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The Bohai Sea

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1. physical features

The Bohai Sea and its adjoining upper Yellow Sea (Figure 1) is a C-shaped semi-enclosed continental shelf sea in northern China in the northwest of the Pacific. The Bohai Sea is situated in temperature latitudes with a climate influenced by monsoon system. It can be divided into five parts: Liaodong Bay, Bohai Bay, Laizhou Bay, Central part and Bohai Strait. It is a shallow water body with an average depth of 18 m, the area which depth less than 30 m accounts for 95%. The total area is 77,000 km^2 with about 350 km wide from west to east and 555 km long from south to north. The water volume is approximately 1,700 km^3. It has a coastline of nearly 3,170 km and has about 45 rivers runoff inputting into the Bohai Sea along the coast, including the Yellow River, the Luanhe River, the Liaohe River, and several more smaller rivers.

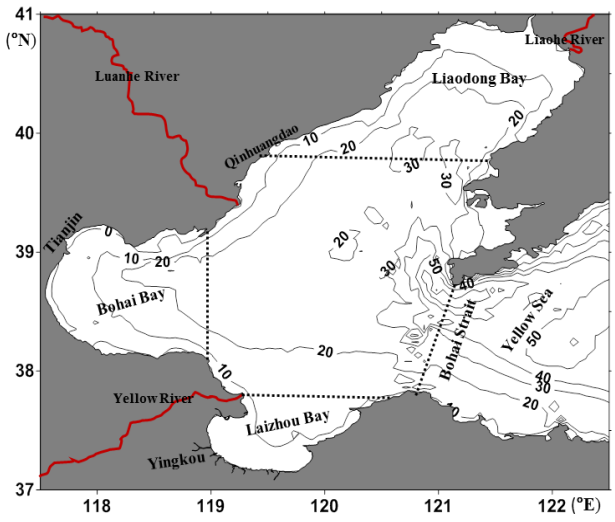

Figure 1: The Bohai Sea and its watershed. The rectangular box inside defines the Central part.

The Bohai Sea strait is the only waterway connecting the Bohai and the Yellow Sea. It is about 90 km wide with a maximum depth of about 70 m in the northern channel and a mean depth of about 20 m in the southern region where there are also several islands and shoals obstructing the through-strait flow.

In the Bohai Sea, the motion of water masses is dominated by semidiurnal and diurnal tides, which account for about 60% of the current variation and kinetic energy there. The net flow through the Bohai Strait is mainly driven by the wind and long waves in the Yellow Sea and it is very small; indeed the net rate of water exchange/flushing of the Bohai Sea is very small, so that the average water residence time exceeds 1 year (Li et al., 2015 and 2018). Thus the Bohai Sea is very much an enclosed sea following EMECS's definition.

The Yellow River was the world's second largest river in terms of sediment load over the last several thousand years. However the water discharge has sharply decreased (Figure 2) since 1950 due to the water regulation by dams and reservoirs, and the annual mean of sediment discharge has decreased from 1.6 billion tons/yr before 1950 to < 10 million tons/yr. In turn this has generated major ecohydrology changes and stresses to the Bohai Sea (Wu et al., 2016; and references therein). At present water is in short supply in the catchment and additional water is now imported in the catchment from the Yangtze River via the South-North Water Transfer Project but probably none of this water ultimately reaches the Bohai Sea (Li and Chen, 2019).

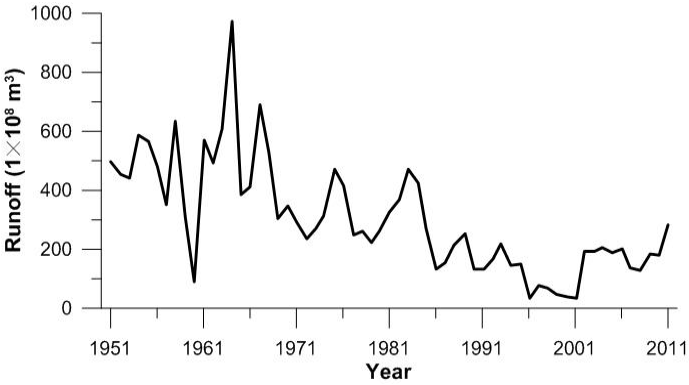

Figure 2. Annual runoff of the Yellow River.

Several oceanographic studies of the Bohai Sea have been carried out. Huang et al. (1999) and Li et al. (2015) investigated the baroclinic circulation in the Bohai Sea due to seasonal density variations; they found that the inflow from the Yellow Sea was mainly confined to a narrow passage in the northern Bohai Strait, but the outflow was weak in the rest of the strait. Based on half-life water quality model, Wei et al. (2002) pointed out that there were evident regional variations for exchange ability distributed in different areas. Laizhou Bay has the highest water exchange rate, while Liaodong Bay, especially in the northwest part, has the lowest water exchange rate. Hainbucher et al. (2004), using a three-dimensional, prognostic baroclinic hydrodynamics model, calculated turnover times and taken into account comprehensive environmental conditions, such as river runoff, wind, tides and thermohaline effects except surface waves. By calculating water age of Yellow River in the Bohai Sea, Liu et al. (2012) found that tidal forcing was the dominant role for water renewal in the Bohai Sea, followed by the wind forcing. Wave actions significantly impact the spatial distribution of suspended sediment in the Bohai Sea (Wang et al., 2014) and the temperature pattern in the Yellow Sea (Zhang et al., 2011).

2. Ecological impact

These changes to the water and sediment input, combined with the rapid economic development and urbanization over the past few decades around the Bohai Sea, have changed the ecosystem of the Bohai Sea. Following the economic reform in the "Bohai-Rim-Economic" initiated in 1985, various impacts on the Bohai Sea have emerged resulting from the intense urbanization, mud flat reclamation, rapid industrialization, and intense aquaculture (Figure 3) have emerged.

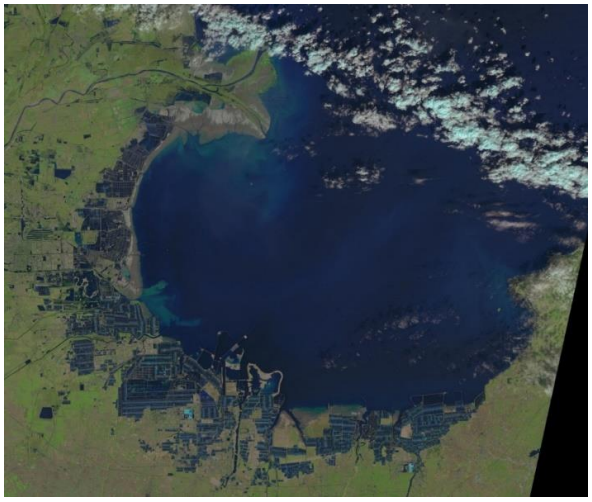

Figure 3. Intense coastal developments in Laizhou Bay.

The Bohai Sea receives ~ 40% of the sewage discharge from the entire country every year. The marine ecosystem has been heavily contaminated also by the input and discharge of toxic chemicals through the atmosphere, runoff, and surrounding rivers. In particular, water pollution in the Liaohe, Haihe, and Huanghe estuaries is the most serious. In 2016, in spring and summer, about 23,720 and 23,770 km^2, respectively, of seawater did not reach first class seawater quality. Compared to the mid-1980s, the water quality has substantially deteriorated. For instance the Secchi depth of water visibility in summer had decreased from 8.7 m to 3.9 m. The average DIN concentration in the Bohai Sea increased by approximately 7% per year and the area with excess DIN criteria increasing by 1% per year. Trace metals of As, Cr, Pb and Zn in the seawaters had high concentration. In the Bohai Sea the major risk agents were Hg and Pb, and localized risk was Cu, while the risk from Cd was at an acceptable level. Recently plastic pollution has been recognized as an additional serious, emerging threat to the ecosystem (Li et al., 2018).

As a result, the Bohai Sea has become a particularly vulnerable area and its ecosystem is being rapidly degraded. For instance, also influenced by fishing activities, the fish community structure has changed such that the mean trophic level of the fishing catch has decreased by 0.2 per decade. The relative biomass has declined to only 4.3% in 1998 of that in 1982. In Laizhou Bay the biomass of fishery resources has from 164.6 kg $haul^{-1}$ h^{-1} in 1982 to less than 8 kg $haul^{-1}$ h^{-1} in 1998-2008.

3. Environmental problems in the Bohai Sea

Due to the high development of the Bohai Economic Rim, the coastlines are suffering severe pressure, from both coastal erosion and reclamation. Algal blooms occurred increasingly from 2000 to 2014 with an average size of ~2,600 km^2. Owing to the high level of nutrients inputs and long water residence times, the Bohai Sea is susceptible to summer hypoxia. While bottom acidification was observed in summer induced by remineralization of local biogenic organic matters originating from frequent harmful algae blooms and intensive aquaculture. Also the occurrence frequency and disaster category of giant jellyfish has continuously increased. Since 2008 the increased jellyfish had seriously affected fishery resources and safety of beach swimmers.

(1) "Red tides"

Since the beginning of the 1990s, harmful algal blooms (HAB) events have become more frequent in the Bohai Sea and have greatly affected aquaculture, tourism, and marine ecology in this area. Most occurrences of "red tides" are in the summer time, during June to August. There are four areas with a high frequency: Bohai Bay, the coastal waters of Qinhuangdao and Yingkou city, and the Yellow River Estuary. From 1952 to 2014, HAB events occurred a total of 172 times. There were 99 occurrences affecting areas less than 50 km^2, 12 affecting areas of 50~100 km^2, 33 affecting areas of 100~500 km^2, 7 affecting areas of 500~1,000 km^2, and 21 affecting areas larger than 1,000 km^2. The event in 1989 occurred in the Bohai Bay caused an economic loss of 2 billion yuan with an area of 1,300 km^2. However, between 2000 and 2014, HABs with massive extents occurred 11 times, indicating that they have become more frequent. Since 2010, the annual mean area of red tides in the Bohai Sea exceeds 2200 km^2. Around Qinhuangdao there are micro-algal bloom occurred in six successive years, and in 2012 the maximum area covered over 3,400 km^2, with a duration of 1~2 months. In 2016 in the Bohai Sea there was 10 events covering a total area of 740 km^2.

(2) Hypoxia

Past investigations in the Bohai Sea have not recorded hypoxia, although the dissolved oxygen concentration (DO) in the bottom water has decreased since 1979. Recent studies found a minimum DO value of 3.2 mg/L in August 2011. The minimum DO value in August 2014 was 2.56 mg/L, nearing hypoxia (defined as DO less than 2 mg/L); there were two oxygen-deficient zones with DO less 2.94 mg/L. Hypoxia in the Bohai Sea is transient and seasonal. Considering the rapid population growth and economic development, the situation is not optimistic, as the DO concentration in the bottom water will likely continue to decrease, and the exposure time of hypoxia is expected to lengthen. Increasing harmful algal blooms are conductive to its formation.

(3) Jellyfish blooms

Jellyfish blooms in pelagic ecosystems are regarded as a response to anthropogenic disturbance and climate change and can cause numerous deleterious consequences for industry and the community, such as reduced fishery production from the competition for food with fish, clogging of intakes of coastal power plants, and stinging of swimmers. The decline of fisheries in the East China Sea and the Yellow Sea is believed to be associated with the increase of jellyfish blooms. In the autumn of 2003, a bloom of the jellyfish *Nemopilema nomurai* occurred in the East China Sea with an average biomass of 1555 kg/ha and the maximum biomass of 15,000 kg/ma, consequently, the CPUE of the commercial fishery for *Pseudosciaena polyactis* declined 20% during the period of the bloom. In 2004 in Liaodong Bay of Bohai Sea the bloom of jellyfish *Cyanea nozakii* caused approximately 80% decline of edible jellyfish Rhopilema esculentum and about US$70 million direct economic losses. Now jellyfish blooms are becoming an annual event in the Bohai Sea, Yellow Sea and northern East China Sea. *A. aurita* blooms usually occurred in July and August in Qinhuangdao and Shandong province. In July 2008 over 4,000 tons of *A. aurita* were cleaned up from the clogged intake screens in a coastal power plant of Qinhuangdao. Subsequently, in August 20~50 tons of *A. aurita* were cleaned up from the clogged intake screens in the coastal power plant of Weihai. From July 7 to 8 in 2009, over 10 tons of *A. aurita* were cleaned up in the coastal power plant of Qingdao.

(4) Seagrass beds

Owing to the impact of human activities and global change, the seagrass beds in the Bohai and Yellow Seas have been severely degraded. Taking Weihai city as an example, more than 90% of seagrass fields have disappeared within the past 20 years, with a disappearance rate much greater than the global rate from 1879 to 2006 (29%). At present, there are two seagrass fields in the Bohai and Yellow Seas, the Shandong seagrass field and the Liaoning seagrass field. The total area of Liaoning seagrass field is about 100 ha with *Zostera marina* dominated, while in Shandong seagrass field is less than 300 ha and mainly exists along the coast of Rongcheng city, such as Yue Lake (~191 ha), Sanggou Bay (60 ha), Lidao Bay (30 ha), and Shuangdao Bay (5 ha), which has two main types: *Zostera marina* beds and *Phyllospadix iwatensis* beds. These four sites are the main research bases for seagrass in both the Bohai and Yellow Seas. There are other sporadic distributions of seagrass along the coast of Yantai, Dongying, and Qingdao cities and Laizhou Bay.

(5) Natural coastlines

Reclamation activities conducted in the Bohai Sea were intensive from 2001 to now. The total area of the Bohai Sea that is landfilled is 2,803.5 km^2 with an average annual landfill of 87.61 km^2 from 1982 to 2014. In recent 10 years, the total area of reclamation was about 53 km^2, making the natural coastline loss of more than 40 km per year. In 2011, the natural shoreline had shrunk to 26.7%. These coastal reclamations have a historically cumulative effect on water quality, the benthic environment and the ecosystem health (Ma et al., 2017), and affects the breeding and nursery areas

for fish and seabirds in Bohai Bay and Laizhou Bay. This is contributing to a regional decline of shorebirds migrating through the East Asian- Australasian Flyway (Murray et al., 2015; Fang, 2019).

Another significant factor influencing coastlines is coastal erosion. The Bohai Sea coast has suffered from heavy erosion in recent years. The mean erosion rate of the coastline is about 1.0~2.0 m yr^{-1}, and up to 5~8 m yr^{-1} in some places. This erosion mainly occurs on the sandy coasts of the Liaoning, Hebei, and Shandong Provinces and Tianjin city, and almost all of the sandy coasts of the Bohai Sea are now severely eroded. The erosion of the coastline of the Bohai Sea accounts for 46% of the total coastal erosion in China. It manifests itself as coarsening beach sand, berm narrowing, steeper gradients, and increase of bare rocks, which seriously restricts the development of beach tourism.

4. Environmental conservation of the Bohai Sea

The Bohai Sea is considered as one of the most polluted marine areas in China with negative effects on human health and welfare, the economy, the environment and the quality of life. Addressing this issue is difficult because there are multiple stressors such as mudflat reclamation, coastal erosion, land and marine-based pollution, climate change, overfishing, while intensive shipping and oil pumping have resulted in further threats of oil spills to ecosystems. Ecological disasters such as red tides and jellyfish blooms now frequently happen.

Since 1978, China has formulated a series of laws and regulations, including “Territorial Sea and the Contiguous Zone Law of the People's Republic of China,” “Exclusive Economic Zone and the Continental Shelf Law of the People's Republic of China,” “Marine Environmental Protection Law of the People's Republic of China,” and the “Fishery Law of the People's Republic of China.” The State Council and relevant departments of the state also formulated a series of administrative regulations and department rules, such as the Plan of Cleaning Action for Bohai Sea, the Integrative Governance Actions of the Bohai Sea, the Action Plan of Management on Bohai Coastal Resources and Environmental Management Strategy of Bohai Sea. The promulgation and implementation of these laws and regulations play an important role in promoting better management of marine resources and improved environmental protection in the Bohai Sea. In addition, three provinces around the Bohai Sea also have formulated a series of regulations for local marine environmental protection, such as “Measures for the administration of environmental protection in Tianjin City (1996),” “Marine Environmental Protection Ordinance in Shandong Province (2004),” “Marine Environmental Protection Measures in Liaoning Province (2006)” and “Environmental Protection Ordinance in Hebei Province (2005)”.

Billions of yuan have been spent in slowing down, halting and finally reversing the environmental deterioration of the Bohai Sea. In 2001, China launched a 15-year program called “Bohai Sea Action Plan” to regulate and restore the ecosystem of the Bohai Sea with a budget of about 55.5 billion yuan, about 6.7 billion US dollars. The goal of the program are that by 2015 the Bohai Sea’s environment could improve markedly and its ecosystem could improve preliminarily. However the program did not gain the expected satisfying achievements and it seems that no major improvement has been accomplished after more than 12 years since the program was implemented. Thus in 2008 another 40 billion yuan (about 5.8 billion US dollars) was planned to be invested in remediating and surveillance, and building the warning and emergency systems during the 11th five-year plan of China. This is very much work in progress.

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