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Spatial Decision Analysis on Wetlands Restoration in the Lower Reaches of Songhua River (LRSR), Northeast China, Based on Remote Sensing and GIS

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ABSTRACT: Wetlands in the Lower Reaches of Songhua River (LRSR), Northeast China, are rich in biodiversity and natural resources, which provide crucial staging and wintering habitats for various endangered species. However, in the past five decades, the size of this wetland area has decreased, and its quality has deteriorated because of increased natural and human activities. Wetland restoration is critical to improve these conditions. In this study, hydrological regulation and habitat suitability, the most important wetland functions, were selected and analyzed to identify suitable wetland restoration sites. By using these two function layers, together with the geographic information system (GIS) spatial analysis function and remote sensing (RS) image data, we identified and prioritized suitable sites for wetland restoration in the LRSR. Areas with high hydrological regulation and good or fair waterbirds' habitat suitability can support wetland restoration. The potential sites were prioritized in terms of patch size and proximity to natural wetlands and water bodies. Finally, we obtained two priority classes (high and low) of wetland restoration in a spatial scale. The results from this study showed that the areas with high and low priority classes for wetland restoration are 82,628 and 247,039 ha, respectively, which account for 1.23% and 3.67% of the total study area. The high-priority class areas would be used for the wetland restoration.

Key words: Wetlands restoration, Hydrological regulation, Waterbirds' habitat suitability, Biodiversity conservation, the Lower Reaches of Songhua River (LRSR)

INTRODUCTION

Wetlands, which significantly influence the global environment, provide many ecosystem services. They contribute organic matter to the soil, act as filtering systems for sediments and other substances, and provide habitat for aquatic organisms and waterbirds (Liu, 2002; Kim *et al.*, 2011). Throughout the world, wetlands are increasingly being recognized as important elements of the landscape because of the high biodiversity, goods, and services that they provide to mankind (Acreman *et al.*, 2007). Unfortunately, these valuable services are seldom recognized by people. The loss and destruction of wetlands is a common problem that results from increased natural and human activities (O'Neill *et al.*, 1997). The degradation and shrinkage of wetlands seriously threaten the security of the ecological environment and biodiversity conservation (Bedford, 1999). Environmental sustainability urgently needs the development of methods to sustain, protect, and restore wetlands. Therefore, balancing wetland conservation and socioeconomic development, as well as the effective identification of suitable sites for wetland restoration, is important (Mateos and Comin, 2010).

Recognizing the value of wetlands, some countries and scientists have developed plans and methods for wetland restoration in some important regions. Theories and methodologies of wetland restoration have become hot issues in the research field of wetland ecology. For example, Findlay et al. (2002) combined the wetland functions with the GIS method to analyze potential wetland restoration sites. By analyzing the high productivity, hydrological regulation, and special features of habitat in wetlands, Richardson et al. (2005) researched the restoration potential of the

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Mesopotamian marshes in Iraq. Flanagan and Richardson (2010) proposed a multi-scale approach to prioritize wetland restoration for watershed-level water quality improvement in the Harrison Creek watershed in eastern North Carolina. Kauffman and Steinberg (2010) developed an automated GIS tool to identify suitable wetland restoration area. The Coos estuary and watershed was used as an example of the regional application. The result showed that the automated tool presented flexible and repeatable methods for evaluation and prioritization of a large number of potential restoration sites in the study area. However, most traditional wetland restoration investigations suffer from limitations. First, because of the lack of relevant scientific basis and effective technical support, many ongoing wetland projects have ignored the ecological feature and wetland functions. Second, one single restoration scheme can hardly serve the complicated decision making that covers the ecological and socioeconomic targets. Finally, some studies only provided relative qualitative information on the wetland restoration. The qualitative information depends on the researcher's experience and descriptions; hence, it did not provide accurate information. With these disadvantages, our understanding of wetland restoration is relatively poor. Thus, a considerable number of sites suitable for conversion into wetlands must be identified and studied. The LRSR, Northeast China, is an ideal area to conduct this research.

The LRSR has many lakes and wetlands with abundant water, biological, and land resources. It is one of the regions with rich biodiversity (Ma *et al.*, 2006). However, because of large-scale reclamation, the natural wetland area decreased from 1,438,972 ha in 1990 to 671,690 ha in 2010, accounting for only 6.19% of the study region. Meanwhile, the area of the other land cover increased significantly. Because of large-scale natural and human activities, the LRSR wetlands have been seriously isolated with the reduction in their water sources. Most of the wetlands became fragmented (Liu and Ma, 2002). The loss of wetland function led to the decrease in plant species and biological production and increased the number of endangered species (Liu and Ma, 2002; Liu *et al.*, 2004). To reverse this trend, the government of Heilongjiang Province mandated measures to restore some important wetland regions (Huang *et al.*, 2010). However, the identification of suitable sites for wetland restoration in this region is relatively limited.

Wetland is classified into eight types: swamps, lakes, rivers, paddy fields, reservoirs, pits, canals, and channels. In the present study, we focused only on swamp wetlands. Select suitable wetland sites for sustainable long-term restoration require consideration of the hydrology, special habitat, topographical variability, land use, and so on (Russell *et al.*, 1997). However, considering all the factors that affect the wetlands is impossible. The choice of the factors is always a compromise between feasibility and accuracy. Therefore, the hydrological regulation and habitat suitability functions, which are the most important factors in the establishment and maintenance of wetlands (Hollis and Thempson 1998; Zedler and Kercher 2005), were selected in our study for wetland restoration.

The overall aim of the current study is to identify suitable sites for wetland restoration based on the hydrological regulation and habitat suitability functions in the LRSR. The specific objectives are the following: (1) to analyze the hydrological regulation and habitat suitability functions in the LRSR; (2) to select suitable sites for wetland restoration using GIS techniques and RS data; and (3) to discuss the implications of wetland restoration. The results of this study are intended to provide an approach to optimize effectively the wetlands and to serve as a tool for improving the regional environment in the LRSR.

MATERIALS & METHODS

The LRSR is located in the Heilongjiang Province, Northeast China, which ranges from 119°522 202 2 E to 132°312 102 2 E longitude and from 41°422 552 2 N to 51°482 562 2 N in latitude. It is the largest area and the most common type of fresh-water wetland distribution in the Sanjiang Plain. It comprises 25 counties with an area of 67,362.13 km^2 (Fig. 1) and has an elevation ranging from 12 m to 213 m. The climate in this area is temperate humid/sub-humid continental monsoon climate. The air temperature spatially increases from the north to the south with a mean annual value of 1.2 °C to 3.9 °C, an average annual maximum of 18 °C to 20 °C in July, and an average annual minimum of -20 °C to -29 °C in January. The mean annual precipitation (PRE) is from 510 mm to 630 mm, and 80% of the rainfall occurs between May and September. The frost-free period is from 110 days to 130 days (Sun *et al.*, 2011). Two rivers, the Amur and Songhua, provide the major waterway system as well as the alluvial deposits in this area. The rivers are characterized as wetland rivers with slight gradients and large channel curve coefficients. Approximately 22 wetland nature reserves exist in the LRSR. Three of them (Bachadao, Honghe, and Raolihe) have been listed as wetlands of international importance to waterbird conservation by the Ramsar Convention Bureau (Fig. 1). These nature reserves are part of one of the largest wetlands in Northeast China. The Landsat Thematic Mapper (TM) RS images and the digital elevation model (DEM), land cover, normalized difference vegetation index (NDVI), leaf area index (LAI), meteorological, and ancillary data were used in the current research. The Landsat TM RS images and DEM data were obtained from the International Scientific Data Service Platform (http://datamiror.Csdb.cn/index.jsp) and U.S. Geological Survey (http://glovis.usgs.gov). Twelve cloud-free Landsat TM image scenes that cover the entire study area were acquired. The Landsat TM image has a resolution of 30 m. The images were recorded from May to October in 2009–2011 when the plant growth peaks in Northeast China to improve the identification of the land cover types. The dates of images are as follows: 114/27 (18 May 2010; 21 July 2010), 114/28 (27 October 2010; 29 July 2009), 115/27 (8 June 2010; 4 August 2010), 115/28 (13 May 2009; 7 August 2010), 116/27 (21 May 2010; 17 July 2010), and 116/28 (14 June 2009; 24 July 2010). The main ancillary data included the road vector data, digital photographs, and global positioning system (GPS) data. The digital photographs and GPS data were obtained by field investigation, which were used to verify the accuracy of the land cover classification. To verify the evaluation accuracy of the waterbirds' habitat suitability, we collected the location data of the nests and stopovers of the waterbirds during the breeding season in late May in 2010. The locations of all nests and stopover points were recorded using a handheld GPS unit. The ERDAS 9.2 image processing software and ArcGIS 9.3 software were used for the data processing. The different spatial data were integrated into the Albers Equal Area Conic Projection System and the Beijing 1954 Coordinate System.

The 2010 land cover data of the LRSR were obtained by object-oriented classification, together with the manual interpretation method. Object-oriented image classification was performed using the eCongnition 8.64 software (Muller & Jena, 2003). This method consists of two important processes: image segmentation and object-oriented classification.

The Landsat TM 4 (near infrared), 3 (red), 2 (green) bands was used to perform the image segmentation algorithm. There are many types of image segmentation algorithms, such as measurement–space guided spectral chestering, central linkage region growing,

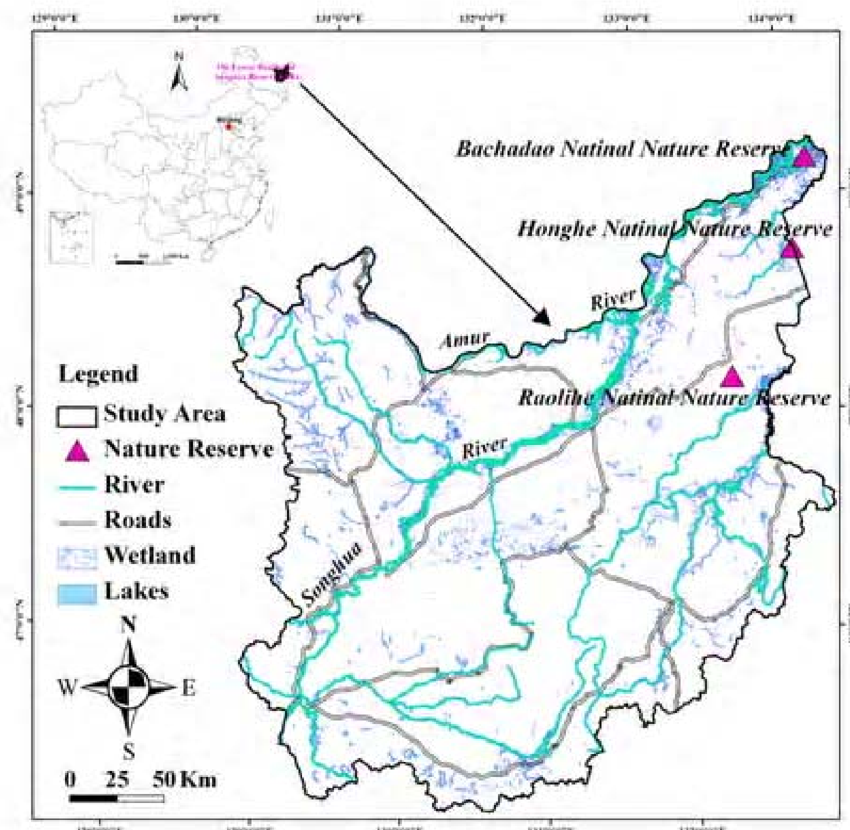

Fig.1. Location of the Lower Reaches of Songhua River (LRSR)

multi–resolution segmentation and so on (Frohn et al. 2008). The algorithm used in this study was multi-resolution segmentation, which uses a number of parameters for creating images objects (Baatz & Schäpe, 2000). The scale parameter determines the maximum allowed heterogeneity within an object. The segmentation scale was 10. The shape parameter (0–1) controls the inûuence of spectral information. The boundaries or shapes of most features considered in this work cannot be adequately represented by Landsat TM data at 30 m resolution, so the shape parameter was always set to 0.1 to maximize the inûuence of spectral information. The smoothness/compactness parameter (0–1) controls the ûnal shape of an image object. This parameter was always set to 0.5, so that no preference in shape was set. A number of decision rules were utilized to classify the images, which were determined according to feature attributes of objects. The classification rules are related to the characteristics of an object such as brightness, height, size, shape, adjacency, etc. In this study, NDVI (Normalized Differential Vegetation Index) was used to identify woodland and grassland. Bare index (NIR+R) and length/width index were utilized to classify barren land. Cropland was identified by the shape and NDVI. Brightness index was used to identify built-up land and water body. Furthermore, multi-season Landsat TM data were used to increase classification accuracy. NDVI is commonly used to reflect the vegetation growth status and its coverage at large scales (Running *et al.*, 2004), which is calculated from the spectral reflectance measurements in the red and near-infrared (NIR) regions. The NDVI data were obtained from the Landsat TM 4 (NIR) and TM 3 (red) images (Potter *et al.*, 1993). These data were calculated as (NIR–R)/(NIR+R), where NIR and R are the reflectance in the NIR (from 0.76 µm to 0.96 µm) and red (from 0.62 µm to 0.69 µm) bands.

LAI is a dimensionless parameter that characterizes the plant canopies. It is used to predict the photosynthetic primary production and as a reference tool for crop growth. LAI can be determined by direct and indirect methods. In this study, the extraction of the LAI data utilized the techniques proposed by Sun et al. (2008). The method was derived from NDVI based on the relationship between NDVI and LAI for different types of land cover.

$$
\begin{aligned}
&LAI=0.7271*\exp(3.0236*NDVI) && \text{Cropland} \\
&LAI=0.9428*\exp(2.4725*NDVI) && \text{Woodland} \\
&LAI=0.8253*\exp(0.3309*NDVI) && \text{Grassland} \\
&LAI=1.1273*NDVI-0.3468 && \text{Wetland}
\end{aligned} \quad (1)
$$

To calculate the evapo-transpiration (ET) and potential evapo-transpiration (PET) in the LRSR region, seven climatic parameters were used in this study in addition to the annual PRE: monthly mean air temperature, maximum temperature, minimum temperature, relative humidity, average station pressure, average wind velocity, and sunshine duration. These meteorological data distributed throughout the LRSR were collected from the China Meteorological Data Sharing Service System (http://old-cdc.cma.gov.cn).

Water yield was used as an indicator of hydrological regulation. The hydrological regulation was modeled as PRE minus ET, based on the assumption of negligible water storage change in the LRSR region on an annual time scale (Lu *et al.*, 2012). ET (mm) was estimated by:

$$ET=9.78+0.0072*PET*PRE+0.05*PRE*LAI \quad (2)$$

PET was calculated using the Penman–Monteith (P–M) method proposed by the Food and Agriculture Organization (Allen *et al.*, 1998). In this study, GIS was employed to analyze and assess the habitat suitability in the LRSR. By analyzing the relationships between the waterbirds and the key habitat environmental factors, we selected human disturbances (the density of roads and residences), water source (the density of lakes and rivers), food abundance (NDVI), and shelter condition (land cover and slope) as the habitat factors that directly affect the foraging and resting of waterbirds. The weight of each factor was assigned by the analytic hierarchy process. In this way, the assessment of the habitat suitability could be performed on a unified geographic coordinate framework. All affecting factors were classified into four grades (Table 1). We assessed the waterbird habitat suitability in the LRSR by overlaying the densities of the lakes, rivers, roads, residences, NDVI, land cover types, and slope data layers using the ArcGIS 9.3 software. These data layers were translated into numerical data before the index of habitat suitability was calculated, and all data were standardized. The waterbird habitat suitability was rated as good (75 to 100), fair (50 to 75), poorly suitable (25 to 50), and not suitable (0 to 25). The AHP method, developed by Saaty (1980), was adopted to determine the reliability and objective weight of the factors. A linear function was adopted to calculate the integrated index of waterbirds habitat suitability. It combines the relationships between the habitat suitability factors (David *et al.*, 2006).

$$HSI = \sum_{i=1}^{n} w_i f_i \quad (3)$$

Where *HSI* is the integrated index of habitat suitability of waterbirds; W_i (i =1, 2, 3……n) is the factor weight; f_i (i =1, 2, 3……n) is the suitability factor value; and n is the number of the factors.

Table 1. Value of suitable habitat factors

<table>
<tr><th colspan="2">Indicator</th><th rowspan="2" colspan="2">Good Suitable</th><th rowspan="2" colspan="2">Fair Suitable</th><th rowspan="2">Poor Suitable</th><th rowspan="2" colspan="2">Not Suitable</th></tr>
<tr><th>Criterion level</th><th>Index level</th></tr>
<tr><td rowspan="2">Water source</td><td>Lakes</td><td colspan="2">>0.5</td><td colspan="2">0.3-0.5</td><td>0.15-0.3</td><td colspan="2">0-0.15</td></tr>
<tr><td>Rivers</td><td colspan="2">>0.38</td><td colspan="2">0.25-0.38</td><td>0.1-0.25</td><td colspan="2">0-0.1</td></tr>
<tr><td rowspan="2">Human disturbance</td><td>Roads</td><td colspan="2">0-0.1</td><td colspan="2">0.1-0.2</td><td>0.2-0.4</td><td colspan="2">0.4</td></tr>
<tr><td>Residences</td><td colspan="2">0-0.15</td><td colspan="2">0.15-0.2</td><td>0.2-0.4</td><td colspan="2">0.4</td></tr>
<tr><td rowspan="2">Shelter condition</td><td>Land cover</td><td>Wetland</td><td>Grassland</td><td>Woodland</td><td>Cropland</td><td>Water-body</td><td>Barren-land</td><td>Build-up land</td></tr>
<tr><td>Slope</td><td colspan="2">0-5</td><td colspan="2">5-10</td><td>10-20</td><td colspan="2">20</td></tr>
<tr><td>Food abundance</td><td>NDVI</td><td colspan="2">0.8-1</td><td colspan="2">0.5-0.8</td><td>0.1-0.5</td><td colspan="2">≤ 0</td></tr>
</table>

Finally, the natural factors, including human disturbances, water source, food abundance, and shelter condition, were added to produce the potential waterbird habitat suitability map in the LRSR in 2010. We identified the wetland restoration sites by overlaying the hydrological regulation and waterbird habitat suitability function layers using the spatial analysis tools in the ArcGIS 9.3 software. Our focus was on the areas with high hydrological regulation function and suitable waterbird habitat grade (good or fair) because most of these areas were formerly wetlands and have a high potential for restoration (Richardson and Hussain, 2006). Furthermore, because they are rated with suitable waterbird habitat grade (good or fair), their contribution to other applications (for example, conversion to farmland) is small. By combining the data of the area with high hydrological regulation and suitable waterbird habitat grade (good or fair), we identified potential sites for wetland restoration. Then, considering that the purpose of the wetland restoration is to improve the fragile ecological environment in the LRSR, we presented the proximity criterion. The model for identifying the suitable sites for conversion to wetlands is shown in Fig. 2. The potential sites with good waterbird habitat suitability and high hydrological regulation were assigned a high priority for wetland restoration. The sites with fair waterbird habitat suitability grade and high

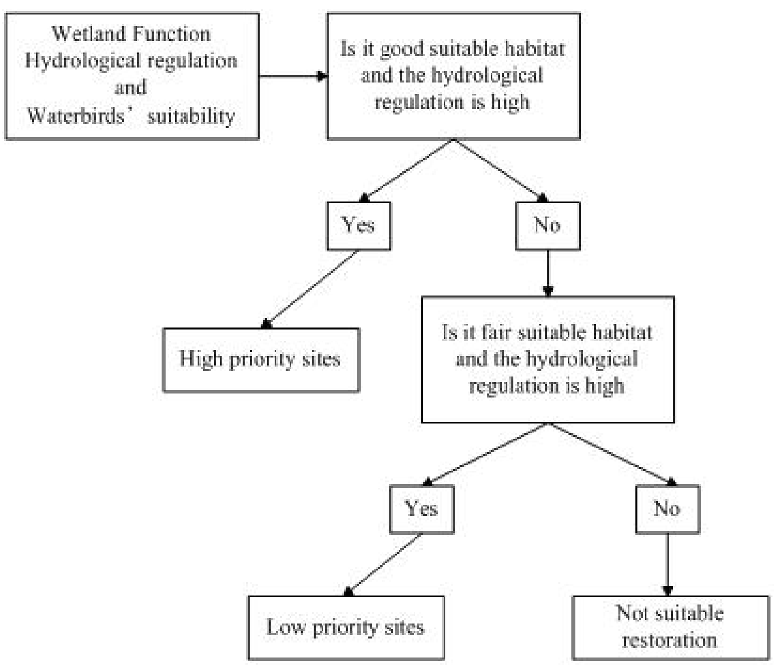

Fig. 2. The model for identifying suitable sites

hydrological regulation area were assigned a low priority. Currently, we have no quantitative data to support this method; however, previous studies indicated that maximum benefit can be obtained by restoring the areas near extant sites. In addition, the smaller the area, the lesser is its potential for conservation of the biodiversity and climate regulation (Bohn and Kershner, 2002; Huang *et al.*, 2010).

RESULTS & DISCUSSION

2010 Land cover data of the study area was obtained by interpretation of Landsat TM images, which are presented in Fig.3. The land cover maps showed seven land cover types: woodland, grassland, cropland, water body, wetland, residential, and barren land. The wetland was mainly marsh and did not include the constructed wetlands. The cropland included the dry cropland and paddy field. The classification accuracy of the land cover data in 2010 was assessed through field investigation from July to August in 2011. Some 124 typical ground objects were identified using the GPS, measuring rope, and digital camera. The producer, user, overall accuracy, and Kappa coefficient were used to evaluate the classification results (Lu *et al.*, 2003; Ramita *et al.*, 2009). The classification accuracy results are presented in Table2. The total accuracy of the land cover in 2010 was approximately 92.56%, and Kappa was 0.9184. The interpretation accuracy of the croplands and wetlands was 87.68% and 93.96% respectively. NDVI value was extracted by computing a mean value from the Landsat TM image pixels for each unit, ranging from 0.65 to -0.31. PET [Fig. 4(a)] was calculated using the P–M method based on the meteorological data. The PET value ranged from 385 mm to 582 mm. The high value was mostly obtained in the northeastern and western part of the LRSR. By spatial analysis of the meteorological, NDVI, LAI, and PRE data, the actual ET value was obtained by the model described in Formula 2. The distribution map for the ET, which ranged from 294 mm to 487 mm, is shown in Fig. 4(b). Most of the high ET values were obtained on the coast of the Songhua River. The ET value in the southern sites was lower. The hydrological regulation value was extracted by the model as PRE minus ET, which ranged from 187 mm to 394 mm, as shown in Fig. 4(c). The areas with high hydrological regulation value (> 300) were mostly distributed in the eastern border and northwest of the study area. These areas have high potential for wetland restoration. The integrated index of habitat suitability for waterbirds was calculated, which was rated as having a good, fair, poor or not suitable at all, as shown in Fig. 5 and projected onto a unified geographic coordinate frame (Jacquin *et al.*, 2005; Tian *et al.*, 2008). The areas of the habitat in each suitability group are summarized in Table 3. The distribution of the habitat suitability for each grade shows significant spatial differences (Fig. 5). The areas with good habitat grade were scattered in the wetlands and water bodies, and these areas are mostly located in the northern and middle part of the LRSR. The fair grade areas were primarily located adjacent to those with good grade. Most of these areas are located north of the study area. The poor and not suitable grades sites mainly existed in broader areas and were distributed far from wetlands, rivers, and farmland. Compared with those with a good grade, the poor and not suitable graded areas were primarily located south of the LRSR. The good and fair grade areas were spatially distributed throughout the study area but were highly concentrated in the northern part.

Most of the habitat suitability sites with good grade were located on the coast of rivers or the middle part of the LRSR. The total area of these sites is 969×10^3 ha, accounting for 14.38% of the total study area. The Bachadao, Honghe, and Raolihe National Nature Reserve in the study region all belonged to this grade. These nature reserves have the greatest concentration of waterbirds in the LRSR. The fair grade sites has the largest area ($2{,}019\times10^3$ ha) and comprised 29.97% of the total area. The second site in terms of area was that with poor suitability grade, which has an area of $1{,}894\times10^3$ ha or 28.12% of the study area. The area of the site with the not suitable grade was $1{,}855\times10^3$ ha, accounting for 27.53% of the total study area.

In summary, seven nesting locations in the Honghe National Nature Reserve were used to validate the accuracy of the waterbird habitat suitability in 2010 (Fig. 4). All waterbirds nesting locations were located in the good suitability grade. To a certain extent, these data verified the results of our evaluation. Using the model shown in Fig. 2, we identified and prioritized the wetland restoration sites in the entire LRSR (Fig. 6). Most of these sites were located on the Coast of Amur and Songhua Rivers, with smaller areas in the north, south, and middle of the LRSR. The total area of the priority wetland restoration sites was 329,667 ha, accounting for 4.90% of the study area. The distribution of each priority class for the wetland restoration in the LRSR showed significant spatial differences. The high-priority class sites were scattered on both sides of the extant wetlands and water bodies, with smaller sites distributed throughout the whole study area. Most of these sites are located northeast and in the middle of the study area. The high-priority class area was 82,628 ha, which comprised 1.23% of the total area. Compared with the high-priority class sites, the low-priority class sites were primarily located adjacent to the high-priority class sites. Most sites in this class are located in broader areas and distributed

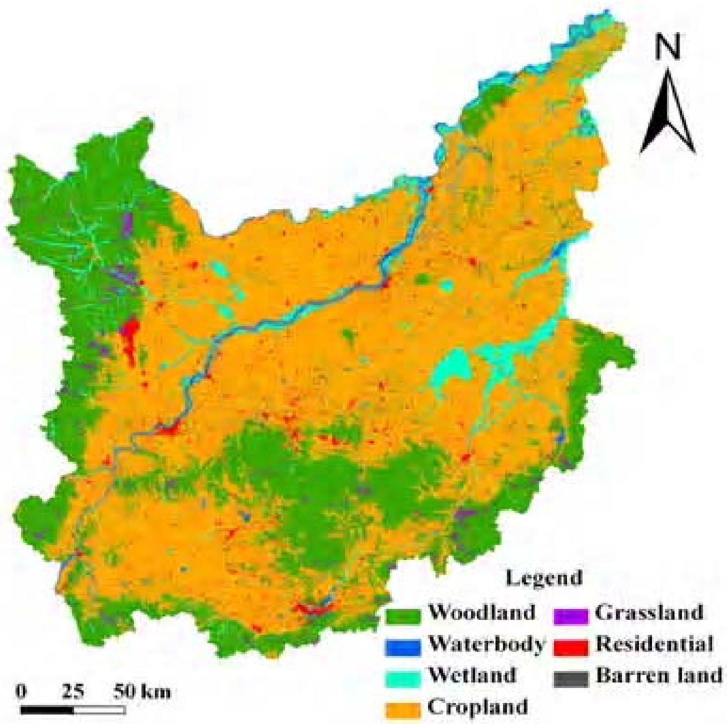

Fig. 3. Land cover data of the study area

Table 2. Land cover accuracy of classification results in 2010

Land cover category	Producer accuracy (%)	User accuracy (%)
Woodland	92.53	90.13
Water-body	95.79	95.52
Residential	90.46	89.29
Grassland	90.31	91.12
Wetland	93.96	94.96
Cropland	87.68	88.56
Barren land	89.52	89.71
Overall accuracy=92.56% Kappa coefficient=0.9184		

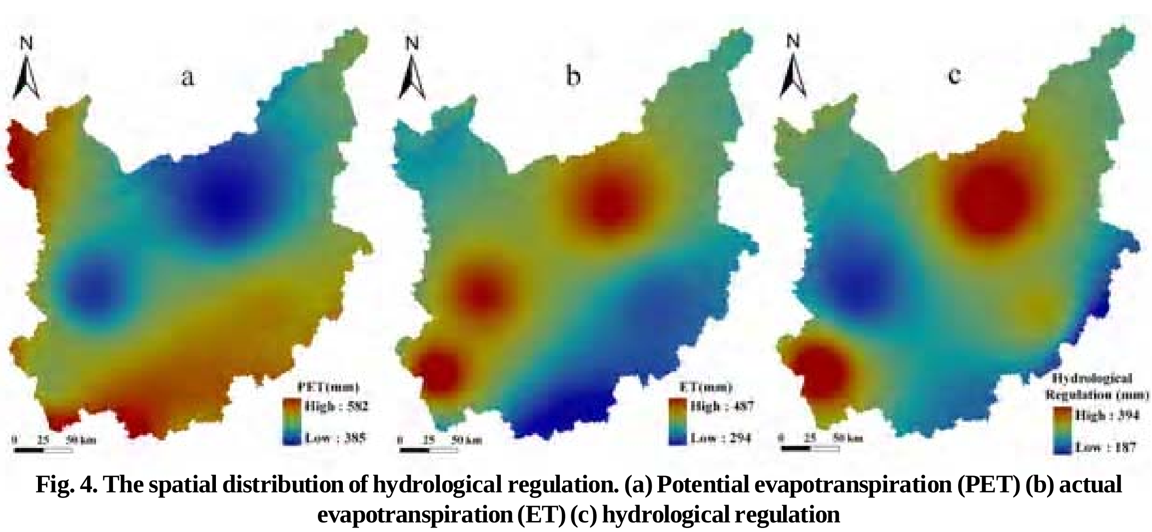

Fig. 4. The spatial distribution of hydrological regulation. (a) Potential evapotranspiration (PET) (b) actual evapotranspiration (ET) (c) hydrological regulation

Table 3. The area of each grade of habitat suitability for the waterbirds in the LRSR

Grade system	Good	Fair	Poor	Not suitable
Area (ha)	969×10^3	2019×10^3	1894×10^3	1855×10^3
Percentage (%)	14.38	29.97	28.12	27.53

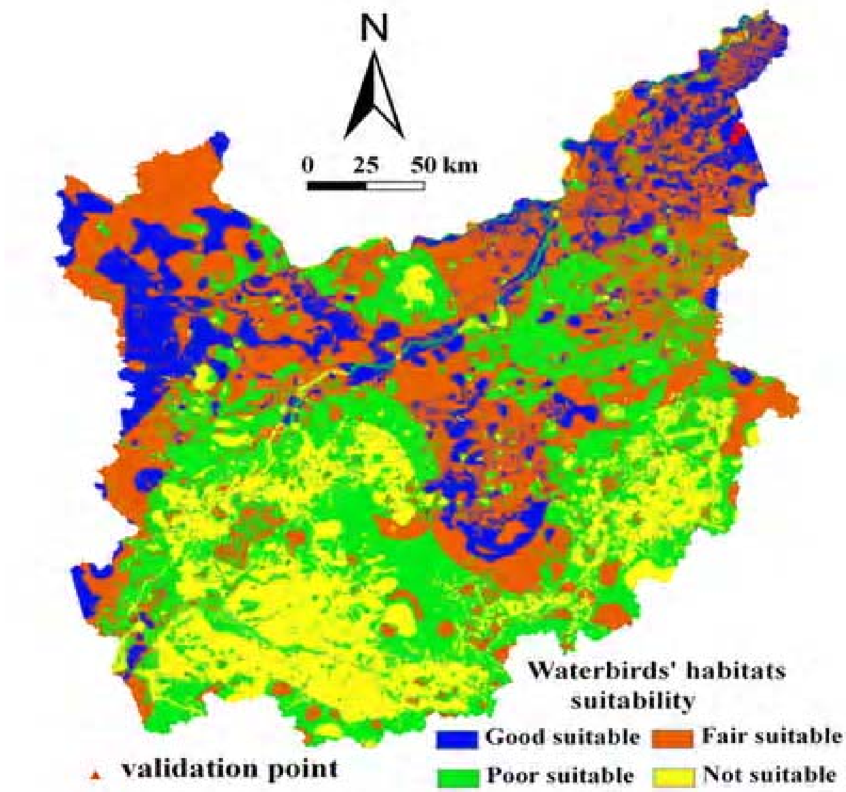

Fig. 5. The result of habitat suitability at the Lower Reaches of Songhua River (LRSR) for waterbirds

throughout the whole extent of the potential sites for wetland restoration. The low-priority class sites had the area of 247,039 ha or 3.67% of the study area. The results from this study indicated that a considerable number of areas in the LRSR suitable for conversion into wetlands must be identified and studied. We obtained two priority classes for wetland restoration. Generally, the high-priority class sites were located in the plain area, had enough water, and provided good suitable habitat for species. These areas were not suitable for other land use (for example, farmland, woodland, or residential purpose), and the potential for converting them to wetlands was high. The low-priority class sites were usually near the high-priority class sites and often had a larger patch area. If these sites are converted to wetlands, they would help increase the connectivity among the wetland patches and reduce wetland fragmentation. Thus, we believe that the low-priority class sites are ideal sites for wetland restoration in the middle and long term. Meanwhile, the areas that were classified as not suitable for restoration had the largest area and extensive distribution. Considering the importance of LRSR as a grain base in Heilongjiang Province, these sites are not suitable for wetland restoration.

Many of the investigations conducted on wetland restoration focused on qualitative analysis (O'Neill *et al.*, 1997; Robert *et al.*, 2004). Compared with the traditional methods, we quantitatively identified the suitable wetland restoration sites. We generated the model for identifying the suitable wetland restoration sites by combining the hydrological regulation with the waterbird habitat suitability functions. Using the readily available data and the GIS spatial analysis tool, we identified and prioritized the wetland restoration sites in the entire LRSR region. Our efforts did not intend to replace the field studies in selecting suitable wetland restoration sites but rather to improve the field

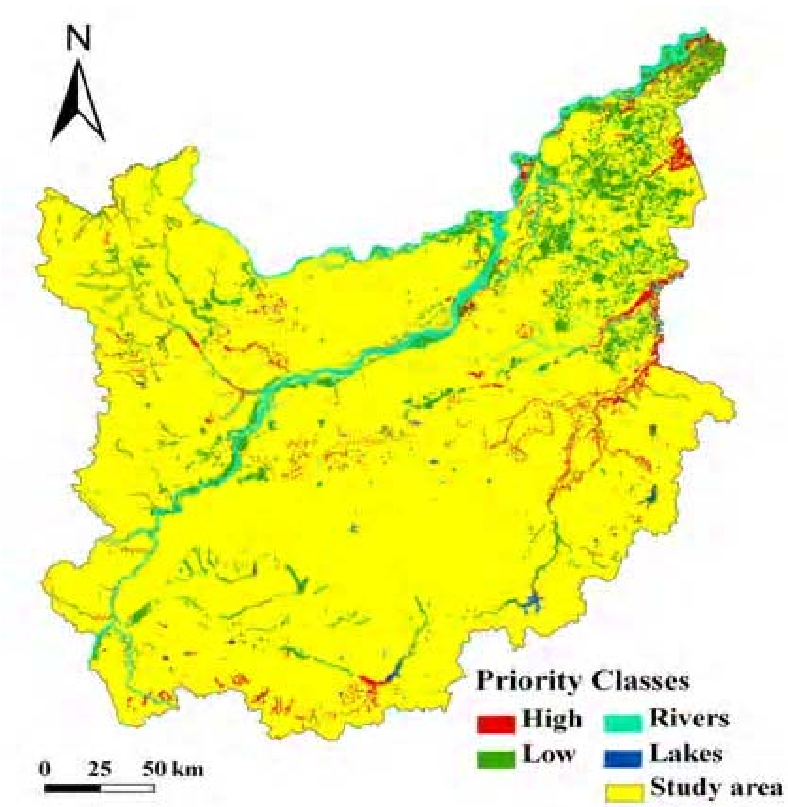

Fig. 6. The spatial distribution of wetlands restoration in the Lower Reaches of Songhua River (LRSR)

efficiency by focusing on the wetland restoration and conservation. Generalizing the site-specific practice is difficult. Different ecological principles must be applied based on different conflicting values and sites (Olsson and Rogers, 2009). In our study, the methodology employed hydrological regulation and waterbird habitat suitability factors as indicators for wetland restoration. We believe that greater success in wetland restoration will be achieved if additional factors are considered. For example, landscape, freshwater sources, ecological niche, and other relevant biophysical factors also influence the wetland restoration. However, including all the factors that affect the wetland restoration is impossible. The choice of the factors is always a compromise between feasibility and importance. Some researchers have used a similar approach to wetland restoration (White and Fennessy, 2005; Huang *et al.*, 2010). In their studies, the primary focus was on the conversion of farmlands to wetlands, whereas the focus of our study was primarily to locate suitable sites for wetland restoration. In our study, the analysis of wetland hydrological regulation and waterbird habitat suitability functions were all based on the 2010 land cover data of the LRSR; thus, the accuracy of the land cover data obtained from them strongly affects the functions. However, identifying the distinct land cover types based on the spectral data proved to be a difficult task (Kartikeyan *et al.*, 1998). The land cover data on the study region in 2010 were obtained by object-oriented classification, in conjunction with the manual interpretation method. The object-oriented classification method is a new object-recognition technique, which can solve traditional image classification limitations. The advantage of the object-oriented approach is that features that incorporate texture, spectral values, context relationship, and shapes are used to define an image object (Frohn *et al.*, 2008). However, the wide variation in spectral signatures and the similar spectral characteristics of the classes of interest made a purely automated classification impossible (Foody, 2002). Future research should focus on utilizing high-resolution imagery to improve the classification accuracy and increase the efficiency of visual interpretation and field works.

Evidence showed that wetland loss and fragmentation are the primary cause of the decrease in biodiversity and species extinction (Zhao *et al.*, 2009). The current study showed that a considerable number of areas in the LRSR can be converted into wetlands. The method presented here is a simple approach to restore wetlands, which may be helpful for researchers to identify sites for further wetland restoration evaluation. However, the scientific effort spent on wetland restoration in the developing countries is limited. The value of wetland restoration is seldom recognized by the public. In 1990, approximately 30% of the available wetland was drained for intensive human activities in Asia, 8% in South America, and 4% in Africa (Finlayson *et al.*, 2001). To reverse this trend, first, governments should give great importance to wetland restoration and reconstruction. National and provincial ecological restoration projects should be adopted. Second, they must pay attention to the influence of human activities on the wetlands and avoid or reduce human activities that adversely damage them. In the short term, wetland restoration would influence the farmland productivity. However, in the long term, conducting wetland restoration is very important for biodiversity conservation and ecological environment improvement (Li *et al.*, 2010).

Traditionally, wetland management strategies have focused on a single familiar objective such as improving hydrological regulation, strengthening biodiversity, or providing flood control (Thiere *et al.*, 2009). Despite the relevant amount of studies focused on wetland creation or restoration with these and other objectives, little is known on how to integrate the objectives of wetland creation or restoration based on the wetland functions. Wetland restoration and creation has only been recently approached from a multipurpose perspective (Knight, 1992). In our study, hydrological regulation improvement and strengthening biodiversity priority objectives were selected for wetland restoration. The first priority objective is hydrological regulation improvement, including consideration of the nutrients, solids, and water source. Hydrology is the most important factor in the establishment and maintenance of wetlands. The second priority objective is the strengthening of biodiversity in wetland restoration. Our study focused on the effect of wetland restoration or creation on waterbirds as indicators of biodiversity. Although other species must also be considered in the evaluation of biodiversity in the environment (Duelli, 1997), special attention is commonly given to waterbird population (Chamberlain and Fuller, 2000). Wetland restoration projects that are focused on multiple objective functions adapted to local needs require a higher investment but will provide more services than those devoted to a single function. Restored and created wetlands would be similar to natural ecosystems and possess similar ecological functions. Wetland restoration could then provide an array of integrated environmental services adapted to local ecological and social needs, mitigating the human effects on wetland loss and degradation (Benton *et al.*, 2003).

CONCLUSION

Natural and human activities caused the loss and degradation of wetlands in the LRSR. Remotely sensed data products can be used effectively in wetland restoration. The combination of hydrological regulation and waterbird habitat suitability functions is an objective and effective method to identify and prioritize sites for wetland restoration. Given that no quantitative methods are currently available for the study of wetland restoration, our approach presents a sensible starting point for such studies. It is proven to be accurate for suitable wetland restoration site selection. The results from this study indicated that the areas with high- and low-priority classes for wetland restoration are 82,628 ha and 247,039 ha, respectively, which accounted for 1.23% and 3.67% of the total study area. Based on the priority class, we determined the site order for conversion. The analyses in this paper can improve our understanding of the implications of wetland restoration in undeveloped regions in Northeast China and other developing countries. The method presented here is a simple approach to a complex problem; however, it can help planners identify sites for further wetland restoration evaluation. These conclusions are useful in biodiversity conservation and proper ecosystem management under increased pressure from population increase.

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