Climate envelope predictions indicate an enlarged suitable wintering distribution for Great Bustards' (*Otis tarda dybowskii*) in China for the 21st century

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ABSTRACT

Rapidly changing climate makes humans realize that there is a critical need to ~~rethink the current conservation and to~~ incorporate climate change adaptation into conservation planning. Whether Great Bustards (*Otis tarda dybowskii*), a globally endangered migratory subspecies whose population is approximately 1,500~2,200 individuals in China, would still exist in a changing climate environment, and how, is an important protection issue. In this study, we selected the most suitable species distribution model for bustards using climate envelopes from four machine learning models, combining two modelling approaches (TreeNet and Random Forest) with two sets of variables (correlated variables removed or not). We used common evaluation methods (AUC and TSS) as well as independent test~~ing~~ data to identify the most suitable model. As often found elsewhere, we found Random Forest with all environmental variables outperformed in all assessment methods. When we projected the best model to the latest IPCC-CMIP5 climate scenarios (RCPs ~~of~~ 2.6, 4.5 and 8.5 in three GCMs), and averaged the project results of the three models, we found that suitable wintering habitats~~,~~ in the current bustard~~s~~ distribution would increase during the 21st century. The Northeast Plain and the south of North China were projected to ~~would~~ become two major ~~suitable~~ wintering ~~habitats of~~ areas for bustards. However, the models suggest that some currently suitable habitats will experience a reduction, such as Dongting Lake and Poyang Lake in the Middle and Lower Yangtze River Basin. Although our results suggested that~~e~~ suitable habitats in China would widen with climate change~~ in China~~, greater efforts should be undertaken to assess and mitigate unstudied human disturbance, such as pollution, hunting, ~~inappropriate~~ agricultural~~e~~

Comment [UConn1]: Please spell out all acronyms when first used in the abstract, and the again when first used in the main paper. Similar RCP and GCM need defining later in this paragrap

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development, infrastructure construction, habitat fragmentation, ~~as well as~~and oil and mine exploitation~~ for instance~~. All of these are negatively and intensely linked with global change.

Keywords: Climate change, Species distribution models (SDMs), Great Bustards (*Otis tarda dybowskii*), Random Forest，China

INTRODUCTION

Climate is among the most dominant factors that affect species across broad spatial scales (Woodward 1987, Pearson and Dawson 2003). Long-term studies indicate that the anomalous climate of the last half-century is already affecting the physiology, distribution, and phenology of many species, especially for many of the already endangered species (Sykes and Prentice 1996, Hughes 2000). Species distribution models (SDMs) are able to successfully quantify the relationship between species distribution and climate (Drew et al. 2011). Increasing attention has been given to projecting potential species distributions under various climate change scenarios by applying those methods (Dyer 1995, Iverson and Prasad 1998, Prasad et al.~~,~~ 2006, Wu et al.~~,~~ 2012), and incorporating~~ed~~ climate change impacts into species conservation strategies (Araújo and Rahbek 2006, Strange et al.~~,~~ 2011, Baltensperger et al.~~,~~ 2015).

Knowing species distributions represents an essential foundation in conservation biology (Araujo and Guisan 2006, Tanneberger et al., 2010, Drew et al., 2011). Understanding where species emerge temporally and spatially across large geographic areas is important to conserving, monitoring, and managing species effectively (Wu and Smeins 2000). For this purpose, SDMs, including process-based and bioclimatic envelope approaches, have been suggested as an effective tool ~~to meet these needs~~ (Guisan and Thuiller 2005, Elith et al.~~,~~ 2006, Hu and Jiang 2010). There has been rapid progress in this field of SDMs, and tools and workflows are now openly available to assess distributions and the impacts of climate change on species and habitats (Peterson et al.~~,~~ 2002, Hijmans and Graham 2006, Drew et al.~~,~~ 2011).

The Great Bustard (*Otis tarda*) is one of the world's heaviest flying birds, occupying grassland habitats. It is categorized as a globally ~~threatened~~ vulnerable (VU) species according to the IUCN. Its world population ~~for~~ in 2010 was estimated to be 44,100 to 57,000 individuals; and approximately 4-~~∼~~10% of the global population is located in China and believed to be declining (Alonso and Palacín 2010). This species is divided into two subspecies: *O. t. tarda* and *O. t. dybowskii*. The latter subspecies (Taxonomic Serial No.:707876) is our research target. It is distributed throughout eastern Asia in areas such as Russia, Mongolia, China, and South and North Korea (Kong and Li 2005). In China, *O. t. dybowskii is* distributed in Heilongjiang, Jilin, Inner Mongolia, and Hebei Province during summer. It winters in Heilongjiang, Jilin, Inner Mongolia, Shaanxi, Hebei, Henan, Shandong, Jiangsu, Jiangxi, Hubei, Hunan (Jiang 2003, Wang and Yan 2002), Shanxi, and Anhui Province (Wu et al., 2001). Until the early twentieth century, ~~it's well supported that~~ there was a large population of *O. t. dybowskii* in ~~the~~ Asia~~n region~~, ~~and~~ with eastern Russia alone ~~is~~ estimated to have held more than 50,000 individuals prior to the 1940s (Chan and Goroshko 1998). However, numbers have declined during the twentieth century, with a particularly rapid drop in counts from the wintering grounds during the 1950s and 1960s ~~(according to data from the wintering grounds)~~ (Chan and Goroshko 1998). ~~In China,~~

~~t~~Taking Poyang Lake, ~~located in the~~ Jiangxi Province, China, as an example, hundreds of bustards were present in winter until the 1980s (Kennerley 1987). B~~ut b~~y the late 1990s ~~just~~ fewer than 20 individuals could be found (Wang Qishan in litt.1999), and in the last 10 years, bustards have~~were~~ not been observed~~ ever since~~. The wintering population of *O. t. dybowskii* in China was recently estimated at only 1,500~2,200 individuals (Goroshko 2010). ~~Arguably, in China, a~~This rapid decline ~~appeared in~~ of the past four decades~~,~~ is seemingly ~~directly~~ linked to more efficient methods of hunting, the large-scale conversion of steppe to agricultural land ~~at its~~ on the breeding grounds, and habitat loss on the wintering grounds in China (Chan and Goroshko 1998).

How to protect *O. t. dybowskii* and to keep this subspecies alive in the next 100 years, ~~and with a population increase even, including considerations of how to deal with habitat loss and hunting, climate change~~ remains a non-trivial question to be resolved. In order to assess ~~more specific~~ the likely effect of ~~caused by~~ climate change on ~~to~~ bustards in the 21st century, we employed species distribution models based on machine learning (TreeNet and Random Forest) to predict the distribution of ~~suitable~~ habitats for ~~of~~ this subspecies in the future. ~~According t~~To the best of our knowledge, this work is the first predictive, spatial model of the wintering distribution of Great Bustards and i~~. I~~t presents a step toward developing a national conservation effort to assess bustards' management. ~~More specifically, the goal of this study is to estimate the spatial impacts of climate change on the future wintering distribution of bustards.~~ At minimum, the results of this study are expected to provide information on what habitat changes may occur, and guide future sampling, surveying, and conservation efforts across China. Further, we try to infer ~~on~~ the wider status of this bird during times of g~~G~~lobal ~~C~~change.

MATERIALS AND METHODS

Study area and data

The ~~species~~ data ~~we~~ used in this study came from our own fieldwork investigations of 2012 and 2013, consisting of recorded bird occurrence GPS locations, and~~. Also, we~~ extracted data from ~~used previously~~ published ~~literature data~~ papers in Chinese journals, all of which we ~~and~~ mapped ~~it all~~ in ArcGIS10.1 (see Supplement S1). Overall, we used 102 geo-referenced bird sighting locations across China from the ~~for a time~~ period 1990-2013 ~~across China)~~. Because of the lack of wintering data in Russia and Mongolia, we restricted our projected area just to China (Figure 1). The boundaries~~y~~ of ~~N~~nature ~~R~~reserves were downloaded from the World Database on Protected Areas (WDPA, http://www.protectedplanet.net/)~~. Then we~~ and clipped ~~the protected area~~ to the range of China in ArcGIS 10.1. We used the geographic projection of WGS1984 Mercator.

Put Figure 1 here

Nineteen bioclimatic variables ~~at a 30s resolution~~ were obtained from the WorldC~~c~~lim database (Hijmans et al., 2005, http://www.worldclim.org/) to describe ~~for current~~ climate conditions during ~~(~~1950–2000~~)~~. Other environmental variables that are considered to be important drivers of the Great Bustard's distributions were also used to build the ~~bustards'~~ habitat distribution model. Those included topographical factors (altitude, slope, and aspect), water-related factors (distance to river, distance to lake, distance to coastline), human interference factors (distance to road, distance to rail road, and distance to settlement), and land cover. Aspect and slope layers were derived in ArcGIS 10.1 from the altitude layer~~ in ArcGIS10.1, which was~~ obtained from the World~~e~~Clim database.~~;~~ Road, rail road, river, lake and coastline and settlement maps were taken from the Natural Earth database, while~~;~~ the land cover map was taken from the ESA database (detailed information is provided for all layers in Supplement S2). All spatial layers ~~of these environmental variables~~ were resampled to a resolution of 30 s to correspond to that of the bioclimatic variables. Reliable future projections of land cover, distance to road, distance to rail road, distance to settlement, distance to river, and distance to lake predictors we~~a~~re not available. ~~,~~ ~~while s~~Including static variables based on current information ~~included~~ in SDMs alongside dynamic variables could improve model performance (Stanton et al., 2012), ~~. T~~therefore, we kept these variables in our future projections.

~~Models in~~ Although machine learning models are difficult to overfit, especially ~~. That is specifically the case for r~~Random Forest and methods that employ bagging~~. Further~~, we first calculated correlations among the 19 bioclimatic ~~variables~~ and ~~other~~ 10 other environmental variables in ArcGIS and~~. We~~ removed ~~a~~ variables whenever a correlation coefficient >|0.90| was obtained (Costa et al. 2010; see correlation matrix in Supplement S3 ~~(Costa et al., 2010~~). A total of 15 bioclimatice variables were removed, leaving 4 bioclimatic variables and 10 other environmental variables~~ were left~~. Subsequently, we constructed two sets of bustard distribution models: one ~~was~~ based on the reduced set of ~~the result of a correlation test that only kept 4 bioclimatic variables and 10 environmental predictors used to construct SDMs (~~14 predictors~~)~~; the other ~~approach was to~~ used all ~~of the 19 bioclimatic and 10 environmental variables for model construction (~~29 predictors~~)~~. The models were named TN14, TN29, RF14 and RF29, where TN denotes a TreeNet analysis

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Please check that the edits have not altered the meaning.

Comment [UConn4]: This assertion needs a supporting reference.

and RF denotes a Random Forest analysis.

Species distribution modeling and testing

We chose the TreeNet (~~hereafter TN,~~ generally referred to as boosted regression trees (BRT), stochastic gradient boosting, Friedman 2002) and Random Forest (~~hereafter RF,~~ Breiman 2001) ~~–~~software produced by~~by~~ Salford Systems Ltd to build~~as~~ our species distribution models because of their good performance and common usage (Zhai and Li 2003, Elith et al.~~,~~ 2006, Drew et al. 2011, Lei et al., 2011). These algorithms are among the best modeling algorithms available and perform so well due to their inherent optimizations in Salford Predictive Modeler (SPM). Additional benefits of SPM over the R version are that it continues to undergo research and improvement under one of the algorithm's original co-authors. It runs under a convenient GUI, and could produce a number of descriptive results and graphics which are not available in the R version (Herrick 2013). For more details on TreeNet and Random Forest, we refer readers to read the user guide (https://www.salford-systems.com/ products/spm/userguide) and references within (~~S~~see also Drew et al. 2011). About 10,000 pseudo-absence points were taken by random sampling across all of China ~~by~~ using the freely available Geospatial Modeling Environment software (~~GME;~~ Hawth's Tools). We used a 10-fold cross-validation procedure for TN, where it divided our dataset 10-fold using 80% of the data for model calibration and retaining 20% of the data for evaluation; and out of bag ~~(OOB)~~ data used to test RF. In addition, we used balanced class weights, and 1000 trees were built for all models to find an optimum within.

For model assessments, independent Great Bustard~~s~~ location records during 1980-2000

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Comment [UConn5]: This sounds like promotional material from the company – is there any evidence that their software is better? (Note, I am not saying that it is not, I just think that there should be independent verification, rather than simply expecting readers to take it on faith.) Herri appears to be an unpublished PhD thesis – although the full citation is not given so I'm not certain – on avian influenza, so it seems unlikely t have the requisite mathematical work to back up this claim. I would suggest deleting these sentenc The authors do not need to justify their choice of software package, they just need to be clear that Salford Systems is the software used, not the statistical techniques themselves.

Comment [UConn6]: Note that there is no need to give acronyms such as OOB if they are no going to be used later in the paper.

were acquired from the book of the Threatened Birds of Asia (Collar et al.~~,~~ 2001, see Supplement S4). We extracted the relative index of occurrence (RIO) for these testing data from four projected maps (TN14, TN29, RF14, RF29). ~~And then, b~~Boxplots with 95% confidence intervals for these RIO value were used to analyze the fit~~ting effectiveness~~ of each model. Furthermore, the testing and pseudo-absence points were used to calculate ~~A~~area under the ROC curves (AUC) and the True Skill Statistic (TSS) (Allouche et al.~~,~~ 2006) using~~. This was done with~~ the ‘SDMTools’ package in R 3.1.0. The best suitable SDM for bustards was ~~finally~~ determined by comparing the boxplots, AUC and TSS of all models in concert.

Future projections for Great Bustards

After ~~obtaining~~ determining the final model technique, we ~~tried to~~ constructed models for future climate scenarios for 2070 (average for 2061–2080). The data applied here are the most recent IPCC-CMIP5 climate projections from three G~~lobal~~ C~~irculation~~ M~~odels~~ (BCC-CSM1-1, CNRM-CM5 and MIROC-ESM, hereafter BC, CN and MR) under three representative concentration pathways (RCPs of 2.6, 4.5 and 8.5, which are named after a possible range of radiative forcing values in the year 2100 relative to pre-industrial values (+2.6, +4.5, +6.0, and +8.5 W/m2, respectively). We used the average predicted probability of occurrence across the three GSMs for each grid as our consensus forecast (named BCM). This method was considered as one of the best ~~methods~~ for developing an ensemble forecast (Hole et al.~~,~~ 2009). Subsequently, we applied the sensitivity-specificity equality approach as the suitable habitat threshold using a threshold probability of 0.85 to define the presence~~-~~–absence distribution of Great Bustards wintering habitats~~,~~ as this ~~method is have~~

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has been found to be a robust approach (Liu et al.~~,~~ 2005).

Spatial analysis of potential effects of climate change envelopes

We ~~applied~~ used ArcGIS 10.1 to calculate the suitable habitat area of Great Bustards for two time periods (current and 2070) under three scenarios (RCP 2.6, 4.5 and 8.5) from three GCMs (BC, CN and MR) and their average (BCM). We also used the overlay analysis ~~(in ArcGIS 10.1)~~ to assess the potential distribution changes of bustard wintering habitats, which~~. This~~ allowed us to identify areas of the habitat range that are projected to be lost, gained or remain under future climate scenarios. Also, we overlaid four presence-absence distribution maps (current, RCP2.6, RCP4.5 and RCP8.5) with the boundaries ~~y~~ of China's ~~N~~nature ~~R~~reserves~~ of China~~ to explore how much Great Bustard~~s~~ habitat~~s are~~ is currently found in ~~the~~ reserves, and how that amount ~~they~~ is projected to~~would~~ vary with climate change.

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RESULTS

Boxplots created using~~by~~ the independent test~~ing~~ data taken from ~~literature (the~~ Collar et al. (2010~~Threatened Birds of Asia~~)~~. Figure 2~~ indicated that the Random Forest analysis showed a higher relative index of occurrence (RIO) than the TreeNet analysis, and a stronger focus on a narrow range of values (>0.9; Figure 2). The model based on 29 predictors performed a little better than the one based on 14 predictors, and was thus preferred ~~which matters~~ for ~~large area~~ prediction~~ and makes them better overall~~. ~~This means for us that Random Forest with 29 predictors obtained the best fitting effectivity for testing data.~~

Put Figure 2 here

The high AUC values (>0.91) for all four Great Bustard models ~~of Great Bustards~~ (Table 1) indicated that our models can accurately capture bustards' habitat relationships, as~~nd~~ values above 0.75 generally indicate an adequate model performance for most applications (Pearce and Ferrier 2000). AUCs of Random Forest models were higher than TreeNet models, and SDMs with 29 predictors performed better than the more parsimonious models with just 14 predictors. TSS had the same trends as AUC, and Random Forest performed better than TreeNet~~, Again, models with more predictors (29) performed better than models with relatively few predictors (14) (Note: Judged by the current use and literature, models with 14 predictors are still a relatively high number of predictors in most model studies to date. However, we clearly show that more predictors perform even better and to be precise on the large scale).~~ . ~~According to the above three consistent~~ Given these results, we ~~then~~ selected a Random Forest model with 29 predictors as our final SDM with which to ~~and~~ project~~ed to~~ future climate.

Put Table 1 here

Put Figure 3 here

~~The threshold (=0.85) to define the presence-absence distribution was obtained by the sensitivity-specificity equality approach by Liu et al (2005) for the Random Forest, 29 predictors' model. We then transformed four continues distribution maps (Current, BCM 2.6, BCM 4.5, BCM 8.5) to binary presence-absence maps.~~ The results indicated that when solely judged by climate change envelopes the suitable wintering habitat~~s~~ of Great Bustards would enlarge (Figure 3 and Table 2). More specifically, under the RCP 2.6 climate change scenario, the suitable habitat area for bustards would improve from the

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current 290,~~.~~640 ~~(1000*km^2)~~ to 374,~~.~~410 ~~(1000*~~ km^2~~)~~, an improvement of 29~~8.82~~%; Under RCP4.5, a median radiative forcing, climate change would result in a habitat increase of 8.88% by 2070 (from 290.64 to 316.46 (1000* km^2)). And under RCP 8.5, the highest radiative forcing, the habitat area would still increase from 290.64 to 304.17 (1000* km^2) by 1.04% to 2070 (Table 2). This trend is arguably explained by how the climate areas are distributed in the study area, currently and in the future.

Put Table 2 here

Table 2 and Figure 3 show that 23 to 31%~~some~~ of the original suitable wintering habitats would be lost depending on ~~. About 67.29, 90.56 and 88.08 (1000* km^2; 23.15%, 31.15% and 30.30% of the current distribution area, respectively) habitat area under~~ RCP ~~2.6, 4.5 and 8.5 respectively would transform to being unsuitable for this species~~ scenario (Table 2). Habitat would be severe~~ly get lost in~~ near Dongting Lake, Poyang Lake ~~(which is located~~ in the Yangtze River Basin~~)~~, and Tianjin, Beijing ~~which is~~ near ~~the~~ Bohai Bay (see Figure 3). Meanwhile, the long-term traditional wintering ground in Anhui, Jiangsu, Henan, Hebei, Shaanxi and Heilongjiang Provinces would ~~still~~ remain. Our model shows that the area west of Shandong, the northeast of Henan, and the north of Jilin would gradually become suitable wintering grounds for Great Bustards (Figure 3).

Put Figure 3 here

The expansion and shift of bustards' habitats would also affect the conservation effectiveness of current reserves where this subspecies lives. ~~Table 2 showed o~~Only about 8~~.24~~% (23,~~.~~950 ~~(1000*~~ km^2)~~)~~ of the current ~~total bustards~~ wintering habitat~~suitable ground~~ is ~~currently~~ located in nature reserves, but ~~. T~~this area would increase under all three~~to~~

Comment [UConn13]: Convert areas to km^2 throughout, as shown here. This format is easier [for] readers to quickly comprehend and takes up less space.

Comment [UConn14]: You do not need this information in the text and the table; one or the other should be delete. I would suggest simplifying the manuscript text to a single summa[ry] sentence, something like "Depending on RCP scenario, the suitable area was projected to increase by between 1% and 29%."

Comment [UConn15]: This sentence is self-evident and should be deleted.

~~29.53 (1000* km^2, 7.89%) in the~~ RCP ~~2.6~~ scenarios (Table 2)~~; in the median radiative forcing scenario (RCP 4.5), the area in the reserve would decline by only 22.58 (1000* km^2; 7.13%); while under the RCP 8.5, the highest radiative forcing scenario, 27.30 (1000* km^2), or about 8.98% suitable area would be located in the reserve~~. Nonetheless, ~~Only~~ less than 10% of the ~~area of~~ bustard's wintering distribution ~~ground is and~~ will~~ould~~ be located in the nature reserve under all projections, and these reserves are mainly ~~just~~ located in the w~~W~~est of ~~the~~ Heilongjiang Province and ~~in~~ the ~~N~~north of Jilin Province (Figure 4)~~, assuming no additional reserves are constructed in the bustards wintering habitats~~. ~~(So far, those assumptions are realistic due to the high land and people pressures).~~

Put Figure 4 here

DISCUSSION

Effective conservation of Great Bustards includes ~~a relevant~~ protection and restoration of their ~~suitable~~ habitats. Our model is the first to predict and map, with high accuracy (AUC: 0.98, TSS: 0.94), the winter~~ing~~ distribution of *O. t. dybowskii* in China. Our best climate envelope model ~~results are~~ was non-parsimonious (29 predictors) and based on the RandomForest algorithm, and indicates~~ing~~ that ~~these~~ suitable wintering habitats ~~in the current bustard distribution would~~ will increase during the 21st century (Table 2 and Figure 3). However, some current ~~suitable~~ habitats will ~~experience a reduction~~become unsuitable, such as in the Dongting Lake and Poyang Lake areas in the Middle and Lower Yangtze River Basin. These are areas where observers have no~~'~~t seen any Great Bustards in the last ten years. Our forecast model showed that climate change also was the cause to drive population declines in both of the two lake regions (Figure 3), except for efficient hunting and habitat loss because of human activity. In addition, we found that most wintering grounds (>90%)~~ of bustards~~ were not in ~~the ~~nature reserves~~ at all~~ and carry no relevant area protection (see Table 2). Such findings are ~~very ~~relevant for an improved understanding and ~~for ~~prioritization of~~ing~~ conservation efforts and suggest that new reserves should~~to~~ be established.

According to our model predictions, the Northeast Plain ~~would ~~will become one of the major wintering ~~distribution ~~areas for this subspecies. Originally, the Northeast Plain ~~actually ~~is the traditional breeding ground of bustards, and ~~also several ~~some male individuals overwinter there (Liu 1997). Here we speculate that more bustards, both male and female individuals may remain there, and infer that this habitat will result in ~~become a residential area or that ~~bustards becoming resident in this area or ~~will ~~having~~e~~ a shorter ~~distance for ~~migration distance than ~~in the ~~currently~~ period~~. This situation has already been observed in the Red-crowned Crane (Masatomi et al., 2007) and with the Oriental White Stork (Yang et al., 2007). The suitable wintering habitats in the Northeast Plain are located southeast of the Greater Khingan Mountains, southwest of the Lesser Khingan Mountains, as well as northwest of the Changbai Mountains. It is possible that these mountains might become a natural barrier to the habitat expansion of this subspecies. These areas are used for agriculture and are susceptible to urban expansion. Therefore, the question of how to leave enough space and how to protect and maintain this species under such a situation should be taken into serious consideration~~ first~~, before any new policies and conservation plans are made.

The southeast of Hebei and the northeast of Henan Province are the traditional wintering

Comment [UConn16]: The model predicts th habitat loss will occur in the future, but that cann explain losses over the past 10 years (the current projection says the birds should be there). That suggests that hunting and/or habitat loss have been more important. This sentence should be cut or edited accordingly.

Comment [UConn17]: Note that this will onl happen if the breeding distribution does not also shift with climate change.

Comment [UConn18]: Add scientific names for these species.

grounds for this species. There are at least 300 individuals ~~respectively~~ overwintering in the commercially operated cropland of Cangzhou, Heibei Province and the Yellow River Wetland of Changyuan, Henan Province. However just a few loosely protected area ~~were constructed~~ exist in these areas~~there~~.

To determine ~~One gets quickly interested in the question~~ ‘why ~~are~~ so little ~~few~~ bustard~~s’~~ ~~suitable~~ habitat~~s~~ is located in nature reserves~~’~~, and ~~‘~~which type of land cover ~~are~~ bustards prefer during winter~~?’ To shed more light on this question~~, we overlaid the presence-absence maps with a land cover layer, and quantified the land type of each grid cell of suitable habitat with ArcGIS 10.1. ~~From Table 3, w~~We found cropland and sparse vegetation were the bustards’ main ~~preferred~~ wintering grounds in current and three future scenarios (Table 3; more detail is found in Supplement S5), with~~. It shows that~~ more than 75% of the wintering ground of this subspecies in ~~fell on~~ cropland, a habitat ~~while farmlands are usually~~ not usually included in ~~a~~ nature reserves. ~~This can explain why so little wintering grounds are not located in reserves.~~ From these results~~at~~, we can ~~also~~ infer that this subspecies has become ~~intensively~~ dependent~~d~~ on farmlands, potentially because of ~~specifically on~~ the quantity of food left in farmland and the associated farmland planting mode. Other habitats, even within reserves, are widely not used. Suitable habitat environments such as flat terrain, open landscapes with a far-reaching vision and with adequate food would help this endangered subspecies to overwinter and its population to increase again. Established seasonal protected areas and leaving more food behind on the wintering grounds are well-known management choices to protect bustards further in the landscape. Though~~,~~ the development of China and its landscapes is ongoing with a very

Comment [UConn19]: This sentence should be moved to the Methods section.

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~~p~~fast pace, and urbanization is ~~becoming more and more serious and widespread~~increasing~~.~~ ~~Meanwhile~~, China is now paying more attention to the ecological role of nature and to environmental management. Furthermore, in order to ensure food security, we do not expect~~argue~~ the area of cropland in China ~~would not~~ to decline~~, hardly change significantly~~ in the 21st century and ~~. So we estimate~~ that the area of suitable wintering habitat~~s~~ ~~would still~~ will increase despite urbanization ~~though we do not exactly know how land cover would exactly change into future~~. From fieldwork and the reports of local villagers, we found that hunting (e.g. ~~to disperse~~ poisoned corn on farmland) was~~were~~ among the main factors killing bustards (e.g. Meng 2010). Power lines are also a relevant threat ~~factor~~ (Raab and Schuetz 2012). Other threats like contamination and ~~indirect effects like~~ large-scale water irrigation projects are not well assessed~~, yet~~.

Much is unknown about ~~Macro-ecology and a more holistic large-scale research for~~ Great Bustards ~~(such as distribution, migration, meta-population study, habitat assessment) are not so well developed~~ in Asia~~, yet~~. Location and population data are also insufficient. We believe that more ~~and advanced~~ work of this kind should be undertaken in the future, including efforts ~~tele-coupling~~ to ~~deal~~ better address its status as an~~with the~~ international migratory species. ~~Basic, and t~~The most important work~~,~~ might consist of monitoring this subspecies in order to obtain ~~such~~ fundamental data for effective conservation action.

Our distribution modelling ~~work~~ ~~and distribution map~~ is meant to better indicate where bustards stay during winter and ~~then~~ to be applied for the management of this species. Based on our research finding, we are optimistic ~~on the validity of~~ about the bustard's wintering habitats. However, the breeding grounds located in the steppe land are severely

Comment [UConn22]: This might be true, bu the quality of that farmland might decline if farming methods become more intensive.

Comment [UConn23]: Specify what type of contamination. Are you referring to things like pesticides and heavy metals?

affected by human activities, which has already resulted ~~already~~ in~~to~~ massive habitat loss and habitat fragmentation. More research is ~~should be done~~ urgently needed in the breeding grounds, including~~too (such as to~~ establishment of a monitoring network, ~~carry out~~ a comprehensive distribution and abundance survey, and modelling of ~~also project~~ breeding distributions ~~at least~~ based on ~~the~~ existing data~~, all linked directly to conservation management)~~. Finally, a suitable and effective plan is needed to protect this endangered species nationally and internationally.

The limitations of our research ~~still are~~include: 1) arguably, we ~~somewhat~~ undersampled the current distribution, although~~great bustards but~~ the 102 presence samples ~~(102 records)~~ were enough to produce ~~though for a good and~~ robust~~-~~ model performance ~~(~~as judged by AUC and~~,~~ TSS~~)~~; 2) our model is based on presence-absence data and we ~~consequently we~~ could no~~'~~t ~~yet~~ estimate ~~the~~ current~~ population, and~~ or future population size~~variations during a changing climate~~; 3) we lack ~~any~~ future road, residential, and land cover scenarios, although ~~and~~ such GIS layers ~~but which~~ would be of great value to conservation planning and would likely improved~~to be applied to~~ future projections~~ bustards future distribution~~; and ~~finally~~ 4) bustards ~~are not only wintering in China, but~~ also winter in Mongolia and Russia; our research is currently restricted to China because of we lack~~ing~~ data from~~in~~ these other~~ both of the two~~ countries. We hope this research could help to trigger ~~further~~ the collection of new information ~~urgently needed improvements~~ on those topics.

In summary, our results indicate that there is a critical need to ~~rethink the current approach to parsimony and conservation, and to~~ incorporate climate change adaptation into our conservation planning during an already rapidly changing climate. ~~Based on concrete~~

Comment [UConn24]: Do you have absence data? I thought it was a presence only model?

~~data and a robust modelling approach, o~~Our model ~~w~~could aid ~~be rather useful and insightful to~~ managers currently addressing conservation of bustards ~~issues~~ in China and ~~for bustards overall~~elsewhere. ~~In addition, d~~Distribution maps~~, created in time,~~ could be ~~get~~ overlaid with maps of the current and predicted locations of activities such as~~, let's say,~~ oil, gas, mineral, and wind energy development~~resources~~, in order to identify areas of potential future conflict, estimate the potential ~~size and~~ severity of impacts caused by ~~a specific activity~~development, and prioritize conservation strategies geographically (~~such as based on Marxan applications etc.;~~ cf. Beiring 2014~~ for parts of Asia~~).

ACKNOWLEDGEMENTS

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ADDITIONAL INFORMATION AND DECLARATIONS

Author Contributions

Chunrong Mi analyzed the data, wrote the paper, prepared figures and/or tables, reviewed drafts of the paper.

Falk Huettmann analyzed the data and reviewed drafts of the paper.

Yumin Guo reviewed drafts of the paper.

REFERENCE

Alonso, J C. and Palacín, C. 2010. The world status and population trends of the Great Bustard (Otis tarda): 2010 update. *Chinese Birds* 1(2): 141-147

Allouche, O., Tsoar, A. and Kadmon, R. 2006. Assessing the accuracy of species distribution models: prevalence, kappa and the true skill statistic (TSS). *Journal of Applied Ecology.* 43: 1223-1232.

Araújo MB, and Rahbek C. 2006. How Does Climate Change Affect Biodiversity? *Science* 313:21-22.

Araujo, MB. and Guisan, A. 2006. Five (or so) challenges for species distribution modelling. *Journal of Biogeography* 33: 1677-1688.

Araújo, MB. and Peterson, AT. 2012. Uses and misuses of bioclimatic envelope modeling. *Ecology* 93: 1527-1539.

Beiring, M. 2014. Modeling Migratory Passerines in the Pacific Rim. Unpublished M.Sc. Thesis, University of Vienna, Austria

Breiman, L. 2001. Random Forests. *Machine Learning* 45(supplement 1): 5-32.

Chan S, and Goroshko OA. 1998. Action plan for conservation of the great bustard: Asia Council, BirdLife International.Costa, G., Nogueira, C., Machado, R., and Colli, G. 2010 Sampling bias and the use of ecological niche modeling in conservation planning: a field evaluation in a biodiversity hotspot. *Biodiversity and Conservation* 19: 883-899.

Collar, N.J., Crosby, R., and Crosby, M. 2001. Threatened birds of Asia: the BirdLife International red data book. BirdLife International Cambridge, UK.

Czaplewski, RL. and Forest, RM. 1994. Variance approximations for assessments of classification accuracy. US Department of Agriculture, Forest Service, Rocky Mountain

Forest and Range Experiment Station Fort Collins, CO.

Drew, CA., Wiersma, Y. and Huettmann, F. 2011. Predictive species and habitat modeling in *landscape ecology*: Springer.

Dyer, JM. 1995. Assessment of climatic warming using a model of forest species migration. *Ecological Modelling* 79: 199-219.

Elith, J., H. Graham, C., P. Anderson, R., Dudík, M., Ferrier, S., Guisan, A., J. Hijmans, R., Huettmann, F., R. Leathwick, J., Lehmann, A., Li, J., G. Lohmann, L., A. Loiselle, B., Manion, G., Moritz, C., Nakamura, M., Nakazawa, Y., McC. M. Overton, J., Townsend Peterson, A., J. Phillips, S., Richardson, K., Scachetti-Pereira, R., E. Schapire, R., Soberón, J., Williams, S., S. Wisz, M. and E. Zimmermann, N. (2006) Novel methods improve prediction of species' distributions from occurrence data. *Ecography* 29: 129-151.

Friedman, J. 2002. Stochastic gradient boosting. *Computational Statistics & Data Analysis* 38: 367-378.

Goroshko, OA. 2010. Present status of population of Great Bustard (Otis tarda dybowskii) in Dauria and other breeding grounds in Russia and Mongolia: distribution, number and dynamics of population, threats, conservation. pp. First International Symposium on Conservation of Great Bustard. Beijing.

Guisan, A. and Thuiller, W. 2005. Predicting species distribution: offering more than simple habitat models. *Ecology letters* 8: 993-1009.

Herrick K. 2013. Predictive Modeling of Avian Influenza in Wild Birds. Veterinary Research.

Hole DG, Willis SG, Pain DJ, Fishpool LD, Butchart SHM, Collingham YC, Rahbek C, and Huntley B. 2009. Projected impacts of climate change on a continent‐wide protected area network. *Ecology letters* 12:420-431.

Hu, J., Hu, H. and Jiang, Z. 2010. The impacts of climate change on the wintering distribution of an endangered migratory bird. *Oecologia* 164: 555-565.

Hughes, L. 2000. Biological consequences of global warming: is the signal already apparent? *Trends in Ecology & Evolution* 15: 56-61.

Iverson, LR. and Prasad, AM. 1998. Predicting abundance of 80 tree species following climate change in the eastern United States. *Ecological Monographs* 68: 465-485.

Jiang, J. 2003. The status of resource and conservation of Great Bustard in China. M.Sc. Thesis, Northeast Forestry University. (in Chinese)

Kennerley P. 1987. A survey of the birds of the Poyang Lake Nature Reserve, Jiangxi Province, China, 29 December 1985–4 January 1986. Hong Kong Bird Report1984/1985: 97–111.Kong, Y. and Li, F. 2005. The Status and Research Trends of the Great Bustard. Chinese *Journal of Zoology* 40: 111-115. (in Chinese)

Lei, Z., Liu, S., Sun, P., and Wang, T. 2011. Comparative evaluation of multiple models of the effects of climate change on the potential distribution of Pinus massoniana. *Chinese Journal of Plant Ecology* 35: 1091-1105.

Liu, B. 1997. The Status and Protecion of Great Bustards in Northeast. *Natural Resources Study* 61-63. (in Chinese)

Liu, C., Berry, P., Dawson, T. and Pearson, R. 2005. Selecting thresholds of occurrence in the prediction of species distributions. *Ecography* 28: 385-393.

Masatomi, Y., Higashi, S. and Masatomi, H. 2007. A simple population viability analysis of Tancho (Grus japonensis) in southeastern Hokkaido, Japan. *Population ecology* 49: 297-304.

Meng D. 2010. Study on the Rescue to Great Bustard in Cangzhou, Hebei. The First China International Seminar on Protection of Great Bustard. Beijing. (in Chinese)

Pearce, J. and Ferrier, S. 2000. Evaluating the predictive performance of habitat models developed using logistic regression. *Ecological Modelling* 133: 225-245.

Pearson, RG. and 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.

Pearson, RG., Dawson, TP. and Liu, C. 2004. Modelling species distributions in Britain: a hierarchical integration of climate and land - cover data. *Ecography* 27: 285-298.

Pearson, RG., Raxworthy, C.J., Nakamura, M. and Townsend Peterson, A. 2007. Predicting species distributions from small numbers of occurrence records: a test case using cryptic geckos in Madagascar. *Journal of Biogeography* 34: 102-117.

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

Raab R, and Schuetz C. 2012. Underground cabling and marking of power lines: conservation measures rapidly reduced mortality of West-Pannonian Great Bustards Otis tarda. *Bird Conservation International* 22:299-306.

Stanton, JC., Pearson, RG., Horning, N., Ersts, P., and Reşit Akçakaya, H. 2012.

Combining static and dynamic variables in species distribution models under climate change. *Methods in Ecology and Evolution* 3: 349-357.

Strange, N., Thorsen, B.J., Bladt, J., Wilson, K.A. and Rahbek, C. 2011. Conservation policies and planning under climate change. *Biological Conservation* 144, 2968-2977.

Sykes, M. and Prentice, IC. 1996. Climate change, tree species distributions and forest dynamics: A case study in the mixed conifer/northern hardwoods zone of northern Europe. *Climatic Change* 34: 161-177.

Tanneberger, F., Flade, M., Preiksa, Z. and Schroeder, B. (2010) Habitat selection of the globally threatened Aquatic Warbler Acrocephalus paludicola at the western margin of its breeding range and implications for management. *Ibis* 152: 347-358.

Wang, Q. and Yan, C. 2002. Chinese Cranes, Rails and Bustards, Taiwan: National Fenghuangu Bird Park. (in Chinese)

Wang, Q. 1999. Current status of waterbirds in China wetlands.Pp.1–11 in Proceedings of International Workshop on the Crested Ibis Conservation ‘99, Hanzhong, China. (In Chinese)

Woodward, FI. 1987. Climate and plant distribution: Cambridge University Press.

Wu, W., Gu, S., Wu, J., Cao, M., Juncheng, L. and Xu, H. 2012 Impact of Climate Change on Distribution of Breeding Sites of Red-Crowned Crane in China. J*ournal of Ecology and Rural Environment* 3: 004.

Wu, X. B. and Smeins, F. E. 2000. Multiple-scale habitat modeling approach for rare plant conservation. *Landscape and Urban Planning* 51: 11-28.

Wu, Y., Liu, S., and Cao, J. 2001 The wintering population survey and conservation strategy of Great Bustards. *Anhui Linye* 4: 30. (in Chinese)

Xia, C., Lin, X., Liu, W., Lloyd, H. and Zhang, Y. 2012. Acoustic identification of individuals within large avian populations: a case study of the Brownish-flanked Bush Warbler, South-Central China. *PloS one* 7: e42528.

Yang, C., Zhou, L., Zhu, W. and Hou, Y. 2007. A preliminary study on the breeding biology of the oriental whitestork Ciconia boyciana in its wintering area. *Acta Zoologica Sinica* 53: 215-226 (in Chinese).

Zhai, T. and Li. X. 2003. Climate change induced potential range shift of the crested ibis based on ensemble models. *Acta Ecologica Sinica* 9: 1353-1362. (in Chinese)

Figure Legend:

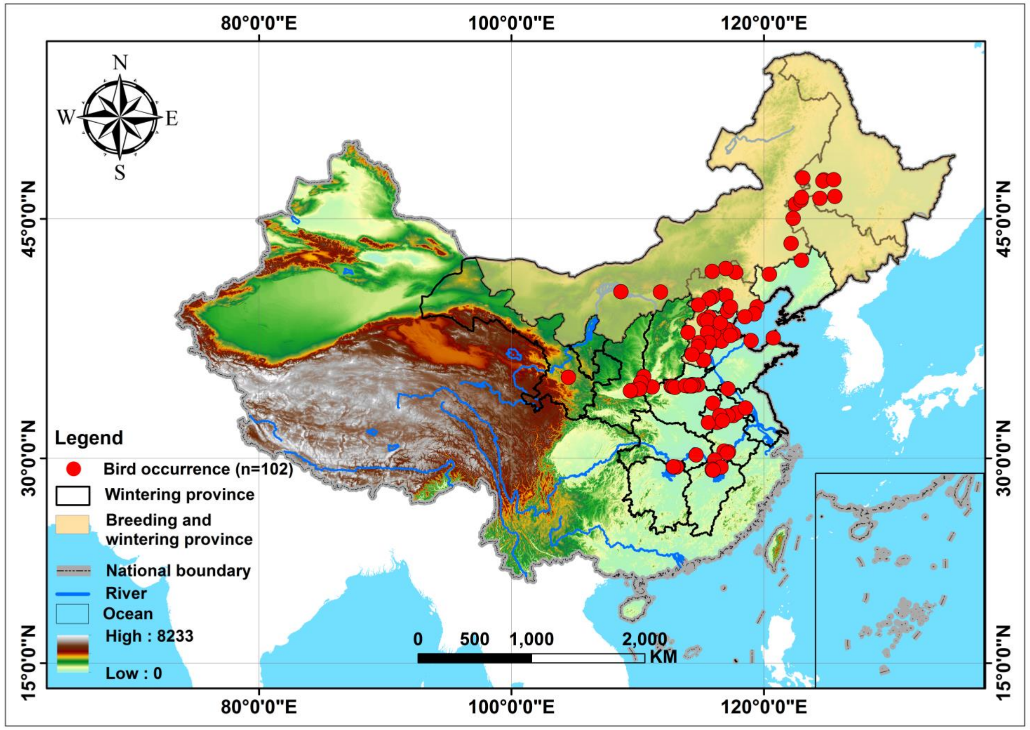

Figure 1 The study area for predicting the distribution of~~of~~ Great Bustards (*Otis tarda dybowskii*) in China. 102 presence records ~~of bustards~~ are shown; the elevation of this study area ranges from 0 to 8,233 m.

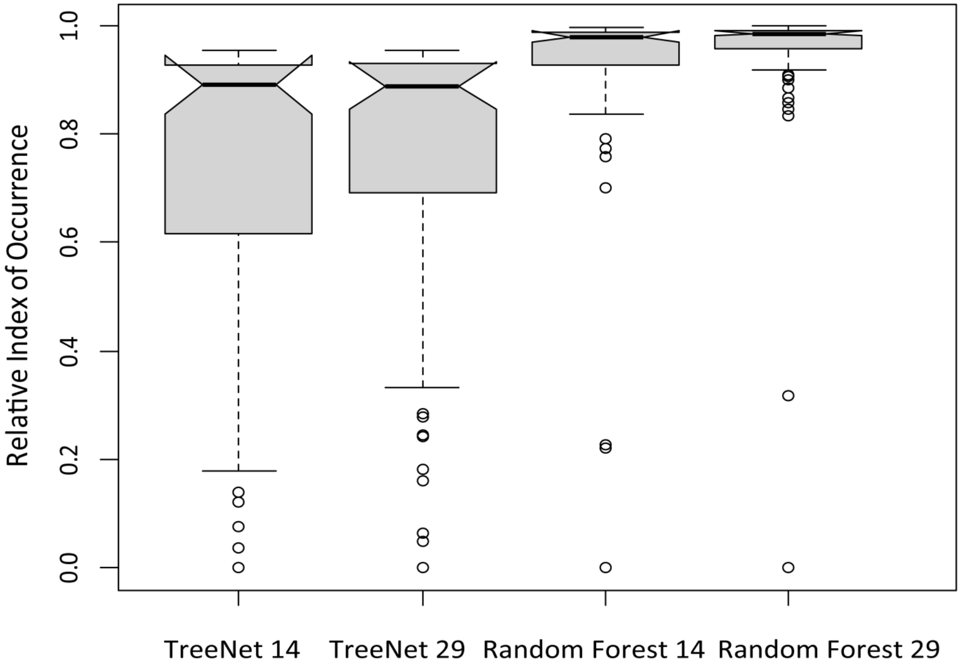

Figure 2 Boxplots ~~of~~from independent test~~ing~~ data taken from the literature (~~the Threaten Birds of Asia, ~~Collar et al. ~~(~~2001~~)~~) ~~extracted~~ derived from four Great Bustards distribution models (TreeNet 14, TreeNet 29, Random Forest 14, Random Forest 29).

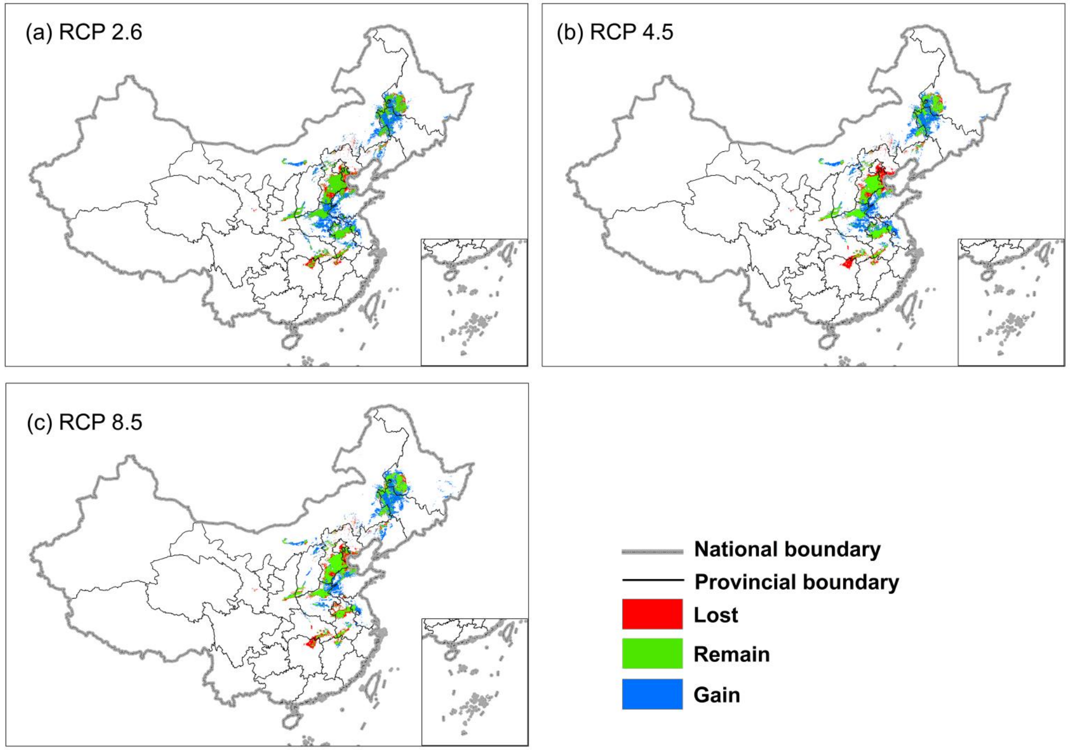

Figure 3 Projected change of the Great Bustard's suitable wintering ~~suitable~~ habitat based~~s~~ on a consensus forecast (BCM) from three GCMs by 2070 under (a~~A~~) RCP 2.6, (b~~B~~) RCP 4.5, and (c~~C~~) RCP 8.5. The projected current ~~Great Bustards habitats~~ distribution was~~were~~ overlaid with future ~~habitats~~ projections to identify areas that would be lost, gained, or remain occupied.

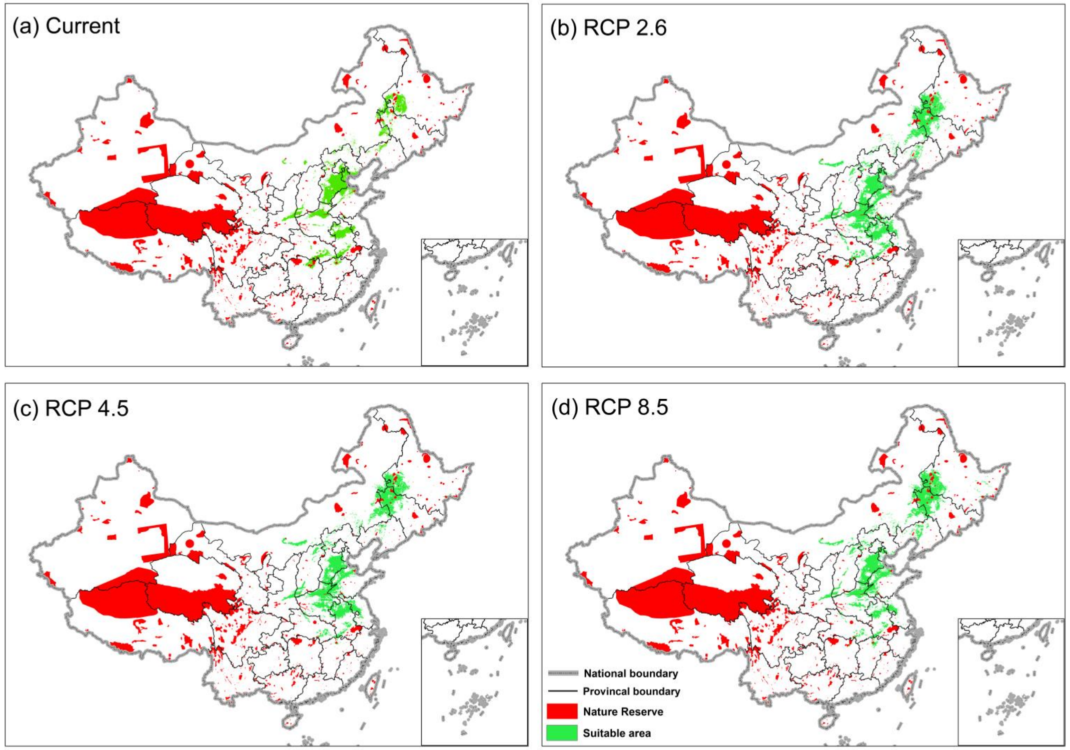

Figure 4 Projection of Great Bustard~~s suitable~~ habitat~~s~~ based on the consensus forecast from three GCMs overlaid with the locations of ~~N~~nature ~~R~~reserves: (a) projected current distribution, (b) projected distribution by 2070 for RCP 2.6, (c) projected distribution by 2070 for RCP 4.5, (d) projected distribution by 2070 for RCP 8.5.

Table Legend

Table 1 The AUC and TSS values of four Great Bustard~~s'~~ distribution models. Bold type indicates the best model according to each measure.

	TreeNet 14	TreeNet 29	Random Forest 14	Random Forest 29
AUC	0.914	0.923	0.961	**0.982**
TSS	0.828	0.846	0.922	**0.965**

Table 2 Projected change in the total area of the Great Bustard's ~~wintering~~ suitable winter habitat~~s area (1000* km^2)~~ and the ~~suitable habitats~~ area ~~(1000* km^2)~~ in current nature reserve based on consensus forecast from three GSMs by 2070. Areas are given in (1000* km^2), with the percent of the current total given in parentheses.

~~Area~~ / Scenario	Area Lost (%)	Area Remaining (%)	Area Gained (%)	New total habitat	Habitat in Reserve (%)
Current	-	-	-	290.64	23.9~~5~~(8.24)
RCP 2.6	67.29(23.15)	223.35(76.84)	218.36(75.13)	374.41(128.82)	29.53(7.89)
RCP 4.5	90.56(31.15)	200.08(68.84)	206.94(71.20)	316.46(108.88)	22.58(7.13)
RCP 8.5	88.08(30.30)	202.56(69.69)	189.69(65.26)	304.17(104.65)	27.30(8.98)

Comment [UConn25]: Please check my interpretation here.

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Comment [UConn26]: Throughout the table give numbers to 1 decimal place, as it is highly unlikely that the models can support better precision. Also put a space before the parenthese As shown in this row. Make similar changes in oth tables.

Table 3 Land cover type for ~~of~~ projections of Great Bustard~~s~~ wintering habitat~~s~~ under ~~the~~ current conditions and three RCP projections by 2070.

Land type / Scenario	Cropland (%)	Sparse (<15%) vegetation (%)	Other (%)	Total
Current	14,211(79.66)	1,210(6.78)	2,418（13.55）	17,839
RCP 2.6	20,828(77.46)	2,783(10.35)	3,278(12.19)	26,889
RCP 4.5	18,544(75.90)	2,941(12.04)	2,949(12.07)	24,434
RCP 8.5	17,054(74.64)	2,887(12.31)	3,065(13.07)	23,456