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MODELING HABITAT SUITABILITY TO PREDICT THE POTENTIAL DISTRIBUTION OF THE KELUNG CAT SNAKE *Boiga kraepelini* STEINEGER, 1902

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Predictive species distribution modeling is a valuable tool for decision-making in different fundamental and applied fields of study and conservation of biological diversity. Predictive models of species distribution expected to be useful for understanding of actual distribution of rare and cryptic species, including many snake species. This study employs one recently proposed modeling technique, MAXENT (http://www.cs.princeton.edu/~schapire/maxent) to investigate the geographic distribution pattern of Square-headed Cat Snake, or Kelung Cat Snake, *Boiga kraepelini* Stejneger, 1902. Constructed model identified dissemination of *B. kraepelini* enough performance: for Vietnam's part of distribution range AUC = 0.945 with dispersion 0.031; for Taiwan's part of distribution range AUC = 0.960 with dispersion 0.002; for entire distribution range AUC = 0.996 with dispersion 0.001. According to the map constructed, the most suitable habitats of *B. kraepelini* in Taiwan are located throughout the island except high elevation in the central mountain regions, and extreme north-western coastal regions. The most suitable habitats in continental part are located in northern and central Vietnam and bordering regions of Laos; predictive potential distribution in continental part was also revealed in Yunnan, Sichuan, Guangdong, Fujian and Guizhou provinces.

Keywords: Eastern Asia; Colubridae; Potential species distribution modeling; *Boiga kraepelini*; MAXENT modeling.

INTRODUCTION

Predictive potential distribution modeling is of increasing value in modern herpetological studies in many fundamental and applied aspects: biogeography, ecology (contribution to ecological niche theory), biodiversity conservation, monitoring and forecast of invasion of alien species as well as increasingly fragmented ranges of threatened and endangered species (Elith et al., 2006; Phillips and Dudík, 2008; Rödder and Lötter, 2010; Bernardes et al., 2013).

The most important positive feature of MAXENT as a modeling technique is an opportunity to transform the problem of "habitat models" in quantitative verifiable level, and quantify the ratio of historical and competitive factors as well as ratio of potential and actual habitats in the formation of the range (Lissovsky and Obolenskaya, 2014).

Practical testing of species distribution modeling or niche modeling has been successfully made for many groups of organisms. This method is frequently used for determination of contribution of environmental priorities and provides successful results of distribution and environmental suitability analysis in many groups of animals such as amphibians (Litvinchuk et al., 2010; Barabanov and Litvinchuk, 2015), agamid (Ananjeva and Golynsky, 2013; Hosseinian et al., 2013; Ananjeva et al., 2014), and lacertid lizards (Kaliontzopoulou et al., 2008; Doronin, 2012; Sillero and Carretero, 2013; Oraie et al., 2014). Predictive models of species distribution are considered as especially perspective for estimation of actual and potential distribution of rare, threatened and poorly known species including many snake species. Some important results of an application of Maximum entropy modeling are referred to alien invasive Brown tree snake, *Boiga*

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irregularis (Beshtein, 1802) (Rödder and Lötters, 2010), Southern smooth snake, *Coronella girondica* (Daudin, 1803) (Bombi et al., 2010), Orsini's viper, *Vipera ursinii* (Bonaparte, 1835) (Lyet et al., 2013), 39 species of New World coral snakes (genera *Micrurus* Wagler 1824, *Micruroides* Schmidt, 1928, and *Leptomicrurus* Schmidt, 1937, including 6 species from North America, 7 from Central America and 26 from South America) (Terribile et al., 2010), and Eastern Hog-nosed Snake, *Heterodon platirhinos* Latreille, 1801 in Ontario, Canada (Thomasson and Bloudin-Demers, 2015). Comparison of congener's potential distribution deals only with one species, the Alien Invasive Brown Tree Snake, *B. irregularis*. The authors investigate the potential invasive range of this species (Rödder and Lötters, 2010) and showed that "annual precipitation" with 33.3% has the highest explanative power, followed by "maximum temperature of the warmest month" (28.5%), "annual mean temperature" (13.8%), "precipitation of the driest month" (11.7%), "precipitation of the wettest month" (7.7%), and the "minimum temperature of the coldest month" (4.9%). Under current climatic conditions it is geographically wide potentially distributed throughout almost all the tropics and adjacent subtropical regions what increases the danger of invasions.

Using MAXENT as the modeling technique and *B. kraepelini* as a model of tropical colubrid snake species we made an attempt to construct a bioclimatic model for East Asian species and compare input of bioclimatic factors in continental and island parts of range. We expect to receive additional information of ecological requirements to predict its potential geographical distribution.

The genus *Boiga* encompasses more than 30 species distributed in the tropics of the Old World. They inhabit tropical rain forests, mangrove thickets and even sandy deserts and dry foothills. In the tropical mountainous forest they go at the altitude up to 3000 m a.s.l. They are nocturnal arboreal snakes. Oviparous, the clutch contains from 5 up to 25 eggs. The majority of species are found in South and Southeast continental and insular Asia, including the Indian subcontinent with Andaman, Nicobar Islands and Sri Lanka, Indochina, Taiwan, southern China with Hainan island, Philippines and Indo-Australian Archipelago; in the north-west boigas reach Iran and Middle Asia. The most northern record of Palearctic species, *B. trigonata melanocephala* is known from Kyzyl-Kum desert in Uzbekistan. One species, *B. irregularis* is introduced into northern Australia and Oceania and was listed among the 100 worst alien invasive species worldwide (Rödder and Lötters, 2010).

In this study we used maximum entropy modeling to study the real and potential distribution of East Asian species, Square-headed Cat Snake, or Kelung Cat Snake, *B. kraepelini* based on geographical distribution data and environmental predictor variables, with the following objectives: 1) to determine how we can use this method for analysis of distribution pattern combining island and continental parts; 2) to determine which environmental factors are correlated with the distribution of this species; and 3) to compare the highest contribution of environmental factors influencing the distribution of this species in island (Taiwan) and continental part of range.

MATERIAL AND METHODS

We combined literature records, localities data on museum specimens from Taiwan and continental eastern Asian part of range stored in California Academy of Sciences (CAS), Zoological Institute, Russian Academy of Sciences (ZISP), Zoological Museum, Moscow State University (ZMMGU), and original data of the field surveys of authors and colleagues to describe the distribution of *B. kraepelini* through its entire range. We also gathered all the available literature records with exact coordinates from Taiwan Roadkill Observation Network (Endemic Species Research Institute of Taiwan, ESRI), Socialist Republic of Vietnam, Lao People's Democratic Republic, and People's Republic of China. The data (Table 1) were used to prepare a new updated distribution map for *B. kraepelini* and served as baseline to build a correlative species distribution model identifying the most suitable areas.

TABLE 1. Bioclimatic Variables Used in MAXENT Modeling

BIO1	Annual average temperature
BIO2	Annual daily temperature difference
BIO3	Isothermal parameter (BIO2/BIO7)(×100)
BIO4	Temperature seasonality (standard deviation * 100
BIO5	Maximum temperature of the warmest month
BIO6	Minimum temperature of the coldest month
BIO7	Annual temperature scale (BIO5-BIO6)
BIO8	Average temperature of the wettest quarter of the year
BIO9	Average temperature of the driest quarter of the year
BIO10	Average temperature of the warmest quarter of the year
BIO11	Average temperature of the coldest quarter of the year
BIO12	Average annual precipitation
BIO13	Precipitation of the wettest month
BIO14	Precipitation of the wettest month
BIO15	Seasonality of precipitation (coefficient of variation
BIO16	Precipitation of the wettest quarter of the year
BIO17	Precipitation of the driest quarter of the year
BIO18	Precipitation of warmest quarter of the year
BIO19	Precipitation of the coldest quarter of the year

TABLE 2. All Coordinate Data for *Boiga kraepelini* for Its Entire Distribution Used in This Study

No.	Latitude	Longitude	Locality
1	21.5000	105.5833	Tam Dao, Vinh Phuc Province, Vietnam
2	23.1833	104.7333	Bat Dai Son Nature Reserve, Ha Giang Pr., Vietnam
3	21.1667	104.5167	Xuan Son National Park, Phu Tho Pr., Vietnam
4	21.2167	106.9667	Yen Tu National Reserve, Bac Giang Pr., Vietnam
5	20.4000	105.5667	Cuc Phuong National Park, Nich Bich Pr., Vietnam
6	20.3722	105.5750	Cuc Phuong National Park, Nich Bich Pr., Vietnam
7	18.9356	104.9333	Pu Mat National Park, Nghe An Pr., Vietnam
8	17.6744	105.9181	Phong Nha-Ke Bang National Park, Quang Binh Pr.
9	20.3506	105.1033	Pu Luong Nature Reserve, Thanh Hoa Pr., Vietnam
10	16.2103	107.8300	Bach Ma National Park, Thua Thien Hue Pr., Vietnam
11	18.2842	105.3686	Vu Quang Nature Reserve, Ha Tinh Pr., Vietnam
12	19.3167	105.0500	Pu Huong Nature Reserve, Nghe An Pr., Vietnam
13	21.1775	106.7992	Yen Ti Nature Reserve, Bac Giang Pr., Vietnam
14	21.0524	107.5958	Bai Tu Long National Park, Ba Mum Isl., Quang Nich Pr., Vietnam
15	21.8669	106.9658	Mau Son Mountain, Lang Son Pr., Vietnam
16	20.6325	105.4219	Tuong Tien Nature Reserve, Hoa Binh Pr., Vietnam
17	21.8642	107.8889	Shiwan Dashang Nature Reserve, Guanxi, China
18	25.2099	121.5109	New Taipei City, San-Zhi District, Taiwan
19	25.1816	121.5707	Taipei City, Shi-Lin District, Taiwan
20	25.1777	121.5647	Taipei City, Shi-Lin District, Taiwan
21	25.1481	121.7770	Keelong City, Zhong-Zheng District, Taiwan
22	25.1201	121.7665	Keelong City, Xin-Yi District, Taiwan
23	25.0622	121.3344	Taoyan County, Gui-Shan Township, Taiwan
24	25.0187	121.5928	Taipei City, Nan-Gan District, Taiwan
25	24.8217	121.1819	Hsinchu County, Guan-Xi Town, Taiwan
26	24.7907	121.3650	Taoyan County, Fu-Xing Township, Taiwan
27	24.6879	121.4031	Taoyan County, Fu-Xing Township, Taiwan
28	24.6292	1213270	Hsinchu County, Jian-Shi Township, Taiwan
29	24.5538	121.4866	Yi-Lan County, Da-Tong Township, Taiwan
30	24.5397	121.4563	Yi-Lan County, Da-Tong Township, Taiwan
31	24.4238	120.6938	Miaoli County, Yuanli Township, Taiwan
32	24.2329	121.0820	Taichung City, He-Ping District, Taiwan
33	24.1778	121.5186	Hualien County, Xiu-Lin Township, Taiwan
34	24.1729	121.5622	Hualien County, Xiu-Lin Township, Taiwan
35	24.0507	120.9350	Nantou County, Guo-Xing Township, Taiwan
36	23.9796	120.8694	Nantou County, Guo-Xing Township, Taiwan
37	23.8546	120.8383	Nantou County, Ji-Ji Township, Taiwan
38	23.6252	121.5018	Hualien County, Feng-Bin Township, Taiwan
39	23.5213	120.4607	Nantou County, Zhong-Liao Township, Taiwan
40	23.4766	120.4703	Jiayi City, East District, Taiwan
41	23.4619	120.5952	Jiayi County, Fan-Lu Township, Taiwan
42	23.4533	120.5615	Jiayi County, Fan-Lu Township, Taiwan
43	23.2792	120.4985	Tainan City, Dong-Shan District, Taiwan
44	23.2380	120.3770	Tainan City, Liu-Jia District, Taiwan
45	23.2362	120.3860	Tainan City, Liu-Jia District, Taiwan
46	23.2346	120.4142	Tainan City, Liu-Jia District, Taiwan
47	23.2251	120.3662	Tainan City, Liu-Jia District, Taiwan
48	23.2050	120.1796	Tainan City, Xin-Hua District, Taiwan
49	23.1597	121.0531	Taidong County, Ha-Rei Township, Taiwan
50	23.0703	120.3775	Tainan City, Zuo-Zheng District, Taiwan
51	23.0631	120.5643	Kaohsiung City, Jia-Xian District, Taiwan
52	23.0171	120.6930	Kaohsiung City, Taoyan District, Taiwan
53	23.0083	120.3837	Tainan City, Xin-Hua District, Taiwan
54	23.0069	120.4148	Tainan City, Zuo-Zheng Distrcit, Taiwan
55	22.9012	121.1734	Taidong County, Yan-Ping Township, Taiwan
56	22.8344	121.0086	Taidong County, Bei-Nan Township, Taiwan
57	22.7735	121.0618	Taidong County, Bei-Nan Township, Taiwan
58	22.4123	120.7417	Pingdong County, Chun-Ri Township, Taiwan
59	22.0498	120.6989	Pingdong County, Che-Cheng Township, Taiwan
60	22.0206	120.8496	Pingdong County, Man-Zhou Township, Taiwan
61	21.9579	120.8096	Pingdong County, Heng-Chun Township, Taiwan
62	21.9460	120.8565	Pingdong County, Heng-Chun Township, Taiwan
63	24.1853	120.7353	Hill in Dakeng, Taichung County, Taiwan

Maximum Entropy modeling (MAXENT) was used to assess the potential distribution of *B. kraepelini* in Eastern Asia. MAXENT combines distribution data with environmental factors and assesses the probability of presence of one species in a given cell on the basis of environmental features in that cell. The model was fitted using linear, quadratic and hinge features.

In present paper, the records from 63 localities from Taiwan, Socialist Republic of Vietnam, and People's Republic of China were analyzed (Table 2). The absolute majority of records with exact localization refer to Taiwan (island part of range) and Vietnam (continental part of area). In the latter have the exact geographical coordinates of 17 localities concentrated mainly in Vietnam. In Vietnam, *B. kraepelini* has been reported from Cao Bang (Nguyen Binh), Lang Son (Mau Son), Vinh Phuc (Tam Dao), Nghe An (Pu Mat), Ha Tinh (Ky Anh), and Thua Thien-Hue (Hai Van Mt.) (Nguyen et al., 2009). Some additional records for Bac Giang Province (Tay Yen Tu Nature Reserve) and for Hoa Binh Province (Thuong Tien Nature Reserve) were reported by Ziegler et al. (2010). In China the species occurs in the southern regions including Hainan westward to Sichuan and Guizhou. We used data from 19 and 27 parameters obtained from WorldClim database (http://www.worldclim.org/current) and CliMond database (http://www.climond.org) with resolution of geospatial layers 30″, or 1 km for pixel and 10′, or 20 km for pixel, respectively, as well as the geographic coordinates of 63 known locations records collected in different periods.

Initially we plan to separate 27 bioclimatic parameters in two groups due to specifity of MAXENT program, to create the primary predictions of habitat selection, and to organize into a separate group of those parameters which contribution to the forecasts amounted as minimum as 10%. The next stage expected to be a re-forecasting using a selected group, correlation analysis and construction of final prediction. Initially we try to construct the model (Fig. 3) using the complete set of data and using five of the six parameters (Table 3); parameter of minimum temperature in the coldest month was excluded due to the fact that for both Taiwan and continental part its value is very low.

The first stage of our work resulted to construction of the map of potential distribution which does not correspond to real and predicted range of *Boiga kraepelini*. In particular, the resulting map of the continental part was greatly reduced and range on Taiwan was seriously distorted. For explanation of this model deformation two hypotheses has been considered: errors occur 1) due to very low resolution maps (20 km per pixel from CliMond database; 2) due to fact that relevant factors from one part of the area has a strong influence on the construction of the forecast in another part where they in reality are not so important; it is associated with prevalence of statistic data from Taiwan.

To test the first hypothesis layers were taken from another resource (http://www.worldclim.org) with high resolution (30″ or 1 km per pixel) which allows analyzing the distribution not only in entire range, but for both parts of the range separately. To test second hypothesis we randomly reduced the number of localities from Taiwan to get a roughly equal comparable number of localities from both parts of the range. If second assumption will be refuted it could be possible to speculate that actual differences in biological requirements of *B. kraepelini* in its habitats in Taiwan and continental part of range make impossible to combine two datasets. According to our test deformations of range is not associated with an influence of predominance of Taiwan data and such an assumption should be refuted. We prefer to believe that actual differences in biological requirements of *B. kraepelini* in Taiwan and continental part of range make impossible to combine two datasets. Different limiting bioclimatic factors are of different value in Taiwan and continental parts of range.

In the model, we used accessibility (Nelson, 2008; Uchida and Nelson, 2010) as a measure of sampling bias and a logistic output, with MAXENT suitability ranging from zero (no suitability) to one (maximum suitability).

RESULTS

We obtained 63 records of *Boiga kraepelini* in island and continental Eastern Asia. Its type locality is Kelung (= Keelung or Chilung), Formosa (= Taiwan), Taiwan. This snake is known from China, Taiwan, Vietnam and Lao PDR on the altitudes from 100 to 2000 m a.s.l. (Uetz and Hošek, 2015; Zhou and Lau, 2012).

Comparison of the two methodical approaches demonstrated greater reliability for separate analysis of the insular and continental parts of the range. The results confirm the known distribution of *B. kraepelini*. Predictive potential distribution in continental part was revealed in Yunnan, Sichuan, Guangdong, Fujian and Guizhou provinces and Hainan Island, northern and central Vietnam and bordering regions of Laos. Since according to our test deformations of range is not associated with an influence of predominance in the sample of Taiwan data such an assumption should be refuted. Different limiting bioclimatic factors are of different value in Taiwan and continental parts of range.

Forecasts were made for continental and island (Taiwan) parts of the range from 19 bioclimatic parameters (Table 1). As a result of our test it has been shown that

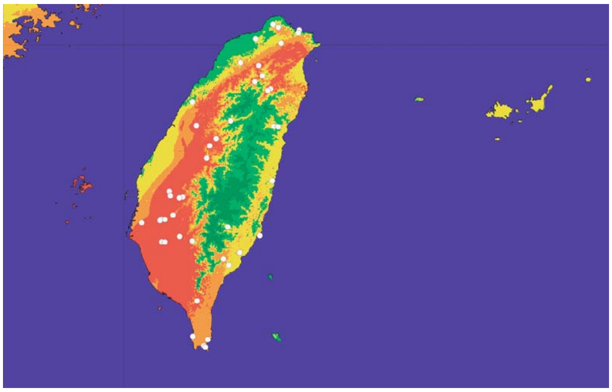

Fig. 1. Potential distribution modeling of *Boiga kraepelini* in Taiwan obtained with MAXENT 3.3. 3k. Colors in the map designate different suitability values: high (100 – 74%; red), medium (74 – 56%; orange), low (56 – 37%; yellow), and extremely low (37 – 19%; light-green). Localities are marked by white circles.

three parameters make a maximum contribution to the model for final prediction: the average daily temperature difference, isothermal parameter and annual temperature scale for continental part; temperature seasonality, precipitation of warmest quarter of the year, and the minimum temperature in the coldest month. The contribution of the last parameter was low amounted to 8.8% and it was not used in the best model (Table 3). Constructed model identified dissemination of *B. kraepelini* enough performance: for Vietnam's part of distribution range AUC = 0.945 with dispersion 0.031; for Taiwan's part of distribution range AUC = 0.960 with dispersion 0.002. Difference in dispersion could be explained by fact that the continental sample was significantly lesser than that of Taiwan, hence the index AUC is somewhat lower and deviation much higher.

According to the model the most suitable habitats of *B. kraepelini* in Taiwan are distributed throughout different parts of island with the exception of the highest area of the Central Mountain Range and the Hsuehshan Mountain Range, and extreme north-western coastal regions (Figs. 1 and 4).

The forecast for the mainland part will recognize some probability of occurrence in Yunnan, Sichuan, Guangdong, Fujian and Guizhou provinces, where it was earlier noted by some specialists however without exact localities (Figs. 2 and 4).

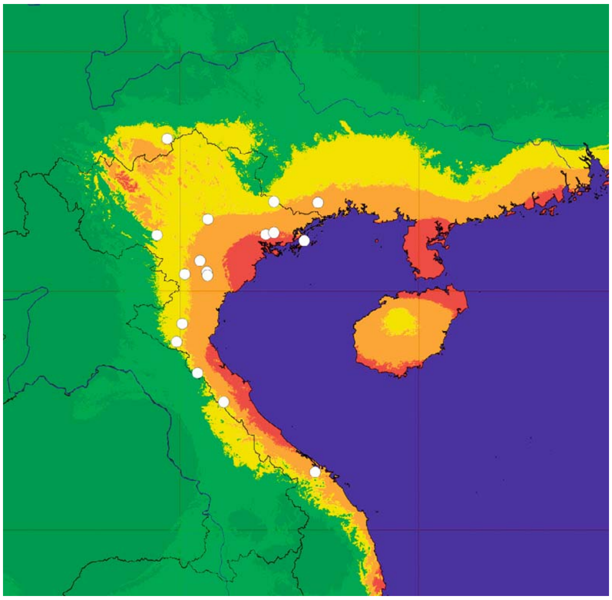

Fig. 2. Potential distribution modeling of *Boiga kraepelini* in continental Eastern Asia obtained with MAXENT 3.3.3k. Colors in the map designate different suitability values: high (100 – 74%; red), medium (74 – 56%; orange), low (56 – 37%; yellow), and extremely low (37 – 19%; light-green). Localities are marked by white circles.

Also, according to the MAXENT model there is high probability of record in Hainan Island, where sometime this forest snake was probably numerous, and in the coastal areas of central Vietnam (provinces of Quang Nam, Qung Nai) and Laos.

AUC reliability index for this whole range forecast had a very high value (AUC = 0.996 with dispersion 0.001). However the resulting model of potential distribution looks doubtful (Fig. 3): in particular there were shown no records of *B. kraepelini* in mainland southeastern China; one of the centers was shown to be located as Fansipan Mountain; the area of potential habitat in the southern part in Northern Vietnam, in Central Vietnam and Laos was greatly reduced.

TABLE 3. Relative Importance of Variables Included in the Best Model

	Taiwan	Continental Eastern Asia	Entire range
BIO2 (Annual daily temperature difference)		21.4	9.9
BIO3 [Isothermal parameter (BIO2/BIO7)(×100)]		40.1	8.6
BIO4 [Temperature seasonality (standard deviation × 100)]	70.2		6.1
BIO7 (Annual temperature scale (BIO5-BIO6))		38.5	3.5
BIO18 (Precipitation of warmest quarter of the year)	21		71.9

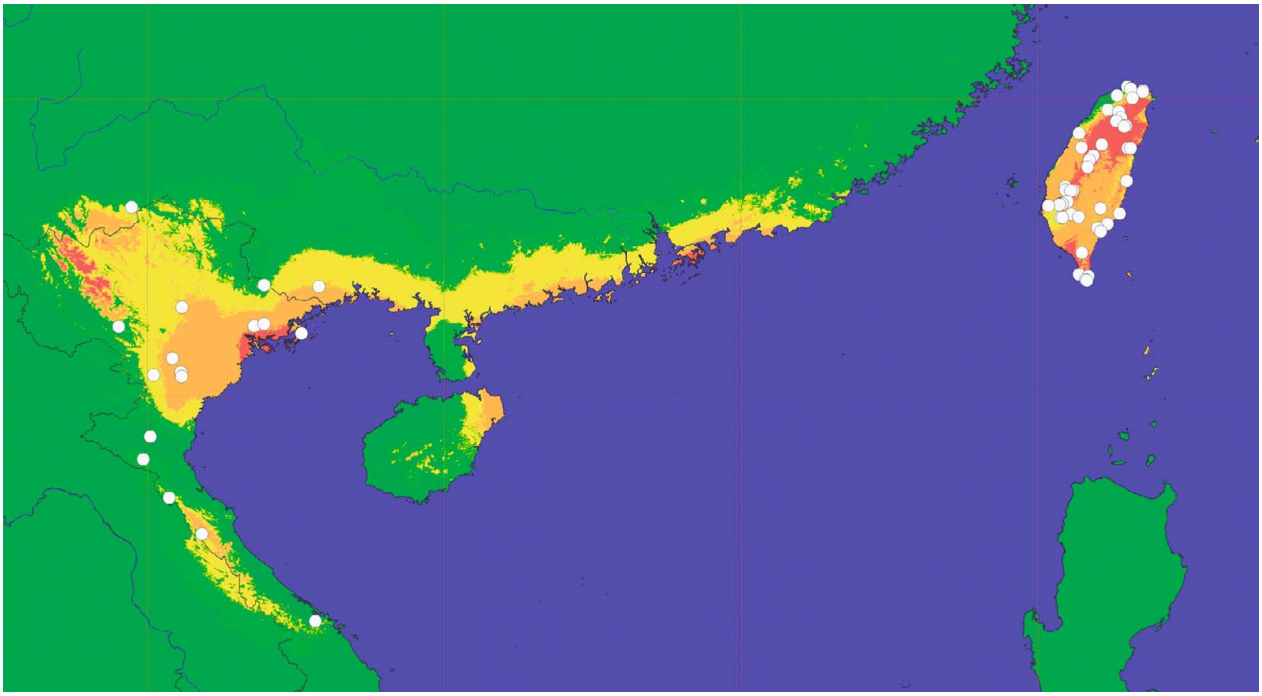

Fig. 3. Potential distribution modeling of *Boiga kraepelini* for entire distribution range. Colors in the map designate different suitability values: high (100 – 74%; red), medium (74 – 56%; orange), low (56 – 37%; yellow), and extremely low (37 – 19%; light-green). Localities are marked by white circles.

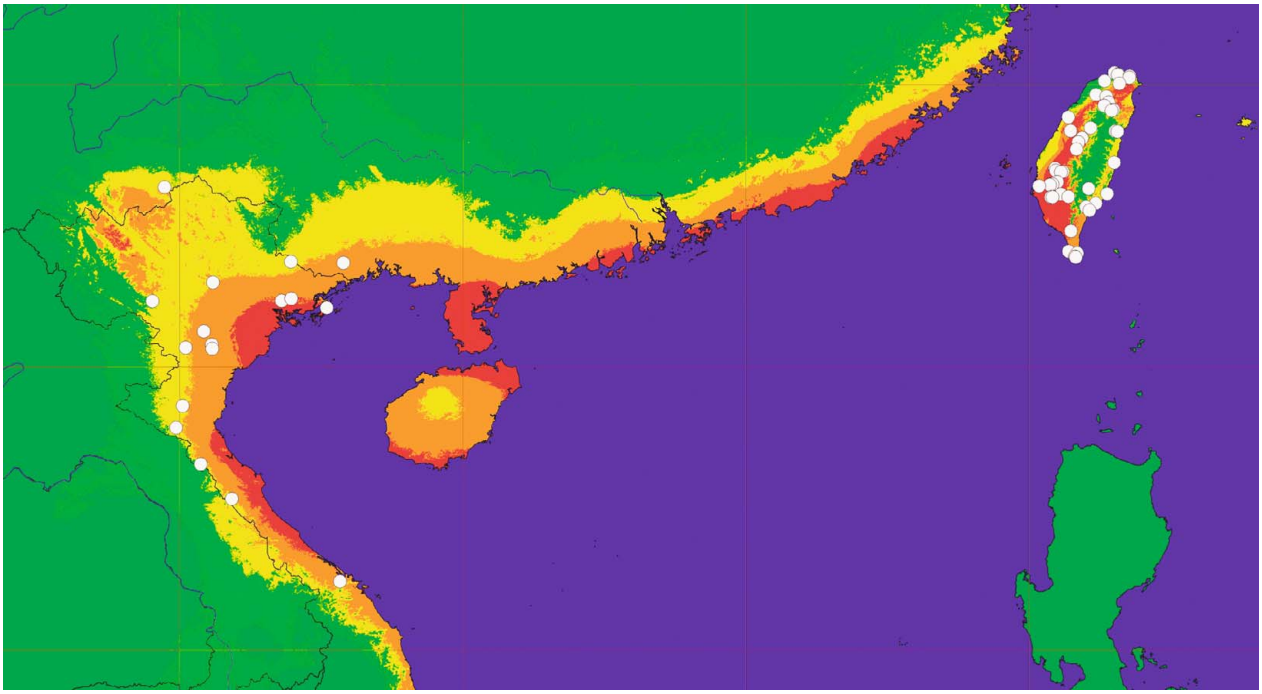

Fig. 4. Consolidated distribution model of *Boiga kraepelini* in Eastern Asia. Colors in the map designate different suitability values: high (100 – 74%; red), medium (74 – 56%; orange), low (56 – 37%; yellow), and extremely low (37 – 19%; light-green). Localities are marked by white circles.

Fig. 5. *Boiga kraepelini*. Taiwan.

Constructed model of whole range demonstrates serious misstatement of actual and potential distribution in Taiwan too: it indicated that entire territory of island is occupied by suitable habitats for *B. kraepelini*.

DISCUSSION

Boiga kraepelini was described from Kelung (= Keelung or Chilung), Formosa (= Taiwan) by Steineger in 1902. Vogel (1994) showed on the base of pholidosis analysis that the name *B. multitemporalis* Bourret, 1935 described from Tam Dao, Vietnam is a junior synonym for *B. kraepelini*. Biology of this colubrid snake is poorly studied. It inhabits Taiwan (Fig. 5), southern China (including Hainan, westward to Sichuan and Guizhou), northern and central Vietnam (Fig. 6) and Laos. Listed as Least Concern on the basis that, although its forest habitat is under pressure from varied human activities throughout its range, it occurs over a wide area and is not thought to be declining fast enough (populations are largely stable) to warrant listing in a more threatened category (Zhou and Lau, 2015).

Fig. 6. *Boiga kraepelini*. Ha Tinh Province, Vietnam.

Our study constructs the first reliable model of its actual and potential distribution (Figs. 1 – 3). Analysis of relative importance of variables included in the best model show differences in two parts of range. Combination of models for both parts demonstrates the high importance (71.9) of Bio18 parameter — Precipitation of warmest quarter of the year (Table 3); the same parameter is important for distribution range in Taiwan. Among five important factors there are four temperature parameters which are key factors affecting ectothermic species like reptiles. Boiga's distribution covers not only the northern part of Taiwan as it was erroneously noted in Reptile Database (Uetz and Hošek, 2015) but recorded throughout different parts of island except the highest region of the Central Mountain Range and the Snowy Mountain Range, and the north-western coastal regions (Fig. 1).

Comparison of the known and potential pattern showed that according to the known records the northern distribution limit passes through Guanxi Province that approximately corresponds to the forecast in the model. With lower probability we can expect the findings in Yunnan, Sichuan, Guangdong, Fujian and Guizhou provinces (Fig. 2). In addition, in the continental part of the area there is some probability of potential distribution in suitable habitats (if any) along the coastline of the South China Sea.

The same potential areas of distribution are constructed in our model (Figs. 2 and 4) southwards from known range in Vietnam (Thua Thie-Hue Province) along the coastline of the South China Sea where total deforestation took place nowadays. We can explain this pattern by the fact that it corresponds to average January

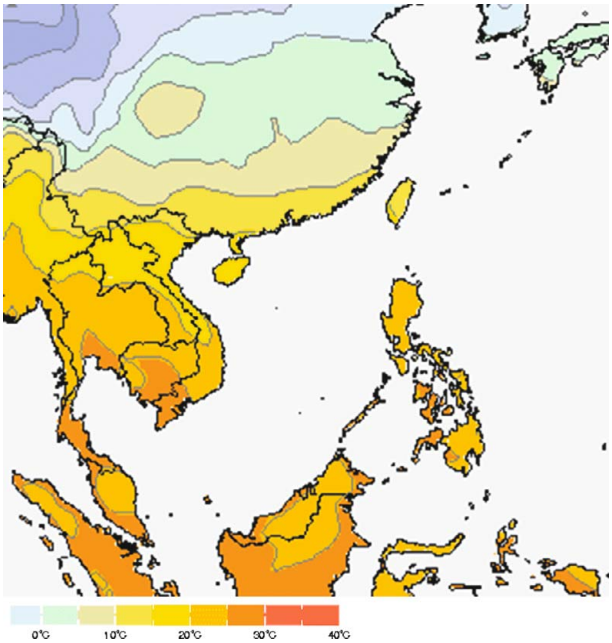

Fig. 7. January isotherms in Southeast Asia.

temperature, 15 – 20°C (Fig. 7) which could be considered as limiting factor for snake distribution.

Our experience in model constructing using two data sets from different parts of the area is methodologically useful. Result of the analysis of whole data set looks incorrect in the light of the known data on the distribution and ecology of the species. Testing hypotheses about the causes of a possible deformation due to the errors of the very low-resolution maps (20 km per pixel) or the impact of a larger sample to forecast of the other, we have shown that it is more correct to use the data WorldClim database (http://www.worldclim.org/current). It also was shown that the random alignment of sample sizes of the two parts of the range does not influence the results of the forecast, which confirms the assumption that the different habitat conditions and bioclimatic requirements of boiga's populations in the two different parts of the range are of greater importance.

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