Ocean & Coastal Management 138 (2017) 1–10

Contents lists available at ScienceDirect

Ocean & Coastal Management

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

Coastal wetlands facing climate change and anthropogenic activities: A remote sensing analysis and modelling application

Wen-ting Wu, Yun-xuan Zhou, Bo Tian*

State Key Laboratory of Estuarine and Coastal Research, East China Normal University, Shanghai 200062, PR China

A R T I C L E I N F O

Article history:
Received 28 April 2016
Received in revised form
5 January 2017
Accepted 5 January 2017

Keywords:
Estuarine and coastal wetland ecosystems (ECWEs)
Remote sensing
Object-oriented classification
CLUE-S
SLAMM

A B S T R A C T

Under high-intensity anthropogenic activities and accelerated climate change globally, estuarine and coastal wetland ecosystems (ECWEs) are facing the great challenge of surviving the destructive effects brought about by human activities and sea level rise (SLR). In this study, time-series Landsat images and object-oriented classifications were adopted to monitor the trends and status of ECWEs in the PNA (Pudong New Area) of Shanghai from 1989 to 2013. To study landward and seaward threats to the ECWEs, two types of models were employed to simulate the dynamics of the ECWEs at different time scales. A Markov Chain model and CLUE-S (Conversion of Land Use and its Effects at a Small regional extent) were used to assess the impact of anthropogenic activities on the ECWEs from the landward direction in 2025. Additionally, SLAMM (Sea Level Affecting Saltmarsh Model) was utilized to evaluate the influence of SLR on the ECWEs from the seaward direction in 2100. The results showed that (1) more than 15,000 ha of the ECWEs were lost or degraded from 1989 to 2013 and (2) most of the ECWEs were transformed into drained lands for agriculture, aquaculture, or industrial or residential use under the rapid expansion of the city. Moreover, 54% of the agricultural land was converted to built-up areas or other uses. (3) The loss of agricultural land and increase in built-up areas will continue in the short-term future (up to 2025), and the sprawl of the built-up areas will extend in every direction in the PNA. (4) As modelled by the process-based SLAMM, the landscape changes in the ECWEs will be slight due to SLR by the end of the century, rather than distinct erosion in tidal flats being caused by SLR. In summary, driven by different forces, the ECWEs will be altered greatly and threatened by the impact of human activities and SLR from landward and seaward directions. On a short-term time scale, human activities will play a more important role in the modification and evolution of the ECWEs through direct exploitation of and interference with the structure and biogeochemical processes of the ECWEs. However, on a long-term time scale, the accelerated SLR will cause the continuous narrowing of the ECWEs. Considering the blockade due to the construction of dikes along the shoreline, destructive effects will influence the ECWEs, despite the feedback among the dominant plant species, geomorphology and hydrology.

1. Introduction

Estuarine and coastal wetland ecosystems (ECWEs) are among the most valuable ecosystems on the planet due to the various ecosystem services they provide to millions of people worldwide (Costanza et al., 1997; Barbier et al., 2011; Webb et al., 2013). Because of the unique biogeochemical processes and ecosystem structures and locations of ECWEs, these ecosystems provide purified water, shoreline protection and an ecological buffer from storm surges and coastal erosion (Chen and Zong, 1998); carry out carbon sequestration (Huang et al., 2010; Langley and Megonigal, 2010; Barbier et al., 2011); and provide a habitat for wetland plants and animals (Aiello-Lammens et al., 2011; Fulford et al., 2014). Additionally, in the transitional zone between land and the ocean, ECWEs are among the most productive and dynamic ecosystems on earth due to the frequent interaction between land-based fluvial processes and the coastal ocean (Ericson et al., 2006). A report by the Intergovernmental Panel on Climate Change (IPCC) indicates that the coastal zone is the most sensitive area under global climate change (IPCC, 2007). Thus, research on the coastal zone, especially in ECWEs, can reveal significant

* Corresponding author. State Key Laboratory of Estuarine and Coastal Research, East China Normal University, 3663 North Zhongshan Road, Shanghai 200062, PR China.

E-mail address: btian@sklec.ecnu.edu.cn (B. Tian).

http://dx.doi.org/10.1016/j.ocecoaman.2017.01.005

indicators of climate change.

With the development of society and the economy, accelerated climate change and intensive anthropogenic activities have resulted in dramatic threats to ECWEs, interfering with biogeochemical and physical processes, causing losses and a reduction of the ecosystem functions (Chen et al., 2001; Kirwan and Megonigal, 2013; Webb et al., 2013; Tian et al., 2016). Moreover, coastal eutrophication (Deegan et al., 2012), water pollution (Siddiqui, 2011; Findlay and Fischer, 2013), reduction of sediment loads from catchments (Yang et al., 2011) and land subsidence (Wang et al., 2012; Yang et al., 2014) alter the structure and biogeochemical process of the ECWEs, thereby degrading ecosystem functions and services. More than 50% of salt marshes, 35% of mangroves, 30% of coral reefs and 29% of seagrasses have been lost or degraded globally due to enhanced human activities (Barbier et al., 2011). Most coastal wetlands have been transformed into drained lands due to rapid urbanization or for farming purposes (Huang et al., 2010; Kirwan and Megonigal, 2013).

Many studies have been conducted to evaluate the status and trends of ECWEs under accelerated climate change and high-intensity anthropogenic activities using various methods (Townend et al., 2011; Fagherazzi et al., 2012; Kirwan and Megonigal, 2013). Since the first launch of a land observation satellite in the 1970s, the remote sensing technique has been widely utilized to monitor land use and cover change (LUCC), which indicates the spatial and temporal dynamics of human activities (Chen et al., 2000; Brooks et al., 2006; Liu et al., 2008; Klemas, 2013a, b). In addition, future LUCC can be modelled qualitatively and quantitatively based on different driving forces and the spatial relationships between different types of land cover (Veldkamp and Fresco, 1996; Verburg et al., 2002; Yu et al., 2011). The evolutionary trends of ECWEs have been simulated under different future climate change scenarios using numerical models, considering the combined effects of sediment transportation, hydrological processes, biological components and environmental conditions (Temmerman et al., 2003; D'Alpaos et al., 2007; Kirwan and Murray, 2007; Craft et al., 2009; Schuerch et al., 2013). However, most previous studies have evaluated the impacts of anthropogenic activities and climate change on ECWEs separately, which may result in inaccurate assessment of the impacts on ECWEs.

Hence, in the present study, to comprehensively assess the impact of human activities and climate change on the evolutionary trends of ECWEs in the past and the future, a time-series of Landsat images was used to evaluate the spatial and temporal dynamics of anthropogenic activities in the PNA (Pudong New Area), which is a rapidly developing region in Shanghai, China. Simultaneously, the CLUE-S (Conversion of Land Use and its Effects at a Small regional extent) model and SLAMM (Sea Level Affecting Saltmarsh Model) were employed to predict landscape changes in the PNA under the existing anthropogenic activities and an accelerated sea level rise (SLR), respectively. By analysing landscape changes, we sought to evaluate the following: (1) the land use and land cover changes in the past and future due to human activities on a short time scale; (2) how ECWEs evolve under accelerated SLR at different time scales; and (3) the combined effects of anthropogenic activities and SLR on ECWEs.

2. Study area

The PNA is located in the eastern part of Shanghai (30°50′-31°23′N, 121°26′-121°59′E), which is situated between the Yangtze Estuary and Hangzhou Bay (Fig. 1). Similar to most of the southern coastal areas in China, the PNA has a subtropical monsoon climate with abundant precipitation (1233.4 mm annually) and warm temperatures (average long-term annual temperature of 16.3 °C). Due to special policies for development, the PNA has experienced great changes since the implementation of the reform and opening policy. Currently, the PNA has the largest population (approximately 5.26 million) in Shanghai and exhibits a gross domestic product (GDP) of 644.87 billion Yuan. With the rapid rate of urbanization, the proportion of the built-up area in the PNA has increased quickly in recent years.

The largest wetland in the PNA is the Nanhui Dongtan wetland. This wetland is located on the southern bank of the Yangtze Estuary and is affected by complex interactions between the river and the ocean. The Yangtze River is the third longest river in the world and the fourth largest river in terms of its water discharge and sediment load (Yang et al., 2007). Due to the influence of the sediment load from the upper stream, the river has been expanding seaward for the past hundred years. The Yangtze Estuary exhibits a semi-diurnal tide, with an average tidal range of 2.66 m (Liu et al., 2010). Due to the impact of diluted water and tidal currents, the Nanhui Dongtan wetland is periodically inundated by brackish water. Additionally, three distinct vegetation communities (*Scirpus mariqueter, Spartina alterniflora* and *Phragmites australis*) grow in the Nanhui Dongtan wetland, associated with special physical and chemical conditions. Due to the complicated interactions among the hydrological, geomorphological and ecological components of the Nanhui Dongtan wetland, it has developed as a suitable habitat for wetland animals and plants. This wetland represents an important stopover for migratory birds in East Asia, with 20 orders, 60 families and 317 species of birds being recorded in this area as of 2012 (Cai et al., 2014).

3. Data and methods

3.1. Data sources and preprocessing

To detect LUCC in the PNA, high-quality Landsat archive images (i.e., during no or low cloud coverage in a relative-low tide period) (Table 1) were download from the United States Geographical Survey website (USGS, http://www.usgs.gov) and were used to perform the classification, assessing long-term records of the observation of land resources. Geometric correction was performed on an image acquired in 2000 with a 1:50,000 topographical map using ERDAS IMAGE software, which was taken as the basic geographical reference for the images obtained at other time points. In the next step, image-to-image geographical registration was performed between every image and basic image to ensure that the root mean square error (RMSE) was less than 0.5 pixels. Furthermore, to improve the accuracy of the classification, atmospheric correction and image enhancement were conducted for all of the images.

Due to tidal inundation, it was difficult to acquire an image at the lowest tidal level for every time point in the rainy and cloudy coastal zone. Therefore, a nautical chart was utilized to delineate the landscape in the intertidal zone. The water depth and the elevation of the tidal flat were digitised, and Kriging interpolation was used to form a digital elevation model (DEM) of the intertidal zone with ArcGIS software.

3.2. Detection of wetland change based on object-oriented classification

Traditionally, a pixel-based classification method, such as maximum likelihood classification and minimum distance classification, is used to perform classification (Ozesmi and Bauer, 2002). However, in China's coastal zone, with the development of urbanization, there are large, rapid changes in the structure of land use and land cover, causing serious fragmentation of coastal wetlands