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Prediction of changes in distribution area of *Scopura laminate* in response to climate changes of the Odaesan National Park of South Korea

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Abstract

This study was performed to provide important basic data for the preservation and management of *Scopura laminata*, a species endemic to Korea, by elucidating the spatial characteristics of its present, potential, and future distribution areas. Currently, this species is found in the Odaesan National Park area of South Korea and has been known to be restricted in its habitat due to its poor mobility, as even fully grown insects do not have wings. Utilizing the MaxEnt model, 20 collection points around Odaesan National Park were assessed to analyze and predict spatial distribution characteristics. The precision of the MaxEnt model was excellent, with an AUC value of 0.833. Variables affecting the potential distribution area of *S. laminata* by more than 10% included the range of annual temperature, seasonality of precipitation, and precipitation of the driest quarter, in order of greatest to least impact. Compared to the current potential distribution area, no significant difference in the overall habitable area was predicted for the 2050s or 2070s. It was, however, demonstrated that the potential habitable area would be reduced in the 2050s by up to 270.3 km from the current area of 403.9 km; further, no potential habitable area was anticipated by the 2070s according to our predictive model. Taken together, it is anticipated that this endemic species could be significantly affected by climate changes, and hence effective countermeasures are strongly warranted for the preservation of habitats and species management.

Key words: climate change, endemic species, MaxEnt, Odaesan National Park, *Scopura laminata*, species conservation

INTRODUCTION

The Scopuridae are known to inhabit Korea and Japan in Northeast Asia. Notably, species in the Scopuridae do not have wings, significantly limiting their geographical distribution (Uéno 1938, Uchida and Maruyama 1987). *Scopura laminata* is an endemic Korean species in the family Scopuridae. The main habitat of *S. laminata* is around the headwater streams of Baekdudaegan in South Korea. Four known species of *Scopura*, *S. laminata*, *S. gaya*, *S. scorea*, and *S. jiri*, are currently found in Korea, and their distribution areas are divided among geological locations (Jin and Bae 2005). In particular, *S. laminata*, a species endemic to Korea, has been known to inhabit the

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area around Odaesan National Park in South Korea (Yoon and Aw 1985, Uchida and Maruyama 1987, Jin and Bae 2005). This insect prefers to live near the cold, shallow water of mountain streams and is mostly found where sand or silt piles up between very large rocks. *S. laminata* consumes the leaves of deciduous broad-leaved trees (e.g., oak and maple trees) (Komatsu 1970). Adult insects are mostly found between late September and late October and crawl along the waterside, as they have no wings to fly with (Jin and Bae 2005).

In monsoon areas, such as South Korea, the amount of precipitation has been known to significantly affect riparian ecosystems. The distributions of various species are influenced by water temperature, and temperature differences tend to be greater in downstream areas; hence, benthic macroinvertebrates (Allan and Castillo 2007) living in the upstream regions of small rivers with minor temperature differences may undergo major distributional changes in response to increases in water temperature due to climate change (Kong et al. 2013).

Further, according to the climate change scenario, it is clear that precipitation between July and September will increase by approximately 20.4% (Representative Conservation Pathway, RCP 8.5) by the end of the 21st century (Lee et al. 2011). In Korea, severe rainfall is often concentrated in certain periods, and this can wash out riparian ecosystems, acting as a considerable disturbance for the species that dwell there (Underwood 1996). Recently, climate changes have become faster, and the rate of change has exceeded the rate of adaptation of various species; hence, it is anticipated that the habitats of species might be rapidly and considerably modified.

Therefore, in the present study, we predicted the potential distribution area of *S. laminata* based on its current habitat, providing basic information for the establishment of preservation strategies.

MATERIALS AND METHODS

Species data

In the study, we utilized 1) data from previous investigations, and 2) natural resources research data from Odaesan National Park. Data were collected from 13 and 7 locations in 2004 and 2013, respectively, where *S. laminata* was found, including major rivers of the Odaesan area such as the Odaecheon, the Songcheon tributary

Table 1. Location information for *Scopura laminata* in Odaesan National Park.

No	Locality	Latitude	Longitude	Altitude (m)	Collection Date (year/month/day)
1	Dongsan-ri, Jinbu-myeon, Pyeongchang-gun, Gangwon-do, Korea	37°47′16.30″	128°34′00.02″	880	2004/05/19
2	Dongsan-ri, Jinbu-myeon, Pyeongchang-gun, Gangwon-do, Korea	37°47′08.66″	128°35′01.46″	859	2004/05/19
3	Dongsan-ri, Jinbu-myeon, Pyeongchang-gun, Gangwon-do, Korea	37°46′42.90″	128°34′39.66″	819	2004/05/19
4	Dongsan-ri, Jinbu-myeon, Pyeongchang-gun, Gangwon-do, Korea	37°42′18.87″	128°36′27.82″	614	2004/05/19
5	Byeongnae-ri, Daegwanryeong-myeon, Pyeongchang-gun, Gangwon-do, Korea	37°45′24.78″	128°37′42.44″	841	2004/05/19
6	Byeongnae-ri, Daegwanryeong-myeon, Pyeongchang-gun, Gangwon-do, Korea	37°43′24.85″	128°36′36.62″	675	2004/05/19
7	Byeongnae-ri, Daegwanryeong-myeon, Pyeongchang-gun, Gangwon-do, Korea	37°42′58.28″	128°37′34.16″	735	2004/05/21
8	Myeonggae-ri, Nae-myeon, Hongcheon-gun, Gangwon-do, Korea	37°50′58.31″	128°30′48.16″	650	2004/05/21
9	Samsan-ri, Yeongok-myeon, Gangneung-si, Gangwon-do, Korea	37°46′45.36″	128°36′58.19″	754	2004/05/21
10	Samsan-ri, Yeongok-myeon, Gangneung-si, Gangwon-do, Korea	37°47′44.46″	128°41′19.87″	481	2004/05/21
11	Samsan-ri, Yeongok-myeon, Gangneung-si, Gangwon-do, Korea	37°47′13.89″	128°39′49.57″	681	2004/05/21
12	Samsan-ri, Yeongok-myeon, Gangneung-si, Gangwon-do, Korea	37°48′06.54″	128°41′04.81″	374	2004/05/21
13	Hoenggye-ri, Daegwanryeong-myeon, Pyeongchang-gun, Gangwon-do, Korea	37°43′12.48″	128°43′22.31″	841	2004/05/21
14	Dongsan-ri, Jinbu-myeon, Pyeongchang-gun, Gangwon-do, Korea	37°48′11.2″	128°34′1.1″	1,273	2013/06/16
15	Samsan-ri, Yeongok-myeon, Gangneung-si, Gangwon-do, Korea	37°46′35.4″	128°36′55.7″	788	2013/08/15
16	Samsan-ri, Yeongok-myeon, Gangneung-si, Gangwon-do, Korea	37°47′8.8″	128°39′11.5″	878	2013/08/15
17	Byeongnae-ri, Daegwanryeong-myeon, Pyeongchang-gun, Gangwon-do, Korea	37°42′51.8″	128°37′19.4″	718	2013/06/02
18	Byeongnae-ri, Daegwanryeong-myeon, Pyeongchang-gun, Gangwon-do, Korea	37°45′14.7″	128°36′34.3″	855	2013/08/15
19	Chahang-ri, Daegwanryeong-myeon, Pyeongchang-gun, Gangwon-do, Korea	37°44′38.6″	128°40′9.8″	1,156	2013/08/15
20	Chahang-ri, Daegwanryeong-myeon, Pyeongchang-gun, Gangwon-do, Korea	37°43′58.0″	128°41′2.7″	901	2013/08/15

of the Namhan river, the Kyebangcheon tributary of the Bookhan river, and the Yeongogcheon and Gangreun Namdaecheon, which flow into the East Sea (Table 1).

Climate data

In order to predict changes in the distribution of *S. laminata* in response to climate changes, 19 bioclimatic variables were utilized from the free database (Table 2) of the WorldClim website (http://www.worldclim.org). The spatial resolution of the variables is 30″ (approximately 1 km), and climate data collected over a long period of time (1950–2000) were applied with a thin-plate smoothing spline interpolation to generate biologically meaningful monthly average temperatures and precipitation (Hijmans et al. 2005). These variables are used in various studies to predict the potential habitats of species via ecological niche models. They are characterized by climate extremes (temperature and precipitation of the coldest and warmest months), annual tendencies (e.g., the annual mean temperature and precipitation), and seasonality (e.g., annual ranges in annual mean temperature and precipitation). Data from the HadGEM-AO model, a CIMP5 model that utilizes the RCP, was used for the study; the RCP was determined based on the IPCC's Fifth Assessment Report on the 2050s (2040–2060) and the 2070s (2060–2080) and used to predict the current and future geological distribution of *S. laminata* (WorldClim 2005).

Data analysis

The MaxEnt modeling algorithms were adopted to predict changes in the geographical distribution of *S. laminata* in response to climate changes (Phillips et al. 2006). The MaxEnt model is one of the most popular machine-based learning methods using geographical information on locations where species are found (Elith et al. 2011). Utilizing environmental features of specific locations, the model statistically provides locations that have similar environmental characteristics to those that are put into the model. To obtain background data on environmental characteristics in order to compare areas, we randomly extracted 10,000 data points from the research area in accordance with methods used by Phillips and Dudik (2008).

Compared to previous models utilizing presence information, the MaxEnt model has high predictive accuracy, which has been validated in previous studies (Phillips et al. 2006). It can also develop a useful model with limited data (e.g., spatial errors related to location data and five given points), which is another benefit of the model (Baldwin 2009).

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

ID	Variable name	Contribution (%)
BIO7	Temperature Annual Range (BIO5–BIO6)	43.3
BIO15	Precipitation Seasonality (Coefficient of Variation)	11
BIO17	Precipitation of Driest Quarter	10
BIO13	Precipitation of Wettest Month	8.5
BIO6	Min Temperature of Coldest Month	7.4
BIO12	Annual Precipitation	6.3
BIO3	Isothermality [100 × (BIO2/BIO7)]	6.1
BIO18	Precipitation of Warmest Quarter	3.8
BIO5	Max Temperature of Warmest Month	2.5
BIO4	Temperature Seasonality (standard deviation × 100)	0.7
BIO16	Precipitation of Wettest Quarter	0.2
BIO9	Mean Temperature of Driest Quarter	0
BIO10	Mean Temperature of Warmest Quarter	0
BIO19	Precipitation of Coldest Quarter	0
BIO8	Mean Temperature of Wettest Quarter	0
BIO11	Mean Temperature of Coldest Quarter	0
BIO14	Precipitation of Driest Month	0
BIO2	Mean Diurnal Range [Mean of monthly (max temp - min temp)]	0
BIO1	Annual Mean Temperature	0

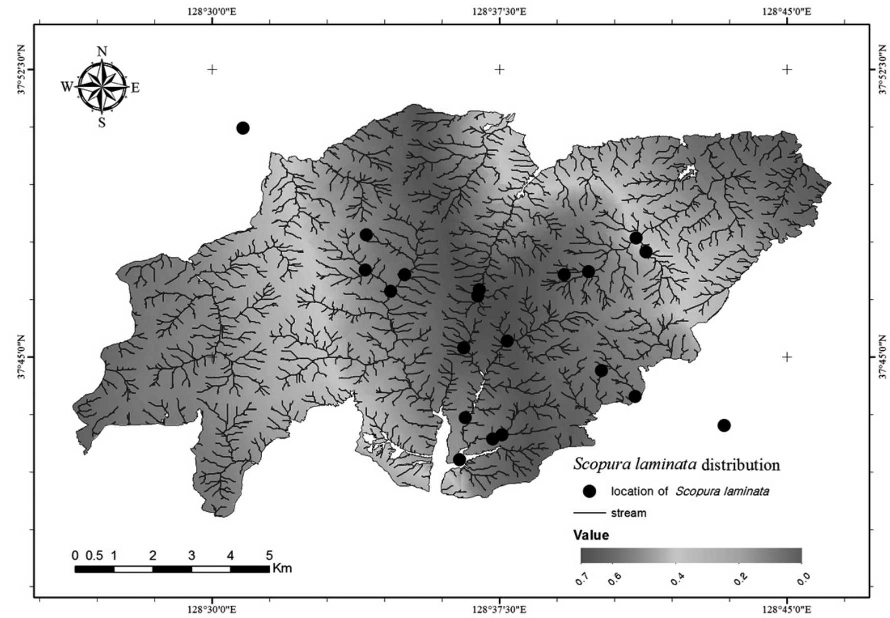

Fig. 1. Current potential distribution of *Scopura laminata* in Odaesan National Park. Black spots (•) indicate sampling sites.

In order to predict potential changes in habitable areas for *S. laminata*, changes in the potential distribution area of *S. laminata* were assessed through applying current and future climate data provided by WorldClim into the MaxEnt model based on the statistical associations between obtained location data and their corresponding climate variables. In order to do this, we first analyzed the current potential distribution area of *S. laminata* via the MaxEnt model based on 19 bioclimatic variables; the spatial resolution of the variables was approximately 1 km and created through the interpolation of the meteorological data recorded between 1950 and 2000. Then, the future potential distribution area was analyzed utilizing the RPC climate change scenario data for the 2050s and 2070s based on the HadGEM-AO model. The resulting distribution maps were cross-analyzed to evaluate the direction and range of changes in the current and future potential distribution areas of *S. laminata.*

The explanatory power of the model was assessed using the area under the curve of the receiver-operating characteristic (ROC). The significance of the climate variables that affect potential habitat distributions was validated using the jackknife technique (Phillips et al. 2006). For the analysis of distributional changes, MaxEnt 3.3.3k (Phillips et al. 2006) and ArcGIS 10.0 (ESRI, Redlands, USA) were used, and statistical analysis was done using R-3.1.1 (http://www.R-project.org/).

RESULTS AND DISCUSSION

Prediction of the current potential distribution zone of *Scopura laminata*

In this study, we confirmed that *S. laminata* is often found in the range of approximately 374–1,273 m in altitude and is most abundant in the approximate range of 600–900 m in altitude (Fig. 1). Notably, it was most abundant in streams in the upper areas of Odaecheon and Yeongogcheon (i.e., stream order approximately 1–3). Individuals found at approximately 300–500 m might have been transported downstream by wash-off effects following heavy rainfalls.

Previously, it was known that *S. laminata* is found at altitudes higher than 800 m on streams approximately of order 1–2. Specifically, *S. laminata* was known to inhabit Odaesan headwater streams higher than 1,200 m in altitude (Jin and Bae 2005). However, in the present, we demonstrated that the distribution was not limited only by altitude, but also by physical and biological factors. Notably, we found a high probability of habitation around the west area of the Kyebangcheon; hence, further research might be warranted with regard to its distribution and the environment of its habitat.

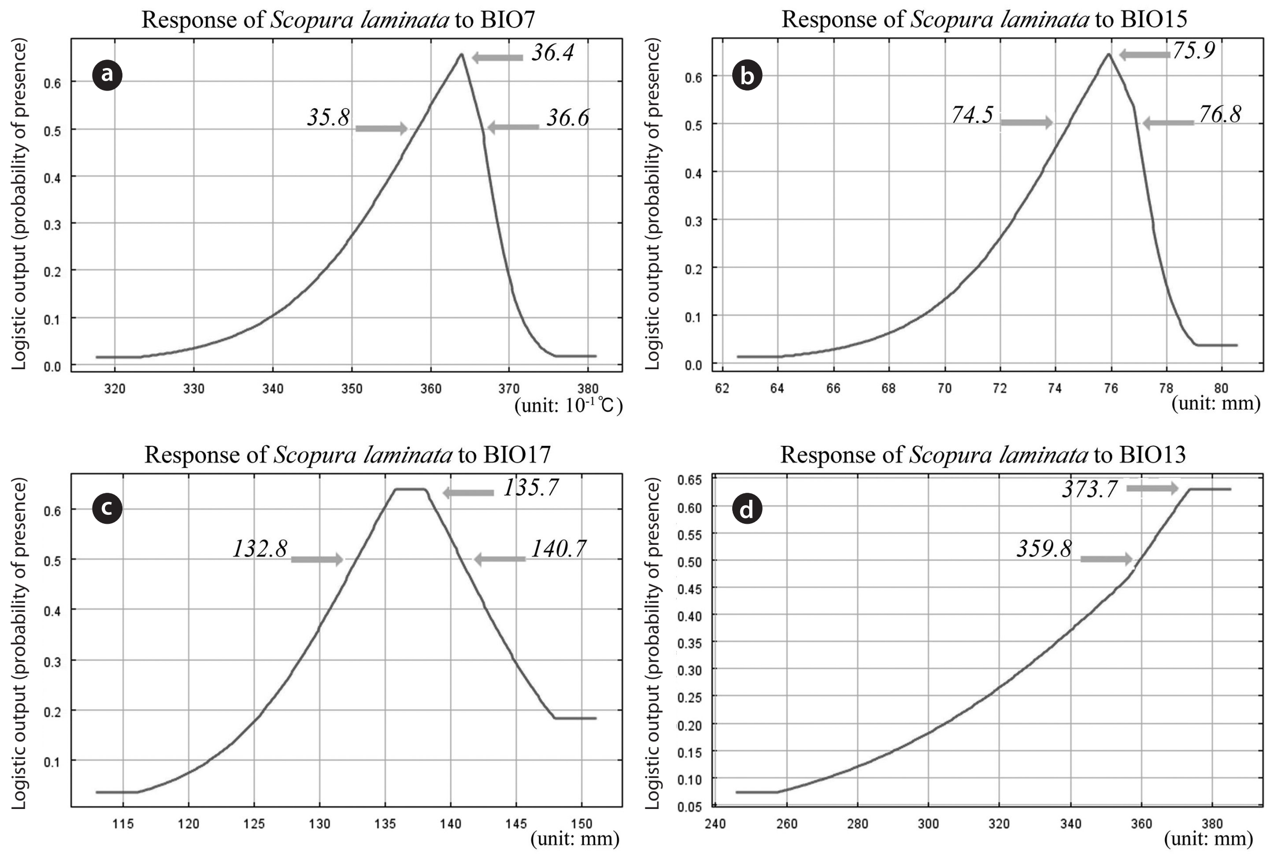

Fig. 2. Four important factors affecting the potential distribution of *Scopura laminata* in Odaesan National Park. (a) BIO7 (Temperature Annual Range (BIO5-BIO6), (b) BIO15 (Precipitation Seasonality (Coefficient of Variation)), (c) BIO17 (Precipitation of Driest Quarter), (d) BIO13 (Precipitation of Wettest Month).

Evaluation of model accuracy and importance of variables

In order to predict the potential distribution area of *S. laminata*, the MaxEnt model was utilized; the area under the curve (AUC) of the receiver operating characteristics (ROC) curve evaluates the precision of the MaxEnt model where 1.0 indicates perfect prediction, with a minimum value of 0.5. The model is often assumed to significantly explain distribution characteristics of species when the AUC value is higher than 0.7 (Phillips and Dudik 2008). In this study, the AUC value was 0.833, which indicates that the model might be suitable for predicting the distribution of *S. laminata*.

BIO7, BIO15, and BIO17 (see Table 2 for descriptions of variables), in order from most to least impact, had an impact of more than 10% on the potential distribution of *S. laminata*, while BIO1, BIO2, BIO8, BIO9, BIO10, BIO11, BIO14, and BIO19 did not affect distribution. Of all variables, BIO7 was found to have the most impact (i.e., 43.3%), and BIO6, BIO7, BIO13, BIO15, and BIO17 combined to contribute 80.2% of the total impact on the predicted distribution (Table 2).

The range of annual temperature (the variable “Temperature Annual Range”), BIO07, with the highest probability of *S. laminata* distribution was 36.4°C, and the probability of its distribution was higher than 50% when temperature deviations were in the range of 35.8–36.6°C (Fig. 2a). The probability of distribution was highest when BIO15, the coefficient of variation of the seasonality of precipitation, was 75.9; the distribution probability was higher than 50% if it was in the range of approximately 74.5–76.8 (Fig. 2b). The probability of distribution was highest when BIO17, the amount of precipitation of the driest quarter, was 135.7 mm. It was higher than 50% when BIO17 was in the range of 132.8–140.7 mm (Fig. 2c). Lastly, the distribution probability was higher than 50% if BIO13 (the amount of precipitation of the wettest month) was 359.8–373.7 mm (Fig. 2d).

In South Korea, the average temperature over the last 200 years has increased by 1.5°C, which is more than twice the global average. Further, the number of rainy

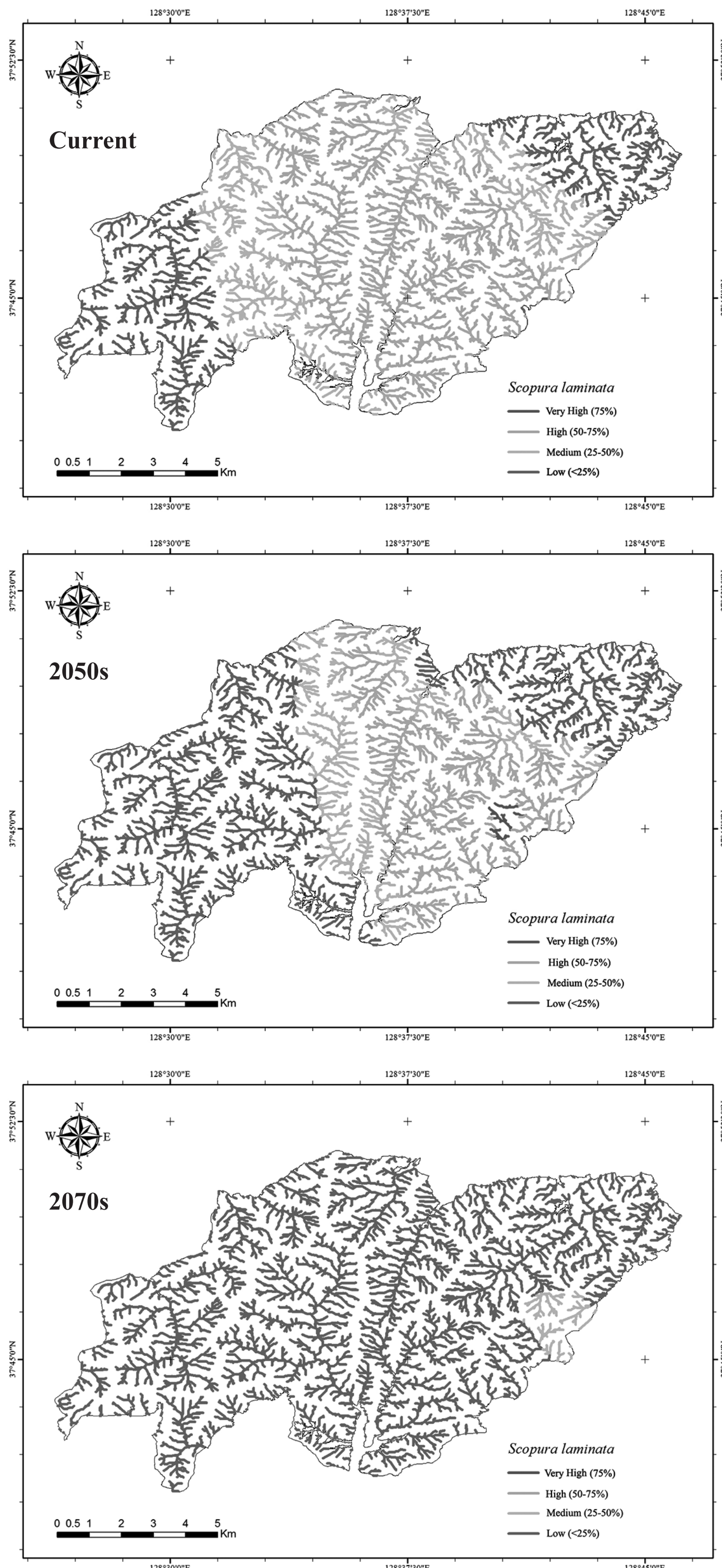

Fig. 3. Simulated geographic distribution of *Scopura laminata* in Odaesan National Park using the MaxEnt model (Current → 2050s → 2070s).

days declined over the last 50 years, while the frequency of heavy rain (more than 80 mm of precipitation in a day) increased (Choi 2002). Such climatic changes are expected to change the life history and lifecycle of *S. laminata*. Specifically, changes in temperature and precipitation are thought to cause drastic changes in the environment of their habitats, as they are only able to travel within the upstream areas of their habitats.

Changes in *Scopura laminata* distribution with climate change

Utilizing the MaxEnt model, habitats around Odaesan National Park were extracted and then divided into four levels based on the probability of *S. laminata* presence: Low (0–25%), Medium (25–50%), High (50–75%), and Very High (> 75%).

Compared to the current potential distribution area, no significant difference was indicated between the 2050s and 2070s with regard to the entire potential distribution area (Table 3). However, the area with a higher than 50% probability of distribution was expected to be reduced by 133.6 km by the 2050s from the current status (Table 3). Further, it was predicted that the area with a higher than 50% probability of distribution would completely disappear by the 2070s (Table 3). Similarly, potential areas with a higher than 25% probability of distribution were expected to be reduced by 71.5 km and 206.7 km in the 2050s and 2070s, respectively (Table 3).

Compared to the present status, it was also considered that most of the potential distribution area would be threatened by the 2070s, and northwestern habitats, the upstream areas of Kyebangcheon, Namdaecheon, and Odaecheon, were particularly susceptible (Fig. 3). The long-term rise in water temperature is generally related to rising temperatures (Kaushal et al. 2010). In Korea, it is thought that the water temperature of a river rises due to climate change (Chung et al. 2011, Kang et al. 2013). We cannot exclude the possibility of errors caused by space and time limits and the lack of data. Further data on climate and species distribution should improve the accuracy of the research results.

Table 3. Potential distribution areas (km) for *Scopura laminata*, according to probability categories

	Current	2050s	2070s
Low (< 25%)	245.5	450.6	856.2
Medium (25–50%)	231.4	159.9	24.7
High (50–75%)	403.9	263.0	-
Very High (> 75%)	-	7.3	-

S. laminata is an endemic species of Korea, and there is scant information about its distribution, ecology, and behavioral characteristics. Given its limited habitats, there is concern that it might become extinct or have its population greatly reduced when climate changes persist (e.g., the elevation of average temperature and changes in precipitation). Therefore, effective countermeasures are strongly warranted for vulnerable habitats of *S. laminata*.

LITERATURE CITED

Allan JD, Castillo MM. 2007. Stream Ecology; Structure and Function of Running waters 2nd Ed, Springer, Dordrecht.

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

Choi Y. 2002. Trends in daily precipitation events and their extremes in the southern region of Korea. Korean Soc Environ Impact Assess 76: 189-203.

Chung NI, Park BK, Kim KH. 2011. Potential effect of increased water temperature on fish habitats in Han river watershed. J Korean Soc Water Environ 27: 314-321.

Elith J, Phillips SJ, Hastie T, Dudik M, Chee YE, Yates CJ. 2011. A statistical explanation of MaxEnt for ecologists. Divers Distrib 17: 43-57.

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.

Jin YH, Bae YJ. 2005. The wingless stonefly family Scopuridae (Plecoptera) in Korea. Aquat Insects 27: 21-34.

Kang H, Park MY, Jang JH. 2013. Effect of climate change on fish habitat in the Nakdong river watershed. J Korea Water Resour Assoc 46: 1-12.

Kaushal SS, Likens GE, Jaworski NA, Pace ML, Sides AM, Seekell D, Belt KT, Secor DH, Wingate RL. 2010. Rising stream and river temperatures in the United States. Front Ecol Environ 8: 461-466.

Komatsu T. 1970. Notes on the growth of nymph of *Scopura longa* Uéno (Plecoptera). New Insect 14: 37-40.

Kong DS, Kim JY, Son SH, Oh MW, Choi AR, Byeon MS. 2013. Development and application of Korean Thermality Index (KTI) for biological assessment on climate change. J Korean Soc Water Evniron 29: 114-126.

Lee JH, Jee YG, Lee TY, Shin HS, Kim SD. 2011. Water resources system network building for climate change (II). Korea Environment Institute , Seoul.

Phillips SJ, Anderson RP, Schapire RE. 2006. Maximum en-

tropy 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.
Uchida S, Maruyama H. 1987. What is *Scopura longa* Uéno, 1929 (Insecta, Plecoptera)? A revision of the genus. Zool Sci 4: 699 -709.
Uéno M. 1938. Scopuridae an aberrant Family of the Order Plecoptera. Insecta Matsumurana 2: 154-159.
Underwood AJ. 1996. Spatial and temporal problems with monitoring. In: River restoration. Selected extracts from the Rivers Handbook (Petts G and Calow P, eds). Blackwell Science, Oxford, pp182-204.
WorldClim. 2005. WorldClim - Global Climate Data. http://www.worldclim.org. Accessed 20 August 2009.
Yoon IB, Aw SJ. 1985. A taxonomic study on the stonefly (Plecoptera) nymphs of Korea (I) - Suborder Holognatha and Systellognatha. Entomol Res Bull 11: 111-139.