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The landscape change and theory of orderly reclamation sea based on coastal management in rapid industrialization area in Bohai Bay, China

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1. Introduction

More than one-third of the world's population lives in coastal areas, which account for just 4% of the Earth's total land area and provides a disproportionate number of ecosystem services (Tian et al., 2016; Feng et al., 2014; Healy and Hickey, 2002). Coastal wetland ecosystems produce significant economic benefits and play vital roles in maintaining ecological balance and human welfare in coastal areas (Jiang et al., 2015; UNEP, 2006; Lotze et al., 2006). Intensive land reclamation from the sea occurs in many coastal countries and is an effective approach to acquiring land resources to accommodate the increasing need for agriculture, mariculture, and industrial and urban development. Land reclamation is the most important driver of the degradation and loss of coastal ecosystems (He et al., 2014; Yan et al., 2013; Wang et al., 2010). Reclamation from the sea brings enormous economic benefits on the one hand; however, it often results in major disturbances to the natural coastal ecosystems, including a loss of coastal habitat, changes in coastal landscape diversity (Jin et al., 2016; Pan and Wang, 2012; Perry et al., 2008; Suzuki, 2003), increases in manmade shoreline (Wang and Meng, 2011), blocked connectivity of wetland ecology and hydrology (Cui et al., 2016), deterioration of disaster prevention capacity, and depletion of fishery resources (Yu and Zhang, 2011). These effects further increase the uncertainty of ecosystem-based management (Tian et al., 2016; Wang et al., 2014) and destroy the balance between tidal systems and sediment transport (Gao et al., 2014).

Coastal reclamation has the potential to ease the pressure of a high population density and expand industrial development space (Bao and Gao, 2016). Therefore, it is important to scientifically assess the effects of reclamation activities on coastal ecosystems (Jin et al., 2016; Cheong et al., 2013). Many previous studies have investigated the responses of environmental quality and biotic communities to reclamation activities (Park et al., 2009; Cheng et al., 2016). The comprehensive effects (Liu and Mou, 2016; Wang et al., 2010; Miao, 2007), estimated loss of ecosystem services and suitability assessment of coastal reclamation (Feng et al., 2014), and cumulative impact of reclamation activities on coastal ecosystem health as well as the strategies of ecosystem-based and adaptive management were all compared at different phases of reclamation between the Laizhou Bay and Tianjin coastal area in the Bohai Sea (Shen et al., 2016). Zainal et al. (2012) assessed the cumulative effects of the ecological and economic impacts of reclamation and believed that reclamation could promote the sustainable utilization of maritime and marine resources. Li et al. (2009) established a qualitative "driver-response" framework for the relationship between reclamation activities and estuarine environments. Zhang et al. (2016) compared the distribution and composition of microbial taxa between reclaimed and non-reclaimed coastal wetlands in the Yellow River Delta (YRD). Jin et al. (2016) proposed an evaluation of land reclamation intensity and developed a comprehensive assessment index system to

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quantify the response of river delta wetlands to a wide range of reclamation activities in the YRD. Feng et al. (2014) applied an integrated framework to employ a fuzzy comprehensive evaluation method and an analytic hierarchy process (AHP) to identify the suitability of coastal reclamation for future sustainable development in the coastal area of Lianyungang, China. Wang et al. (2010) presented a method to assess the loss of service value of coastal ecosystems caused by land reclamation to help stakeholders and decision-makers make informed choices and promote sustainable marine resource utilization.

The coastal region of China covers 13% of the nation's territory and contributes 60.8% of the national gross domestic product (GDP) (Zhu et al., 2016; SFA, 2014). China has more than 32,000 km of coastline, including more than 18,000 km of maintained shoreline and 14,000 km of island shoreline (Tian et al., 2016; CCICED Task Force, 2013). China has undergone large-scale reclamation activities since the establishment of P.R. China and has experienced unique reclamation patterns at different time periods, including agriculture in the 1960s and 1970s (Bi et al., 2012), salt production pans in the 1950s, mariculture in the 1980s and 1990s, and industrial uses since the 1950s (Wang et al., 2014; Temmerman et al., 2013). The cumulative loss of coastal wetland area is approximately 22,000 km^2 since 1949 due to land reclamation (Tian et al., 2016; Wang et al., 2014). The total reclamation area grew from 8241 km^2 to 13,380 km^2 between 1990 and 2008 (Cui et al., 2016). In addition, vegetated wetland sharply decreased and coastal areas shifted from vegetated coastal wetland to intertidal mudflats and sub-tidal zones due to the application of advanced engineering equipment and technology. This area of Bohai Bay is the most important economic center in North China, it is approved by the nation's strategies and is experiencing rapid industrialization. This rapid industrialization has triggered the local government and enterprises to reclaim areas of the sea for land-use purposes. Many researchers have determined the destructive influences of land reclamation on coastal ecosystems in Bohai Bay (Xie et al., 2010). Research has identified the process of coastal land-use changes caused by reclamation activities and has addressed the use of an orderly multi-function integrated utility model in the coastal area. In this study, Landsat imagery data and China-Brazil Earth Resource Satellite (CBERS) data from 1974 to 2010 at 1-year intervals were used to determine the reclamation status as well as the associated changes in the spatial distribution. The objectives are to provide detailed information on reclamation changes in Bohai Bay since the 1970s; review the history, traits, and associated ecosystems effects of reclamation; and present an orderly theory of coastal reclamation in Bohai Bay, China.

2. The reclamation traits in coastal countries

2.1. Sea reclamation in Netherlands, Japan, and Korea

Restrictions of the natural geographic environment, population, and economic growth have prompted the Netherlands to become pioneers of land reclamation. Reclamation in the Netherlands began in the 13th century, and the country has a total reclamation area of 7000 km^2 today. The reclamation area increased from 300 km^2 in the first hundred years to 2500 km^2 in the 20th century. Reclamation has led to the disappearance of natural landscapes, a reduction in species diversity, and an increase of erosion of coastal banks. All of these changes triggered the government to launch the *Natural Policy Plan* in 1990, which aimed to restore natural coastal landscapes. The main experiences obtained from land reclamation in the Netherlands include the establishment of planning systems, comprehensive evaluation and post-evaluation systems; integrated damage-benefit analyses; and approval systems of the public, government, and parliament.

Japan has high population density, which creates special appeal for land reclamation. Approximately 3000 km^2 of land area has been reclaimed since large-scale reclamation activities were established in the middle of 19th century. Reclamation of mudflats and estuarine deltas is used to obtain more arable land to construct port, industrial, and urban areas. Industrial reclamation in Japan has led to a weakened ability of sea water to self-clean, proliferation of red tides and disappearance of fish. To promote the sustainable utilization of marine resources, Japan has gradually reduced reclamation areas since the 1970s.

Korea's initial reclamation activities date back to 1256 with the construction of a dam to reclaim land near Jianghua Island and increase the army grain supply. Approximately 2328 km^2 of mudflat has been reclaimed to meet the demand of wide-spread agricultural development, accounting for 93.6% of the total reclaimed area over the past 100 years. The reclamation of land to develop industrial and urban sprawl has become a new phenomenon over the past 30 years. Agricultural projects include the Pyeongtaek Reclamation, with a total area of 184 km^2 and 35 km^2 of arable land (1970–1977); the Incheon International Airport project, with an area of 11.7 km^2 (1992–2001), which represents urban and industrial projects; and the Saemangeum project, with an area of 401 km^2, which represents comprehensive development projects, with 30% of the area used as agricultural land (1991-present). More importantly, the area is an important stopover for migratory birds in the Asia-Pacific region, and reclamation has influenced bird diversity (Xing and Chen, 2010).

2.2. The characteristics and laws of land reclamation around the world

The changes in reclamation areas in the main coastal countries since the 13th century are presented in Fig. 1.

The total area of reclamation has shown a rising trend in the middle of 20th century, followed by a declining trend in the Netherlands and Japan. The Netherlands, one of the countries that performs large-scale land reclamation, reached the peak of its reclamation area in the 1950s and had the most reclaimed area before the 1960s. Japan became the country with the largest amount of reclaimed area in the 1960s and reached its peak in the 1970s. The population densities in South Korea, the Netherlands, and Japan in 2000 were 477 people/km^2, 390 people/km^2, and 336 people/km^2, respectively, all of which are higher than the world average of 40 people/km^2. There are many mountains in Japan and Korea, and flat area accounts for less than 1/3 of their territories. The low-lying terrain, frequency of storm surges and scarcity of arable land prompted the counties to reclaim land to obtain more development space. The land-use proposed for reclaimed areas has included the development of farmland, a transportation hub, industry/urban development, and tourism.

3. Study area

3.1. Site description

Bohai Bay is located at 117°4′33″–119°18′31″ E, 37°33′40″–39°39′31″ N and has a total area of 22,133 km^2. The northwest bank of Bohai Bay is a typical semi-enclosed area that promotes the reclamation process as well as interactions between the ocean and terrestrial ecosystems (Fig. 2). The average water depth is only 14 m; the mudflat plain is from 55 m ~ 10 m, and the slope is 0.1% ~ 0.6%. The geomorphic units consist of alluvial plains, coastal plains, mudflats, and submarine slopes. The coastal sediment in Bohai Bay is sand from rivers, and the largest scale mudflat