Population and habitat responses to the global climate change in a widespread species, the Asiatic Toad (Bufo gargarizans)

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Abstract

Abstract: Global climate change is gradually changing the distribution and diversity pattern of species. In order to study the change of distribution area and distribution barycenter of Bufo gargarizans under climate change, we adopted the maximum-entropy modeling (Maxent) model and barycenter migration analysis. And four General circulation models (GCMs) under four representative concentration pathways (RCPs), 29 environment variables (including bioclimate, topography, habitat and human impact) were used to predict the current and future (2050 and 2070) distribution of B. gargarizans. The results show that the Mean temperature of Driest quarter (Bio9), Precipitation of driest month (Bio14) and population (POP) have greater influence on the distribution of B. gargarizans, it indicates that climate and anthropogenic factors have greater influence on the distribution of B. gargarizans than other environmental factors such as topography and landform. And in the next 30 to 50 years, from the perspective of the large spatial scale of the whole China, the distribution area of B. gargarizans is in the eastern part of China, the southeastern part is reduced, and the Midwest and northwest part is expanded. On the whole, the suitable habitat of B. gargarizans will be reduced in the future and will migrate to the high latitude and altitude area. In this study, B. gargarizans was used as a sentinel species to study the response of amphibians to climate change, this paper aims to reveal the mechanism of amphibian response to climate change from the current and future dispersal patterns of B. gargarizans.

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Running Head: The Asiatic Toad respond to the climate change

Abstract: Global climate change is gradually changing the distribution and diversity pattern of species. In order to study the change of distribution area and distribution barycenter of*Bufo gargarizans* under climate change, we adopted the maximum-entropy modeling (Maxent) model and barycenter migration analysis. And four General circulation models (GCMs) under four representative concentration pathways (RCPs), 29 environment variables (including bioclimate, topography, habitat and human impact) were used to predict the current and future (2050 and 2070) distribution of*B. gargarizans*. The results show that the Mean temperature of Driest quarter (Bio9), Precipitation of driest month (Bio14) and population (POP) have greater influence on the distribution of *B. gargarizans* , it indicates that climate and anthropogenic factors have greater influence on the distribution of *B. gargarizans* than other environmental factors such as topography and landform. And in the next 30 to 50 years, from the perspective of the large spatial scale of the whole China, the distribution area of *B. gargarizans* is in the eastern part of China, the southeastern part is reduced, and the Midwest and northwest part is expanded. On the whole, the suitable habitat of *B. gargarizans* will be reduced in the future and will migrate to the high latitude and altitude area. In this study, *B. gargarizans* was used as a sentinel species to study the response of amphibians to climate change, this paper aims to reveal the mechanism of amphibian response to climate change from the current and future dispersal patterns of *B. gargarizans* .

Key words: *Bufo gargarizans* , Maxent, distribution, barycenter migration, climate change, sentinel species

1. Introduction

The distribution and interaction of species are closely related to climate (Nogues-Bravo & Rahbek, 2011), and global climate change is a major challenge facing mankind and the biological world in the 21st century (Bertrand et al., 2011). According to the Intergovernment Panel on Climate Change (IPCC), average global temperatures have risen by about 1.5 compared with pre-industrial levels. And the rising global average temperature poses a serious threat to the sustainability of the global ecosystem and alters global biodiversity patterns (Dawson, Jackson, House, Prentice, & Mace, 2011). If species can find niches to satisfy their needs, their habitats will expand or shrink as the climate changes. However, if climate-friendly habitats disappear or are affected by landscape barriers, some less diffuse species will become extinct as a result of climate warming.

Amphibians are at higher risk of extinction than other groups of vertebrates(Stuart et al., 2004; Wake & Vredenburg, 2008), with 41 percent at risk, and due to their complex life history and unique physiological structure, their distribution and diffusion are greatly affected by climate and landscape, and their ability to cope with climate change is weak, which may be one of the reasons for the decline of the global amphibians population (Lambers, 2015; Sinervo et al., 2010).

In order to study the response of species to climate change, SDMs (SDMs) is usually chosen to simulate the distribution area of species. SDMs can calculate the relationship between the existence point of species and local climate variables, perform function fitting through different algorithms, and then project the function to a specific research area and time, and finally obtain the distribution of the target species' adaptive area (Elith, 2009; Guisan & Thuiller, 2010). Although the SDMs has some shortcomings, for example, it cannot fully take into account the interactions between species (Pearson & Dawson, 2003), SDMs is still one of the effective methods for predicting species distribution, assessing the risk of species extinction, planning and construction of protected areas (Li et al., 2014; Preston, Rotenberry, Redak, & Allen, 2010). SDMs are often used to predict the distribution of endangered or narrow species, and there are relatively few studies on the prediction of widespread species (Yang, Tang, & Luo, 2020).

B. gargarizans is one of the most widely distributed amphibians in China, and compared with other amphibians, it has a relatively low sensitivity to environmental factors, so it is a great sentinel species for revealing amphibian responses to temperature changes in this study. And the study of the genealogical geography of*B. gargarizans* shows that the differentiation of the subspecies of *B. gargarizans* is mainly caused by dominant dispersion rather than vicariance, and showed a trend of dispersion from west to east (Fu, Weadick, Zeng, Wang, & Hu, 2005; Hu et al., 2007). Relevant studies show that in the future, the ecological niche of a large number of amphibians in China will migrate to the west or north, and the fragmentation of the distribution area will be serious year by year. (Duan, Kong, Huang, Varela, & Ji, 2016). Although the genealogical geography of *B. gargarizans* is relatively thorough, its spatial distribution prediction has not been carried out in depth. Starting from the distribution area of *B. gargarizans* , this study aims to clarify the current and future trend of the *B. gargarizans* 's dispersion under the context of climate change, so as to provide certain data support for the response model of amphibians to climate change.

The Maxent model was selected to simulate the current and future spatial distribution of *B. gargarizans* under the background of global climate change and the migration of the centroid point, in order to solve the following problems: i) to simulate the current and future distribution of *B. gargarizans* in China; ii) to predict the change of suitable habitat of *B. gargarizans* in different parts of China under climate change; iii) to predict the distribution barycenter migration of *B. gargarizans* in China under climate change, and reveal the mechanism of amphibian response to climate change.

2. Materials and methods

2.1 Occurrence records of *B. gargarizans.*

The distribution data of*B. gargarizans* used in this study were mainly from two sources: i) Data accumulated through years of laboratory fieldwork, 69 records were recorded; ii) and were obtained from the Global Biodiversity Information Facility (GBIF), 287 records were obtained. GBIF is a global scientific organisation that specialises in providing basic data on biodiversity, the data is obtained by searching for the keyword *B. gargarizans* (visited in June 2020) (Jiang, Zhang, Gao, Cai, & Zhang, 2019). Distance between all species distribution data >1Km by processing in ArcGis10.2 software. Finally, there are 274 pieces of data for this study (Table S1).

2.2 Environmental variables

We collected 29 environmental variables for this study, which can be roughly divided into four categories: bioclimate, topography, habitat, and human impact, source of all variables show in Table S2. In order to avoid model overfitting, all collected variables were processed by the band collection statistics function in ArcGIS 10.2. Remove the environment variables with high correlation (r>0.7). After screening, Bio3, Bio5, Bio9, Bio14, Bio15, slope, Veg, NDVI, POP, GDP and HI were used for this study. Bio3, Bio5, Bio9, Bio14, Bio15, slope, Veg, NDVI, POP, GDP and HI. Since variables other than future bioclimatic factors cannot be predicted and change relatively little over a short period of time, we assume that they remain constant and use their projections of the future distribution of *B. gargarizans*(Yang et al., 2020).

In order to reduce the uncertainty of model prediction, we chose four internationally recognized GCMs (BCC-CSM1-1, HadGEM2-ES, IPSL-CM5A-LR, MIROC5) and four RCPs (RCP2.6, 4.5, 6.0 and 8.0) published in the IPCC fifth Assessment report for prediction in 2050 and 2070.

2. 3 Model optimization and parameter setting

To establish the most stable and reliable model, we choose model calibration, which includes regularization multiplier (0.5 to 6, interval 0.5) and combination of basic feature classes and from one different sets of all layers**.** The best parameters were selected based on statistical significance (partial ROC), predictive ability (miss rate E=5%) and complexity level (AICc) by useing R package kuenm (Cobos, Peterson, Barve, & Osorio-Olvera, 2019). After the model parameters were determined, chose the data output format of mathematical logic to ensure that the output data was between 0 and 1. And the jackknife method was selected to evaluate the contribution of environmental variables. Then the distribution data of*B.gargarizans* were randomly divided into two groups: 25% were randomly selected as the test set, and the remaining 75% were used as the training set, repeat Bootstrap replicates 10 times in MaxEnt.3.4.1. Other model parameters are selected by system default. Finally, the predictive performance of the model was validated by using the area under the receiver-operating characteristic (ROC) curve (AUC) and the mean omission error. The higher the AUC value, the more accurate the model performance. Normally, AUC > 0.9 represents excellent prediction performance of the model. The ensemble threshold of model was calculated according to the Maximizing Sensitivity and Specificity (MSS) by using the dismo package in R. The MSS method is commonly used in presence only kind of occurrence data(Hijmans, Phillips, Leathwick, & Elith, 2017; Liu, White, Newell, & Pearson, 2013).

2.4Distribution barycenter migration under different scenarios of future global climate change

We divided the study area into small grids of 0.1degx0.1deg to evaluate the distribution barycenter migration of *B. gargarizans* in China. Assuming that our research area is composed of N small grids, the proportion of the k^{th} grid is $G_K=P_K x S_K$, and P_K represents the probability of the species appearing in the k^{th} small grid, and $S_K$represents the area of the k^{th} small grid. The coordinates of each grid are obtained by Arcgis10.2. The following formula is used to obtain the coordinates of the barycenter:

$$X= \frac{\sum_{k=1}^{k} G_k X_k}{\sum_{k=1}^{k} G_k}; \ Y=\frac{\sum_{k=1}^{k} G_k Y_k}{\sum_{k=1}^{k} G_k}$$

Here, X and Y represent the longitude and latitude of the k^{th} grid, respectively(He et al., 2011).

The results of four GCMs under four RCPS were averaged to obtain P_f, using $^{P}(^{P} = P_f - P_c, P_c represents the current distribution probability of B.\ gargarizans) to evaluate the change trend of B.\ gargarizans distributio$ $-0.1<DP[?]0.1 indicated that the habitat suitability changes were not obvious. 0.1<DP[?]0.3, 0.3<DP[?]0.5 and 0.5<DP[?]0.7 rep$ $0.3<DP[?]-0.1, -0.5<DP[?]-0.3 and -0.7<DP[?]-0.5 represented slight, moderate and severe declines in habitat suitability, r$

3.Results

3.1 Model optimization

Through different combinations of feature classes and regularized multipliers, the best model parameter is selected as among all combinations (feature classes: linear, product, threshold, and hinge; regularized multipliers=2), the parameters of all candidate models are shown in Table S3.

In the simulation of the current and future distribution of *B. gargarizans* , the AUC value indicated that the simulation results of all models reached an excellent level (0.9202[?] Training AUC[?]0.9306, 0.9001[?] Test AUC[?]0.9165, SD[?]0.014), all AUC values are presented in Table S4

3.2 Current distribution

After running maxent model for 10 times, the average AUC value was 0.926**,** Standard deviation is 0.01 (Fig.1),. The model validation results show that the model prediction results are excellent and can be used in the following analysis

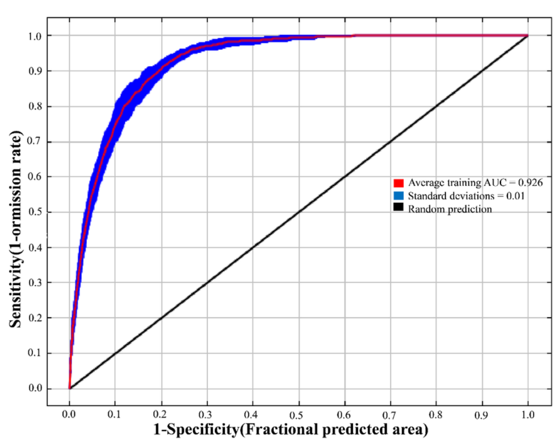


Fig. 1. Receiver operating characteristic (ROC) curve and average test AUC for accuracy analysis of Bufo gargarizan by MaxEnt model under the current situation.

We found that the most suitable habitats were mainly in the midwest and the eastern coastal areas from current distribution of B. gargarizans(Fig.2). The threshold value of MSS method is 0.33, and according to the distribution probability of B. gargarizans, China is divided into four grades: highly suitable habitat (HS, P[?]0.75); medium suitable habitat (MS, 0.5[?]P<0.75); poorly suitable habitat(PS, threshold[?]P<0.5); unsuitable habitat(US, threshold<P[?]0), and the areas of these four types of habitats were calculated in Arcgis, as shown in Table 1. Among them, the unsuitable habitat is 7,216,700 square kilometers, accounting for 75.69 percent of Chinese areas.

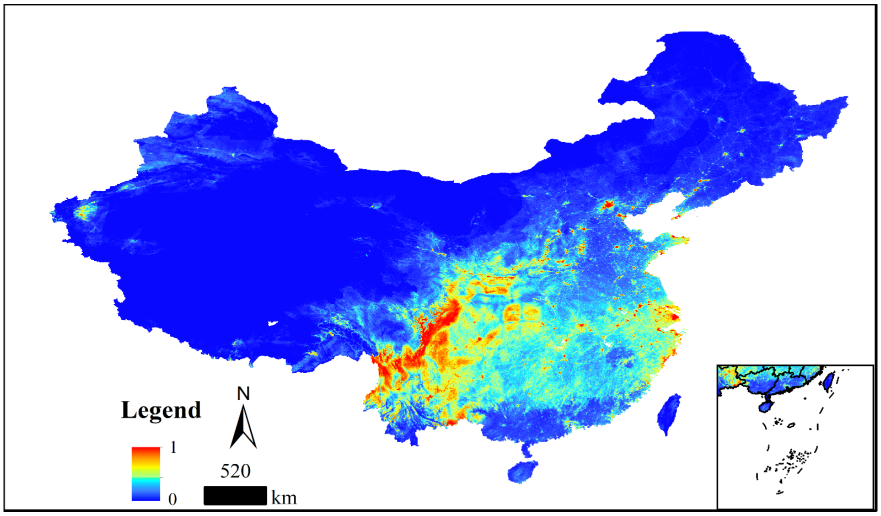


Fig.2 Current distribution of MaxEnt models for *B. gargarizans* in China. The color scale from blue to red indicates the habitat suitability value from 0 to 1.

Table1 Current habitat composition of *B. gargarizans* in China under MaxEnt model.HS: highly suitable habitat; MS: medium suitable habitat; PS: poorly suitable habitat;US: unsuitable habitat.

Species	Area\ 10^4 km^2	Area\ 10^4 km^2	Area\ 10^4 km^2	Area\ 10^4 km^2	Percentage\%	Percentage\%	Percen
	US	PS	MS	HS	US	PS	MS
B. gargarizans	721.67	134.16	67.63	30.35	75.69	14.07	7.1

3.3 Contribution of environmental variables

The Jackknife analyses results showed that the variables with high contribution to the model were Bio9, Bio14, and POP, with a total contribution of 70.8%. Among them, the contribution rate of Bio9 is 38.4%, that of Bio14 and POP is 16.2%, detailed analysis results are shown in the Table S5. Meanwhile, the range, mean value and optimal range of each variable (the probability of species existence>0.5) is shown in Table S6 and Fig.3. For variables with higher contribution (Bio9, Bio14, POP), there were significant differences in the mean values between the locations of occurrence and absence.

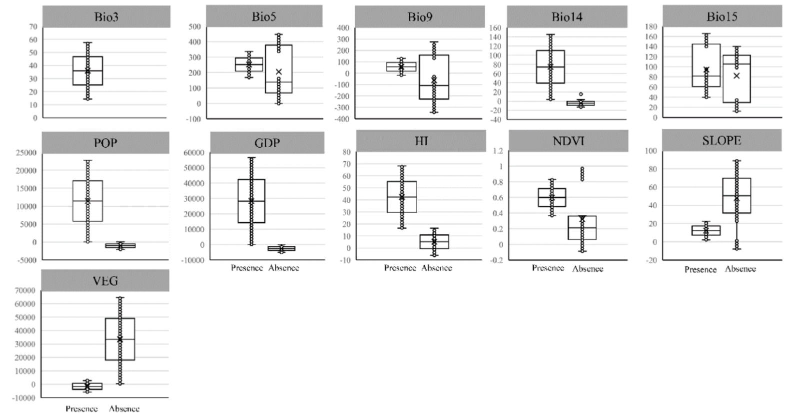


Fig.3 The distribution of predictor bioclimatic and topographic variables over the study area on presence and absence (background) locations.

3.4 Analysis of future habitat changes

The areas and proportions of the four habitats of *B. gargarizans*by 2050 and 2070 are shown in the Table S7. Compared with the current distribution, the future suitable habitat of *B. gargarizans* will be reduced in 2050, and the ranges of highly suitable habitat, medium suitable habitat, poorly suitable habitat are -1.3 ~ 0, -3.41 ~ -0.68, and -3.98 ~ 1.32, and the mean values are -0.72, -2.43, and -1.42 respectively. The suitable habitat of *B. gargarizans* will shrink further in 2070, and the ranges of highly suitable habitat, medium suitable habitat, poorly suitable habitat are -1.42 ~ -0.37, -3.71 ~ -1.59, and -3.94 ~ -0.03, and the mean values are -0.93, -2.71, -2.04 respectively(Fig.4). And the overall change trend and degree of suitable habitats of *B. gargarizans* in China is shown in Fig.5 and Table S8. In addition, the potential distribution area of Chinese toad in the future shows a trend of fragmentation, which is gradually serious over time, and this trend is related to RCPs to a certain extent (RCPS8.5 is the most serious)(Fig. S1)

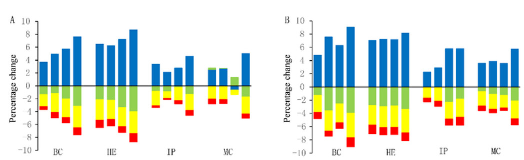
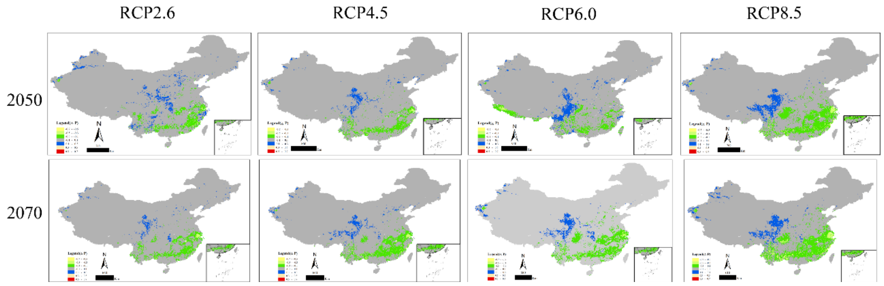


Fig.4 The four levels of suitable habitat fluctuation ranges of*B. gargarizans* under different future climate scenarios in China. Red, orange, green, and blue represent increases (positive number) or decreases (negative number) of the proportion of highly suitable, medium

suitable, poorly suitable, and unsuitable habitat, respectively. BC, HE, IPand MC represent BCC-CSM1-1, HadGEM2-ES, IPSL-CM5A-LR and MIROC5, respectively, which are different global climate models. A is in 2050, B is in 2070.



Φιγ.5 ἄριατιονς ιν ηαβιτατ συιταβιλιτψ οφ Βυφο γαργαριζανς υνδερ διφφερεντ φυτυρε ςλιματε σςεναριος ιν ῄινα. $\Delta\Pi=\Pi_{\varphi}-\Pi_{\varsigma}$, Π_{ς} ρεπρεσεντεδ τηε προβαβιλιτψ αλυε οφ συιταβιλιτψ ιν τηε ςυρρεντ σιτυατιον ανδ Π_{φ}ρεπρεσεντεδ τηε αεραγε προβαβιλιτψ αλυε οφ συιταβιλιτψ υνδερ τηε φυτυρε σιτυατιον οφ φουρ γλοβαλ ςλιματε μοδελς. Γραψ (-0.1<ΔΠ[;]0.1) ινδιςατεδ τηατ τηε ηαβιτατ συιταβιλιτψ ςηανγες ωερε νοτ οβιους. Βλυε (0.1<ΔΠ[;]0.3) , πινκ (0.3<ΔΠ[;]0.5) ανδ ρεδ(0.5<ΔΠ[;]0.7) ρεπρεσεντεδ σλιγητ, μοδερατε ανδ σεερε ινςρεασειν ιν ηαβιτατ συιταβιλιτψ, ρεσπεςτιελψ. Γρεεν (-0.3<ΔΠ[;]-0.1), Λιγητ γρεεν (-0.5<ΔΠ[;]-0.3) ανδ ψελλοω (-0.7 <ΔΠ[;] -0.5) ρεπρεσεντεδ σλιγητ, μοδερατε ανδ σεερε δεςλινες ιν ηαβιτατ συιταβιλιτψ, ρεσπεςτιελψ.

3.5 Διστριβυτιον βαρψςεντερ μιγρατιον

Το στυδψ τηε εςολογιςαλ βαρψςεντερ μιγρατιον υνδερ τηε ςοντεξτ οφ ςλιματε ςηανγε, τηε ςεντροιδ ςοορδινατες ανδ μιγρατιον διστανςες οφ τηε ςυρρεντ ανδ φυτυρε(2050 ανδ 2070) διστριβυτιον οφ *Β. γαργαριζανς*ωερε ςαλςυλατεδ(Ταβλε Σ9, Ταβλε Σ10). Ανδ τηε ρεσυλτς οφ διστριβυτιον βαρψςεντερ μιγρατιον σηοω τηατ τηε διστριβυτιον ςεντερ οφ *Β. γαργαριζανς* ωιλλ ηαε μοεδ το 107.05°E ~ 108.94°E, 31.38°N ~ 32.74°N, and the distance of barycenter migration will reach 38.47km ~ 249.45km. And by 2070, the distribution of *B. gargarizans* will continue to change, and its distribution center will migrate to 107.00°E ~ 108.75°E, 31.95°N ~ 32.37°E, the migration distance is between 93.15 Km and 270.67 Km. Fig.5 and Fig.6 show that the suitable distribution area of *B. gargarizans* will decrease in the southeast, and gradually migrate and increase to the midwest in China.

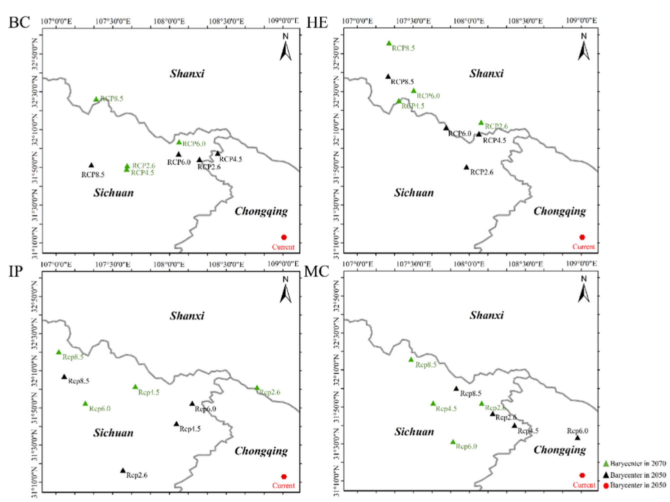


Fig. 6 Barycenter transfer of *Bufo gargarizans* in China. The red hexagon represents the barycenter of a suitable habitat under current scenarios. The black and green triangles represent the barycenter of suitable habitats in 2050 and 2070, respectively, using four global climate models.

4 Discussion

4.1 Maxent model and environmental variables

Maxent model can connect the distribution data of species with geographic and ecological information, and calculate the maximum entropy value of species distribution, so as to predict the potential distribution area of species(Giannakopoulos et al., 2019). Maxent model can achieve a good prediction effect only by using limited species distribution data. Therefore, it is often used to simulate the potential distribution area of species, drift of potential distribution area, suitability evaluation and other studies on global climate change involving species distribution and genetic diversity in conservation biology and invasion biology(Hannah et al., 2007; Mays, Hung, Shaner, Denvir, & Primerano, 2018; Prieto-Torres, Navarro-Sigüenza, Santiago-Alarcon, & Rojas-Soto, 2016).

Environmental variables commonly used for Maxent model analysis include climate variables, landscape variables such as topography and landform, and the impact of human factors on species distribution is rarely considered (Pearson, Raxworthy, Nakamura, & Townsend, 2010; Penman, Pike, Webb, & Shine, 2010). However, the influence of human factors on ecological environment is extensive and continuous, and its role cannot be ignored(Li et al., 2014). From the contribution of the four environmental factors selected in this study, the climate factor is still the main factor affecting distribution of *B. gargarizans* in China. Among them, the contribution of Bio9 and Bio14 is relatively large, the contribution was 38.4% and 16.2%, and the optimal distribution range of *B. gargarizans* was -1.85 ˜ 13.01 and 3.59mm ˜ 145.20mm, respectively. Secondly, human influence also has a certain degree of contribution, and the overall influence trend shows that, within a certain range, the distribution probability of *B. gargarizans* increases with the enhancement of human influence (Table S5, Fig.3), this is caused by the overlap of the ecological niche of the *B. gargarizans* and the area of human activities and some human infrastructure is more conducive to the distribution of amphibians(Tytar, Sobolenko, Nekrasova, & Mezhzherin, 2015). Compared with other environmental factors, the overall contribution of topographic and geomorphic factors is relatively low, and see Fig.7 for details.

Fig.7 Results of jackknife train of relative importance of predictor variables forB. gargarizans

4.2 Future distribution change and barycenter migration of B. gargarizans

Many studies suggest that global temperatures are rising and will continue to do so for some time to come, with an expected increase of 0.6 in the 20th century and 1.4 ˜ 5.8 by the 21th century (Budikova, 2009; Mccarthy, Canziani, Leary, Dokken, & White, 2007). The rising global temperature will inevitably affect the change of species distribution, which will eventually lead to two results: one is the reduction of species distribution, which will eventually lead to extinction of species; the other is the migration of species to previously undistributed areas, which will expand the distribution (Bellard, Bertelsmeier, Leadley, Thuiller, & Courchamp, 2012; Morueta-Holme, Camilla, & Svenning, 2010; Thomas et al., 2004).

In this study, under the background of climate change, the suitable distribution area of *B. gargarizans* will continue to decrease in the next 30˜50 years. In comparison to three other global Change Scenarios, we can see the smallest reduction in suitable habitat for *B. gargarizans* under RCP2.6 Scenarios (The most optimistic scenario is that greenhouse gas emissions peak between 2010 and 2020, then continue to decline, with a negative value by the end of the century). And the suitable habitat of*B. gargarizans* will be further reduced Under the scenarios of RCP4.5 and RCP6.0(That represents a decline after greenhouse gas emissions peaked in 2040 and 2080, respectively). the suitable habitat of *B. gargarizans* of China decreased to the maximum extent under the condition of RCP8.5(Greenhouse gas emissions continue to rise in this century). The results show that with the increase of greenhouse gas emission concentration, the area of suitable habitat of *B. gargarizans* decreases more, on the other hand, it suggests the importance of energy conservation and emission reduction to the maintenance of ecological balance.

As show in Fig. 4 and Fig. S5, the suitable habitat of*B. gargarizans* will decrease in the south, southeast coast and central part of China, and correspondingly increase in the central and western part of China from now to 2050. And the trend will become more pronounced by 2070. In the next 30 to 50 years, the distribution centers of *B. gargarizans*will gradually move from Yunyang County in northeast Chongqing City to Wanyuan County, Tongjiang County and Xuanhan County in northeast Sichuan Province and Langao County, Ziyang County, Zhenba County, Nanzheng County and Chenggu County in southwest Shaanxi Province. Compared with the present, the distribution focus has gradually shifted to the northwest, and this trend has not weakened with time. In addition, it can be seen from Figure 1 that Bio9 and Bio14, two climatic factors that have a great influence on the distribution of *B. gargarizans* . are increasing from 2050 to 2070 compared with the present, and the growth trend is more obvious in eastern and southern China. And these are the areas where *B. gargarizans* , will be less concentrated in the future. And the reason for this phenomenon is that the average temperature and precipitation in these regions are higher at present, and the further increase of temperature and precipitation in the future will make the values of these factors beyond the range suitable for the distribution of *B. gargarizans* (Table S6) .

Four GCMs under four RCPs were used in this study, and the results show that under the global climate change, like other species that have been reported, the distribution area of *B. gargarizans* will migrate to the high latitude and high altitude area (China's terrain is low in the east)(Kelly & Goulden, 2008; Parmesan & Yohe, 2003). On the other hand, this paper is more inclined to think that the current distribution pattern of *B. gargarizans* , is caused by the dispersion, because from the perspective of the current distribution, there is no obvious geographical isolation between the distribution areas of different regions of *B. gargarizans* ,, and the future distribution of*B. gargarizans* , showed that the future distribution of *B. gargarizans* , would gradually break up, and the geographical separation would gradually form between different regions (Fig.2, Fig. S1). The results of this study indicated that the distribution area of *B. gargarizans* would be reduced in the future, and the habitat connectivity, resilience and gene exchange between the populations would be reduced with the serious habitat fragmentation year by year, finally leading to the gradual decline of *B. gargarizans* population(Duan et al., 2016). And it suggests that some amphibians, which are more sensitive to environmental changes and narrower than *B. gargarizans* , the changes to their niches from climate change will be even more dramatic and even devastating. Due to the influence of the resolution of the environmental layer, the prediction results cannot be very accurate. However, we still believe that this study will provide theoretical support for the direction of conservation and ecological management of *B. gargarizans* , and it is believed that it can provide a research direction for other amphibians to cope with climate change.

Data Accessibility:

Occurrence records of *B. gargarizans* were obtained from laboratory survey and global biodiversity information platform (GBIF), and the data finally used for analysis are listed in Table S1 in the attachment.

Environment variables are derived from official websites such as Worldclim, Resource and Environment Science and Data Center and Last of the Wild Data. Please refer to the Table S2 in the attachment for the specific download sites.

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