



Characterizing the spatiotemporal evolutions and impact of rapid urbanization on island sustainable development



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ABSTRACT

Islands, which deliver a diversity of fundamental services, are subject to increasing pressure from urbanization and human activities, particularly in developing countries. This paper integrates socioeconomic drivers, topographic variables, and policy guidance to characterize the spatiotemporal dynamics of urban expansion between 1980 and 2013 in the Zhoushan islands, China. Our results indicate that the Zhoushan islands experienced remarkable urban expansion and economic prosperity over that period, with a clear acceleration since 2000. The increase in built initially occurred in urban cores and then spread to peri-ocean areas over the last decade. These hotspots were the outcomes of co-occurrence of ports, harbors, and coastal industries or tourism establishments, suggesting a considerable disparity among islands with different functions. We further quantified the socioeconomic drivers of urban expansion using multivariable regression. Generally, the major drivers were secondary and tertiary industry growth because of the effect of governmental interventions and changing economic conditions on coastal industries and tourism development. Cross-sea bridges also served to accelerate island development, while population had a lesser impact. Compared with other successful cases worldwide, extensive development and inefficient land use are prevalent in the Zhoushan islands. Available land has become more rare on the islands and reclamation from the ocean has been increasingly applied to expand land area for construction. There are still large gaps in island sustainable development, suggesting that intensive and reasonable land-use planning should be prioritized over exploring the potential for urban development. The results of this study can inform ecological management, and provide a scientific case for urban development and contributed to sustainability of islands and coastal regions.

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1. Introduction

Coastal regions have experienced rapid urbanization, coupled with economic prosperity and demographic concentration, which accommodate more than 50% of the world's human population (Bertolo, Lima, & Santos, 2012; Li & Cheng, 2006). This trend has continued to increase, and it is predicted that by 2025 three-fourths of the world's population will be living on coasts (Anilkumar,

Varghese, & Ganesh, 2010). Particular emphasis has been put on coastal metropolitan cores or developed regions, because these places continuously experience dramatic changes (Alhawaish, 2015; Anilkumar et al., 2010; Antrop, 2004; Haas & Ban, 2014; Pauleit, Ennos, & Golding, 2005; Pijanowski & Robinson, 2011). Islands, which are isolated from the surrounding natural and cultural landscapes, had historically experienced slower development than other coastal regions (Tzanopoulos & Vogiatzakis, 2011). However, as globalization links countries and economic systems, rapid urbanization has spread to many island regions. Today, islands play an integral part in the social, economic, and cultural sectors of surrounding communities; and the interactive development between coastal cities and islands has been strengthened by improved transportation and governmental policies (Bertolo et al., 2012; Chen et al., 2013; Li, 2013; Shoyama & Braimoh, 2011). They

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now fulfill multiple functions (e.g., acting as ports and harbors, sites of coastal industry, tourism and dwelling) and have a significant role in marine economies. However, inadequate research focus on the ecological changes associated with socioeconomic development in island areas.

Rapid urbanization and increasing human interference have posed grave threats to islands' environment, profoundly affecting ecosystem functioning and the services they provide to humans and other life (Kalnay & Cai, 2003; McKinney, 2008; Vitousek, Mooney, Lubchenco, & Melillo, 1997). Compared to continental territory, islands are more vulnerable to anthropogenic disturbance and land use change because of their simple ecosystem structure, poor economic foundation, and weak technology support (Farhan & Lim, 2012; Hay, 2013; Tzanopoulos & Vogiatzakis, 2011). Islands can be considered to be indicators of global environmental changes (Liverman, 1990); they currently sustain increasing pressure from human activities, and the ecological consequences of island urbanization must be addressed.

Most previous studies focused on the intensive development islands, such as the industrial islands on Jurong, Singapore and Kashima in Japan, or tourism islands, such as Malta (on the Mediterranean coast) and Hawaii (in the United States). These studies mainly characterized the islands' economic patterns and ecological consequences of urbanization (e.g., Qin & Zhang, 2013; Zhou, 2009). The induced changes influence a variety of ecological processes and functions, including land-use change, water quality, coastline geometry, biodiversity, and vegetation cover (Bertolo et al., 2012; Farhan & Lim, 2012; Hay, 2013). Recent literature has therefore paid considerable attention to monitoring island sustainable development (Hay, 2013; Lagabrielle et al., 2011; Qin & Zhang, 2013). Although most islands in the world are still in initial development faced with a series of natural and social problems (i.e., the earthquake, tsunami, sea level rise, and trade losses) (Qin & Zhang, 2013), ill-planned development and poor management is evident in many islands of developing world, including Brazil (Bertolo et al., 2012), Indonesia (Farhan & Lim, 2012) and China (Li, Sun, Zhu, & Cao, 2010; Wang & Liu, 2013). Few efforts had been spared on multi-temporal monitoring of island development associated with socioeconomic development because of the high cost of field surveys and the scarcity of long-term observational data (Shao, You, Cai, Lu, & Wang, 1999). As a developing country on the fast track, China has attracted many researchers to estimate the spatiotemporal dynamics of urbanization, particularly on the terrestrial and developed cities (Chen, Jia, & Lau, 2008; Haas & Ban, 2014; Li et al., 2014; Wu, Zhao, Zhu, & Jiang, 2015; Zhang, Su, Xiao, Jiang, & Wu, 2013). Urban sprawl in island regions is less well understood, with past research largely limited to island agricultural development (Qin & Zhang, 2013). Traditional statistical data has been applied to describe the urbanization process of islands (Li & Cheng, 2006; Liu & Xu, 2014; Zhou, 2009), but the interrelated factors of population, economic statistics, and policy planning that govern island urban expansion remain poorly understood (Li et al., 2010; Lu, Zhan, Ye, Chen, & Mou, 2010; Wang & Liu, 2013). Simple analysis may not be sufficient to characterize sustainable island development because it fails to reflect the spatial patterns of island urban development and their driving forces. Islands generally have different urban expansion characteristics because of their distinct geologic, geographic, and economic features (Bertolo et al., 2012). Thus, comparing various islands can offer an expanded perspective of island urbanization characteristics for island management.

With more satellites being sent into space and the increased accessibility of satellite imagery, remote sensing surveys have proven to be an effective means of monitoring urbanization dynamics and improving natural resources management (Bertolo et al., 2012; Shoyama & Braimoh, 2011). This paper aims to

characterize the spatiotemporal dynamics of urbanization from 1980 to 2013 on the Zhoushan islands, a typical island region undergoing rapid development in eastern coastal China. Strongly affected by the coastal economy of the mainland, it has been a notable center of marine economic development but also been one of the areas most threatened by human activities in recent years (Chen et al., 2013). Particularly, when the Zhoushan Archipelago was nominated as the first marine economic zone of China in 2011, this induced a sharp conflict between economic growth and ecological conservation (Chen et al., 2013; Li, 2013). Despite intense development in this region, though, there are few historical dataset of its urban development. The precise objectives of this study (Fig. 1) are to: (1) investigate the spatiotemporal dynamics of island urban expansion and trace the major land types contributing to the urban land growth over each study interval; (2) quantify the relationship between urban expansion and socioeconomic drivers; (3) discuss how human-dominated processes have influenced island urban growth over time, interacted with topographical variables and planning strategies; and (4) compare the different urban growth patterns among the various types of islands and cities. This historical study provides critical information for island economic development, decision-making and ecological management. It also highlights the importance of islands in the debate over urban studies and sustainability in the scientific community.

2. Materials and methods

2.1. Study area

The Zhoushan islands are located on the eastern seaboard of Zhejiang, China (Fig. 2), and they include four county districts: Dinghai, Putuo, Daishan, and Shengsi. The largest inhabited island, Zhoushan Island, is the centre of economy, culture, shipping, and fishing in this region. Most of the islands are nearshore within a 20-m ocean depth, and the main types of coastline are rocky coast and manmade coast, followed by gritty coast and muddy coast. The climate is typical of subtropical monsoon areas, with a mean annual temperature of 16 °C (Zhejiang Islands Investigation Staff, 1995). Dominated by hilly terrain, the study region lacks flat land, which has led to a long history of reclamation to meet development needs (Shao et al., 1999; Xu & Yu, 2003).

The superior natural and geographical advantages of the Zhoushan islands highlight the significance of this region during the last decade. The islands have experienced an unprecedented level of development concurrent with a series of strategic plans by the state and local governments, such as *The Overall Planning of Tidal Enclosures in Zhejiang Province (2005–2020)*, *Zhejiang Coastal Port Layout (2006–2020)*, *The Development, Utilization and Protection Planning of Important Islands in Zhejiang Province, (2011)*, and *Zhoushan Archipelago New Area (2011)*. Additionally, the municipal government completed a Peninsula Project in 1999 to build a cross-sea bridge between Zhoushan and the city of Ningbo to improve transportation in the area. The Ningbo–Zhoushan port has been ranked as one of the five most significant ports in the world. Similarly, the Zhoushan Islands Link Project was initiated in 1999 to strengthen regional development (Li, 2013). With the current marine economic boom in China, this region has great potential to accelerate economy and construction of port infrastructure.

2.2. Data sources and pre-processing

The main dataset used in this study are described as follows: (1) a series of multi-temporal remote sensing data (Landsat Thematic Mapper with a spatial resolution of 30 m for 1980, 1990, and 2000;

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