Ecological Indicators 85 (2018) 729–741

Contents lists available at ScienceDirect

Ecological Indicators

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

Evaluation of the ecological sensitivity and security of tidal flats in Shanghai

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ARTICLE INFO

Keywords:
Tidal flat resources
Ecological sensitivity analysis
Ecological security evaluation
PSR model
Shanghai

ABSTRACT

As the data acquisition is difficult, not only the ecological sensitivity study of tidal flats is relatively less, moreover, ecological sensitivity analysis is rarely correlated with ecological safety evaluation, and the temporal and spatial correlation of adjacent mudflats is rarely focused on. In the present study, we build a new index system integrated biological, ecological process and development and utilization sensitivities, to evaluate the ecological sensitivity of the seven main tidal flats of Shanghai. Then, we associate ecological sensitivity with ecological security and construct an index system for evaluating their ecological security based on the Pressure-State-Response (PSR) model, using the entropy method and analytic hierarchy process (AHP) to determine the weights. The results were as follows: (1) Chongming East beach and Jiuduansha are the highly ecologically sensitive type, Chongming North beach and Nanhui beach are the medium ecologically sensitive type, Hengsha and Changxing beaches are the relatively low ecological sensitive type, and the North beach along Hangzhou Bay is the low ecological sensitive type. The ecological security indices of these seven beaches from high to low are: Chongming East, Jiuduansha, Changxing, North beach along Hangzhou Bay, Hengsha, Chongming North and Nanhui. (2) There is a close relationship between the ecological sensitivity and ecological security index of the tidal flats. (3) There is the temporal and spatial relevance of adjacent tidal flats.

1. Introduction

In this urban era, urban governance has become a global issue (Connolly et al., 2014; Koop et al., 2017). It is concerned with the alleviation or resolution of various urban issues and is closely related to the sustainable development of cities and regions (Mortberg et al., 2013; Glinskiy et al., 2015; Miguez et al., 2015). Facing the environmental risk of the increasing scarcity of natural resources, the development and protection of reserved resources has been given greater attention (Ebeke and Etoundi, 2017; Rosol et al., 2017; Fiorini et al., 2017; Falco, 2017). Tidal flats, which include the entire intertidal, supratidal and subtidal zones, are an example of reserved land resources in coastal areas. The areas available for exploitation usually include the "-5" m contour lines. Currently, the development and sustainable utilization of coastal zone resources (Shi et al., 2001; Kostecki et al., 2012; Olyaie et al., 2015; Chen and Chau, 2016; Zhang et al., 2017; Anfuso et al., 2017), the protection of tidal wetland (Oliva et al., 2017; Fletcher et al., 2011; Furukawa, 2013), and ecological restoration and management (Macfarlane and Booth, 2001; Weinstein and Kreeger, 2002; Wainger et al., 2010; Andrés et al., 2017; Turner and Essex, 2016) have become key issues for academics. In China, the research projects of tidal flats have mainly concentrated on their development and utilization, with the main purpose being the interest to the economy. With the gradual implementation of a sustainable development strategy, the ecological value and safety of the tidal flats have also become valued. As a result, the research on tidal flats has shifted from a single economic orientation to one of both protection and utilization (Guo et al., 1988; Peng et al., 2003; Wang and Zhu, 2009; Zhang et al., 2013; Xu and Pu, 2014). Scholars in Shanghai have carried out preliminary studies that cover resources surveys(Huang et al., 2005), the regularity and stability of sediment movement (Li et al., 2006), development and utilization (Chen et al., 2007; Yang et al., 2009; Li et al., 2003), the characteristics of spatio-temporal evolution (Ruan et al., 2010), ecosystem services value estimation (Su, 2007), ecological health and evaluation (Tan, 2013; Tan et al., 2014), and the effect of engineering construction and reclamation on tidal flats (Du and Yang, 2007; Lu and Jiang, 2013). In recent years, the carrying capacity of tidal resources, zoning of ecological red line etc. have also received attention (Pan, 2009; Wang and Pan, 2017).

Currently, the evaluation of the ecological sensitivity and security of the transition zone is increasingly important, and research methods and evaluation systems are continuously improving. However, there are still

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https://doi.org/10.1016/j.ecolind.2017.11.033
Received 5 September 2017; Received in revised form 17 November 2017; Accepted 17 November 2017

some problems, for instance, the definition of ecological sensitivity is still vague; studies in land ecology to date have barely considered tidal flats (Liu and Fang, 2014; Metzger et al., 2006; Wang et al., 2016a,b; Wu et al., 2016; Su et al., 2011), focusing instead on eco-city elements and evaluation (Wang et al., 2015; Singh, 2016; Ilyichev et al., 2015 ; Rastyapina and Korosteleva, 2016), lakes and wetlands (Li et al., 2010; Qin et al., 2011; Wang et al., 2016a,b), rural areas (You and Zhang, 2017; Zhu et al., 2009). Although the development of an evaluation system for ecological safety has been relatively well-established, it has rarely been applied to tidal flats. As an important reserve land resource, tidal flat resources are an important material foundation and ecological guarantee for social and economic sustainable development in Shanghai. Analysing the ecological sensitivity and evaluating the ecological safety of tidal flat resources is not only an important prerequisite and foundation for sustainable development, utilization and protection but also a major practical task facing Shanghai. It is also an important issue for Shanghai to implement an overall development strategy of land and sea.

As the data acquisition is difficult, not only the ecological sensitivity study of tidal flats is relatively less, moreover, ecological sensitivity analysis is rarely correlated with ecological safety evaluation, and the temporal and spatial correlation of adjacent mudflats is rarely focused on. Compared with the previous studies, our work is innovative in three aspects. First, the integrated evaluation index system of ecological sensitivity includes biological, ecological process and development and utilization sensitivities, and the development potential and risk of the beach are also considered. Second, the evaluation of ecological security is associated with the analysis of ecological sensitivity, and the artificial influence factors such as beach protection grade and reclamation input are included in the ecological safety evaluation index system. Third, we discuss the temporal and spatial relevance of adjacent tidal flats aimed at sustainable conservation and utilization.

2. Material and methods

2.1. Study area

Shanghai, the economic, financial, trade, transportation and shipping, scientific and technological innovation center of China, is to be built as the global city in 2040. And the rich tidal flats resources provide space and resource condition for Shanghai. However, the research of Shanghai tidal flats is scarce. So, the future development of Shanghai needs to strengthen the research of tidal flats. Besides, the important role of the Yangtze River tidal flat wetland has aroused great attention both at home and abroad. In July 1999, the Wetland International Asia-Pacific Organization formally accepted Chongming East as a member of the " East Asia − Australia wading bird migration protection network ". In 2002, Chongming established the Yangtze River Estuary Chinese Sturgeon Nature Reserve. In the same year, Chongming East was ranked by the World-Wide Fund for Nature as an ecologically sensitive area of international importance and was recognized by the International Secretariat of Wetlands as an important international wetland. In 2005, the State Council approved the establishment of two national nature reserves of Jiuduansha and Chongming East.

Shanghai's tidal flat resources are mainly located in the Chongming northern, southern, and eastern border beaches; the North Port northern sand beach; and those of Hengsha eastern, Yangtze Estuary southern border, Hangzhou Bay northern border, the Yangtze Estuary central bar and other areas (Fig. 1). By 2013, the total area of Shanghai tidal flat resources above 0 m (the theoretically lowest tide level), −2 m, and −5 m, were 755 km^2, 1306 km^2 and 2422 km^2, respectively (Table 1). According to the current level of tidal flats resource development and utilization and protection of Shanghai, seven beaches, i.e., Chongming North, Chongming East, Changxing, Hengsha, Jiuduansha, Nanhui and the north beach along the Hangzhou Bay, are selected as the study area.

The growth of Shanghai's tidal flat resources depends upon the quantity of sediment and the speed of the tidal flat being converted to land. Over the past 30 years, the Shanghai tidal flat resources have generally indicated that "a small increase in the number of flats above zero m, −2 m and −5 m low-lying tidal flat resources are basically stable, and the total amount of resources is basically balanced" (Table 1, Fig. 2). Since 1980, the average speed of tidal flat reclamation has been 20 km^2 per year, which can maintain the dynamic balance of change in the tidal flat area. However, due to the decreasing amount of incoming sediment from the Yangtze River, and increasing reclamation, the balance is being destroyed. Due to reclamation, the area above 0 m is growing rapidly, while the area above −2 m is growing slowly, and the area above −5 m is showing a decreasing trend.

2.2. Data collection

Data sources and statistical methods for ecological sensitivity analysis are shown in Table 2.

Data sources and statistical methods for ecological safety evaluation are as below (Table 3).

2.3. Methods

2.3.1. Ecological sensitivity analysis method

2.3.1.1. Ecological sensitivity analysis indicators selection. Ecological sensitivity refers to the degree of reflection of ecosystem interference in human activities and changes in the natural environment (Wang and Bian, 2011; Li et al., 2010), that is, the degree to which the ecosystem responds to environmental changes caused by the combination of internal and external factors. Some soft computing techniques have been widely used in various case studies (Wu et al., 2010; Wang et al., 2014; Sefeedpari et al., 2016; Nabavi-Pelesaraei et al., 2017). Evaluating ecological sensitivity and identifying the distribution characteristics of different sensitive areas can help to identify areas that should be a priority for development or be the focus of ecological protection. Located at the boundary of the sea and land, the tidal flat has dual characteristics of marine and terrestrial ecosystems and is also disturbed by human beings due to its particular ecological values. In this paper, combining with the history and present situation of the exploitation and utilization of Shanghai tidal flat resources, the ecological sensitivity evaluation index system is constructed using 12 specific indicators of three aspects, which are biological, ecological process, and development and utilization process sensitivities (Fig. 3).

The biological sensitivity index was mainly composed of shellfish diversity, fish and shrimp diversity and aquatic plant diversity. Considering that the Shanghai beach is an important channel and winter habitat for migratory birds, the birds species should also be taken into account to reflect the ecological sensitivity of the Shanghai tidal flat.

In the ecological process sensitivity index, the sediment quality and water quality reflect the dual characteristics of marine and terrestrial ecosystems. The area and the shape replaced the indicator, the process of erosion and deposition, which is difficult to use quantitative way to express. In addition, according to the definition of sensitivity in this paper, comparing with the area, the area changes, can better reflect the extent to which the beach reflects the disturbance of human activities and changes in the natural environment. Therefore, the area change is selected as one of the ecological process sensitivity indicators.

The development and utilization sensitivity and the above-mentioned two categories of natural environmental sensitivity complement each other. It reflects the relationship between the tidal flats and human social activities. The three indicators, reclamation area, development potential and development risk are selected to reflect the influence of human activities on the sensitivity of the tidal flats, and the suitability and feasibility of the development and utilization of the tidal flats.