The Relationships of the Nutrients in the Changjiang River Estuary and the Flow of the Changjiang River Water

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Abstract In the Changjiang estuary, the high concentration area of phosphate (PO_4–P), SiO_3–Si and NO_3–N gradually reduced with the reduction of the area of the Changjiang diluted water from summer, autumn to winter. The seasonal distributions of the nutrients were mainly controlled by the river flow and were also related to the growth and decline of phytoplankton. The conservation of SiO_3–Si and NO_3–N in the estuary in the flood season was poorer than that in the dry season. The behaviour of PO_4–P shows that in addition to biological removal, the buffering of PO_4–P is possible in the estuary. The Changjiang's annual nutrient transports to the sea were estimated. The investigation shows that the seasonal variations of the nutrient transport closely correlate with that of the flow of the Changjiang River and is confirmed by the investigations in 1997–1998 (Shen et al. in Ambio 32:65–69, 2003; Shen in Acta Geogr Sinica 61:741–751, 2006) and 2004 (Shen et al. in Environ Monitor Assess 184:6491–6505, 2012).

Keywords Nutrients · Seasonal variations · Transport · Flow · Changjiang River Estuary

It is well known that the 6300-km-long Changjiang River is the largest river in China and the third largest in the world. The average Changjiang River runoff into the East China Sea is 9282×10^8 m^3 a^{-1} or 29,000 m^3 s^{-1}. Flood season (May to October) runoff is 71.7% of annual runoff. After entering the sea, the Changjiang River diluted water is mixed continuously with Taiwan Warm Current Water from the south and Yellow Sea water from the north. The convergence of various water masses in the area near the Changjiang River estuary and the great quantity of nutrient material transported annually by river water to the estuary makes the area a most important fishing ground in China and known as one of the best in the world. This study is mainly based on the results of eleven investigations in the Changjiang River estuary from August 1985 to July 1986 (station locations in Fig. 1). The seasonal variations of the

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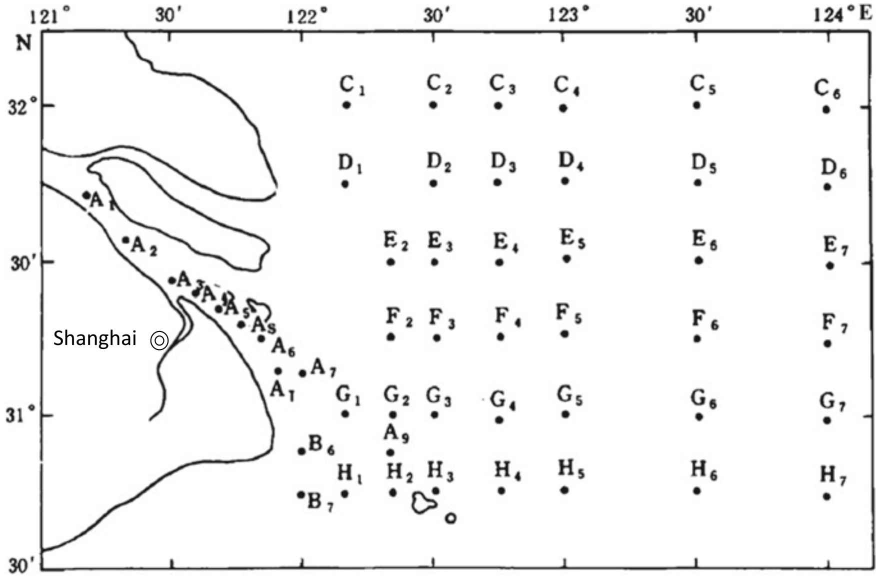

Fig. 1 Sampling stations

phosphate (PO_4–P), silicate (SiO_3–Si) and nitrate (NO_3–N), and their relation to the Changjiang River flow, and effects on the transportation, distributions, variations and the behaviour of the nutrients in the estuary, nutrients transport, etc., are discussed.

1 The Seasonal Variations of the Nutrients in the Changjiang River Mouth

The seasonal variations of the average nutrient concentrations in the Changjiang River mouth freshwater and the average flow of the Changjiang River at Datong hydrological station are indicated in Fig. 2. The concentrations of PO_4–P and NO_3–N were high (average 0.62 and 63.7 μmol L^{-1}, respectively) in the flood season and low (average 0.48 and 51.1 μmol L^{-1}, respectively) in the dry season. The highest concentrations were in August for PO_4–P (average 0.88 μmol L^{-1}) and in May for NO_3–N (average 81.6 μmol L^{-1}), and the lowest were in March (average 0.34 and 43.7 μmol L^{-1}, respectively). The relationship between the seasonal variation of SiO_3–Si concentration and the flow of the Changjiang River water was not regular. The highest concentration of SiO_3–Si was 191.5 μmol L^{-1} in November, and the lowest was 58.5 μmol L^{-1} in April.

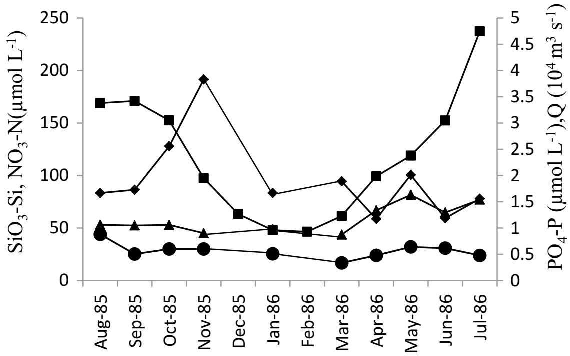

Fig. 2 Seasonal variations of the nutrients and flow in the Changjiang River water: filled diamond—SiO_3–Si; filled triangle—NO_3–N; filled circle—PO_4–P; filled square—Q

2 The Relationships Between the Seasonal Variations of the Nutrient Concentrations in the Changjiang River Estuary Sea Water and the Flow of the River Water

The relationships among the seasonal variations of the average concentrations of the nutrients in the surface sea water (the area west of 123°30′ E), the flow of the river water and phytoplankton are indicated in Fig. 3, which shows that during the annual phytoplankton peak in the flood season (August to September) PO_4–P, SiO_3–Si and NO_3–N concentrations all decreased. After September, although the flow was higher, there was a rapid decrease of phytoplankton and marked increase in the concentrations of SiO_3–Si and NO_3–N to the annual maximum of 30.9 μmol L^{-1} for SiO_3–Si and 13.3 μmol L^{-1} for NO_3–N in November. The concentration of PO_4–P rose only after October and reached a peak in November. In late autumn and winter (dry season), phytoplankton was at low ebb; the concentrations decreased a little for PO_4–P and markedly for SiO_3–Si and NO_3–N. The annual lowest values of SiO_3–Si and NO_3–N appeared in April. Then, all nutrient concentrations increased with the increase of the river water flow. In May to June, due to phytoplankton bloom, all of them decreased. The seasonal variations of PO_4–P, SiO_3–Si and NO_3–N show that in addition to control by the Changjiang River water flow, their concentrations were also related to the growth and decline of phytoplankton.

The seasonal variations of the nutrient concentrations in the sea area were similar in many ways to those in the Changjiang River mouth. The maximum concentrations of PO_4–P all appeared in August, and the seasonal variations were small. The monthly average concentrations of PO_4–P at the seaward side of the river mouth were between 0.29 and 0.68 μmol L^{-1} and a little higher in winter than in summer, which may be related to oxidation and decomposition of organisms. The change of SiO_3–Si concentration here was very similar to that in the river freshwater, the maximum in November, second in October, and the minimum in April. The relationship between them was as follows:

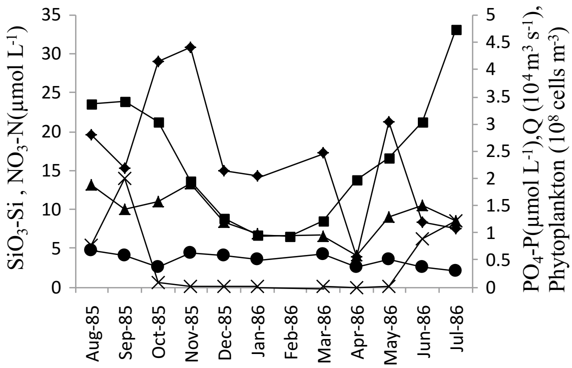

Fig. 3 Relationships among the seasonal variations of the nutrients in the Changjiang River estuary sea water and the flow of the Changjiang River water and phytoplankton: filled diamond—SiO_3–Si; filled triangle—NO_3-N; filled circle—PO_4–P; filled square—Q; multiplication sign—phytoplankton

$$SiO_3-Si \text{ (in seawater)} = 0.200\ SiO_3-Si - 2.454 \text{ (in river water)} \ (r = 0.877, n = 10)$$

The concentration of NO_3–N in the sea area was also higher in the flood season (average 10.4 μmol L^{-1}) than in the dry season (average 7.6 μmol L^{-1}), and there was a delay in the seasonal variation as compared with that in the river water area. The concentration of NO_3–N in the river water area decreased to minimum from October to next March, rapidly rose again until May and then decreased again. NO_3–N concentration in the sea area decreased from November to next April (minimum in April), rapidly rose again until June and then decreased again.

3 The Effects of the Changjiang River Water Flow on the Distributions and Changes of the Nutrients in the Sea Area

From August, November to January (from the flood to dry season), the average Changjiang River runoffs into the sea were 3.38×10^4, 1.95×10^4 and 0.96×10^4 $m^3\ a^{-1}$, respectively. The Changjiang River diluted water area gradually reduced from August to January, and the 30 isohalines contracted towards the river mouth. The research shows positive linear correlationships between the Changjiang River diluted water area and the Changjiang River runoff into the sea (Zhang et al. 1987). With the reduction of the area of the diluted water, the higher concentration areas of the nutrients were reduced and all the isograms gradually moved towards the river mouth. For SiO_3–Si and NO_3–N (Figs. 4 and 5), the areas covered by the 20 μmol L^{-1}

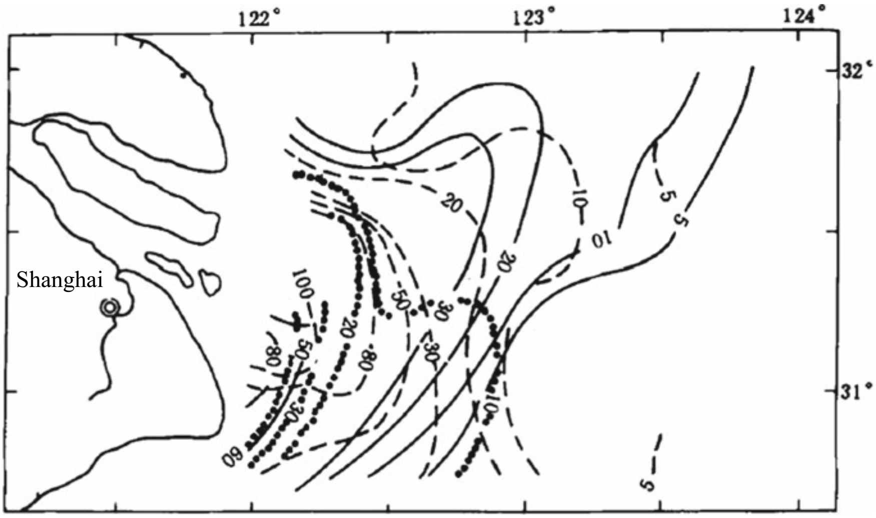

Fig. 4 Distribution of SiO_3–Si (μmol L^{-1}) in surface sea water: solid line—August; dashed line—November; dotted line—January

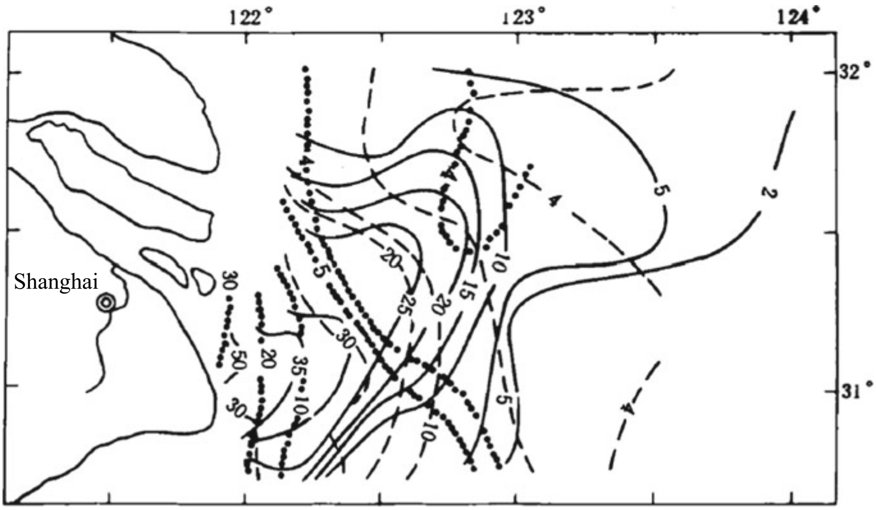

Fig. 5 Distribution of NO_3–N (μmol L^{-1}) in surface sea water: solid line—August; dashed line—November; dotted line—January

isogram were smaller and smaller from summer to winter, and in winter the waters of 20 μmol L^{-1} concentration for SiO_3–Si were limited to west of 122°30′ E and for NO_3–N near the river mouth. This shows that the seasonal distributions and changes of the nutrients are mainly controlled by the flow of the Changjiang River.

4 The Effects of the Changjiang River Flow on the Behaviours of the Nutrients in the Estuary

Correlation statistics show that there were monthly negative linear correlationships between SiO_3–Si or NO_3–N and salinity and that the correlationship between PO_4–P and salinity was not close. The correlation coefficients and statistical ranges are listed in Table 1, showing that the correlationships between SiO_3–Si or NO_3–N and salinity, respectively, in the flood season were poorer than that in the dry season. This was due to the phytoplankton bloom (average 7648×10^4 cells m^{-3} in August). In the Changjiang River flood season, nutrients were largely taken up by phytoplankton in surface seawater and the decomposition of organisms released nutrients in the lower seawater (mainly in the waters of salinity higher than 30). It is evident that the change of SiO_3–Si with salinity was similar to that of NO_3–N with salinity and that there was positive linear correlationship between SiO_3–Si and NO_3–N (in August) indicated as:

$$NO_3{-}N = 0.582\, SiO_3{-}Si + 0.913\ (r = 0.936,\ n = 51)$$

It clearly shows that part of them were removed through biological processes.

The correlationship between PO_4–P and salinity was poor in the flood or dry season. The investigations show that the concentration of PO_4–P in surface water

Table 1 Correlationships of the nutrients and salinity

Months	Water layers	Salinity ranges	PO_4–P		SiO_3–Si		NO_3–N	
			r	*n*	*r*	*n*	*r*	*n*
August	All layers	0–34.5	−0.177	153	−0.815	153	−0.889	153
September	Surface	0–31.7	−0.086	39	−0.819	39	−0.816	39
October	All layers	0–33.6	−0.625	149	−0.871	150	−0.921	150
November	All layers	0–33.8	−0.249	114	−0.918	114	−0.933	114
December	Surface	15–33.2	−0.630	36	−0.914	35	−0.910	36
January	All layers	0–33.7	−0.145	109	−0.925	109	−0.964	109
March	Surface	0–34.0	0.063	43	−0.898	43	−0.920	43
April	Surface	0–33.7	−0.834	36	−0.936	36	-0.940	36
May	All layers	0–33.6	−0.183	122	-0.888	123	−0.905	123
June	Surface	0–31.1	−0.864	37	−0.781	37	−0.860	37
July	Surface	0–31.1	−0.645	39	−0.761	39	−0.796	39

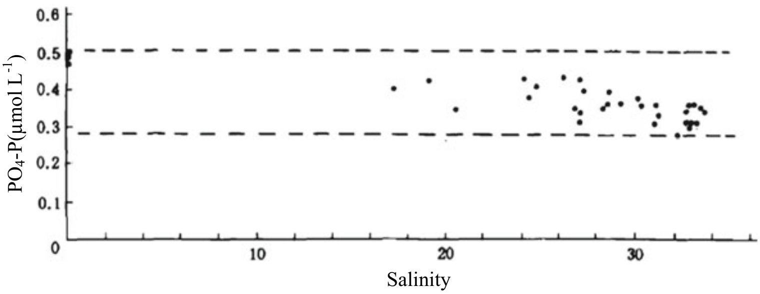

Fig. 6 Relationship between PO_4–P and salinity (April)

outside the river mouth was higher than that within the river mouth in many months, and that its distribution was even in some months. In April (Fig. 6), the concentration of PO_4–P was 0.38 ± 0.058 μmol L^{-1} all over the surveyed area where salinity was between 0 and 33.7. The behaviour of PO_4–P in the estuary shows that in addition to biological removal, PO_4–P removal can also possibly be caused by the buffering action of suspensions and sediments of the estuary. The author thinks this is the main reason that in the long term PO_4–P content is at the same level in the sea area of the Changjiang River estuary.

5 Nutrient Transport to the Sea from the Changjiang River

The monthly average concentrations of the nutrients in the river water area of the Changjiang River mouth can be used to calculate the nutrient transport from the Changjiang River. Their seasonal variations and the relationships between them and the Changjiang River runoff to the sea are indicated in Fig. 7. Related statistics show that the seasonal variations of the nutrient transports F (kg s^{-1}) of PO_4–P, SiO_3–Si, NO_3–N, NO_2–N, NH_4–N and DIN (dissolved total inorganic nitrogen) and the water flow Q (m^3 s^{-1}) of the Changjiang River were very closely correlated as indicated in the equations:

$$\begin{aligned}
\mathrm{F(PO_4{-}P)} &= 0.110\exp\,(0.0000497Q)\ (r = 0.880, n = 10)\\
\mathrm{F(SiO_3{-}Si)} &= 23.070\exp\,(0.0000366Q)\ (r = 0.735, n = 10)\\
\mathrm{F(NO_3{-}N)} &= 4.899\exp\,(0.0000518Q)\ (r = 0.929, n = 10)\\
\mathrm{F(NO_2{-}N)} &= 0.0342\exp\,(0.0000446Q)\ (r = 0.850, n = 10)\\
\mathrm{E(NH_4{-}N)} &= 29.212\exp\,(-0.0000759Q)\ (r = -0.692, n = 10)\\
\mathrm{F(DIN)} &= 16.270\exp\,(0.0000208Q)\ (r = 0.754, n = 10)
\end{aligned}$$

That clearly shows that the nutrient transports are mainly controlled by the Changjiang River flow. Monthly calculations summing up the Changjiang's annual

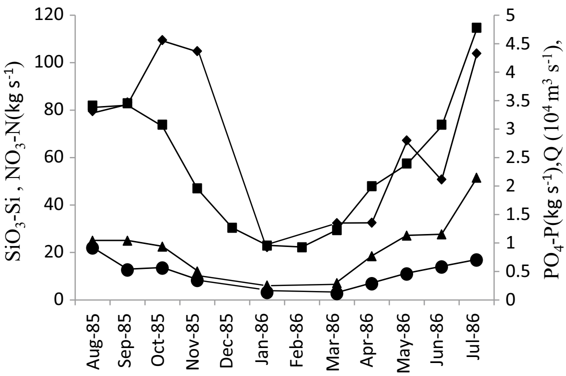

Fig. 7 Relationships between the nutrient transports and the flow Q of the Changjiang River: filled diamond—SiO_3–Si; filled triangle—NO_3–N; filled circle—PO_4–P; filled square—Q

Table 2 Nutrient transports

Nutrient transport	PO_4–P	SiO_3–Si	NO_3-N	NO_2–N	NH_4–N	DIN
Kg s^{-1}	0.43	63.3	20.0	0.12	7.79	27.9
10^4 t a^{-1}	1.4	204.4	63.6	0.38	24.9	88.9

nutrient transports to the sea listed in Table 2 show them to be 1.4 × 10^4 tons for PO_4–P, 204.4 × 10^4 tons for SiO_3–Si, 63.6 × 10^4 tons for NO_3–N, 0.38 × 10^4 tons for NO_2-N, 24.90 × 10^4 tons for NH_4–N and 88.9 × 10^4 tons for DIN, which are about 10 times that from the Huanghe River (Shen et al. 1988).

The above results of close correlations between nutrient transport from the Changjiang River mouth and the Changjiang River runoff have already been confirmed by the investigations in 1997–1998 (Shen et al. 2003; Shen 2006) and 2004 (Shen et al. 2012).

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