

# Scavenging Processes of Marine Particles in Osaka Bay

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The scavenging processes of marine particles in Osaka Bay was investigated using bioelement (C,N,P) distribution as an indicator. Nutrient concentrations in the water and bioelement contents in suspended particles, sinking particles and surface sediments were monitored for three years (1985 to 1987). Large variations appeared to depend on environmental conditions. Bioelement concentrations in suspended particles and sinking particles decrease remarkably going from the inner part of the bay to the offshore water area.

Our results suggested that the position of the tidal front in Osaka Bay agrees very closely with 20 - 30 m water depth; the chemical character of suspended particles and sinking particles was considerably different from across the tidal frontal area. According to the chemical character of sinking particles at the offshore water area station, these particles are mainly made up of "old particles" of which the labile organic matter fraction was already decomposed. Sedimentation of nitrogen in the inner part of the bay accounts for approximately 6 % of all nitrogen inputs to Osaka Bay. These results are very important in learning how marine particles participate in scavenging and cycling in Osaka Bay.

This work was designed to investigate, from the chemical point of view, the fate of inorganic and organic pollutants introduced by human activities into Osaka Bay through integrated studies of their transformation processes by organisms and scavenging mechanisms. Coordinated field investigations were conducted on (1) distribution of marine particles, (2) distribution and recycling of bioelements which are responsible for eutrophication of the coastal area, and (3) processes of deposition and scavenging of bioelements.

Osaka Bay is one of the most utilized coastal water regions in Japan. The bay is elongated in the northeast direction with dimensions of 60 km x 25 km and an area of about 1,500km<sup>2</sup>. The mean depth is about 27 m and its bathymetry shows shoaling from the entrance of 60 m to the northeast. Considering that the narrow entrance of Kitan Strait of less than 10 km wide does not provide ample exchange with the open sea (Kii Channel and Kuroshio), it is surprising that the bay still survives as a fishery and recreation area. Osaka Bay has a big river (R. Yodo) in the inner part of the bay. The environmental conditions and biological processes will be different in each part of the bay. Usually, the tidal front of Osaka Bay is located in a position with a 20 - 30 m water depth especially in the summer season; the dynamics of marine particles seem to be different across this tidal front.

## Materials and Methods

Marine particle samples were collected at 14 stations all over Osaka Bay, the Seto Inland Sea (Figure 1) using T/S Toyoshio-Marun belonging to Hiroshima University. This area is an eutrophic region and red tides often occur during the summer.

The sediment trap system consisted of a stainless steel frame and two sets of six transparent acrylic resin cylinders, 30 cm high and 8 cm across. The cylinder trap contained a 5 cm deep x 1 cm x 1 cm grid at the bottom (Montani et al., 1988). The two-layer sediment trap systems collected sinking particles for 22-24 h at three stations. After retrieval of the trap, a portion of the trap sample was filtered through a Nucleopore filter and a pre-combusted (450 °C) Whatman GF/C glass-fiber filter; the filter with residue was rinsed with a small amount of redistilled water. The filter was freeze-dried, stored in a silica gel desiccator, and weighed later. Another portion of the trap sample was filtered through pre-combusted GF/F and GF/C filters. The filter was freeze-dried and stored for later determination of particulate organic carbon, organic nitrogen and total phosphorus. The remaining sinking particle samples were collected by centrifugation of the sample in a cylinder

at 3,000 r.p.m. for 15 min, then freeze-drying and pulverizing the sample.

Water samples were collected from various depths by 10-L Van Dorn bottles, and the suspended matter was collected by filtration through a pre-combusted, pre-weighed GF/F and GF/C filters. The filters were rinsed with redistilled water, dried and later weighed ashore.

Particulate organic carbon and nitrogen were determined with a Yanagimoto MT-3 CHN analyzer. Total phosphorus was determined by a spectrophotometric method (Parsons et al., 1984) after decomposition of organic matter by 1 h of autoclaving with 4 %  $K_2S_2O_8$  solution. Chlorophyll *a* was determined by a spectrophotometric method after 90 % acetone extraction (Parsons et al., 1984). ATP (adenosine triphosphate) was extracted in boiling 0.25 % Tris-buffer (pH=7.75) for 5 min. The sample was frozen at -20 °C until the time of analysis. ATP was determined using an ATP photometer (Holm-Hansen and Booth, 1966). Nutrients ( $NO_3^-$ ,  $NO_2^-$ ,  $NH_4^+-N$ ,  $PO_4^{3-}-P$  and  $Si(OH)_4-Si$ ) were determined using a Technicon autoanalyzer II.

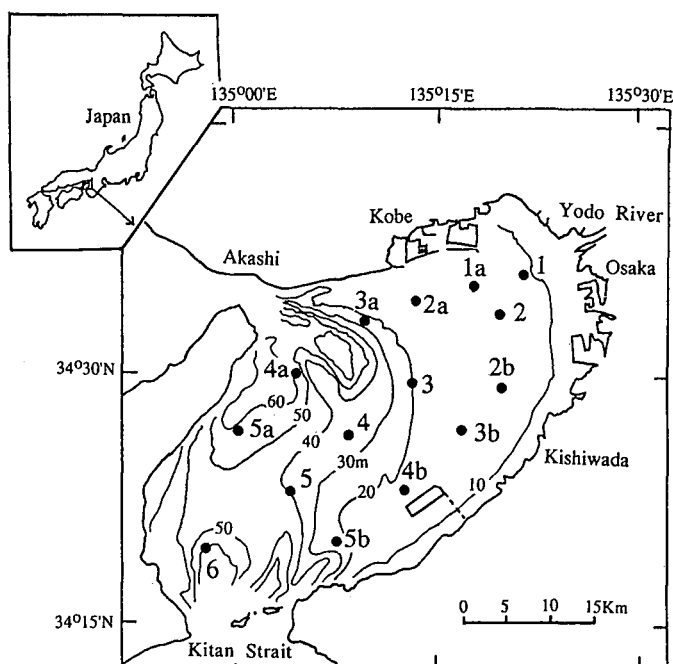


Figure 1 Location of sampling stations in Osaka Bay.

## Results and Discussion

Figure 2 shows the horizontal distribution of the amounts of suspended particles in the surface layers on June and December, in 1985. It seems that on June, suspended particles were very high concentration (more than 30 mg/L) in the inner part of the bay, and decrease remarkably going to the mouth part of the bay, then in the Kii Channel, where the abundance of suspended particles was the range from 5 to 6 mg/L. On the other hand, the abundance of suspended particles in December was relatively constant (3 to 4 mg/L) all over the bay. These tendencies were observed in both 1986 and 1987.

Vertical distribution of the cross section from Stn.1 to Stn.6 is shown in Figure 2. On June in the surface water, the abundance of suspended particles was quite high, this distribution pattern was similar to particulate organic carbon (POC) and chlorophyll *a* (Chl *a*). Indicating that phytoplankton origin bioelements were consistent in the suspended particles in December, the abundance of suspended particles did not vary much vertically and horizontally (3-4 mg/L).

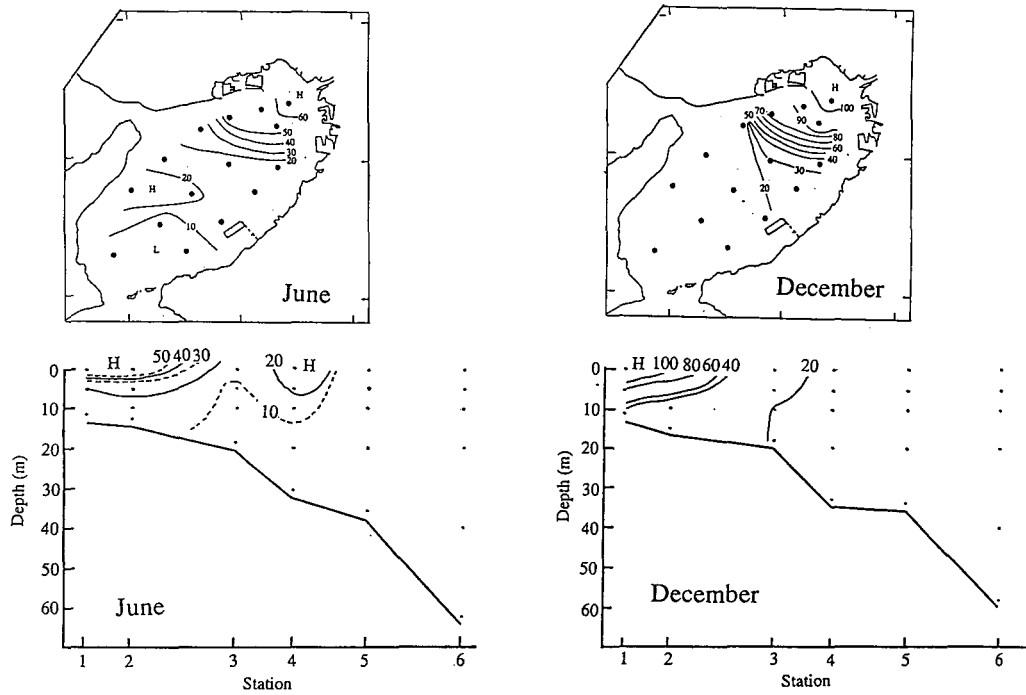
Matsumoto (1975) reported that the suspended particles collected at the inner part of Osaka Bay, the size spectrum ranged from 13  $\mu m$  to 21  $\mu m$  in diameter. This size spectrum pattern was usually observed in a high production area (Sheldon et al. 1972).

Table 1 shows the correlation relationships of Chl *a* to POC, PON and PP for two different seasons. In the case of June, correlation coefficients were very high numbers ( $r = 0.905 - 0.942$ ). C:N:P atomic ratios (117:18.8:1) derived from phytoplankton origin debris was calculated by the slope of the correlation equations. These numbers are quite similar to the Redfield ratio (106:16:1). On the other hand, correlation coefficients on December (Table 1) are lower than that obtained on June.

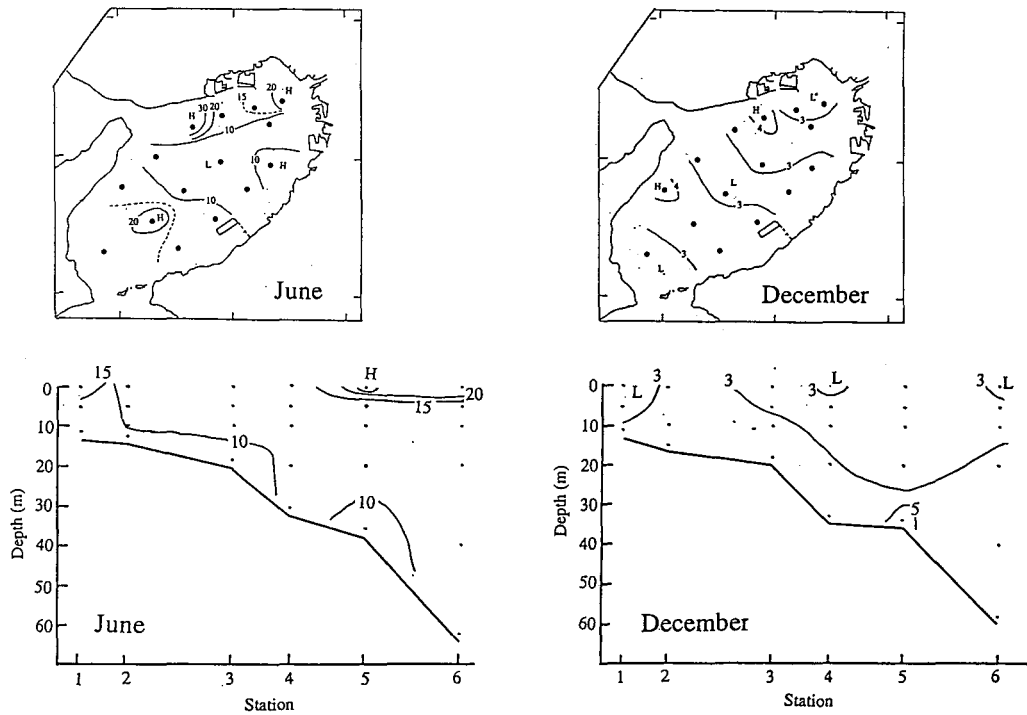
Figure 3 shows the horizontal and vertical distribution of dissolved inorganic nitrogen (DIN;  $NH_4^+-N + NO_2^-+N + NO_3^-+N$ ). In the both seasons, the DIN concentrations in the inner part of the bay were relatively

**TABLE 1**  
Coefficient correlations Chl *a* to C,N,P in the suspended particles

		June			
POC	=	22.3	x Chl <i>a</i> +	212.3	r = 0.905
PON	=	4.19	x Chl <i>a</i> +	26.9	r = 0.942
PP	=	0.49	x Chl <i>a</i> +	0.26	r = 0.909
		December			
POC	=	43.3	x Chl <i>a</i> +	223.5	r = 0.524
PON	=	10.7	x Chl <i>a</i> +	29.6	r = 0.643
PP	=	3.10	x Chl <i>a</i> +	2.50	r = 0.903



**Figure 2** Horizontal distribution in the surface water and vertical cross sections of the water column of suspended particles (mg/g) in June and December, 1985.



**Figure 3** Horizontal distribution in the surface water and vertical cross sections of the water column of DIN ( $\mu\text{g-at/l}$ ) in June and December, 1985.

high compared with in the entrance of Osaka Bay. However, the decrease pattern of DIN concentration was not continuous from the inner part to the entrance of the bay, but a stepwise decreasing pattern was observed from Stn. 3 to Stn. 4. This decreasing pattern was also observed in another nutrient distributions. The tidal front existed around Stn. 3 and Stn. 4 regardless of the season, (especially in the summer), Osaka Bay could then be separated into two different parts by the tidal front. The position of the tidal front agrees very closely with the range of 20 m to 30 m water depth.

These results supposed the belief that the chemical character of the suspended particles and the sinking particles was remarkably different across the tidal front boundary. In order to clarify the difference in the scavenging processes of the parts of Osaka Bay, sediment trap experiments were carried out at Stn. 2, 3, and 5.

The results obtained are shown in Table 2. In this paper we will be discussing only 4 periods of experiments which were collected in May and June over three years. The total mass fluxes varied significantly in each bottom layer sediment trap, changing the range of the total mass fluxes between  $3.0\text{g/m}^2/\text{day}$  and  $61.8\text{g/m}^2/\text{day}$ .

At the same station, the total mass fluxes which were obtained in December are greater than that obtained in June. The total mass fluxes which were collected at Stn.5 are greater than that of Stn.2, and that observed at Stn.3 is close to the value of Stn.2. The difference in bioelement contents in the sinking particles were not so great among sampling stations and times, compared with total mass fluxes. For example, the maximum carbon content in the sinking particles was  $100.5\text{mgC/g}$  and the minimum value was  $28.9\text{mgC/g}$ . Then, the calculated bioelement fluxes at Stn.5 were greater than those at Stn.2, and the bioelement fluxes at Stn.3 were nearly the same as that of Stn.2.

In order to clarify the chemical character of the sinking particles, the C:N:P atomic ratios in sinking particles and surface sediments and the C/Chl *a* ratios were also compared in Table 3.

TABLE 2  
Comparison of mass fluxes and organic matter contents in sinking particles

Date	Stn.	Depth	Mass flux	Org.-C	Org.-N	TP	Bio-Si	Chl <i>a</i>	ATP
		(m)	( $\text{g/m}^2/\text{d}$ )	(mg/g)			( $\mu\text{g/g}$ )		
June, 1985	Stn.2	2	8.1	77.0	10.4	2.23	48.3	-	85.9
		5	7.7	53.8	5.7	1.87	45.4	-	30.6
		10	9.7	48.2	5.3	1.58	23.8	-	15.0
June, 1986	Stn.2	5	1.1	100.5	15.5	1.43	30.7	1070	96.5
		10	3.0	43.3	6.2	0.66	19.1	1010	28.4
May, 1987	Stn.3	5	1.3	56.5	8.2	1.08	24.8	289	67.6
		15	12.5	28.9	3.5	0.87	29.3	164	6.56
June, 1986	Stn.5	15	5.5	36.5	4.8	0.25	19.5	116	9.80
		30	61.8	33.7	3.8	0.21	8.5	70	1.90

TABLE 3  
Comparison of the bioelement atomic ratios and C/Chl *a* in sinking particles and surface sediments

		C	N	P	Bio-Si	C/Chl <i>a</i>
Stn.2	5 m	109	12.6	1	25.9	143
	10 m	119	12.9	1	27.0	103
	sediment	77.4	9.5	1	14.1	225*
Stn.3	5 m	135	16.8	1	25.2	200
	15 m	85.7	8.9	1	37.2	178
	sediment	81.1	9.9	1	32.0	285*
Stn.5	15 m	283	30.9	1	69.6	421
	30 m	376	36.2	1	45.1	487
	sediment	126	14.3	1	41.7	278*

\* C/Pheo-pigments

**TABLE 4**  
Burial fluxes of carbon, nitrogen and phosphorus at Osaka Bay

	Sedimentation area	Sedimentation rate *	Mean concentration in surface sediment			Burial flux		
			C	N	P	C	N	P
	(km <sup>2</sup> )	(g/cm <sup>2</sup> /y)	(mg/g)			(ton/d)		
Inner part (20m>)	765	0.22	17	2.4	0.50	78.4	11.1	2.31
Offshore (20m<)	510	0.20	12	1.8	0.35	33.5	5.0	0.98
Total	1275	-	-	-	-	111.9	16.1	3.39

\* after Matsumoto & Yokota (1978); Hoshika & Shiozawa (1986)

These results suggest that the C:N:P ratios of sinking particles at Stn.2 and 3 were significantly different from that at Stn. 5. The phosphorus content in the sinking particles at Stn. 5 is very low compared with that at Stn. 2 and 3. Although the order of the C/Chl *a* ratios in the sinking particles is as follows : Stn. 2 < Stn. 3 < Stn. 5, the order of the C/Chl *a* ratios in the suspended particles is very similar among these three stations. The ATP content in the sinking particles at Stn. 5 was also very low; then the C/ATP ratio is calculated to very high numbers (3,700 - 17,700). These results show that the sinking particles at Stn.5 contained a relatively small fecal pellet fraction derived from the feeding activity of marine animals. According to the chemical character of the sinking particles at Stn. 5, these particles are mainly made up of "old particles" of which the labial organic matter fraction was already decomposed.

The integrated standing stock of suspended particles from the surface to the depth above the sediment trap system is compared as shown in Table 3. It seems that the settling efficiency of the sinking particles at Stn. 5 is extremely high. However, organic matter contents in the surface sediment at Stn. 2 and 3 are 1.4 times higher than at Stn. 5 in situ. The percentages of these bioelements burial fluxes relative to total sinking fluxes varied from 12 - 18 % at Stn. 2 and 3, and only 2 - 8 % at Stn.5. In the inner part of the tidal front, primary production was very high (2.4 gC/m<sup>2</sup>/day; Joh, 1986) and herbivorous zooplankton would convert the phytoplankton to large sinking particles such as fecal pellets. The organic matter content in the sinking particles is very high in the inner part of the bay; this material sinks and becomes buried in the sediment. On the other hand, in the outer part of the tidal front, where the total mass fluxes are very high, sinking particles have a low organic matter content and then the sinking bioelements and burial fluxes are relatively low.

Table 4 shows that the annual sedimentation rates of carbon, nitrogen and phosphorus to the bay bottom can be calculated by multiplying their average concentrations in surficial sediments at each part of the bay by the accumulation rate (Matsumoto and Yokota, 1978; Hoshika and Shiozawa, 1986). Sedimentation of nitrogen in the inner part of the bay accounts for approximately 6% of all the nitrogen inputs to Osaka Bay, and 16% of all phosphorus inputs (Joh, 1986). These results are very important in learning how the particles participate in scavenging and recycling in the eutrophic and enclosed coastal waters, such as Osaka Bay.

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