Distribution and *in situ* conservation of a relic oil woody species yellowhorn *(Xanthoceras sorbifolium* Bunge) base on China's National Nature Reserves

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Conservation and protected areas have been recognized as the last shelter for wild animal and plant species. To understand the Chinese wild *Xanthoceras sorbifolium* contemporary and future (next 30-50 years) distribution under the anticipated climate change and to improve the species' *in situ* conservation strategy within China's National Nature Reserves network, we used BiodiversityR to predict the species' distribution utilizing the method's "always-suitable" map concept. Then, we delineated the "always-suitable" distribution areas with the existing China's National Nature Reserves to identify potential conservation areas after considering the role of human influence (i.e., utilization) and the anticipated changes of climate change. Seven bioclimatic variables predictors and 12 Environmental Niche Modelling sub-models successfully contributed to the final model assembly (AUC = 0.916, kappa = 0.398). The species range delineation indicated that 71 of the 427 National Nature Reserves were included in the "always-suitable" area, accounting for 26,007 km^2 (1.58% of the species total distribution). This mapping endeavour highlighted the anticipated negative impact of climate change with 15-20% habitat decline and expected species' distribution centers shift from the country's northwest to the southeast. Since woody plants with bio-energy potential have increased economic values for their environment-friendly predisposition, our results predicts *X. sorbifolium* continuous deterioration. The adoption of flexible management strategy embracing acceptable tradeoff between conservation and development/utilization within China's National Nature Reserves could effectively alleviate the expected species decline.

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ABSTRACT

Conservation and protected areas have been recognized as the last shelter for wild animal and plant species. To understand the Chinese wild *Xanthoceras sorbifolium* contemporary and future (next 30-50 years) distribution under the anticipated climate change and to improve the species' *in situ* conservation strategy within China's National Nature Reserves network, we used BiodiversityR to predict the species' distribution utilizing the method's "always-suitable" map concept. Then, we delineated the "always-suitable" distribution areas with the existing China's National Nature Reserves to identify potential conservation areas after considering the role of human influence (i.e., utilization) and the anticipated changes of climate change. Seven bioclimatic variables predictors and 12 Environmental Niche Modelling sub-models successfully contributed to the final model assembly (AUC = 0.916, kappa = 0.398). The species range delineation indicated that 71 of the 427 National Nature Reserves were included in the "always-suitable" area, accounting for 26,007 km^2 (1.58% of the species total distribution). This mapping endeavour highlighted the anticipated negative impact of climate change with 15-20% habitat decline and expected species' distribution centers shift from the country's northwest to the southeast. Since woody plants with bio-energy potential have increased economic values for their environment-friendly predisposition, our results predicts *X. sorbifolium* continuous deterioration. The adoption of flexible management strategy embracing acceptable tradeoff between conservation and development/utilization within China's National Nature Reserves could effectively alleviate the expected species decline.

Subjects Conservation Biology, Ecology

Keywords Bioenergy, species distribution model, climate change, GAP analysis, China's National Nature Reserves, Utilization-conservation tradeoff

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INTRODUCTION

Decreasing greenhouse gas emission is an effective method for ameliorating the negative effects of climate change, hence the worldwide increased attention (Rogelj et al., 2016). The positive effect of forests contribution to decreasing greenhouse gas emission was prominently recognized in the United Nations Framework Convention on Climate Change (http://unfccc.int/paris_agreement/items/9485.php (*The Paris Agreement*)). Bioenergy crops such as woody plants offer a "win-win scenario" for both eco-society and environment (Li et al., 2010). Bioenergy crops benefits are multifaceted as they offer opportunities for decreasing greenhouse gas emission, protecting against water, soil, and wind erosion, and increasing employment and the economic vitality in mountain area.

As a relic oil woody plants, *Xanthoceras sorbifolium* Bunge (yellowhorn or Wenguanguo) is the only species in this genus that is endemic to China (Yang et al., 2005). Due to its high seed oil content (60%), *X. sorbifolium* is recognized as one of the most important economic species in Northern China and the species has been earmarked as one of the next-generation alternative biofuel crop (Zhou & Zheng, 2015). However, it should be recognized that a tradeoff between the resource utilization and conservation is a precondition for effective management, specifically for those species that are under constant threat due to their substantial economic value.

Conservation of yellowhorn wild populations should be based on basic biological attributes and inventory information of the species' natural distribution. Prior research was mainly focused on the chemical and medicinal properties of the species' oil and its cultivation and growth with limited studies dedicated to its range distribution (Yang et al., 2005).

In situ conservation is effective in maintaining species' genetic diversity (Iriondo et al., 2008); however, the development of sound *in situ* conservation strategy requires in-depth gap analysis to identify areas of high biological importance to highlight their conservation priority consideration. Constructing species' temporal and spatial distribution is the first step of gap analysis (Hochman et al., 2016); unfortunately for most species, the lack of available reliable records often hampers conservation efforts. Species distribution modeling (SDMs, ecological niche or habitat suitability models) has rapidly progressed in recent years (Elith & Leathwick, 2009; Franklin, 2010; Rovzar et al., 2016) and became an informative tool for understanding major habitat requirements for endangered species contemporary distribution and the projected changes under globe warming (França & Cabral, 2015). SDMs results can help ecologists prioritizing conservation areas through the identification of suitable habitats and, in turn, provide relevant information to policy makers (Franklin, 2010; Vroh et al., 2016). Biodiversity and ecological communities assessments have benefited from the recently developed Graphical User Interface computer package named "BiodiversityR" (Kindt & Coe 2005). This program is specifically designed for analyzing biodiversity and ecological communities utilizing general linear models and machine learning algorithms for assessing, among other things, species presence-absence as well as species abundance (Kindt, 2014; Ranjitkar et al., 2016). BiodiversityR incorporates 19 Environmental Niche Modelling (ENM) algorithms that are proven to produce more robust results than those relying on a single algorithm, thus delivers greater confidence regarding the species in question (Kindt, 2014; Ranjitkar et al., 2016). Then the gaps can be identified after comparing with the distribution of existing protected areas (in the present study our focus is directed towards China's National Nature Reserves). In order to conduct an effective *X. sorbifolium in situ* conservation, information generated from the gap analysis should be considered along with the social-economy of the species. Here, based on the gap analysis results, we will attempt to provide a new conservation approach whereby the species' biologically important areas are identified and extending our work through proposing alternative management/utilization objectives.

By elucidating wild *X. Sorbifolium* contemporary and future distribution, we conducted this reserach to meet the following objectives: 1) illustrate the anticipated future range change (30-50 years) and 2) identify the most effective *in situ* conservation plans utilizing the existing China's National Nature Reserves.

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MATERIALS AND METHODS

Study area

Xanthoceras sorbifolium, yellowhorn, is native and widely distributed species in northern China. For the purpose of this study, we divided the species' range into 4 regions; namely, Xibei (Shaanxi, Gansu, Qinghai, and Ningxia), Huabei (Beijing, Tianjin, Hebei, Shanxi, and Inner Mongolia), Dongbei (Shandong, Henan, Jilin, and Liaoning), and Tibet A.P. (exclude Lingzhi area). These four regions including 14 provinces, Autonomous Prefectures, and cities (Wang et al., 2009), covering 4,858,271 km^2 and accounting for more than 50% of the terrestrial area of the People's Republic of China (Fig 1). The research area has a complex landform and vast range extending between 75.14°～132.58°E and 26.50°～53.28°N, with high (>4000 m asl) and low (<100 m asl) elevations in the southeast and northeast, respectively. This region is relatively dry, belonging to a typical arid to the semiarid region on China, representing a suitable habitat for *X. sorbifolium* due to its drought tolerance (Xia & Gadeek, 2007).

Data collection

Distribution data

Species occurrence data of *X. sorbifolium* natural populations were collected from the following three sources:

1) New gazetteers, such as recent research highlights with valuable information for conservation (Turvey et al., 2015; Yang et al., 2016; Zhang et al., 2016). New gazetteers have been recognized as a reliable resource of information for ecologists specifically in situations where data shortage is prevalent (Guisan et al., 2013). More than 2,800 of new gazetteers have been published (2000 - 2016) and all were accessed from the National Library of China (http://www.nlc.gov.cn/) of which

57 recorded the occurrence of *X. sorbifolium* (Table S1),
2) Specimens from Chinese Virtual Herbarium database (http://www.cvh.ac.cn), and
3) Online publications from the China National Knowledge Internet (CNKI http://www.cnki.net/).
We compiled the species location data from the above sources for a period spanning 2000 to 2016.

Climate data

Biologically significant climatic variables, land cover, and elevation were combined to predict *X. sorbifolium* potential distribution in the next 30-50 years. Current and future (2050 - 2070) bioclimatic variables data were download from WorldClim Version 1 (http://worldclim.org/). There were 19 GCMs (Global Climate Models, also known as General Circulation Models), and each has four Representative Concentration Pathways (RCPs: RCP 2.6, 4.5, 6.0, and 8.5), representing the greenhouse concentration trajectories following the IPCC 5th Assessment Report (Intergovernmental Panel on Climate Change 2015 Report (https://www.ipcc.ch/report/ar5/)). Generalized Variance Inflation Factors (GVIF) were used to select the least correlated predictor variables and GVIFs with more than ten were removed (Guisan et al., 2013). High correlated GVIF variables were also removed (Table S2), and 7 out of the 19 bioclimatic variables (bio 1, 2, 4, 13, 14, 15, and 19) were selected for producing the species distribution model.

Protected area and human influence data

China's National Nature Reserves and Human Influence data from 427 Reserves were acquired for 2015 from the School of Nature Conservation, Beijing Forestry University (Zhang et al., 2016). Human influence data included human population pressure (population density), human land use and infrastructure (built-up areas, nighttime lights, land use/land cover), and human access (coastlines, roads, railroads, navigable rivers) were download from Socioeconomic data and applications center (WCSP, 2005).

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Data analysis

Species occurrence data

Species occurrence data were assembled, overlaid by their representing land cover (The United States Geological Survey; http://landcover.usgs.gov/landcoverdata.php), elevation (The CGIAR Consortium for Spatial Information (GIAR-CSI); http://srtm.csi.cgiar.org/), and administrative regions. Species occurrence data were done at the county level with a spatial resolution of about 10 km, to reduce spatial auto-correlation. Species occurrence in the same grid with a spatial resolution of about 10 km or duplicate recordings were removed (Ranjitkar et al., 2014). After data mining, the three data resources produced a total of 269 species occurrence points.

Modelling

The “BiodiversityR” computer program was used to predict yellowhorn suitability map and understand its future distribution (Ranjitkar et al., 2016). The analysis was conducted using four steps modelling method: 1) “ensemble-test-splits” function to calibrate the ENM sub-models, “ensemble-best” parameter to select 9-12 best models according to each model’s AUC (Area Under the Curve); 2) “ensemble-test” function to exclude those sub-models with weight below 0.05 and obtain consensus map using the “ensemble-raster” function; 3) models within each RCP (Representative Concentration Pathways) were combined into a majority ensemble result and the ensemble models’ performance were evaluated using the threshold-independent AUC value and threshold-dependent (kappa) (Zomer et al., 2014); and 4) “ensemble-Habitat-change” function was carried out to determine habitat change (Ranjitkar et al., 2016). Area change includes the percentage of predicted range gain or loss (RGL), and range turnover (RT). The percentage of predicted range gain or loss (RGL) was calculated as follows: $RGL = 100(RG – RL)/CR$ with RGL divided into two modes: dispersed and undispersed (without area gain). The range turnover (RT) was estimated by RT = 100*(RL + RG) / (CR + RG) (Potts et al., 2013).

GAP analysis

The first step of GAP analysis is mapping the contemporary spatial distribution data (Hochman et al., 2016). Based on the "biodiversityR" analysis result of the distribution map of current, 2050 (RCP 2.6, 4.5, 6.0, and 8.5), and 2070 (RCP 2.6, 4.5, 6.0, and 8.5) were overlaid to obtain the "always-suitable" area distribution map. The second step is to examine the existing Chinese National Nature Reserves System using the "always-suitable" distribution map for inclusion in the analysis. These National Nature Reserves are reclassified into four levels based on the Importance-Performance Analysis (IPA; Sever, 2015). Based on the presence of yellowhorn in each of the National Nature Reserves, the yellowhorn protected areas are classified as either large (≥ 50%; occupancy of more than or equal to the median value) or small (≤ 50%; occupancy of less than the median value). Based on the size of the protected area and the yellowhorn percent presence, this classification resulted in four scenarios: 1) large protected area with large yellowhorn percent presence (Quadrant 1); small protected area with large yellowhorn percent presence (Quadrant 2); small protected area with small yellowhorn percent presence (Quadrant 3); and large protected area with small yellowhorn percent presence (Quadrant 4) (Sever, 2015). Since the human influence index on these National Nature Reserves ranges from 4 to 27 (average value of each Nature Reserve), with the high value representing high influence, the human influence impact was grouped in three levels; namely, 0, 1 and 2 with human influence values under 10, between 10 - 20, and more than 20, respectively (SEDAC, http://sedac.ciesin.columbia.edu/).

RESULTS

Ensemble model performance and habitat change

A total of 12 sub-models (MAXENT, GBM, GBMSTEP, GLM, GLMSTEP, MGCV, MGCVFIX, RPART, NNET, SVME, BIOCLIM, and DOMAIN) contributed to building the final ensemble model (AUC = 0.916, kappa = 0.398). Comparison among current and future ensemble model of Representative Concentration Pathways (RCP: 2.6, 4.5, 6.0 and 8.5) scenarios for 2050 and 2070, showed a substantial change in range suitability according to the predicted climate change (Fig 2). The yellowhorn distribution areas showed significant change among current, 2050, and 2070 with total distribution area declining with the different scenarios from 1 to 17% and 14 to 20% under with and without habitat gain, respectively (Table 1). Habitat gain ranged from 3 to 11% while the turnover area was around 20% (Table 1). The species' distribution center has changed slightly from northwest to southeast without any appreciable change in elevation (in 40 m, Fig 3).

China's National Nature Reserves based GAP analysis

The GAP analysis identified 71 of the 427 National Nature Reserves to be included in the "always-suitable" area and, counting only for 1.58% of the total area (26,007 out of 3,662,958 km^2) (Fig 4 and Table S3) and permitted their classification to forest (45), inland wetlands and water (4), desert (2), and grassland and meadow (1) ecosystems, with additional 19 in wild animals (18) and plants (1) territories (Table S3). According to the Importance-Performance Analysis (IPA), 44 Nature Reserves were included in quadrant 1 (Table S3), with total areas ranging from 94 to 2,131 km^2 with protected area ratios between 63.79 to 100% and human influence value ranging from 14 to 25. Quadrant 2 included 3 Nature Reserves (Table S3) with total areas ranging from 46 to 67 km^2 with protected area ratios ranging between 68.66 to 98.00% and human influence value ranging from 16 to 17. Quadrant 3, accommodated 10 Nature Reserves (Table S3) with total areas ranging from 82 to 445 km^2 with protected area ratios ranging between 0.11 to 9.57% and human influence values between 4 and 18. Finally, quadrant 4 included 14 Nature Reserves (Table S3) with total areas ranging from 241 to 240,394 km^2 with protected area ratios between 0.45 to 49.04 %, and human influence values from 4 to 19 (Table S3, Fig 3).

DISCUSSION

The present study represents the first attempt of assessing the distribution of wild yellowhorn populations and its predicted range change under globe climate warming scenarios. While the wild yellowhorn contemporary range is large and extending from Northeastern China to the Tibetan Plateau, this range is anticipated to decrease in the coming 30-50 years due to climate change, along with expected distribution center shift from the northwest to southeast coupled with elevational increase. The change of the species distribution center could be accelerated by the intensified acidification in northwestern China which is expected to force the species shift to more humid regions (Coleman, 1989; Du et al., 2016). This anticipated range shift could be further accentuated by the species' heat resistance as it belongs to the pantropical distribution family - Sapindaceae (Nianhe & Xianrui, 1995). Furthermore, the projected elevational increase is in line with previous globe warming projections (Pauli et al., 2012; Priti et al., 2016).

Yellowhorn, is a species with economic value, thus it is under constant utilization and this poses a potential threat from overutilization (biological resource use). The size of yellowhorn seed is large, thus opportunities for range expansion through seed dispersal are limited (Zhou & Zheng, 2015). While our analyses show a steady decrease of about 5 to 7% per 10-year period without habitat gain, the authentic decrease may be even greater than the model's predictions and this could be caused by the effects of habitat fragmentation and overutilization. Additionally, our result indicated the presence of a substantial gap accounting for 1.58% of the total 71 National Nature Reserves' area and this could exasperate the species conservation efforts as yellowhorn management is not considered as high priority.

Yellowhorn *in situ* conservation within the China's National Nature Reserve Network can be effectively and easily accomplished through wild populations maintenance. Based on the concept of GAP and Importance-Performance Analysis framework (IPA), we classified the National

Nature Reserves into four quadrants (Sever, 2015). Reserves present in Quadrant 1 (large protected area with large yellowhorn percent presence) should receive the highest priority as protected areas accompanied with dedicated research and management plans that accommodate human influence values of ≥ 20 (e.g., the Yellow River Wetland Birds National Nature Reserve of Xinxiang Henan that showed the highest human influence in this quadrant) (Fig. 5). Additionally, National Nature Reserves with human influence value of <20 should be considered as a future conservation priority with considerations of establishing yellowhorn genetic reserves (e.g., Habahu National Nature Reserve) (Maxted et al., 1997).

Combining utilization and conservation should be considered as a fundamental forest management goal (Davidson & El-Kassaby, 1997). So, for National Nature Reserves included in Quadrant 2 (small protected area with large yellowhorn percent presence), conservation and research plan are urgently needed and efforts such as wild species genetic reserves should be considered (Maxted et al., 1997). Reserves present in Quadrant 3 (small protected area with small yellowhorn percent presence), could be defined as reserves border areas and are most likely considered as population sinks lead by edge effects (Woodroffe et al., 2017). In these areas, a yellowhorn seed production populations (i.e., seed orchards) could be established for industrial managed seed production (Wang et al., unpublished paper). Finally, Reserves included in Quadrant 4 (large protected area with small yellowhorn percent presence) represent the greatest conservation challenge as the cost and efforts dedicated to conservation will not yield appreciable return on the investment; however, these populations offer an ideal opportunity for *ex situ* conservation as their genetic sources could act as a supplementary means to maintaining their genetic legacy. In general, our aim is to balance the conservation and utilization efforts with high value populations receiving the most conservation resources within the Chinese National Nature Reserves Network.

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Several plant species' life-history attributes are associated with their geographic distributions (e.g., *Pseudotsuga menziesii* (El-Kassaby & Ritland, 1996), *Picea sitchensis* (Chaisurisri & El-Kassaby, 1994), *Collinsia heterophylla* (Lankinen & Armbruster, 2007)), therefore, studying the various attributes of *X. sorbifolium* populations in their natural habitat should provide fundamental information for conservation efforts as well as the raw-material for effective selection and breeding programs.

Although we used 12 sub-models to produce the final ensemble model and species occurred utilizing data collected from three sources to produce the most "relatively" reliable suitability habitat, we should highlight the fact that other important policy, local economy, and biological (e.g., self-incompatible, male and female reproductive success and recruitment, inbreeding depression) factors were not considered and all independently or in concert could also lead to the projected distribution uncertainty. In the present study, we highlighted the importance and value of the Chinese National Nature Reserves Network as a reliable source for yellowhorn wild populations' conservation. We also highlighted the fact that future yellowhorn research should be consider including: 1) mapping artificial populations' distribution; 2) uncovering the species wild populations range change utilizing long-term ecological data; 3) considering the completion of the International Union for Conservation of Nature (IUCN) assessment; and 4) auditing *in situ* and *ex situ* conservation performance.

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ADDITIONAL INFORMATION AND DECLARATIONS

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Competing Interests

The authors declare there are no competing interests.

Author Contributions

Author contributions: Q.W., L.Y., Y.A.E. and W.G. conceived the study; Q.W., L.Y., J.W., X.W., D.Z., Z.W., Y.Z., Z.Q. and L.B. collected material and data; S.R. provided coding script; Q.W., L.Y., S.R. and X.W. analyzed the data; Q.W., L.Y. and Y.A.E. wrote the manuscript; S.R., X.L., Y.A.E. and W.G. read and corrected the manuscript.

Data Accessibility

The following information was supplied regarding data availability:

The research in this article did not generate any raw data. We used a previously published papers and other publications. The raw data has been supplied as Supplemental Files. R script for this analysis is available on GitHub: https://github.com/cran/BiodiversityR.

Supporting information

Additional supporting Information may be found in the online version of this article:

Table S1 Occurrence data of *X. sorbifolium* from different resources.

Table S2 Generalized Variance Inflation Factor (VIF) used for final calibration and prediction of climatic space.

Table S3 The distribution of China's 71 National Nature Reserves or portions distributed in the always-suitable area of *X. sorbifolium*.

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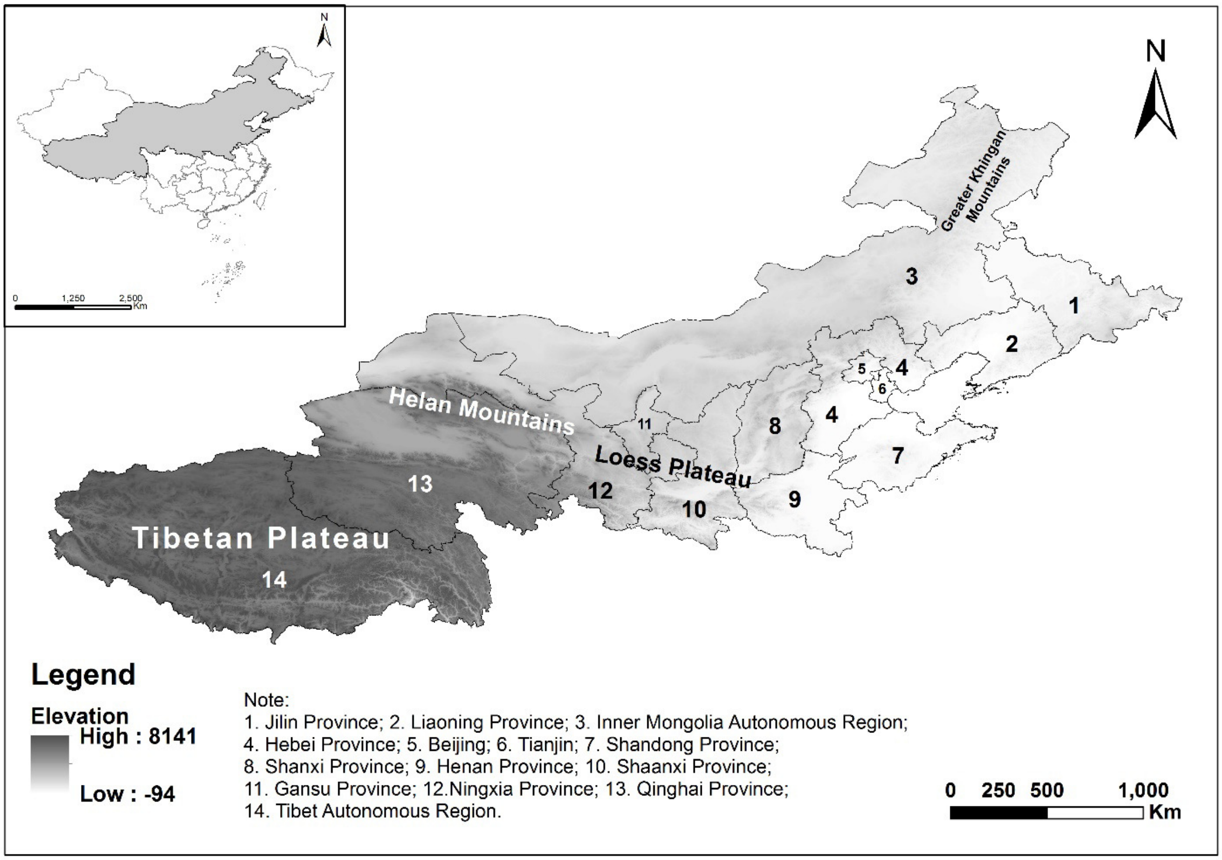

Figure 1 Study area of *X. sorbifolium* covering 14 Chinese provinces.

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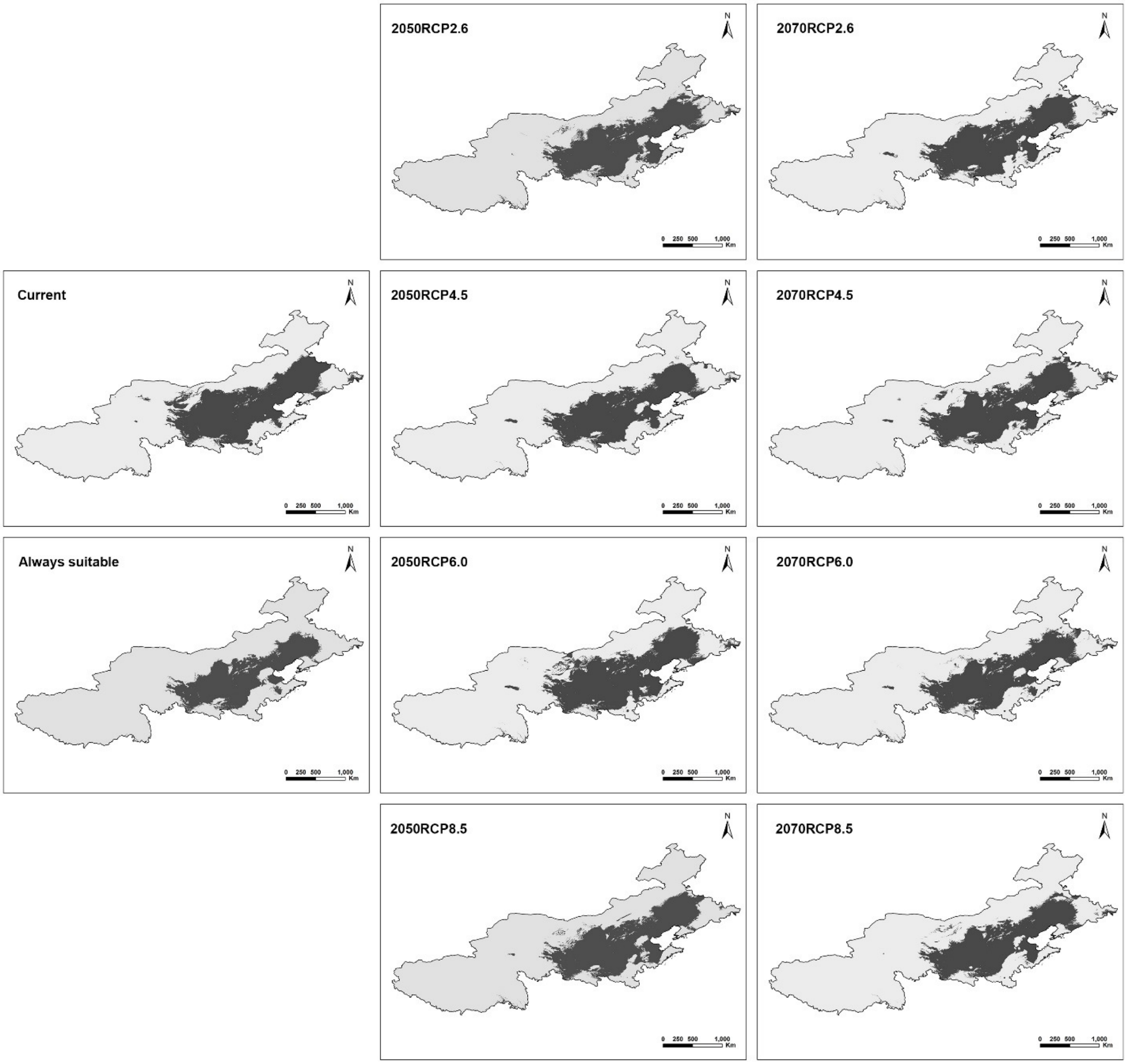

Figure 2 Current and future distribution maps of Representative Concentration Pathways (RCP: 2.6, 4.5, 6.0, 8.5) scenarios for 2050 and 2070; "always-suitable" map was overlaid on all maps above.

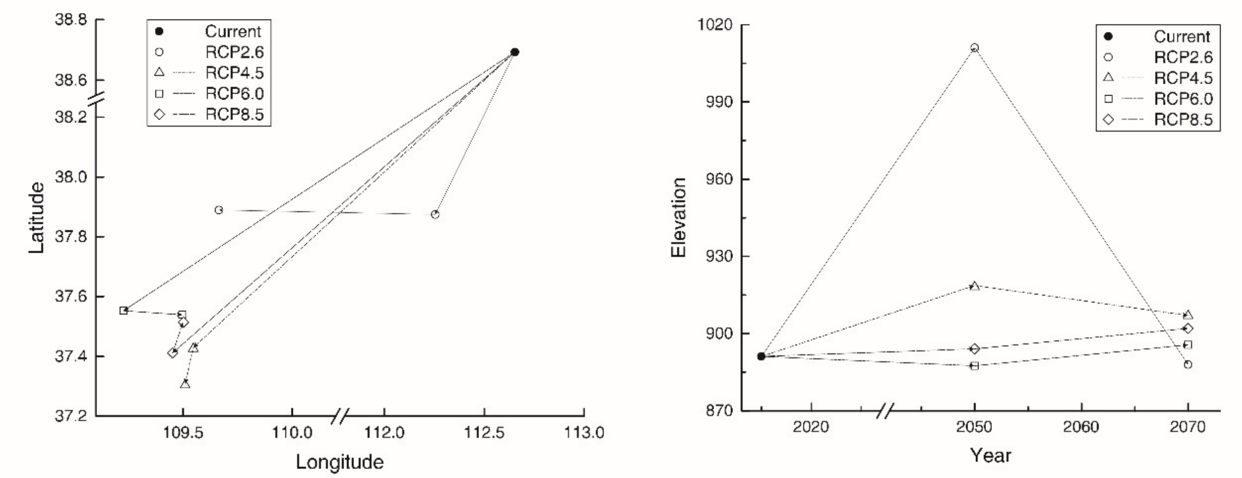

Figure 3 Distribution niche center changes (climate change adaptation and mitigation) from current to future Representative Concentration Pathways (RCP: 2.6, 4.5, 6.0, 8.5) scenarios for 2050 and 2070.

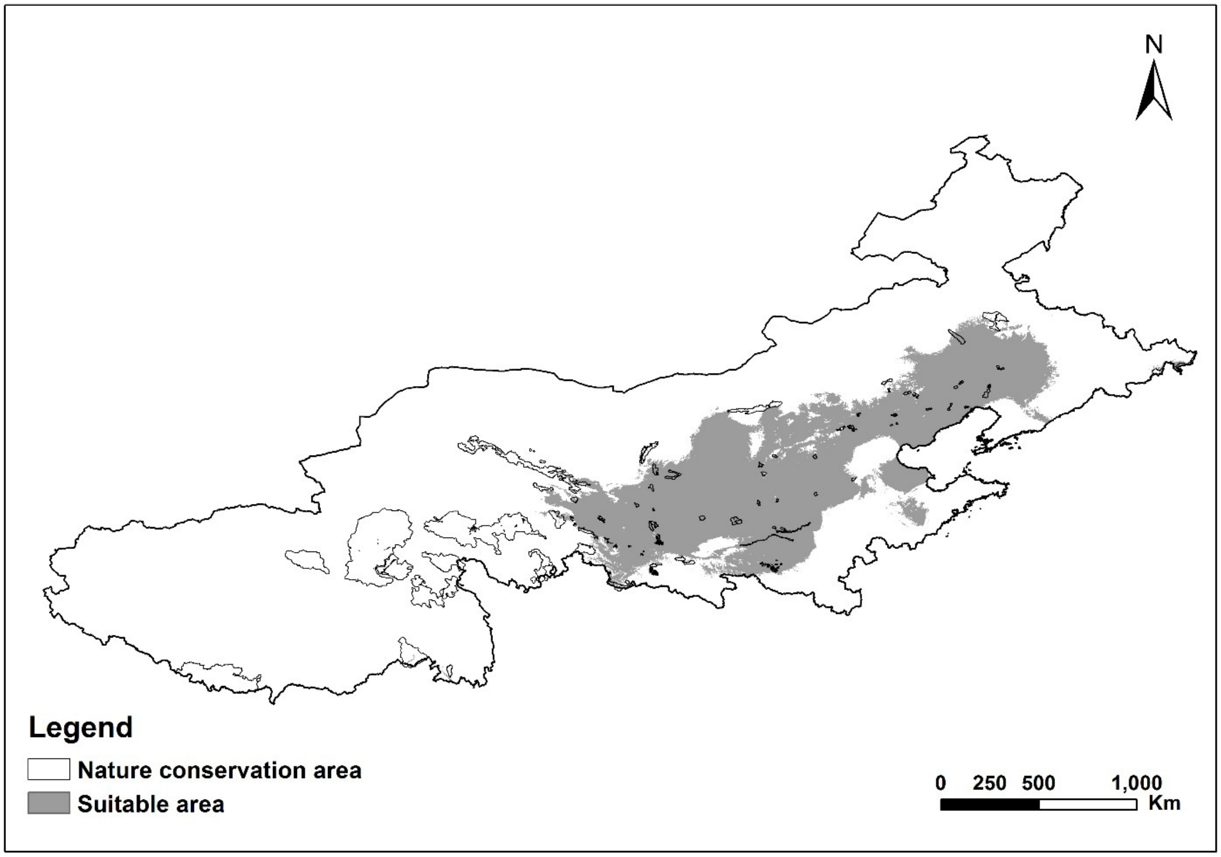

Figure 4 GAP based on China's National Nature Reserves.

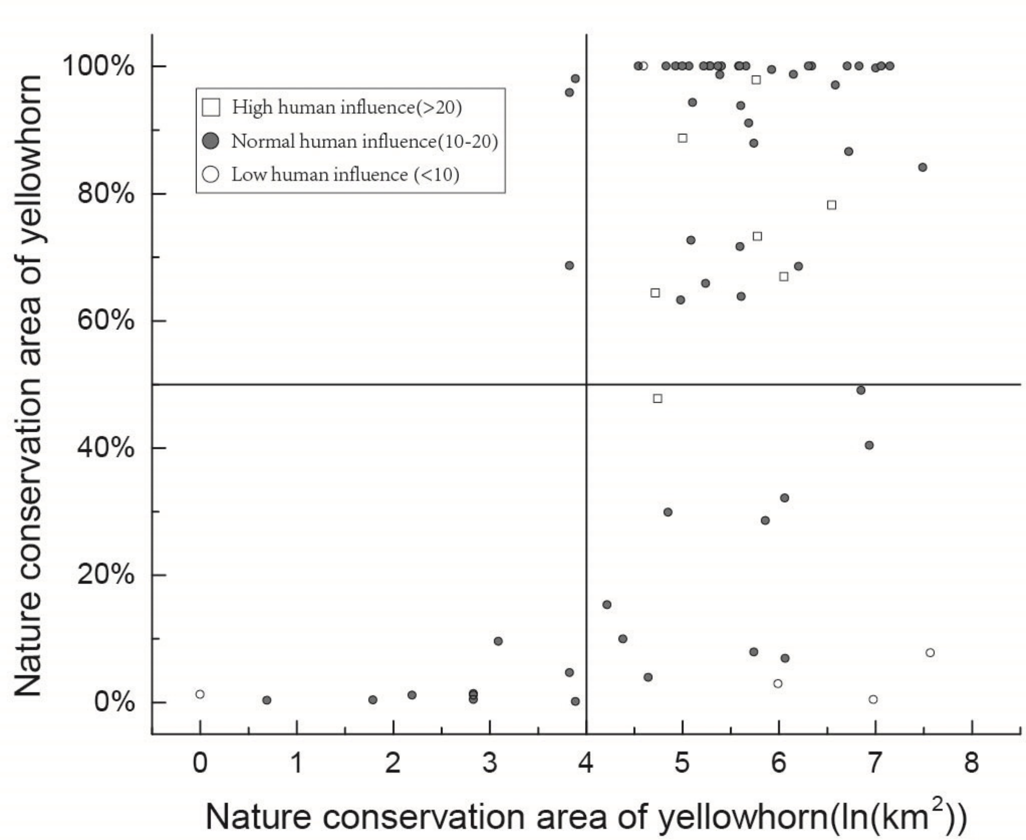

Figure 5 China's National Nature Reserves protected area (km^2) vs. percent of yellowhorn protected area (Nature conservation area of yellowhorn (%) = nature conservation area occupied by yellowhorn / total area of nature conservation).

Table 1 Habit change in different Representative Concentration Pathways (RCP: 2.6, 4.5, 6.0, 8.5) scenarios for 2050 and 2070 (areas are in km^2).

	NS	AL	RL	RG	PH	AL%	RL%	RG%	RGL %	RT%
Current	4886765	NA	NA	NA	2056188					
2050RCP2.6	4883566	1693076	363112	132121	1057754	83.29%	17.66%	6.42%	-11.24%	22.63%
2505RCP4.5	4817008	1684890	371298	69757	1754647	81.94%	18.06%	3.39%	-14.67%	20.75%
2050RCP6.0	4662175	1828256	227932	224590	2052846	88.91%	11.09%	10.92%	-0.16%	19.84%
2050RCP8.5	4751863	1712997	343170	134902	1847899	83.31%	16.69%	6.56%	-10.13%	21.82%
2070RCP2.6	4807574	1638842	417346	79191	1718033	79.70%	20.30%	3.85%	-16.45%	23.25%
2070RCP4.5	4811105	1628653	427535	75660	1704313	79.21%	20.79%	3.68%	-17.11%	23.60%
2070RCP6.0	4756416	1708714	347474	130349	1839063	83.10%	16.90%	6.34%	-10.56%	21.85%
2070RCP8.5	4794783	1747801	308387	91982	1839783	85.00%	15.00%	4.47%	-10.52%	18.64%

NS: never suitable; AL: always suitable; RL: range loss; RG: range gain; PH: habit %; RGL: % of predicted range gain/loss; RT: range turnover.

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