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Changes in *Aporia crataegi's* potential habitats in accordance with climate changes in the northeast Asia

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Abstract

This study was conducted in an effort to provide important clues pertaining to the conservation and restoration of *Aporia crataegi* by identifying the spatial distribution characteristics of the current habitats, prospective habitats, and future habitats of *A. crataegi* in accordance with climate changes. To determine the distribution of *A. crataegi*, data from a total of 36 collecting points throughout South Korea, North Korea, China, Japan, Mongolia, and Russia are used. The spatial distributions of the data were examined through MaxEnt modeling. The distribution probability rates exceeded 75% at 18 locations among the 36 species occurrence locations, with Gangwon province showing the highest distribution probability in South Korea. The precision of the MaxEnt model was remarkably high, with an AUC value of 0.982. The variables that affect the potential distribution of *A. crataegi* by more than 10% are the degree of temperature seasonality, the amount of precipitation in the warmest quarter, the annual mean temperature, and the amount of precipitation in the driest month, in that order of importance. It was found that the future potential distribution area of *A. crataegi* continuously moves northward over time up to 2070s. In addition, the area of the potential distribution showing a habitable probability rate that exceeds 75% in northeast Asia was 28,492 km^2, where the area of potential distribution in the north part of Korean peninsula was 20.404 km^2 in size. Thus, it is anticipated that the most important future habitats of *A. crataegi* in the northeast Asia will be North and South Hamgyeong provinces and Ryanggang province near Mt. Baekdoosan in the northern area of the Korean peninsula.

Key words: *Aporia crataegi*, climate change, MaxEnt, endangered species, species conservation

INTRODUCTION

Aporia crataegi is a butterfly that belongs in the genus *Aporia* of the family Pieridae. They are widely found in orchards and bushes throughout most of Korea, Japan (Hokkaido), China, Mongolia, Russia, and Europe (Kim 2002, Park et al. 2012, 2013). *A. crataegi* appears between mid-May and mid-June in South Korea and between mid-June and early August in North Korea (Paek and Shin 2014). In Japan, their flight time in flatlands is mid-June while in mountain areas it is early July (Kawazoé and Wakabayashi 1998). There are records stating that this species had been observed in Gyonggi, North Chungcheong, and Gangwon provinces of South Korea; however, they are now found only in Ssangyong of Youngwol in Gangwon province (Park et al. 2013, Paek and Shin 2014). Thus, in Korea, *A. crataegi* is designated as an Endangered Species Level I. However, since 1997, none have been seen in South Korea, even in Ssangyong, Youngwol in Gangwon province (Park 2005).

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A. crataegi is a species that can be very easily found in countries neighboring Korea, such as China, Japan (Hokkaido), Mongolia, and Russia, and it is even considered as a pest in China (Jiang and Huang 2004). As stated above, however, *A. crataegi* is no longer found in Korea. The causes of the disappearance of *A. crataegi* in Korea include global warming, reckless catching activities in limited habitats, and a reduction of their habitat area (Choi and Kim 2012, Park 2005, Park et al. 2013). One important reason for the disappearance of *A. crataegi* in Korea is that there are fewer than 10 known habitats in the country (Paek and Shin 2010, Park et al. 2013). The other factors including global warming, i.e., the small habitable area, reckless catching activities and the fact that the central region of Korea—as the southern limit line of a northern butterfly—have synergistically worsened its habitable environment.

The annual mean temperature of Korea during the past century has increased by 1.7°C, which is significantly higher than the change in the global mean (0.74 ± 0.03°C). In addition, annual mean temperature is expected to rise at least another 2°C by 2050 (Korea Adaptation Center for Climate Change 2015), implying that *A. crataegi*, a species that is sensitive to environmental changes, will no longer inhabit Korea.

Thus, the purpose of this study is to provide important clues with regard to the preservation and restoration of *A. crataegi* in the northeast Asia by identifying the spa-

Table 1. Geographical information of *Aporia crataegi* in the northeast Asia

No.	Country	Province	Locality	Latitude	Longitude	Altitude (m)	Collected Date
1	S. Korea	Gangwon-do	Ssangyong-ri, Hanbando-myeon, Yeongwol-gun	37.16988889	128.3318889	264	1990 / 05 / 17
2	S. Korea	Gangwon-do	Changwon-ri, Nam-myeon, Yeongwol-gun	37.16831389	128.3662778	361	1986
3	N. Korea	Ryanggang-do	River Karim, 10km NEE from Bochonbo	41.52381944	128.3034444	1,100	1975 / 07 / 27
4	China	Jilin	He Long Shi, Yanbian	42.45152929	129.231224	553	2013 / 06 / 21
5	China	Jilin	He Long Shi, Yanbian	42.45147167	129.231235	554	2013 / 06 / 22
6	China	Jilin	An Tu Xian, Yanbian	42.34196328	129.595258	610	2013 / 06 / 22
7	China	Jilin	An Tu Xian, Yanbian	42.35577566	128.542585	1,033	2013 / 06 / 23
8	China	Jilin	An Tu Xian, Yanbian	43.11215908	128.463307	755	2013 / 06 / 23
9	China	Jilin	An Tu Xian, Yanbian	42.30515837	128.315663	894	2013 / 06 / 24
10	China	Jilin	Dun Hua Shi, Yanbian	43.83046289	128.574535	510	2013 / 06 / 23
11	China	Jilin	Dun Hua Shi, Yanbian	43.17486972	128.364841	684	2013 / 06 / 23
12	China	Jilin	Fu Song Xian, Baishan	42.21211689	127.579834	782	2013 / 06 / 24
13	Japan	Hokkaido	Chuo, Shimukappu-mura Yufutsu-gun	42.97826802	142.39835	353	2014 / 06 / 27
14	Japan	Hokkaido	Shimukappu, Shimukappu-mura Yufutsu-gun, Hokkaido	43.02785603	142.39866	380	2014 / 06 / 27
15	Japan	Hokkaido	Higashishikagoe, Minamifurano-cho Sorachi-gun	43.14864999	142.482932	362	2014 / 06 / 27
16	Japan	Hokkaido	Higashishikagoe, Minamifurano-cho Sorachi-gun	43.15928201	142.490876	354	2014 / 06 / 27
17	Japan	Hokkaido	Ikutora, Minamifurano-cho Sorachi-gun	43.17442602	142.518601	363	2014 / 06 / 28
18	Japan	Hokkaido	Nunobe Ishiwata, Furano-shi, Hokkaido	43.21772399	142.38605	241	2014 / 06 / 29
19	Japan	Hokkaido	Misawa, Biei-cho Kamikawa-gun	43.54598698	142.529609	322	2014 / 06 / 29
20	Japan	Hokkaido	Shirogane, Biei-cho Kamikawa-gun	43.46012201	142.639847	755	2014 / 06 / 29
21	Japan	Hokkaido	Fukiage, Kamifurano-cho Sorachi-gun	43.41396899	142.643205	1262	2014 / 06 / 29
22	Japan	Hokkaido	Niniu, Shimukappu-mura Yufutsu-gun	42.93298798	142.374065	371	2014 / 06 / 30
23	Japan	Hokkaido	Niniu, Shimukappu-mura Yufutsu-gun	42.90983398	142.370293	420	2014 / 06 / 30
24	Japan	Hokkaido	Hobetsu Inasato, Mukawa-cho Yufutsu-gun	42.91742303	142.119692	366	2014 / 06 / 30
25	Mongolia	Arkhangai	Tsenkher	47.15085278	101.7375028	1948	2010 / 07 / 03
26	Mongolia	Arkhangai	Tsetserleg	47.50724444	101.415575	1913	2010 / 07 / 03
27	Mongolia	Bulgan	Bayan-Agt	49.03473611	101.6477861	1684	2010 / 07 / 07
28	Mongolia	Hovsgol	Hatgal	50.53277778	100.1105778	1800	2010 / 07 / 06
29	Mongolia	Hovsgol	Hatgal	50.47085278	100.048075	1925	2010 / 07 / 06
30	Mongolia	Hovsgol	Ikh Uul	49.33668333	101.1897472	1214	2010 / 07 / 07
31	Mongolia	Selenge	Bayangol	48.64557222	106.0905778	1214	2010 / 07 / 08
32	Mongolia	Tov	Lun	47.87083333	105.2516667	1033	2010 / 07 / 02
33	Mongolia	Tov	Batsumber	48.26222222	106.8472472	1262	2013
34	Russia	Primorsky Kray		43.61279444	132.0038611	30	2008 / 06 / 24
35	Russia	Primorsky Kray	Kaymanovka	43.61213889	132.2361111	116	2008 / 06 / 25
36	Russia	Primorsky Kray	Khasansky-District between Zanadvorovka & Kravtsovka	43.03469444	131.5609444	0	2008 / 06 / 24

tial distributions of its current habitats, habitable areas, and future habitats. To do this, we assess the size and the current direction of this shifting distribution area, which changes in accordance with climate changes, by identifying climate factors that can be assumed to have the greatest impact on the habitats of *A. crataegi* and by developing current and future potential distribution models using only occurrence information pertaining to *A. crataegi*.

MATERIALS AND METHODS

Species data

Samples of *A. crataegi* were collected throughout northeast Asian countries that are adjacent to the Korean peninsula. Samples owned by individual persons were used for South Korean samples, and samples obtained through an exchange program between the National Institute of Biological Resources and the Hungarian Natural History Museum, which took place in 2010, were used for the North Korean samples. Additionally, data obtained from Google Earth were used for the coordinates and sea level altitudes of South and North Korea. Chinese samples were collected in Yanbian and Baishan of Jilin Province in 2013; Japanese samples were collected from Hokkaido in 2014; Mongolian samples were collected from Arkhangai, Bulan, Hovsgol, Selenge, and Tov in 2010 and 2013; and Russian samples were collected in Primorsky Kray in 2008. Except for North Korea and South Korea, the coordinate and altitude data of all other countries were measured at the time of collection. A total of 36 collection points were used for the analysis, and the collection points of each country were as follows: 2 in South Korea, 1 in North Korea, 9 in China, 12 in Japan, 9 in Mongolia, and 3 in Russia (Table 1).

Climate data

It is necessary to incorporate current and future climate data to predict and assess the change in the distribution of *A. crataegi* in accordance with climate change. The WorldClim website (http://www.worldclim.org) provided current climate data. The spatial resolution used by WorldClim is 30” (approximately 1 km), and this organization provides climate information for the entire planet through its use of thin-plate smoothing spline interpolation on climate data that were collected over a long period of time (1950-2000) (Hijmans et al. 2005).

The HadGEM-AO model data, from one of the many models of CIMP5, which use the Representative Concentration Pathway (RCP), as determined by the IPCC’s Fifth Assessment Report on the 2050s (2040-2060) and the 2070s (2060-2080), was used as the climate scenario to predict the future distribution of *A. crataegi* (http://www.worldclim.org).

To apply the data to the MaxEnt species distribution model, bioclimatic variables, which were converted to add more biological significance to the monthly mean temperatures and precipitations (Table 2), were used. These variables have been used often in a range of studies that attempt to predict the potential habitats of biological species through ecological niche models. These variables represent climate extremes such as annual tendencies of the annual mean temperature and the annual precipitation, the seasonality of annual ranges such as the annual mean temperature and the annual precipitation ranges, the mean temperatures of the coldest and the warmest months, and the temperatures of the driest and the most humid seasons by quarter.

Data analysis

MaxEnt modeling algorithms were used to predict the changes in the geographical distribution of the *A. crataegi* species in accordance with climate change (Phillips et al. 2006). The MaxEnt model is a popular machine-based learning method which utilizes geographical informa-

Table 2. List of bioclimatic variables used in the modeling

ID	Variable name	Units
BIO1	Annual Mean Temperature	°C
BIO2	Mean Diurnal Range (Mean of monthly (max temp - min temp))	°C
BIO3	Isothermality (BIO2/BIO7) (* 100)	%
BIO4	Temperature Seasonality (standard deviation *100)	%
BIO5	Max Temperature of the Warmest Month	°C
BIO6	Min Temperature of the Coldest Month	°C
BIO7	Temperature Annual Range (BIO5-BIO6)	°C
BIO8	Mean Temperature of the Wettest Quarter	°C
BIO9	Mean Temperature of the Driest Quarter	°C
BIO10	Mean Temperature of the Warmest Quarter	°C
BIO11	Mean Temperature of the Coldest Quarter	°C
BIO12	Annual Precipitation	mm
BIO13	Precipitation the Wettest Month	mm
BIO14	Precipitation the Driest Month	mm
BIO15	Precipitation Seasonality (Coefficient of Variation)	%
BIO16	Precipitation the Wettest Quarter	mm
BIO17	Precipitation the Driest Quarter	mm
BIO18	Precipitation the Warmest Quarter	mm
BIO19	Precipitation the Coldest Quarter	mm

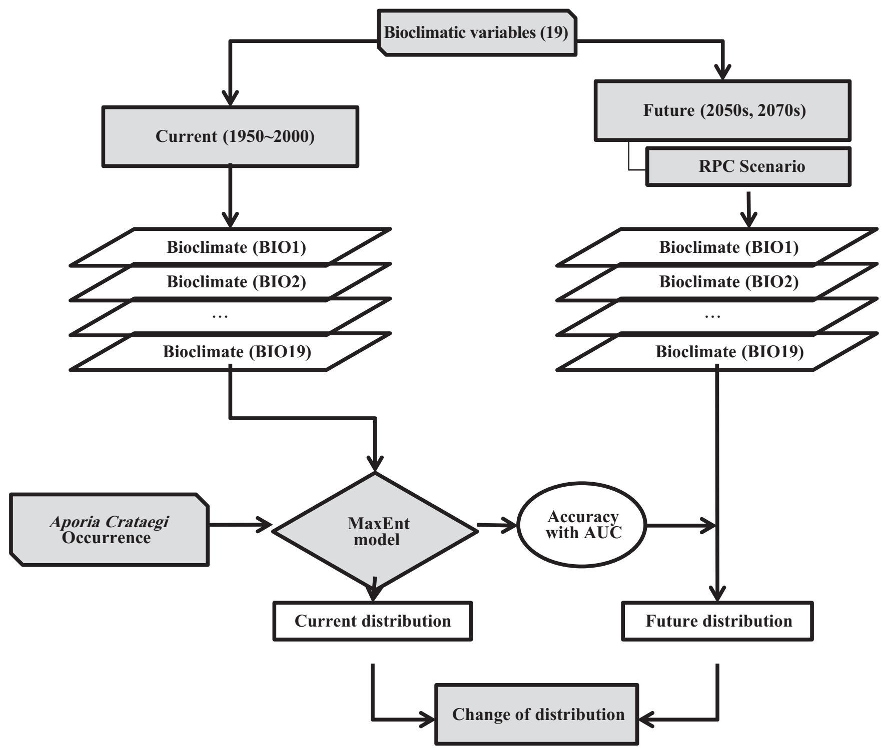

Fig. 1. Flow of this study.

tion pertaining to locations in which species are known to exist as input. The model then statistically presents locations, from among a list of research object locations, which possess environmental features similar to those of the locations where species are known to exist at the time of input (Phillips et al. 2006). This model has high predictive accuracy compared to other models which only utilize presence information, and its superiority has been proven through numerous previous studies. Another advantage is that it is possible to develop a useful model by utilizing only a small number of datasets, such as spatial errors related to location data and five given points (Baldwin 2009).

In order to predict changes in the habitable zones of *A. crataegi*, the subject of this study, we assessed changes in potential habitable areas of *A. crataegi* by applying current and future climate data provided by WorldClim to the MaxEnt model based on the statistical correlations between the location data collected at each site and the corresponding climatic variables. First, we analyzed the current potential distribution zones of *A. crataegi* using the MaxEnt model based on 19 bioclimatic variables of which the spatial resolution, created after applying interpolation of the meteorological data observed between 1950 and 2000, is approximately 1 km. Then, we predicted future potential distribution zones, using the RPC meteorological scenario data for the 2050s and 2070s based on HadGEM-AO models (Fig. 1). The resulting distribution map was then cross-analyzed to assess the direction and range of changes in the current and future potential distribution zone of *A. crataegi*.

The model's explanatory power was validated by using the area under the curve of the receiver operating characteristic (ROC). Jackknife validation was used to validate the importance of the climatic variables which affect the potential habitats predicted as a result of the model simulation (Phillips et al. 2006). The programs used for the analysis of the distribution changes were MaxEnt ver. 3.3.3k (Phillips et al. 2006) and ArcGIS ver. 10.0 (ESRI 2011). Additionally, R-3.1.1 (http://www.R-project.org/) was used for the statistical analysis.

RESULTS AND DISCUSSION

Prediction of the current potential distribution zone of *Aporia crataegi*

Current potential distribution zone of *Aporia crataegi*

The results, obtained through a prediction method

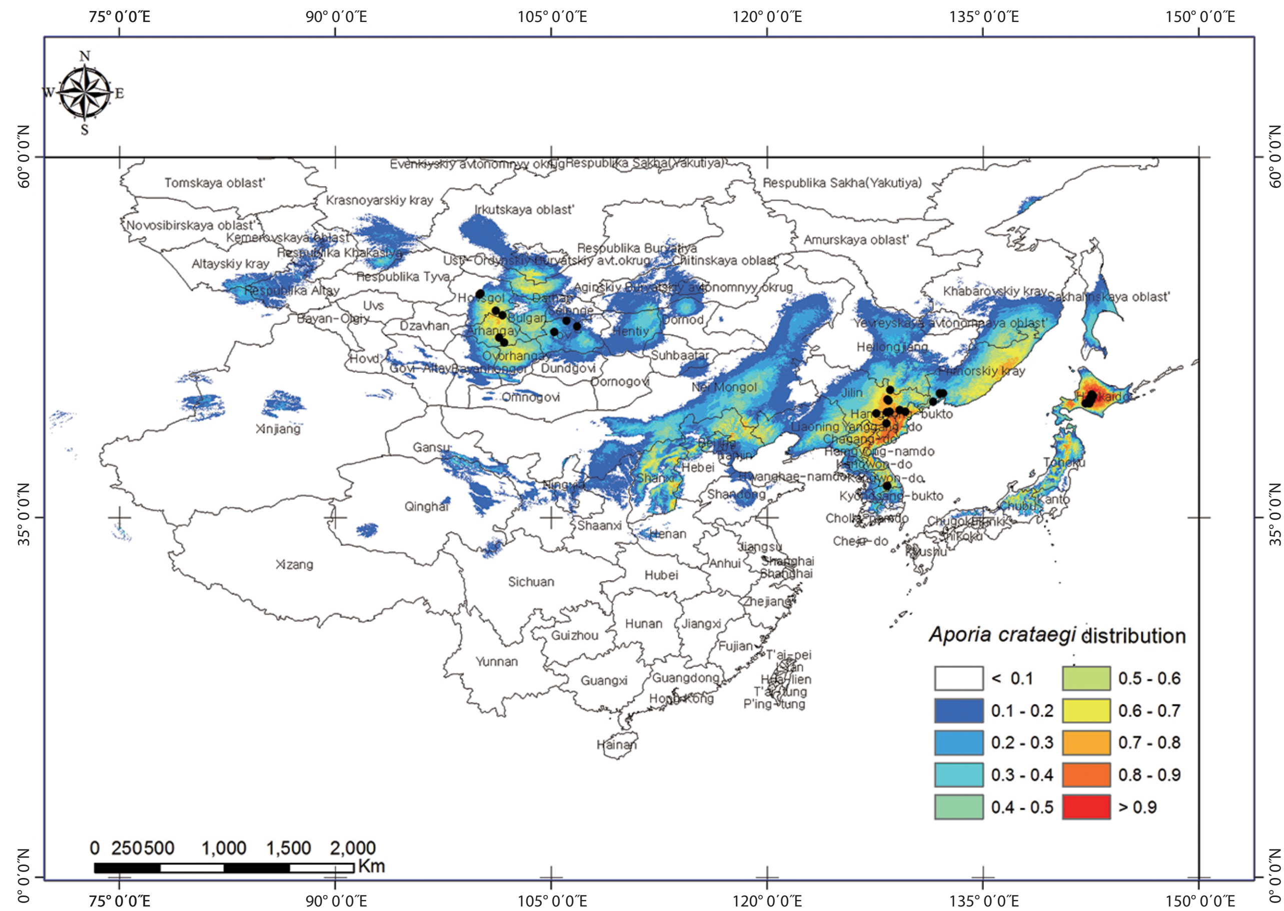

Fig. 2. Current potential distribution of *Aporia crataegi* in the northeast Asia. The black spots (•) show the sampling site.

with 19 bioclimatic variables applied to the MaxEnt model, showed that 18 of the 36 presence locations had a probability above 75%; 26 locations showed a rate that was 50% or higher and 32 locations had a rate that was 25% or higher (Fig. 2). In South Korea, locations with probability rates of 75% or higher were limited to Gangwon province, whereas in North Korea, they were concentrated in Ryanggang, Jagang, and Hamgyeong provinces. In China, they were concentrated in the Jilin area, neighboring North Korea, including Liaoning, Chengde, and Shaanxi. Hokkaido had the highest probability in Japan, and it appeared that *A. crataegi* inhabited mostly the western region of Japan, from Tohoku to Chubu. Also, it was found that the probability was high in the regions north to Arhangay in Mongolia and Primorsky Kray in Russia. The probability of the presence *A. crataegi* in the 36 investigated regions ranged from 15% in Khovsgol and Tov of Mongolia to 90% on the border of China and North Korea, and Hokkaido in Japan.

Evaluation of model accuracy

The area under the curve (AUC) of the receiver operating characteristics (ROC) curve, which evaluates the MaxEnt model's predictive accuracy, indicates 1.0 if the predictive accuracy is perfect, with a minimum value of 0.5. The MaxEnt model as used here is considered to be significant when the AUC value exceeds 0.7 (Phillips and Dudik 2008). The AUC value of the MaxEnt model here was 0.982; in other words, the model will be effective when applied. In fact, the data obtained from the Global Biodiversity Information Facility (GBIF) shows that the probabilities of the presence of *A. crataegi* in Liaoning, Shanxi, Shaanxi, Sichuan, Sichuan, Gansu of China and Khabarovsk and Irkutsk of Russia ranged from 20 to 80%. This finding was in good agreement with the predictions made by the MaxEnt model used in this study. In Korea and Japan, however, it appeared that there was a large gap between the current distributions and the predictions. It is known that *A. crataegi* currently inhabits only Gangwon

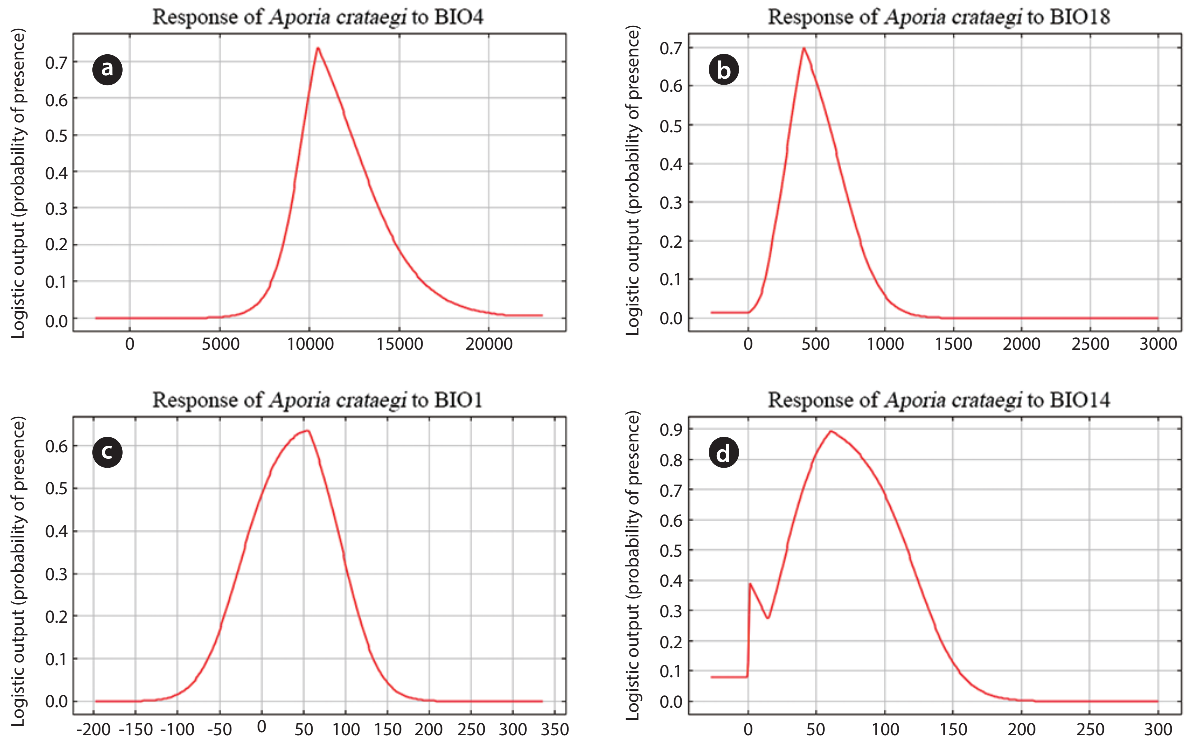

Fig. 3. Four important factors affecting the potential distribution of *Aporia crataegi* in northeast Asia: (a) BIO4 (Temperature Seasonality, standard deviation × 100), (b) BIO18 (Precipitation during the Warmest Quarter), (c) BIO1 (Annual Mean Temperature), and (d) BIO14 (Precipitation during the Driest Month).

province (Kim 2002), but the prediction included portions of South Jeolla province and South Gyeongsang province as well. Also, it is known that *A. crataegi* inhabits only Hokkaido in Japan (Kawazoé and Wakabayashi 1998). However, the predictions showed that the distribution zone included regions in Chugoku. However, we conclude that the predictive results of the MaxEnt model can be trusted, especially considering that Seok (1937) reported that *A. crataegi* inhabited Gyeongju in North Gyeongsang province and Mt. Mudeungsan in South Jeolla province. In addition, one record by Gorbunov (2001) extended the distribution zone to the 35° north latitude line, i.e., the temperate area of Asia.

Evaluation of importance of variables

Among the 19 variables, BIO1 to BIO19, which affect the potential distribution of *A. crataegi*, it was found that BIO6, BIO8, BIO10, BIO11, and BIO15 had no effects whatsoever (Table 3). The variables BIO4, BIO18, BIO1 and BIO14 had impacts that exceeded 10%, while the rest had impacts that were below 5.3%. The variables that had impacts higher than 10% were as follows, in the order of significance: 1) BIO4 (Temperature Seasonality): 25.9% (calculated by the deviations in the monthly mean temperatures), 2) BIO18 (Precipitation in the Warmest Quarter): 21.3%, 3) BIO1 (Monthly Mean Temperature): 12.7%, and 4) BIO14 (Precipitation in the Driest Month): 12.2% (Table 3).

For the variable BIO4, which is the deviations in the monthly mean temperatures, the probability was highest at 73.7% in the regions where the deviation was 10.4°C. This result shows that the probability of the presence of *A. crataegi* is above 50% in regions where the temperature deviations were between 9.6°C and 12.3°C (Fig. 3a).

Table 3. The descriptive statistics of bioclimatic variables

Variable	Percent contribution	Variable	Percent contribution
BIO4	25.9	BIO19	1.6
BIO18	21.3	BIO7	1.1
BIO1	12.7	BIO12	0.8
BIO14	12.2	BIO17	0.6
BIO13	5.3	BIO15	0
BIO9	4.9	BIO8	0
BIO16	4	BIO10	0
BIO3	3.7	BIO11	0
BIO5	2.9	BIO6	0
BIO2	2.8		

For BIO18, the precipitation during the warmest quarter (a three-month period), the probability of the presence of *A. crataegi* was approximately 70% in regions where the precipitation was around 400 mm. It was also greater than 50% in regions where the precipitation ranged from 315 mm to 590 mm (Fig. 3b). For BIO1, the annual mean temperature, the probability of the presence of *A. crataegi* was the highest at 64% in the regions where the value was 5.5°C (Fig. 3c). For BIO14, the amount of precipitation during the driest month, the probability of the presence of *A. crataegi* was nearly 90% when the precipitation amount was approximately 65 mm. The rate was 50% when the precipitation amount was between 30 mm and 115 mm (Fig. 3d).

Changes in the *Aporia crataegi* distribution in accordance with climate change

We divided the changes in the potential habitable zones of *A. crataegi* in northeast Asia into four levels according to the probability of its presence. These four levels are labeled here as Low (0-0.25), Medium (0.25-0.5), High (0.5-0.75), and Very High (0.75-1) based on the probability of the presence of *A. crataegi* as presented by Chefaoui et al. (2005) and Santos et al. (2009).

Compared to the current potential habitable zones, the future potential habitable zones were expanded in 13% of the regions and reduced 60% of the regions, with 26% of the regions showing no changes by 2050. The future potential habitable zones expanded in the Primorsky, Khabarovsk, and Sakhalin regions of Russia were reduced in the neighboring regions between North Korea and China; Hokkaido in Japan; and the Chengde, Shanxi, Shaanxi, Sichuan, and Gansu regions of China (Fig. 4). Also, the future potential habitable zones for the 2070s were expanded in 20% of the regions, reduced in 66% of the regions, and remained the same in 14% of the regions. The future potential habitable zones expanded in the Primorsky, Khabarovsk, and Sakhalin regions of Russia and Heilongjiang in China were reduced in the neighboring regions between North Korea and China; Hokkaido in Japan; and the Chengde, Shanxi, Shaanxi, Sichuan, and Gansu regions of China (Fig. 4). Specifically, it was noted that the habitable zones with a high probability of the presence of *A. crataegi* largely disappear in Hokkaido. The final results show that *A. crataegi*'s potential distribution zones with a high probability of the presence of *A. crataegi* continuously move northward with time up to the 2070s. This northward movement was more apparent in Russia than in China or Japan.

Table 4. Changes in the potential distribution area (km^2) of *Aporia crataegi* in northeast Asia

Country	Suitability Class		Current	2050s	2070s
Northeast Asia	Low	<25%	41,375,049	42,350,309	42,407,096
	Medium	25-50%	1,422,648	705,338	760,377
	High	50-75%	653,205	462,057	380,636
	Very High	>75%	124,107	58,897	28,492
Korean Peninsula	Low	<25%	122,339	220,762	251,874
	Medium	25-50%	74,422	39,361	23,740
	High	50-75%	76,769	29,447	24,951
	Very High	>75%	47,717	31,399	20,404
China	Low	<25%	12,778,494	13,408,764	13,424,448
	Medium	25-50%	646,986	201,805	218,923
	High	50-75%	223,020	51,306	24,311
	Very High	>75%	23,266	9,221	3,414
Japan	Low	<25%	318,344	393,130	479,112
	Medium	25-50%	89,342	70,200	31,564
	High	50-75%	67,455	43,276	11,760
	Very High	>75%	49,734	17,537	1,707
Mongolia	Low	<25%	2,244,329	2,405,206	2,457,880
	Medium	25-50%	290,979	148,377	118,440
	High	50-75%	121,278	103,003	80,266
	Very High	>75%	0	0	0
Russia	Low	<25%	10,256,153	10,267,011	10,137,151
	Medium	25-50%	307,432	239,020	362,275
	High	50-75%	163,822	234,713	239,091
	Very High	>75%	3,385	740	2,967

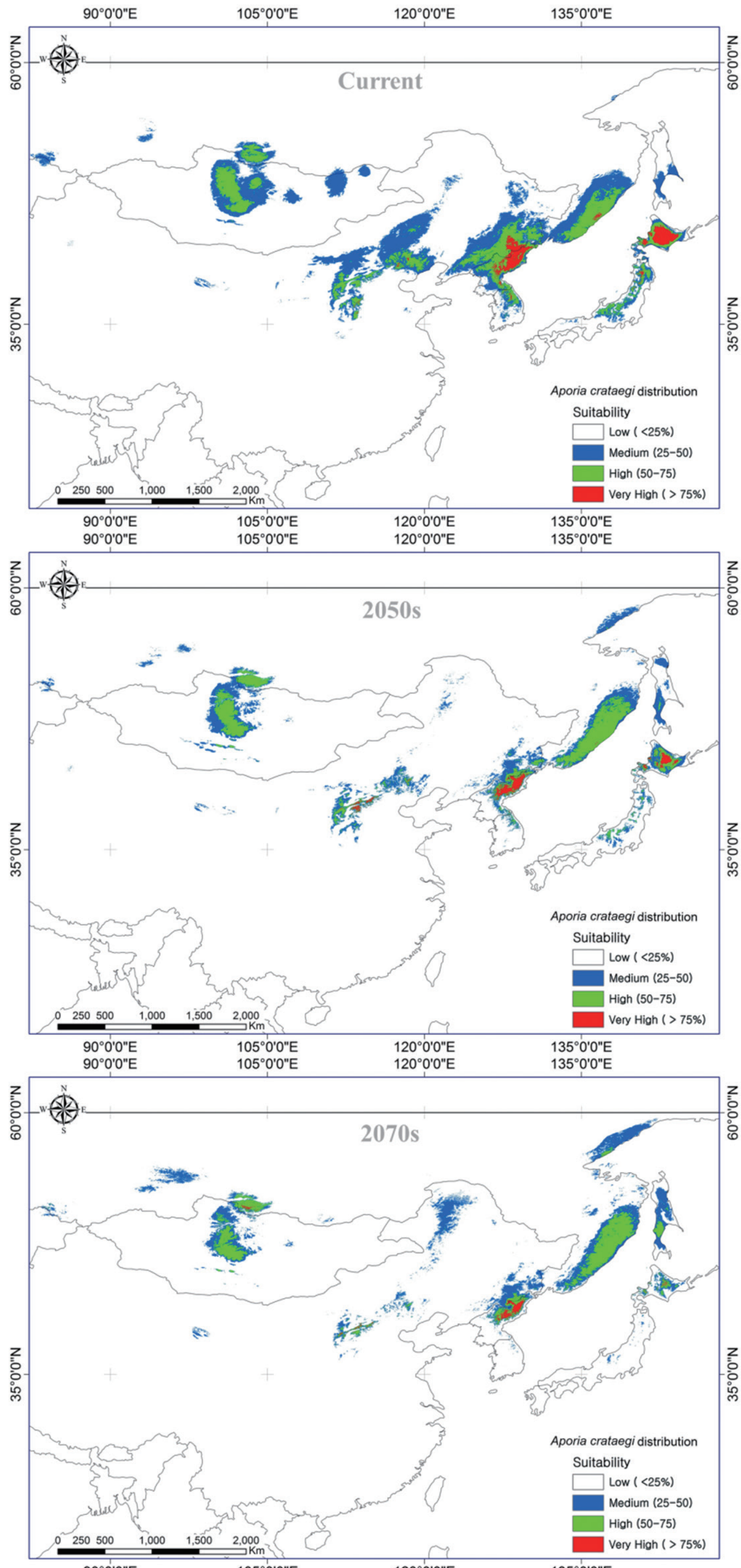

Fig. 4. Simulated geographic distribution of *Aporia crataegi* in the northeast Asia using the MaxEnt model (Current → 2050s → 2070s).

Compared to the current habitable zones, the zones with probabilities lower than 25%, in other words the 'Low' zones, appeared to increase slightly, whereas the Medium, High, and Very High zones decrease overall in the 2050s and 2070s (Table 4). The Very High zones, with 75% or above probabilities throughout northeast Asia will dramatically reduce to 58,897 km^2 in size by the 2050s and 28,492 km^2 in size by the 2070s, from 124,107 km^2 at present. Especially in Japan, the total Very High zone area in Hokkaido is currently 49,734 km^2, but it will be reduced to 1,707 km^2 by the 2070s. In Russia, however, the area of the High zones, with probabilities between 50-75%, will increase to 239,091 km^2 from 163,822 km^2, while the area of the Very High zones with probabilities above 75% will decrease only slightly, from 3,385 km^2 to 2,967 km^2 in 2070s.

The area of the Very High zones with probabilities above 75% in 2070s for all of northeast Asia is expected to be 28,492 km^2, of which 20.404 km^2, accounting for 71.6%, will be located in the region north of the Korean peninsula. Thus, it is expected that *A. crataegi* will be found most abundantly in the Hamgyeong province and the Ryanggang province near Mt. Baekdoosan in the northern regions of the Korean peninsula.

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LITERATURE CITED

Boldwin RA. 2009. Use of maximum entropy modeling in wildlife research. Entropy 11: 854-866.

Chefaoui RM, Hortal J, Lobo JM. 2005. Potential distribution modelling, niche characterization and conservation status assessment using GIS tools: a case study of Iberian *Copris* species. Biol Conserv 122: 327-338.

Choi SW, Kim SS. 2012. The past and current status of endangered butterflies in Korea. Entomol Sci 15: 1-12.

ESRI. 2011. ArcGIS Desktop: Release 10. Environmental Systems Research Institute (ESRI), Redlands, CA.

Gorbunov PY. 2001. The butterflies of Russia: classification, genitalia, keys for identification (Lepidoptera: Hesperioidea and Papilionoidea). PhD Dissertation. Institute of Plant and Animal Ecology, Russian Academy of Sciences, Ekaterinburg, Russia.

Hijmans RJ, Cameron SE, Parra JL, Jones PG, Jarvis A. 2005. Very high resolution interpolated climate surfaces for global land areas. Int J Climatol 25: 1965-1978.

Jiang T, Huang R. 2004. A preliminary investigation of damage in forest by *Aporia crataegi* and *Nymphalis xanthomelas* in Xinjing. Entomol Knowl 41: 238-240.

Kawazoé A, Wakabayashi M. 1998. Colored Illustrations of the Butterflies of Japan. Hoikusha, Higashiosaka. (in Japanese)

Kim YS. 2002. Illustrated Book of Korean Butterflies in Color. Kyo-Hak Publishing, Seoul. (in Korean)

Korea Adaptation Center for Climate Change. 2015. Korea's future climate. http://ccas.kei.re.kr/english/menu_1_2.do. Acessed 25 January 2015.

Paek M, Shin Y. 2010. Butterflies of the Korean Peninsula. Nature and Ecology, Seoul. (in Korean)

Paek M, Shin Y. 2014. Guide Book of Butterflies in Korean Peninsula. Nature and Ecology, Seoul. (in Korean)

Park HC. 2005. Endangered plants and animals: insect 4: *Aporia*. http://www.hani.co.kr/arti/society/environment/85300.html. Accessed 07 December 2005. (in Korean)

Park HC, Han T, Kang TW, Yi DA, Kim SS, Lee YB. 2013. DNA barcode analysis for conservation of an endangered species, *Aporia crataegi* (Lepidoptera, Pieridae) in Korea. J Seric Entomol Sci 51: 201-206.

Park JS, Cho Y, Kim MJ, Nam SH, Kim I. 2012. Description of complete mitochondrial genome of the black-veined white, *Aporia crataegi* (Lepidoptera: papilionoidea), and comparison to papilionoid species. J Asia-Pac Entomol 15: 331-341.

Phillips SJ, Anderson RP, Schapire RE. 2006. Maximum entropy modeling of species geographic distributions. Ecol Model 190: 231–259.

Phillips SJ, Dudik M. 2008. Modeling of species distributions with Maxent: new extensions and a comprehensive evaluation. Ecography 31: 161-175.

Santos X, Brito JC, Caro J, Abril AJ, Lorenzo M, Sillero N, Pleguezuelos JM. 2009. Habitat suitability, threats and conservation of isolated populations of the smooth snake (*Coronella austriaca*) in the southern Iberian Peninsula. Biol Conserv 142: 344-352.

Seok DM. 1937. On the butterflies collected in Is. Quelpart, with the description of a new subspecies. Zephyrus 7: 150-174.