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Wetland ecosystem integrity and its variation in an estuary using the EBLE index

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ABSTRACT

The estuary wetland in the coastal zone faces the risk of ecological integrity loss because of global environmental change and human activities. The evaluation of the estuary ecological integrity and its variation provides the basis for the environmental management of estuary wetland and coastal zone. In this study, we generalised the previous studies, extended the concept of estuary wetland ecological integrity and developed a multi-scale evaluation index system including environmental quality, biology and ecology, landscape pattern and ecosystem management (EBLE) based on dissipation theory. We applied the method to evaluate the ecological integrity in Jiulongjiang estuary in 2004 and 2009. The result indicated that the IEBLE scores in Jiulongjiang estuary were 0.64 in 2004 and 0.58 in 2009, and the IEQ, IBE, ILP and IEM scores were 0.72, 0.64, 0.57 and 0.60 in 2004 and 0.56, 0.62, 0.60 and 0.51 in 2009, respectively. The comprehensive scores had decreased in the past five years.

1. Introduction

Estuary wetland in the coastal zone is a special ecosystem formed by land-sea interaction. Its ecosystem usually consists of treasure wetland plant habitats, muddy sand beaches and numerous marine resources. Estuary wetland plays an important role in, e.g., resisting natural disaster, regulating runoff, improving local climate, controlling runoff pollutants and maintaining ecological balance in a region. In the past, the wetland area reduced 50% globally and faced a risk of deterioration because of natural causes and human activities (Stephanie et al., 2000). Currently, the pressures associated with human population growth, economic development, land use changes and climate change are common and can easily cause deterioration in estuary wetland ecosystems and their sea area (Cao and Wong, 2007; Dong et al., 2011).

The evaluation based on the proposed and developed ecological integrity theory provides a scientific basis for environmental protection and management. Researchers worldwide learned the importance of ecological integrity evaluation during the 1970s (Cowardin et al., 1979). Karr and Dudley (1981) considered ecological integrity to be the natural habitat in a region that is capable of keeping its equilibrium, integrity and adaptability. The ecosystem not only can maintain its equilibrium and biological integrity with respect to integrity but also provide different services to humans and society. Castela et al. (2008) found that ecological integrity of an ecosystem results from both structural and functional components. Whereas structural integrity relates to the quantitative and qualitative composition of communities and their resources, functional integrity refers to the rates, patterns and relative importance of ecosystem level processes. Li and Tian (2012) considered the ecosystem in a region to have ecological integrity if it could maintain the complexity, self-organisation ability and diversity of its structure and function under the impact of natural and human activities as time goes by.

The methods for studying aquatic ecosystem integrity is relatively mature, such as species indicator, species richness index (Qi, 2010), biological integrity index and pressure–response index (Zhang et al., 2005). However, the methods for studying terrestrial ecosystem integrity do not form an independent system (Huang et al., 2006). Andreasen et al. (2001) developed a terrestrial index of ecological integrity that integrates aquatic and terrestrial ecosystems in multiple scales. Zampella et al. (2006) used multiple indicators to study the ecological integrity in a coastal plain stream system that suffered from human-induced watershed alterations. Zhai et al. (2010) used the river ecosystem integrity index to predict the ecological integrity after a cascade hydropower dam construction on the mainstream of rivers. Reza and Abdullah (2011) demonstrated different compositional, structural and functional

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indicators of fragmentation, representativeness in protected area, ecosystem sensitivity and landscape connectivity for the development of the Regional Index of Ecological Integrity. Tönblom et al. (2011) indicated that forest cover is an effective bioindicator in headwater catchments for predicting the ecological status of headwater streams.

The methods used for evaluating the wetland ecological integrity are wetland elevation technique, hydrogeomorphic assessment (Federal, 1996; William and Gosselink, 2000), index of biotic integrity, habitat suitability index (Schroeder and Allen, 1992), index of butterfly riparian quality (Nelson and Andersen, 1994; Croonquist and Brooks, 1991; Chovanec and Raab, 1997), riparian, channel and environmental inventory and system for evaluating rivers for conservation (Raven et al., 1997). Borja et al. (2008) prepared an overview of the integrative tools and methods to assess the ecological integrity in estuarine and coastal systems worldwide. Viana et al. (2012) provided information on the ecological integrity of an industrial district and applied a selection of fish-based multi-metric ecosystem integrity indices. Michez et al. (2013) used a single aerial LiDAR dataset, new mapping tools and keystone riparian zone attributes to assess the ecological integrity of the riparian zone on a network scale.

The estuary wetland ecosystem is a special ecosystem located in the ecotone between a river or an ocean and land. It integrates the ecosystems of fresh water, marine, salt-fresh water, tidal flat wetland, Islands in estuary and shoal wetland. The estuary wetland ecosystem has spatial and scale heterogeneity. For space, differences in the environmental background value, species distribution and landscape types can be found. For scale, different kinds of ecological characteristics exist, from micro to macro scope. Moreover, human activities are usually intensive in estuary wetland ecosystems, which alter land use and obtain the ecosystem services from the region, thus posing a threat to the environmental quality of the region. We generalised and extended the previous concepts: an estuary wetland ecosystem has ecological integrity if its lands, waters, living beings and ecological structure and function are intact in different spaces and scales under pressure and can sustainably provide ecosystem service to humans.

In this study, we considered previous studies and the factors of environmental quality, biology and ecology, landscape pattern and ecosystem management according to dissipation structure theory in building the estuary wetland ecological integrity index system. We took the Jiulongjiang estuary as an example and studied its ecological integrity and its variations from 2004 to 2009 using a comprehensive evaluation method, with multiple sources of remote sensing data and field measurements, by using comprehensive evaluation method.

2. Methods

2.1. Comprehensive evaluation index system

2.1.1. Dissipation structure theory

According to dissipation structure theory, the ecosystem and the environment continuously exchange materials and energy to generate system internal gradient during the natural succession, observing the thermodynamics law. The system transforms the disorderly structure into a stable order structure through a self-organisation process (Huang et al., 2006). The order structure needs to continuously exchange materials or energy with the outside environment to sustain itself; this process is called dissipation structure (Nicolis and Prigogine, 1977; Prigogine et al., 1972). The ecosystem maturing succession process is the process of dissipating more input energy through self-organisation. The dissipative ecosystem has a strong energy capture ability, respiration and transpiration functions; more material and energy flow approaches; higher level nutrition structure; higher biodiversity; and larger biomass as self-organisation evolves (Schneider and Kay, 1994). In essence, these elements are the concrete ecosystem composition manifestation (i.e., physical, chemical and biological composition) and the ecological process integrity (i.e., ecosystem function) (Huang et al., 2006). The ecosystem possesses good integrity if it can maintain its organisation structure, stable state, resistance, resilience and self-organisation under external interference (Müller et al., 2000).

2.1.2. Evaluation index system

We built the estuary wetland ecological integrity comprehensive evaluation index system based on dissipation structure theory and the characteristics of the study region. Table 1 shows that the system is divided into four parts: environmental quality, biology and ecology, landscape pattern and ecosystem management. The whole index system is divided into four hierarchies, namely, target, rule, element and indicator layers, which correspond to hierarchy 1 (A), hierarchy 2 (B), hierarchy 3 (C) and hierarchy 4 (D), respectively. Environmental quality reflects the physical and chemical compositions; biology and ecology reflects the biological composition; landscape pattern indirectly reflects the structure and function of the region; and the ecosystem service indirectly reflects the eco-environment of the region.

2.1.3. Metrics of evaluation index

Some of the index values were obtained through direct measurement and the others through formula calculation.

2.1.3.1. Eutrophication status. The eutrophication status index was introduced to China in 1983. It is widely used by researchers to assess the eutrophication status in the coast of China.

$$E = \frac{\mathrm{COD} \cdot \mathrm{DIN} \cdot \mathrm{DIP}}{4500} \times 10^6 \tag{1}$$

Many researchers having a deep understanding of eutrophication found that different sea regions have different thresholds for Chemical Oxygen Demand (COD), Dissolved Inorganic Nitrogen (DIN) and Dissolved Inorganic Phosphorus (DIP). Chen et al. (2002) replaced 4500 by COD’, DIN’ and DIP’ because 4500 in the denominator represents the product of the COD, DIN and DIP thresholds in a specific sea region. The formula is expressed as:

$$E = \frac{\mathrm{COD} \cdot \mathrm{DIN} \cdot \mathrm{DIP}}{\mathrm{COD}' \cdot \mathrm{DIN}' \cdot \mathrm{DIP}'}, \tag{2}$$

where E is the eutrophication index. If $E \geq 1$, the water is eutrophicated. COD′, DIN′ and DIP′ represent the thresholds of COD, DIN and DIP, respectively, in a sea region.

The sea area of Jiulongjiang estuary is nitrogen rich and phosphorus deficient according to the eutrophication threshold studies in Xiamen Bay (Guo et al., 1998; Ji et al., 1996; Lin et al., 1992; Lin and Lin, 1999) and China seawater quality standard (GB3097-1997). We obtained 3.0, 0.29 and 0.023 as the thresholds of COD′, DIN′ and DIP′ in Jiulongjiang estuary, respectively.

2.1.3.2. Heavy metal ecological risk index. Heavy metal ecological risk index was used to evaluate the heavy metal ecological risk in sediments (Hakanson, 1980). However, the selection of a different background value caused different results. The sediment’s heavy metal potential ecological risk index in the region is expressed as:

$$E^i r = T^i r \cdot c^i f \tag{3}$$

$$c^i f = \frac{c^i s}{c^i n} \tag{4}$$