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Integrated ecosystem health assessment based on eco-exergy theory: A case study of the Jiangsu coastal area

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ABSTRACT

The main objective of ecosystem health management is to preserve the capacity of ecosystems to respond to disturbances and future changes. We proposed a set of ecological indicators for coastal ecosystem health assessment using physical stressors such as total suspended matter, chemical stressors including nutrients and heavy metal pollutants, community structure metrics including species richness, diversity and evenness, and ecosystem level eco-exergy indicators. The results of our case study indicate that the health status of the Jiangsu coastal ecosystem is limited by environmental stressors and factors that affect the community species diversity. The health status of nektonic and benthic communities is reflected by water quality and sediment physicochemical properties, respectively. The results of our case study demonstrate that the integrated ecological health indicator system can provide a comprehensive assessment that corresponds with the current health of coastal ecosystems and a reliable theoretical basis for regional coastal management.

1. Introduction

Ecosystem health emerged as a new concept in environmental management in the 1980s. Ecosystem health assessment is now a fundamental factor in ecosystem protection and monitoring. Maintaining a healthy ecosystem is a key management objective for a growing number of environmental sectors. Therefore, a comprehensive and accurate indicator system for ecosystem status is urgently needed (Tang et al., 2013). Due to its complexity, a number of indicators ranging from single species to composite indicators have been proposed for ecosystem health assessment by ecologists, managers, philosophers, and even economists (Karr et al., 1986; Schaeffer et al., 1988; Rapport, 1989; Kay, 1991; Haskell et al., 1992; Norton, 1992; Ulanowicz, 1992; Xu et al., 2004; Beyer et al., 2014). Many attempts have been made to assess the health of ecosystems such as lakes, estuaries, lagoons, and agricultural areas (Fonseca et al., 2002; Xu et al., 2005, 2011; Zhang et al., 2007; Zhai et al., 2010; Brigolin et al., 2014).

Proposed indicators for assessing ecosystem health include ecosystem stress indicators (Rapport et al., 1985), gross ecosystem product (Hannon, 1985), single sensitive species (Munawar et al., 1994), eco-exergy and structural eco-exergy (Jørgensen et al., 1995), biodiversity and network ascendancy (Ulanowicz, 1986; Marques et al., 1997), and other reductionist and holistic indicators. Ecosystem health is a concept that integrates environmental conditions with the impacts of anthropogenic activities (Burkhard et al., 2008). Most of reductionist indices were found to be restrictive in terms of the integrity of the ecosystem as a whole (Zhang et al., 2012). For holistic assessments, indicator sets that combine different features have to be used. Spatial heterogeneity, multi-level phenomena, and multiple variables of interest at multiple timescales have to be taken into account with regard to the special characteristics of ecosystems. Marine ecosystem is a complex system influenced by wave, tidal currents, coastal currents, and other factors; therefore, the holistic indicators are more appropriate than the reductionist indicators. According to marine environmentalists, a group of indicators provides a more comprehensive determination of ecosystem health than a single indicator (Raftopoulou

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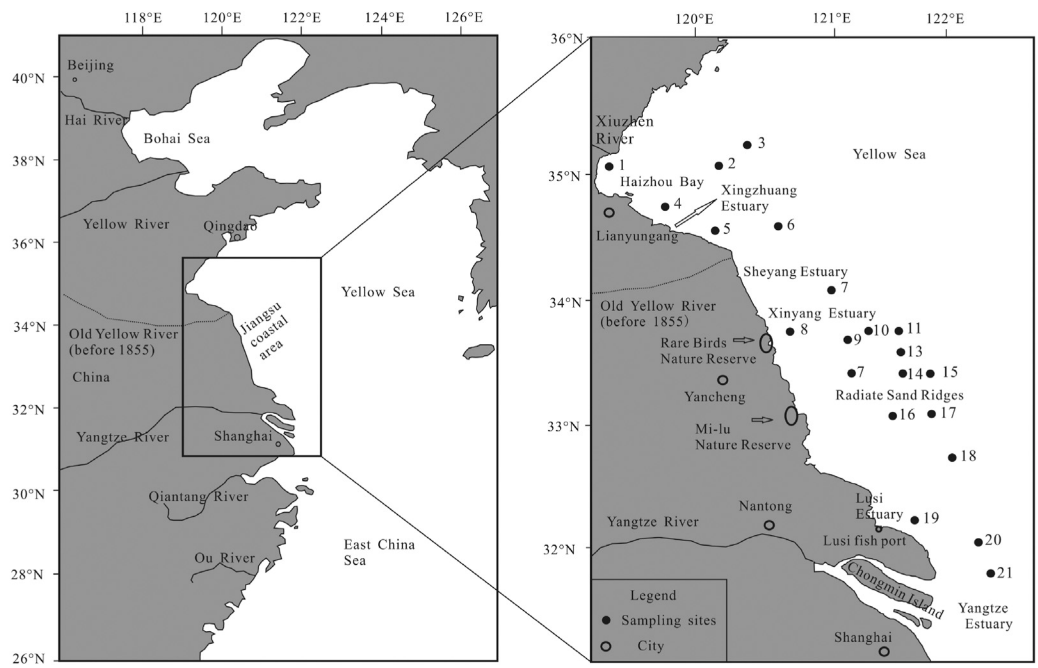

Fig. 1. Map of the study area with locations of the sampling sites.

and Dimitriadis, 2010). Therefore, an integrated ecological health assessment method may require the simultaneous application of multiple indicators (Karr, 1992; Zhang et al., 2012).

Exergy was first applied to ecological study in the late 1970's (Jørgensen and Mejer, 1977, 1979). Eco-exergy has a solid theoretical basis in thermodynamics, which can be used as a holistic indicator for ecosystem development and health (Jørgensen, 2006). It is closely related to information theory and other goal functions, and involves relatively simple computations (Jørgensen and Bendoricchio, 2001). It measures the distance in units of energy between a system's present state and the state in thermodynamic equilibrium with the environment. The two thermodynamic indicators of eco-exergy are derived from ecosystem theory (Jørgensen et al., 1995; Jørgensen, 2002; Xu et al., 1999) and have been the most useful indicators for ecosystem health assessment in recent decades.

Every species is subject to physical, chemical, and biological factors that constitute its habitat. Systematically determining environmental conditions is a critical step required for assessing ecosystem health (Herrera-Silveira and Morales-Ojeda, 2009). This procedure includes defining ecological quality or health status of coastal waters and sediments, which is a complex process due to natural gradients and variables that are intrinsic to coastal areas, and ongoing changes arising from human activities. Numerous indices and analytical metrics have been used in previous research to increase the credibility of coastal ecosystem health status assessments (Borja et al., 2004; Borja, 2005; Zhu et al., 2012).

The coastal area of Jiangsu Province of China is heavily impacted by fishing, marine transportation, aquaculture, agriculture, tourism, excess nutrients, and heavy metal concentrations in seawater or sediments, all of which are main factors in determining ecosystem status. All three regions in this area (i.e., Haizhou Bay in the North, Central Radial Sand Ridges, and Yangtze River Estuary in the South) have a wide range of biological resources. Community structure has been a basis for the evaluation of ecological health in the region. Therefore, our specific objectives are: (1) to establish a comprehensive relationship of eco-exergy theory with external environmental indicators and internal community structure in order to build an integrated framework to assess the health status of coastal ecosystem; (2) to study the relationships between the environmental and coastal communities with different health status; (3) to provide recommendations for integrated coastal ecosystem health assessment approach.

2. Materials and methods

2.1. Study area

Study sites were located north of the Yangtze River in the Jiangsu coastal area (30°45′–35°20′N, 116°18′–121°57′E, Fig. 1). The region has a monsoon climate ranging from warm temperate to northern subtropical. The Jiangsu coastal area extends 954 km from Xiuzhen Estuary south to the north shore of the Yangtze Estuary. The region belongs to twelve counties and urban districts of the municipalities of Lianyungang, Yancheng and Nantong. Sandy coasts and rocky coasts are found in Lianyungang, accounting for 3% and 4% of the Jiangsu coast, respectively, the rest (93%) is muddy coast (Zou, 2004).

Geomorphologic features vary along the coast of Jiangsu Province (Fig. 1). The 70 km northern coast is part of the North China Platform with a crust that is dominated by a long-term upward-force and is bordered by mountain scenery in the north of the Xingzhuang Estuary in Lianyungang. The central beach landscape from Xingzhuang to Lusi Estuary is dominated by erosion in the north because of the diversion of the Yellow River. However, the southern part is affected by tidal waves from both the East China Sea and the Yellow Sea. The southern Lusi Estuary is part of the Yangtze Platform Fold Belt and is characterized by the ongoing subsidence neotectonism. The Jiangsu coastal landscape was shaped during the diversion of the Yangtze River Estuary. Our research focused on nektonic and benthic communities in three different geographical areas (from north to south): Haizhou Bay, the Radial Sand Ridges, and the north shore of Yangtze Estuary, which encompass a variety of different hydrological, physiographic, and nutrient conditions.