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Spatial heterogeneity of ecosystem health and its sensitivity to pressure in the waters of nearshore archipelago

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ABSTRACT

The ecosystem-based management of nearshore waters requires synthesis of spatial data on the distribution of ecological conditions and intensity of anthropogenic perturbations, and the overlay of their effects on the ecosystem health. An assessment framework for ecosystem health incorporating 4 components namely vigor, organization, resilience and maintenance was proposed in this paper, based on which an analytical approach was developed to quantify the integrated effects of island mass and anthropogenic pressures on the waters of nearshore archipelago. The southern waters of Miaodao Archipelago, which are located in the intersection of the Bohai Sea and the Yellow Sea, China, were taken as a typical example to acquire the spatial heterogeneity of the ecosystem health and its sensitivity to multiple anthropogenic pressures. Results indicated that there was a relatively significant performance of the spatial heterogeneity for the ecosystem health. It presented that the interisland waters were poorer health than the external waters, and the waters adjacent to the continent functioned less well than those in a relatively open area. This phenomenon was primarily determined by the performance of vigor as well as resilience of ecosystem. For the 4 components of ecosystem health, there were an obvious spatial heterogeneity of vigor as well as the resilience, a seasonal succession of organization, and a spatiotemporal uniformity of maintenance. Moreover, the ecosystem health was more sensitive to the stressors of inland activities and coastline exploitation especially in the waters of Miaodao Bay and Changdao Port. The analytical process and resulting maps provide flexible tools for regional efforts to implement ecosystem-based management in the waters of archipelago and further nearshore waters so as to promote their sustainable development.

1. Introduction

Anthropogenic perturbations as well as climate change have made increasing and complicated impacts on marine ecosystem nowadays (Lotze et al., 2006; MA, 2005). Halpern et al. (2008) has expounded that there is no maritime area unaffected by human activities of which 41% is strongly impacted by multiple pressures. The subsequent report showed that the overall index to assess the health and benefits of ocean concerning the exclusive economic zone is globally 60 out of 100 (Halpern et al., 2012). Nevertheless, the performance of ecosystem health varies both in the ecological conditions of habitats and in the intensity of anthropogenic impacts (Halpern et al., 2008). We urgently need integrated and quantitative approaches to guide how to map the spatial heterogeneity of ecosystem health and its sensitivity to multiple anthropogenic pressures and thus to connect human development to the capacity of ecosystem to sustain progress.

As a desired state of sustainable development (Costanza, 2012; Moldan et al., 2012), ecosystem health has been widely applied in the fields of aquatic, forest, grassland and marine ecosystem. It was primarily developed by Rapport (1989) and Costanza (1992) which was identified as the ability of ecosystem to maintain its structure and function over time in face of external pressure (Costanza, 2012; Costanza and Mageau, 1999; Rapport et al., 1998). Despite the difficulties in direct measure, efforts have been made to quantify ecosystem health, of which constructing an indicator system based on a causal or multi-component framework is a general approach (Chen et al., 2010; Ma et al., 2012a,b; Zhang et al., 2012a,b,c). In the field of marine and costal ecosystem, individual or multiple indicators are determined ranging from physicochemical and biological properties to the function and services of ecosystem according to the ecological questions raised (Chen et al., 2010; Halpern et al., 2012; Ma et al., 2012a; Peng et al., 2013; Rombouts et al., 2013). However, existing research principally focuses on the overall

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performance of health and few studies with respect to its spatial distribution are always at a national or global level (Shi et al., 2012).

For the waters of archipelago, compared to the coastal waters of a general continent, they are characterized by the habitat fragmentation due to the geographic isolation of islands which makes an influence on the ecosystem and is also called the effects of island mass (Blain et al., 2001; Gilmartin and Revelante, 1974). That means, there is a significant heterogeneity under a basically same environment of atmosphere within a relatively small scale in the aspects of water change, nutrients, primary productivity, plankton community, fish community, and so on (Blain et al., 2001; Gilmartin and Revelante, 1974; Harwell et al., 2011; Medina et al., 2007). Furthermore, the waters of nearshore archipelago have been suffering various human-induced stressors, which are derived from socioeconomic activities within oceanic islands and their surrounding waters as well as their adjacent continent and its coastal waters (Mueller-Dombois, 1981; Potter et al., 1993; Wang and Zhang, 2007). It makes much sense to understand how and how much the island mass and anthropogenic perturbations synthetically affect the health of the ecosystem in the waters of nearshore archipelago and how to quantify and map it. However, the assessment of ecosystem health of the waters of nearshore archipelago is often incorporated in that of the whole nearshore waters, leading to the lack of integrated and specific research on the archipelago waters especially on the spatial heterogeneity of ecosystem health and its sensitivity to multiple anthropogenic pressures.

An assessment framework and analytical approach were developed in this paper to quantify the integrated effects of island mass and anthropogenic pressures so as to map the ecosystem health in the waters of nearshore archipelago and its sensitivity to pressure. Taking the southern waters of Miaodao Archipelago (SWMA) located in the intersection of the Bohai Sea and the Yellow Sea of China as an example, the spatial heterogeneity of ecosystem health and its sensitivity to multiple anthropogenic pressures were illustrated. By doing this, we hope to facilitate the ecosystem-based management of archipelago and further nearshore waters so as to promote their sustainable development.

2. Materials and methods

2.1. Study area

Miaodao Archipelago, also named Changdao Island, belongs to Changdao County, Yantai City of Shandong Province, China. It is located in the Bohai Strait and the intersection of the Bohai Sea and the Yellow Sea (Fig. 1) and is characterized by a temperate, semi-humid continental and marine climate (Wang and Zhang, 2007). Therein, the southern Miaodao Archipelago, with a maritime area of 1200 km^2 and a terrestrial area of 31.5 km^2, is located between 2 waterways and adjacent to the north of Shandong Peninsula which is under a national strategy to advance its development (Fig. 1). The southern Miaodao Archipelago comprises 15 islands whose terrestrial areas are larger than 500 m^2 and shows a clustered pattern, causing an apparent appearance of habitat fragmentation. Among them, 5 islands are dominated with a terrestrial area larger than 1.0 km^2, namely South Changshan Island (S.C.I.), North Changshan Island (N.C.I.), Miaodao Island (M.I.), Large Heishan Island (L.H.I.) and Small Heishan Island (S.H.I.) (Fig. 1). It is with a depth less than 10 m in the west waters, more than 15 m in the east waters and less than 5 m in the Miaodao Bay located in the middle waters.

As the administrative and economic center of Changdao County, the southern Miaodao Archipelago is with a relatively stable resident population of 26,000 and an annual increase of 15% for its economic income of which the tourism and marine fishery are dominated. Additionally, there are multiple waterways surrounding the SWMA implying a very busy marine traffic due to its particular location (Fig. 1). Increasing human activities have altered the ecosystem of the archipelago waters and adversely affected its health (Zheng et al., 2014). An integrated and analytical approach is urgently required to guide ecosystem-based management of the SWMA so as to sustain human development.

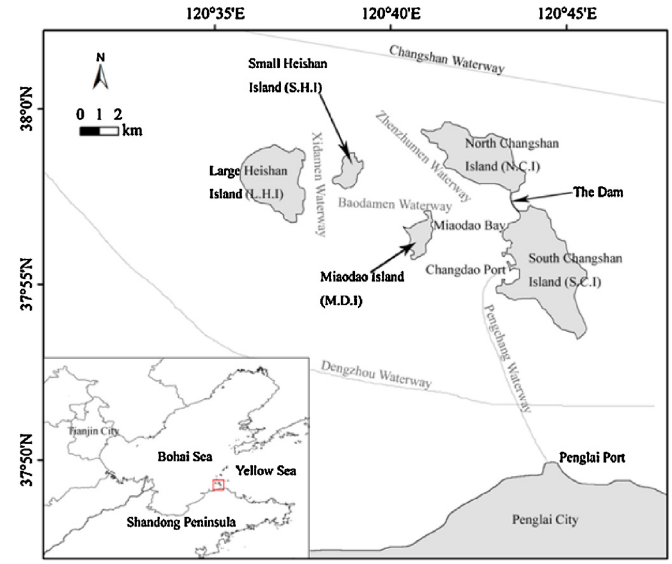

Fig. 1. Location of study area.

2.2. Assessment model

2.2.1. Indicator system

Based on the generally accepted attributes of ecosystem health (Costanza and Mageau, 1999; Halpern et al., 2012; MA, 2005; Rapport et al., 1998), an indicator system was proposed in this paper as shown in Table 1, according to the features of archipelago waters and data availability.

Particularly, besides the 3 primary attributes of ecosystem health namely vigor, organization and resilience, a component termed maintenance was put forward to describe the ability of system to maintain its associated services. That means, contrarily speaking, an additional indicator of decline in ecosystem health

Table 1
Indicator system of ecosystem health in the waters of nearshore archipelago.

1st grade indicators	2nd grade indicators	3rd grade indicators
1. Vigor (V)	1. Productivity	1. Marine primary productivity
2. Organization (O)	2. Community structure	2. Phytoplankton diversity
		3. Zooplankton diversity
3. Resilience (R)	3. Pressure	4. Stressors of inland socioeconomic activities in each island and adjacent continent
		5. Stressors of coastline exploitation in each island and adjacent continent
		6. Stressors of marine traffic in each adjacent waterway
	4. Correction factor	7. Current speed
4. Maintenance (M)	5. Habitat quality	8. Seawater quality

Note: The 3rd grade indicator of stressors of inland socioeconomic activities includes 2 sub-indicators namely resident population and economic income; the sub-indicators of seawaters quality refer to pH, dissolved oxygen (DO), chemical oxygen demand (COD), oil pollutant, volatile phenol, dissolved inorganic nitrogen (DIN), soluble reactive phosphorus (SRP), and so on.