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An approach based on M-AMBI for assessing benthic ecological status of a broad intertidal zone: A case study in the Jiangsu intertidal zone, China

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ABSTRACT

Intensive anthropogenic activities have a serious negative effect on the Jiangsu coastal area of China, especially on the distinctive intertidal zone. Humans are trying to eliminate this effect by taking protection and eco-compensation measures. However, when trying to determine the ecological status and quantify the anthropogenic impact for this area, the complex relationship between ecosystems and environmental stress leads to difficulties in reflecting general environmental quality. This study assessed the benthic ecological status of 10 transects (three stations/transect) across six different typologies over six years (2007, 2009–2013) in the Jiangsu intertidal zone. A unitary assessment of each transect was conducted using the multivariate AZTI Marine Biotic Index (M-AMBI), along with a radar chart (and its parameters). In the Jiangsu intertidal zone, the ecological status was noted as good or moderate at most sampling stations. Among the six assessed years, 2010 had the highest ecological status, while 2007 had the lowest. As for transects, transect 1 had the highest ratings, and transect 3 had the lowest ratings. Various stresses and advantageous human intervention and contributed to the ecological status for the different areas. The M-AMBI could be used in the future as a suitable index to assess the benthic ecological status of the Jiangsu intertidal zone. In addition, the new unitary method validated in this study could be used to assess ecosystems with several small biotopes, while accurately reflecting environmental quality.

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1. Introduction

Coastal areas, with intensive anthropogenic activity, are vital to human society and the economy, with most of the global economic wealth being produced in coastal areas (Turner et al., 1995). In addition, coastal wetlands play an important role in maintaining species diversity, climate regulation, siltation prevention, and habitat provision, and thus have high ecological value (Cui et al., 2015). Thus, for coastal areas, impacts of intensive anthropogenic activity during rapid development are of concern.

Jiangsu is an eastern coastal province in China. Approval of development plans/strategies over the last twenty years, such as the “Maritime Su Dong” in 1995 and the “Jiangsu Coastal Development Planning” in 2009, has resulted in extensive coastal development in Jiangsu. Rapid industrialization and urbanization, especially the construction of coastal industrial parks, has resulted in large quantities of pollutants being discharged into the coastal area and serious damage to the coastal ecosystem. In addition, Northern Jiangsu Plain has always been a major region for grain production, and the excessive use of pesticides jeopardizes and undermines the coastal ecosystems. Other intensive anthropogenic activities (e.g., fishing, marine transportation, sewage discharge, aquaculture, and tourism) also have impacts on the environment (Tang et al., 2015). Meanwhile, a series of marine conservation activities has been implemented in Jiangsu coastal area to help the recovery of the ecosystems, including artificial propagation and release, and other eco-compensation measures. In order to understand the effect of recent developments and protections on the Jiangsu coastal area, an ecological status assessment needs to be conducted. This assessment will not only clarify the current situation, but will also provide a reference for future development and ecological protection plans.

To date, there has been very little ecological status research conducted in Jiangsu, and the research that has been undertaken has been at a relatively limited spatial and temporal scale. In terms of indices, chemical indices have been frequently used in the relevant studies (Liu et al., 2015), but there has been very little use of biological indices. Using data collected offshore (July–August 2006 and October–November 2007), Tang et al. (2015) assessed the ecosystem health of the Jiangsu coastal area by using thermodynamic indices, eco-exergy and structural eco-exergy, which are based on genetic information and biomass. However, in order to illustrate the ecological statuses of different zones over

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different years, new research needs to be conducted at a larger spatial (i.e., whole coastal area of Jiangsu) and temporal scale. In addition, alternative indicators that are more sensitive to human pressure need to be utilized.

Macrobenthos are the most extensively used biota for evaluating ecological status of water bodies, due to their rapid response to anthropogenic and natural stress, and unique community characteristics (e.g., relatively sedentary, long life span, different species composition with different tolerances to stress, and an important role in bioturbation and bioirrigation) (Borja et al., 2000; Dauer, 1993; Lohrer et al., 2004; Pearson and Rosenberg, 1978). In terms of bio-indices, according to the rank of benthic quality assessment indices, AZTI Marine Biotic Index (AMBI) and multivariate AMBI (M-AMBI) are relatively more responsive to human pressures (Borja et al., 2015). AMBI and M-AMBI were proposed by AZTI-Tecnalia to establish the ecological status of European coasts, according to the requirements of the Water Frame Directive (WFD, 2000/60/EC) (Borja et al., 2000). AMBI is based on a classification of macrobenthos species (ecological groups; EG) according to their different tolerances to anthropogenic stress; M-AMBI is a multivariate index that combines density, diversity (H′), and the AMBI of the benthic community, and is a comparison to a reference condition (REFCOND) (Borja et al., 2000). Both indices have been successfully used and validated in many case studies of various coastal areas of the North Sea, Bohai Sea, Yangtze Estuary (China), Yellow Sea, Norwegian Sea, Atlantic Ocean (lagoons and estuaries in eastern Florida, USA), Mediterranean Sea, and Indian Ocean (Nandgaon coastal water) (Muxika et al., 2007; Cai et al., 2013, 2014; Li et al., 2013; Borja and Tunberg, 2011; Paganelli et al., 2011; Sivaraj et al., 2014; Simboura and Zenetos, 2002; Simboura and Argyrou, 2010; Medeiros et al., 2012).

The WFD requires member states to assess the ecological quality status (EcoQS) of water bodies by setting REFCOND standards to enable the assessment of the biological quality by contrast (European Community, 2000). Several integrative approaches have been developed involving biological (Borja et al., 2000, 2009, 2011), chemical (Borja et al., 2004; Tueros et al., 2008), and physico-chemical components (Bald et al., 2005). For a water body, its REFCOND is a description of the biological elements, which corresponds totally, or nearly totally, to undisturbed conditions (as mentioned by the WFD). A type-specific REFCOND must summarize the spatial and temporal range of possibilities and values for the biological quality elements (Vincent et al., 2002). For deriving reference conditions, the WFD identifies four options: (i) comparison with an existing undisturbed site (or a site with very minor disturbance); (ii) historical data and information; (iii) models; or (iv) expert judgments. More recent studies on WFD requirements have proposed alternative methods for defining a REFCOND. For another multivariate benthic index, i.e., the BEQI (Benthic Ecological Quality Index) Level 3, REFCONDs were established based only on one third of the available time series (Van Hoey et al., 2007). However, lack of monitoring data with such a long temporal scale was common in most cases, thus necessitating “virtual” REFCONDs. In some applications of M-AMBI, REFCONDs were set based on the lowest AMBI value, and a 15% increase of the highest diversity (H′) and richness (S) values, for the assessed zone (Borja et al., 2010; Cai et al., 2013; Li et al., 2013). Multi-scenarios for REFCONDs were set and used by Forchino et al. (2011), including increased diversity (H′) and richness (S) and decreased AMBI. In this study, we set relatively rigorous REFCONDs with the same method: decreased (85% of the lowest) AMBI values and increased (115% of the highest) diversity (H′) and richness (S) values.

In this study, we combined the multivariate index (M-AMBI) with parameters of radar charts (for details, see Fig. 3, Eq. (1), (Cui et al., 2015) and (Afli et al., 2008)) to create a unitary assessment of ecological status and environmental stress of each transect, i.e., a certain district. Owing to the complexity of the Jiangsu intertidal zone, to ensure a thorough and accurate assessment of the ecological statuses, we (Turner et al., 1995) divided the whole intertidal zone into six typologies and established detailed reference conditions for use with the M-AMBI, and in other studies; (Cui et al., 2015) assessed (using AMBI and M-AMBI) the ecological status of the benthic communities in the intertidal zone for six years (2007 and 2009–2013); and (Afli et al., 2008) evaluated the general status based on the parameters of radar charts.

2. Materials and methods

2.1. Study area

The study was conducted in the Jiangsu coastal area (31°40′-35°20′ N, 116°18′-121°57′E, Fig. 2), which extends 954 km (from the Xiuzhen Estuary in the south to the Yangtze Estuary in the north). This area has a relatively flat coastline, and a monsoon climate ranging from warm temperate to northern subtropical. The region belongs to twelve counties and the urban districts of three cities (Lianyungang, Yancheng, and Nantong). The substrata and sediment varies across the region, with sandy and rocky coasts found in Lianyungang (3% and 4% of the Jiangsu coast, respectively), with the remaining 93% being muddy coast (Zou, 2004).

The intertidal zone of Jiangsu Province is very distinctive, with large tidal ranges (average of 2–4 m, with maximum of 9.27 m) and a strong tidal action. Estuaries of the Yangtze River and the Yellow River were once located in northern Jiangsu, and these rivers deposited an enormous amount of sediment, which contributed to the formation of one of the most typical mudflats in the world. The tidal flat in this coastal area extends 10–13 km, is 36 km wide, and has an average slope of 2% (Wang and Zhu, 1990). The intertidal zones are very broad, with clear upper, mid, and lower zones, and the benthic communities vary considerably between these zones. Ecological units in the tidal flat are distributed parallel to the coastal line, as shown in Fig. 1. In contrast, because of the tide, the environmental impacts from human activities spread across the ecological units. Because of the different layouts of the ecological and environmental impact units in the Jiangsu coastal zone, environmental impacts need to be assessed using a unitary ecological approach.

2.2. Data collection

This study was based on six years of data (2007 and 2009–2013). The 2007 data were obtained from the “908 National Marine Special Investigation Project.” The 2009–2013 data were obtained from the Marine Biological Survey conducted by the Institute of Oceanology & Marine Fisheries of Jiangsu. Biological samples were collected at 10 transects distributed along the intertidal zone, with each transect normal (shown in Fig. 1) to the coastline (Fig. 2). Three stations were distributed on each transect, representing upper, mid, and lower intertidal zones (30 stations in total). Samples were collected at high tide, from the upper to the lower zone, as the tide was ebbing. Each station contained four independent replicates (5 m between replicates). Each sample was collected (in November) within a 0.25 m^2 quadrat using a 25 cm × 25 cm × 30 cm sampler. The collected sediment was sieved through a mesh (0.5 mm) in order to obtain the macrobenthic organisms. Macrobenthic samples were preserved in 5% formalin (70% ethanol for polychaeta samples), until they were identified (lowest possible taxonomic level), counted, and weighted.

Given the differences in sediments and tidal levels at the different sampling sites, the 30 sampling stations were divided into six typologies, based on tidal zone (upper, mid, and lower) and sediment type (sand or silt and clay; Table 1).

2.3. Establishment of references

A REFCOND was established for each of the six typologies. For the high ecological quality status (high EcoQS, with the M-AMBI value, i.e., ecological quality rate (EQR), being 1), the lowest AMBI value was decreased by 15%. The highest diversity (H′) and richness (S) from the

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