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Modeling the geographic distribution of the epiphytic moss *Macromitrium japonicum* in China

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Using 76 presence-only data, altitude, percent tree cover and 11 bioclimatic variables, we modeled the geographical distribution of *Macromitrium japonicum* in China with an aid of a maximum entropy algorithm modeling program (MaxEnt). We found habitats suitable for *M. japonicum* in the major mountains in southeastern, southern, and southwestern China, and also in the Changbai Mountains, Taihang Mountains, Yanshan Mountains, Tainwan and Hainan Island. With increasing percent of tree cover, mean temperatures in the driest quarter, the warmest quarter and the coldest quarter, and with decreasing annual temperature range and mean diurnal temperature range, habitat suitability for *M. japonicum* increases. The MaxEnt model also indicated that areas with precipitation of the wettest month being 300 mm, and precipitation of the warmest quarter being 500–600 mm are favourable for *M. japonicum*. It also favours lower altitudes (0–1000 m a.s.l.), while with increasing altitude (from 1000 to 6000 m a.s.l.), habitat suitability decreases. Habitat suitability for *M. japonicum* firstly increases rapidly with increasing precipitation in the driest month and the coldest quarter at lower altitudes, and then slightly increases after the factors exceed a certain threshold value.

Introduction

Information on the geographic distribution and potential habitats for bryophytes is essential for their conservation and management. However, distribution data for bryophytes are usually not available and acquiring such data is laborious and complex. With the advent of Geographical Information Systems (GIS), numerous mathematical techniques have been developed to predict the geographical distribution of a given species (Soberón & Peterson 2005). Combined with GIS tools, the models generate maps with areas where the habitats (defined by data sets representing several ecological factors) are most similar to those at the localities where the species have been found. Among these models, MaxEnt (maximum entropy algorithm modeling program) has been widely used in recent studies (Elith *et al*. 2006, Phillips *et al*. 2006).

As compared with other higher plants, bryophytes are poorly known. Due to the lack of information on the distribution, and habitats potentially hosting a given bryophyte species, important regions for bryophyte conservation may be difficult to identify at the country scale. Moreover, as the number of biologists involved in biodiversity studies and habitat assessment is very low considering the magnitude of the task, predictions using GIS and mathematical techniques may help focusing attention on regions with environments and habitats for subsequent field investigation. In fact, Kruijer *et al*. (2010) used MaxEnt to predict the potential distribution ranges of *Hypopterygium tamarisci* in Central and South America, and found that the predicted distribution ranges of the species matched the actual collecting localities very well.

Macromitrium japonicum, an obligate epiphytic moss belonging to the family Orthotrichaceae, has many records from China. The species is of ecological value when assessing forest health. The International Union for Conservation of Nature (IUCN) has paid attention to the conservation of the species of *Macromitrium*. Therefore, geographical distribution prediction for *M. japonicum* is of practical significance.

Macromitrium japonicum grows mainly on trunks of broad-leaved trees in natural forests. Epiphytic plants are expected to be distributed in areas with similar bioclimatic variables and vegetation as in the areas where they are known to occur. Different locations within a given area in China, although climatically uniform, may differ in tree coverage, thus their suitability as habitats for epiphytic bryophytes is also different. For example, in the lower reaches of the Yangtze River, the climate is relatively similar at different locations, so *M. japonicum* could be found in the mountains with natural vegetation, but not in the large agricultural areas. Therefore, not only climate, but also tree cover should be included when predicting distributions of epiphytic plants.

Material and methods

MaxEnt model

MaxEnt was ranked among the most effective applications for species distribution modeling from presence-only data (Elith *et al*. 2006). MaxEnt employs climatic, soil, altitudinal, and vegetation-coverage variables to identify areas where a given species may potentially occur. The model generates predictions indicating suitable and unsuitable habitats for the occurrence of a focal species. MaxEnt is also superior to other species distribution models, even with small sample sizes (Elith *et al*. 2006). It produces a prediction of specific presence on a scale from 0 to 1; values closer to 0 indicating low, and those closer to 1 high habitat suitability for the focal species. The resulting map provides additional information for plant conservation (Young *et al*. 2001, Jeganathan *et al*. 2004). We downloaded MaxEnt 3.3.2 (Phillips *et al*. 2006) from http://www.cs.princeton.edu/~schapire/maxent/.

Variables

To predict the geographical distribution of *M. japonicum*, we considered 76 occurrences of the species in China based on the field data collected for the present study, and on the relevant literature (*see* Appendix 1).

We downloaded 19 bioclimatic variables and an altitude variable from Worldclim (http://www.worldclim.org). It is a set of climate layers representing bioclimatic variables, derived from monthly temperatures and rainfall recorded worldwide (Graham & Hijmans 2006). We used the 2.5 arc-minutes database, which is roughly equivalent to 22 km^2 cells. Although MaxEnt performs a jackknife test, which is used to identify the effect of each variable (even if they are correlated) on the gain of the model when they are used in isolation or are excluded, we decided to use only those bioclimatic variables whose Pearson correlation coefficients with the other variables were between 0.7 and –0.7. This resulted in the following 11 bioclimatic variables:

1. mean diurnal temperature range [= mean of monthly × (max temp – min temp)],
2. isothermality (the mean diurnal temperature range/temperature annual range),
3. annual temperature range,
4. mean temperature of the driest quarter,
5. mean temperature of the warmest quarter,
6. mean temperature of the coldest quarter,
7. precipitation of the wettest month (mm),
8. precipitation of the driest month (mm),
9. precipitation seasonality (coeff. of variation),
10. precipitation of the warmest quarter (mm),
11. precipitation of the coldest quarter (mm).

In addition to the above, we also used percent tree cover and altitude (meters above sea level) in our model.

To evaluate percent tree cover (i.e. density of trees on the ground), we downloaded a world vegetation map from http://www.iscgm.org/ (Geospatial Information Authority of Japan, Chiba University and collaborating organizations). The data show the ratio of the area covered with branches and leaves of trees (tree canopy) to the ground surface as seen from above (vertical direction). Satellite images of the whole globe at every 1 km^2 from the MODIS sensor of Terra were used for the data creation. As for deciduous trees, their maximum leaf-bearing period in a year (maximum percent tree cover) was considered percent tree cover.

Before modeling, we extracted 11 bioclimatic variables, altitude, and percent tree cover for China using ArcGis 9.3, and then converted the data to ASCII format files.

Procedures

We divided the occurrence data into training data (75% of occurrence point data used for model prediction) and test data (25% of occurrence point data used for model validation), and set the other parameters as defaults.

We evaluated the resulting model with the Receiver Operating Characteristics Curve (ROC) calculating the area under the curve (AUC). The higher the AUC score, the better the model predicts presence/absence, indicating environmental variables that highly correlate with the predicted distribution of species, thus the prediction given by the model is of high quality. When the AUC values are < 0.6, 0.6–0.7, 0.7–0.8, 0.8–0.9 or 0.9–1.0, the predictions are invalid, poor, fair, good or excellent, respectively (Swets 1988).

We performed the analysis ten times to generate ten random models, and reported an average predicted layer and an average AUC value from the ten test datasets.

Using a heuristic estimation during training of the model and using a jackknife test, we evaluated the importance of each environmental variable in the 10-replicated MaxEnt model. We then reclassified the 10-replicated prediction layer using equal breaks into ten classes of habitat suitability to show different distribution probabilities for *M. japonicum* in China. Finally, we plotted the actual occurrence points of *M. japonicum* on the predicted distribution map. We also calculated the area percentage of the corresponding habitat suitability class for each province (municipality or autonomous region) by using GIS. Finally we computed the integrated habitat suitability index (IHSI) of *M. japonicum* for each province (municipality or autonomous region) as follows:

$$\mathrm{IHSI} = \sum_{i=1}^{10} H_i \times \mathrm{AP}_i$$

where H_i is the average index of habitat suitability inclass i, and AP_i is the area percentage of the corresponding habitat suitability H_i.

We used the method of equal breaks of ArcGis to divide the habitat suitability (HS) of *M. japonicum* into ten classes: I (0–0.098), II (0.098–0.196), III (0.196–0.294), IV (0.294–0.392), V (0.392–0.489), VI (0.489–0.587), VII (0.587–0.685), VIII (0.685–0.783), IX (0.783–0.881), and X (0.881–0.980).

Results

Application of 57 training and 19 test presence records in MaxEnt yielded an average AUC of 0.858 for the test data, suggesting high predictive power of the model (Phillips *et al*. 2006).

We found higher habitat suitability for *M. japonicum* in the main mountains in southeastern, southern, and southwestern, and also in the Changbai Mountains, Taihang Mountains, Yanshan Mountains, Taiwan, and Hainan Island (Fig. 1). IHSIs of *Macromitrium japonicum* are the highest in Taiwan (0.68), Hainan (0.60), Zhejiang (0.56), Fujian (0.52), Hongkong (0.49), Guizhou (0.47), Hunan (0.46), Beijing (0.43), Shanghai (0.43), Guangdong (0.40), Chongqing (0.40), Jiangxi (0.40), Hubei (0.39), Jiangsu (0.38) and Yunnan (0.37); and the lowest in Xinjiang (0.05), Qinghai (0.05), Ningxia (0.06), Xizang (0.06), Inner Mongolia (0.08), Guangsu (0.08) and Helongjiang (0.08) (Table 1).

Variables which mostly contributed to the model are precipitation of the driest month,

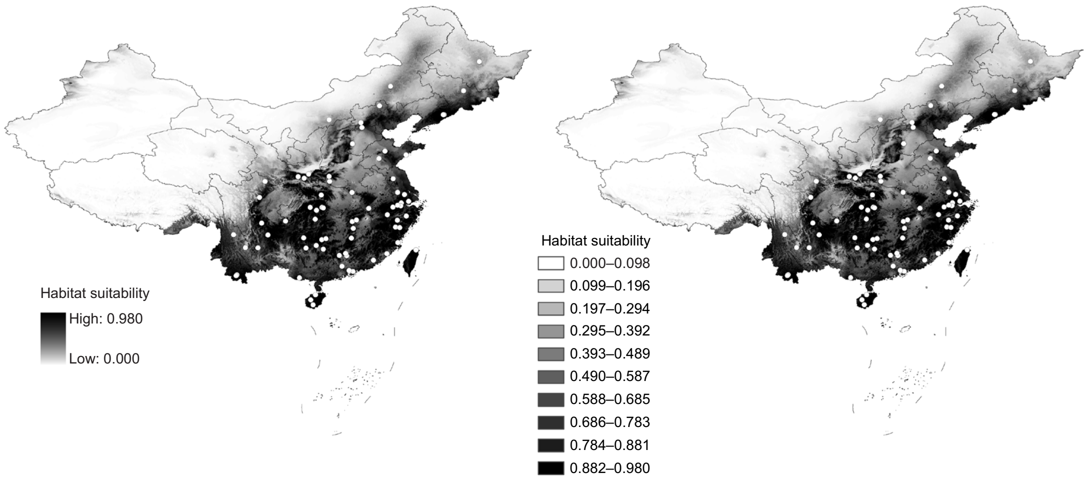

Fig. 1. Distribution of *Macromitrium japonicum* predicted using altitude, percent tree cover and 11 bioclimatic variables using MaxEnt (left: before reclassification, right: after reclassification).

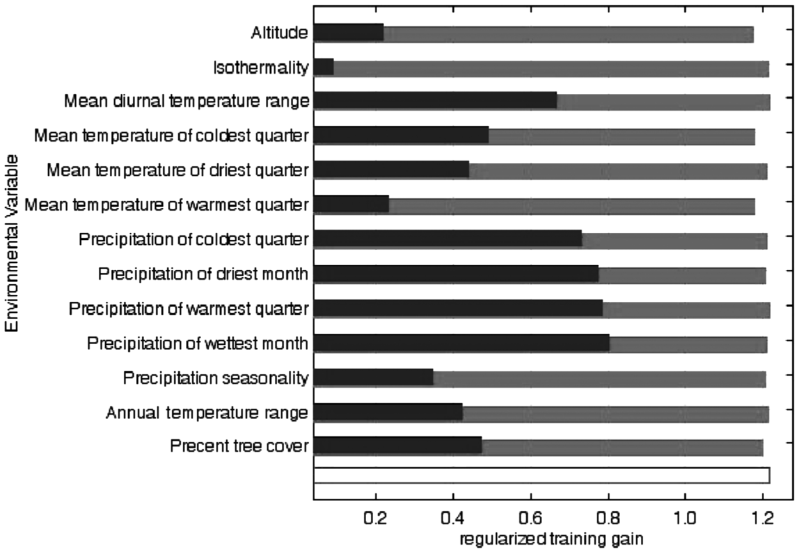

Fig. 2. Gains of the variables in the MaxEnt model (jackknife test). Light-grey bars: model gain without the corresponding variable; dark-grey bars: model gain with only the corresponding variable; white bar: total gain using all the features.

precipitation of wettest month, and percent tree cover, with 36.7%, 28.6% and 11.0% contributions to the model, respectively (Table 2).

The jackknife test showed that the variables that produce the greater gain in the model when considered in isolation are precipitation of the wettest month, precipitation of the driest month, warmest quarter, coldest quarter and the mean diurnal temperature range (dark grey bars in Fig. 2). These five bioclimatic variables are thus the most important for the distribution of *M. japonicum*.

The MaxEnt model indicated that predicted habitat suitability for *M. japonicum* varies with the change of the bioclimatic variables. With increasing percent tree cover, mean temperatures in the warmest quarter, coldest quarter and the driest quarter, and with decreasing mean diurnal temperature range and the temperature annual range, habitat suitability for *M. japonicum* increases. The MaxEnt model also indicated that predicted suitability for *M. japonicum* is higher in the areas with precipitation of the wettest month being 300 mm, and precipitation of warmest quarter being 500–600 mm. Areas at lower altitudes (0–1000 m) are better for *Macromitrium japonicum*, while with the increasing altitude (from 1000 to 6000 m), its habitat suitability decreases. Habitat suitability increases rapidly with increasing precipitation of the driest month and the coldest quarter, and then increases only slightly after these variables exceed certain values.

Discussion

Bryophytes are small plants and have a limited number of morphological traits useful in species identification. Additionally, bryofloristic information is lacking for numerous regions. Therefore, predictions of the species' geographical distribution based on the information available would be beneficial for the future field

Table 1. Percentages of every suitability class for *Macromitrium japonicum* in the provinces, municipalities, and autonomous regions of China (based on its prediction with 11 bioclimatic variables, altitude and percent tree cover; *see* text). IHSI = integrated habitat suitability index.

Location*	Suitability classes**										IHSI
	I	II	III	IV	V	VI	VII	VIII	IX	X	
Taiwan	0	0	0	3.81	18.86	11.71	11.77	18.2	23.22	12.43	0.68
Hainan	0	0.66	0.78	1.55	13.06	26.61	35.02	20.23	1.49	0.6	0.60
Zhejiang	0	0	1.79	12.87	23.35	21.68	18.08	13.22	8.22	0.79	0.56
Fujian	0	0.6	7.05	11.79	22.85	24.7	18.19	9.74	4.87	0.21	0.52
Hongkong	0	0	0	13.46	61.54	1.92	9.62	13.46	0	0	0.49
Guizhou	0.25	3.79	4.82	14.11	28.79	29.64	15.34	2.74	0.48	0.04	0.47
Hunan	0	0	16.55	26.28	18.95	15.77	10.99	6.37	4.06	1.03	0.46
Beijing	0	0	0.51	41.13	31.75	21.57	5.04	0	0	0	0.43
Shanghai	0	0	0	42.6	39.65	12.13	1.48	3.25	0.89	0	0.43
Guangdong	0	0.12	13.09	35.99	33.79	11.07	3.67	1.94	0.33	0	0.40
Jiangxi	0.26	2.64	21.85	29.25	20.9	13.07	6.87	3.41	1.48	0.27	0.40
Chongqing	1.59	26.62	15.44	11.31	10.5	9.46	9.31	8.93	6.8	0.04	0.40
Hubei	0.1	13.77	34.43	13.69	8.99	7.69	6.69	7.09	6.87	0.68	0.39
Jiangsu	0	9.2	14.18	36.34	25.33	7.23	3.53	2.6	1.59	0	0.38
Guangxi	0.41	6.2	16.44	40.8	22.37	6.34	3.34	2.22	1.51	0.37	0.38
Yunnan	0.75	4.53	19.73	35.63	26.42	8.35	3.18	1.35	0.06	0	0.37
Tianjin	0	0	24.57	55.4	11.51	3.27	5.11	0.14	0	0	0.35
Anhui	0	27.41	27.61	14.62	7.09	8.93	7.7	3.92	2.34	0.38	0.34
Liaoning	1.3	30.83	18.08	16.23	12.83	9.61	9.39	1.7	0.03	0	0.33
Shandong	0.07	32.04	29.24	20.49	13.76	3.18	1.03	0.19	0	0	0.27
Shanxi	9.55	28.73	27.22	20.24	9.64	3.96	0.66	0	0	0	0.25
Hebei	9.85	36.08	20.75	21.05	8.87	2.66	0.71	0.03	0	0	0.24
Jilin	19.31	27.4	20.18	14.9	11.4	6.1	0.7	0.01	0	0	0.24
Shanxi	34.57	27.32	10.19	7.38	7.21	6.51	4.49	1.98	0.35	0	0.22
Henan	5.74	56.31	22.15	6.39	4.05	2.92	1.98	0.46	0	0	0.21
Sichuan	28.39	27.22	21.19	9.38	6.68	4.66	1.97	0.5	0.01	0	0.21
Heilongjiang	72.61	22.24	3.73	1.15	0.22	0.05	0	0	0	0	0.08
Gansu	76.6	18.07	3.93	1.15	0.2	0.05	0	0	0	0	0.08
Inner Mongia	76.46	19.79	3.6	0.11	0.04	0	0	0	0	0	0.08
Xizang	93.26	2.42	2.9	1.04	0.38	0	0	0	0	0	0.06
Ningxia	92.88	5.8	1.19	0.13	0	0	0	0	0	0	0.06
Qinghai	99.93	0.07	0	0	0	0	0	0	0	0	0.05
Xinjiang	98.93	1.03	0.01	0.01	0.02	0	0	0	0	0	0.05
China	57.8	12.21	8.34	7.98	6.1	3.59	2.15	1.11	0.61	0.11	0.17

* country, municipality or autonomous region. ** I: 0.000–0.098, II: 0.098–0.196, III: 0.196–0.294, IV: 0.294–0.392, V: 0.392–0.489, VI: 0.489–0.587, VII: 0.587–0.685, VIII: 0.685–0.783, IX: 0.783–0.881, X: 0.881–0.980.

Table 2. Relative contributions of the environmental variables to the MaxEnt model.

Variable	Contribution (%)
Precipitation of the driest month (mm)	36.7
Precipitation of the wettest month (mm)	28.6
Percent of tree cover	11.0
Mean temperature of the warmest quarter (°C)	5.3
Altitude	4.7
Mean temperature of the coldest quarter (°C)	3.3
Mean diurnal temperature range (°C)	3.2
Precipitation seasonality	2.5
Precipitation of the coldest quarter (mm)	2.1
Isothermality (P2/P7) (× 100)	0.9
Temperature annual range (°C)	0.9
Mean temperature of the driest quarter (°C)	0.4
Precipitation of the warmest quarter (mm)	0.4

investigation, specimen collection and ecological research.

The predicted distribution naturally includes most of the actual occurrences of *M. japonicum* in China (Fig. 1). According to our results, *M. japonicum* could be found in larger areas in Taiwan and on Hainan Island, in Zhejiang, Fujian, Hongkong, and Guizhou. Although *M. japonicum* is also known from Inner Mongolia, the main part of that autonomous region is not suitable for the species. On the other hand, *M. japonicum* could occur in southeastern Xizhang, whereas the main part of that autonomous region is not suitable for the species. Even though only few occurrences of *M. japonicum* are known from Jiangxi, Hunan, Fujian, the habitats in a large part of these provinces are suitable for the species.

One potentially significant contribution of the models is to identify areas of higher probability of occurrence to guide future survey expeditions or conservation of the target species. The method used here may speed up the process of selection of habitats of prime importance for the conservation of a given species.

Our model was based on altitude, percent tree cover, and 11 climatic factors. There may be other factors influencing the distribution of *M. japonicum*, such as e.g. vegetation type. Future work may improve validity and precision of predicted distributions of epiphytic species.

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Appendix 1. Occurrences of *Macromitrium japonicum* in China based on field work, literature and herbarium specimens.

Location*	Long. (°E)	Lat. (°N)	Source	Location*	Long. (°E)	Lat. (°N)	Source
Fujian	118.160	24.658	Present study	Jiangsu	120.214	31.559	Present study
Fujian	119.465	25.967	Present study	Jiangxi	114.015	26.465	Chang (1989)
Guangdong	112.622	24.433	Present study	Jiangxi	114.122	28.415	Present study
Guangdong	112.914	23.201	Present study	Jiangxi	114.228	27.612	Present study
Guangdong	113.335	24.685	Zeng & Lin (2001)	Jiangxi	114.622	28.587	Present study
Guangdong	113.485	24.418	He *et al.* (2004)	Anhui	118.887	30.093	Present study
Guangdong	113.823	22.634	Present study	Liaoning	124.783	40.912	Present study
Guangdong	114.212	22.583	Jia *et al.* (2001)	Liaoning	124.859	40.892	Present study
Guangdong	116.591	23.881	Present study	Inner Mongolia	111.423	40.334	Bai & Xu (2009)
Guangxi	107.946	21.833	Present study	Inner Mongolia	118.614	44.229	Zhao (2009)
Guangxi	108.716	25.295	Jia *et al.* (1995)	Shandong	117.243	35.797	Present study
Guangxi	109.914	25.634	Present study	Shandong	117.955	36.654	Present study
Guangxi	110.555	26.285	Zhu *et al.* (2000)	Shandong	117.955	36.656	Xu (1987)
Guizhou	104.258	26.854	Present study	Shandong	120.422	36.215	present
Guizhou	108.422	26.545	Zhou (2007)	Shaanxi	107.798	33.662	Li (2006)
Guizhou	110.743	25.194	Present study	Shaanxi	108.493	33.486	Present study
Hainan	109.253	19.251	Present study	Shaanxi	109.015	33.962	Niu (2009)
Hainan	109.540	18.683	Present study	Sichuan	103.292	31.233	Present study
Hainan	109.830	19.832	Present study	Sichuan	103.527	28.217	Present study
Hebei	114.131	37.569	Tang & Lin (2003)	Sichuan	103.928	33.110	Present study
Hebei	115.142	39.984	Present study	Chongqing	106.325	28.473	Present study
Hebei	115.241	39.409	Present study	Taiwan	121.565	25.087	Present study
Hebei	115.242	39.476	Present study	Yunnan	100.233	26.867	Present study
Hebei	117.334	41.948	Li *et al.* (2006)	Yunnan	100.532	22.072	Present study
Henan	111.409	33.709	Present study	Yunnan	100.631	22.175	Wang *et al.* (2008)
Henan	111.483	33.106	Present study	Yunnan	101.613	25.364	Present study
Henan	114.073	31.833	Present study	Yunnan	103.142	25.353	Present study
Helongjiang	128.971	47.109	Present study	Zhejiang	118.907	28.953	Hong & Hu (1984)
Hubei	109.205	30.1063	Wang *et al,* 2010	Zhejiang	118.232	29.2053	Tian *et al.* (1999)
Hubei	109.937	29.744	Present study	Zhejiang	119.189	27.750	Zhu *et al.* (1993)
Hubei	110.509	31.523	Present study	Zhejiang	119.383	27.226	Present study
Hubei	110.575	30.083	Peng (2002)	Zhejiang	119.383	28.550	Present study
Hunan	109.773	28.685	Wu (2006)	Zhejiang	119.425	30.312	Present study
Hunan	110.732	29.996	Present study	Zhejiang	119.648	27.711	Present study
Hunan	111.032	26.425	Present study	Zhejiang	119.873	30.622	Present study
Jilin	127.135	43.714	Present study	Zhejiang	120.453	29.055	Present study
Jiangsu	118.898	33.476	Present study	Zhejiang	120.734	30.774	Present study
Jiangsu	119.414	31.821	Present study	Zhejiang	121.953	30.683	Present study

* province, autonomous region, or municipality.