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Using Landsat images to quantify different human threats to the Shuangtai Estuary Ramsar site, China

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A B S T R A C T

Multiple human activities can impose significant negative effects on wetland ecosystem. This study aimed to identify and quantify the human threats on the Shuangtai Estuary Ramsar site (SERS) by means of detecting wetland landscape changes using Landsat images from 1988 to 2014. Land-cover changes induced by agricultural reclamation, urban expansion, petroleum industry, aquaculture, and the increases in transportation land were identified using an object-oriented classification method and a decision tree. Human-triggered wetland conversions and landscape metrics-characterized wetland changes were documented in order to assess the protection effectiveness after this wetland was listed as a national nature reserve (1988) and a Ramsar site with international importance (2005). Results indicate that wetlands area at this Ramsar site decreased from 127,526 ha in 1988–117,805 ha in 2005, 113,705 ha in 2014 at an annual averaged loss rate of 531.6 ± 72 ha/yr. The only two vegetated wetland types, *Phragmites australis* and *Suaeda heteroptera*, have lost 4788 ha and 12,856 ha, respectively. Aquaculture ponds increased by 9715 ha, and almost all were transformed from natural wetlands. The landscape metrics used in this study show notable fragmentation trend of wetland as a result of the expansion of transportation lands. Multiple human activities occupied large areas of various wetland types. Compared to agricultural reclamation and urbanization, wetland changes at the study site were affected primarily by the development of aquaculture and petroleum industry. Obvious wetland loss and fragmentation determined by the analysis of Landsat images suggests that the protection effect has been relatively low in spite of the fact that the SERS is a national natural reserve and Ramsar site. As an internationally critical rest habitat for migration waterfowl, ecological degradation of the SERS and severe human threats create great challenges for ecosystem managements. This study also indicates that the protection effectiveness of other costal wetland should also be assessed using remote sensing to objectively track the conservation or restoration of these areas.

1. Introduction

Wetland ecosystems are important due to their multiple ecosystem services (Cao and Fox, 2009; Jafari, 2009; Keddy, 2010). Climate change and human activities can drive changes in wetlands (Junk et al., 2013; Wang et al., 2012; Wright and Wimberly, 2013). Tremendous loss and fragmentation of wetlands have been examined worldwide, indicating these changes in wetlands affect ecosystem services such as habitat supporting, water regulation, biodiversity conservation etc. (Amler et al., 2015; Coleman et al., 2008; Gong et al., 2010; Rebelo et al., 2009). Humans have great difficulties to respond to the climate-resulted wetland changes, but could adjust their behavior to reduce the direct effects on wetland ecosystems. The quantification of direct threats from human activities on wetlands is thus vital for scientific management and conservation of wetlands.

Previous studies have documented shrinkage and fragmentation of wetlands on account of multiple human activities (An et al., 2007; Murray et al., 2014). Agricultural reclamation has been identified as the leading factor for vanished wetlands and their

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weakened ecosystem services (Rebelo et al., 2009; Finlayson and Rea, 1999; Song et al., 2014; Wang et al., 2011a). Urban expansion was determined to have significant effects on wetlands in different regions of the world, especially in deltas or coastal regions (Bolca et al., 2007; Lee et al., 2006; Kentula et al., 2004). The rapid development of industrialized landscape has been reported to impose evident impacts on wetland (Ren et al., 2010). Typical examples include oil exploitation causing the fragmentation of wetlands in the Yellow River delta of China (Zhang and Sun, 2005) and the loss of ecosystem services in North America (Allred et al., 2015), and construction of roads, ports, and dams resulting in noticeable disappearance and fragmentation of wetlands (Bi et al., 2011; Giosan et al., 2014; Li et al., 2014). In addition, Seto and Fragkias (2007) revealed that aquaculture in Vietnam occupied substantial mangrove wetlands for economic benefits. Although assessing human threats on wetlands is beneficial for addressing wetland loss and degradation as well as achieving effective protection and management, the lack of information on wetland shrinkage and their linkages to different human activities for a long period have been a major barrier to such efforts.

Satellite remote sensing has the potential to provide information for assessing human threats to wetland ecosystems (Gallant, 2015; Seto and Fragkias, 2007), and thus has been widely used in evaluating habitat conditions and monitoring conservation effects (Barker and King, 2012; Nagendra et al., 2013; Zheng et al., 2012). Satellite images were used to document the status and distribution of mangrove forest over the world (Giri et al., 2011), and to evaluate the protection efficacy of national wetland reserves in China from 1978 to 2008 (Zheng et al., 2012). Accessing a large area landscape is challenging using the tradition field investigation method. Remote sensing can provide both the latest images to characterize the current status of wetlands at different scales and historical datasets to determine the changes of wetland surface features. These advantages of remote sensing makes it the best way to identify human-triggered wetland conversion. Furthermore, various threats from human activities can be quantified to contribute to the wetland management and conservation.

Wetland ecosystems have been largely protected in natural reserves. Up to now, 2218 sites covering 214,131,110 ha wetlands in the world were listed as the wetland with international importance (Ramsar site, https://ramsar.org), and 46 sites of these sites covering 4,002,240 ha wetlands are in China. As one of the Ramsar sites, Shuangtai Estuary wetland has the largest coastal *Phragmites australis* (reed) wetland in Asia and the most famous *Suaeda heteroptera* (saline seepweed) wetland named as "red beach", located in the south of the Liao River delta and the north of the Bohai Sea Economic Rim. Although the present wetland was approved to be national nature reserve in 1988 and has been a Ramsar site since 2005, over the past decades, land expansions for agriculture, urbanization, petroleum industry, aquaculture, and tourism, as well as road and port construction have imposed significant impacts on wetlands in Shuangtai Estuary Ramsar site (SERS) as a result of local economic development (Mao et al., 2014), and numerous striking features emerged at this site, for example, enhanced oil industry and expansion of aquaculture ponds. Therefore, it is important to assess potential threats from these human activities to wetland in SERS and develop proactive conservation strategies in order to maintain ecosystem structure and services, and ensure the regional ecological security. This objective motivated us to use remote sensing to investigate the wetland types of this area from 1988 to 2005 and 2014, and to quantify the spatiotemporal pattern of wetlands in response to anthropogenic occupation.

2. Material and methods

2.1. Study area

The Shuangtai Estuary Ramsar site (No.1441) covering 1352 km^2, with latitude ranging from 40°45′ to 41°10′N and longitude from 120°30′ to 122°00′E, is located in the northern Liaodong gulf of Northeast China (Fig. 1). A temperate semi-humid monsoon climate prevails in the study area with the mean annual temperature being 8.5 °C and the mean annual precipitation being 650 mm. This wetland has more than 126 plant species with dominated plants being *Phragmites australis*, *Suaeda heteroptera*, *Typha*, and *Hemarthria* etc., and these plants grow from April to October. About 700 wild animals and bird species have been found in this wetland (www.ramar.org). SERS is thus the important rest habitat for migration waterfowl in the East Asia-Australasian Flyway (EAAF), in which 45 bird species being protected.

Evident human disturbances to the wetlands of this area occurred because of oil field prospection. Liaohe Oil Field was once the third largest oil field in China, in which oil wells, factories, roads, residences were extensively constructed. Meanwhile, the enhanced aquaculture development and paddy cultivation were promoted for their considerable economic benefits. In addition, the red beach (*Suaeda heteroptera* marshland) attracts numerous tourists to this region. All these human activities imply significant disturbances to the SERS, and are responsible for the shrinkage and fragmentation of natural wetlands in the SERS.

2.2. Remote sensing dataset

We select the 1988, 2005 and 2014 as the study nodes because the study area was approved to be a national natural reserve since 1988 and a Ramsar site since 2005. Cloud-free Landsat image scenes (path 120, row 31/32, Fig. 1) were acquired for the three years from the American Earth Resources Observation and Science Center (EROS). Both TM (Thematic Mapper) and OLI (Operational Land Imager) images acquired from August were analyzed to obtain land covers of the study area considering that land cover types can be easily identified during this month (Lin et al., 2015; Ozesmi and Bauer, 2002).

Before land cover classification can be done, the acquired images were processed for atmospheric correction using the 6S radioactive transfer model and geo-rectified with reference to 1:50,000 topographic maps, and at least 30 ground control points (GCPs) were used for geo-rectifying each image. The root mean squared error of geometric rectification was less than 1 pixel (or 30 m). The ENVI 5.0 image processing software was used in this geo-rectification step.

2.3. Extracting land covers information

For examining landscape dynamics, land cover of SERS in 1988, 2005, and 2014 was classified into 4 land cover categories (natural wetland, human-made wetland, cropland, built-up land) and 12 land cover classes (Table 1) using the eCognition software. Although paddy field is one of the important human-made wetland types, it wasn't considered in this analysis since it is more appropriate classify them into cropland. The object-oriented classification method, proven to be more accurate and robust than the traditional pixel-based method (Dronova, 2015), was used for the land cover classification consisting of three steps (Wang et al., 2015). Segmentation is the first step of the object-oriented method, which is the process of segmenting an image into groups of homogeneous pixels so that the variability within the object was minimized (Baatz and Schäpe, 2000). Images segmentation parameters include scale, shape and compactness. The multi-