Duan R, Kong X, Huang M, Varela S, Ji X. 2016. The potential effects of climate change on amphibian distribution, range fragmentation and turnover in China. PeerJ 4:e2185 https://doi.org/10.7717/peerj.2185

The potential effects of climate change on amphibian distribution , range fragmentation and turnover in China

Ren-Yan Duan, Xiao-Quan Kong, Min-Yi Huang, Sara Varela, Xiang Ji

Many studies predict that climate change will cause species movement and turnover, but few studies have considered the effect of climate change on range fragmentation for current species and/or populations. We used MaxEnt to predict suitable habitat, fragmentation and turnover for 134 amphibian species in China under 40 future climate change scenarios spanning four pathways (RCP2.6, RCP4.5, RCP6 and RCP8.5) and two time periods (the 2050s and 2070s). Our results show that climate change will cause a major shift in the spatial patterns of amphibian diversity. Suitable habitats for over 90% of species will be located in the north of the current range, for over 95% of species in higher altitudes, and for over 75% of species in the west of the current range . The distributions of species predicted to move westwards, southwards and to higher altitudes will contract, while the ranges of the species not showing these trends will expand . Amphibians will lose 20% of their original ranges on average; the distribution outside current ranges will increase by 15% . Climate change will likely modify the spatial configuration of climatically suitable areas. Changes in area and fragmentation of climatically suitable patches are related, which means that species may be simultaneously affected by different stressors as a consequence of climate change.

PeerJ PrePrints | https://doi.org/10.7287/peerj.preprints.1681v1 | CC-BY 4.0 Open Access | rec: 26 Jan 2016, publ: 26 Jan 2016

The potential effects of climate change on amphibian distribution, range fragmentation and turnover in China

Ren-Yan Duan[1,2†], Xiao-Quan Kong[2†], Min-Yi Huang [1,2], Sara Varela[3,4] and Xiang Ji[1]

[1] Jiangsu Key Laboratory for Biodiversity and Biotechnology, College of Life Sciences, Nanjing Normal University, Nanjing 210023, Jiangsu, China

[2] College of Life Sciences, Anqing Normal University, Anqing 246011, Anhui, China

[3] Departamento de Ciencias de la Vida, Edificio de Ciencias, Campus Externo, Universidad de Alcalá, 28805 Alcalá de Henares, Madrid, Spain

[4] Museum für Naturkunde, Leibniz Institute for Evolution and Biodiversity Science, Invalidenstraße 43, 10115 Berlin, Germany

Running title: Climate change and amphibian distribution

Corresponding author: Xiang Ji, xji@mail.hz.zj.cn

†These authors contributed equally to this manuscript

PeerJ PrePrints | https://doi.org/10.7287/peerj.preprints.1681v1 | CC-BY 4.0 Open Access | rec: 26 Jan 2016, publ: 26 Jan 2016

ABSTRACT

Many studies predict that climate change will cause species movement and turnover, but few studies have considered the effect of climate change on range fragmentation for current species and/or populations. We used MaxEnt to predict suitable habitat, fragmentation and turnover for 134 amphibian species in China under 40 future climate change scenarios spanning four pathways (RCP2.6, RCP4.5, RCP6 and RCP8.5) and two time periods (the 2050s and 2070s). Our results show that climate change will cause a major shift in the spatial patterns of amphibian diversity. Suitable habitats for over 90% of species will be located in the north of the current range, for over 95% of species in higher altitudes, and for over 75% of species in the west of the current range. The distributions of species predicted to move westwards, southwards and to higher altitudes will contract, while the ranges of the species not showing these trends will expand. Amphibians will lose 20% of their original ranges on average; the distribution outside current ranges will increase by 15%. Climate change will likely modify the spatial configuration of climatically suitable areas. Changes in area and fragmentation of climatically suitable patches are related, which means that species may be simultaneously affected by different stressors as a consequence of climate change.

Keywords Amphibians, MaxEnt, Climate impacts, Distribution, Fragmentation, Turnover, Dispersal, Range shifts

INTRODUCTION

The global climate is changing rapidly because of anthropogenic greenhouse gas emissions, with unexpected consequences (Solomon, 2007). The average temperature on the earth's surface is projected to rise by 1.1–6.4 °C between 1990 and 2100 (Solomon, 2007). Climate change can alter the distribution of organisms by causing shifts in area, latitude, longitude and/or altitude and thus impact their geographic ranges (Pearson & Dawson, 2003; Raxworthy et al., 2008). Range changes can impact ecosystem function and biodiversity (Raxworthy et al., 2008).

The prediction of climate-driven shifts in species' potential ranges under future climate scenarios relies on the application of species distribution model (SDM) (Collevatti et al., 2013; Eskildsen et al., 2013). SDM uses current climate data to model species' existing distributions, and forecast potential future distributions under various climate scenarios (Elith & Leathwick, 2009). These models are needed to understand the possible responses of species to future climate change and how current species' ranges are determined by potential causal factors (Zhang et al., 2012). For example, Pounds et al. (2006) observed a decline in amphibian populations under climate warming using SDMs and Lawler et al. (2006) used SDMs to assess the relative vulnerability of amphibians to future climate change, observing that several regions in Central America will experience high species turnover. More recently, Ochoa-Ochoa et al. (2012) showed that species with a low dispersal capability have high extinction rates, and that climate-driven population declines may be species- and region-specific.

Amphibians are sensitive to changes in thermal and hydric environments due to unshelled eggs, highly permeable skin and unique biphasic life-cycles (Ochoa-Ochoa et al., 2012; Stuart et al., 2004). With at least one third of some 6000 known species threatened with extinction, amphibians are one of the most threatened groups of animals (Hof et al., 2011; Stuart et al., 2004). The reasons for the worldwide decline in amphibian numbers and populations and the increase in threatened species are numerous and complex, but for many species climate change cannot be precluded as one of the main causes (Stuart et al., 2004).

Locations and regions with many endemic or endangered species, known as hotspots, are more sensitive to future climate change (Malcolm et al., 2006). China is a confluence of two main biogeographical divisions, the Oriental and Palaearctic Realms, and contains many priority-eco-regions for global conservation (Fei et al., 2009). Of some 410 amphibian species found in China, 263 are endemic (Fei et al., 2009). The IUCN (2015) reported that 27.6% of amphibians in mainland China are at risk of extinction or threatened and 65.2% of them are endemic. Most of those species are distributed in forests, farmland and wetlands. Thus, climate change would have severe synergistic effects on Chinese amphibians, because it would increase the effects of habitat destruction and fragmentation associated with anthropogenic land-use change, that are one of the main drivers of amphibian's extinction risk (Hof et al., 2011). Quantifying the general trends of the climate-change driven shifts in species distribution and abundance is extremely important for applying adequate conservation policies. However, despite the high endemism and richness of amphibian species in China, this is the first attempt to predict climate change-driven shifts in their distribution and abundance.

Many studies showed that climate change causes species' movement (Pearson & Dawson, 2003; Raxworthy et al., 2008) and significant species turnover (Peterson et al., 2002), but few studies considered the effect of climate change on fragmentation of current species populations. Here we used MaxEnt (a common SDM) and 40 different future climate scenarios to study the effect of different greenhouse gas scenarios on the distribution of amphibians in China. We want to quantify the effect of the current global warming on the Chinese amphibians, namely, potential range shifts, the directions of those predicted range shifts and the fragmentation of the future predicted distributions. Further, we aim to calculate the temporal turnover of species composition in order to identify priority areas for amphibian conservation in China.

MATERIALS AND METHODS

Species data

Occurrence points for amphibians were collected from the Global Biodiversity Information Facility (GBIF; http://www.gbif.org) and published papers. In order to improve the accuracy of prediction, we did not include species with less than ten different geo-referenced occurrences. We obtained a total of 134 species [20 urodeles of the families Cryptobranchidae (1), Hynobiidae (7) and Salamandridae (12), and 114 anurans of the families Bombinatoridae (3), Bufonidae (6), Dicroglossidae (17), Hylidae (6), Megophryidae (27), Microhylidae (10), Ranidae (35) and Rhacophoridae (10) (Table S1).

Climate variables

To build SDMs we chose five climatic variables: (1) annual precipitation; (2) annual mean temperature; (3) temperature seasonality; (4) minimum temperature of the coldest month; and (5) maximum temperature of the warmest month. Although more bioclimatic variables were available we used these five variables because (1) precipitation and temperature are critical climatic factors in all atmospheric ocean general circulation models (AOGCMs) and reflect the availability of water and energy and directly impact amphibian physiology(Collevatti et al., 2013); (2) these variables are very important in determining the distribution of amphibians (Collevatti et al., 2013; Munguía et al., 2012); (3) the addition of other climatic variables to SDMs generally increases the danger of over-fitting (Collevatti et al., 2013) and the uncertainty (Varela et al., 2015). All climate data were obtained at a 5 arc-min grid scale from WorldClim (http://www.worldclim.org/).

Climate layers

Our prediction is based on bioclimatic envelope modeling, which changes with coupled AOGCMs. Different AOGCMs and greenhouse gas scenarios will lead to various changes in species' distributions in the future. The Intergovernmental Panel on Climate Change (IPCC) in its Fifth Assessment Report (AR5) proposes four Representative Concentration Pathways (RCPs). RCPs may be better than the emission scenarios developed in the Special Report on Emissions Scenarios (SRES) and hence RCPs have replaced SRES standards (Wayne, 2013). The four pathways (RCP2.6, RCP4.5, RCP6 and RCP8.5) represent the four possible radiative forcing values (+2.6, +4.5, +6.0 and +8.5 W/m^2, respectively) (Wayne, 2013). We used data from 1950–2000 as baseline climate data. Five AOGCMs [Integrated Earth System Model (MIROC-ESM), Beijing Climate Center Climate System Model (BCC-CSM1-1), Goddard Institute for

Space Studies (GISS-E2-R), Community Climate System Model (CCSM4) and Institut Pierre Simon Laplace (IPSL-CM5A-LR)] were used for the years 2050s and 2070s. For each AOGCM, we used all four RCPs to evaluate different greenhouse gas scenarios. Hence, the total number of climate scenarios considered was 40 (20 scenarios and two time steps).

Species distribution modelling

MaxEnt is a commonly used algorithm in species distribution modelling because of its good predictive performance (Elith et al., 2011; Varela et al., 2014). MaxEnt predicts species' probability distributions of habitat suitability by calculating the maximum entropy distribution and constraining the expected value of each of a set of environmental variables to match the empirical average (Phillips et al., 2006). Using presence-only data, MaxEnt fits an unknown probability distribution within the environmental space defined by the input variables of the cells with known species occurrence records. This unknown probability distribution is proportional to the probability of occurrence (Elith et al., 2011).

Analyses were performed in R using the dismo package to simulate species distributions (R Core Team, 2013; Hijmans et al., 2015). We carried out SDMs following Elith et al. (2011). For each species, occurrence points were randomly partitioned into two subsets (calibration and validation, at a ratio of 4:1); this was repeated 100 times, each time choosing different random combinations of occurrence points for the calibration/validation datasets. Next, we calculated model parameters and used them to predict future distributions.

The prediction results of the SDMs were evaluated using the area under the receiver

PeerJ PrePrints | https://doi.org/10.7287/peerj.preprints.1681v1 | CC-BY 4.0 Open Access | rec: 26 Jan 2016, publ: 26 Jan 2016

operating characteristic curve (AUC) (Elith et al., 2011; Eskildsen et al., 2013; Freeman & Moisen, 2008; Guisan et al., 2013). We used the maximum value of (sensitivity + specificity) as a threshold, in order to minimize the mean of the error rate for both positive and negative observations (Freeman & Moisen, 2008). This is equivalent to maximizing (sensitivity + specificity − 1), otherwise known as the true skill statistic (TSS) (Freeman & Moisen, 2008).

Species' range shift and turnover

We used four indicators to illustrate changes in amphibian distribution under climate change scenarios: (1) area change (AC); (2) altitude change; (3) latitude change; and (4) longitude change. Area is the number of grid cells occupied by the species and AC is the area of a species' distribution in the future (A_f) minus its current area (A_c), divided by its current area: $AC = (A_f – A_c)/A_c \times 100\%$. We then calculated the distribution space loss (DSL): $DSL = (DS_c – DS_{fc}) / DS_c \times 100\%$, new distribution space (NDS): $NDS = (DS_f – DS_{fc}) / DS_f \times 100\%$, here DSL represents the proportional decrease in original distribution area under climate change; DS_c is the distribution space under current climatic scenarios; DS_f is the distribution space under future climatic scenarios; DS_{fc} is the overlapped distribution space between future and current climatic scenarios; and NDS represents the proportion of new distribution area in future distribution under climate change.

To evaluate overall changes in amphibian diversity and distribution in China we calculated species turnover sum (TS) and turnover ratio (TR) in each grid cell within the potential geographical range shifts for all species. TS was calculated as the total number of newly occurring species (*NC*) and extinct species (*NE*) in a given grid cell: $TS = NC + NE$. *TR* was calculated as *TS* divided by the sum of current species in each grid cell (*NT*) and *NC*: $TR = TS / (NT + NC) \times 100\%$ (Peterson et al., 2002). We considered grid cells with a *TR* greater than 50% and a *TS* greater than 20 as areas of significant future change.

Fragmentation

We studied the fragmentation of species distributions according to methods for calculating habitat fragmentation. We used SDMTools (VanDerWal et al., 2014) to generate patch information from a raster map. To measure species fragmentation we used the coherence index (Jaeger, 2000). The coherence index (*CI)* is a measure of the probability that two animals placed in different patch areas find each other (Jaeger, 2000). The coherence index is calculated as: $CI = \sum_{i=1}^{n} (\frac{A_i}{A_t})^2$, where n is the number of patches; A_i is the size of i-th patch; and A_t is the total area of the species distribution. An increase in the coherence index means distribution fragmentation decreases (Jaeger, 2000). We chose the coherence index as our measure and not conventional fragmentation (Cerezo et al., 2010) because of (1) its low sensitivity to very small patches as opposed to mean patch size; (2) the monotony of its reaction to different fragmentation phases; and (3) its ability to distinguish spatial patterns.

RESULTS

MaxEnt shows great predictive performance for all distributions under the baseline scenario, with high values for AUC (> 0.8). The 134 amphibians show varying sensitivities to future climate change and most species have large changes in RCP8.5 in the 2070s (Figs 1, S1–S2).

The suitable habitat of the majority of species (92.5% in the 2050s, and 91.8% in the 2070s) will move northwards (mean latitude increased), with a mean latitude shift of 0.60° by the 2050s and 0.83° by the 2070s (Fig. 2A). The suitable habitat of the majority of species (76.9% in the 2050s, and 84.3% in the 2070s) will move westwards (mean longitude will decrease) across all future scenarios ranging from 0.03–4.51° (mean 1.35°) in the 2050s, and from 0.03–6.87° (mean 1.72°) in the 2070s. The number of species with the furthest longitudinal movement (more than 0.5° and more than 1°) are 75 and 56 in the 2050s, respectively, and 84 and 68 in the 2070s (Fig. 2B). The suitable habitat of virtually all species (95.5% in the 2050s, and 97.0% in the 2070s) will move to higher altitudes under climate change, with a mean range shift of 287.2 m by the 2050s and 387.8 m by the 2070s (Fig. 2C).

Area change will vary from -52.8–324.5% by the 2050s and from -57.6–418.1% by the 2070s. 70.9% of species in the 2050s (38.1% for area contraction and 32.8% for area expansion) and 75.4% of species in the 2070s (37.3% for area contraction and 38.1% for area expansion) will undergo a significant change in distribution of greater than 10% (Fig. 2D). Among these species, three and six species in the 2050s, and 13 and 11 species in the 2070s will respectively show substantial area contraction (greater than 50%) and expansion (greater than 50%) (Fig. 2D).

By the 2050s, the mean value of distribution space loss will be 20.7%, and nine species will lose more than 50% of their original distribution space; by the 2070s, the mean value of distribution space loss will be 23.9%, and 22 species will lose more than 50% of their original distribution space (Fig. 2E). By the 2050s, the mean value of the new distribution space ratio for amphibians will be 15.9%, and three species will have a new distribution space greater than 50%; by the 2070s the mean value of the new distribution space ratio will be 21.1%, and five species will have a new distribution space greater than 50% (Fig. 2F).

Area change and area change ratio were correlated with changes in latitude, longitude and altitude (Table 1). In other words, under climate change, suitable habitat of amphibians that move westwards, southwards and to higher altitudes will undergo overall range contraction.

For species undergoing declines in distribution, the mean value of coherent index (*CI*) change will be -16.2% for the 2050s and -19.6% for the 2070s; for species undergoing increases in distribution, the mean value of CI change will be 5.9% for the 2050s and 6.6% for the 2070s. Under climate change, species with higher area change (decrease or increase) will have higher CI changes (Fig. 3).

Different regions have different TR and TS (Fig. 4). Areas with the highest TR are located in Northwest China where amphibian species richness is lower. Areas with high TS are located in Central and Southern China and these areas were inconsistent with areas of high TR. According to our composite indicator (with TR > 50% and TS > 20), climate strongly influenced amphibian distributions in five regions: the Qinling Mountains, Wuyi Mountains, Dabie Mountains, Sichuan Basin and surrounding areas, and western Guizhou province (Fig. 4).

DISCUSSION

Climatic shifts to warmer, drier regimes can have profound effects on the distribution of amphibians (Araújo et al., 2006). The 134 amphibians studied here exhibited a variety of climate-driven range shifts. Climatic shifts to warmer temperatures were more substantial by the 2070s than by the 2050s. RCP8.5 represents the highest greenhouse gas emission trajectory (Wayne, 2013) and as expected we detected the greatest change in amphibian distribution under RCP8.5 and by the 2070s.

Effects of climate change on the direction of movement

The average temperature of Earth's surface will rise by up to 6.4 °C by 2100, and species will need to migrate to higher latitudes and/or elevations (Pearson & Dawson, 2003; Raxworthy et al., 2008). When temperature undergoes one degree change, elevation needs to change 100–200 m and latitude about 0.5° (about 55 km of polar movement, though latitude has a complex and variable relationship with temperature) (Peterson & Vose, 1997). Our study confirmed these general trends and that under climate warming the suitable habitat of amphibians will predominantly migrate to higher altitudes and latitudes. The direction and speed of migration depend on the climate scenario and species being modelled.

The annual average temperature is expected to rise to 3.2 °C and 4.5 °C by the 2050s and 2070s respectively, and if temperature has a consistent rate of increase we should see 320–900 m elevation shifts and/or 1.6–2.3° (176–253 km) of northern movement. However, our results indicate that species move only 0.60–0.83° and upword 287–387 m. Thus, future climate change may push many amphibians into unsuitable climatic zones and increase their risk of extinction.

Our analysis showed that the majority of amphibians will move westwards. This result contradicts other studies where no trend in longitudinal displacement was found (Peterson et al., 2002). However, the longitudinal trend observed in China is plausible given that the terrain of the country is high in the west and low in the east (amphibians will move to higher altitudes under climate warming), and that East China is adjacent to the sea without space for amphibians to migrate.

Organisms often show species-specific environmental requirements and global climate change has different effects on the ranges of different species (Erasmus et al., 2002; Peterson et al., 2002; Varela et al., 2015). For example, Midgley et al. (2003) found that under climate warming, 11 plant species in the Cape Floristic Region expanded their distributions and five species faced elimination of all suitable habitat. Erasmus et al. (2002) found climate-induced shifts in ranges: 78% of animal species in South Africa underwent range reduction, 17% expanded, 3% showed no change and 2% became locally extinct. Foden et al. (2013) found that 11–15% of amphibians, 6–9% of birds and 6–9% of coral species were highly vulnerable to climate change. Our study confirmed that future climate change is a double-edged sword for the distribution of amphibians: some amphibian species will undergo distribution reduction, and others will expand. Following our results, if amphibians move west (drier habitats), south (warmer habitats), and to higher altitudes, their distribution will decrease. In other words, the direction of movement of amphibians may control the eventual change in distribution area.

Effects of climate change on fragmentation

Under climate warming, the increase in fragmentation (lower *CI*) caused a decrease in distribution areas. Distribution fragmentation can reduce populations and habitat connectivity, interfere with gene communication, and reduce migration rates and resilience (Chen & Bi, 2007; Sarmento Cabral et al., 2013), negatively affecting the long-term viability of threatened and endangered amphibians. To our knowledge, this is the first evidence that climate warming will cause a fragmentation in the distribution of amphibians, though some studies have documented that climate change can cause habit fragmentation (Opdam & Wascher, 2004). Distribution fragmentation causes population disjunction and most populations in small fragments can easily disappear because small populations are sensitivity to genetic, demographic and environmental fluctuation. The negative effect of distribution fragmentation can be explained by island biogeography theory and meta-population models. Many species are rare with specialized habitat requirements making them particularly vulnerable to habitat fragmentation and modification (Andreone et al., 2005).

Our study shows that the lost habitat for some species is not at the edge of distributions but mainly in the core region (Fig. S3). The core distribution region is very important for a species because it acts as a hub that connects patches, allowing the genetic exchange between different populations. Habitat loss and fragmentation have been identified as one of the major causes of amphibian decline globally (Stuart et al., 2004). Our study shows that future climate change might not only shrink the distribution area of some amphibians, but also make their distribution area more fragmented. This is a synergic effect which would accelerate the decline and/or local extinction of certain amphibians. On the other hand, species predicted to undergo area expansion such as *Hynobius leechii*, *Hylarana macrodactyla* and *Fejervarya multistriata* were not affected by fragmentation, which would benefit them and allow them to expand more easily.

Species turnover and high impact areas

The identification of critical habitats for amphibian protection under climate change is important for making robust conservation management decisions (Guisan et al., 2013). Areas of high species turnover may be sites with largest shifts in population. Many studies conduct turnover assessments using turnover ratios (Erasmus et al., 2002; Peterson et al., 2002), however our results revealed that areas with high turnover ratios were not the same as areas with high turnover sums. This is because an area with a low turnover sum can have a high turnover ratio if the area has a very low species richness under the current climate (e.g. northwestern China). We considered grid cells with turnover ratios greater than 50% and turnover sums greater than 20 as areas of potentially large future shifts in amphibians. We found several such areas including the Sichuan Basin and surrounding areas, the Qinling Mountains, the Dabie Mountains, the Wuyi Mountains and western Guizhou, and hypothesize that these regions may see major shifts in amphibians as a result of the combined action of several factors. First, the Sichuan Basin and surrounding areas, western Guizhou province and Dabie Mountains are located in an area of transition from the northern subtropics to warm temperate climate; there are relatively large climatic gradients in these areas (Xie et al., 2007). Second, these five areas contain the boundaries of many species' distributions (Fei et al., 2009); areas containing many range limits are expected to experience greater turnover than those containing few range limits. Third, mountainous regions, such as the Qinling Mountains form a natural (north or south) boundary for many species and so may experience significant faunal change. Under climate change, habitat loss, especially that resulting from changes to freshwater ecosystems, is the greatest risk to amphibians (Solomon, 2007).

Conservation implications

We found overlapping key amphibian regions, such as important endemic amphibian regionalization (e.g. Sichuan and Guizhou provinces) and global biodiversity hotspots (e.g. Sichuan) (Chen & Bi, 2007). Nature reserves provide the most effective approach for biodiversity conservation, especially for the in situ conservation of wildlife and natural ecosystems (D'Amen et al., 2011). The current natural reserve network in China does not provide adequate coverage for amphibians. Only two national nature reserves have been established to protect amphibians, one in Zhangjiajie and the other in Zhongjianhe, both for the protection of the Chinese giant salamander (*Andrias davidianus*). The creation of new nature reserves, in important regions identified here with high predicted amphibian turnover, is a critical conservation requirement for China. For other species projected to suffer from large range contraction, we need to develop and implement management plans for the protection of their habitat and translocate individuals into these regions. Climate change will change the current distribution area of species and impact distribution fragmentation, and so we should pay additional attention to fragments and the connectivity of distribution spaces in the design of future conservation strategies.

ACKNOWLEDGEMENTS

We would like to thank Xiao-Li Fan, Liang Fei, Jian-Ping Jiang and Zhi-Hua Lin for help with confirming distribution and diversity of amphibians in China.

ADDITIONAL INFORMATION AND DECLARATIONS

Funding

This work was supported by grants from the National Natural Science Foundation of China (31300342 and 31570417), Anhui Provincial National Science Foundation (1608085MC63), Priority Academic Program Development of Jiangsu Higher Education Institutions and Chinese Postdoctoral Science Foundation (2014M561683). SV is supported by a postdoctoral contract at Universidad de Alcalá in Madrid, Spain. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Grant Disclosures

The following grant information was disclosed by the authors:

National Natural Science Foundation of China: 31300342 and 31570417.

Anhui Provincial National Science Foundation: 1608085MC63.

Chinese Postdoctoral Science Foundation: 2014M561683.

Nanjing Normal University: Priority Academic Program Development of Jiangsu Higher Education Institutions.

Competing Interests

The authors declare there are no competing interests.

Author Contributions

- Ren-Yan Duan, Xiao-Quan Kong and Min-Yi Huang conceived and designed the experiments, performed the experiments, collected and analyzed the data, contributed reagents/materials/analysis tools, prepared figures and/or tables, reviewed drafts of the paper.
- Sara Varela analyzed the data, reviewed drafts of the paper.
- Xiang Ji conceived and designed the experiments, wrote the paper, reviewed drafts of the paper.

REFERENCES

Andreone F, Cadle JE, Cox N, Glaw F, Nussbaum RA, Raxworthy CJ, Stuart SN, Vallan D, Vences M. 2005. Species review of amphibian extinction risks in Madagascar: conclusions from global amphibian assessment. *Conservation Biology* **19:**1790–1802.

Araújo MB, Thuiller W, Pearson RG. 2006. Climate warming and the decline of amphibians and reptiles in Europe. *Journal of Biogeography* **33:**1712–1728.

Cerezo A, Perelman S, Robbins CS. 2010. Landscape-level impact of tropical forest loss and fragmentation on bird occurrence in eastern Guatemala. *Ecological Modelling* **221:**512–526.

Chen Y, Bi J. 2007. Biogeography and hotspots of amphibian species of China: implications to reserve selection and conservation. *Current Science* **92:**480–489.

Collevatti RG, Terribile LC, Oliveira G, Lima-Ribeiro MS, Nabout JC, Rangel TF, Diniz-Filho JAF. 2013. Drawbacks to palaeodistribution modelling: the case of South American seasonally dry forests. *Journal of Biogeography* **40:**345–358.

D'Amen M, Bombi P, Pearman PB, Schmatz DR, Zimmermann NE, Bologna MA. 2011. Will climate change reduce the efficacy of protected areas for amphibian conservation in Italy? *Biological Conservation* **144:**989–997.

Elith J, Leathwick JR. 2009. Species distribution models: ecological explanation and prediction across space and time. *Annual Review of Ecology, Evolution, and Systematics* **40:**677–697.

Elith J, Phillips SJ, Hastie T, Dudík M, Chee YE, Yates CJ. 2011. A statistical explanation of MaxEnt for ecologists. *Diversity and Distributions* **17:**43–57.

Erasmus BFN, Van Jaarsveld AS, Chown SL, Kshatriya M, Wessels KJ. 2002. Vulnerability of South African animal taxa to climate change. *Global Change Biology* **8:**679–693.

Eskildsen A, Roux PC, Heikkinen RK, Høye TT, Kissling WD, Pöyry J, Wisz MS, Luoto M. 2013. Testing species distribution models across space and time: high latitude butterflies and recent warming. *Global Ecology and Biogeography* **22:**1293–1303.

Fei L, Hu SQ, Ye CY, Huang YZ. 2009. *Fauna Sinica Amphibia Vol.3 (Anura; Ranidae)*. Beijing: Science Press.

Foden WB, Butchart SHM, Stuart SN, Vié JC, Akçakaya HR, Angulo A, DeVantier LM, Gutsche A, Turak E, Cao L, Donner SD, Katariya V, Bernard R, Holland RA, Hughes

AF, O'Hanlon SE, Garnett ST, Şekercioğlu ÇH, Mace GM. 2013. Identifying the world's most climate change vulnerable species: a systematic trait-based assessment of all birds, amphibians and corals. *PLoS One* **8:**e65427.

Freeman EA, Moisen GG. 2008. A comparison of the performance of threshold criteria for binary classification in terms of predicted prevalence and kappa. *Ecological Modelling* **217:**48–58.

Guisan A, Tingley R, Baumgartner JB, Naujokaitis-Lewis I, Sutcliffe PR, Tulloch AIT, Regan TJ, Brotons L, McDonald-Madden E, Mantyka-Pringle C, Martin TG, Rhodes JR, Maggini R, Setterfield SA, Elith J, Schwartz MW, Wintle BA, Broennimann O, Austin M, Ferrier S, Kearney MR, Possingham HP, Buckley YM. 2013. Predicting species distributions for conservation decisions. *Ecology Letters* **16:**1424–1435.

Hijmans RJ, Phillips S, Leathwick J, Elith J. 2015. Dismo: species distribution modeling, R package version 1.0-5.

Hof C, Araújo MB, Jetz W, Rahbek C. 2011. Additive threats from pathogens, climate and land-use change for global amphibian diversity. *Nature* **480:**516–519.

IUCN. 2015. Geographic patterns. Available online follow website http//www.iucnredlist.org/initiatives/amphibians/analysis/geographic-patterns#diversity.

Jaeger JAG. 2000. Landscape division, splitting index, and effective mesh size: new measures of landscape fragmentation. *Landscape Ecology* **15:**115–130.

Lawler JJ, White D, Neilson RP, Blaustein AR. 2006. Predicting climate-induced range shifts: model differences and model reliability. *Global Change Biology* **12:**1568–1584.

Malcolm JR, Liu C, Neilson RP, Hansen L, Hannah L. 2006. Global warming and extinctions of endemic species from biodiversity hotspots. *Conservation biology* **20:**538–548.

Midgley G, Hannah L, Millar D, Thuiller W, Booth A. 2003. Developing regional and species-level assessments of climate change impacts on biodiversity in the Cape Floristic Region. *Biological Conservation* **112:**87–97.

Munguía M, Rahbek C, Rangel TF, Diniz-Filho JAF, Araújo MB. 2012. Equilibrium of global amphibian species distributions with climate. *PLoS One* **7:**e34420.

Ochoa-Ochoa LM, Rodríguez P, Mora F, Flores-Villela O, Whittaker RJ. 2012. Climate change and amphibian diversity patterns in Mexico. *Biological Conservation* **150:**94–102.

Opdam P, Wascher D. 2004. Climate change meets habitat fragmentation: linking landscape and biogeographical scale levels in research and conservation. *Biological Conservation* **117:**285–297.

Pearson RG, Dawson TP. 2003. Predicting the impacts of climate change on the distribution of species: are bioclimate envelope models useful? *Global Ecology and Biogeography* **12:**361–371.

Peterson AT, Ortega-Huerta MA, Bartley J, Sánchez-Cordero V, Soberón J, Buddemeier RH, Stockwell DRB. 2002. Future projections for Mexican faunas under global climate change scenarios. *Nature* **416:**626–629.

Peterson TC, Vose RS. 1997. An overview of the global historical climatology network temperature database. *Bulletin of the American Meteorological Society* **78:**2837–2849.

PeerJ PrePrints | https://doi.org/10.7287/peerj.preprints.1681v1 | CC-BY 4.0 Open Access | rec: 26 Jan 2016, publ: 26 Jan 2016

Phillips SJ, Anderson RP, Schapire RE. 2006. Maximum entropy modeling of species geographic distributions. *Ecological Modelling* **190:**231–259.

Pounds JA, Bustamante MR, Coloma LA, Consuegra JA, Fogden MP, Foster PN, La Marca E, Masters KL, Merino-Viteri A, Puschendorf R, Ron SR, Sánchez-Azofeifa GA, Still CJ, Young BE. 2006. Widespread amphibian extinctions from epidemic disease driven by global warming. *Nature* **439:**161–167.

R Development Core Team. 2013. *R*: *a language and environment for statistical computing*. Vienna: R Foundation for Statistical Computing. r-project.org.

Raxworthy CJ, Pearson RG, Rabibisoa N, Rakotondrazafy AM, Ramanamanjato JB, Raselimanana AP, Wu S, Nussbaum RA, Stone DA. 2008. Extinction vulnerability of tropical montane endemism from warming and upslope displacement: A preliminary appraisal for the highest massif in Madagascar. *Global Change Biology* **14:**1703–1720.

Sarmento Cabral J, Jeltsch F, Thuiller W, Higgins S, Midgley GF, Rebelo AG, Rouget M, Schurr FM. 2013. Impacts of past habitat loss and future climate change on the range dynamics of South African Proteaceae. *Diversity and Distributions* **19:**363–376.

Solomon S. 2007. *Climate change 2007 - the physical science basis: working group I contribution to the fourth assessment report of the IPCC*. Cambridge University Press.

Stuart SN, Chanson JS, Cox NA, Young B., Rodrigues AS, Fischman DL, Waller RW. 2004. Status and trends of amphibian declines and extinctions worldwide. *Science* **306:**1783–1786.

VanDerWal J, Falconi L, Januchowski S, Shoo L, Storlie C. 2014. SDMTools: Species distribution modelling tools: tools for processing data associated with species distribution modelling exercises. Accessible online at http://cran.r-project.org/web/packages/SDMTools/SDMTools. pdf.

Varela S, Anderson RP, García-Valdés R, Fernández-González F. 2014. Environmental filters reduce the effects of sampling bias and improve predictions of ecological niche models. *Ecography* **37:**1084–1091.

Varela S, Lima-Ribeiro MS, Terribile LC. 2015. A short guide to the climatic variables of the Last Glacial Maximum for biogeographers. *PloS One* **10:**e0129037.

Wayne GP. 2013. The beginner's guide to representative concentration pathways. Available online follow website: www. Skept. com.

Xie F, Lau MWN, Stuart SN, Chanson JS, Cox NA, Fischman DL. 2007. Conservation needs of amphibians in China: A review. *Science in China Series C* **50:**265–276.

Zhang MG., Zhou ZK, Chen WY, Slik JWF, Cannon CH, Raes N. 2012. Using species distribution modeling to improve conservation and land use planning of Yunnan, China. *Biological Conservation* **153:**257–264.

Figure legends

Figure 1 Predicted species movement in a climate scenario, using the BC45 scenario as an example. The arrow represents the distance and direction of species geometric mean point at different periods. The black arrow presents climatic scenario of the 2050s, blue arrow presents climatic scenario of the 2050s-2070s. The wind roses summarize the distance and direction of shift for each species. The radiuses of rings on each wind rose represent geographical distance (inner circus: 2 degrees; outer circus: 5 degrees). The grey axis bars on wind roses represent a length of 7 degrees. BC45 scenario represents BCC-CSM1-1 as AOGCM and using RCP4.5 as greenhouse gas scenarios. The figure was generated using R (http://www.R-project.org/), ggplot2 (http://had.co.nz/ggplot2/boo) and raster (http://CRAN.R-project.org/package=raster) softwares, and the map was created using data downloaded from the GADM database (http://www.gadm.org/) for free use.

Figure 2 Distribution patterns of 134 species of amphibians from different aspects.

Figure 3 Percent of coherence index (*CI*) change. *CI* is the probability that two animals placed in different areas (patches) will find each other. The order of 134 species in *X* axis from left to right depends on the order of mean value of area change (from low to high, to make thing to be comparable, the 2070s using the order of the 2050s).

Figure 4 Turnover of species under climate change, using the BC45 scenario in the 2070s as example. A: species richness in current; B: turnover rate; C: turnover sum of 134 species. The

PeerJ PrePrints | https://doi.org/10.7287/peerj.preprints.1681v1 | CC-BY 4.0 Open Access | rec: 26 Jan 2016, publ: 26 Jan 2016

figure was generated using R (http://www.R-project.org/), ggplot2 (http://had.co.nz/ggplot2/boo) and raster (http://CRAN.R-project.org/package=raster) softwares, and the map was created using data downloaded from the GADM database (http://www.gadm.org/) for free use.

Figure S1 Species movement under different AOGCM models and RCP in the 2050s. Y axis presents different AOGCM models. X axis presents different RCP models. The arrow and wind rose are same with Figure 1.

Figure S2 Species movement under different AOGCM models and RCP in the 2070s. Y axis presents different AOGCM models. X axis presents different RCP models. The arrow and wind rose are same with Figure 1.

Figure S3 Distribution change under climate change using *Megophrys major* as an example. The figure was generated using R (http://www.R-project.org/), ggplot2 (http://had.co.nz/ggplot2/boo) and raster (http://CRAN.R-project.org/package=raster) softwares, and the maps were created using data downloaded from the GADM database (http://www.gadm.org/) for free use.

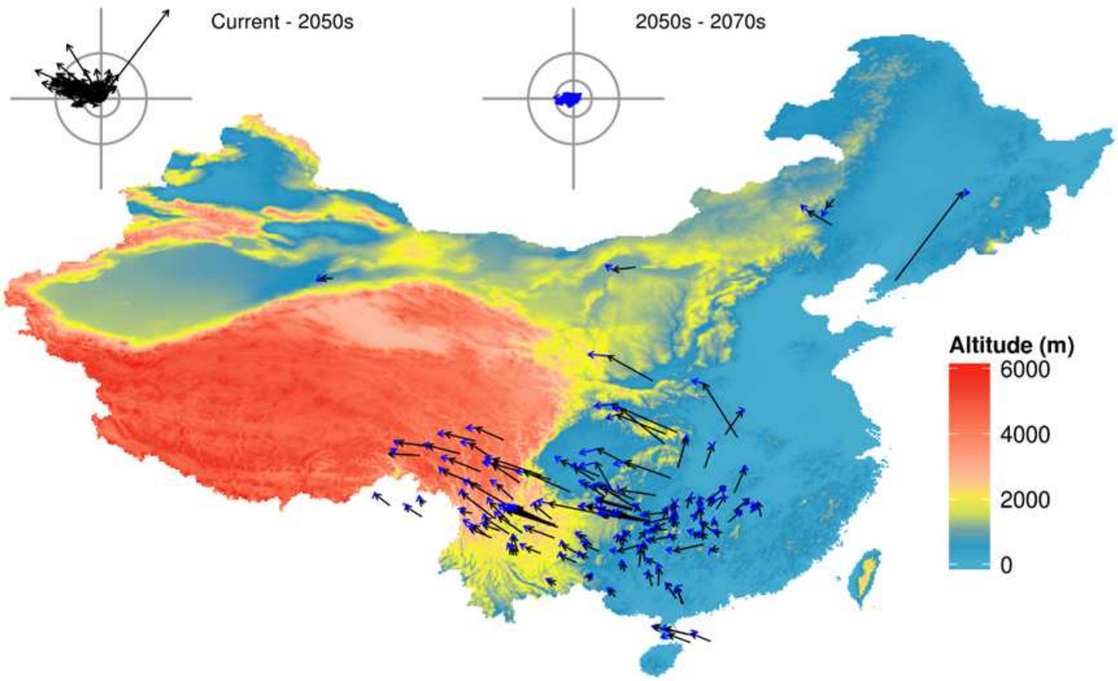
506 **Table 1 Correlation coefficients between parameters.** * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

	2050s		2070s	
	Area change	Area change ratio (%)	Area change	Area change ratio (%)
Current area	0.363***	0.108	0.358***	0.069
Current latitude	0.058	0.135	0.049	0.118
Current longitude	0.053	0.226**	0.060	0.220*
Current altitude	–0.074	–0.146	–0.084	–0.144
Latitude change	0.28**	0.516***	0.355***	0.524***
Longitude change	0.340***	0.477***	0.371***	0.464***
Altitude change	–0.405***	–0.374***	–0.432***	–0.373***
New distribution area	–0.027	–0.116	–0.016	–0.123
Distribution area loss	–0.011	–0.074	–0.012	–0.072
Change of coherence index	0.656***	0.517***	0.624***	0.534***

507

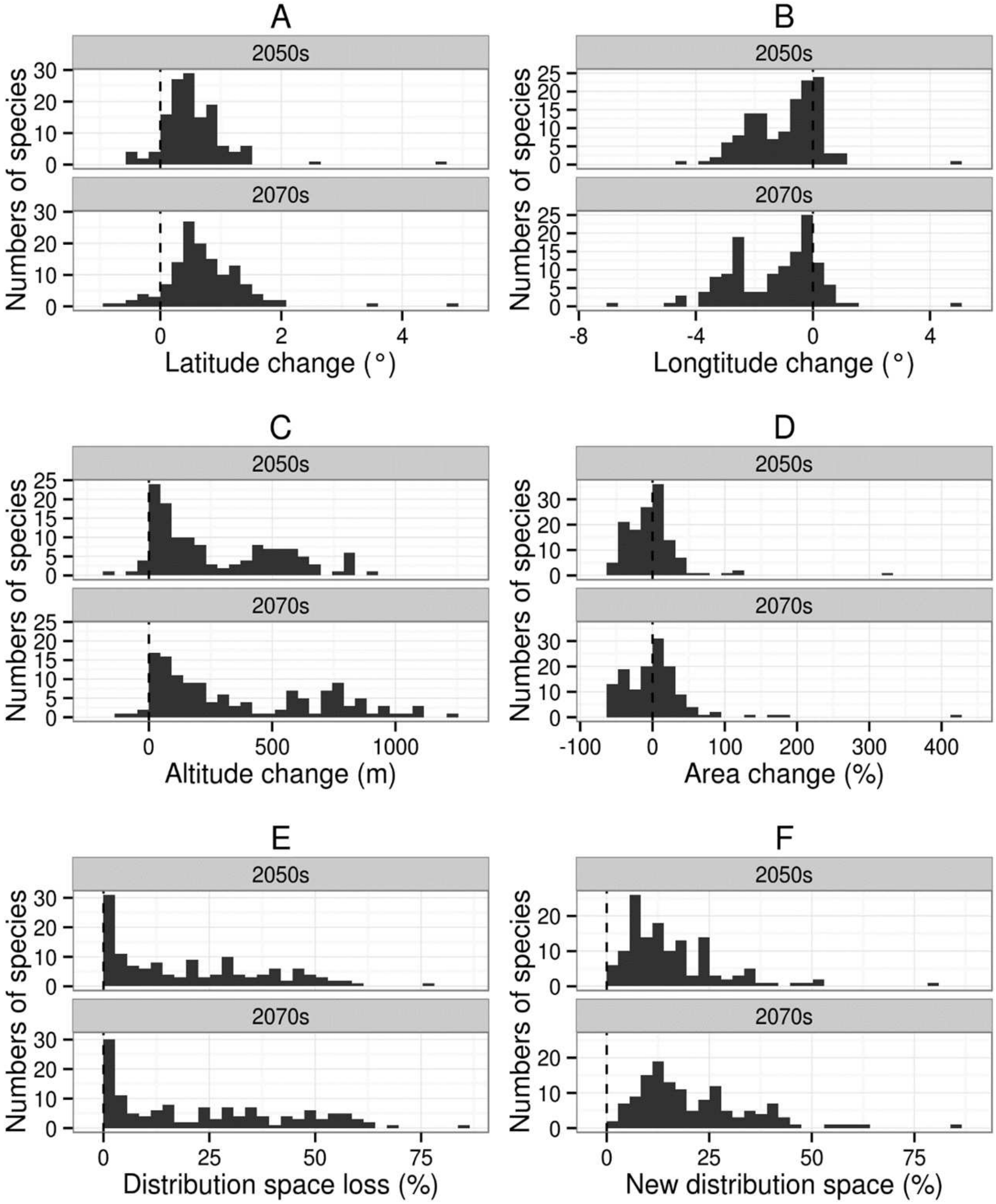
PeerJ PrePrints | https://doi.org/10.7287/peerj.preprints.1681v1 | CC-BY 4.0 Open Access | rec: 26 Jan 2016, publ: 26 Jan 2016

509 **Figure 1**



510

512 **Figure 2**



513

PeerJ PrePrints | https://doi.org/10.7287/peerj.preprints.1681v1 | CC-BY 4.0 Open Access | rec: 26 Jan 2016, publ: 26 Jan 2016

Figure 3

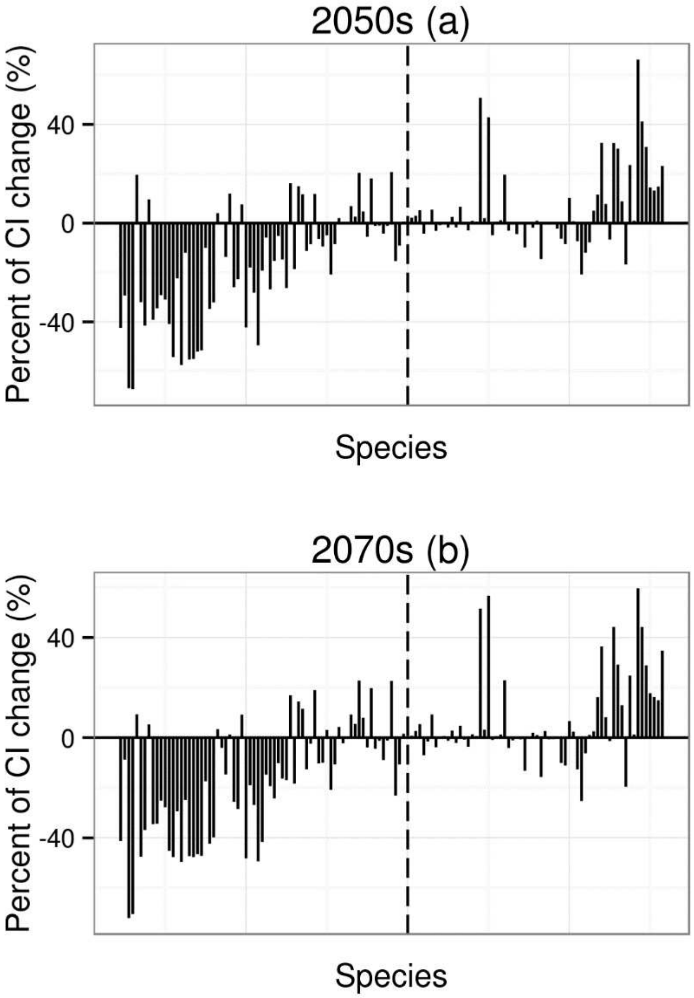
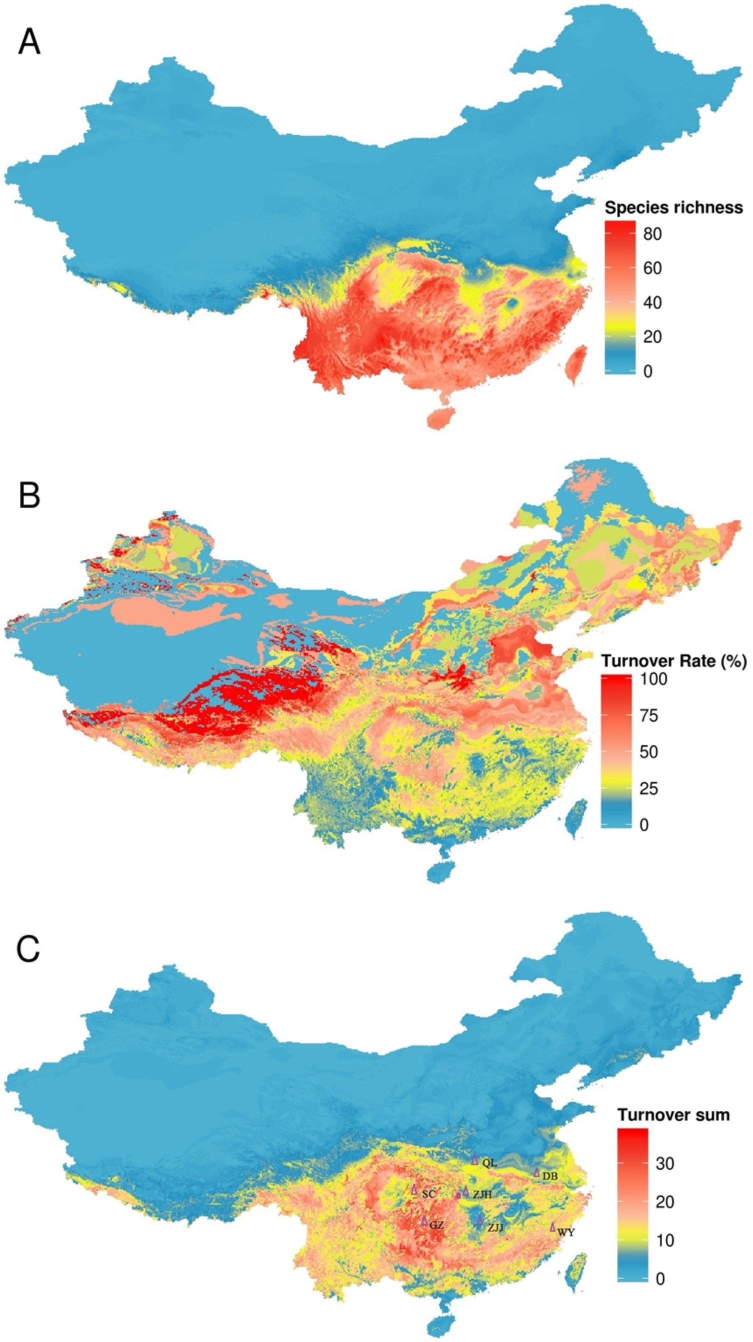

2050s (a)
Percent of CI change (%)
40
0
-40
Species
2070s (b)
Percent of CI change (%)
40
0
-40
Species

Figure 4


A
Species richness
80
60
40
20
0
B
Turnover Rate (%)
100
75
50
25
0
C
Turnover sum
30
20
10
0
QL
DB
SC
ZJH
GZ
ZJJ
WY