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Prediction of present and future distribution of the Schlegel's Japanese gecko (*Gekko japonicus*) using MaxEnt modeling

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Abstract

Background: Understanding the geographical distribution of a species is a key component of studying its ecology, evolution, and conservation. Although Schlegel's Japanese gecko (*Gekko japonicus*) is widely distributed in Northeast Asia, its distribution has not been studied in detail. We predicted the present and future distribution of *G. japonicus* across China, Japan, and Korea based on 19 climatic and 5 environmental variables using the maximum entropy (MaxEnt) species distribution model.

Results: Present time major suitable habitats for *G. japonicus*, having greater than 0.55 probability of presence (threshold based on the average predicted probability of the presence records), are located at coastal and inland cities of China; western, southern, and northern coasts of Kyushu and Honshu in Japan; and southern coastal cities of Korea. Japan contained 69.3% of the suitable habitats, followed by China (27.1%) and Korea (4.2%). Temperature seasonality (66.5% of permutation importance) was the most important predictor of the distribution. Future distributions according to two climate change scenarios predicted that by 2070, and overall suitable habitats would decrease compared to the present habitats by 18.4% (scenario RCP 4.5) and 10.4% (scenario RCP 8.5). In contrast to these overall trends, range expansions are expected in inland areas of China and southern parts of Korea.

Conclusions: Suitable habitats predicted for *G. japonicus* are currently located in coastal cities of Japan, China, and Korea, as well as in isolated patches of inland China. Due to climate change, suitable habitats are expected to shrink along coastlines, particularly at the coastal-edge of climate change zones. Overall, our results provide essential distribution range information for future ecological studies of *G. japonicus* across its distribution range.

Keywords: Lizard, Distribution range, Climate change, Temperature seasonality, Urban

Background

Data on the geographical distribution are basic information needed for studying the ecology, evolution, and conservation of a species (Franklin 2009). In recent years, determining the explicit distribution range of a species and predicting future changes has become more important because of rapid population declines due to habitat destruction and alteration, climate change, and introduced

species (Gibbons et al. 2000; Thomas et al. 2004; Todd et al. 2010; Urban 2015). In particular, accurate species distribution is a key for predicting dispersal possibilities and assessing the potential ecological impacts in the face of changing ecosystems (Fujisaki et al. 2014; Kraus 2015). Studies determining current and predicting potential future distributions, based on changing environmental conditions, are increasingly important for reptiles (Sinervo et al. 2010; Acheson and Kerr 2018; Sancholi 2018). Being ectotherms, reptiles are highly vulnerable to future climate change (Angilletta Jr. et al. 1999).

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Identification of suitable habitats, potential distribution range, and investigation of distribution changes have been studied using species distribution models (Guisan and Thuiller 2005; Ortega-Huerta and Peterson 2008), such as maximum entropy (MaxEnt), ensemble, and envelope (Guisan and Thuiller 2005; Norberg et al. 2019). Among them, the MaxEnt model reliably predicts suitable habitat using presence records and pseudo-absence points (Phillips et al. 2006, 2009; Elith et al. 2006). Reptile studies have used MaxEnt to estimate potential distributions (Rödger et al. 2008; Huang et al. 2011; Solhjoui-Fard et al. 2012), predict distribution changes due to climate change (Srinivasulu and Srinivasulu 2016; Ofori et al. 2017; Berriozabal-Islas et al. 2018), and evaluate range expansions of introduced species (Buckland et al. 2014; Fujisaki et al. 2014; Weterings and Vetter 2018).

Schlegel's Japanese gecko (*Gekko japonicus*), a small, nocturnal gecko, was first described based on specimens collected from Japan (Duméril and Bibron 1836), followed by those from Chusan Island, Zhejiang Province, China (Cantor 1842) and Busan, Korea (Stejneger 1907). In Japan, *G. japonicus* broadly occurs on the main islands (exclusive of high altitude and latitude areas) and some peripheral islets (Wada 2003). The current distribution of *G. japonicus* in China includes the eastern coast extending westward to eastern Sichuan and northward to southern Shaanxi and Gansu Provinces (Zhao and Adler 1993). In Korea, populations are only found in southern coastal cities such as Busan, Changwon, and Mokpo (Lee et al. 2004; Kim et al. 2017). Only few basic ecological and genetic studies have been done on *G. japonicus* (Toda et al. 2003; Zhang et al. 2009; Kim et al. 2018, 2019; Park et al. 2019). Recent concerns regarding area of origin and genetic relationships among populations are growing due to range expansions of *G. japonicus* in Korea and Japan, possibly due to anthropogenic factors or climate change (Toda et al. 2003; Kim et al. 2017). Without clarifying its distributional range, it is difficult to interpret the morphological and genetic divergence patterns in a geographic context (Kim 2019a; b). Although *G. japonicus* is distributed widely in Northeast Asia and artificial introductions have been suggested in Korea and Japan (Lee et al. 2004; Toda and Yoshida 2005), its distribution range is not fully resolved.

In this study, we use the MaxEnt species distribution model to predict the present distribution of *G. japonicus* across China, Japan, and Korea, as well as future changes following two climate change scenarios. These results contribute to future ecological studies of *G. japonicus* across its distributional range.

Materials and methods

Collecting species location data for modeling

We compiled location coordinate data of *G. japonicus* through literature review and fieldwork across China, Japan,

and Korea (Table 1). For the literature review, we examined all reliable data from peer-reviewed papers and officially published booklets. For data from China, only a few locations (< 30) had coordinate data. To fill in this data gap, two researchers (Y.Z. and S.L.) with more than 20-year experience with *G. japonicus* in China, determined coordinates using the verbatim locality and Google Maps. For Japan, the distributional data is based on interviews with local residents and researchers (Wada 2003) and evaluated by H.O., who has more than 30-year experience with the species. In Korea, data was compiled from previous literature (Lee et al. 2004; Son et al., 2008; Kim et al. 2017), and only used for locations that we could confirm directly. In the Global Biodiversity Information Facility database (GBIF, <https://www.gbif.org/>), we found 37 locations of *G. japonicus* (10 in China, 22 in Japan, and 5 in Korea), all of which overlapped with our collected data. We conducted field surveys from August 2015 to October 2018 in regions of China (Wenzhou, Yancheng), Japan (Fukuoka, Tsushima and Innoshima Islands, Kobe, and Kyoto), and Korea (Busan, Changwon, Masan, Geoje, Mokpo, Ulsan, and Jeju) to confirm and gather new location data.

Table 1 Location and number of the occurrence points of *Gekko japonicus* obtained across China, Japan, and Korea and used for the modeling

Country	District (no. of included cities)	No. of occurrence points
China	Guangxi (3)	3
	Guizhou (5)	7
	Shaanxi (3)	6
	Shanghai (1)	3
	Anhui (7)	15
	Jiangxi (7)	18
	Jiangsu (8)	13
	Zhejiang (7)	15
	Chongqing (1)	10
	Fujian (5)	7
	Henan (2)	2
	Hunan (5)	8
	Hubei (8)	18
	Japan	Kyushu (9)
Kansai (7)		103
Chugoku (6)		27
Kanto (2)		39
Shikoku (4)		48
Chubu (7)		33
Korea	Busan (1)	12
	Kyeongnam (2)	3
	Cheonnam (1)	1
Total	22 (101)	432

Our species distribution models included most regions in China, Japan, and Korea, and encompassed the entire known distribution range of *G. japonicus* (Zhou et al. 1982; Zhao and Adler 1993; Wada 2003; Lee et al. 2004). We excluded areas from our distribution models where it is known that *G. japonicus* is absent: Taiwan (Zhao and Adler 1993) and the Ryukyu Islands in Japan (H. O., Pers. Comm.). To avoid possible model biases due to the different amount of data collected among the modeling regions (Phillips et al. 2009; Fourcade et al. 2014), we selected each one coordinate from a 9-km² square, based on territory size (Park et al. 2019), using the Google random number generator (Google Inc., CA, USA). Finally, we used 432 total data points (125 in China, 291 in Japan, and 16 in Korea; Fig. 1, Additional file 1: Table S1) in our model (Table 1).

Climate and environmental variables for modeling

A 30 arc-seconds (c.a. 1 km) unit grid size was used for extracting and modeling data. We used a total of 24 variables in the modeling: 19 climate variables (Bio 1–Bio 19) provided by WorldClim (ver. 1.4, Additional file 1: Table S1) and five environmental variables (see below). Since there were many significant correlations between the extracted climate variables (Pearson's $r > 0.101$, $p < 0.05$, of 128 out of 171 correlation cases), we conducted a principal component analysis (PCA) on the 19 climate variables using the *rasterPCA* function in the *Rstoolbox* (Leutner and Horning 2017), performed in R (ver. 3.4.0; R Core Team 2018). The first two principle components (PCA1 and PCA2) accounted for 99% cumulative variation of the climate data (Additional file 1: Table S1), so

we used these two PCAs in our modeling. The most highly correlated variable to PCA1 was temperature seasonality (Bio 4) and for PCA2 was annual precipitation (Bio 12). To predict the future potential distribution following climate change (Samy et al. 2016), we applied the same PCA analysis rate to the future climate variables. The present climate variables were derived from the past 30-year climate data (1960–1990) and the future climate variables were predicted over the 30-years of 2061–2080, provided by WorldClim (ver. 1.4). As future climate scenarios, we used the Representative Concentration Pathways (RCP 4.5 and RCP 8.5), which adopted the Hadley Center Global Environmental Model ver.2 Earth System (HadGEM2-ES), for predicting future suitable habitat distribution in 2070 (Collins et al. 2011; IPCC 2013).

The five environmental variables used in the model were selected based on previous studies and our expert knowledge from field survey of *G. japonicus*: altitude, slope, land cover type, Normalized Difference Vegetation Index (NDVI), and distance to the nearest urban and built-up area (Fattahi et al. 2014; Zhang et al. 2014; Acheson and Kerr 2018; Kim et al. 2018; Ribeiro et al. 2018). The altitude and slope for each location were extracted from the WorldClim database (ver. 1.4), and the land cover type and distance to the nearest urban and built-up area were extracted from MODIS Land Cover Type Product (MCD12Q1) (source: Global Land Cover Facility, <http://glcf.umd.edu/data/lc/>, Additional file 1: Table S2). NDVI was obtained from the United States Geological Survey (USGS; https://landcover.usgs.gov/green_veg.php). The distance to the nearest urban and built-up area was calculated as the distance between the center of

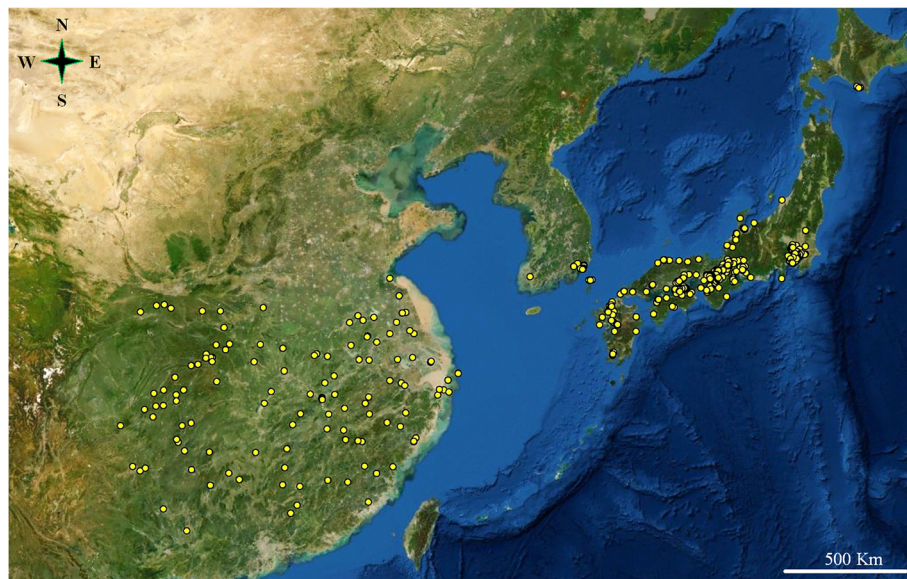


Fig. 1 Presence records of *Gekko japonicus* in China, Japan, and Korea, which were used in the MaxEnt species distribution modeling

the presence-grid square and the boundary of the nearest urban and built-up area using the Euclidean distance tool in ArcGIS (ver. 10.1 ESRI Inc., Redlands, USA). When the center of a presence-grid square was within urban and built-up area, the distance was considered 0 km. The current-state values of the five environmental variables were used for both the present and future distribution models. Overall, climate and environmental variable data for 432 occurrence points, were obtained at present and future (2070) timeframes and used in our modeling design (Additional file 1: Table S3).

Conducting present and future species distribution modeling

We conducted the species distribution modeling for suitable habitats of *G. japonicus* using MaxEnt software (ver. 3.3.3 K) (Phillips et al. 2009). A randomly selected 75% of the presence records were used as training data, while the remaining 25% were used as testing data for model validation (Cianfrani et al. 2010; Berriozabal-Islas et al. 2018). Modeling was replicated 15 times using a bootstrap method, with each replicate having 5000 iterations. The fitness of the model was evaluated by using area under the curve (AUC), which is the area under the receiver operating characteristics (ROC) curve (Jiménez-Valverde 2012). For AUC (range, 0.1–1), the model is more reliable when the value is closer to 1.0. The contribution of the environmental variables to the model was evaluated by the permutation importance of each variable, considering that there were many significant correlations between the variables used in the modeling (Pearson's $r > 0.138$, $p < 0.05$, 11 out of total 15 comparison cases; Fattahi et al. 2014). The independent contribution of each environmental variable to the model was assessed using a Jackknife test for the AUC (Jiménez-Valverde 2012). We set the major suitable habitats to be more than 0.55 probability of presence in the model (Liu et al. 2005; Phillips et al. 2009), taking the average predicted probability of species-presence of the presence records as the 0.55 threshold. The average probability/suitability approach was known as an effective threshold-determining approach (Liu et al. 2005).

In the analysis of the future potential distribution according to the climate change scenarios, we evaluated the effects of climate change on the distribution of *G. japonicus*, analyzing the changes in the major suitable habitat areas between current and future (2070) timeframes.

Results

The present distribution of suitable habitat

The AUC value of the model was 0.936. Major suitable habitats were found in 62,297 out of evaluated 4,491,379- km^2 grid squares (1.4%). By country, Japan had 69.3% (43,176 km^2) of the major suitable habitats, followed by China with 27.1% (16,895 km^2), and Korea with 4.2% (2624 km^2).

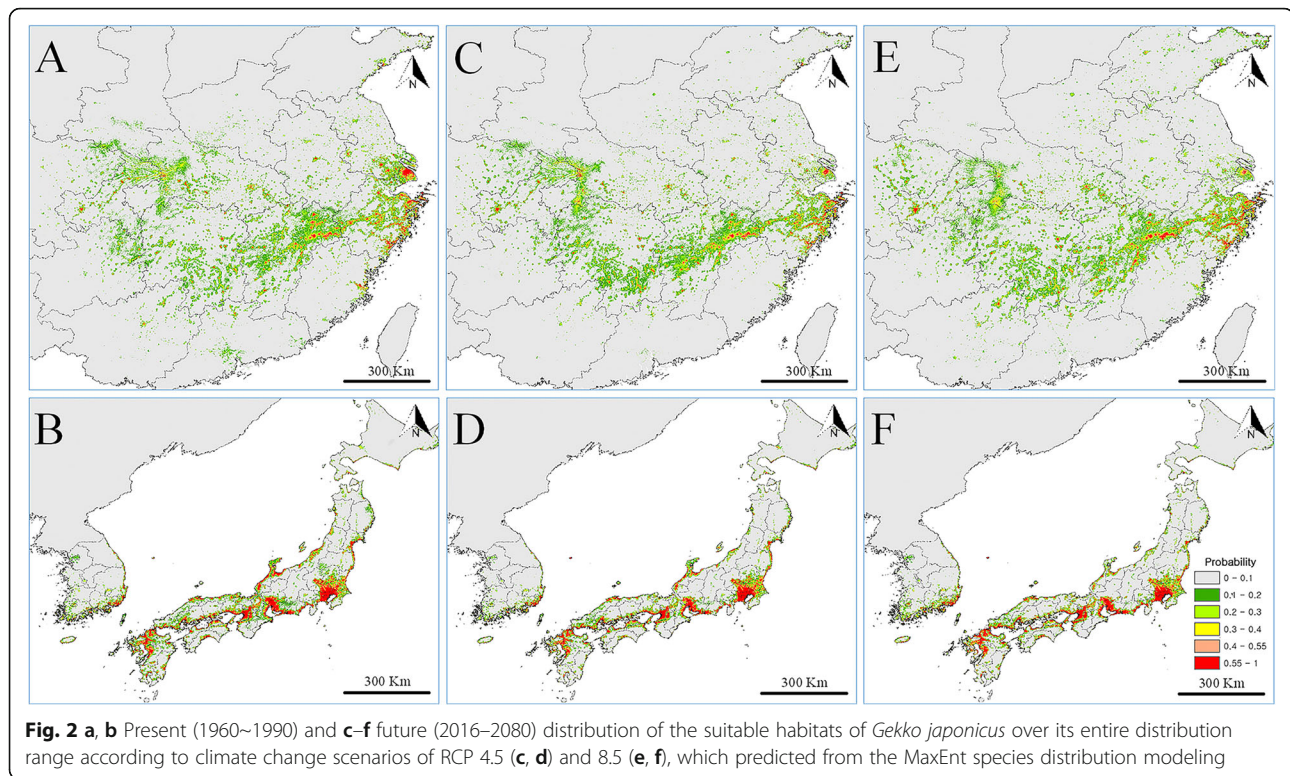
Most major suitable habitats were located in urban areas such as coastal (Shanghai and Ningbo) and inland cities (Chongqing, Yingtian, and Quzhou) in China; western, southern, and northern coastal cities (Fukuoka, Osaka, Nagoya, and Kyoto) of Kyushu and Honshu in Japan; and at southeastern coastal cities (Busan and Changwon) in Korea (Fig. 2a, b). In the non-urban areas, major suitable habitats were sporadically found in the mid-western inlands of China and suburban areas of Japan. Also, suitable habitats were predicted where *G. japonicus* is previously unrecorded, in Qingdao, China, and Jeju Island and southeastern cities (Pohang and Ulsan) in Korea (Figs. 1 and 2a, b).

We list the major environmental variables in order of permutation importance: climate PCA1 (66.5%), altitude (13.0%), distance from the urban and built-up area (9.3%), slope (4.3%), climate PCA2 (4.2%), NDVI (1.4%), and land cover type (1.4%). In the response curves of the variables, greater habitat suitability was predicted at middle values of climate PCA1, climate PCA2, and NDVI, while that was at lower of altitude and higher of slope (Additional file 1: Figure S1). In the Jackknife tests, when each variable independently evaluated for its model contribution, the two variables with the greatest contribution were distance to nearest urban and built-up area and climate PCA1. When each variable was independently evaluated through the omitting process, climate PCA1 had the greatest effect on the distribution model (Additional file 1: Figure S2).

Future distribution according to climate change

In 2070 based on RCP 4.5, suitable habitats will decrease by 18.4% (11,463 km^2) compared to the present habitats (Fig. 2a–d). For individual countries, habitats will decrease by 19.8% (3545 km^2) in China, 16.3% (7038 km^2) in Japan, and 12.5% (328 km^2) in Korea. In China, suitable habitats are expected to decrease in and around Shanghai and Huangshan Mountain, but increase in coastal (Taizhou) and inland (Chongqing, Yichang, Suzhou, and Quzhou) cities. In Japan, a decrease of suitable habitats are predicted in northern coastal cities of Honshu (Niigata, Kanazawa, and Toyama) and southern areas (Kyushu and Shikoku), and eastern coastal cities (Nagoya and Fukushima). In Korea, decrease is predicted in a coastal city (Ulsan) (Fig. 2c, d).

In 2070, based on RCP 8.5, suitable habitats are predicted to decrease by 10.4% (6479 km^2) compared to the present habitats (Fig. 2a, b, e, f). In China and Japan, the habitats are predicted to decrease by 5.5% (929 km^2) and 14.8% (6390 km^2), respectively, while in Korea, increase by 22.3% (585 km^2). Decrease of the suitable habitats in China is greater in Shanghai and Huangshan Mountain areas, while increases of the habitats are more evident in inland cities such as Chongqing and Quzhou and eastern coastal cities such as Ningbo and Taizhou. In Japan, some increase is predicted in Fukuoka, but even greater



decreases are expected in northern coastal cities of Honshu and in Fukushima and Tokyo. Unlike China and Japan, suitable habitats in Korea are predicted to increase in major coastal (Busan, Changwon, and Kimhae) and inland cities (Gwangju and Daegu) (Fig. 2e, f).

Discussion

In this study, we predicted the current and future distributions of *G. japonicus*. Current predictions identified suitable habitats in large or mid-size cities along the eastern coast and inland areas of China; western, southern, and northern coastal cities of Honshu and Kyushu in Japan; and in southern coastal cities of Korea. More than 69% of current suitable habitats were found in Japan. Temperature seasonality (climate PCA1), altitude, and the distance to the nearest urban and built-up area were major determinants of the distribution. Following climate change, decreases of suitable habitats are predicted to occur in some major coastal habitats of China and Japan, but partial increases are also expected in inland areas of China and southern parts of Korea.

The distribution of suitable habitats of *G. japonicus* can be described as coastal cities and isolated non-urban areas, regardless of country. These results show that *G. japonicus* is well adapted to urban ecosystems, where favorable environments are available, such as a variety of shelters, low predation rates, and abundant food supplies (McKinney 2002; Parris 2016; Kim et al. 2018, 2019). *Gekko*

japonicus seems to fit the concept of a synurbic species or urban dweller—when the distributional range is wider and the population density is greater in a city compared to natural areas (Francis and Chadwick 2011; Fischer et al. 2015). Although it is not known how many populations are still present in natural areas and the level of genetic diversity in urban populations, urban cities seem to be important habitats for *G. japonicus*. Studies on the basic ecology and genetic diversity of *G. japonicus* in isolated, non-urban areas (e.g., inland areas of China and suburban areas in Japan) are needed because these populations might represent pre-urban, wild populations of the species (Wada 2003). Furthermore, presence of *G. japonicus* populations in Qingdao city in China, where commercial trade is active among China, Japan, and Korea (Mitsuhashi et al. 2005), may represent potential anthropogenic dispersal routes of the species among the countries.

In the modeling, key environmental variables determining distributions of suitable habitats included climate PCA1 (mostly represented by temperature seasonality; annual standard deviation in temperature), altitude, and the distance to the nearest urban and built-up area. In nocturnal ectothermic species, appropriate temperature conditions guarantee nocturnal activity and winter hibernation and is crucial for their distribution (Angilleta jr et al. 1999; Park et al. 2019). Similarly, climate PCA1 explained more than 66% of the suitable habitat distribution of nocturnal *G. japonicus*. Previous studies observed

that low winter temperature reduced the survivorship of introduced Burmese pythons (*Python bivittatus*) in Florida (Mazzotti et al. 2011), and limited expansion of introduced many-lined sun skinks (*Eutropis multifasciata*) to lower altitudes in Taiwan (Lin et al. 2019). Second, the importance of low altitude seems to be related to the nocturnal lifestyle and interspecific competition of *G. japonicus*. *G. japonicus* seems to prefer lowlands where night temperature are higher relative to the highlands. In a recent radio-tracking study, *G. japonicus* used only lowland areas as habitats (Park et al. 2019), although both lowland and highland forests were available. Interspecific competition between *G. tawaensis* and *G. japonicus* may also restrict the species to lowland areas (Toda et al. 2003). Third, the importance of the distance to the nearest urban and built-up area might reflect favorable urban environmental conditions for *G. japonicus*, such as abundant refuges, food, and mild temperatures (McKinney 2002; Parris 2016). In other words, a combination of favorable elements in urban environments likely contributes to *G. japonicus* flourishing in cities. In general, when considering that climate change affects cities greater than natural habitats (McCarthy et al. 2010), suitable habitats located in urban areas are highly vulnerable to future climate change.

Although a partial increase in suitable habitats is predicted in some parts of Korea and China, an overall decrease is expected across *G. japonicus* range due to climate change. Effects of climate change on the distribution of lizards are somewhat controversial, having both positive and negative effects depending on species (Huey and Tewksbury 2009; Sinervo et al. 2010; Bonino et al. 2015; Weterings and Vetter 2018). Three major patterns are predicted due to climate change in our modeling. First, suitable habitat is expected to almost disappear (RCP 8.5; 2070 projections) at the frontier zone of climate change: coastal areas of China (Shanghai and neighboring areas) and northern coastal areas of Honshu, Japan (Kanazawa, Niigata, and Toyama). Losing these major habitats would likely cause population size to decrease in these areas. Such large climatic effects at the front distribution-range edge of the climate change zone are predicted in other reptile species (Sinervo et al. 2010; Rehm et al. 2015). Second, the size of suitable habitats in large cities will decrease. These reductions are evident in Shanghai, Nagoya, Fukushima, and Tokyo. Considering that climate change generally impacts cities more severely than natural areas (McCarthy et al. 2010), our results suggest that if the appropriate habitat is not maintained or provided for *G. japonicus*, the population size of *G. japonicus* in urban areas will greatly decrease in the future due to climate change. Third, some increases in suitable habitats are predicted in China (Chongqing, Yingtan, and Quzhou) and Korea (Busan, Ulsan, Daegu, and Gwangju). Unfortunately, such increases are relatively small

and will not compensate for the decreases of suitable habitats in other regions (see above) (Fig. 1). This result also shows that, depending on the region, climatic changes can cause the partial expansion of suitable habitat area (Parmesan 2006; Bonino et al. 2015) and these regions might function as potential refuges for preservation of the species under rapidly changing climate.

Conclusions

In conclusion, we predicted the present and future distributions of *G. japonicus*. Predicted suitable habitats for the present are located in coastal cities of Japan, China, and Korea, as well as isolated patches of inland China. Important variables influencing distribution were temperature seasonality, altitude, and the distance to the nearest urban and built-up area, which might be related to lowland, coastal environmental conditions. Following predicted scenarios of climate change, suitable habitat is expected to shrink along coastlines, particularly at the coastal-edge of climate change zone. Overall, our results provide essential distribution range information for future ecological studies of *G. japonicus* across its distribution range.

Supplementary information

Supplementary information accompanies this paper at <https://doi.org/10.1186/s41610-020-0147-y>.

Additional file 1: Table S1. Description of the 19 climate variables and their component score coefficient matrix from the principal component analysis (using the *RStoolbox* package of the statistical program R) of the climate variables. **Table S2.** The MODIS Land Cover Type Product (MCD12Q1) codes and the labels for each code. **Table S3.** Raw data of the environmental and climate variables, used in *Gekko japonicus* distribution modeling at present and future. **Figure S1.** Response curves of the seven important environmental variables that affect the distribution of suitable habitats of *Gekko japonicus*: A) Climate PCA1 (temperature seasonality), B) Altitude, C) Distance to the nearest urban and built-up area, D) Slope, E) Climate PCA2 (annual precipitation), F) Land cover type (MCD12Q1), and G) NDVI. **Figure S2.** Jackknife evaluations of the relative importance of the seven variables affecting the distribution of suitable habitats of *Gekko japonicus*.

Abbreviations

AUC: Area under the curve; MaxEnt: Maximum entropy; MCD12Q1: MODIS Land Cover Type Product; MODIS: Moderate resolution imaging spectroradiometer; NDVI: Normalized Difference Vegetation Index; PCA: Principal component analysis; RCP: Representative Concentration Pathway; ROC: Receiver operating characteristics

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Authors' contribution

DIK, IKP, SYB, and DP designed the study, performed the analysis, and wrote the manuscript. YPZ, SRL, and JSK gathered the data and reviewed the manuscript. JJF and HO conceived the study and reviewed the manuscript. DIK and IKP made equal contributions to this study. All authors read and approved the final manuscript.

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Availability of data and materials

The datasets generated during and/or analyzed during the current study are available from supplementary tables.

Ethics approval and consent to participate

This research was conducted within the guidelines and approval of the Institutional Animal Care and Use Committee of Kangwon National University (KW-161128-2).

Consent for publication

Not applicable

Competing interests

The authors declare that they have no competing interests.

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