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On approaches of estuarine ecosystems health studies

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ABSTRACT

This paper presents some points of view on the approach of estuarine ecosystem health scientific research based project experience of the Chinese Research Academy of Environmental Sciences (CRAES). A practical approach (functional zone designation, classification, grading and scheduling) is introduced for managing estuarine ecosystem health at the drainage basin scale. The importance of habitat assessment and functional zone designation is emphasized. The principles for selecting evaluation indicators are presented. The paper noted that Chinese national environmental quality standards should be further developed for emerging pollutants. Special attention should be given to sediment which is important contamination carriers and potential pollution sources.

1. Introduction

Estuaries are major corridors for the mass exchange between drainage basins and the sea. As the interface where land and sea interact, estuaries have been the focus of scientific research (Muxika et al., 2005; Sarkar et al., 2007; White and Wolanski, 2008; Wolanski et al., 2008; Wolf et al., 2009). Using bioindicators or other ecological indices, the health status of many estuaries which impacted by anthropogenic activities was also evaluated (Carrasco et al., 2007; Domingos et al., 2007; Carollo et al., 2009; Hagger et al., 2009). The primary requirements for a healthy estuarine ecosystem are that the system be stable and sustainable, with a strong resistivity to adverse external pressures. Healthy ecosystem must also meet the recreational requirements of surrounding communities. Unfortunately, estuarine ecosystems located at the downstream ends of drainage basins, frequently suffer significant degradation due to upstream development and associated water basin pollution. It is therefore important that the causes of such degradations are diagnosed and understood sufficiently that, where necessary, active measures can be taken to protect and restore the health of endangered estuarine ecosystems.

The following points of view on the approach of estuarine ecosystem health research are based on specific estuarine and coastal zone projects undertaken by the Chinese Research Academy of Environmental Sciences (CRAES).

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2. Managing estuarine ecosystem health at the drainage basin scale

Over the past few decades, lots of new technologies have been applied to monitor estuarine and coastal ecosystems and it can be anticipated that more and more measures will become available in the future. However, the value of data collected in estuaries only is limited for understanding estuarine ecosystems. The estuarine ecosystems are largely controlled by the quantity and quality of water, nutrients and sediment coming from inland (Jaworski et al., 1997; King et al., 2005). For example, the exogenous carbon in the Hudson estuary of the United States, a highly heterotrophic estuarine ecosystem, is mainly from the agriculture land erosion, with the most heterotrophic estuary corresponding to the most intensive agriculture activities (Howarth et al., 1996). Therefore, a healthy drainage environment must be preserved in order to maintain a healthy estuarine ecosystem. It is imperative that protection programs consider the interaction between groundwater, surface water and wetlands at the drainage basin level.

"Functional zone designation, classification, grading and scheduling" is a fundamental principle for developing pollution reduction plans. Functional zone designation recognizes the spatial differences within a drainage basin and enables different management policies for different functional zones. Classification associates distinctive control measures with specific pollutants. Grading establishes water quality targets for different functional zones, and scheduling implements stage-by-stage pollution control and considers seasonal variation.

The following approaches should be considered in developing a basin scale ecosystem health protection and restoration program:

1. Divide the basin into basic management zones whilst keeping the ecological integrity of the basin;
2. Take all aspects of the aquatic environment into consideration, including chemical and physical processes, habitat and biodiversity, as well as human health and more;
3. Prioritize predominant problems and required remediation measures;
4. Fully utilize expertise from all relevant disciplines, resources and government bodies (Meng, 2008).

3. Selecting evaluation indicators of estuarine ecosystem health

Selecting appropriate evaluation indicators is a crucial step in estuarine ecosystem health studies. It plays a decisive role for the subsequent evaluations. With the expansion of knowledge of estuarine ecosystems, indicators for diagnosing ecosystem health are continuously being enriched and improved. However, evaluations are often non-comparable due to the choice of different indicators for different evaluation objectives, areas of interest, focus of the studies and even personal academic interests of the scientists (Meyer, 1997; Kingsford, 1999). Moreover, due to the increasingly intensified change of the natural ecosystem, habitat fragmentation and species mutation, or even extinction caused by human activities, it is not realistic to establish an universal indicator system even for diagnosing the ecosystem health of the same estuary. Therefore certain flexibility should be permitted in selecting specific evaluation indicators for dynamic estuarine ecosystems whilst the rationalities and principles should be kept consistent in such selections to ensure that the evaluations are comparable.

Health evaluation indicators should provide:

1. Representation: Indicators should adequately convey the environmental status of a particular estuarine environment as a whole or of a particular aspect.
2. Coverage: Indicators should provide a comprehensive description of ecosystem status.
3. Comparability: Indicators should be spatially and temporally comparable, so that changes in ecosystem health over time and space can be evaluated.
4. Measurability: Indicators should be clearly defined and easy to measure.
5. Consistency: Indicators should be consistent and harmonized.

By way of example, CRAES evaluated the ecosystem health of the Yangtze River estuary using a “Pressure-State-Response” (“PSR”) model (OECD, 1993; Borja and Dauer, 2008). Twenty two (22) indicators were chosen for the three elements (Pressure, State, Response) of the model, including population density, compliance percentage of industrial wastewater discharges, non-compliance of COD of the discharges, benthos biodiversity index, and plankton diversity index. For each indicator, five levels of health status were designated: very healthy, healthy, sub-healthy, not healthy and sick. Using these indicators it was possible to evaluate the overall health of the estuary and its adjacent seas over time. The assessment revealed that the health of Yangtze River estuary deteriorated in the early years and then was recovering gradually from 1996 to 2005. In 2005 and 2006, it was in a sub-healthy status in general but a significant portion of it was in a not healthy or sick status. The whole ecosystem is not in a desirable condition. Controls of nitrogen and phosphorus should be further enforced throughout the whole drainage basin.

4. Estuarine habitat assessment and functional zone designation

Traditionally, a habitat is defined as a region inhabited by a specific organism. A broader perspective of ecosystem indicates that the habitat contains all environments on which consumers directly or indirectly depend when living there (Ayvazian et al., 1992).

In order to assess the health of ecosystems, to distinguish between natural fluctuations and human influences, and to minimize adverse impacts, it is essential to understand, both spatially and temporally, the habitat components and how they vary and interact with the key processes in the ecosystem. This is a prerequisite to the assessment of environmental quality and ecosystem health, and to the further delineation of zones for ecosystem restoration and management.

In a study of habitat classification and assessment for Tianjing coastal zones, the study area was divided into seven primary scale landscape elements, with each primary scale element further subdivided into several secondary elements, according to its ecological function and utilization. Thirty four indicators were selected for evaluating the environmental quality and ecosystem health, including: inorganic nitrogen, inorganic phosphorus, fresh water discharges, sediment loads, reclamation area, and discharges of pollutants. The assessment revealed that the pressures to the coastal habitat of Tianjing are mainly: (1) Intense utilization of land. From 1954 to 2000, the area of highly valuable ecological land decreased by over 50% due to coastal developments. (2) Decreases in water and sediment discharges. Since the 1960s, the fresh water and sediment discharges through the Tianjing segment of the coast into the Bohai Sea have decreased dramatically. The water and sediment discharges of the Haihe River have been near zero since the 1970s. (3) Increases in pollution discharges. The discharged pollutant of most concern is COD, followed by inorganic nitrogen, inorganic phosphorus, hydrocarbons and heavy metals such as mercury, cadmium, lead, arsenic, zinc and cyanide.

5. Emerging pollutants

Emerging pollutants may be ignored in estuarine ecosystem management as they are not well known. They may cause severe damage, and even lead to irreversible consequences, to ecosystem and human health once their concentrations exceed critical levels (Hoenicke et al., 2007). Nowadays the number of chemicals produced is difficult to know but estimated at as many as 100,000, still with around 1000 new chemicals emerging every year. For example, the organotin compounds such as tributyltin (TBT) and triphenyltin (TPT) have been extensively applied in industry and agriculture over the past few decades. Therefore, large amounts of organotin compounds have entered aquatic environments, and have subsequently been accumulated along the food chain. As estuaries receive many pollutants from their drainage basin, now the residues of organotin compounds have continually been found in many organisms which living in estuarine waters, including molluscs, fishes and marine mammals (Meng et al., 2009). Among these potential pollutants, efforts should be focused on screening of those chemicals that are bio-accumulative and have no typical degradation approach or prone to damage organism functions. Recently, Padmini et al. (2009) carried out a combination of biochemical and energy studies to observe the changes in fish liver mitochondria in response to environmental pollutant induced nitrative stress in natural field conditions. The fish samples were collected from polluted and unpolluted estuaries for a period of two years. The results revealed notable changes in the mitochondrial function and elevated mitochondrial heat shock protein 70 expression to a significant extent in fish from the polluted estuary than in the unpolluted estuary.

In China, the present "Surface Water Environmental Quality Standards" (GB3838-2002) do not specify standards for some of the more recently emerged pollutants such as Benzo-b-Fluoranthen, Benzo-k-Fluoranthene and n-propyl nitrosamines, which are already a concern in the Yangtze River estuary. It is important that water quality standards are further developed for emerging pollutants.

6. Sedimentation and the health of estuarine ecosystems

Most of the pollutants imported to estuaries from land will eventually deposit at the bottom. Therefore, pollution of the sedimentation environment will produce harmful effects on the aquatic organisms, especially benthos, which in turn impact on the ecosystem health. Sedimentary environment is a complex of multimedia, multi-components, and restrained by multiple dynamic factors. It controls to a large degree the exchange of the pollutants on the interface between the sediment and water, thus affecting the pollutant behaviour and its ecological effect. In general, in the estuarine water, if sediment deposits quickly, the exchange of the pollutant on the interface between water and sediment will be inhibited, whereas in the water where deposition is slow, the exchange will be remarkable.

In the context of estuarine ecosystems, sedimentation has the following characteristics:

1. Enrichment. The carrying capacity of sediment contaminated with pollutants is much higher than water, and therefore the concentrations of contaminants in sediments are usually several orders of magnitude higher than in water. Toxic pollutants invariably accumulate first in sediments and organisms.
2. Consequence and stability. Pollutant distributions in sediment deposition are consequential and relatively stable both spatially and temporally. The analysis of sediment deposition profiles could reveal both the average levels of contamination and the historical evolution of the environment.
3. Pollution Potential. Sediment can be both a "sink" for pollutants, and also a "source". Under certain conditions, pollutants can be released from sediment and endanger organisms, accumulate in food chains, and cause secondary contamination.
4. De-contamination. Once sediment is contaminated, it is extremely difficult to de-contaminate.

Take the polycyclic aromatic hydrocarbons (PAHs) as an example The PAHs with more than four rings accounted for the majority of the PAHs in sediment in the Yangtze River estuary and the adjacent sea, of which the predominant form of PAHs was Perylene with five rings. According to the annual records of total PAHs in Yangtze River estuary and its adjacent sea, in the past 50 years, the total content of PAHs drastically increased in the following three stages:

1. From 1960 to 1980, the total content of PAHs was low (25.44 ~ 53.25 ng/g). In that period, the whole industry in the Yangtze River estuary region was weak, and pollution sources in the vicinity of the estuary were rare.
2. From 1980 to 1990, the concentration of PAHs fluctuated but increased. In this period, the industrial economy in the Yangtze River estuary area grew rapidly.
3. From 1990 to 2006, the PAHs showed a rapidly increasing trend, with the highest concentration of PAHs reaching 567.35 ng/g in the surface sediment. Since 1990, China's industrial and agricultural economy had been developing rapidly. The environmental pollution became more and more serious at the same time.

The PAHs in the sediment around Yangtze River estuary and its adjacent sea resulted mainly from the incomplete combustion of land-based higher plants and fossil fuels. Ribeiro and Ferreira (2003) found that there existed a close relationship between the deposited PAHs flux in the column sediment sample and the amount of coal use. For example, the coal use in Europe and USA reached the peak in 1850, and the PAHs flux in the column sediment sample also reached the highest value in the same period. The deposition records of PAHs in the sediment in Yangtze River estuary also reflect well the economic change of the surrounding areas, and reflect from one aspect the impact of human activities on the natural environment.

In summary, the study and management of estuarine ecosystem health should be integrated at drainage basin scale with full spectrum considerations of spatial, temporal and functional variations within the system. Estuarine habitat assessment and functional zone designation should be further promoted. Special attention should be given to emerging pollutants and sediment as a pollution potential.

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