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Vulnerability assessment of the coastal wetlands in the Yangtze Estuary, China to sea-level rise

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ABSTRACT

Sea-level rise (SLR) caused by global climate change will have significant impacts on the low-lying coastal zone. The coastal wetlands in the Yangtze Estuary, with their low elevation, are particularly sensitive to SLR. In this study, the potential impacts of SLR on the coastal wetlands in the Yangtze Estuary were analyzed by adopting the SPRC (Source–Pathway–Receptor–Consequence) model. Based on the SPRC model and IPCC vulnerability definition, an indicator system for vulnerability assessment on the coastal wetlands to SLR was developed, in which the rate of SLR, subsidence rate, habitat elevation, mean daily inundation duration of habitat and sedimentation rate were selected as the key indicators. A spatial assessment method based on a GIS platform was established by quantifying each indicator, calculating the vulnerability index and grading the vulnerability. Vulnerability assessment, based on the projection of SLR rates from the present trend (0.26 cm/yr) and IPCC's A_1F_1 scenario (0.59 cm/yr), were performed for three time periods: short-term (2030s), medium-term (2050s) and long-term (2100s). The results indicated that in the 2030s, 6.6% and 9.0% of the coastal wetlands were within the grade of low vulnerability under the scenarios of present trend and A_1F_1, respectively. In the 2050s, the percentage of coastal wetlands within the grades of low and moderate vulnerability increases to 9.8% and 0.2%, 9.5% and 1.0% under the scenarios of present trend and A_1F_1, respectively. In the 2100s, 8.1% and 3.0% of the coastal wetlands were within the grade of low vulnerability, 0.8% and 2.8% were within the grade of moderate vulnerability under the scenarios of present trend and A_1F_1, respectively. The percentage of coastal wetlands within the grade of high vulnerability increases significantly, amounting to 2.3% and 6.9% under the scenarios of present trend and A_1F_1, respectively. The application of the SPRC model, the methodology developed and the results could assist with the objective and quantitative assessment of the vulnerability of coastal wetlands undergoing the impacts of SLR elsewhere. Without proper mitigation measures, the potential decrease in the area and loss of habitats and ecosystem services from the wetlands is inevitable. Based on the results of this study, mitigation measures should be considered for securing the future of the coastal wetlands in the Yangtze Estuary, which include the management of sedimentation, rehabilitation and re-creation of wetland habitat, reduction of land subsidence and control of reclamation.

1. Introduction

In recent decades, the prospect of climate change, in particular sea-level rise (SLR) and its impacts on low lying coastal areas, has generated worldwide attention from managers of coastal ecosystems (IPCC, 2007a; Nicholls and Cazenave, 2010; Nicholls et al., 2013). According to the report from the Chinese State Oceanic Administration (SOA), SLR in the Yangtze Estuary, China has occurred at a rate of 0.26 cm/yr over the past 30 years (1980–2010) and is predicted to accelerate in the future (SOA, 2011).

The coastal wetland ecosystems occur at the intertidal zone and provide valuable ecosystem services, including habitat biodiversity, agriculture and food supply and coastal protection (Tian et al., 2010). Located in the transition zone between the land and ocean

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systems, the coastal wetlands ecosystems are particularly sensitive to SLR (Nicholls and Cazenave, 2010). Since a coastal vulnerability analysis was completed in the early 1990s using the IPCC Common Methodology (Nicholls, 2002), many studies involving vulnerability assessment have been carried out to evaluate the potential impacts of SLR on coastal systems. A coastal vulnerability index (CVI) was designed to assess the impacts of SLR on the coastal ecosystems in U.S., Canada and Mexico (Gornitz, 1991). Bryan et al. (2001) projected the coastal vulnerability to SLR in tide-dominated, sedimentary coastal regions by distributed coastal process modelling. Dwarakish et al. (2009) assessed the coastal vulnerability of the future SLR in the west coast of India by selecting the mean SLR rate, coastal slope, mean significant wave height and mean tide range and shoreline erosion/accretion and Glick et al. (2013) applied a Sea Level Affecting Marshes Model (SLAMM) to predict the potential effects of SLR on the coastal wetlands in southeastern Louisiana. It was predicted that SLR could cause a loss of up to 22% of the world's coastal wetlands and, if combined with other habitat destruction due to human activities, up to 70% of the world's coastal wetlands could be lost by the 2080s (Nicholls et al., 1999, 2007). All these studies indicated that SLR could have significant impacts on the coastal wetlands and without adaptive responses, a global loss of coastal wetlands is inevitable.

In China, the coastal wetlands located at the intertidal zone are facing a significant threat from SLR. In recent decades, several studies of the impacts of climate change on the coastal wetlands have been carried out. The potential impacts of SLR on the coastal wetlands in the Yellow River Delta and Bohai coast were analyzed qualitatively (Xiao et al., 2003; Zhang et al., 2006). The possible impacts of SLR on the coastal wetlands at Chongming Dongtan in the Yangtze Estuary were projected under the IPCC SLR scenarios (Tian et al., 2010). Most of these vulnerability assessment procedures and suggested management options to date, however, have been speculative. There is an urgent need to develop a process-based methodology for the quantitative assessment of the vulnerability of the coastal wetlands in China in response to climate change and, especially any associated SLR.

Research into the responses of coastal wetland ecosystems to SLR, the assessment of the impacts of SLR on coastal wetlands ecosystems and the formulation of feasible mitigation strategies are the important prerequisites for securing and conserving these coastal ecosystems. In this paper, taking the coastal wetlands in the Yangtze Estuary as a case study area, a vulnerability assessment of coastal wetlands ecosystems to SLR was carried out. The main objectives of this work were to: 1) develop a process-based methodology for assessing vulnerability; 2) assess quantitatively the vulnerability of coastal wetlands ecosystems to various scenarios of SLR, and 3) propose feasible mitigation measures, based on the results.

2. Study area

The Yangtze Estuary is located on the eastern coast of China, which is neighboured by Hangzhou Bay to south, Jiangsu province to north and opens onto the East China sea, between 30°50′–31°50′N and 121°0′–122°05′E (Fig. 1). The region has a subtropical monsoon climate, with an average annual temperature of 16 °C and average annual precipitation of 1200 mm (Zhou and Xie, 2012). The Yangtze Estuary is a typical meso-tidal estuary with multi-order bifurcations, shoals and sand bars. The maximum and average tidal ranges are 4.62 m and 2.67 m, respectively (Gao and Zhang, 2006). Due to its large sediment supply, the Yangtze delta has prograded more than 200 km into its incised river valley since the mid-Holocene. The Holocene sediment thickness in the river mouth area reaches to about 60 m (Hori et al., 2002) forming extensive shoals and tidal flats. The intensive interactions between runoff and tidal currents and hydrodynamical processes in the estuary have created a unique sedimentological pattern when compared to other similar sized estuaries elsewhere in the world (Yang et al., 2011).

According to the Ramsar International Wetland Conservation Treaty – 1971 (Mitsch and Gosselink, 2007), the total area of coastal wetlands in the study area is 2318.5 km^2. The wetland habitats include tidal saltmarshes (mainly occupied by communities dominated by *Scirpus mariqueter*, *Phragmites australis* and *Spartina alterniflora*), tidal mudflats and shallow open waters (Fig. 1). Zonation of coastal wetland is widely recognized in the Yangtze Estuary and distinct zones of habitat, related to elevation, can be identified within the tidal flats in the region (Ge et al., 2013). The tidal mudflats, with an elevation of less than 2 m (the local Wusong bathymetric benchmark), are characterized by mudflats. The intertidal zone, between 2.2 m and 2.9 m, is dominated by a pioneer community of *S. mariqueter*. Above 2.9 m, the saltmarsh is characterized by the *P. australis* community. *Spartina alterniflora*, as an exotic species, was introduced to the coastal wetlands in the Yangtze Estuary during the 1990s. Over the past twenty years this species has gradually invaded large areas formerly covered by *P. australis* and has also started to invade the upper parts of the *S. mariqueter* zone (Li and Zhang, 2008).

3. The methodology for vulnerability assessment of saltmarshes threatened by SLR

3.1. The conceptual model for vulnerability assessment

To assess the vulnerability of coastal wetlands to SLR, a conceptual model – the SPRC (Source–Pathway–Receptor–Consequence) model (Narayan et al., 2012) was used, as shown in Fig. 2.

Source (S) is the factor directly impacting on the coastal wetlands, namely SLR. If the relative SLR exceeds the tolerance range of the coastal wetland habitat, it will change the coastal wetlands' structure and function, and result in loss of habitat (Glick et al., 2013).

Receptors (R) are the coastal wetland ecosystems that would be impacted by SLR events within the case study boundaries. The coastal wetlands in the Yangtze Estuary can be divided into the mainland coastal wetland and island/shoal wetland by their geomorphological characteristics (Huang, 2009), which include Naihui Biantan, Jinshan-fengxian Biantan, Chongming island, Hengsha island, Changxing island and Jiuduansha shoal (Fig. 1). According to the key characteristics of the wetland habitats and ecosystems, these locations can be divided further into the receptors of *Phragmites australis* marsh, *Scirpus mariqueter* marsh, *Spartina alterniflora* marsh and mudflat (Fig. 2).

Pathways (P) are the routes between the source and the receptors, including subsidence/uplift and sedimentation (Fig. 2). Coastal subsidence can increase the rate of SLR and further exacerbate the impacts of SLR on coastal wetlands, while uplift can mitigate or offset the impacts. High volumes of sediment carried down by rivers and also from the open sea to coastal wetlands may mitigate or even offset the impacts of SLR, while negative sedimentation rates will further exacerbate the impacts of SLR and result in coastal erosion and loss of coastal habitats (Kirwan and Temmerman, 2009).

Consequences (C) are the habitat damage or improvement to the coastal wetlands which may result from SLR. Consequences are the result of the location and magnitude of exposure (i.e. the severity of SLR), the susceptibility of the receptor (e.g. the effectiveness of any natural response within the system) and the adaptation to the stresses (i.e. ability to 'absorb' the event) (Romieu et al., 2010). Consequences can be expressed