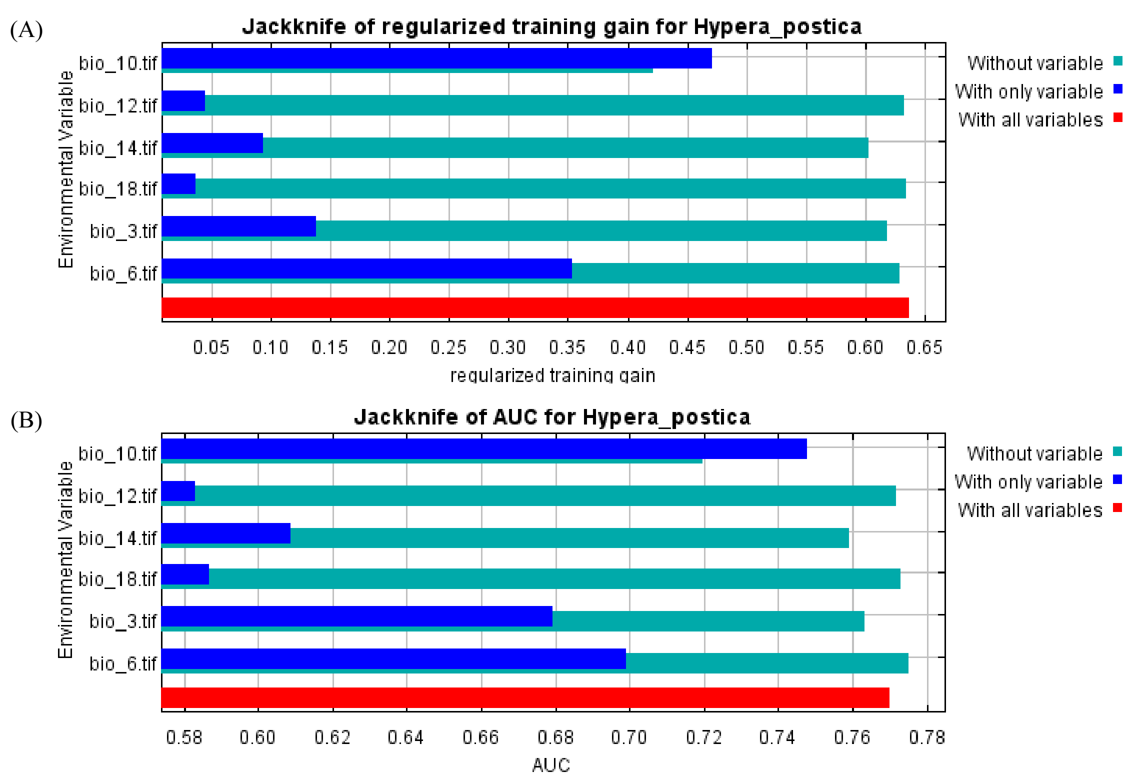

Fig. 2. Jackknife test of the individual environmental variable importance (blue bars) relative to all environmental variables (red bar) for the MaxEnt model. Values shown are averages over 10 replicate runs. Graphics show variable contributions to (a) regularized training gain, and (b) area under curve (AUC).

the temperature of the warmest quarter at 14℃, and sharply surged at a temperature of 20-25.5℃ (bio10; Fig. 3C), indicating that it had a higher correlation with the temperature than with the precipitation (Fig. 3).

Distribution of potential habitats of *H. postica*

According to the results of the model, the potential inhabitation areas of *H. postica* reveal high distribution probabilities when the mean temperature of the warmest quarter was 25.5℃ and when the lowest temperature of the coldest quarter was 5℃ (Fig. 3B, C). Results showed that high probabilities were recorded when yearly precipitation (bio12) were over 2,000 mm, when precipitation of the dry month (bio14) was more than 80 mm, and when rainfall of the warm quarter (bio18) was 700 mm (Fig. 3D, E, F). If one looked at the results after applying the threshold value, potential inhabitation areas account for 42,498.54 km^2, almost half size of South Korea.

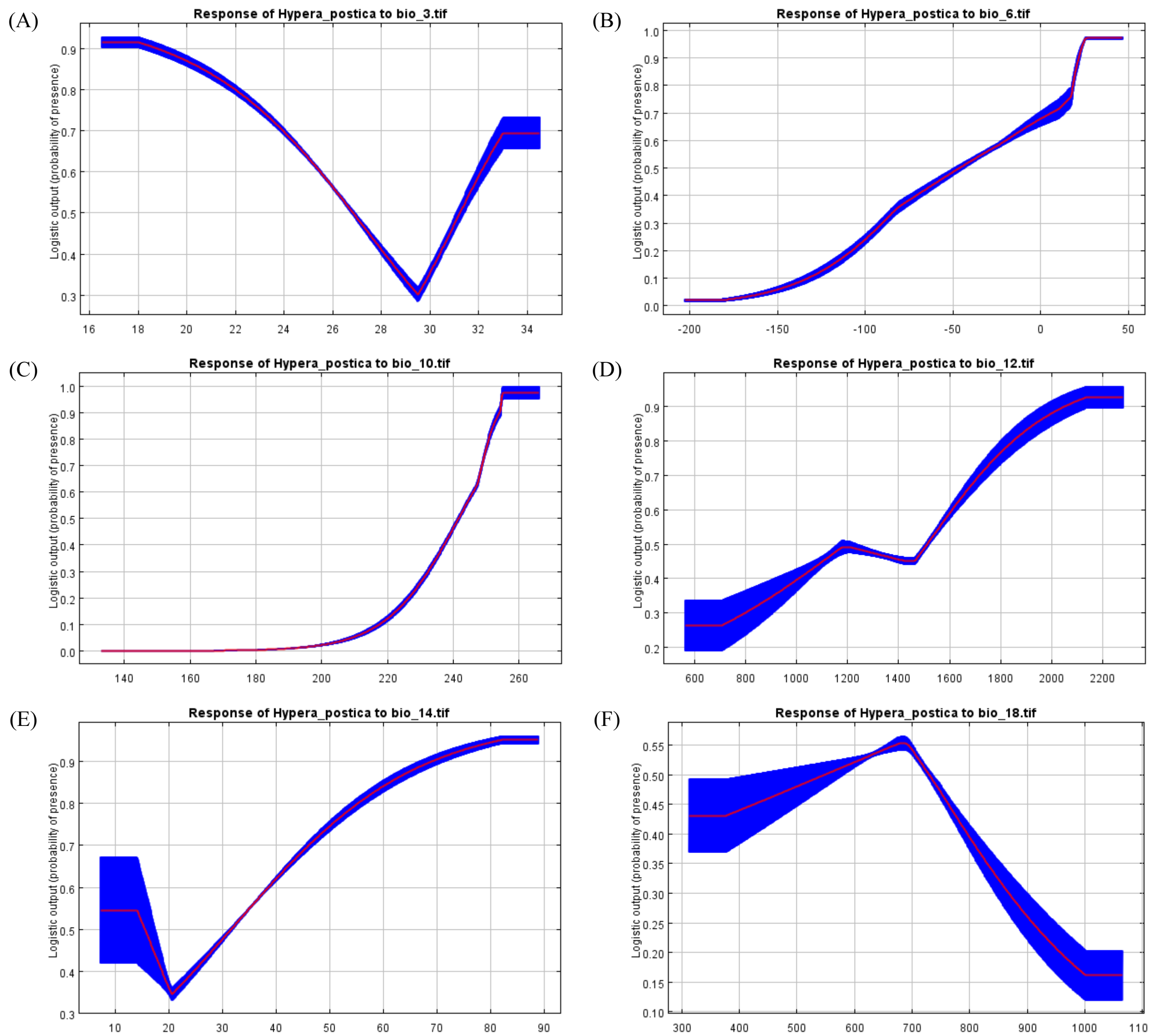

Fig. 3. Response curves for the variables related to the presence of *H. postica*. Red lines are mean values for the 10 runs of the MaxEnt model, and blue bars represent ±1 standard deviation. (A) isothermality (bio2/bio7)(bio3), (B) minimum temperature of coldest month (bio6), (C) mean temperature of warmest quarter (bio10), (D) annual precipitation (bio12), (E) precipitation of driest month (bio14), and (F) precipitation of warmest quarter (bio18).

Changes in future potential habitats of *H. postica*

Using climate models such as RCP 4.5 and RCP 8.5, this study produced predictions of the changes in future potential habitats of *H. postica* for the years 2050 and 2070 (Fig. 4). As a result of predicting the changes, if RCP 4.5 was applied, the potential habitat areas were projected to increase by 38,758.11 km^2 from the current level to 81,256.65 km^2 in the year 2050 (an almost 191% increase), and were expected to increase by 46,499.24 km^2 to 88,997.78 km^2 in the year 2070 (an almost 209% increase). In contrast, if RCP 8.5 was applied, the potential habitat areas were projected to increase by 47,303.2 km^2 from the current level to 89,801.75 km^2, in 2050 (an almost 211% increase) and were expected to increase by 54,006.0 km^2 to 96,504.54 km^2 in 2070 (an almost 227% increase). When the bioclimatic variable had high contribution level (bio10) a greater increase in temperature was predicted in RCP 8.5 than RCP 4.5, indicating a greater risk for habitat expansion.

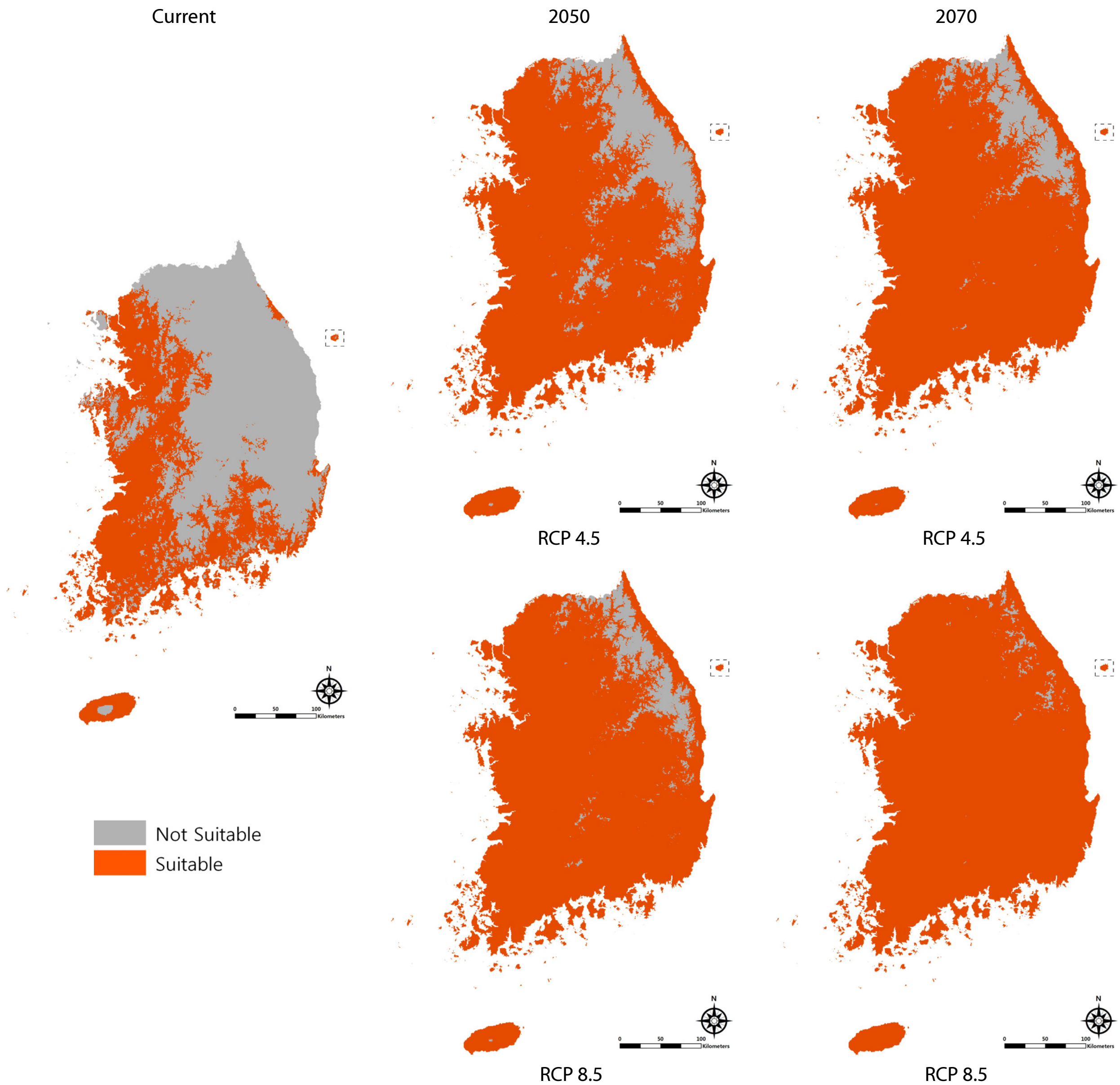

Fig. 4. Potential distribution and simulated MaxEnt of *H. postica*.

Discussion

This study analyzed the spread of *H. postica* habitat according to rising temperature. The MaxEnt model predicted that the habitat of *H. postica* would be the areas with the warmest average temperature of 25.5℃, the lowest coldest month with a minimum temperature of 3℃, and with annual precipitation (bio12) of 2,000 mm more. This model predicted that low latitude or low altitude areas had a high potential for habitation, and the 2050 and 2070 habitats were extended to the northeast according to the climate change scenarios (RCP 4.5, 8.5). This could be because of the current low temperatures in the coldest months (<3℃) in these areas, which are not optimal for *H. postica* growth. According to Zahiri et al. (2010), *H. postica* can grow at 11.5-36℃, but the survival rate decreases at both ends of the temperature range, and eggs do not hatch at 9℃ and 37℃. In addition, the relationship between the habitat of *H. postica* and temperature has been proved by observing that each growth stage takes a longer period of time as the temperature is lowered. Carey (1993) and

Enkegaard (1993) suggested the importance of understanding the effects of climate on insects, which is a limiting factor for the effective management of *H. postica*. Our country's temperature is expected to increase by 1.8-4.9℃ over the next 100 years due to the change in terrain. Given this, combined with the results of the present study, the distribution of *H. postica* throughout the whole country in concerning.

Performance of the SDM depends on the species characteristics, spatial resolution, and extent of the study area, as well as the choice of predictor variables (Guisan et al., 2007a, 2007b). Regardless of these and other conceptual and practical problems, SDMs are increasingly used to predict potential distributions of species of concern (Elith et al., 2010; Peterson et al., 2011) because resource managers need accurate maps of species distribution and abundance in order to perform risk analysis (Kumar and Stohlgren, 2009).

This study presents a preliminary map of the potential distribution of *H. postica* in South Korea using an SDM. The model was considered potentially useful, and temperature was found to be an important factor in determining the distribution. The MaxEnt model was successful in predicting the potential distribution of *H. postica* across the country, and confirmed the distributional change with climate change. The results of the study can be used to plan local and national management policies for pests with similar ecological characteristics as *H. postica*. Predicted maps can be used as a verifiable alternative for areas where alfalfa weevils are not distributed, and may be useful for planning and controlling the cultivation of green crops. It is also possible to understand the habitat change of invasive insects due to climate change and to find out potential distribution areas earlier, in order to respond quickly. Additionally, they can be used to establish sampling strategy and management ranking in future, which will help to prevent spread to vulnerable areas. However, there is a limit to habitat analysis studies such as model development using only climate data, because there is not enough information on the habitat and survival of the species under study.

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