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Changes in the Distribution of Lesser Adjutant Storks (*Leptoptilos javanicus*) in South and Southeast Asia: A Plausible Evidence of Global Climate and Land-use Change Effect

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ABSTRACT
Species distribution Models (SDMs) illustrate the relation between species and environmental variables. In an attempt to model the historical and current distribution of Lesser Adjutant Stork (*Leptoptilos javanicus*) and gain qualitative insight into range shift, maxEnt modeling approach was applied. The model was projected into maps to illustrate the variation in spatial distribution of the species in South and Southeast Asia over time. A distributional shift was observed towards the north accompanied by range contraction to the south and expansion to the north. Besides, annual precipitation and temperature of the coldest period of a year appeared to be the major climatic determinants of species distribution. It provides plausible evidence of global climate and land-use change effect on the bird's distribution and suggests avenues for further research.

Key words: Lesser adjutant stork, maxEnt, SDM, Southeast Asia, range shift, climate-change

INTRODUCTION
Natural distribution of species is dominantly controlled by climate and it determines the past and future distributions of biodiversity (Rosenzweig *et al.*, 2008). There has been a consistent relationship between species distribution and the physical environment (Elith and Leathwick, 2009) and the fossil record suggests a profound effect of changing climate on the species range expansion and contraction (Walther *et al.*, 2002). Distribution of a species, however, has been increasingly influenced by escalating human populations and accompanied habitat loss, habitat degradation, overexploitation, pollution, exotic species, new pathogens and climate change (MEA, 2005; Butchart *et al.*, 2010). For example, latitudinal and elevational distribution changes have been observed for a variety of species (Grabherr *et al.*, 1994; Pounds *et al.*, 1999; Baur and Baur, 2013) increasing threats of extinction of species with low dispersal capabilities and limited suitable habitat (Thomas *et al.*, 2004; Lee and Jetz, 2007). Thus, predicted global climate change apparently has a significant impact on the distribution of species driving species ranges towards the poles (Parmesan and Yohe, 2003). Additionally, land use change has been projected to have a profound impact on biodiversity and its distribution by 2100 (Sala *et al.*, 2000). Thus, comparison of the historical and current distribution of species and correlating the distribution with climate and land-use change pattern potentially provides evolutionary and ecological insights with future predictability and the fate of a species (Elith and Leathwick, 2009). Moreover, understanding the

geographic distributions of species appears to be an important and crucial aspect with variety of applications in ecology and conservation (Graham *et al*., 2004).

Species Distribution Models (SDMs) are the tools that have been increasingly used to estimate the relationship between species occurrence and the associated spatial characteristics (Franklin, 2009). With an increasing availability of species occurrence data, SDMs have been widely used and are often extended to the maps to make spatial predictions (Elith and Franklin, 2013). Thus, modeling the distribution of species and projecting the models on the maps appear to give an insight on the potential habitat availability and niche shifts of the species (Peterson, 2011). It is of particular importance because conservation of a species requires knowledge on the requirements of the species for the survival, i.e., its ecological niche (Hutchinson, 1957).

Lesser Adjutant Storks (*Leptoptilos javanicus*) belong to the family Ciconiidae and has been listed as vulnerable in International Union for Conservation of Nature (IUCN) red list (BirdLife International, 2012) owing to its rapid decline in population due to hunting and habitat destruction (BirdLife International, 2001). Native to South and Southeast Asia, small declining populations of the species have been recorded in India, Indonesia, Cambodia, Srilanka, Nepal, Bangladesh, Myanmar, Laos, Malayasia, Bhutan, Brunei, Vietnam, Thailand and is possibly extinct in China and Singapore (BirdLife International, 2012). Besides increasing deforestation leading to nest-tree destruction; urban development, conversion of wetlands to agricultural land along with the increasing use of pesticide and fertilizers appear to be the potential threats to the species (Gyawali, 2004). It, thus, seems that the habitat of the species is shrinking. Importantly, the global climate change and its subsequent effect on wetlands presumably affect distribution of the species. Thus, the present study aims to model and project to map the distribution of the species in South and Southeast Asia to gain a qualitative insight into range shift, shrinkage and expansion (if any) of the species. Additionally, the study also aims to identify the important climatic variables that affect the species distribution. It is expected that the species can be a sentinel to gauge the potential habitat loss and range shift of similar guilds in response to climate and land-use change in the Indian subcontinent.

MATERIALS AND METHODS

Species occurrence data (latitude/longitude) (N = 355) of Lesser Adjutant Storks were extracted from Bird Life International (www.birdlife.org). Species occurrences data before 1950 have been classified as historical occurrences while that after 1950 as recent occurrences. Likewise, climatic data were extracted from www.worldclim.org. It consists of the data (16 climatic variables on temperature and precipitation) on climatic surfaces for global land areas averaged over 1950-2000 (Hijmans *et al*., 2005). The data were used to model the species distribution through maximum-entropy (maxEnt) modeling approach (Phillips *et al*., 2006). Because of its consistent and highest performing capacity, maxEnt modeling approach has been increasingly used for modeling species distribution (Elith *et al*., 2006) despite some criticism of false-positive it provides in the results. However, this downside was circumvented by dividing the data into train and test datasets to verify the outputs. Model fit was evaluated by producing the Receiver Operating Characteristic (ROC) curve and calculating the area under receiver operating curve (AUC) (Liu *et al*., 2005). It is a measure of the ability of a model to discriminate between the sites where a species is present versus sites where it is absent. AUC value ranges from 0 to 1 and values greater than 0.7 are considered to be potentially significant (Elith *et al*., 2006). Finally, models were projected on a map to visualize the historical and current niche distribution of the species using the package 'dismo' and 'maptools' in 'R' (R Development Core Team, 2011).

RESULTS

The maximum entropy model of the Lesser Adjutant Crane's (*Leptoptilos javanicus*) historical distribution had an AUC of 0.903. Minimum temperature of the coldest month and annual precipitation were the most important variables in explaining lesser adjutant historical distribution. Likewise, the maximum entropy model for current distribution of the crane had an AUC of 0.954. Minimum temperature of the coldest month and annual precipitation were the most important variables in explaining the bird's current distribution. Projected models into maps exhibited potential suitable areas for the species with range expansion to the north part and shrinkage to the south over time (Fig. 1 and 2).

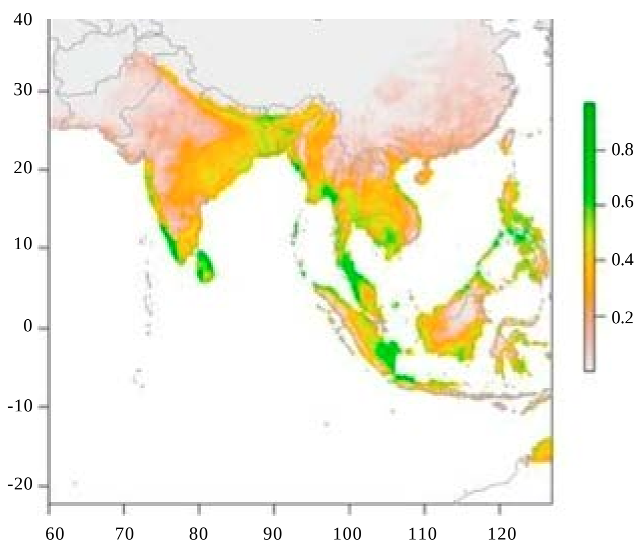

Fig. 1: Historical probability of distribution of the species. The colors show the cumulative probability density

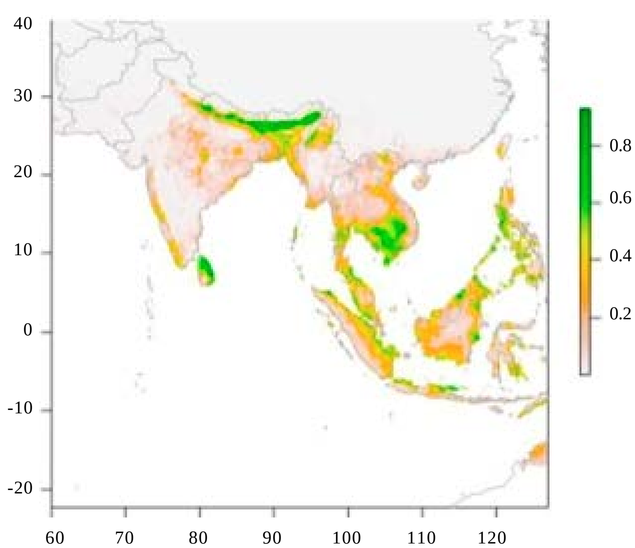

Fig. 2: Current probability of distribution of the species. The colors show the cumulative probability density

DISCUSSION

Minimum temperature of cold season and annual precipitation appeared to be the major determinants of Lesser Adjutant distribution, presumably due to their effects on habitat distribution and breeding ecology of the species. These climatic variables have indeed been found to affect the nestling mortality and breeding success of other species of storks elsewhere (Jovani and Tella, 2004). Models when projected into maps revealed potential suitable areas for the species in South and Southeast Asia. Comparisons of historical to current distributions show a shift in distribution of the species. The shift appears to be towards the North. Similar distributional shifts of snails in Swiss National Park (Baur and Baur, 2013) and of tropical birds in Costa Rica (Pounds *et al*., 1999) in response to change in climatic factors have been documented. Also, the distributional shift seen in the pheasants of Thailand has been presumed to be the effect of global climate change (Round and Gale, 2008). Thus, the observed distributional shift of Lesser Adjutants is presumably a response to change in the climatic factors. However, this finding does not rule-out the plausible effect of land-use change pattern, increased deforestation (Allen and Barnes, 1985) and decline of wetlands (Jha, 2008) in the area. Land-use change has been found to be the potential driving factor to explain the vegetation patterns and thus the potential habitat, for a variety of species in tropics and subtropics (Lee and Jetz, 2007). Although land-use map has not been incorporated in the present study, literatures suggest a dramatic change in land-use pattern and wetlands degradation in areas of range contraction on the map (Goldewijk, 2001; Zhao *et al*., 2006). Moreover, urban development in Southeast Asia has increased dramatically with a tremendous effect on species distributions (APN, 2001).

Identification of priorities for conservation research and/or action is crucial for effective biodiversity conservation. This, however, involves one of two routes: Detection of changes in the system and identification of potential threats to the system (Pullin *et al*., 2013). Findings of the present study undoubtedly have detected a change in the distribution of Lesser Adjutants and plausible underlying factors. Moreover, it helps to predict areas that potentially help to satisfy the requirements of the species fundamental niche. This can have a huge application in conservation biology as it provides an understanding of conditions suitable for the survival of the species and of similar guilds. Further study correlating the ecology of the species with abovementioned climatic factors along with the inclusion of land-use change data would provide an opportunity to gain more insight (and as a proxy measure) into effects of global climate and land-use change on biodiversity conservation.

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