JOURNAL OF
ECOLOGY AND ENVIRONMENT
http://www.jecoenv.org

Research Paper
J. Ecol. Environ. 38(3): 327-334, 2015

Changes in *Biston robustum* and *Camellia japonica* distributions, according to climate change predictions in South Korea

Tae Guen Kim[1†], Yong-Gu Han[2, 3†], Jong Chul Jeong[1], Youngjin Kim[1], Ohseok Kwon[2, 3], Youngho Cho[2, 3,*]

[1]National Park Research Institute, Wonju 220-947, Korea
[2]School of Applied Biosciences, College of Agriculture and Life Sciences Kyungpook National University, Daegu, 702-701, Korea
[3]Institute for Phylogenomics and Evolution, Kyungpook National University, Daegu, 702-701, Korea

Abstract

We investigated the current and potential spatial distributions and habitable areas of *Biston robustum* and *Camellia japonica* in South Korea in order to provide useful data for the conservation of *C. japonica* and minimize the damage caused by *B. robustum*. It was predicted that, by 2070, although *B. robustum* would be widely distributed throughout the Korean Peninsula, except for the western and eastern coastal areas, it would be narrowly distributed along the Sokcho-si and Goseong-gun coastlines in Gangwon Province. *C. japonica* is currently located along the southern coastline but its critical habitable area is predicted to gradually disappear by 2070. Assessment of the potential distribution probabilities of *B. robustum* and *C. japonica* revealed that the area under the curve (AUC) values were 0.995 and 0.991, respectively, which indicate high precision and applicability of the model. Major factors influencing the potential distribution of *B. robustum* included precipitation of wettest quarter and annual precipitation (BIO16 and BIO12), whereas annual mean temperature and mean temperature of wettest quarter (BIO1 and BIO8) were important variables for explaining *C. japonica* distribution. Overlapping areas of *B. robustum* and *C. japonica* were 11,782 km^2, 5447 km^2, and 870 km^2 for the current, 2050-predicted, and 2070-predicted conditions, respectively, clearly showing a dramatic decrease in area. Although it is predicted that *B. robustum* would cause continuous damage to *C. japonica* in the southern part of the Korean Peninsula, such impacts might diminish over time and become negligible in the future.

Key words: *Biston robustum*, *Camellia japonica*, climate change, MaxEnt, species conservation

INTRODUCTION

Biston robustum belongs to the family Geometridae and it is widely distributed throughout the Korea Peninsula; it also inhabits other countries, including Japan, China, Russia, Taiwan, and Vietnam (Jiang et al. 2011, Shin 2001). *B. robustum* imagoes are found twice a year (April through May and June through July) and cause the most severe damage to plants in July (Korea Forest Service 2015). Plants in Korea that *B. robustum* feed upon include *Cornus controversa*, *Quercus acutissima*, *Rhododendron mucronulatum*, *Prunus serrulata* var. *spontanea*, *Pueraria lobata*, and *Cinnamomum camphora* (Shin 2001). In Japan, *Malus pumila*, *Pyrus pyrifolia* var. *culta*, *Urtica thunbergiana*, *Quercus serrata*, *Quercus acutissima*, *Castanea crenata*, *Eurya japonica*, *Prunus serrulata* var. *spontanea*, *Camellia sinensis*, *Cornus controversa*, *Camellia japonica*, *Acer palmatum*, *Rosa multiflora* are the known

http://dx.doi.org/10.5141/ecoenv.2015.033

Received 11 May 2015, **Accepted** 4 June 2015

***Corresponding Author**
E-mail: themoth05@gmail.com
Tel: +82-53-950-5762

†These authors contributed equally to this paper.

food plants for *B. robustum* (Esaki et al. 1999). Globally, *B. robustum* has been known to cause damage to more than 30 plant species belonging to the families Theaceae, Caprifoliaceae, Aceraceae, Lardizabalaceae, Cornaceae, Fagaceae, Seguminosae, and Rosaceae; plants belonging to Rosaceae and the genus *Prunus* are the major food plants for *B. robustum* (Natural History Museum 2015). This polyphagous insect has been reported to damage 57 plant species in and around the Geomundo-area of South Korea (Park et al. 2005).

After the first major outbreak of *B. robustum* in 1989 near Soowoel Mountain in the Dadohaehaesang National Park of Korea (Jeollanam province Yeosu-si, Samsan-myeon Geomun-ri), significant damage to plants was reported within the same area in 2003 and 2004 (Park et al. 2005). Prior to this, non-periodic damage was often reported, resulting in flowerless trees or a weakening of tree vigor (Park et al. 2005). Although *B. robustum* is polyphagous, non-periodic outbreaks on a specific tree (i.e., *C. japonica*) have occurred, likely due to the reckless lumbering of the evergreen broad-leaved forest around *C. japonica* to obtain camellia flowers; this also led to reduction in species diversity (Park et al. 2005). In case of the bark beetle, which causes serious damages to forests worldwide, multiple studies have shown cascading changes in forest species compositions and diversities as well as increasing tree mortality as a result of decreasing forest structural complexity (Veblen et al. 1991).

Temperature may directly influence insect ontogenetic development, survival, and reproduction, and indirectly affect generation time and population growth rate (Nelson et al. 2013). Thus, temperature is one of the critical factors determining the timing of major insect outbreaks. Over the last century, the annual mean temperature of Korea has increased by 1.7°C, and is expected to further rise by 2°C by 2050 (Korea Adaptation Center for Climate Change 2015). Therefore, the habitat of *C. japonica* may not be limited to the southern part of the peninsula, and widespread, continuous damages by *B. robustum* can be expected. Therefore, it is particularly important to investigate interactions between *B. robustum* and *C. japonica* because there are more than 20 natural monuments (Cultural Heritage Administration of Korea 2015) and monuments designated by cities/provinces in South Korea that may be consistently affected by *B. robustum*. We investigated the current and potential spatial distributions and habitable areas of *B. robustum* and *C. japonica* in South Korea in order to provide useful data for the preservation of *C. japonica* and minimize damage caused by *B. robustum*. To accomplish this, we (1) identified the most influential climate factors for predicting the potential distribution of *B. robustum* and *C. japonica* and (2) measured the overlapping areas of the distribution of these two species under the current, 2050-predicted, and 2070-predicted climatic conditions.

MATERIALS AND METHODS

Species data

B. robustum data were collected from 45 points (Fig. 1a), and data obtained from the Global Biodiversity Information Facility (GBIF) until 2014 were used for further analyses. A total of 177 data collection points were used for the analyses of *C. japonica* (16 points from Lee and Yim 2002), 122 points from the Korea Biodiversity Information System, and 39 points from the Cultural Heritage Administration) (Fig. 1b). Data with uncertain collection information were not used. Representative coordinates were obtained from Google Earth.

Climate data

Current and future climate data were needed to predict and assess climate change induced changes in *B. robustum* and *C. japonica* distributions. The WorldClim website (http://www.worldclim.org) provided current climate data. The spatial resolution used by WorldClim is 30” (approximately 1 km^2). This organization provides climate information for the entire planet through its use of thin-plate smoothing spline interpolation of climate data that were collected from 1950 to 2000 (Hijmans et al. 2005). Climate scenarios from the HadGEM-AO model (one of the many models of CIMP5), which uses the Representative Concentration Pathway (RCP), as determined by the IPCC’s Fifth Assessment Report on 2050 (2040–2060) and 2070 (2060–2080), were used to predict the future distribution of *B. robustum* and *C. japonica*.

Data analysis

To investigate changes in the distribution areas of *B. robustum* and *C. japonica*, we used the MaxEnt 3.3.3k (Phillips et al. 2006) species distribution model, which is based on maximum entropy algorithms. The MaxEnt species distribution is a machine-based learning method utilizing environmental characteristics of spatial information from areas where specific species are located. This model has been widely used in the ecological fields of biological

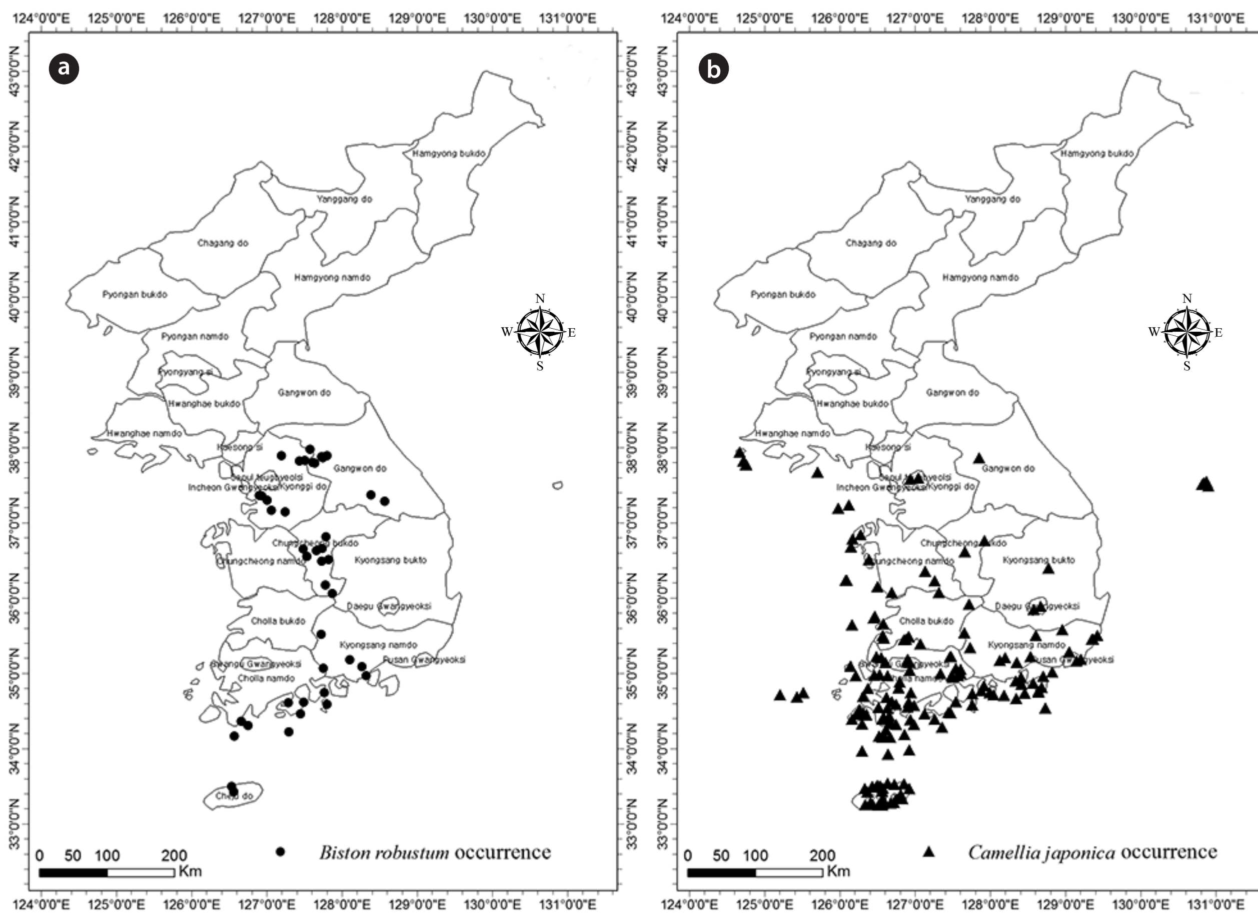

Fig. 1. Recorded locations for *Biston robustum* (a) and *Camellia japonica* (b).

geography and conservation biology (Phillips et al. 2006). The model compared the similarity of climate properties within the entire research area with climate properties in areas where *B. robustum* and *C. japonica* currently occur. A probability map of species distributions was created, ranging from 0 to 1, where the closer a value is to 1 the higher the likelihood that a species will be located in that area. The accuracy of the prediction model for *B. robustum* and *C. japonica* distribution areas was validated using the area under the curve of receiver operating characteristic (AUC of ROC). The Jackknife validation was then performed to validate the significance of the climatic variables that influence the predicted distribution areas (Phillips et al. 2006). The size and direction of changes in distribution areas, in response to climate changes, were evaluated by overlapping the current area with future areas. In order to map and analyze the effects of climate change on species distributions, ArcGIS 10.0 (ESRI, Redlands, USA) was used, and R-3.1.1 (http://www.R-project.org/) was used for the statistical analyses.

RESULTS

Prediction of current and potential future distribution area and size

Incorporation of bioclimatic variables into the MaxEnt model showed that *B. robustum* will be distributed throughout Jeollanam, Gyeongsangnam, Chungcheongnam, Chungcheongbuk, Gyeonggi, and Gangwon provinces in South Korea, except for the western and eastern coastal areas (Fig. 2a). All areas, except for a few areas in the western and eastern coasts, were predicted to be habitable zones for *B. robustum* by 2050 (Fig. 2b). The area was predicted to decrease in size and shift eastward by 2070 (Fig. 2c). The current critical habitable area of *B. robustum* (Very High: >75%; Table 1) includes part of Gyeonggi Province located south of Seoul, Wan Island of Jeollanam Province, as well as the islands of Bogil, Soan, Chungsan, Yeosu-si, Dolsan, and Geogeum (Fig. 2a). These critical habitable areas were predicted to expand throughout

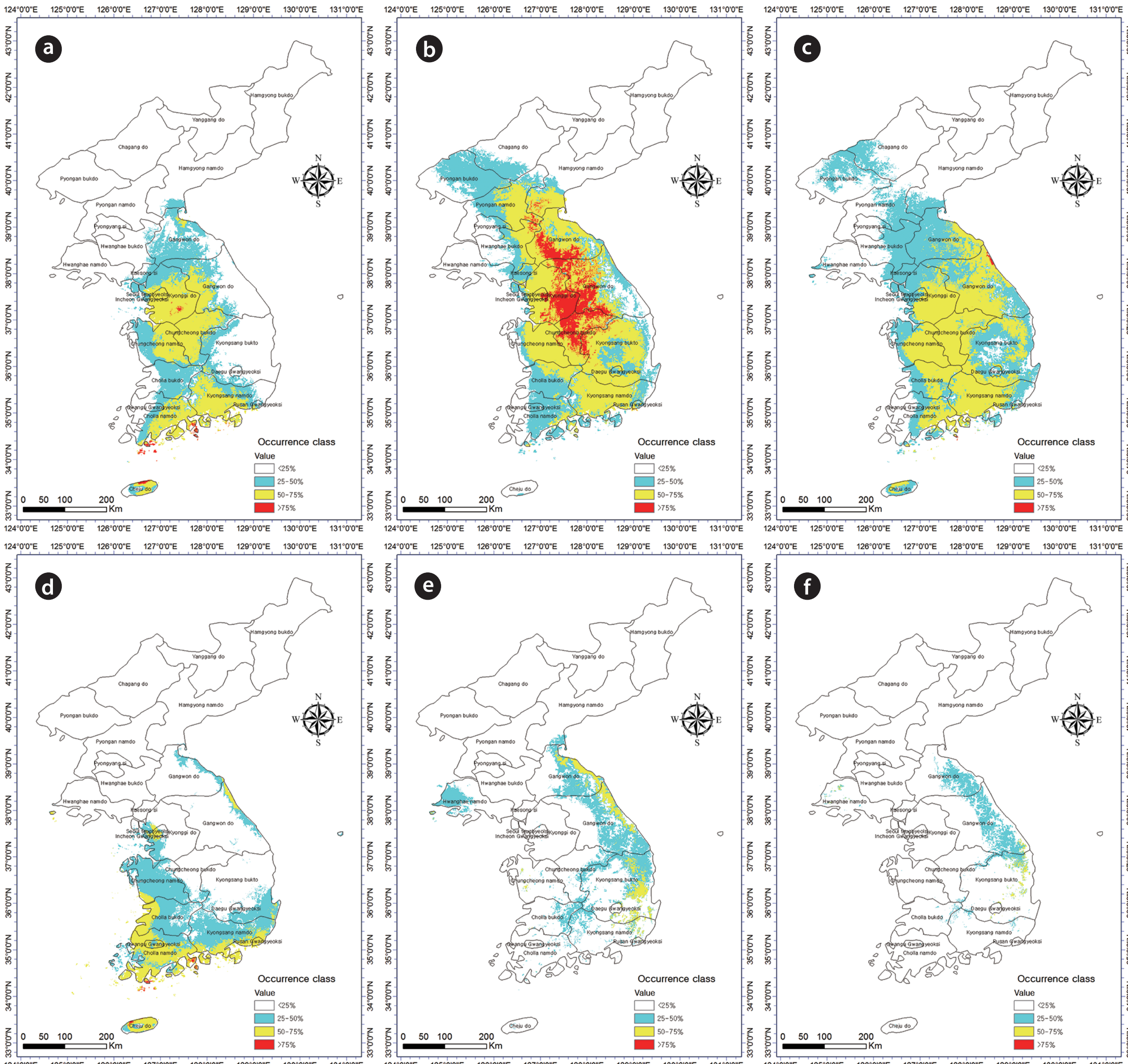

Fig. 2. MaxEnt model simulated geographic distributions of *Biston robustum* (a–c) and *Camellia japonica* (d–f) for current, 2050-predicted, and 2070-predicted climatic conditions.

Table 1. Potential distribution areas (km^2) for *Biston robustum* and *Camellia japonica*, according to probability categories

		Current	2050-predicted	2070-predicted
Low (< 25%)	*Biston robustus*	225,544	146,352	155,731
	Camellia japonica	257,145	287,441	313,523
Medium (25–50%)	*Biston robustus*	52,707	68,274	92,732
	Camellia japonica	47,553	34,250	14,569
High (50–75%)	*Biston robustus*	50,163	92,663	80,699
	Camellia japonica	24,275	7,669	1,268
Very High (> 75%)	*Biston robustus*	946	22,071	198
	Camellia japonica	387	-	-

Chungcheongnam, Chungcheongbuk, Gyeonggi, and Gangwon provinces by 2050 (Fig. 2b). However, the model predicted that by 2070, the critical habitable areas would be narrowly distributed along the coastlines of Sokcho-si and Goseong-gun of Gangwon Province (Fig. 2c).

Currently, *C. japonica* inhabits Seoul, some areas of Gyeonggi, Chungcheongnam, Chungcheongbuk, Jeollanam, Gyeongsangnam, and Gyeongsangbuk provinces, and the coastal areas of Gangwon Province (Fig. 2d). It was predicted that by 2050, *C. japonica* would not be distributed along the western coastal areas, but it would be found mainly in Gyeongsangnam and Gyeongsangbuk provinces, and along the coasts of Gangwon (Fig. 2e). In contrast, by 2070, habitable areas will be significantly smaller than the 2050 areas, and will be restricted to limited areas in Gyeongsangbuk Province and the southern coastal lines of Gangwon Province (Fig. 2f). Currently, the critical habitat of *C. japonica* includes the northern coastal lines of Jeju, Wan, Bogil, Soan, Yeosu-si, and Dolsal islands, but it will disappear from these areas by 2050 and 2070 (Fig. 2d–f).

The current potential habitable area of *B. robustum* (categorized as "High" 50–75%) is 50,163 km^2, and was predicted to gradually expand to 92,663 km^2 by 2050, and then decrease to 80,699 km^2 by 2070 (Table 1). In contrast, for the "Very High" (>75%) category, the current potential habitable area was predicted to be 946 km^2 and will dramatically increase to 22,071 km^2 by 2050, and then significantly decrease to 198 km^2 by 2070. The current potential habitable area of *C. japonica* in the 'High' category was 24,275 km^2 and was predicted to significantly decrease to 7,669 km^2 and 1,268 km^2 by 2050 and 2070, respectively. Similarly, the "Very High" category was 387 km^2 under the current conditions, but was predicted to completely disappear by 2050 and 2070.

Evaluation of model accuracy and importance of variables

The AUC of ROC, which validated the accuracy of the MaxEnt model for predicting possible distribution areas of *B. robustum* and *C. japonica*, ranged from 1.0 (perfect predictive accuracy) to 0.5 (least predictive accuracy). Species distribution predictions from the MaxEnt model were considered to be significant only if the AUC value exceeded 0.7 (Phillips and Dudik 2008). The AUC values for our MaxEnt model were 0.995 and 0.991 for *B. robustum* and *C. japonica*, respectively, indicating that the model effectively predicted distributions.

In the order of significance, BIO16, BIO12, BIO15, and BIO17 had impacts that exceeded 10% for the potential distribution of *B. robustum*, while BIO1, BIO3, BIO4, BIO5, BIO7, BIO9, BIO13, and BIO19 had no effect on distribution (Table 2). The variables of BIO16, BIO12, BIO15, and BIO17 are all related to the amount of precipitation; the sum of the contribution of these four variables was

Table 2. Descriptive statistics for bioclimatic variables used in MaxEnt analyses

Contents		Contribution (%)		Unit
		Biston robustus	*Camellia japonica*	
BIO1	Annual Mean Temperature	0.0	39.7	°C
BIO2	Mean Diurnal Range (Mean of monthly (max temp - min temp)	0.7	1.8	°C
BIO3	Isothermality (BIO2/BIO7) (* 100)	0.0	0.3	%
BIO4	Temperature Seasonality (standard deviation * 100)	0.0	7.1	%
BIO5	Max Temperature of Warmest Month	0.0	0.1	°C
BIO6	Min Temperature of Coldest Month	1.4	3.5	°C
BIO7	Temperature Annual Range (BIO5–BIO6)	0.0	0.2	°C
BIO8	Mean Temperature of Wettest Quarter	3.1	12.2	°C
BIO9	Mean Temperature of Driest Quarter	0.0	0.9	°C
BIO10	Mean Temperature of Warmest Quarter	2.2	2.7	°C
BIO11	Mean Temperature of Coldest Quarter	0.4	3.5	°C
BIO12	Annual Precipitation	18.2	2.1	mm
BIO13	Precipitation of Wettest Month	0.0	0.0	mm
BIO14	Precipitation of Driest Month	4.6	7.1	mm
BIO15	Precipitation Seasonality (Coefficient of Variation)	13.4	6.2	%
BIO16	Precipitation of Wettest Quarter	45.2	2.5	mm
BIO17	Precipitation of Driest Quarter	10.5	0.2	mm
BIO18	Precipitation of Warmest Quarter	0.1	7.2	mm
BIO19	Precipitation of Coldest Quarter	0.0	2.7	mm

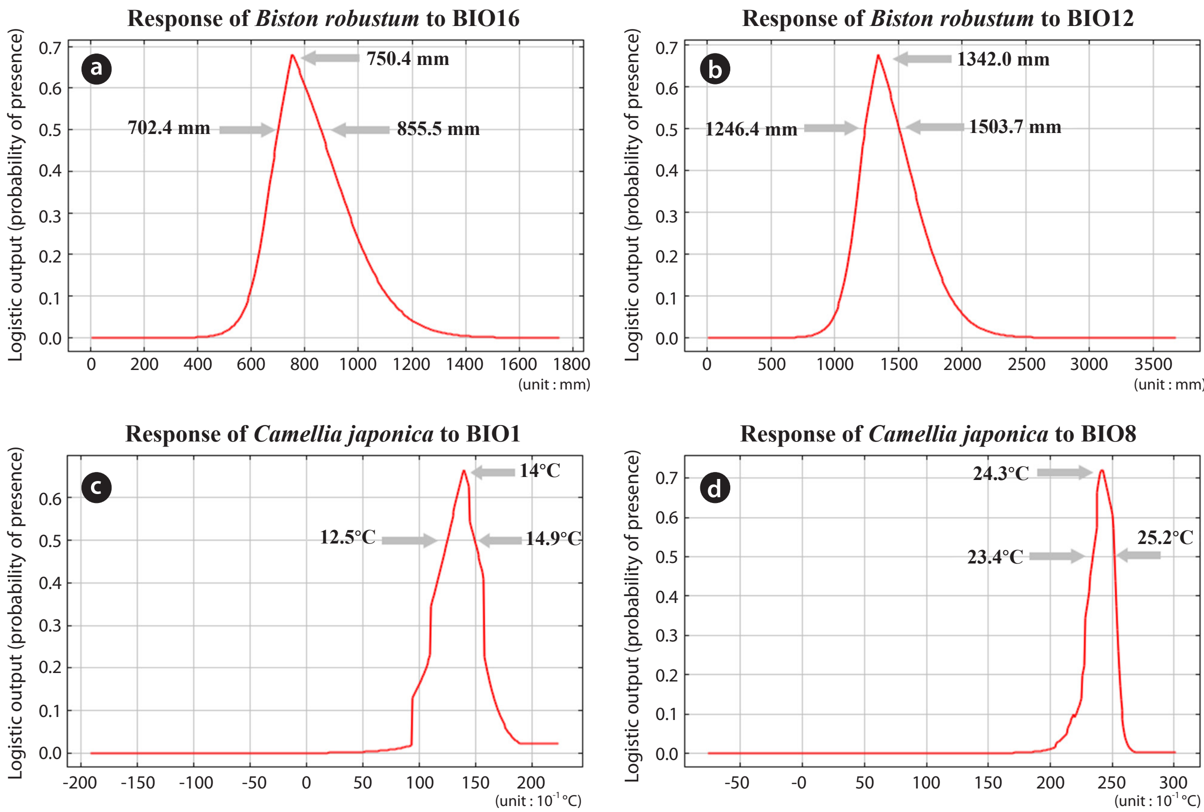

Fig. 3. Two significant factors affecting the potential distributions of *Biston robustum* (a, b) and *Camellia japonica* (c, d): (a) BIO16 (Precipitation of Wettest Quarter), (b) BIO12 (Annual Precipitation), (c) BIO1 (Annual Mean Temperature), (d) BIO8 (Mean Temperature of Wettest Quarter).

87.3%, clearly indicating that precipitation is one of the most critical factors determining *B. robustum* distributions (Table 2). In contrast, BIO1 and BIO8 had effects that exceeded 10% for *C. japonica* potential distribution; these two variables were related to temperature and had a combined contribution of 51.9% (Table 2).

The two most influential factors for *B. robustum* distribution were BIO16 (Precipitation of the Wettest Quarter; 45.2%) and BIO12 (Annual Precipitation; 18.2%) (Table 2). The distribution probability of *B. robustum* was approximately 70% for precipitation of 750.4 mm (Fig. 3a). The probability was above 50% where BIO16 ranged between 702.4 mm and 855.5 mm (Fig. 3a). For BIO12, the probability of *B. robustum* occurrence was very close to 70% in the regions where the annual precipitation was 1,342.0 mm (Fig. 3b). The probability of *B. robustum* occurrence was greater than 50% in areas where the precipitation ranged from 1,246.4 mm to 1,503.7 mm (Fig. 3b). The two most significant variables related to *C. japonica* distribution were BIO1 (Annual Mean Temperature; 39.7%) and BIO8 (Mean Temperature of Wettest Quarter; 12.3%) (Table 2). For BIO1, the probability of distribution of *C. japonica* was approximately 70% in regions where this variable was 14°C (Fig. 3c). The probability was higher than 50% in areas where the temperature was between 12.5°C and 14.9°C (Fig. 3c). However, for BIO16, the distribution probability of *C. japonica* was approximately 70% if the amount of precipitation was 24.3°C (Fig. 3d). The probability was above 50% where BIO8 ranged between 23.4°C and 25.2°C (Fig. 3d).

Correlation analysis between *B. robustum* and *C. japonica*

Given that there was no location that had greater than 75% ('Very High') probability for *C. japonica* presence in 2050 and 2070, only regions where the probability was higher than 50% but less than 75% were included for the correlation analyses (i.e., overlapping areas) between *C. japonica* and *B. robustum*. Overlapping areas for the presence of *B. robustum* and *C. japonica* included Seoul, some parts of Gyeonggi Province, Jeju Island, Jeollanam province, and Gyeongsangnam provinces (Fig. 4a). By 2050, the overlapping areas were in Gyeongsangnam and

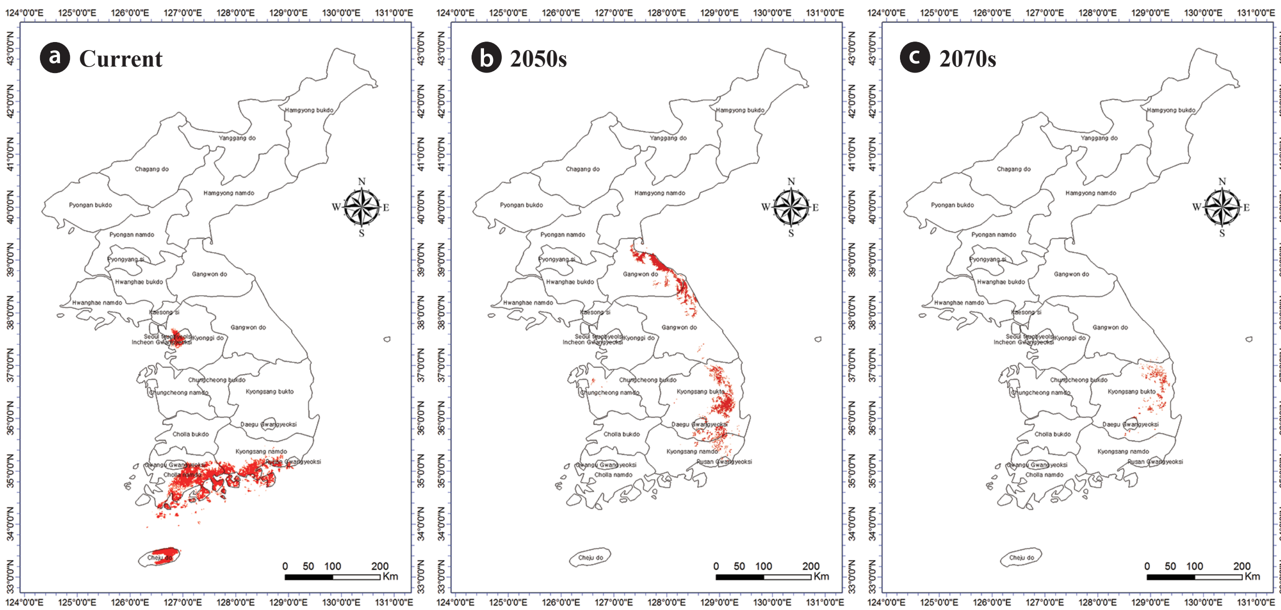

Fig. 4. MaxEnt model simulated areas of overlap between *Biston robustum* and *Camellia japonica* for current (a), 2050-predicted (b), and 2070-predicted condition (c).

Gyeongsangbuk provinces, and along the costal lines of Gangwon Province. By 2070, the overlapping areas were in limited areas of Gyeongsangbuk Province (e.g., Andong and Youngju) and Daegu City (Fig. 4b and 4c). Overall, these overlapping areas gradually shifted toward the eastern coastal areas from the southern coast of the Korea peninsula. The overlapping areas of *B. robustum* and *C. japonica* were 11,782 km^2, 5,447 km^2, and 870 km^2 for the current, 2050-predicted, and 2070-predicted conditions, respectively, clearly showing a dramatic decrease in the overlapping area (Fig. 4a–c).

DISCUSSION

We predicted the distribution of *B. robustum*, a species found in South Korea (An et al. 2012), for current, 2050-predicted, and 2070-predicted conditions using climate change scenarios. Our analyses showed that these species are distributed mostly in inland provinces, but they may migrate to some eastern coastal areas in the future. It was predicted that the regions where the distribution probability of *B. robustum* is higher than 50% but less than 75% would dramatically increase until 2050 and then slightly decrease by 2070 (Table 1). As reported by Lee and Kim (1992), the potential habitable areas for *C. japonica* were concentrated around the southern coast of the Korean peninsula, whereas in our study, the area was extended to Daecheong Island and Ulreung Island to the west and the east, respectively. There was no habitable area predicted for *C. japonica* by 2050 and 2070, in which the probability was higher than 75%. Previously, other studies determined that *C. japonica* might inhabit the central inland area of Korea, including Seoul, if the average annual temperature were elevated by 2°C (Korea Forest Service 2015). Further investigations might be warranted to evaluate this discrepancy.

The two most influential variables for the potential distribution of *B. robustum* and *C. japonica* were BIO16 (Precipitation of Wettest Quarter) and BIO12 (Annual Precipitation), and BIO1 (Annual Mean Temperature) and BIO8 (Mean Temperature of Wettest Quarter), respectively (Table 2). According to the National Weather Service data, the Precipitation of Wettest Quarter and Annual Precipitation of Yeosu-si and Wan Islands, where the probability of presence for both *B. robustum* and *C. japonica* was higher than 75%, were 766.2 mm and 773.9 mm, and 1439.0 mm and 1532.7 mm, respectively (Cultural Heritage Administration of Korea 2015). The annual mean temperature and mean temperature of wettest quarter of these areas were 14.3°C and 14.1°C, and 23.7°C and 23.6°C, respectively (Cultural Heritage Administration of Korea 2015). Except for the Annual Precipitation of Wan Island (1532.7 mm), such results are in agreement with our predictions in which the probability of *B. robustum* and *C. japonica* was higher than 50% (Fig. 3). Thus, predictions for the potential distribution of *B. robustum* and *C. japonica*, for present as well as future conditions, might be accurate. Finally, the overlapping regions where the probability of occurrence was higher than 50% but less than 75% for both *B. robustum* and *C. japonica* were predicted to be drastically reduced, and the overlapping area where the probability of occurrence was higher than 75% was shown for current conditions, but not predicted for future ones.

Using climate change scenarios, we predicted current and future distribution of *B. robustum* and *C. japonica* in Korea. Although it is predicted that *B. robustum* would cause consistent damage to *C. japonica* in the southern part of the Korean peninsula, the risk of a *B. robustum* outbreak seems to be extremely, considering the differences in factors determining its potential future distribution.

LITERATURE CITED

An JS, Choi SW, Kim T, Yang B. 2012. Moth diversity and distribution of Mt. Jirisan national long-term ecological research site. Nature and Ecology, Seoul. (in Korean)

Cultural Heritage Administration of Korea. 2015. Natural monument. http://search.cha.go.kr/srch_new/search/search_top.jsp?home=total&subHome=0&sort=&searchField=&page=1&query=%EB%8F%99%EB%B0%B1%EB%82%98%EB%AC%B4. Accessed 29 April 2015. (in Korean)

Esaki T, Issiki S, Inoue H, Ogata M, Okagaki H, Kuroko H. 1999. Icones Heterocerorum Japonicorum in Coloribus Naturalibus (Moths of Japan in Color Vol. 1). Hoikusha Publishing, Higashiosaka. (in Japanese)

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 N, Xue D, Han H. 2011. A review of *Biston* Leach, 1815 (Lepidoptera, Geometridae, Ennominae) from China, with description of one new species. ZooKeys 139: 45-96.

Korea Adaptation Center for Climate Change. 2015. Korea's future climate. http://ccas.kei.re. kr/english/menu_1_2.do. Accessed 29 April 2015.

Korea Forest Service. 2015. Climate change and forest. http://www.forest.go.kr/newkfsweb/html/HtmlPage.do?pg=/policy/policy_02010401.html&mn=KFS_03_09_01_04_01. Accessed 29 April 2015. (in Korean)

Korea Forest Service. 2015. Disease and insect pests. http://www.forest.go.kr/newkfsweb/mer/fip/dbhis/selectInsectDetail.do?dbhisIdno=86&dbhisTpcd=20&searchCnd=&searchWrd=&pageIndex=1&orgId=kfs. Accessed 29 April 2015. (in Korean)

Korea Meterological Administration 2015. Climate of Korea-30 years. http://www.kma.go.kr. Accessed 29 April 2015. (in Korean)

Lee SH, Kim SK. 1992. Natural distribution and characteristics of populations of *Camellia japonica* in Korea. J Korean Soc Hort Sci 33: 196-208.

Lee WC, Yim YJ. 2002. Plant geography with special reference to Korea. Kangwon National University Press, Chuncheon. (in Korean)

Natural History Museum. 2015. Hosts – a Database of the World's Lepidopteran Hostplants. http://www.nhm.ac.uk/research-curation/research/projects/hostplants/search. Accessed 29 April 2015.

Nelson WA, Bjørnstad ON, Yamanaka T. 2013. Recurrent insect outbreaks caused by temperature-driven changes in system stability. Science 341: 796-799.

Park SC, Kim CY, Wi AJ. 2005. Biology and control of the giant geometrid, *Biston robustum* Butler, damaging camellia forests in Guomundo Islands. Agric Sci & Tech 40: 21-31.

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.

Shin YH. 2001. Coloured Illustrations of the Moths of Korea. Academy book Publishing, Seoul. (in Korean)

Veblen TT, Hadley KS, Reid MS, Rebertus AJ. 1991. The response of subalpine forests to spruce beetle outbreak in Colorado. Ecology 72: 213-231.