The Journal of the Korean Society of Oceanography
Vol. 29, No. 2, pp. 107-118, June 1994

Annual Change and C:N:P ratio in Particulate Organic Matter in Chinhae Bay, Korea

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한국진해만 입자유기물 함량과 C:N:P비의 연변화

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An investigation of the annual change and C:N:P ratio in particulate organic matter (POM) in Chinhae Bay, a semi-enclosed bay of the southern coast of Korean Peninsula, was carried out for a period of 12 months between January and December, 1993. The concentrations of POM have a broad range: 198~4,416 μgC/*l*, 24~792 μgN/*l* and 4.5~69.0 μgP/*l*. Marked seasonal changes of POM, particularly particulate organic carbon (POC) and nitrogen (PON), were observed in the surface water. Generally, the concentration of POM peaks in summer. The C:N:P composition ratio of particulate organic matter, which is high in summer, also shows a seasonal change. The C:N assimilation ratio is constant at 6.53, which is consistent with the Redfield ratio. The significant linear relationship between POM and chlorophyll-*a* in the surface water during the survey period (except for January and February) and the C:N ratio suggest that the concentration of POM is controlled by phytoplankton biomass. POM peaks in summer, a period characterized by high freshwater input and the strong stratification. as a result of the intense proliferation of phytoplankton by a large amount of nutrient loading from the tributaries. On the other hand, the high C:P and N:P ratios in summer indicate that P is limited for phytoplankton growth owing to N-enrichment from a high input of freshwater with a high dissolved inorganic N:P ratio.

반폐쇄성 내만인 진해만의 입자유기물(POM)함량과 C:N:P비의 변화를 1993년 1월부터 12월 까지 1년간 조사하였다. 입자유기탄소와 질소 및 입자 인의 농도는 각각 198~4,416 μgC/*l*과 24~792 μgN/*l* 및 4.50~69.00 μgP/*l*범위였고 특히 입자유기탄소와 질소농도는 여름철에 가장 높고 그외 계절에는 유사한 농도분포를 보이는 uni-modal한 계절변동이 나타났다. 입자물질의 C:N:P 원자비 역시 여름철에 가장 높았다. C:N 원소비는 년중 6.53으로 Redfield ratio와 거의 일치하며 겨울철(1, 2월)을 제외한 조사기간중 표층수중의 POM 농도와 chlorophyll-*a* 사이에 높은 상관관계가 나타난다. 이와같은 결과들은 조사해역의 입자유기물농도가 식물플랑크톤 생물량에 의해 조절된다는 것을 보여주고 특히 많은 육수유입과 함께 강한 성층이 형성되는 여름철의 높은 POM농도는 육상으로 부터 다량의 영양염 공급에 의한 식물플랑크톤의 대증식에 기인하는 것으로 보인다. 한편 여름철의 높은 POC:PP와 PON:PP ratio는 인산염에 비하여 과다한 질소계 영양염을 함유한 육수유입의 영향으로 인산염이 제한요인으로 작용한다는 것을 시사한다.

INTRODUCTION

Particulate organic matter (POM) in the sea is comprised of living organisms and non-living particles. The composition and relative proportions of these two classes vary with location and depth (Menzel, 1974). POM plays a basic role in material and energy transfer in marine food webs (Parsons *et al.*, 1984). The considerable amount of POM produced in the water column also reaches the seafloor in the form of detritus and enters the benthic food chain (Stephens *et al.*, 1967). The trophic state of an area could be expressed as the standing crop of algae and/or the POM concentration, because eutrophication is the phenomenon in which the productivity of phytoplankton is increased through the accumulation of nutrients (Matsuda, 1982). In general, eutrophication in semi-enclosed bays increases productivity of phytoplankton and causes red tide outbreaks. Water pollution by phytoplankton makes the bottom waters oxygen-deficient.

As a result of rapid industrial development and urbanization, the coastal area of Korea is extremely polluted by industrial and domestic wastes. Eutrophication has also been accelerated in Korean coastal waters. Chinhae Bay is a semi-enclosed bay and one of the most eutrophicated bays of the southern coast of Korea. Frequent red tide outbreaks have been reported in Chinhae Bay system (Park and Kim, 1967; Yoo and Lee, 1980; Park, 1982; Lee *et al.*, 1981; Park *et al.*, 1989). Lee *et al.* (1993) reported the seasonal variations of the oxygen-deficient water mass and estimated a reasonable pollution load for environmental conservation. Yang and Hong (1988) reported the distribution of organic materials in the surface sediments and the impact of organic material degradation for the surrounding environment, particuarly oxygen consumption in the bottom waters. In addition, the Chinhae Bay system has been the subject of many other studies: heavy metals in sediment (Lee and Lee, 1982; Lee *et al.*, 1986; Hong *et al.*, 1986), nutrient and chlorophyll-*a* variations (Yang and Hong, 1982), benthos (Hong and Lee, 1983; Hong, 1987). Recently, the annual cycles of plant major nutrients and dissolved oxygen were presented by Hong *et al.* (1991).

Although various oceanographic parameters have been previously measured in this bay, we have little information on the concentration and change of POM with the exception of the report that Yang *et al.* (1984) measured the vertical and horizontal distributions of chemical oceanographic parameters just after the rainy days.

The processes controlling nutrient and phytoplankton interactions in productive coastal waters have been studied (Sakshaug and Olsen, 1986; D' Elia *et al.*, 1986; Matsuda, 1993). From the results of these studies, it is obvious that the phytoplankton C:N:P ratio and limited nutrients in coastal waters and polluted waters, characterized by large temporal and spatial variability in water condition and nutrient concentration, vary with the conditions. Accordingly, it is important to correlate the C:N:P composition ratio of POM and total input of nutrients in order to solve the problem "which nutrient is limited?".

In the present study, annual changes in particulate organic carbon (POC), nitrogen (PON) and particulate phosphorus (PP) were monitored with reference to chlorophyll-*a* standing stock and nutrient concentrations. We also examined the relationship between the atomic C:N:P ratio and the nutrient input and assessed the variation in N or P limitation.

MATERIALS AND METHODS

Site description

Chinhae Bay is situated on the southeastern part of Korean Peninsula (Fig. 1). It stretches 25 km east-west and also 25 km north-south. The total area is approximately 637 km^2 and average depth is 20 m. The tidal current is very weak (Kim *et al.*, 1989; Chang *et al.*, 1993). Masan Bay, located on the northeastern side in Chinhae Bay, is one of the most polluted areas due to the artificial eutrophication. On the other hand, there are intensive culture areas at Chindong Bay and the western side in Chinhae Bay. Ten sampling sites were selected in the bay.

Field methods

Surface water samples were collected using a 3 *l* Van Dorn water sampler once a month for a period of 12 months between January and December, 1993. Two samples for each analysis were

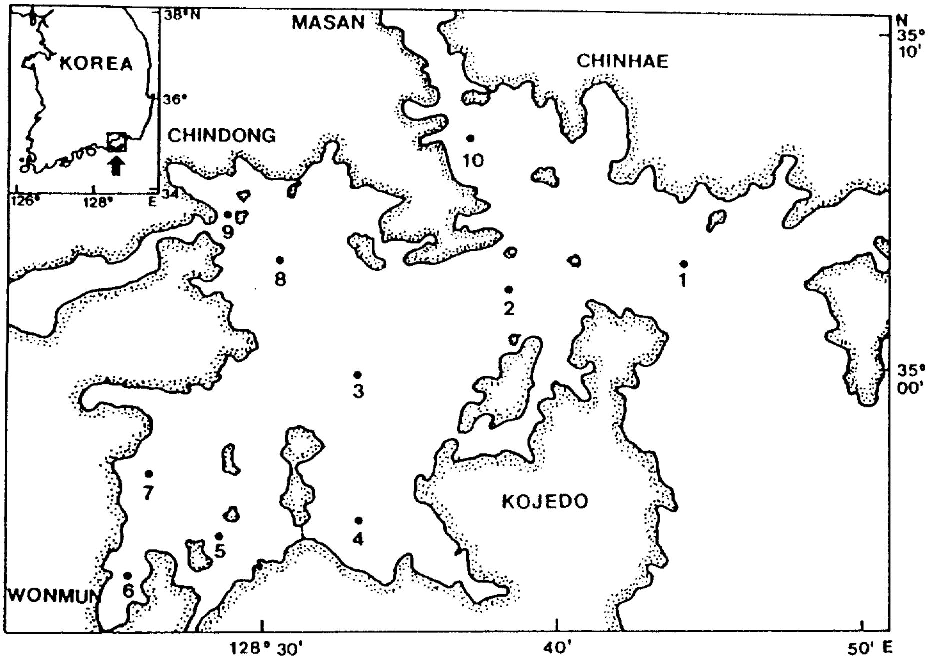

Fig. 1. Map showing the sampling stations.

prefiltered at 350 micron-mesh net to exclude macrozooplankton. An adequate volume, usually 200~300 m*l*, was filtered under low vacuum for the analysis POC, PON, PP and chlorophyll-*a* onto 24 or 45 mm diameter of Whatman GF/C filters preignited for 3 hours at 450℃. The filters were wrapped in aluminium foil and stored below 0℃ until analysed (<2 days). Temperature and salinity were measured in situ using a multiparameter water quality analyzer (Hydrolab. Surveyer III).

Laboratory methods

Filters for analyses of POC and PON were dried at 50℃ for 2 days. A CHN analyzer (Perkin-Elmer model 2400) was used to determine the contents of POC and PON. PP was determined by colorimetric determination of the liberated orthophosphate after destruction of PP with $K_2S_2O_8/H_2SO_4$ during 1 h at 2 atm and 131℃ (Menzel and Corwin, 1965; De Lange, 1992).

Chlorophyll-*a* concentration was determined using fluorometeric method of Holm-Hansen *et al.* (1965) as modified by Parsons *et al.* (1984) with a spectrofluorometer (JASCO FP-550).

Dissolved inorganic nutrients of phosphate, ammonia, nitrate and nitrite were spectrophotometrically measured following to the handbook of Parsons *et al.* (1984).

RESULTS

Temporal changes in Chlorophyll-a and POM contents in the surface waters

There were significant (at 97.5, 99 and 99.9% confidence level for POC, PON and PP, respectively) differences between POM contents in the inlet of Masan Bay (St. 10) and the other stations (Appendix 1). Monthly variations in chlorophyll-*a* and POM contents in the surface waters are presented in Fig. 2, with St.10, which is characterized by much higher POM concentration than the other stations, being separated from the other stations. Chlorophyll-*a* concentration in the surface waters varies from 0.11 μg/*l* to 22.5 μg/*l*. Mean concentrations show a minimum of 0.47 μg/*l* in

February and a maximum of 0.99 μg/*l* in August. Generally, a large difference in the concentrations of chlorophyll-*a* among stations appears in summer when the mean concentration peaks, but there was little difference in concentration in the rest of the year. The concentration (5.79 μg/*l* to 18.91 μg/*l*) at St.10 near the mouth of Masan Bay is much higher than that at the other stations from April to September.

POC concentration in the surface waters varies from 198 μg/*l* to 4,416 μg/*l* and peaks with a mean of 1,908 μg/*l* in August. The mean concentrations show similar levels except for the summer period from July to September, which was characterized by especially high levels. The concentration at St. 10 is higher than that at the other stations throughout the year.

The patterns of distribution and monthly change of PON in the surface waters is very similar to that of POC. PON concentration varies from 24 μg/*l* to 792 μg/*l* and peaks in August. The monthly variation of PP is not clear-cut like POC and PON and shows large differences among stations. PP concentration varies from 4.50 μg/*l* to 69.00 μg/*l*. Though variable, PP concentration at St.10 is higher than that at the other stations from January to August.

Relationships of chlorophyll-*a* to POC, PON and PP are examined for the surface waters in order to investigate the origin of POM (Table 1). High significant (at 95% and 99% confidence level) linear regressions were obtained between POM and chlorophyll-*a* except for January and February. This result indicates that the POM concentration in the surface waters from spring to fall

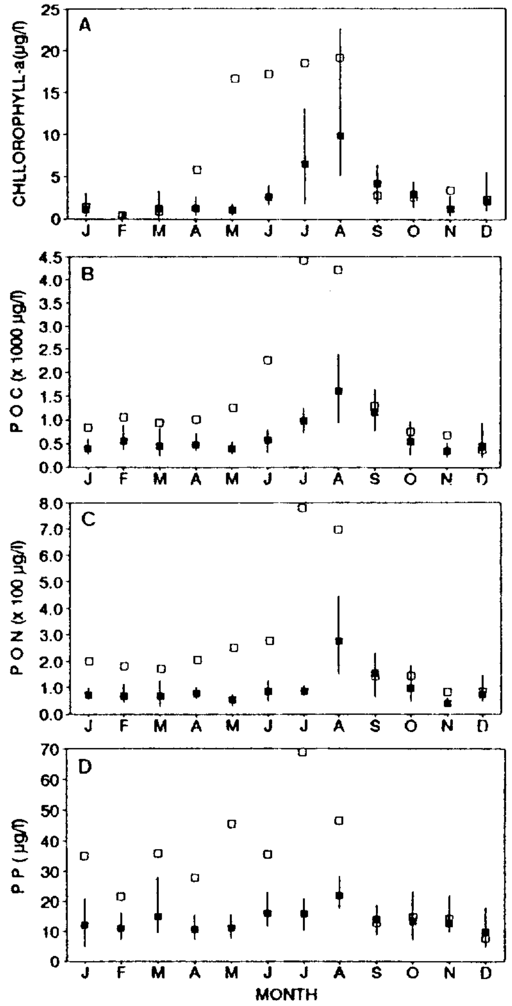

Fig. 2. Monthly variations in chlorophyll-*a* and particulate organic matter contents.
(A) chlorophyll-*a*; (B) particulate organic carbon (POC); (C) nitrogen (PON); (D) particulate phosphorus. ■: mean value for 9 stations except for St.10; □: data at St. 10. Bars represent the range of concentration at 9 stations.

Table 1. Correlation coefficients(r) of chlorophyll-*a* to particulate organic carbon(POC), nitrogen(PON) and particulate phosphorus(PP) in the surface waters

Month	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
POC	.283 —	.349 —	.904 **	.961 **	.970 **	.978 **	.729 **	.783 **	.876 **	.834 **	.959 **	.688 *
PON	.063 —	.253 —	.903 **	.971 **	.987 **	.971 **	.688 **	.839 **	.717 *	.645 *	.854 *	.855 **
P P	.432 —	.199 —	.926 **	.893 **	.981 **	.895 **	.800 **	.633 *	.721 **	.713 **	.852 *	.631 *

Significant at 95%(*) and 99%(**) level; —, not significant

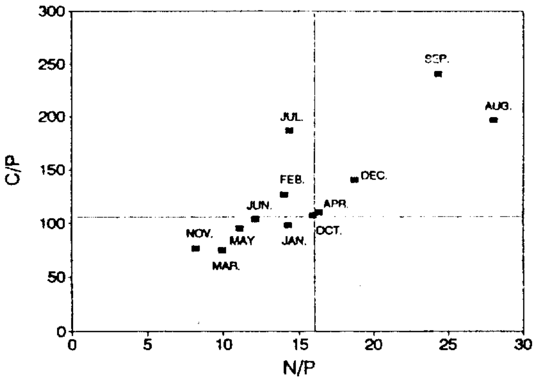

Fig. 3. Monthly variation in the C:N:P atomic ratio of POM in the surface waters.

depends on phytoplankton biomass.

Changes in C:N:P ratio

It is now difficult to determine the phytoplanktonic POM. Hence we investigate the atomic C:N:P ratio of POM in the surface waters that show the high phytoplankton activity.

Monthly changes of mean C/P and N/P ratios are expressed on the axes of coordinates (Fig. 3). The C:N:P atomic composition ratios vary from 76:8:1 and 74:10:1 in November and March to 197:28:1 and 240:24:1 in August and September. The high ratio of C/P=187 is also shown in July. The C:N:P ratios in January, February, April and October are similar to the Redfield ratio (106:16:1).

Linear regressions of POC vs. PON, POC vs. PP and PON vs. PP were done using all the data for the surface waters (Fig. 4). POC and PON are most highly correlated in the correlation coefficient (r) of 0.952 throughout the year and the C:N ratio of 6.53 is very similar to the Redfield ratio (ca. 6.63) which is characteristic of oceans. The POC:PP and PON:PP ratios show the temporal changes. Both the ratios of POC:PP=172 and PON:PP=29 (at 99.9% confidence level) between July and September are much higher than those of POC:PP=82 and PON:PP=12 (at 99.9% confidence level) for the other survey period. The slightly low correlation coefficients relative to the summer period is shown in both POC:PP and PON:PP for the other survey periods.

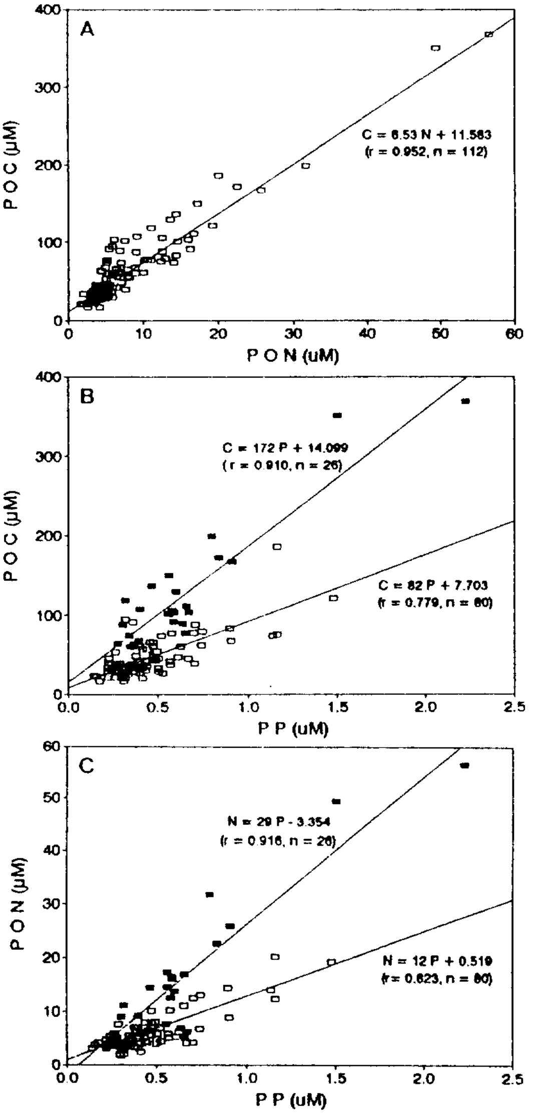

Fig. 4. Plots of C versus N (A), C versus P (B) and N versus P (C) during the survey period. ■ represents the summer data between July and September; ☐ the data for the other survey period except for summer.

Temporal variations in salinity and nutrients

Fig. 5. shows the monthly variations of mean salinity and nutrients in the surface waters. Monthly mean surface salinity varies from 27.15‰

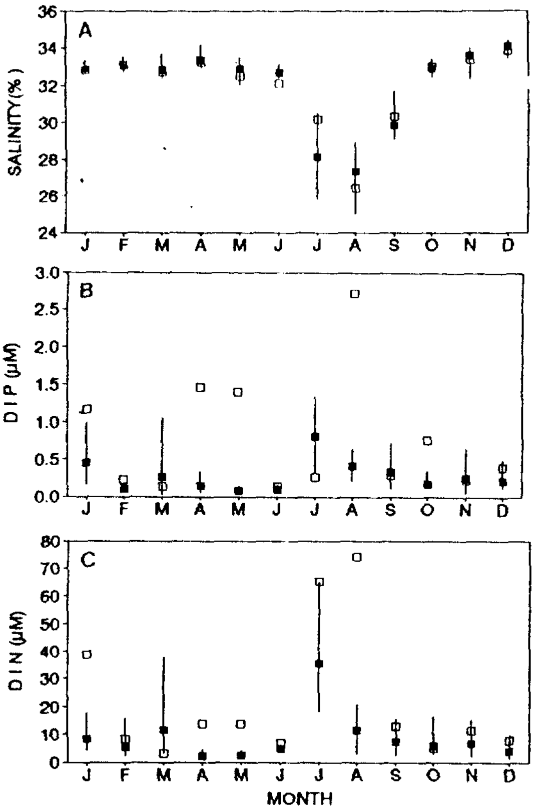

Fig. 5. Monthly variation in salinity (A) and concentration of dissolved inorganic phosphate (DIP, B) and nitrogen (DIN, C) in the surface waters. (■: mean values for 9 stations except for St. 10; □: data at St.10).

(August) to 34.14‰ (December). Surface salinity from July to September is lower than 31.70‰ and, particularly, become lowest at 25‰ at St. 8 in August.

In the surface waters, mean monthly concentration of dissolved inorganic phosphate (DIP) varies from 0.10 µM (February) to 0.81 µM (July). After showing a mean of 0.43 µM in January, mean DIP concentrations are less than 0.30 µM from February to June and increase from 0.34 to 0.81 µM during the low saline period. After the low saline period, mean DIP concentrations decrease to less than 0.30 µM from October to December.

Mean monthly concentration of total dissolved inorganic nitrogen (DIN: ammonium+nitrite+nitrate) is in the range of 2.24 µM (May) to 35.42 µM (July). Similar to the variation of DIP concentrations, mean DIN concentrations in the surface waters are the highest in July and August with 35.42 µM and 11.60 µM, respectively.

Nutrient concentrations in the surface waters tend to be higher in the low saline period than in the other survey periods. In particular, nutrients at St.10 near the mouth of Masan Bay are characterized by abnormally high concentrations, though these are irregular. This indicates the possibility of a large quantity of allochthonous nutrient influx through Masan Bay throughout the year.

DISCUSSION AND CONCLUSION

Temporal variation in POM concentration

The concentrations of POM have a broad range in Chinhae Bay: 198~4,416 (mean 767) µgC/*l*, 24~792 (mean 112) µgN/*l* and 4.5~69.0 µgP/*l*. Distribution of POM concentration in the present study is much higher than those in the other coastal seas of the world and in the other Korean coastal waters investigated: 100~1,000 µgC/*l* in the general coastal sea (Kennish, 1986), 55~648 (mean 392) µgC/*l* and 30~155 (mean 92) µgN/*l* (Choe and Chung, 1972) and 124~1,174 (mean 430.6) µgC/*l* and 10~243 (mean 62.8) µgN/*l* (Kwon, 1993) in Nakton River estuary, 26.7~960.7 (mean 280.5) µgC/*l* in Chonsu Bay (Shim and Shin, 1989) and 199~2,091 µgC/*l*, 8~359 µgN/*l* in Asan Bay (Moon *et al.*, 1993).

Marked seasonal change in POM concentration is observed in the surface waters. The concentrations of POM are high, especially in summer, but remain nearly constant at a relatively lower level in the other survey period. The annual temperature range from the winter minimum to the summer maximum is typical in coastal waters of the Temperate Zone such as the survey area. The solar radiation varies from a minimum in winter to a maximum in June and September (Korea Central Meteorological Office). Because of the stratification due to the increase of solar radiation and fresh water input, the water column become more stable from spring to summer (Lee *et al.*, 1993). Phytoplankton can become limited by the availability of nutrients when light and temperature are adequate (Hecky and Kilham, 1988). By triggering intense phytoplankton growth, stabilization of water column interrupts the upward transport of the nutrient-rich bottom water (Pae and Yoo, 1991). The influence of freshwater runoff in summer is limited to the surface layer (Yang *et al.*, 1984; Yang, 1992). Therefore nutrient loading by freshwater input can therefore play an important role in the phytoplankton growth.

The increase in the concentrations of dissolved nutrients is observed in the surface waters in the low saline summer period (Fig. 5). In particular, DIN at the mouth of Masan Bay is much higher than that at the other stations. These results are consistent with the Lee *et al.* (1991)'s discover that freshwater with a large quantity of nutrients was inputted to the study area in summer and DIN loading of rivers flowing into Masan Bay accounted for about 66% of total DIN loading from rivers to Chinhae Bay in August (about 52% in June). Nutrient concentrations in August and September are relatively lower than those in July owing to the propagation by phytoplankton (Lee *et al.*, 1991). Accordingly, it could be mentioned that the high nutrient loading rates result in the high chlorophyll-*a* concentration during summer.

The linear relationship between POM and chlorophyll-*a* varies seasonally (Menzel and Ryther, 1964). The ratio of POC to chlorophyll-*a* can be changed according to incident radiation and nutrient concentration (Steele and Baird, 1965), species (Zeitzschel, 1970) and the size of phytoplankton (Takahashi and Bienfang, 1983). Though the ratio varies by month in this survey, high significant linear relationships (Table 1) obtained between POM and chlorophyll-*a* in the surface waters from spring to fall indicate that POM concentration is controlled by phytoplankton biomass. No relationships are found between POM and chlorophyll-*a* in January and February. This result indicates that non-living detritus could account for most of POM in winter.

As a result, though the temporal change in POM was understood to be basically originated in phytoplankton growth, extremely high POM concentration is found only in summer, showing the intense proliferation of phytoplankton owing to the high nutrient loading. On the other hand, in winter (January and February), suspended particles are dominated by detrital component which contains organic matter.

A very high concentration of POM is observed in the inlet of Masan Bay. Yang *et al.* (1984) also showed that high amounts of POC and PON were observed with a high nutrient content due to the influence of freshwater input in the low saline surface waters in the narrow inlet of Masan Bay.

C:N:P ratio

Redfield *et al.* (1963) reported that the C:N:P molar ratio of marine plankton was on the average of 106:16:1. This ratio is now referred to as the Redfield ratio and is a clue that treat stoichiometrically the biological activity in open sea. From this fact, the opinion that phytoplankton growth is P limited in C/N>16 and N limited in N/P<16 is regarded as the outlined concept. Goldman *et al.* (1979) found that the chemical compositions of oceanic phytoplankton (by atoms) in the proportions $C_{106}N_{16}P_1$ are only observed for marine phytoplankton at high growth rates when non-nutrient limitation was approached in a laboratory growth condition. Thus, they demonstrated that growth rates of natural phytoplankton population in oceanic waters might be near maximal and non-nutrient limited because of nutrient recycling. Meanwhile, data have been published which, according to stoichiometry, indicate nutrient limitations. Sakshaug *et al.* (1983) found maximal C:P ratios of 357 in the Trondheimfjord and 400 in eutrophic Lake Haugatjern. Maximal C:N ratios were 14 in the Trondheimfjord, 14.7 in the North Sea off Bergen and 12.9 in Haugatjern.

In a recent review, Matsuda (1993) pointed out the changes of the mean C:N:P ratio through growth experiments under semi-natural conditions in coastal waters (Fig. 6): it was obvious that the changes in N:P ratio in natural waters allowed the cellular C:P and N:P ratio, not C:N ratio to cha-

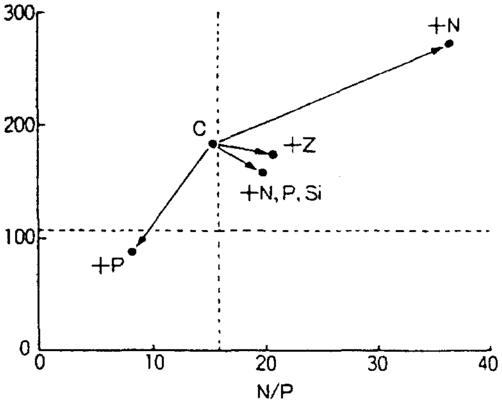

Fig. 6. Change of mean C:N:P ratio at the growth experiments under the semi-natural outdoor conditions (Matsuda, 1993).

nge, but not C:N ratio because the upper-right direction is P-depletion and the lower-left direction is P-excess in Fig. 6. As presented in Fig. 3, both the C:P and N:P ratios (by atoms) of suspended particulate matter are much higher than the Redfield ratio during the low saline summer period when phytoplankton biomass is very high in this bay. The C:N ratio, however, is nearly constant. These high C:P and N:P ratios suggest a possibility that there is P-limitation according to N-enrichment in summer.

Many scientists have reported that the changes in the N:P ratio of the growth medium can greatly influence the cellular C:N:P ratio. D'Elia *et al.* (1986) mentioned that several approaches had been used to assess nutrient limitation of phytoplankton growth in natural waters, and the approaches fell into four categories: physiological, mathehatical, stoichiometric and growth bioassay. Myklestad (1977) reported that the cellular N:P ratio was low under N-limitation and high under P-limitation (2.0 was the lowest and 59.2 the highest ratio, respectively) from the experiments with the N:P ratio changes of the growth medium in batch cultures of marine diatoms Skeletonema costatum (Grev.) Cleve and Chaetoceros affinis var. willei (Gran) Hustedat. Rhee (1974) and Droop (1974) pointed out that the cellular content of phosphorus was constant at low N:P ratios and decreased at high N:P ratios. Rhee (1978) also showed that the level of cell P was high at low N:P (N-limited state) but decreased rapidly until N:P approached the optimal (N:P of 30) and remained constant at a low level at high N:P (P-limited state).

C versus N, C versus P and N versus P plots (Fig. 4) could reflect biological assimilation ratio more closely than the composition ratios of suspended particulate matter could. The C:N ratio is very consistent with the Redfield Ratio. The constant C:N ratio of 6.53 suggests that POM depends mainly on the primary productivity within the bay. However, the C:P and N:P ratios vary with season. The ratios during the low saline summer period are considerably higher than the Redfield ratio, while during the other period they are varying degrees lower. In general, nutrient deficiency becomes more pronounced as the biomass increases (Saksaug and Olsen, 1986). Such high C:P and N:P ratios suggest that during blooms of the low saline period phytoplankton communities are P limited. On the other hand, factors other than phosphorus are limited during the other periods.

In the ocean, particulate C:N:P adheres to the Redfield ratio at which strong nutrient limitation by one element would not be expected, but the mean molar C:N, C:P and N:P ratios in lake particles are substantially higher than the Redfield ratio. Hecky *et al.* (1993) demonstrated that such particulate matter composition in freshwaters implied that a wide variety of conditions exists in lakes, including N and P deficiency, as well as N and P sufficiency. A current dogma of aquatic science is that marine and estuarine phytoplankton tend to be nitrogen limited, while freshwater phytoplankton tend to be phosphorus limited.

While less commonly reported than N limitation, P limitation occurs in some coastal marine ecosystems, especially where the N:P of the nutrient loading is very high (Harrison *et al.*, 1990; Fourgurean *et al.*, 1993). D'Elia *et al.* (1986) reported the great seasonal variability in river flow and nutrient regimes that phytoplankton in the bioassay was N limited during the low-flow, late-summer season and P limited during the high-flow, late-winter season in the Chesapeake Bay estuary. Lee et al. (1991) investigated the nutrient loadings from tributaries to the Chinhae Bay system in August and evaluated the loading rates of 242 KgP/day and 28,532 KgN/day. According to the results, the dissolved N:P ratio in the freshwater loading is very high (about 261). It could therefore be inferred that the supply of excess N in comparison to P from tributries is an important factor responsible for P limitation of the Chinhae Bay system in summer. The high C:P and N:P ratios of suspended particles reflect P limitation for phytoplankton growth during the low saline summer period.

ACKNOWLEDGEMENTS

We would like to thank Dr. J. S. Yang and another examiner for their helpful comments on the manuscript. We also appreciate Mr. P. J. Kim, Y. C. Park and K. H. Ban and Miss H. R. Lee and S. H. Lim for assistance in the field and the laboratory.

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Accepted April 25, 1994

Appendix 1. Data matrix on the surface waters in Chinhae Bay from January to December 1993

Month	St.	T	S	NH_4	NO_2	NO_3	PO_4	POC	PON	PP	Chl.a
	No.	℃	‰		μM				μg/L		
JAN.	1	–	33.23	3.31	0.62	7.21	0.43	346	65	11.2	0.19
	2	6.20	32.67	3.89	0.28	1.84	0.26	446	73	17.7	1.37
	3	6.50	33.29	4.35	0.07	0.25	0.99	527	78	14.7	1.68
	4	6.20	32.81	3.86	0.08	0.33	0.29	585	99	11.7	0.37
	5	6.50	32.56	3.51	0.20	6.07	0.37	431	82	8.2	0.56
	6	6.10	32.67	3.68	0.19	1.75	0.30	267	52	4.9	0.37
	7	6.00	32.54	17.63	0.10	0.13	0.57	458	70	11.2	1.68
	8	7.00	32.67	4.76	0.11	1.83	0.58	542	57	20.7	2.99
	9	6.20	32.81	4.41	0.17	0.62	0.16	338	54	9.6	1.49
	10	5.90	32.80	20.04	1.40	17.57	1.17	885	197	35.3	1.31
FEB.	1	–	32.96	–	–	–	–	782	111	14.7	0.68
	2	6.23	33.02	3.45	0.14	1.49	0.14	474	67	8.9	0.34
	3	5.92	32.89	2.32	0.10	0.19	0.13	378	47	10.0	0.11
	4	6.06	32.68	1.77	0.13	0.39	0.10	402	46	10.1	0.34
	5	6.48	32.81	2.49	0.07	1.40	0.09	359	42	6.9	0.73
	6	6.06	33.15	2.32	0.10	0.19	0.08	425	59	8.8	0.54
	7	5.97	33.55	3.10	0.12	0.14	0.05	451	47	10.9	0.46
	8	6.00	32.94	3.48	0.13	0.14	0.14	885	99	16.2	0.68
	9	5.46	33.21	2.64	0.08	0.12	0.05	723	99	12.5	0.38
	10	–	33.10	5.45	0.31	2.49	0.22	1058	176	21.9	0.50
MAR.	1	9.53	33.72	5.37	0.36	3.99	0.03	343	83	15.6	0.92
	2	7.06	33.15	10.61	1.39	19.45	1.05	492	83	17.6	2.73
	3	6.70	32.56	2.76	0.01	0.41	0.05	412	57	13.7	0.57
	4	7.18	32.63	2.41	0.17	1.96	0.13	397	64	10.9	0.69
	5	7.70	33.00	16.36	1.81	19.69	0.65	398	55	12.8	0.73
	6	7.92	32.38	2.41	0.10	2.11	0.45	303	49	10.3	0.16
	7	7.25	32.58	3.28	0.16	2.37	0.08	568	74	19.0	1.14
	8	7.13	32.65	2.32	0.07	0.45	0.05	243	24	9.3	0.69
	9	7.54	32.54	2.23	0.07	0.50	0.03	809	125	28.6	3.31
	10	7.71	32.73	2.23	0.06	0.42	0.12	910	173	36.0	4.11
APR.	1	13.32	34.15	3.92	0.06	0.64	0.07	388	55	15.6	0.75
	2	12.99	33.25	9.83	0.18	3.38	0.23	719	98	12.2	2.24
	3	12.71	33.01	7.89	0.12	0.74	0.15	402	67	6.9	0.93
	4	12.09	32.95	5.92	0.09	0.75	0.14	375	76	12.5	0.93
	5	13.32	33.32	3.92	0.17	1.08	0.22	357	65	6.9	0.37
	6	12.86	33.12	5.19	0.06	0.34	0.05	335	72	8.8	0.37
	7	–	–	6.21	0.07	0.31	0.13	–	–	–	–
	8	13.06	32.97	8.79	0.17	2.09	0.33	352	62	8.3	1.12
	9	14.39	32.89	6.29	0.11	2.01	0.07	574	100	14.7	2.62
	10	13.75	33.28	27.26	0.67	13.39	1.43	1003	201	27.9	5.79
MAY	1	14.59	33.48	3.51	0.23	3.39	0.06	543	68	15.6	1.31
	2	14.54	33.08	2.44	0.05	0.17	0.07	431	55	10.5	1.12
	3	15.12	32.88	10.06	0.06	0.28	0.08	365	73	13.4	1.68
	4	15.02	33.09	5.37	0.10	0.37	0.13	292	43	9.9	0.37
	5	15.15	32.97	2.99	0.06	0.26	0.09	481	56	7.1	0.37
	6	16.02	32.50	7.48	0.13	1.09	0.11	390	47	11.9	1.31
	7	–	–	–	–	–	–	–	–	–	–
	8	15.62	32.85	3.16	0.02	0.05	0.06	441	64	–	–
	9	15.89	31.99	6.26	0.18	0.96	0.08	257	27	9.1	0.93
	10	15.72	32.48	22.53	1.18	15.75	1.41	1450	270	45.8	16.60
JUN.	1	17.53	33.14	3.04	0.04	0.59	0.05	652	114	15.3	2.62
	2	19.21	32.80	5.47	0.04	0.16	0.11	730	126	–	–
	3	19.41	32.63	4.26	0.04	0.14	0.10	496	76	12.5	3.92
	4	19.37	32.90	2.85	0.02	0.79	0.08	516	62	13.6	2.06
	5	19.87	32.93	4.13	0.07	0.16	0.13	316	46	11.6	1.50
	6	20.62	32.81	5.28	0.07	0.33	0.15	745	95	23.0	3.36
	7	19.86	32.61	5.82	0.06	0.23	0.14	625	80	–	–
	8	20.22	32.64	3.20	0.03	0.22	0.06	779	90	–	–
	9	21.17	32.37	4.26	0.06	0.27	0.10	719	86	19.4	2.43
	10	20.16	32.10	5.38	0.12	0.13	0.17	2236	282	36.0	17.19

Appendix 1. Continued

Month	St. No.	T ℃	S ‰	NH_4	NO_2	NO_3	PO_4	POC	PON	PP	Chl.a
				μM				μg/L			
JUL.	1	20.96	30.50	16.74	0.61	5.72	0.33	893	72	10.6	8.78
	2	21.09	30.10	58.18	0.66	6.20	0.66	922	73	20.4	10.75
	3	22.30	28.50	11.49	0.83	7.01	0.56	1064	97	19.7	8.32
	4	21.81	29.40	16.42	0.48	1.55	0.66	755	63	11.4	2.61
	5	21.93	28.30	16.67	0.45	0.89	0.79	1099	—	—	2.49
	6	23.76	25.80	59.68	0.70	1.17	1.29	1224	106	17.2	7.47
	7	23.22	26.00	57.44	0.36	0.85	1.34	711	77	10.8	2.86
	8	23.18	27.30	16.06	0.72	1.74	0.49	1132	—	—	6.74
	9	24.19	26.80	34.62	0.29	1.22	1.17	1240	86	20.8	13.07
	10	21.40	30.40	9.70	0.50	1.33	0.26	4416	792	69.0	17.28
AUG.	1	21.81	28.00	6.58	0.91	12.94	0.55	929	149	21.7	5.03
	2	22.71	27.70	7.13	1.25	12.34	0.44	1331	236	20.4	5.21
	3	23.36	28.90	4.29	0.21	1.13	0.45	1240	225	18.3	6.78
	4	22.13	28.00	2.61	0.12	0.20	0.21	1211	204	17.4	8.92
	5	23.14	26.90	5.66	0.24	0.31	0.24	1797	242	17.4	8.38
	6	23.81	26.00	4.55	1.32	1.94	0.36	2381	445	24.8	22.59
	7	22.82	—	3.42	0.49	1.01	0.22	—	—	—	—
	8	22.16	25.00	6.32	2.02	6.57	0.64	2008	361	28.2	11.74
	9	23.45	27.50	2.61	4.03	7.48	0.56	2066	316	26.0	11.30
	10	23.18	26.60	20.53	2.50	51.50	2.74	4205	692	46.6	18.91
SEP.	1	20.88	31.70	7.25	0.09	7.30	0.47	764	61	8.6	1.68
	2	22.77	29.70	4.67	0.56	1.80	0.72	1265	176	18.0	4.02
	3	22.98	29.20	3.31	0.12	0.27	0.22	1055	128	9.5	4.39
	4	23.38	29.10	4.96	0.12	0.01	0.30	1552	191	18.6	2.79
	5	22.68	30.50	3.45	0.08	0.17	0.23	809	70	12.2	2.24
	6	23.04	29.80	2.47	0.08	0.02	0.23	1089	229	14.5	3.46
	7	—	—	2.81	0.04	0.06	0.10	—	—	—	—
	8	22.52	29.50	6.26	0.19	0.45	0.45	1411	156	9.9	3.46
	9	22.32	29.50	4.61	2.49	3.51	0.33	1631	201	18.2	6.32
	10	22.18	30.30	4.21	2.40	6.00	0.36	1287	129	12.5	3.55
OCT.	1	19.03	33.40	2.06	0.11	0.38	0.11	792	91	14.1	4.02
	2	19.37	33.20	2.58	0.05	1.74	0.14	324	70	12.4	1.68
	3	19.63	32.70	3.05	0.00	0.37	0.10	921	155	20.3	4.39
	4	19.22	32.80	2.99	0.04	0.13	0.11	499	91	12.1	3.45
	5	19.11	32.70	2.15	0.06	0.41	0.13	255	49	7.0	1.35
	6	19.08	32.40	2.47	0.03	0.19	0.24	250	47	8.0	1.79
	7	19.21	32.90	4.32	0.10	2.62	0.26	309	57	9.2	—
	8	19.73	33.20	3.71	0.01	0.15	0.17	678	112	13.6	3.46
	9	19.44	32.90	15.05	0.89	0.53	0.35	958	182	23.1	3.55
	10	18.91	33.00	3.51	0.85	0.51	0.79	739	142	14.7	2.24
NOV.	1	16.45	34.00	5.63	1.06	5.65	0.14	400	29	—	—
	2	15.73	33.40	2.15	0.04	0.31	0.05	424	44	12.4	2.31
	3	15.97	33.40	4.67	0.84	3.32	0.64	198	37	9.6	0.37
	4	15.65	34.00	12.96	0.44	1.62	0.33	242	35	12.8	0.74
	5	17.13	33.80	4.67	0.84	3.32	0.64	468	58	12.8	1.63
	6	16.14	32.30	1.91	0.03	0.18	0.08	243	29	9.9	0.74
	7	15.42	33.50	3.31	0.10	0.30	0.24	—	—	—	—
	8	15.92	34.00	6.41	0.17	0.59	0.23	508	56	15.2	2.73
	9	15.97	33.90	2.84	0.39	1.12	0.11	252	30	—	—
	10	15.78	33.40	1.86	0.84	8.18	0.26	687	83	21.8	3.31
DEC.	1	12.08	34.40	1.83	0.74	7.33	0.49	641	71	8.2	1.68
	2	10.98	33.90	2.15	0.60	2.06	0.18	355	66	7.5	1.87
	3	11.06	34.00	1.13	0.10	0.11	0.15	922	143	17.8	5.51
	4	11.21	34.40	0.90	0.10	2.35	0.11	322	61	16.4	1.78
	5	—	—	1.13	0.10	0.11	0.15	—	—	—	—
	6	9.95	34.20	3.89	0.23	0.54	0.26	201	59	5.4	1.03
	7	10.26	33.40	1.60	0.07	0.13	0.21	544	52	7.1	0.93
	8	10.49	34.40	1.28	0.09	0.02	0.23	274	44	4.5	2.52
	9	10.44	34.40	1.60	1.43	4.31	0.26	454	75	8.4	1.31
	10	11.39	33.80	1.68	0.76	5.15	0.39	458	75	7.5	2.34