

Long-term variations in biogenic elements of the Bohai Sea and the North Yellow Sea

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Abstract. Based on in situ data of the Bohai Sea and the North Yellow Sea from 1975 to 2000, inter-annual variations in the concentrations of dissolved oxygen (DO), phosphate, and silicate were analyzed. The results showed that DO exhibited a decreasing trend during the last 25 years, and that the trend in winter was stronger than that in summer. Furthermore, we found significant negative correlations between DO and the temperature of sea water, which were stronger in winter than in summer. During the last 25 years, phosphate and silicate concentrations declined with extreme yearly fluctuations. Moreover, the concentrations of phosphate and silicate reached a historically low value in the mid-1980s (1984–1987) during summer. In winter, phosphate concentrations fluctuated, but silicate concentrations showed a significant decline.

1. Introduction

Dissolved oxygen (DO) concentration, an index of seawater quality, plays an important role in marine ecosystems. The production of marine organisms and the decomposition of organic matter affect the concentration of DO, thus affecting marine activity. Nutrients, one of the important indicators for quantifying seawater eutrophication, affects the primary production of phytoplankton in the Bohai Sea (BS) and the North Yellow Sea (NYS), which are known to be high productivity areas and have attracted considerable attention recently. Environmental studies of the BS have focused on physical and chemical oceanographic processes and circulation modeling [1,2]. Few studies have dealt with the spatio-temporal distribution and variations of nutrients. Lin et al. discussed the long-term variations in sea-surface temperature, sea-surface salinity, and air temperature and their influence on the ecosystem using data collected at a few coastal stations during 1960–1997[3]. Zu et al. noted that the DO concentrations of BS showed a gradually decreasing trend in summer and winter from 1979 to 2000. Further, the concentrations of phosphate and silicate decreased in summer, but there was no obvious increasing or decreasing trend in winter [4].

Studies on DO and nutrients in the Yellow Sea tend to focus on the southern Yellow Sea, which showed decreasing trends in the concentrations of DO, phosphate, and silicate between 1976 and 2000 [5,6]. However, there are few studies on the inter-annual variability of DO and nutrients in the NYS. The purpose of this paper is to discuss the concentrations of DO and nutrients by analyzing multidisciplinary environmental parameters related to changes occurring in the DO and temperature from 1975 to 2000, aimed at understanding the level of nutrients and the changes in the phytoplankton



community structure. These investigations can provide basic data support for local environmental protection and sustainable development.

2. Data and methods

2.1. Study area and data

We used data from two seasonally monitored stations (A and B) located in the BS and NYS (Fig. 1). These data were collected by a specialized and skilled survey team of the State Oceanic Administration (SOA) from 1975 to 2000. The data included seawater temperature (T) and biogenic elements such as DO, phosphate (PO₄-P), and silicate (SiO₃-Si). The observations were conducted once in every season (February, May, August, and November) of each year of the study period. The station A (120.0°E, 38.9°N) and station B (122.1°E, 38.1°N) represent the BS and NYS area, respectively. According to the climatic characteristics of the study area, we chose August and February to represent the summer and winter season, respectively, and analyzed the variation in the characteristics of DO and nutrients.

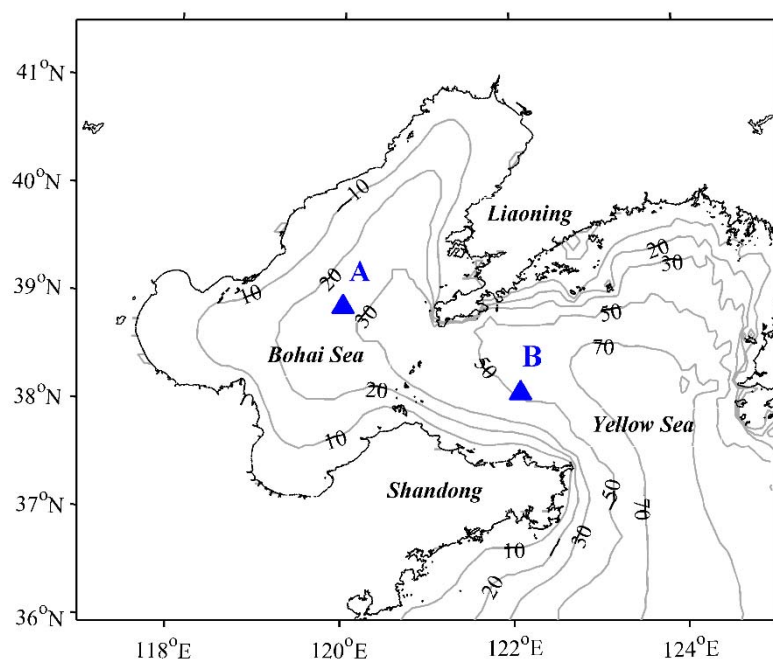


Figure 1. Sketch of the geographical locations of the stations in the BS and NYS.

2.2. Methods

Due to the wide range of sources and large time span, the data format and quality were different. Therefore, it was necessary to control the quality of the measured data. The observational data was processed by World Ocean Atlas before analysis. Sampling depths were 0, 10, 20, 30, and 50 m and the bottom layer was considered for T, DO, and nutrients. Here, we only analyzed the concentrations of DO and nutrients on the surface layer (0 m). We also calculated the standard deviation of the concentrations. If the difference between the measured value and the annual average was more than three times the standard deviation, it was treated as abnormal data and hence not considered. For the entire study period (1975–2000), the monthly mean data were used to analyze the inter-annual variation of DO and nutrients using a linear regression method for trend analysis.

3. Results and discussion

3.1. Changes in seawater DO and temperature

During 1975–2000, DO concentration of the BS and NYS was significantly reduced in winter (Fig. 2a and b). The declining rate of DO in the BS and NYS was 0.031 and 0.025 mg/(L·a), respectively. DO concentrations in the BS changed little in summer compared to that in winter, except in the year 1988, when the concentration decreased in the range of 4.50–5.50 mg/L and DO in the NYS slightly decreased in summer. Zu et al. analyzed the long-term changes of DO in the BS from 1979 to 1999 and found that the DO concentration generally shows a decreasing trend both in winter and summer, which is consistent with the results of this study.

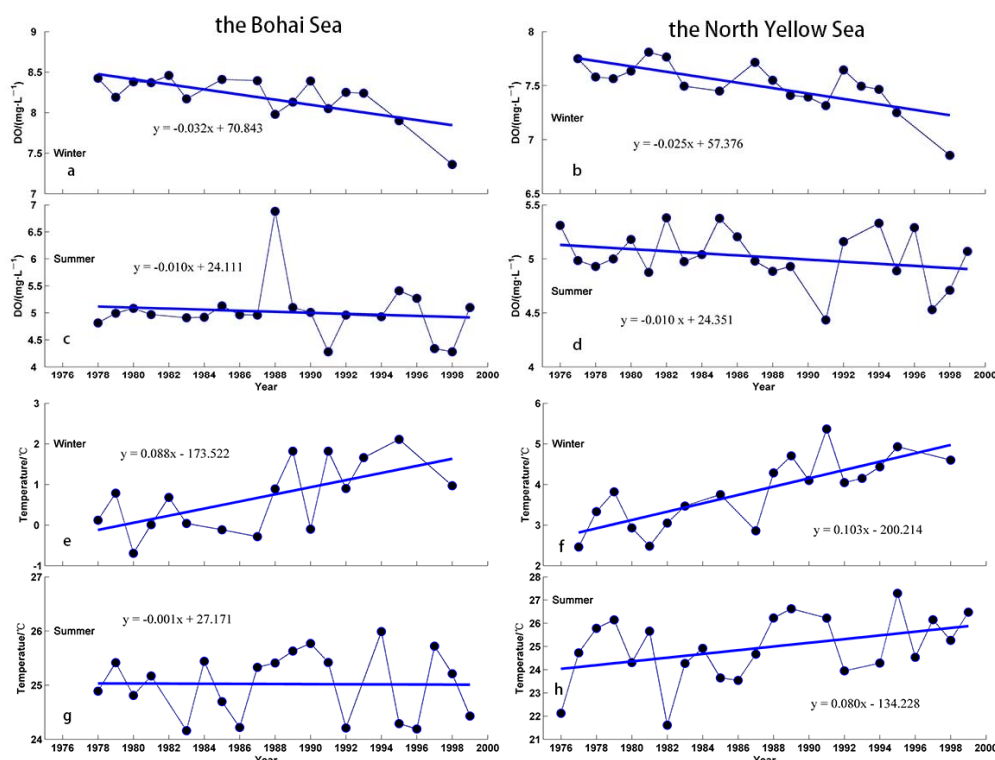


Figure 2. Variation trends of DO in the BS and NYS. (a) and (c) show the annual means of the average DO in the water column in winter and summer and (e) and (g) show the temperature in the water column in winter and summer in the central region of the BS, respectively. (b), (d), (f), and (h) show the trends of the same parameters as (a), (c), (e), and (g), respectively, in the NYS. Blue lines represent linear regression.

It is generally known that gas in seawater is significantly affected by temperature. Combining the curves of DO and seawater temperature, there is a negative correlation between DO and T (Table 1). In addition, we found that the negative correlations between DO and T were stronger in the NYS, with the absolute values exceeding 0.60, than in the BS, and they were stronger in winter than in summer, which indicated that temperature is a major factor affecting DO concentration in the study area. Comparing the correlations between temperature and DO in different seasons, it was found that the correlation between seawater temperature and DO concentration was stronger in winter than in summer, which indicated that the effect of winter seawater temperature on DO concentration was stronger than that of summer seawater temperature, because the number of phytoplankton which also effects the DO in seawater decreased greatly in winter, and then seawater temperature becomes the main factors. Of course,

temperature was not the only factor affecting DO in seawater. Photosynthesis of phytoplankton, decomposition of organic matter, nitrification by ammonization, and oxygen consumption by the sediments also affected seawater DO. On the one hand, the reason for the decrease in DO concentration was the seawater temperature increasing during 1975–2000. On the other hand, the decrease in phytoplankton production and the increase in zooplankton also resulted in a decrease in DO concentration.

Table 1. Correlation coefficient between DO and T.

Season Area	Summer	Winter
BS	-0.22	-0.68
NYS	-0.61	-0.83

3.2. Changes in seawater nutrients

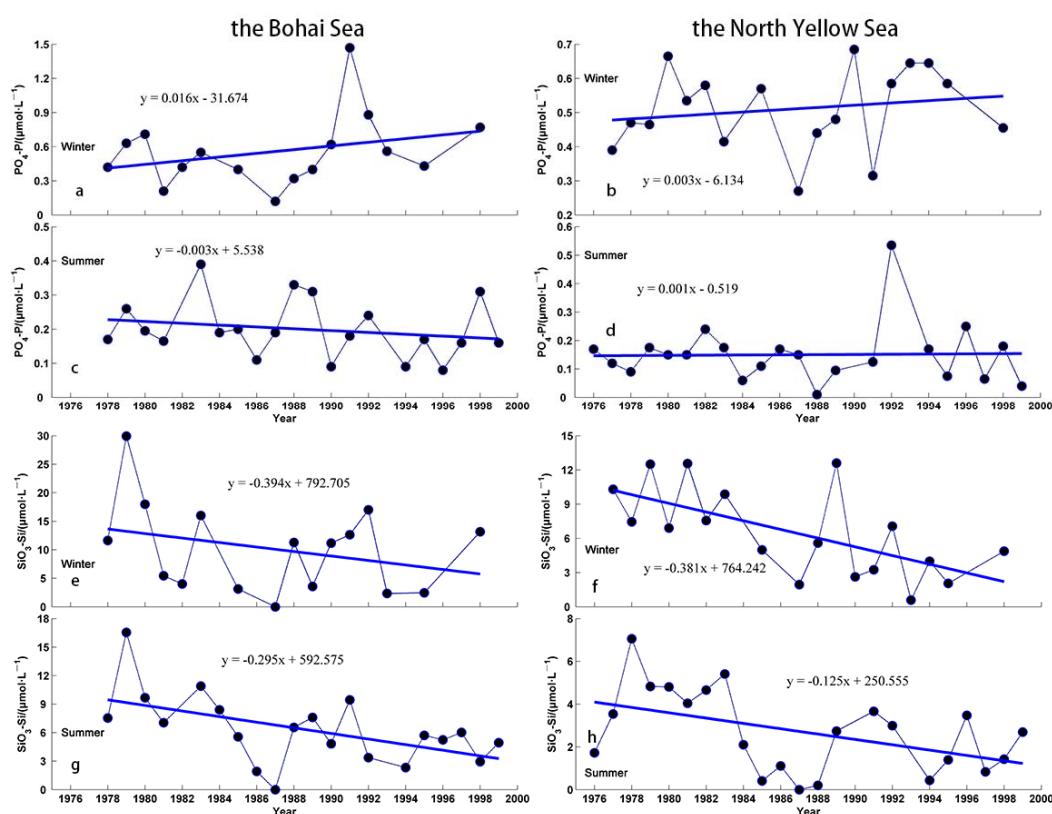


Figure 3. Similar to Fig. 2 but shows annual means of average PO₄-P and SiO₃-Si in the water column.

In winter, the fluctuation in phosphate concentration in the BS decreased before the mid-1980s and the phosphate concentration dropped to its lowest level of the study period in the mid-1980s (1987). After the mid-1980s, the phosphate average concentration increased to 0.7 μmol/L during the 1990s (Fig. 3a), whereas silicate concentration in the BS showed a significant decreasing trend with large fluctuations during the study. However, in the NYS, the phosphate concentration in winter fluctuated

during the study period. Further, the silicate concentration also showed a significant decreasing trend, especially in the mid-1980s (1984–1987).

From the mid-1970s to the mid-1980s, the phosphate concentration in the BS decreased in summer and dropped below $0.2 \mu\text{mol/L}$. Silicate concentration also showed a significant decrease and dropped to nearly zero in summer in the mid-1980s. Subsequently, until the late 1990s, the phosphate and silicate concentrations in the BS fluctuated within the range of $0.1\text{--}0.3 \mu\text{mol/L}$ and $3.0\text{--}9.0 \mu\text{mol/L}$, respectively (Fig. 3c and g). From 1975 to 2000, the results of linear regression showed that the silicate concentration in the BS showed a decreasing trend compared to the phosphate concentration, and the decreasing rates of both were 0.295 and $0.003 \mu\text{mol}/(\text{L}\cdot\text{a})$, respectively. In the NYS, phosphate concentration in summer fluctuated within the range of $0.2\text{--}0.3 \mu\text{mol/L}$. The silicate concentration in the NYS in summer showed an overall weaker downward trend than that in the BS. The silicate concentration dropped to its lowest value, below $2.0 \mu\text{mol/L}$, in the mid-1980s. After then, the concentration slightly increased, with silicate concentration showing fluctuations in the range of $2.0\text{--}8.0 \mu\text{mol/L}$.

After the mid-1980s, the inter-annual variation in the silicate concentration was significant. In the 1990s, although the concentration of nutrients fluctuated, it was lower than that in the 1970s. The reasons for the inter-annual variation in the concentration of nutrients in the study area are complicated. The variation in runoff to the sea, the change in the plankton community structure, and human activities may affect the concentration of nutrients in the study area. On the one hand, the emergence of many factories and fisheries along the coast, the rise of aquaculture, and the increase in inorganic nitrogen in the seawater due to the large amount of nitrogenous fertilizers entering the sea caused phosphate and silicate consumption of plants to increase, leading to structural changes in nutrients, with the N/P ratio increasing almost linearly. On the other hand, during the 1980s and 1990s, many interceptions occurred in the northern rivers of China, especially the Yellow River runoff was suspended for as long as 119 days during the 1990s (1995), which partly explained why concentration of nutrients in the BS and NYS was lower in the 1990s than in the 1970s.

4. Conclusion

Based on the historical data of DO and nutrients from 1975 to 2000 in the BS and NYS, the inter-annual changes in DO and nutrients were analyzed. The results were as follows:

DO of the BS and NYS showed a decreasing trend during the study period, and the decreasing trend in winter was stronger than that in summer. The negative correlation between DO and T in winter was more significant than that in summer. In winter, the DO concentration of the BS and NYS showed a significant decrease, with decreasing rates of 0.031 and $0.025 \text{ mg}/(\text{L}\cdot\text{a})$, respectively. The increase in seawater temperature was one of the main factors causing the decrease in DO in the study area. The DO in summer was also affected by the quantity of phytoplankton and the decomposition of organic matter.

Phosphate and silicate concentrations in winter decreased gradually during the 25-year period in the BS and the NYS, decreasing significantly to near-zero levels in the mid-1980s (1984–1987). Both in the BS and NYS, winter silicate concentrations dropped significantly. In summer, concentration of nutrients in the study area also showed the lowest values in the mid-1980s. This paper argued that the main reason for the decrease in phosphate and silicate concentrations was the increase in inorganic nitrogen, resulting in phosphate and silicate consumption by phytoplankton. Moreover, the reduction in the runoff to the sea caused the silicate concentration in the 1990s to be lower than that in the 1970s.

Acknowledgments

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