Ecological Indicators 91 (2018) 439–446

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Original Articles

Maximum Entropy modeling for habitat suitability assessment of Red-crowned crane

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ARTICLE INFO

Keywords:
Red-crowned crane
Maximum Entropy
Habitat suitability
Remote sensing

ABSTRACT

Habitat suitability assessment is an important approach for conserving and restoring biodiversity and waterfowl's habitats. Previous habitat suitability index (HSI) models define the weights of each habitat feature subjectively in their approach. To address this problem, we utilized a data-driven Maximum Entropy (MaxEnt) model to assess the fine-scaled habitat suitability of Red-crowned crane (*Grus japonensis*) in the breeding period based on the occurrence locations of Red-crowned crane and the habitat features derived from optical, radar imagery and topographical ancillary data. Results of this research show that the developed MaxEnt model improves the performances of previous HSI models. The MaxEnt model could identify the influences of the selected habitat features on the habitat suitability of the species and quantify the optimal habitat conditions for the Red-crowned cranes automatically. We found that habitat composition, water depth, and distance to roads and ditches were most important habitat features for Red-crowned cranes in the breeding period. The optimal conditions for each selected habitat features were recognized according to the response curves of environmental variables to occurrence probability of the species. For the breeding Red-crowned cranes, the desirable land cover type of breeding habitat is reed swamp; the suitable depth of water under the canopy is between 15 and 30 cm approximately; the selected vegetation cover is about 47.5%–74.5%; and the suitable distance from human disturbances is above 2500 m. This study demonstrated the practicability of the developed species distribution model (MaxEnt) on habitat suitability assessment for Red-crowned cranes, and provided a quantitative and automatic habitat suitability evaluation method for endangered waterfowl's protection.

1. Introduction

Wetland ecosystem can provide essential habitats for rare and endangered species (Zhang et al., 2009; Turner et al., 2000). Recently, the loss and deterioration of wetlands habitats associated with human disturbance and global climate change have threatened the existence and reproduction of waterfowl; especially the endangered wild Red-crowned cranes (Torres et al., 2010; Lu et al., 2012; Dong et al., 2013). Therefore, understanding the habitat requirements of the Red-crowned cranes and assessing the habitat quality of this species are the basis of conservation and restoration for the wetlands. Suitable habitat features must be identified to evaluate the habitat suitability of the breeding Red-crowned cranes. Red-crowned cranes nest in shallow marshes dominated by reed vegetation communities (*Phragmites australis*) (Li et al., 1999; Su and Zou, 2012). Previous researches have testified that the breeding Cranes prefer to live in contiguous marshes, high cover vegetation, and fields far from the human disturbances (Baker et al., 1995; Zhang and Yang, 2000; Downs et al., 2008, Wu and Zou, 2011; Li et al., 2012; Wang et al., 2014., Zou et al., 2003; Wang et al., 2010). It is critical to develop a suitable habitat evaluation model to discriminate these sites considered multiple habitat conditions of the species.

Habitat suitability index (HSI) models are widely used tools to evaluate the habitat quality and identify the spatial distributions of suitable habitat (Van der Lee et al., 2006). HSI models incorporated in the land cover types, vegetation fraction, and distance to human disturbances have been used to evaluate the habitat suitability of breeding cranes in ZNNR (Wang et al., 2009; Jiang et al., 2009). Despite their broad applications, HSI models may be especially problematic when implemented with numerous habitat features since the weights for each feature are determined subjectively. Over the past few decades,

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https://doi.org/10.1016/j.ecolind.2018.04.013
Received 24 December 2017; Received in revised form 2 April 2018; Accepted 5 April 2018

empirical species distribution models (SDMs) have become a critical technique for predicting the species habitat distribution through building a correlation between species occurrence and its surrounding habitat features (Guisan and Thuiller, 2005; Elith et al., 2006; Elith and Leathwick, 2009). The spatial distribution of species has been predicted by many SDMs, including Maximum Entropy (MaxEnt) (Elith et al., 2011), genetic algorithm for ruleset prediction (GARP) (Peterson et al., 2007), ecological niche factor analysis (ENFA) (Hirzel et al. 2002), Mahalanobis typicalities (Sangermano and Eastman, 2012), Domain (Carpenter et al. 1993), and Bioclim (Busby, 1991; Booth et al., 2014). Comparisons of these methods suggests that MaxEnt outperforms the other presence-only method mentioned above and is able to produce reasonable quality models for many of the species (Elith et al., 2006; Phillips et al., 2006).

Considering inaccessibility of the absence data for Red-crowned cranes and the reasonable predictive performance of the model, MaxEnt was suitable for predicting the spatial distribution of Red-crowned cranes. Furthermore, MaxEnt model could utilize continuous and categorical data at the same time (Phillips, 2005; Moreno et al., 2011), which provided good opportunities for integrating numerous habitat features derived from remote sensing imagery and thematic maps. In addition, the data-driven model could determine the importance of predictive variables automatically. Having a clear understanding of the impact of selected habitat features on the potential distributions of Red-crowned cranes will help to evaluate the habitat suitability objectively and prioritize the protection measures for the specific wetland reserve (Remya et al., 2015).

MaxEnt has been used to evaluate the suitable distribution of terrestrial birds (Moreno et al., 2011; Naoe et al., 2015), amphibians (Sangermano et al., 2015) and rodent species (Shcheglovitova and Anderson, 2013) for a wide range of regions. To the best of our knowledge, no significant studies have been performed to assess the fine-scaled habitat suitability of the rare and endangered waterfowl using the MaxEnt model. The objectives of this study, therefore, were to examine the feasibility of developing the MaxEnt model to evaluate the habitat suitability for the breeding Red-crowned cranes in a typical wetland Reserve. The current study emphasizes on the ability of the MaxEnt model in identifying the influences of the selected habitat features on the habitat suitability of the species and quantifying the optimal habitat conditions for the Red-crowned cranes automatically. Knowledge of suitable nesting habitats of the Red-crowned cranes in these isolated and inaccessible areas could improve the management and conservation measures for the species.

2. Materials and methods

2.1. Study area

Zhalong National Nature Reserve (ZNNR) covers an area of 2100 km^2 and is located in the northeast of the Songnen Plain, Heilongjiang Province, China (Fig. 1). ZNNR was founded in 1987 with the major purpose of protecting endangered waterfowl, such as *Grus japonensis, Grus leucogeranus* and *Grus monacha* etc. Zhalong wetland is the most important breeding area for Red-crowned crane in north-eastern China and attracts about 200 Red-crowned cranes nesting and hatching their eggs during April to May each year (Qian et al., 2012). Zhalong wetland was listed as a "Wetland of International Importance" by the Ramsar Convention in 1992.

The study area belongs to the temperate continental monsoon climate zone characterized by an average annual temperature of 3.9 °C and an average annual precipitation of 402.7 mm. The water sources of Zhalong wetlands primarily come from the Wuyuer River and Shuangyang River. Reed (*Phragmites australis*) is the dominated vegetation communities, and constitutes 70–80 percent of the total area in Zhalong wetlands. Other land cover types in this area include sedge marsh, wet meadow, and agriculture land. The study area provides critical nesting places for Red-crowned cranes during their migration. Understanding the impact of habitat features on the habitat suitability would be beneficial for the conservation and restoration of the breeding Red-crowned cranes habitats.

2.2. Data preparation

During April and May 2007, we observed 33 breeding Red-crowned cranes upon their nests using a 40 × 100 mm telescope according to a procedure reported by Li et al. 1999. Due to the inaccessibility of the nesting sites, we only walked to 14 Red-crowned cranes nests and recorded the geographical coordinates using a hand-held Magellan eXplorist 610 Global Positioning System (GPS). The habitat features surrounding the nests, including vegetation communities, vegetation cover and water depth under the nests, were also measured. The other 19 nest locations were estimated based on the directions and distances between observing locations and the rangefinder telescope enabling an accuracy of 3–5 m. The locational error in the occurrence records were acceptable compared with the 30 m analysis units used in the MaxEnt models. We also sampled 500 sites along one transect stretched across the Zhalong wetlands through field survey in May 2007. The geographical coordinates, vegetation types, vegetation cover, and average water depth at each sampling sites were recorded using a handheld GPS. The sampling sites were spatially scattered to avoid the autocorrelation issues. The interval of the field works are above 100 m.

We acquired one scene of Landsat-5 Thematic Mapper (TM) image on May 28, 2007, with a 30 m spatial resolution for land cover classification in Zhalong wetlands. The top-of-atmosphere reflectance data were obtained applying the standard calibration method using the coefficients from data header (Markham and Barker, 1987). Top-of-atmosphere reflectance values were then transformed to surface reflectance with the dark-pixel subtraction technique (Chavez, 1988). At last, the TM data were georeferenced using 66 ground control points (GCPs) acquired from topographical maps. The residual of the geometric correction process was less than 0.5 pixels. We obtained one scene of Envisat ASAR imagery from the European Space Agency (ESA) on May 11, 2007 in alternating polarization mode (ASA_APG_1P product), horizontal transmit and horizontal receive (HH) and horizontal transmit and vertical receive (HV) polarization in C-band (5.34 GHz).

The Envisat ASAR image was transformed to backscattering coefficient (σ^0) based on the radiometric calibration method provided by Rosich and Meadows (2004). The standard Lee filter with kernel sizes of five pixels was applied to suppress the speckle noise inherent to the SAR data. The pixel size of Envisat ASAR images, originally 12.5 m, was resampled to 30 m. The digital elevation model (DEM) of the study area were generated from 20 topographical maps at the scale of 1:25,000. The topographical maps were provided by the Heilongjiang Mapping and Surveying Bureau, Harbin, China.

2.3. Modeling procedure

2.3.1. MaxEnt model building

The habitat extent and suitability of breeding Red-crowned cranes in Zhalong wetlands were modeled with MaxEnt software (version 3.3.3k) developed by Phillips et al. (2006), Phillips and Dudík (2008). MaxEnt requires presence data and background data (a sample of available habitat) to model species responses and habitat suitability. Of the 33 observed presence locations of breeding Red-crowned cranes, cross-validation was used to do multiple runs for the MaxEnt model (Pearson et al. 2007; Remya et al., 2015). The occurrence data was randomly split into several equal size folds, and models were built leaving out each fold in turn. The left-out folds were then utilized for evaluation. We got ROC curves and response curves with error bars through summarized statistical information for the cross-validation with 10 replicates. The regulation number was set as the default of 1.0 in order to avoid the over-fitting phenomenon and keep the model close