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Difference of Nutrients Budgets in the Bohai Sea between 1982 and 1992 related to the Decrease of theYellow River Discharge

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Difference of Dissolved Inorganic Phosphorus (DIP), Dissolved Inorganic Nitrogen (DIN) and Dissolved Silicate (DSi) budgets in the Bohai Sea between 1982 and 1992 related the decrease of the Yellow River discharge is discussed on the basis of observed data. The estuarine circulation in the Bohai Sea had been weakened from 1982 to 1992 due to the decrease of the Yellow River discharge and the average residence time of fresh water had become longer. DIN concentration increased but DIP and DSi concentrations decreased from 1982 to 1992 in the Bohai Sea. Primary production was regulated mainly by water temperature and DIN concentration in 1982 but it was regulated mainly by DIP concentration in 1992. Primary production was larger than decomposition plus bottom release and nitrogen fixation was larger than denitrification in 1982. However, decomposition plus bottom release was larger than primary production and denitrification was larger than nitrogen fixation in 1992 in the Bohai Sea.

Key words: Nutrient Cycling, the Bohai Sea, the Yellow River, Lower Trophic Level Ecosystem

INTRODUCTION

The river discharge of the Yellow River has decreased from 1970's due to the overuse of water on land. Lin *et al.* (2001) showed that the Sea Surface Salinity (SSS) in the Bohai Sea has increased by 0.074 psu y^{-1} (from 28.5 psu in 1960 to 31.0 psu in 1997) due to the decrease of the Yellow River discharge. It is interesting to investigate the effect of such decrease of the Yellow River discharge to the material cycling and the lower trophic level ecosystem of the Bohai Sea. As for the variation of the lower trophic level ecosystem, Tang *et al.* (2003) found that the primary productivity decreased from 1982 (312 mgC m^{-2} day^{-1}) to 1992 (216 mgC m^{-2} day^{-1}) but the secondary productivity increased from 1992 to 1998 in the Bohai Sea. However there is no study on the variation of the nutrient cycling in the Bohai Sea related to the decrease of the Yellow River discharge. We investigate the difference of water, salt, Dissolved Inorganic Phosphorus (DIP), Dissolved Inorganic Nitrogen (DIN) and Dissolved Silicate (DSi) budgets of the Bohai Sea between 1982 and 1992 using the observed data.

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USED DATA

The used data in this study are obtained from the published atlas by Tang and Meng (1997) and the paper by Lu *et al.* (1999). Their field observations were carried out in May, August, October 1982 and February 1983 when the Yellow River discharge was large. Other field observations were carried out in August and October 1992 and February and May 1993 when the Yellow River discharge was small (Fig. 1). Water temperature, salinity, DIP, DIN, DSi, chl.a and primary production in the surface and bottom layers at 82 stations in the Bohai Sea (Fig. 2) were observed.

ANALYSIS

The concerned box and the adjacent area are defined as shown in Fig. 2 on the basis of observed salinity distribution and the data in the box and the adjacent area are averaged.

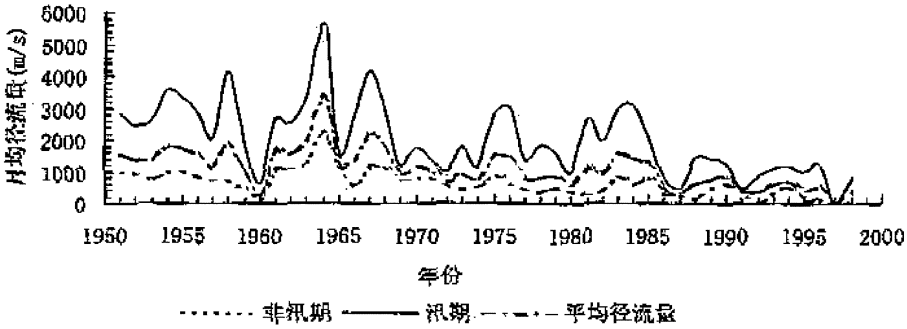
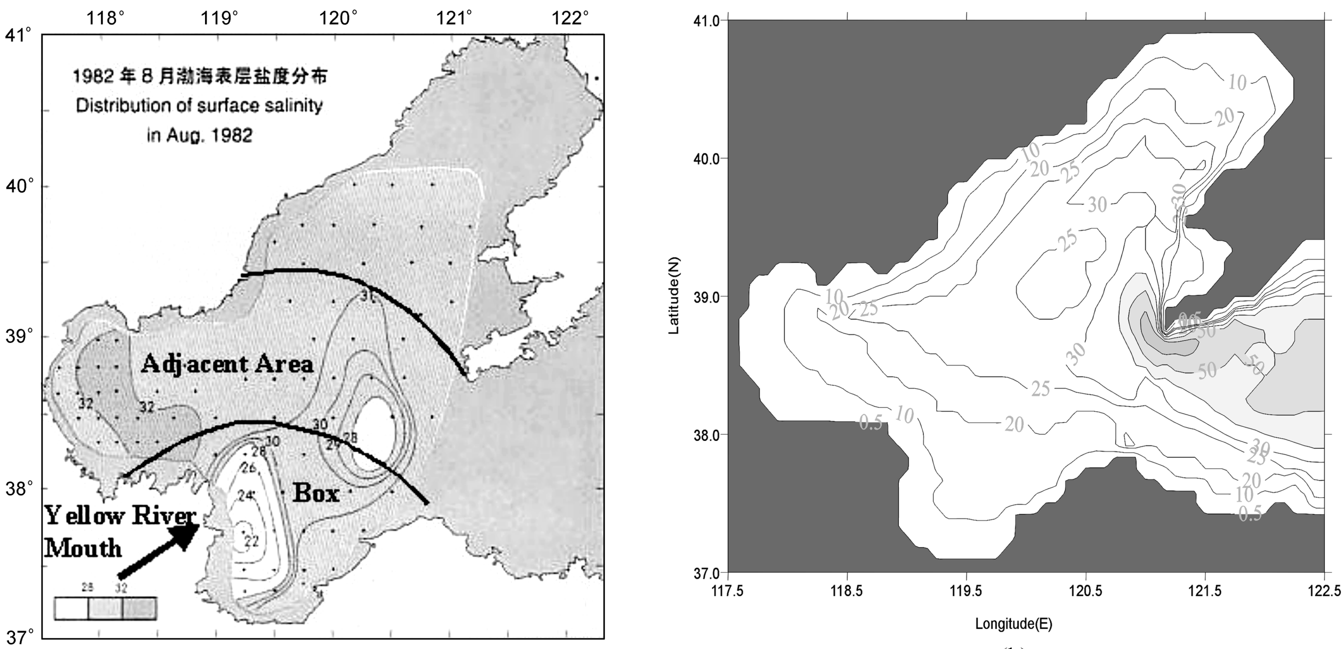


Fig. 1. Year-to-year variation of the Yellow River discharge at Lijin.



(a) (b)

Fig. 2. Definition of the box (inside the full line), the adjacent area (broken line) and observation stations in the Bohai Sea (a). Water depth in meters of the Bohai Sea (b).

Water and Salt Budgets

At first the water and salt budgets are calculated on the basis of LOICZ method (Gordon *et al*., 1996). Water and salt budgets are written by the following equations.

$$dVs/dt = V_Q+V_P+V_E+V_G+V_R \quad (1)$$
$$d(VsSs)/dt = V_RS_R+Vx(So-Ss) \quad (2)$$

where Vs denotes the volume of the box, V_Q the river discharge, V_P the precipitation, V_E the evaporation, V_G the ground water discharge, V_R the residual volume transport from the box to the adjacent area, *Ss* the average salinity of the box, So the average salinity of the adjacent area, $S_R = (Ss+So)/2$, and Vx the water exchange volume between the box and the adjacent area.

dVs/dt is estimated from the seasonal variation of mean sea surface of the Bohai sea, V_Q is estimated from Fig. 1, V_P and V_E are estimated from ECMWF (European Center for the Medium Weather Forecast) data and V_G is assumed to be zero because we have no data of V_G. Temporal variations of V_Q and V_R are shown in Fig. 3.

Residual volume transport V_R decreased by about 1/3 as the river discharge V_Q decreased by about 1/3 from 1982 to 1992. Temporal variations of salinity in the surface and bottom layers of the box are shown in Fig. 4. Salinity in the surface layer increased from 1982 to 1992 but salinity in the bottom layer in August and February decreased from 1982 to 1992. This may be due to that the estuarine circulation in the box had been weakened by the decrease of the Yellow River discharge from 1982 to 1992. Salinity in the bottom layer decreased due to the decrease

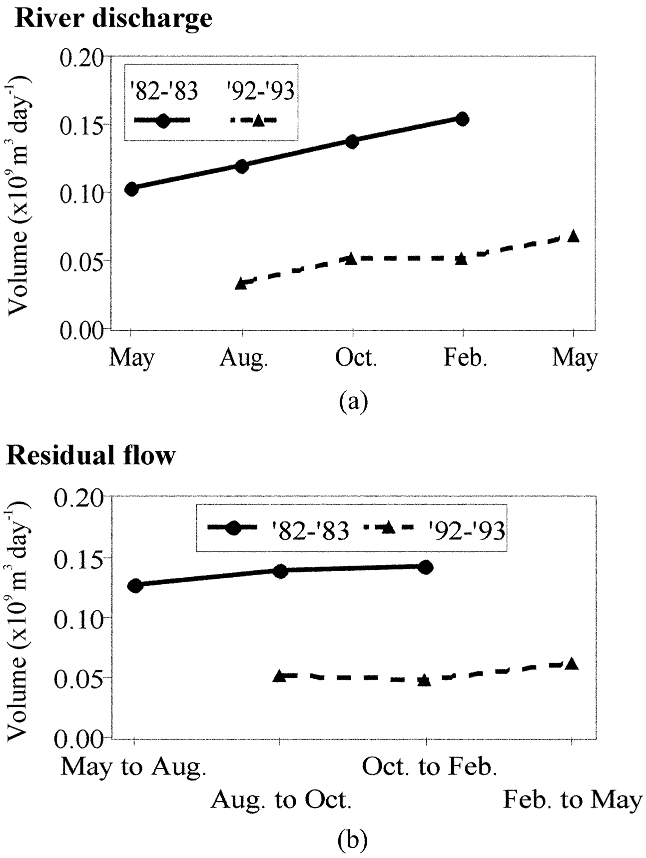


Fig. 3. Temporal variations of river discharge V_Q (a) and residual transport V_R (b).

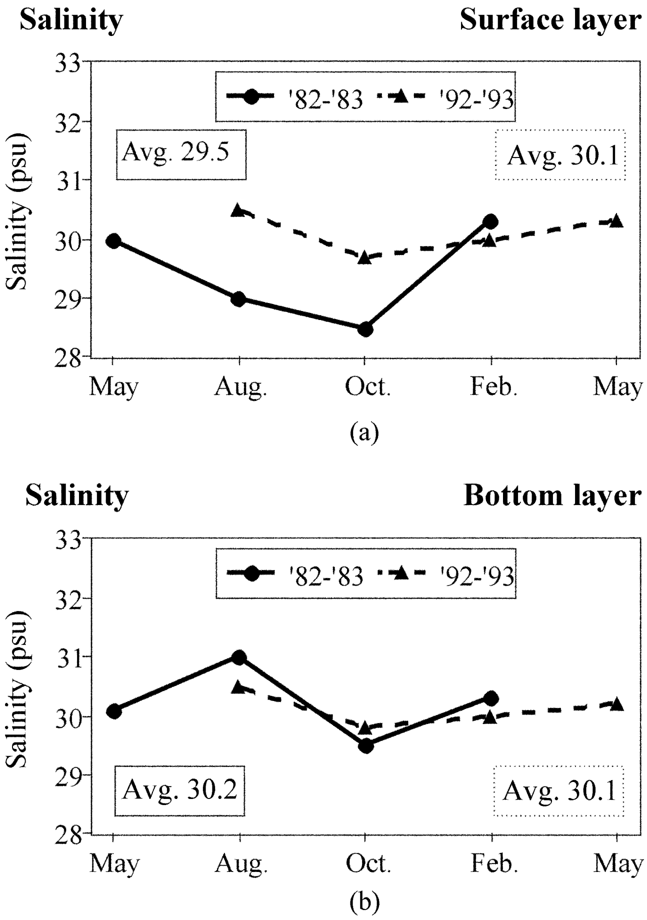


Fig. 4. Temporal variations of salinity in the surface (a) and bottom (b) layers of the box.

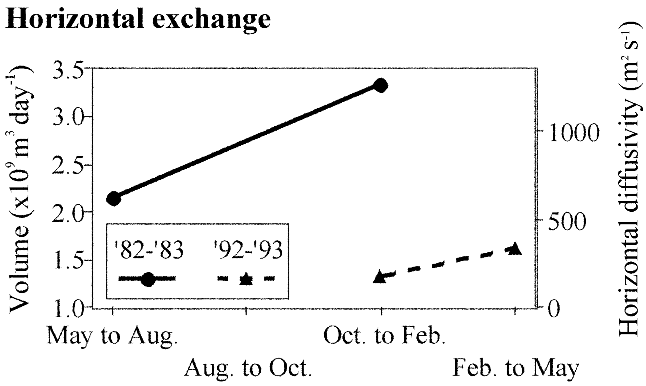


Fig. 5. Temporal variation of horizontal exchange volume Vx.

of high salinity water flux from the lower layer of the adjacent area.

The horizontal exchange volume Vx is estimated from Eq. (2) and the result is shown in Fig. 5. Vx from August to October in 1982 and 1992 was not obtained due to too large temporal variation of salinity in the box. Vx in 1992 is less than half as that in 1982 and this is due to the decrease of the strength of estuarine circulation in the box. Horizontal diffusivity Kh corresponding to Vx is estimated by the following equation,

$$Kh = Vx\Delta L/A \tag{3}$$

where ΔL means the length between the center of the box and that of the adjacent area and A cross-surface area between the box and the adjacent area. Estimated Kh is about 8×10^6 cm^2 s^{-1} in 1982 and 2×10^6 cm^2 s^{-1} in 1992.

Average residence time of the box water Tb and that of fresh water Tf are estimated by the following equation.

$$Tb = Vs/(Vx+V_R),\quad Tf = Vs(So\text{-}Ss)/V_Q So \tag{4}$$

Estimated average residence times are shown in Fig. 6. Tb was 90 days in 1982 and 170 days in 1992. Tf was 130 days in 1982 and 210 days in 1992. Tb is shorter than Tf due to large Vx.

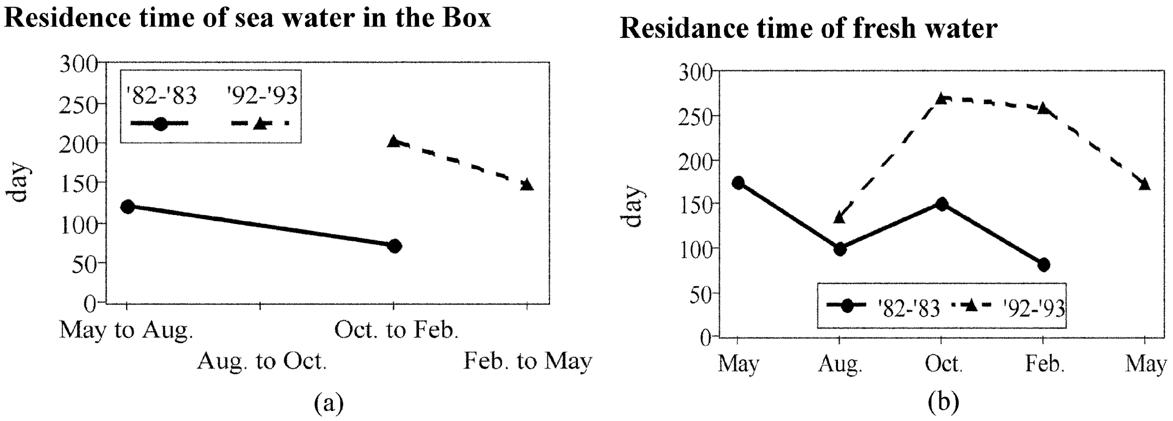


Fig. 6. Temporal variations of average residence time of the box water (a) and the fresh water (b).

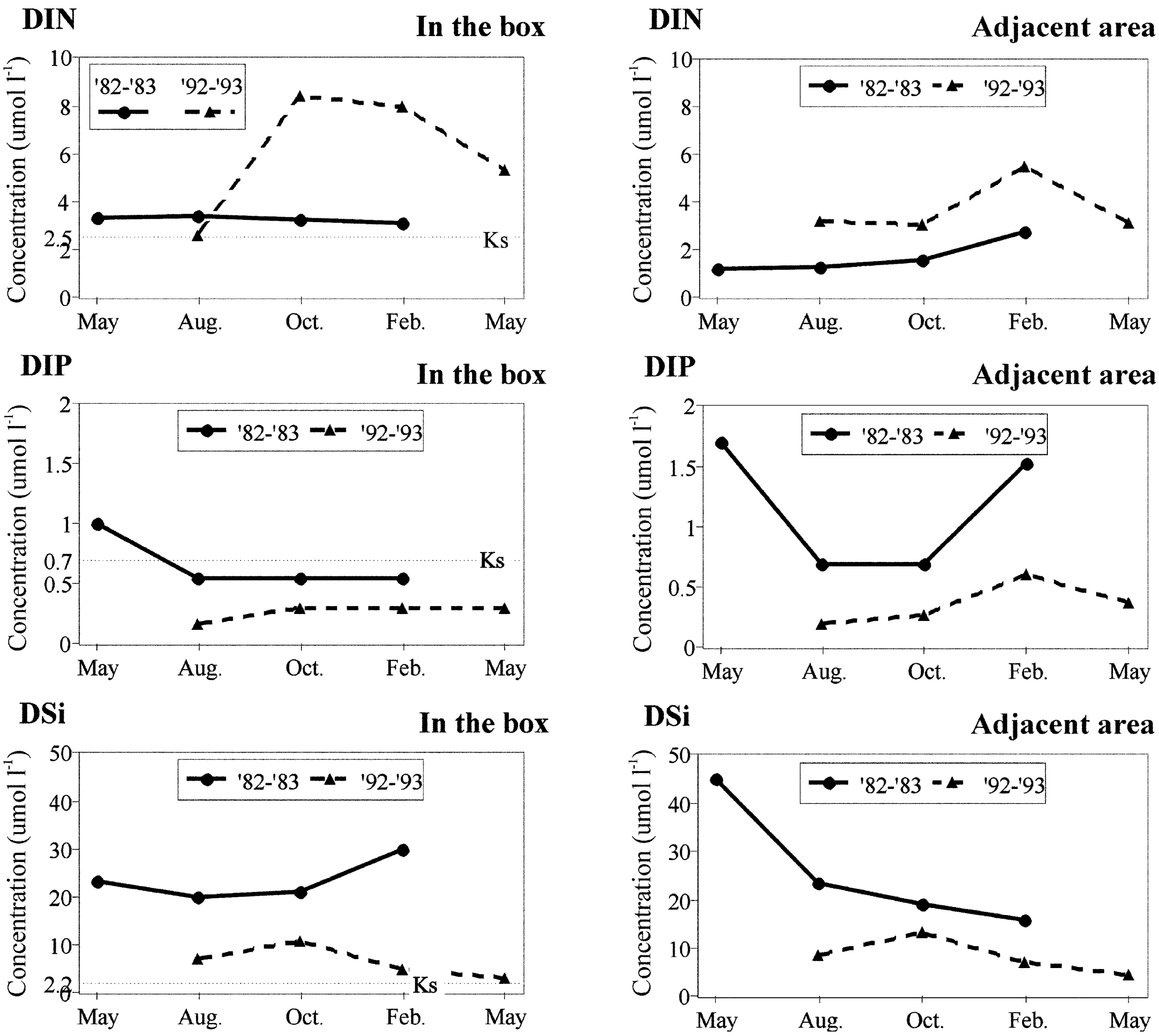


Fig. 7. Temporal variations of nutrients concentrations in the box and adjacent area.

Nutrients Budgets

Nutrient budget of the box is written by the following equation.

$$d\,(VsCs)/dt = V_QC_Q+V_PC_P-V_RCs+Vx(Cs-Co)+\Delta C \quad (4)$$

where Cs denotes the nutrient concentration of the box, C_Q that of river water, C_P that of rain, Co that of the adjacent area and ΔC the nutrient flux by the biochemical processes such as photosynthesis, decomposition and release from the bottom in the box. C_Q is estimated from the observed data (personal communication of Dr. Mi from the Ocean University of China) and C_P is assumed to be 0 because we have no data. In case of DIP budget, positive ΔC means that decomposition plus bottom release is larger than photosynthesis but negative ΔC means that photosynthesis is larger than decomposition plus bottom release. When we assume that the main primary producer in the box is phytoplankton, we may estimate nitrogen fixation (Nfix) minus denitrification (deN) by the following equation (Gordon *et al.*, 1996).

$$\text{Nfix} - \text{deN} = \Delta\text{DIN} - \Delta\text{DIP}\times 16 \quad (5)$$

Temporal variations of average nutrients concentrations in the box and the adjacent area are shown in Fig. 7. DIN concentrations in the box and the adjacent area increased from 1982 to 1992 but DIP and DSi concentrations there decreased.

Temporal variation of DIN/DIP ratio in the box is shown in Fig. 8. DIN/DIP ratio was smaller than the Redfield ratio of 16 in 1982 but it was larger than 16 in 1992. This suggests that the limiting nutrient of photosynthesis in the Bohai Sea was DIN in 1982 but it changed to DIP in 1992.

Temporal variations of chl.a concentration and primary production in the box are shown in Fig. 9. Chl.*a* concentration and primary production decreased from 1982 to 1992 in the Bohai Sea. They were high in August and October with high water temperature and low in February with low water temperature in 1982. The correlation of chl.a concentration and primary production to water temperature was not high

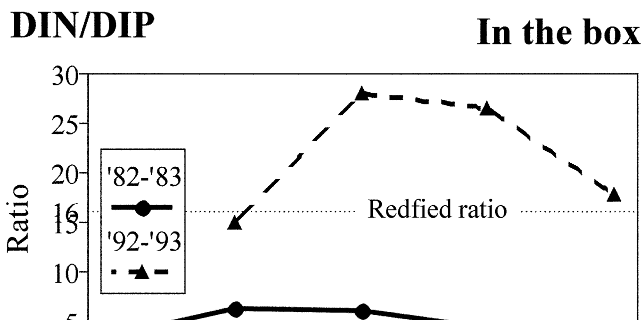
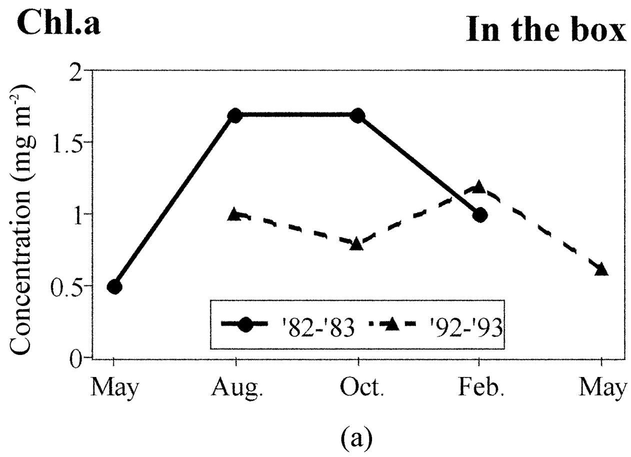


Fig. 8. Temporal variation of DIN/DIP ratio in the box.



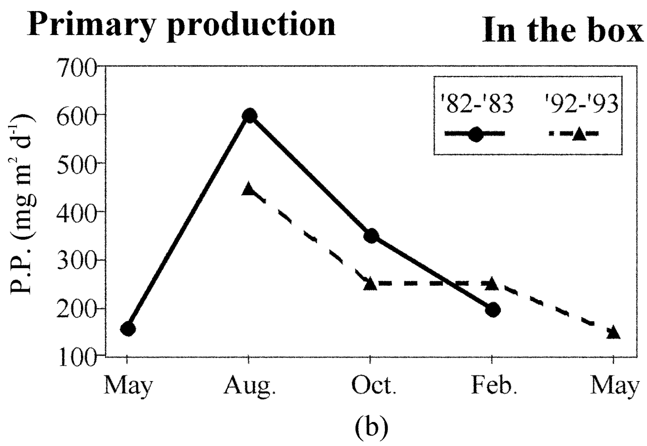


Fig. 9. Temporal variations of chl.a concentration (a) and primary production (b) in the box.

in 1992. This may be due to that the limiting of nutrient concentration to primary production became more severe and the sensitivity of primary production to water temperature decreased in 1992.

Results of ΔDIP and (Nfix-deN) are shown in Fig. 10. Photosynthesis was larger than decomposition plus bottom release in 1982 but photosynthesis was nearly the same as decomposition plus bottom release in 1992. Average primary production was 320 mgC m^{-2} day^{-1} in 1982 (Fig. 9) and 0.25 m mol P m^{-2} day^{-1} when we assume the Redfield ratio of 106. On the other hand, average ΔDIP in 1982 was 0.11 m mol P m^{-2} day^{-1} because the sea surface area of the box is 1.77×10^{10} m^2. This suggests that the phosphorus decomposition and bottom release was 0.14 m mol P m^{-2} day^{-1} in 1982. Nitrogen fixation was larger than denitrification in 1982 but denitirification was larger than nitrogen fixation in 1992.

The changes of physical and biochemical processes in the Bohai Sea from 1982 to 1992 are summarized in Table 1.

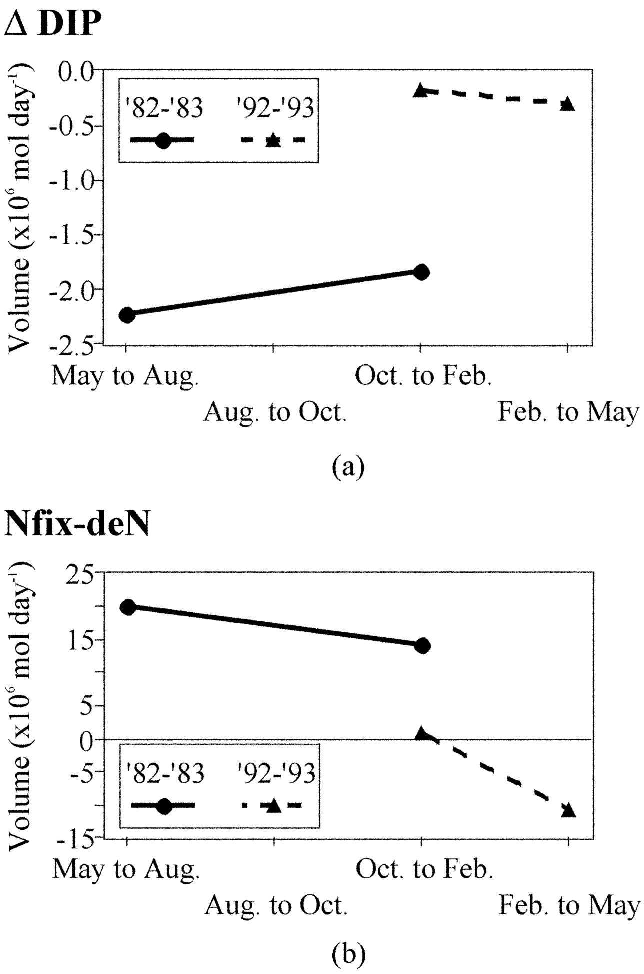


Fig. 10. Temporal variations of ΔDIP (a) and (Nfix-deN) (b) in the box.

Table 1. Changes of physical and biochemical processes in the Bohai Sea from 1982 to 1992

	1982	1992
Estuarine circulation	strong	weak
Surface salinity	low	high
Bottom salinity	high	low
Water exchange ratio	high	low
Residence time of water	short	long
DIN	low	high
DIP and DSi	high	low
Chl.a and primary production	high	low
Limiting nutrient	DIN	DIP
Nitrogen fixation-Denitrification	plus	minus

CONCLUSIONS

The estuarine circulation in the Bohai Sea had been weakened from 1982 to 1992 due to the decrease of the Yellow River discharge and the average residence times of sea water and fresh water in the box had become longer. DIN concentration increased but DIP and DSi concentrations decreased from 1982 to 1992 in the Bohai Sea. Primary production was regulated mainly by water temperature and DIN concentration in 1982 but it was regulated mainly by DIP in 1992. Primary production was larger than decomposition plus bottom release and nitrogen fixation was larger than denitrification in 1982. However, decomposition plus bottom release was larger than primary production and denitrification was larger than nitrogen fixation in 1992 in the Bohai Sea.

We will develop the numerical ecosystem model of the Bohai Sea in order to investigate the change of lower trophic level ecosystem there due to the decrease of the Yellow River discharge in the near future.

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