A Conceptual Ecological Model of Cangzhou Coastal Wetlands, Hebei Province, China

J.H. Tian, J.H. Wang*, Z.C. Liu, H.C. Li, X.Z. Wang, D.Y. Xie, Y.K. Tian, F.C. Liu, X.J. Yu

Cangzhou Teachers’ College, Cangzhou 061001, China

Abstract

Conceptual ecological models (CEM) are non-quantitative tools that identify the major drivers and stressors on ecosystems, the ecological effects of these stressors, and the best biological attributes or indicators of these ecological responses. Located in southeast Hebei Province, just west of the Bohai Bay, the Cangzhou coastal wetlands (CCW) are complex coastal wetlands formed and influenced under the dual driving forces from both rivers and oceans. They cover an area of 136 000 ha, which are mostly dominated by reservoirs, salt fields, shrimp ponds, tidal creeks, coastal brackish and marshes, shallow sea, as well as broad mudflat beaches. In recent years, population growth and economic development, rapid industrialization and urbanization, have result in severely wetland degradation and environment deterioration. A CEM has been developed for the CCW to understand the coastal wetland system and its response to natural and anthropogenic stressors. Drivers on the system are port construction, urbanization, industrial and agricultural practices, and water management. These drivers lead to five major ecosystem stressors: built-up area expansion, irrigation and drainage system, hunting and over-fishing, nitrogen and phosphorus input, and toxic pollutants input. Attributes that are affected by these stressors and can be used as indicators include fishes and aquatic fauna, wading birds, ecological and environmental events. As critical linkages between stressors and attributes, the ecological effects of the stressors are: reduced spatial extent, compartmentalization, altered hydrology, degraded water quality, and altered salinity regime.

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Key words: Conceptual ecological model; Coastal wetlands; Ecosystem management; Cangzhou; China

* Corresponding author.
E-mail address: annwt@163.com.
1. Introduction

1.1. Background

Conceptual ecological models (CEM) are non-quantitative tools that identify the major drivers and stressors on ecosystems, the ecological effects of these stressors, and the best biological attributes or indicators of these ecological responses. Properly developed CEM effectively capture the scientific understanding of an ecosystem and its response to natural and anthropogenic stressors [1]. CEM are flexible tools that, at any given time and place, reflect the current state of scientific knowledge about the landscape or ecosystem, and they can be used with any ecological conservation and restoration program and can become the primary communication, planning, and assessment link among scientists and policy-makers [2]. Wetland CEM are the most basically abstract models developed as means of analyzing, synthesizing, and organizing existing understandings of key ecological linkages of wetland components within an ecosystem management context [3, 4]. A CEM has been developed for the Cangzhou coastal wetlands (CCW) as a framework for supporting integration of science and policy and is a key component of ecosystem management just as those CEM used to guide ecosystem restoration in South Florida [5-12]. The purpose of the CEM developed for the CCW is to build scientific consensus regarding the drivers of major anthropogenic stressors on the wetland system, ecological effects of these stressors, and the best set of living indicators / attributes that can serve as measures of the responses of the system. This wetland CEM was developed by a multi-disciplinary team of local researchers and resource specialists during the period of 2002-2010. The model provides qualitative explanations of how natural systems have been altered by human drivers and ecosystem stressors, ecological effects of these stressors, and important ecological attributes or indicators, which in turn provides planners with the information needed to focus on the best design and assessment strategies for the coastal wetland ecosystem management.

1.2. Study area

Located in southeast Hebei Province, just west of the Bohai Bay, the Cangzhou coastal wetlands (CCW) are complex coastal wetlands formed and influenced under the dual driving forces from both rivers and oceans. Starting from Qikou estuary in the north to Dakouhe estuary in the south, the CCW covers an area of 136,000 ha, which is mostly dominated by reservoirs, salt fields, shrimp ponds, tidal creeks, coastal brackish and marshes, shallow sea, as well as broad mudflat beaches (Fig. 1). In recent years, population growth and economic development, rapid industrialization and urbanization, as well as intensive agriculture and aquaculture, have result in severely wetland degradation and environmental deterioration [13-15]. To date, many studies have been trying to reveal the eco-environmental problems of the coast zone, but these researches usually explain a certain aspect of the phenomenon, e.g. surface and ground water, sediment and biota [16-22]. So, in this article, the overall eco-environment situation of the coastal wetlands is attempted to be focused on by developing and using a CEM, which is used as a template for structuring an integrated regional assessment within an ecosystem management framework. Since this is the first time to analyze wetlands eco-environment situation in China using a CEM, this paper describes the method and process of the CEM development firstly, and followed with concrete analysis of the model components of the CCW.
Table 1. Conceptual ecological model development process

| Step | Delineate |
|------|-----------|
| 1    | Define the objectives and scales / boundaries |
3. Cangzhou Coastal Wetlands Conceptual Ecological Model

The Cangzhou coastal wetlands conceptual ecological model include three major external drivers, five stressors, five ecological effects, and three attributes that illustrate the major cause and effect linkages in the modeled region. A schematic diagram of the model is presented in Fig. 2. Drivers or driving forces (in rectangles) create stressors (in ovals) that have various effects (in diamonds) on the ecosystem, which are reflected in changes to ecosystem attributes (in hexagons). In the narrative text for the model, attributes are discussed before ecological effects though they are at the end of the pathway in the diagram. Chapters are organized in this manner to provide the reader with background information on stressors and attributes prior to reading the discussion of ecological effects and critical linkages that are the basis for causal hypotheses.
3.1. External drivers and ecological stressors

Major drivers affecting the Cangzhou coastal wetlands are identified: port construction and urbanization, industrial and agricultural practices, water management practices. These drivers lead to five major ecosystem stressors: (1) built-up area expansion; (2) irrigation and drainage system; (3) hunting and over-fishing; (4) nitrogen and phosphorus input; and (5) toxic pollutants input. Combined effects from these stressors explain much of the ecological changes that have occurred in this coastal wetland system. The three drivers, their respective stressors, and the ecological severity of the stressed condition in the ecosystem are briefly discussed below.

3.1.1. Port construction and urbanization

In order to transport coals from western China to the east, Huanghua Port has been built officially since the 1980s, along with Shuohuang Railway construction. Over 20 years, its scale has been kept enlarged. Various service equipments and subsidiaries increased ceaselessly around the port. On July 20, 2007, the Bohai Sea New Area of Cangzhou was established to be built according to “the master plan of Huanghua port” approved by Hebei Province government in February 9, 2007. An industrial agglomeration of marine chemical industrial, petrol chemical industrial, mechanical manufacture, and transportation are spring up quickly along the coast. With urban extension, a complex network of transportation including railways, expressways, highways, and stations has been constructed. On March 19, 2009, the Huanghua Comprehensive Port, budget of about $1.8 billion, started to be built to convert the port from single coal export to comprehensive and supplemental port areas. However, intensively anthropogenic influences, such as industrial area expansion, railway and road construction, and urbanization, have resulted in shrinkage in spatial extent and compartmentalization of natural wetlands, leading to the reduction of the suitable habitat and species of aquatic birds.

3.1.2. Industrial and agricultural practices

All five major ecological stressors acting on wetland systems, built-up area expansion, irrigation and drainage system, hunting and over-fishing, nitrogen and phosphorus input, and toxic pollutants input, have had parts or all of their origins in industrial and agricultural practices. Since 1980s, reclamation of wetlands for the purpose of using seawater to breed aquiculture and reclaiming land from the sea for the purpose of industrial zone construction have resulted in the loss of large areas of coastal wetlands. Simultaneously, large amount of wastewater, carrying land-source pollutants, have been discharged into the sea [23,24], leading to the worsening of environmental quality, the loss of species habitats and the lowering of biodiversity. In recent years, coastal industrial and agricultural development has been further accelerated. In 2007, the Bohai Sea New Area was established. It covers 240 000 ha and has a population of 550 000. According to current plans, three industrial parks, including Zhongjie, Nandagang, and a chemical park will be constructed, and a new Huanghua accommodating one million citizens will take shape within 10 years. As a result, more and more coastal wetlands will be altered. Wetland loss will become one of the main problems in this area.

3.1.3. Water management practices

In the past, there were lots of rivers, shallow lakes, and low-lying ponds in this area, which is called “tips of nine rivers”. Flooding, water-logging, as well as droughts occurred frequently. After the foundation of P. R. China, large-scale water irrigation and drainage network projects were constructed to support agricultural production and resident living. Water management practices have mainly included water supply, flood protection and tide control, which have been achieved by means of a complex network of irrigation and drainage system. For water supply, Nandagang reservoir, Yangcheng reservoir, and Huangzhao reservoir were built one after the other during 1960s~1970s. For flood protection, natural waterways were modified and artificial canals and ditches were constructed. For tide control, discharge gates and tide locks were built along the eastern border estuaries. With the development of irrigation and drainage system, straight, regular canals and ditches have replaced curving, shallow, natural flows and rivers. Dams, levees and water gates can be observed occasionally along the coast. The landscape patterns of sheet-
flow wetlands have been compartmentalized into an unnatural mosaic of ponded and drained salt fields and isolated marshes.

3.2. Ecological attributes

Attributes that are affected by those drivers and stressors can be used as indicators to be selected to reflect the overall ecological conditions of the system. In the CCW conceptual ecological model, we have chosen three major attributes including fishes and aquatic fauna, wading birds, ecological and environmental events as indicators to represent known or hypothesized effects of stressors.

3.2.1. Fish and aquatic fauna

Fish and aquatic fauna provide a food resource for animals that feed on them. This includes migratory waterfowls and a variety of fish. The over-fishing and the worsening environment have exhausted the fishing resources and broken down the aquatic ecosystem, which caused a drop in the biota productivity and spoiled the stability of the ecosystem. Jin [25] reported that the number of some high-valued species sharply decreased with their life-span and individual sizes becoming smaller. The dominant species had largely changed, while low-valued species which adapting well to the new and harsher environment had predominated in number. From the beginning of the 1980s to the end of the 1990s, the yield of Bohai Bay’s economic fish kept decreasing, but the yield of high-quality economic fish decreased by 90%, and low-quality fish became the main objects of fishing. On the one hand, aquatic fauna and communities are directly impacted by the volume and intensity of freshwater inflow and the range and rapidity of its variation. Point-source discharges of fresh water with waste heat into the bay via conveyance canals result in widespread, but ephemeral, salinity and heat fluctuations that deleteriously affect aquatic fauna and communities [26-28]. On the other hand, environmental contaminants, such as pesticides and heavy metals, can be concentrated on organisms through food webs. These bio-accumulated toxins can have significant effects on the health of populations of aquatic fauna and, ultimately, on survival of at least some species. Contaminants can also directly affect aquatic fauna without being bio-accumulated, particularly those species with gills or permeable body surfaces [29].

3.2.2. Wading birds

The Cangzhou wetlands along Bohai coastline are important feeding and breeding grounds for waterfowls and wading birds. CEM for other regions of the coastal wetlands, particularly the Florida Everglades CEM [30], present more detailed descriptions of the use of bird populations as ecological indicators and consider a wide variety of birds. For the Cangzhou coastal wetland CEM, we consider only waterfowls and fish-eating birds that are characteristic of the coastal and marine environment, such as whooper swan (Cygnus Cygnus), red-crowned crane (Grus japonensis), grey crane (Grus grus), black-winged stilt (Himantopus), pied avocet (Recurvirostra avosetta), kentish plover (Charadrius alexandrinus), great / little egret (Egretta alba), grey heron (Ardea cinerea), little tern (Stern albinus), white-winged tern (Chlidonias leucophaea), bean goose (Anser fabalis), white-fronted goose (Anser albinus), ruddy shelduck (Tadorna ferruginea), mallard (Anas platyrhynchos), green-winged teal (Anas crecca), oriental pratincole (Glareola maldivarum), and oriental white storks (Ciconia boyciana). These birds are important predators within the bay and are potentially impacted by any stressors that affect their prey base, including salinity changes, nutrient inputs, toxic compounds, and fishing pressure. As with other top predators, these bird species may also be especially vulnerable to toxic contaminants.

3.2.3. Ecological and environmental events

The Cangzhou coastal wetlands are severely impacted by the waste water discharge of the upstream polluted water. Polluted river, air, and soil will bring different levels of wetland pollution. Oil leak can directly lead to plant wilt and death of benthic organisms. In recent years, with the rapid development of the industry, port construction and urbanization, the aquaculture and the increase in population, the industrial and domestic waste water and the relevant pollutants increase dramatically, especially the massive discharging of nitrogen and phosphoric into the sea,
which aggravates the pollution and eutrophication in the coastal water unceasingly. E.g. red tides (algal blooms) occur more frequently and more seriously. The red tide happened in 1998 lasted for 40 days and covered an area more than 500,000 ha. In 1999, the red tide area reached to 630,000 ha which is considered to be the most serious disaster in the Bohai Bay. From 2000 to 2006, 80 times and about 1,980,000 ha of the red tide were recorded, which were 4.2 and 1.6 times than that of the 1990s in frequency and areas [31]. Damaged and loss of balance, the coastal wetlands have ever suffered from widespread droughts for several years. Water shortage, especially reduction of birds, resulted in infestations of locusts (Acrididae). For years, the region became one of the badly locust-infested areas along the country's eastern coast. So, local authorities had to use aircrafts to spray pesticides to kill the locusts, and this has inevitably brought some of environmental pollution, which in turn affected birds through the food chain.

The actually and potentially catastrophic events indicate that the Cangzhou coastal wetlands is facing a huge challenge to serious pollution. Large amount of land-source pollutants discharged into the Bohai Bay through coastal wetlands and accumulated is the principal cause that leads to the worsening of the Cangzhou coastal wetland ecosystem and the Bohai Bay eco-environment.

3.3 Ecological effects

As critical linkages between stressors and attributes, the ecological effects of the stressors in the CCW Conceptual Ecological Model are: reduced spatial extent, compartmentalization, altered hydrology, degraded water quality, and altered salinity regime.

3.3.1. Reduced spatial extent

With the development of coastal exploitations such as the port construction, railway and highway construction, aquiculture and industrial development and seawater desalination projects, large-area wetlands have been or will be occupied or damaged. Development represents a direct loss of spatial extent of the coastal wetlands through conversion of marshes to impervious surface and regular ponds. Spatial extent of natural wetlands in coastal zone has been reduced from an estimated 47,500 ha in the pre-drainage system to 15,000 ha in the current system (a loss of 68%). And these wetlands mainly remained in the Nandagang wetland, the Yangcheng wetland, and some riparian zone. The Nandagang wetland and the Yangcheng wetland are both reservoirs closed and protected by local authorities, and now become freshwater marshes resulted from water shortage, but comparatively high quality of eco-environment conserved in them. The large extent and comparatively longer hydroperiods that characterized the original coastal wetlands system made them the major bases for total primary and secondary production in the freshwater marshes and the most important refuges for survival of aquatic animals during dry seasons and years.

3.3.2. Compartmentalization

Physical alterations to the coastal wetlands include development and compartmentalization. Conversion of eastern portion of the southern coastal wetlands to the port and its infrastructure construction, middle portion to the Bohai Sea New Area to develop heavy chemistry industrial base, have reduced the spatial extent of aquatic habitat and production, essentially removing these areas from the natural ecosystem. Railways, roads and levees that isolate and dissect the coastal wetlands, geographically alter hydrologic patterns and break connectivity of wetlands to adjacent ecosystems. The CCW have been converted from a single, hydrologically integrated ecosystem to a collection of hydrologically independent systems. This change was brought about by the external network of transportation system, and internal network of levees and canals. Therefore, internal levees and canals have disrupted directions, timing and rates of sheet-flow and have created an array of regular salt fields and aquiculture ponds along the coastal belt. Canal flows have degraded water quality by introducing toxins and additional nutrients into interior marshes. Ponding, in place of strong seasonal and multi-year differences in flow rates and volumes has also contributed to disruption of dynamics of cycling and transport of nutrients and has substantially reduced levels of primary and secondary production in the system. Deep-water corridors and habitats have altered dynamics and sizes of fishes and have opened up to invasions by exotic fishes. Wading bird nesting colonies have moved away from traditional estuarine locations and have relocated around less productive pools that have been created in each impoundment.
3.3.3. Altered hydrology

The predominant hydrological effect in the past 50 years is the decrease of water and sediment discharges. Lei et al. [32] reported that the decrease of precipitation and natural runoff are partially responsible for the decrease of water and sediment discharges. Human activities such as the building of reservoirs, floodgates, and water and sediment division along river channels also contribute to the reduction. The decline of water and sediment discharge into the coastal zone has resulted in increased salinity, deterioration of water quality, and pollution of sediments, which have affected the estuarine ecosystem. Besides, the natural water system has been structured and modified to meet the need for water demand, flood protection and tide control. Taking the form of cumulative water-use withdrawals and over drainages, along with regulatory releases from reservoirs, wetland hydrology has been dramatically altered. Altered hydrology is exacerbated by physical changes made in the watershed, which include development of a complex network of canals at different levels, enlargement of rivers and canals to convey more water, and the addition of water-control structures, such as water gates, dikes, culverts, tidal barriers, which regulate flows and prevent tidal water intrusions. Man-made hydrologic modifications have dramatically altered natural quantity, quality, timing, and distribution of flows to the estuary, often without proper regard to the biological integrity of the estuary [33]. During the wet season (summer and fall), rainfall runoff that was historically retained within the undeveloped coastal wetlands now reaches the estuary in greater volume and in less time. Such rapid and unnatural fluctuations in volume can cause damage to estuarine organisms and communities, including impacts on submerged plant abundance and distribution, and may contribute to the loss of the natural gradient of grass species along the mouth of the river.

3.3.4. Degraded water quality

One of the importantly environmental effects is degraded water quality, which resulted from all of the three divers. Particularly from the direct stressors of the increase of nutrients including nitrogen, phosphorus loads, input of pesticides, heavy metals, and other toxic materials, originating as by-products from an array of agricultural and industrial practices, have been hypothesized to have had greatest ecological significance in alterations in water and soil quality in the coastal wetlands. Water management as a driver of nutrient and pollutant stress in that the canal system can transport materials through wetlands toward the Bohai Bay, decreased nutrient retention by wetlands and thereby increased inputs to the bay. Furthermore, the increase of water demand with the growth of economics and population, and the advancement of equipments and abilities of drawing water, especially over exploitation of the ground water, have resulted in the water quantity decrease and the water level drop, causing seawater invasion into the land, and leading to soil and ground water salted. Many studies have reported the water degradation and pollution of the Bohai Bay and its coastal waters. E.g. contamination levels and distribution characters of heavy metals in coastal waters and sediments reported by [19, 34]; cycle of carbon, nitrogen and phosphorus and algae bloom dynamics by [18, 21]; butyltins compounds contamination and potential adverse ecological effects by [35]; pesticides by [36, 37]. Furthermore, as the second largest crude oil production base in China, the Bohai Bay has over fifty offshore platforms, discharging about 9.9 million tons of petroleum-contaminated water into the sea, causing 30% of its water to fail water quality standards IV (State Oceanic Administration, 2006).

3.3.5. Altered salinity regime

Investigation in 1988 showed that the variation ranges from 30.74% to 33.17% within the offshore of Cangzhou coast. But coastal salinity regime varies greatly over space and time. E.g. from estuaries that can be nearly fresh (about 3%) during the wet season, to 40% of the salinity levels during prolonged droughts, to nearly stable marine conditions (about 32.18%) on the centre of the Bohai sea. Wu et al. [38] analyzed the salinity dynamic and its possible driver in the Bohai Bay, and showed that the salinity and its distribution have experienced a noticeable change, and mean salinity of the Bohai Bay has been increasing dramatically in the past decades. The region of the highest salinity is changed from the centre to the coastal area. These variations are caused by the rapid reduction of the runoff to sea as well as the increased evaporation from the sea surface due to the temperature rise. The runoff to the sea has been decreasing sharply since 1960s which mainly caused by natural and human factors in the Bohai Bay coastal zone. In the natural aspect, the precipitation presents descending tendency, but the land surface evaporation
increases in recent years under the background of a worldwide warming. In the aspect of human activity, many river sluices have been constructed in order to satisfy the increasing water demand because of the increasing population and the accelerated economic development of the basin. These activities cut off the surface runoff and decrease the water flux entering into the sea year by year.

4. Summary

Unique location and resource merit make the CCW one of the priorities and hot spots of economic development. However, with the population growth, rapid economic development, urban expansion, large areas of original coastal wetlands have been transforming into built-up areas. Especially in recent years, along with the accelerated building of coastal economic zone, a large number of urban factories have been moving to the coastal area which is relatively cheap in land prices. Intensive economic activities coupled with policy and management vacancies, leading to large areas of wetlands transformed, rivers destroyed, air and soil polluted, and the coastal eco-environment has worsened dramatically. The Cangzhou coastal wetlands CEM can help to understand the eco-factors of driver-stress-effects-attributes and their causal relationships between each other, and provide a reliable basis for ecosystem assessment and management.

Acknowledgements

This study was financially co-supported by the National Natural Science Foundation of China (NSFC 40971110) and Scientific Project of Department of Education, Hebei Province, China (Z2008102).

References

[1] Gentile JH, Harwell MA, Cropper Jr W, Harwell CC, DeAngelis D, Davis S, et al. Ecological conceptual models: a framework and case study on ecosystem management for South Florida sustainability. The Science of the Total Environment 2001; 274: 213–253.

[2] Ogden JC, Davis SM, Jacobs KJ, Barnes T, Fling HE. The use of conceptual ecological models to guide ecosystem restoration in South Florida. Wetlands 2005; 25: 795–809.

[3] Cui BS, Yang ZF. Research advances in wetland ecosystem models. Advance in Earth Sciences 2001; 16: 352–358.

[4] Wang JH, Tian JH, Li XY. Study of wetland conceptual ecological models based on ecosystem management. Ecology and Environmental Sciences 2009; 18: 738–742.

[5] Crigger DK, Graves GA, Fike DL. Lake Worth Lagoon conceptual ecological model. Wetlands 2005; 25: 943–954.

[6] Davis SM, Childers DL, Lorenz JJ, Wanless HR, Hopkins TE. A conceptual model of ecological interactions in the mangrove estuaries of the Florida Everglades. Wetlands 2005; 25: 832–842.

[7] Davis SM, Gaiser EE, Loftus WF, Huffman AE. Southern Marl Prairies conceptual ecological model. Wetlands 2005; 25: 821–831.

[8] Havens KE, Gawlik DE. Lake Okeechobee conceptual ecological model. Wetlands 2005; 25: 908–925.

[9] Ogden JC, Davis SM, Barnes TK, Jacobs KJ, Gentile JH. Total system conceptual ecological model. Wetlands 2005; 25: 955–979.

[10] Simp S, Lucie estuary and Indian River lagoon conceptual ecological model. Wetlands 2005; 25: 898–907.

[11] Rudnick DT, Ortaer PB, Browder JA, Davis SM. A conceptual ecological model of Florida Bay. Wetlands 2005; 25: 870–883.

[12] VanArman J, Graves GA, Fike D, Loxahatchee watershed conceptual ecological model. Wetlands 2005; 25: 926–942.

[13] Liu JL, Hu JY, Wan Y, An W. Distribution of pentachlorophenol in sediments and water from Haihe Basin and Bohai Bay. Environmental Chemistry 2006; 25: 539–542.

[14] Nie HT, Tao JH. Eco-environment status of the Bohai Bay and the impact of coastal exploitation. Marine Science Bulletin 2009; 11: 81–96.

[15] Yuan D, Lin B, Falconer RA, Tao J. Development of an integrated model for assessing the impact of diffuse and point source pollution on coastal waters. Environmental Modelling & Software 2007, 22: 871–879.

[16] Liu C, Wang ZY, He Y, Wu YS. Evaluation on the potential ecological risk for the river mouths around Bohai Bay. Research of Environmental Sciences 2002; 15: 33–37.

[17] Liu C, Wang ZY, He Y, Wu YS. Investigation on sediment quality of the river mouths around Bohai Bay. Acta Scientiae Circumstantiae 2003; 23: 58–63.
[18] Liu H, Yin BS. Annual cycle of carbon, nitrogen and phosphorus in the Bohai Sea: A model study. Continental Shelf Research 2007; 27: 1399–1407.

[19] Mao TY, Dai MX, Peng ST, Li GL. Temporal–spatial trend analysis of heavy metals (Cu, Zn, Pb, Cd, Hg) in Bohai Bay in 10 Years. Journal of Tianjin University 2009; 42: 817–825.

[20] Meng W, Qin YW, Zheng BH, Zhang L. Heavy metal pollution in Tianjin Bohai Bay, China. Journal of Environmental Sciences 2008; 20: 814–819.

[21] Wei H, Sun J, Moll A, Zhao L. Phytoplankton dynamics in the Bohai Sea, observations and modeling. Journal of Marine System 2004; 44: 233–251.

[22] Zhou H, Zhang ZN, Liu XS, Tu LH, Yu ZS. Changes in the shelf macrobenthic community over large temporal and spatial scales in the Bohai Sea, China. Journal of Marine Systems 2007; 67: 312–321.

[23] Qiu J, Liu RZ, Zhao JZ, Deng HB. Establishing eco-compensation mechanism in Bohai Sea waters under framework of ecosystem approach. China Population, Resources and Environment 2008; 18: 60–64.

[24] Hu LM, Guo ZG, Feng JL, Yang ZS, Fang M. Distributions and sources of bulk organic matter and aliphatic hydrocarbons in surface sediments of the Bohai Sea, China. Marine Chemistry 2009; 113: 197–211.

[25] Jin XS. The dynamics of major fishery resources in the Bohai Sea. Journal of Fishery Sciences of China 2000; 7: 22–26.

[26] Montague CL, Ley JA. A possible effect of salinity fluctuations on abundance of benthic vegetation and associated fauna in northeastern Florida Bay. Estuaries 1993; 16: 707–717.

[27] Irlandi E, Macia S, Serafy JE. Salinity reduction from freshwater canal discharge: effects on mortality and feeding of an urchin (Lytechinus variegates) and gastropod (Astraea tecta). Bulletin of Marine Sciences 1997; 61: 869–879.

[28] Browder JA, Alleman R, Markley S, Ortner P, Pitts PA. Biscayne Bay conceptual ecological model. Wetlands 2005; 25: 854–869.

[29] Duever MJ. Big Cypress regional ecosystem conceptual ecological model. Wetlands 2005; 25: 843–853.

[30] Ogden JC. Everglades Ridge and Slough conceptual ecological model. Wetlands 2005; 25: 810–820.

[31] Lin FA, Lu WX, Luo H, Ma MH. History, status and characteristics of red tide in Bohai Sea. Marine Environmental Science 2008; 27: 1–5.

[32] Lei K, Meng W, Zheng BH, Hou XM, Sun YC. Variations of water and sediment discharges to the western coast of Bohai Bay and the environmental impacts. Acta Scientiae Circumstantiae 2007; 27: 2052–2059.

[33] Barnes T. Caloosahatchee Estuary conceptual ecological model. Wetlands 2005; 25: 884–897.

[34] Wang CY, Wang XL. Spatial distribution of dissolved Pb, Hg, Cd, Cu and As in the Bohai Sea. Journal of Environmental Sciences 2007; 19: 1061–1066.

[35] Yang RQ, Zhou QF, Liu JY, Jiang GB. Butyltins compounds in molluscs from Chinese Bohai coastal waters. Food Chemistry 2006; 97: 637–643.

[36] Wang YW, Yang RQ, Jiang GB. Investigation of organochlorine pesticides (OCPs) in mollusks collected from coastal sites along the Chinese Bohai Sea from 2002 to 2004. Environmental Pollution 2007; 146: 100–106.

[37] Liu WX, Chen JL, Lin XM, Tao S. Spatial distribution and species composition of PAHs in surface sediments from the Bohai Sea. Marine Pollution Bulletin 2007; 54: 97–116.

[38] Wu DX, Mu L, Li Q, Bao XW, Wan XQ. Salinity dynamic and the possible driver in Bohai Sea. Progress on Nature Science 2004; 14: 191–195.