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

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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 (\textit{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 (\textit{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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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
crapes and the reasonable predictive performance of the model, MaxEnt
was suitable for predicting the spatial distribution of Red-crowned
crapes. 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 ter-
restrial 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 km² 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”

The study area belongs to the temperate continental monsoon cli-
mate 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 vege-
tation 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

2.2. Data preparation

During April and May 2007, we observed 33 breeding Red-crowned
crapes upon their nests using a 40 x 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 re-
corded the geographical coordinates using a hand-held Magellan eX-
plorer 610 Global Positioning System (GPS). The habitat features sur-
rounding 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 accep-
table 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
cordinates, 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 is-
ues. 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 classi-
ification 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-at-
mosphere reflectance values were then transformed to surface re-
fectance 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 geo-
metric 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 pro-
duct), 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 coeffi-
cient ($\sigma^0$) 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 Dudik (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