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CHANGES IN HABITAT SUITABILITY FOR WATERBIRDS OF THE MOMOGE NATURE RESERVE OF CHINA DURING 1990−2014

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Abstract. There is increasing empirical evidence that changes in habitat quality play an important role in determining species distributions and biodiversity. However, most research has focused on habitat quality, and we still lack approaches for tracking habitat quality dynamics. In this paper, by establishing qualitative and quantitative relationships between waterbird populations and key habitat indicators such as water abundance, food, shelter conditions and disturbance, we developed an object-oriented classification method, in conjunction with a geographic information systems (GIS) based centroid moving method, to assess habitat suitability dynamics for waterbirds at the Momoge Nature Reserve, China. Our results showed that habitat suitability improved during 1990–2000 and declined during 2000–2014. Habitats with very good and good grades increased by 71.47 km^2 (4.88%) during 1990–2000 and decreased by 200.66 km^2 (13.78%) during 2000–2014. The habitat area with a good grade moved to the north, while the habitat area with a poor grade moved to the south during 1990–2014. This was mainly because the surrounding cropland area increased and shifted as oil and gas projects developed. These findings suggest that our object-oriented classification and centroid moving methods have great potential for use in biodiversity conservation and ecosystem management.

Keywords: habitat suitability, waterbirds, centroid, remote sensing, the Momoge Nature Reserve, China.

Introduction

Over the past 50 years, humans have caused rapid and extensive declines in global biodiversity (Millennium Ecosystem Assessment 2005) despite our increased focus on nature conservation and wildlife management. Globally, 85% of threatened bird species are at risk because of habitat loss and degradation. Waterbirds, among the most symbolic ecological assets in wetlands, are good indicators of environmental changes and are natural resources of great ecological value (Reid *et al.* 2013). Waterbirds show high mobility and aggregation in response to the fluctuations in resources and the demands of their different life requirements (Cumming *et al.* 2012). Natural and semi-natural habitats are exposed to growing pressure from the intensification of agriculture, forestry and climate change (Weiers *et al.* 2004). The changes of habitat quality would affect the distribution, diversity and abundance of waterbirds (Şekercioğlu *et al.* 2004). Wetlands support extensive food chains and biodiversity and are natural regulators of a number of environmental problems, such as flooding, drought and water quality (Williams 1990). Wetlands are critical habitats for a large variety of waterbirds (Ramsar 2012), and a major reason for decreasing bird populations is habitat degradation (Rönkä *et al.* 2008). Obtaining information on habitat distribution and monitoring habitat conservation is a prominent research area (Corbane *et al.* 2015) and requires both an evaluation of the current suitability of habitat and detection of habitat changes.

As the coupling of remote sensing and GIS technologies can provide quantitative and cost-effective assessment, these technologies are widely recognized for their applicability in wetland monitoring (Euliss *et al.* 2011) and ecological research. Remotely sensed data provide measurements and surrogates that are directly related to vegetation type and structure, biomass, and other ecosystem variables that collectively improve our understanding of habitat characteristics (Bradley *et al.* 2012). There are

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numerous examples demonstrating that the addition of remotely sensed variables improves the accuracy of habitat suitability models. Waterbirds select habitats that meet their ecological requirements of providing food and shelter, as well as abundant water and minimum disturbance. Therefore, in many studies, remotely sensed variables serve as proxies for water, food, disturbance and other attributes of habitat quality (e.g., Dong *et al.* 2013; Tian *et al.* 2008). Human presence and human-induced environmental changes also affect the suitability of habitats, and thus, land cover change serves as a proxy for habitat loss (Wang *et al.* 2015). Accurate assessment of habitat quality depends on a profound understanding the habitat requirements of waterbirds, followed by effective modelling of habitat suitability.

In many cases, habitats can be very dynamic, affecting animal distributions and populations, so detecting habitat dynamics can improve our understanding of habitat-abundance targets (e.g., Gardner *et al.* 2007; Nakamura *et al.* 2016). Habitats can be dynamic in response to climate changes, conservation efforts, or land use changes (Anteau 2012). Measuring habitat status and understanding habitat dynamics have become important for waterbird conservation (Liu *et al.* 2010). However, to our knowledge, most of the debate to date has focused on habitat quantity, while changes in habitat quality have been overlooked (Hodgson *et al.* 2009). Accurately assessing habitat dynamics would clearly be useful for many aspects of research, conservation and management (Anteau *et al.* 2014).

The West Songnen Plain has the greatest concentration of marsh wetlands in China and is noteworthy for its biodiversity (Wang *et al.* 2009). This area also serves as an important stopover and wintering site for migratory waterbirds. However, wetland degradation, due to climate warming and anthropogenic pressures resulting from the reclamation of farmlands, construction of water conservation projects, and petroleum and gas developments (Pan *et al.* 2006), has become a serious environmental problem. The Momoge Nature Reserve (MNR), which was designated as a reserve of international importance, contains a large area of natural wetland in the Western Songnen Plain and has been severely impacted by intensive human activities. In recent years, waterbird populations in the Momoge Nature Reserve have declined, primarily in response to habitat loss, fragmentation and degradation (Xiao *et al.* 2014). Several of these waterbird species are red-listed (Ramsar 2012). Thus, there is an urgent need to protect and restore waterbird habitat. More attention should be given to quantitatively assessing habitat suitability for waterbirds and the dynamics of habitat quality in this region. The objects of this study were: (1) to select the key ecological indicators that have prominent impacts on waterbird habitat, (2) to quantitatively assess the habitat suitability grades in the Momoge Nature Reserve, and (3) to track and analyse dynamics and spatial characteristics of habitat suitability for waterbirds during 1990–2014. We hope that these results supply accurate information about habitat suitability changes and serve as a tool for biodiversity conservation.

1. Materials and methods

1.1. Study area

The MNR (45°42′33″–46°17′59″N, 123°27′09″–124°4′32″E) is located in the transition zone between deserts and grasslands in the northwestern part of Jilin Province, China (Fig. 1), at an altitude ranging from 128.0–160.7 m above sea level. The total area is

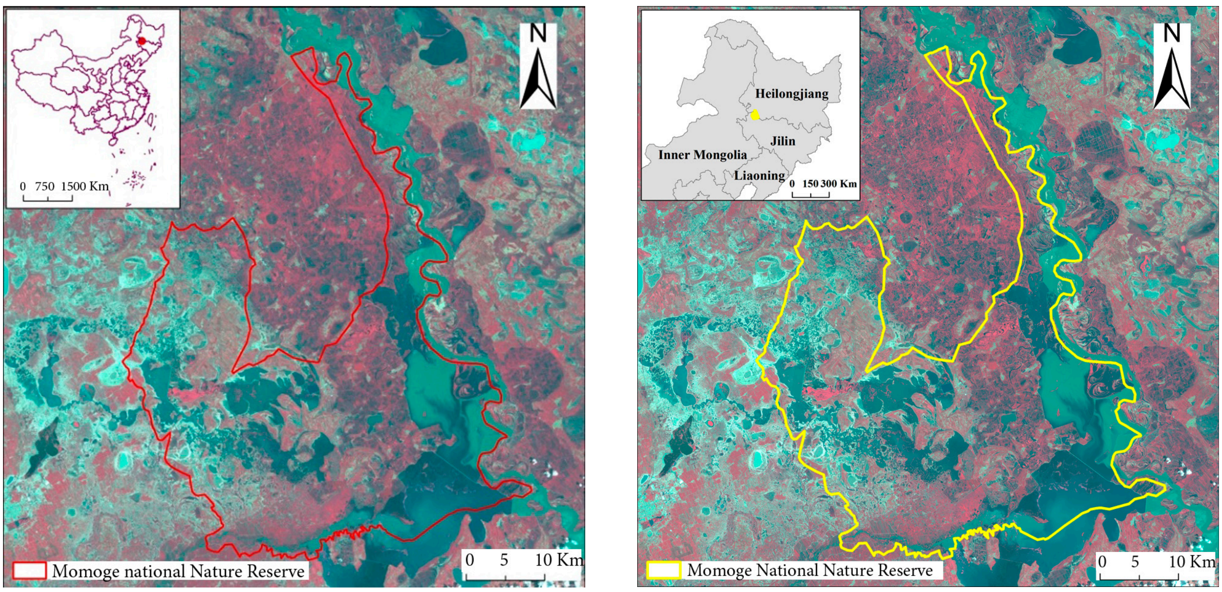

Fig. 1. Location of the Momoge Nature Reserve (Landsat 8 OLI 543 data (07/10/2013))

approximately 1440 km^2. The reserve has a temperate continental monsoon climate, with average annual precipitation of 391.8 mm and an average annual temperature of 4.2 °C (Yang *et al.* 2012). Winter is cold with heavy snow, while summer is hot with heavy rain. The MNR mainly draws off floodwater from the Nenjiang River, Tao'er River and Erlongtao River.

The MNR was established in 1981, listed in the Chinese National Nature Reserves in 1997 and designated as internationally important during the Ramsar Convention in 2013. The MNR plays a key role in regulating the regional climate, conserving biodiversity and protecting endangered waterbird species. Thus, the MNR receives great attention from international organizations, such as the WWF (World Wildlife Fund), GEF (Global Environment Facility) and ICF (International Crane Foundation) (Pan *et al.* 2006). It is an inland wetland ecosystem mainly composed of lakes and marshes, serving as an important habitat for a variety of threatened migratory birds, such as the Siberian crane, hooded crane, red-crowned crane and oriental stork. There are 193 recorded bird species in the MNR (Ramsar 2012). However, human activities, such as petroleum exploitation, have led to the degradation of the waterbird habitat in recent years.

1.2. Data sources

Satellite datasets from the Landsat Thematic Mapper (TM), Enhanced Thematic Mapper (ETM), Operational Land Imager (OLI), digital elevation model (DEM) and other ancillary data were used in this research. Landsat TM images were obtained from the United States Geological Survey (USGS) Landsat archive (http://glovis.usgs.gov/). The study area is located in the Path/Row 120/28 of the World Reference System 2 (WRS-2), and three images acquired from 25 June 1990, 6 July 2000, and 10 July 2014 were available for the study area. Satellite images from the same season were selected in order to decrease seasonal effects. Each Landsat TM image had a resolution of 30 m. DEM data were obtained from the Shuttle Radar Topography Mission (SRTM) (http://srtm.csi.cgiar.org/) with a resolution of 90 m and used to derive the slope factor. The ancillary data included road and river vector data, which were available at the AMUR-HEILONG RIVER BASIN Information Center (http://amur-heilong.net/). Prior to image classification for land cover mapping, all images were geo-rectified to topographic maps using ground control points (GCPs). The ENVI 4.8 software and ArcGIS 9.3 software were used for data processing.

1.3. Habitat suitability assessment approach

The object-oriented classification method was adopted for land cover maps, which were derived from Landsat images acquired in 1990, 2000 and 2014. To quantitatively assess habitat suitability, several indicators, including water availability, food, shelter conditions and disturbance, were selected to represent the habitat requirements of waterbirds. By numerically relating occurrence records for waterbirds to a suite of environmental variables from those locations, remote sensing-based indicators that were well correlated with field-based indicators of habitat status could be used as proxies (Strasser *et al.* 2014). In this paper, six indicators were identified in the analysis of habitat suitability for waterbirds, including shelter condition (land cover type and slope), food abundance (Normalized Difference

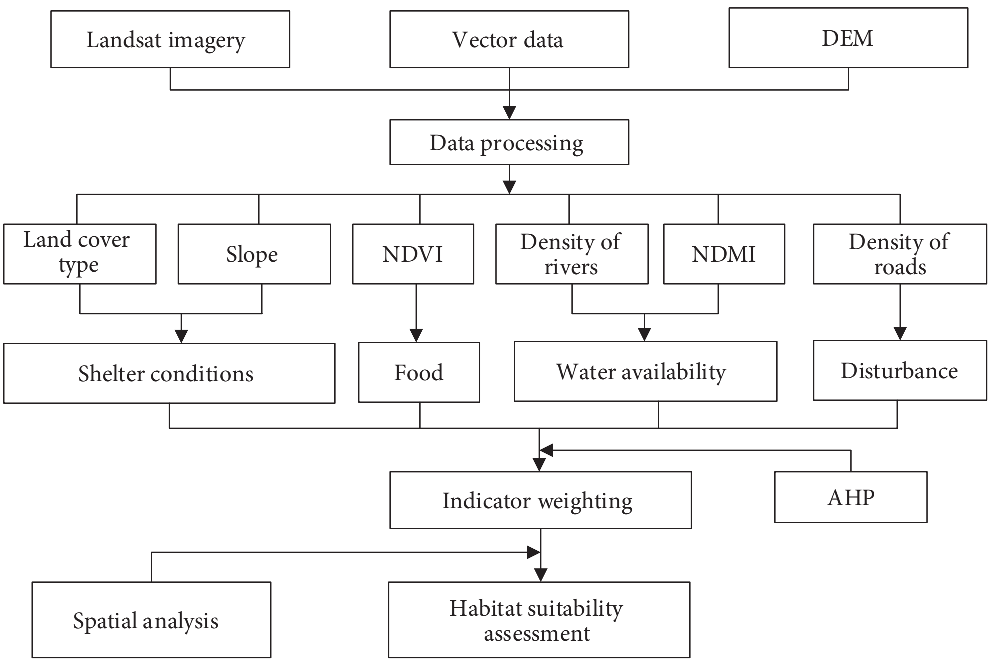

Fig. 2. Flow chart of the waterbird habitat suitability assessment in MNR

Vegetation Index, NDVI), water availability (the density of rivers and NDMI), and disturbance (the density of roads). Then, an analytic hierarchy process (AHP) method was applied to determine indicator weights. In this way, an assessment matrix of indicators and their weights was established. Based on the geo-referenced database, an assessment of habitat suitability could be performed. Figure 2 presents a flow chart showing how to obtain habitat quality information using Landsat imagery with object-oriented and AHP methods.

1.3.1. Identification of habitat indicators

Among the six indicators of habitat quality, land cover was the dominant proxy variable that informed habitat or supporting ecosystem services. Land cover data were obtained from Landsat images by object-based classification in conjunction with visual interpretation. Object-based segmentation is a method that allows for mapping complex, hierarchical habitat systems (Strasser, Lang 2015). The object-based classification was performed using eCognition 8.64 software (Kartikeyan *et al.* 1998). Based on natural vegetation succession and human land use types, land cover maps for 1990, 2000 and 2014 were classified into seven categories: wetland, cropland, woodland, grassland, water body, built-up land and barren land. The classification accuracy was assessed using historical data during 1990–2000 and through field investigations during 2013–2014. The total classification accuracies of the land cover maps for 1990, 2000 and 2014 were >90%, meeting the needs of this study. NDVI was significantly correlated with vegetation biomass, primary production and greenness and also accounted for intra- and inter-annual changes in the environment (Cord, Rödder 2011). NDVI could therefore be used as a potential measure of forage for waterbirds. In this study, NDVI was a normalized transformation of the Landsat near-infrared (TM4, ETM4, OLI5) to red (TM3, ETM3, OLI4) reflectance ratio, with values between –1–1. NDVI values for 1990, 2000 and 2014 were derived from Landsat imagery.

Water availability is another important aspect for waterbirds selecting a stopover and breeding site and depends on the density of rivers at the regional level. Otherwise, the plant community also depends on soil wetness and submersibility. Thus, the moisture of the land surface becomes an important factor at the microhabitat level. The density of rivers was derived from river vector data. The normalized difference moisture index (NDMI) (Wilson, Sader 2002) is the normalization of the difference in bands of moisture between Landsat near-infrared (TM4, ETM4, OLI5) and short wave-infrared (TM5, ETM5, OLI6) reflectance ratios. The NDMI values from 1990, 2000 and 2014 were also derived from Landsat imagery. Land cover and slope reflect the safety of shelter and are crucial for waterbirds selecting a place to rest (Brotons *et al.* 2004). The slope angle of the study area was derived from DEM data.

Finally, wild cranes are particularly wary and will abandon their nests if disturbed by human activity or predators (Zou, Wu 2009). The density of roads has a direct effect on waterbird habitat (Hirzel *et al.* 2001) and was derived from the road vector data using the spatial analysis function of ArcGIS 9.3.

1.3.2. Calculation of habitat suitability index

To calculate the Habitat Suitability Index, all habitat indicators were translated into numerical data, and all data were standardized using the spatial analysis tools of ArcGIS 9.3 software. Habitat suitability was graded as poor (0–25), fair (25–50), good (50–75) and very good (75–100).

As the impact of each indicator had a different effect on habitat suitability, reliable weights had to be determined for each indicator. An AHP method was applied for the indicator weighting. AHP can be used to create decision aids that simplify and expedite the shared decision making process, with effective and feasible results (Dolan 2008). This method can combine the relationships between habitat suitability indicators (Ludwig, Ianuzzi 2006). Table 1 presents the AHP results that were used to determine the weight of each indicator of habitat suitability. Then, a linear function was adopted to calculate an overall index of habitat suitability for waterbirds.

Table 1. The indicator weights for waterbird habitat suitability determined using an AHP method

Objective level	Criterion level		Index level	
	Indicators	Weights	Indicators	Weights
Waterbird Habitat Suitability Index in the Momoge Nature Reserve	Water abundance	0.45	Density of rivers	0.34
			NDMI	0.11
	Food	0.32	NDVI	–
	Shelter condition	0.15	Land cover type	0.12
			Slope	0.03
	Disturbance	0.08	Density of roads	–

1.4. Habitat suitability change detection

Changes in habitat suitability for waterbirds were derived from images acquired during the same season in 1990, 2000 and 2014. The spatio-temporal analysis of changes in habitat grades was performed using ArcGIS 9.3 software. Spatial analysis was carried out to describe patterns of grade changes and to measure the rate of changes that occurred during 1990–2014.

In this study, the centroid coordinates approach (Li *et al.* 2007) was used to obtain habitat suitability patches and to spatially track the dynamics of changes in habitat quality grades. Centroid coordinates were calculated as:

$$X_c = \sum_{i=1}^{n} C_i X_i / \sum_{i=1}^{n} C_i, Y_c = \sum_{i=1}^{n} C_i Y_i / \sum_{i=1}^{n} C_i , \quad (1)$$

where X_c and Y_c are the centroid coordinates of area-weighted suitability types, X_i and Y_i are the centroid coordinates of i th patch, C_i is the area of all patches in i th suitable grade, n is total numbers of all landscape patches.

To offer more details about movement process on centroids of different habitat suitability grades, the movement distance $d_{t_{i+1}-t_i}$ and angle $\theta_{t_{i+1}-t_i}$ were calculated as follows:

$$d_{t_{i+1}-t_i} = \sqrt{(X_{t_{i+1}} - X_{t_i})^2 + (Y_{t_{i+1}} - Y_{t_i})^2} ; \quad (2)$$

$$\theta_{t_{i+1}-t_i} = \arctan \frac{|Y_{t_{i+1}} - Y_{t_i}|}{|X_{t_{i+1}} - X_{t_i}|} \cdot 180° / \pi , \quad (3)$$

where X_{t_i}, Y_{t_i} and $X_{t_{i+1}}$, $Y_{t_{i+1}}$ are the centroid coordinates of a certain suitability type in t_i and t_{i+1} year, t_i and t_{i+1} are the beginning and terminal years.

2. Results

2.1. Indices of suitability indicators

Six suitability indicators were selected in this study. Some indicators were static, such as the density of roads and rivers, and the slope; and some indicators varied with time, such as land cover type, NDVI and NDMI, which were mapped in 1990, 2000 and 2014.

The density of roads and rivers ranged between 0–72.19 and 0–118.99, respectively (Fig. 3a, b). The distribution map of slope, ranging between 0–8.56, is presented in Figure 3c.

Land cover maps of the study area are presented in Figure 4a–c. As the maps show, the wetland area increased by 164.27 km² during 1990–2000 and decreased by 104.57 km² during 2000–2014. The area of cropland increased continuously during 1990–2014, while the area of water body declined continuously during 1990–2014. Meanwhile, the spatial distribution patterns of three main land cover types, namely, wetland, cropland and water body,

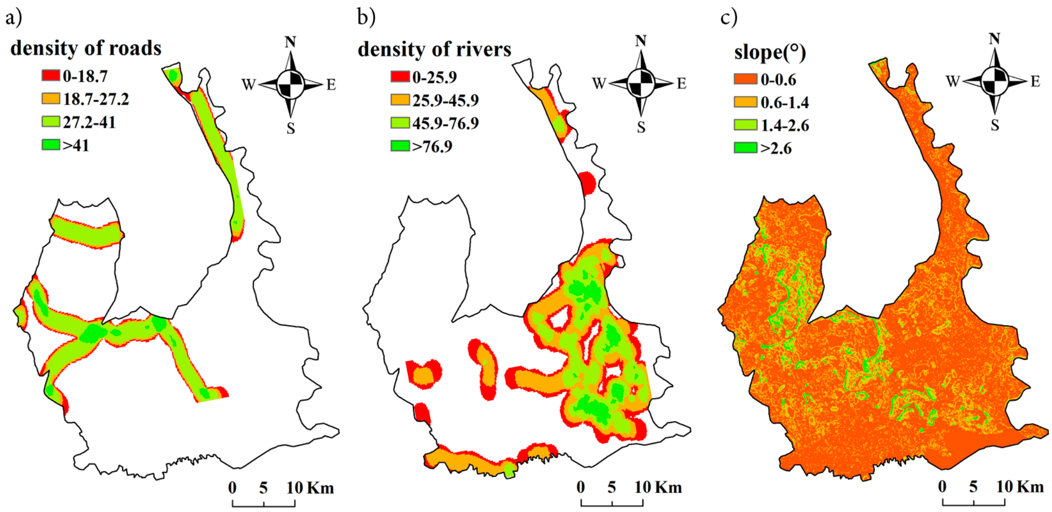

Fig. 3. Static waterbird habitat suitability indicators of the Momoge Nature Reserve: (a) density of roads, (b) density of rivers, and (c) slope

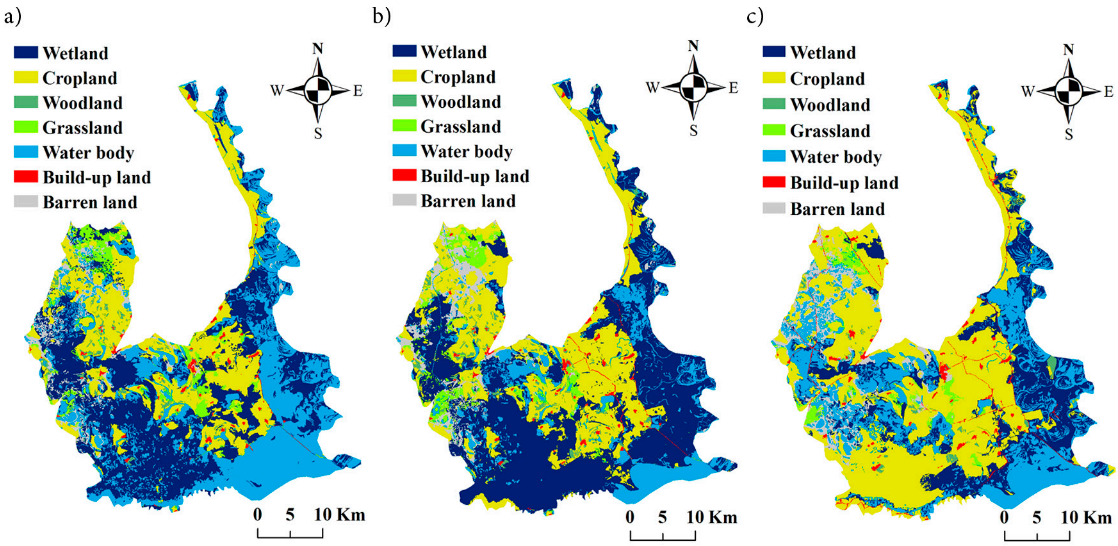

Fig. 4. Land cover maps for the Momoge Nature Reserve in 1990 (a), 2000 (b) and 2014 (c)

changed to different extents. The NDVI values extracted from the Landsat images in 1990, 2000 and 2014 ranged between –0.76–0.76, –0.49–0.74 and –0.48–0.75, respectively, as presented in Figure 5a–c. The area with a NDVI ranging between 0–0.2 increased, and the area with a NDVI of >0.5 declined. In the eastern part of the study area, NDVI values improved, and in the western part of the MNR, NDVI values became degraded. Wetness values were derived by NDMI transformation of Landsat TM images and ranged between –0.70–0.93, –0.53–0.93 and –0.36–0.50, as presented in Figure 6a–c. The area with a wetness value ranging between –80–0 declined, and the area with a wetness value <–80 increased. For the whole study area, the degree of wetness declined during the past 25 years.

2.2. Changes in the area of suitable waterbird habitat

The integrated index of waterbird habitat suitability was calculated according to the grades of very good, good, fair, and poor (Fig. 7). Most of the habitat patches of good and very good suitability were concentrated on both sides of the rivers and around the lakes or wetlands in the Nature Reserve. Habitat patches with a fair grade had the largest area, accounting for approximately 60–70% of the total study area. Habitat with a poor grade was the second-smallest in area, accounting for approximately 10–20% of the total study area. Most of the poor habitat patches were distributed around croplands or build-up lands.

The overall changes in suitability grades for waterbird habitat during 1990–2014 are displayed in Table 2. Our results showed that the least suitable habitat area, that with a grade of poor, decreased by 45.87 km^2 (3.13%), while the area with a fair grade increased by 176.43 km^2 (12.03%). The habitat areas with good and very good grades decreased by 129.19 km^2 (8.90%) during the study period. After the national reserve was established in 1997, local governments greatly improved management and water

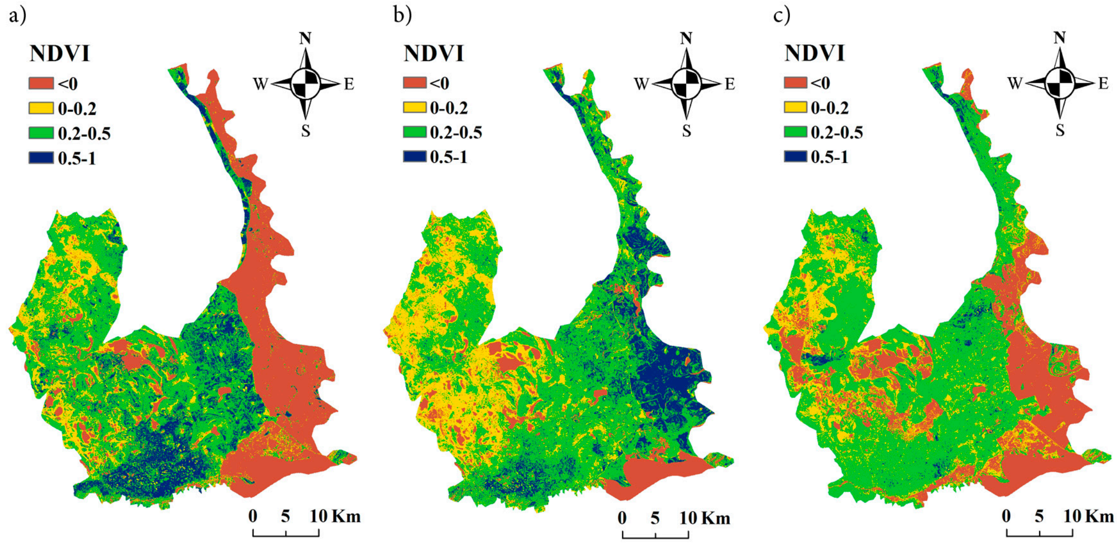

Fig. 5. NDVI maps for the Momoge Nature Reserve in 1990 (a), 2000 (b) and 2014 (c)

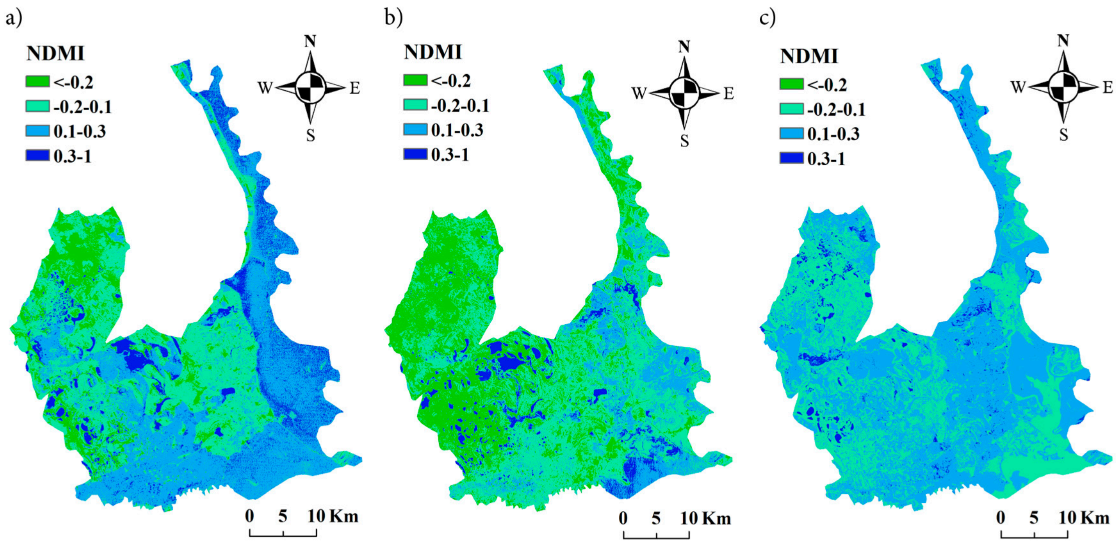

Fig. 6. NDMI maps for the Momoge Nature Reserve in 1990 (a), 2000 (b) and 2014 (c)

transfer projects for the wetlands, improving wetland habitat suitability to some extent. Habitats with very good and good grades increased by 71.47 km^2 (4.88%) during 1990–2000 and decreased by 200.66 km^2 (13.78%) during 2000–2014.

2.3. Trajectories of suitable grade centroids over time

The distribution of habitat suitability of each grade showed significant spatial differences. To determine the spatial habitat movements of each grade during 1990–2014, the moving centroid of each grade was tracked for different periods of time, as displayed in Figure 8. Our results showed that the centroid with a grade of fair shifted almost imperceptibly during the past 25 years. As the habitat with a fair grade always occupies the largest proportion of the study area, movement of the centroid was not obvious. For habitats with a poor grade, the centroid shifted by 10.57 km southwest during 1990–2000 and 6.59 km southeast during 2000–2014. For habitats with a good grade, the centroid shifted by 8.08 km northeast during 1990–2000 and 4.57 km northwest during 2000–2014. For habitats with very good grade, the centroid shifted by 3.72 km northeast during 1990–2000 and 4.44 km northwest during 2000–2014. In general, the habitat centroid shifted northward for habitats with a good grade and southward for habitats with a poor grade.

3. Discussion

3.1. Assessment of habitat suitability

The aim of our study was to determine the applicability of remotely sensed data and existing spatial data in the cost-effective assessment of habitat suitability changes for waterbirds. Most early studies applying species distribution models traditionally used spatial or climatic data only (Guisan, Zimmermann 2000). More recently, ecologists and conservation biologists have been increasingly utilizing remotely sensed indicators, such as NDVI and EVI (Enhanced Vegetation Index), in species habitat assessments. The habitat suitability assessment indicators should be selected carefully on the basis of the existing knowledge of the habitat requirements and characteristics of the species being modelled (Burnham, Anderson 2002). Waterbirds often have species-specific habitat requirements: Siberian Cranes exclusively use wetlands for nesting, feeding, and roosting; hooded cranes are found in shallow open wetlands and natural grasslands; and red-crowned cranes prefer to nest in marshes with relatively deep water and standing dead vegetation. Generally, wild cranes nest in shallow marshes with emergent herbaceous vegetation (Zou *et al.* 2003), and thus, areas distinguished as wetland are regarded as more suitable habitat. The six indicators selected in this study, land cover type, slope, NDVI, NDMI, and the density of rivers and roads,

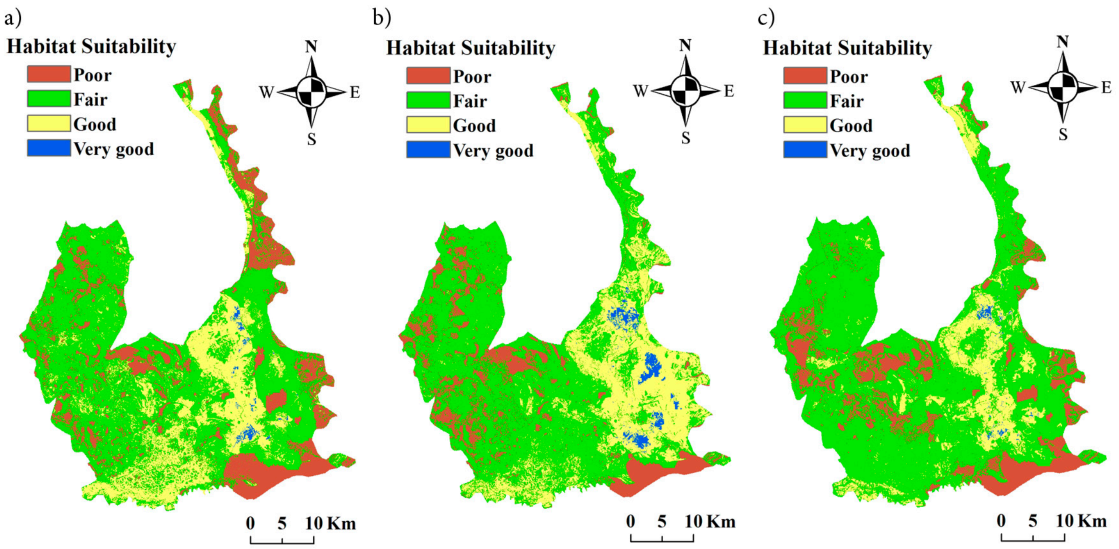

Fig. 7. Waterbird habitat suitability at the Momoge Nature Reserve in 1990 (a), 2000 (b) and 2014 (c)

Table 2. Changes in habitat area and proportion of habitat with different suitability grades

Grades	1990		2000		2014	
	Area (km^2)	Percentage (%)	Area (km^2)	Percentage (%)	Area (km^2)	Percentage (%)
Poor	279.06	19.04	186.85	12.75	233.19	15.91
Fair	853.49	58.22	874.24	59.63	1029.92	70.25
Good	326.27	22.26	379.78	25.91	198.64	13.55
Very good	6.78	0.48	24.74	1.71	5.22	0.29

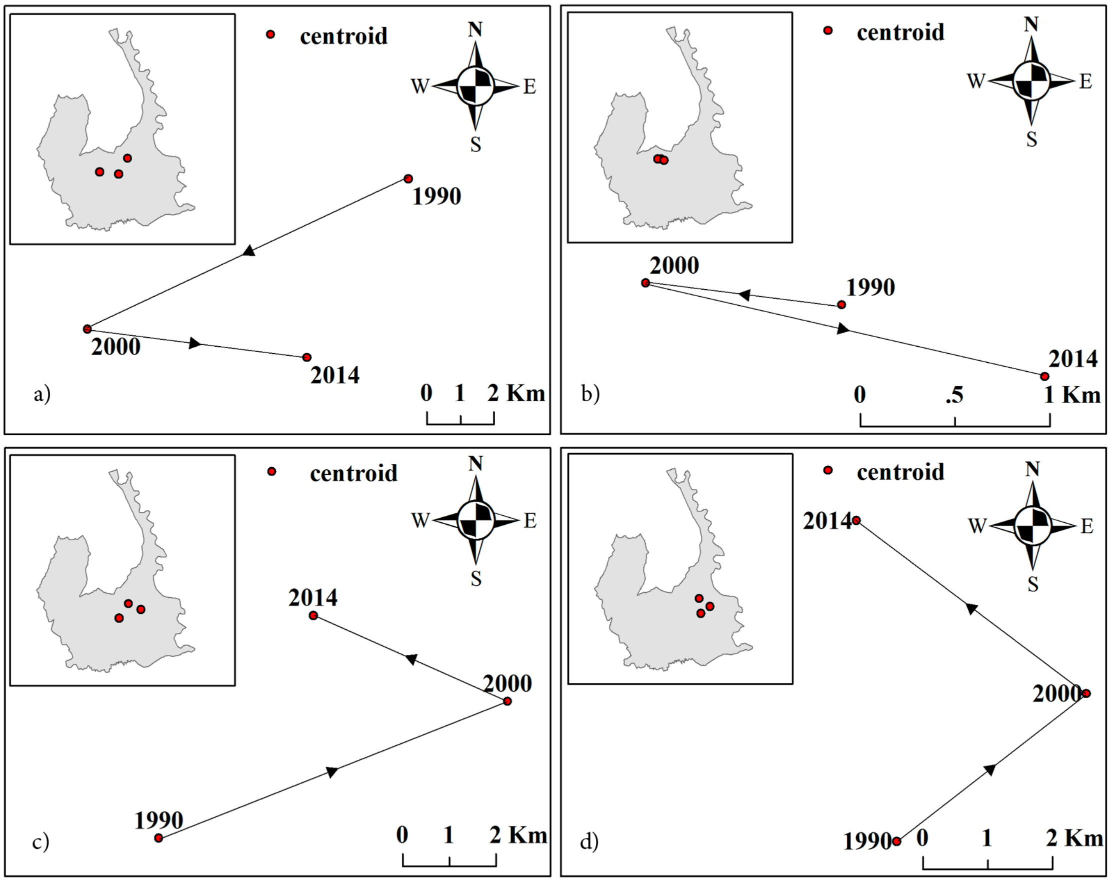

Fig. 8. The centroid trajectories of different habitat grades during 1990–2014: (a) poor suitability, (b) fair suitability, (c) good suitability, and (d) very good suitability

allowed us to calculate a habitat suitability index. Among the six indicators, NDMI has seldom been used as an indicator of habitat suitability, but it has been shown to be sensitive to water content in the vegetation and vegetation structure or cover (McDonald *et al.* 1998). Fiorella and Rippley (1993) reported that TM 4/5 was highly correlated with NDMI ($R^2 = 0.97$) and had a higher correlation than the Tasseled Cap Index. Thus, NDMI was selected as one of the indicators in this study. In addition to the indicators used here, other variables could be incorporated in the study of habitat suitability, such as climatic variables (Austin 2007), water quality, soil properties (Rönkä, Häkkilä 2005), water depth (Na *et al.* 2015), landscape and oil field distribution. Meanwhile, in order to quantify a broader range of vegetation characteristics, we could also extract summary statistics from the NDVI time series (e.g., start of season, length of growing season, and growth magnitude) (Wen *et al.* 2015). Moreover, the selection of all of the indicators could be applied at different spatial scales (e.g., sub-habitat level, patch level and landscape level), and multi-scale results for habitat suitability could be acquired. This multi-scale indicator selection method would make an analysis of habitat suitability more reasonable and feasible. However, although waterbirds co-exist and share common habitat elements, each species has its own particular habitat requirements. Future studies on habitat suitability would be most informative if applied to each individual species of interest. In addition, data on nest sites would be desirable for future research. The AHP method used in this research provided a simple and effective way for weighting indicators. Future research could involve structuring multiple criteria into a hierarchy, comparing alternatives of each criterion, and determining the weights of each factor (Saaty 2008).

One of the advantages of our research over previous studies that employed an HSI (Habitat Suitability Index) for waterbirds (Dong *et al.* 2013) was that we monitored the dynamics of habitat suitability. Habitat degradation tends to be widespread, and thus, developing methods to quantify and monitor changes in habitat quality or pressures are critical for adaptively managing protected areas (Nagendra *et al.* 2013). In this study, the direction and distance of changes were acquired by representing habitat shifts as vectors linking centroids from different time periods, describing details about the moving process of suitable habitats for waterbirds. Previous studies also gave more attention to habitat area, having no classification for habitat quality (Delgado, Marin 2013; Wen *et al.* 2015), while in this study, we made a detailed classification of the habitat area into very good, good, fair and poor grades.

In addition to applying unique methods satellite imagery from the same season was used to monitor temporal trends in habitat suitability. Multi-temporal characterizations of land cover, NDVI and wetness derived from imagery were good predictors of waterbird habitat and presented spatio-temporal characteristics in a form that was immediately usable in a geographic information system. This final result would add to evidence showing the importance of monitoring habitat dynamics. Possibly, environmental managers or researchers can use the methods described in this study to make habitat predictions as a substitute for field data when field surveys are not available. Silva *et al.* (2008) and Zomer *et al.* (2009) found that when dealing with wetland vegetation, Landsat images were useful for mapping macrophyte communities but not necessarily individual species. In the current research, high-spatial-resolution imagery (Belluco *et al.* 2006) and LiDAR (Zlinszky *et al.* 2012) have been used to map flooded and non-flooded vegetation types. Thus, further work could objectively consider using high-spatial-resolution imagery, aerial imagery and LiDAR data to perform genus-level wetland classification in order to improve the habitat suitability maps.

3.2. Changes in habitat suitability for waterbirds

Habitat loss, fragmentation and degradation are the greatest extinction threats to biodiversity (Fischer, Lindenmayer 2007). In the last few decades, over 50% of wetlands in the world have been lost, and the remaining wetlands have been degraded to different degrees because of human activities (Fraser, Keddy 2005). In that paper, it indicated that habitat recovery in the MNR occurred in the initial 10 years, but then habitat suitability became degraded during 2000–2014. In this study, we identified a 5.31% decline in the areas of very good and good habitat. The process of degradation involves gradual deterioration of habitat quality. In a degraded habitat, the number of species may decline or species may occur at lower density (Hazell *et al.* 2004) or have lower fitness. In the MNR, habitat degradation was associated with an increase in nearby cropland (62.34%) and a loss of water body (66.98%) during 1990–2014. Beginning in 1999, droughts lasting six years were another factor leading to the habitat degradation that occurred during 2000–2014 (Wang *et al.* 2009). Additionally, many hydraulic engineering projects that were built during the study period seriously damaged hydrological processes of the MNR wetlands.

Another concern for the MNR is the rich underground petroleum resources in the West Songnen Plain (Pan *et al.* 2006). The oilfield was listed as one of the four important oilfields that would be exploited more rapidly by the Sino-Petroleum Company in 2000. Crude oil output increased from 4 million tonnes to 260–300 million tonnes by the end of 2005 (Pan *et al.* 2006). Petroleum exploitation drives local economic development, but it leads to severe environmental impacts. Crude oil is toxic to water, soil and vegetation (Pan *et al.* 2006), with a great impact on land cover type. Petroleum exploitation led to wetland and water decline, causing habitat loss for waterbirds and imposing a great threat on the survival of waterbirds. This is consistent with the results that the habitat suitability of the study area declined from 2000–2014. To resolve the contradiction between a nature reserve and economic development, the boundaries of the core, buffer and transition ranges of the MNR were reshaped in July, 2002 (Wang *et al.* 2010). Meanwhile, the area of cropland surrounding the MNR has increased and shifted to the southwest in the past 25 years, which will also affect the spatial distribution of suitable habitat. As our results demonstrate, the centroid of habitat with a good grade shifted northward, while the centroid of habitat with a poor grade shifted southward. Generally, the moving process of suitable habitat reflected the impact of human activities.

In recent years, many researches have done much work on environmental protection (Ilgürel *et al.* 2016; Zhu *et al.* 2017; Li, Zhao 2017), and the results from this study could give some perspectives on environmental protection through assessing the present status of habitat quality and monitoring the changes in habitat quality for waterbirds. Considering the changing impact on waterbirds habitat, the ecological planning, design and construction of nature reserves is needed to meet the environmental requirement.

Conclusions

Landsat images and vector data, object-oriented segmentation, AHP and a calculation of centroid movement were used to assess the dynamics of habitat suitability for waterbirds in the MNR. These approaches showed that remote sensing and GIS can provide applicable information for spatial analysis methods, and thus be useful tools in assessing habitat quality and monitoring changes. Our results indicated that the habitat with a grade of poor decreased in area by 45.87 km^2 (3.13%), habitat with a fair grade increased in area by 176.43 km^2 (12.03%), and habitat with good and very good grades decreased in area by 129.19 km^2 (8.90%) from 1990–2014. The habitat suitability of the study area improved during 1990–2000, but habitat suitability declined during 2000–2014. As a whole, the centroid of habitat with a poor grade moved to the south and the centroid habitat with a good grade moved to the north during 1990–2014. For the habitat with a poor grade, the centroid shifted by 10.57 km to the southwest during 1990–2000 and 6.59 km to the southeast during 2000–2014. For the habitat with a good grade, the centroid shifted by 8.08 km to the northeast during 1990–2000 and 4.57 km to the northwest during 2000–2014. In conclusion, the approaches used here have great potential in modelling habitat suitability in highly heterogeneous and dynamic environments and may be used to help track habitat suitability dynamics in protected areas in other regions. Our findings provide up-to-date spatial information for biodiversity conservation in the MNR.

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