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Distribution of Particulate Organic Matter in the Gampo Upwelling Area of the Southwestern East Sea

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The distribution of particulate organic carbon and nitrogen (POC and PON) and chlorophyll *a* of particulate organic matter was investigated in the southwestern East Sea in August and October 1995. The upwelled "cold water mass" with temperature less than 14°C occurred near the Gampo coast in August. At most of the onshore stations, concentrations of POC and PON were high in surface water, rapidly decreased with depth down to 30 m and then remained constant. Differences in their concentrations between surface and bottom waters were larger in August than in October. At the offshore stations, POC and PON were higher in surface than in deep waters though the differences in concentration were small. The highest, vertically integrated inventories of POC, PON and phytoplanktonic carbon in the upper mixed waters of the onshore stations occurred in August. The mixed layers at onshore stations showed relatively high percentages of POC, PON and chlorophyll *a* in total suspended matter, low ratios of POC to chlorophyll *a* and high inventories of phytoplanktonic carbon, compared with the values at offshore stations. These phenomena were more obvious in August, when cold water mass developed strongly, than in October. These results indicate that primary production plays a significant role for the budget of particulate organic matter in the upwelled cold water mass of the southwestern East Sea.

INTRODUCTION

A cold water mass is known to occur along the southeastern coast of Korea Peninsula in every summer (Lim and Chang, 1969; Lee, 1978; Park, 1978; Kim and Kim, 1983; NFRDA, 1987). According to Lim and Chang (1969), the cold water mass at intermediate or bottom layer ranges from 3 to 10°C in temperature, and is between 34.00 and 34.30 psu in salinity. Lee (1978) reported that surface temperature of Ulsan coastal water in summer decreased below 16°C by the cold water mass. Yang *et al.* (1994) showed that the cold water with temperature of 2—6°C does not originate from the mixed water of East Sea Proper Water (ESPW) and Tsushima Middle Water (TMW) but from North Korean Cold Water (NKCW) from the data of radium isotopes.

Particulate organic matter (POM) is important in the marine food chain as a potential food for secondary producers and in turn for the organisms of higher trophic levels. POM is usually characterized by the carbon content, because particulate organic carbon (POC) occupies a significant portion of POM in seawater. The POC consists largely of detritus and phytoplankton with minor amounts of bacteria, yeasts and fungi (Riley and Chester, 1971). Zooplankton and fish make up only a small fraction of POC in the water column. A desirable and useful tool for the estimation of phytoplankton biomass is the determination of organic carbon or nitrogen content in phytoplankton. However, at present, it is not possible to measure organic carbon and nitrogen of an individual phytoplankton cell in the field (Smayda, 1978). Phytoplanktonic carbon has been estimated indirectly from its cell volume (Strathmann, 1967), ATP concentration in the water column (Holm-Hansen, 1973), POC (Eppley *et al.*, 1977) or chlorophyll *a* labeled with C-14 (Redalje, 1983).

Some studies on POM have been done in coastal waters of Korea. Moon *et al.* (1993) showed that resuspended detritus from the bottom plays an important role in determining the POC concentration of water column in Asan Bay where strong tidal mixing occurs. Kang *et al.* (1993) reported that primary production is the main source of POC in semi-enclosed Wonmun Bay. According to Lee *et al.* (1994), concentration of POC in Chinhae Bay was high as a result of terrestrial input. However, there have been only a few studies on POM in the East Sea. Moon *et al.* (1996) reported relatively high weight ratios of POC/PON (6.73—7.31) in water column of the Ulleung Basin. Yang *et al.* (1997) also showed the spatial distribution patterns of POC and PON and their relations with water masses in the coastal area off Sogcho.

The purpose of this study is primarily to observe the distribution patterns of POC and PON in the southwestern East Sea and then to investigate the composition of POM to assess the contribution of phytoplankton to POC. Phytoplanktonic carbon contents were estimated from POC concentrations and discussed.

MATERIALS AND METHODS

Seawater samples were collected with Van Dorn water samplers along 3 transections in the southwestern East Sea on board R/V *Kyeong-Buk 885* of National Fisheries Research and Development Institute in August and October 1995 (Fig. 1).

Seawater of 200 ml for POC and PON analysis was filtered through 25 a pre-combusted mm GF/C filter (1.0 μm nominal pore size) under a low vacuum less than 15 cm Hg. After HCl fuming to remove carbonate from the sample filter, the filters were stored frozen on board, later were dried for 24 hours at 50°C and then were measured for POC and PON with a CHN analyzer of Perkin Elmer model 2400 (Telek and Marshall, 1974).

For the determination of total suspended matter (TSM) contents, 500 ml of each water sample was filtered through a pre-combusted GF/C filter. The sample filters were kept frozen on board and later dried for 2 hours at 100°C. After drying, the difference between the filter weights before and after filtering was calculated.

Chlorophyll *a* concentration was determined fluorometrically as described by Holm-Hansen *et al.* (1965). The samples were collected onto a membrane filter of 0.45 μm in pore size and then the filters were soaked in a glass tube with 10 ml of 90% acetone for 24 hours in a dark refrigerator. After extraction, the fluorescence was measured for 30 seconds before and after acidification with a drop of 5% HCl.

Water samples for nutrient analysis were filtered on board through a GF/C filter and kept frozen for latter procedures. Nutrients were determined colorimetrically by the method of Strickland and Parsons (1972). Water temperature and salinity were measured using the CTD apparatus (Sea Bird-9).

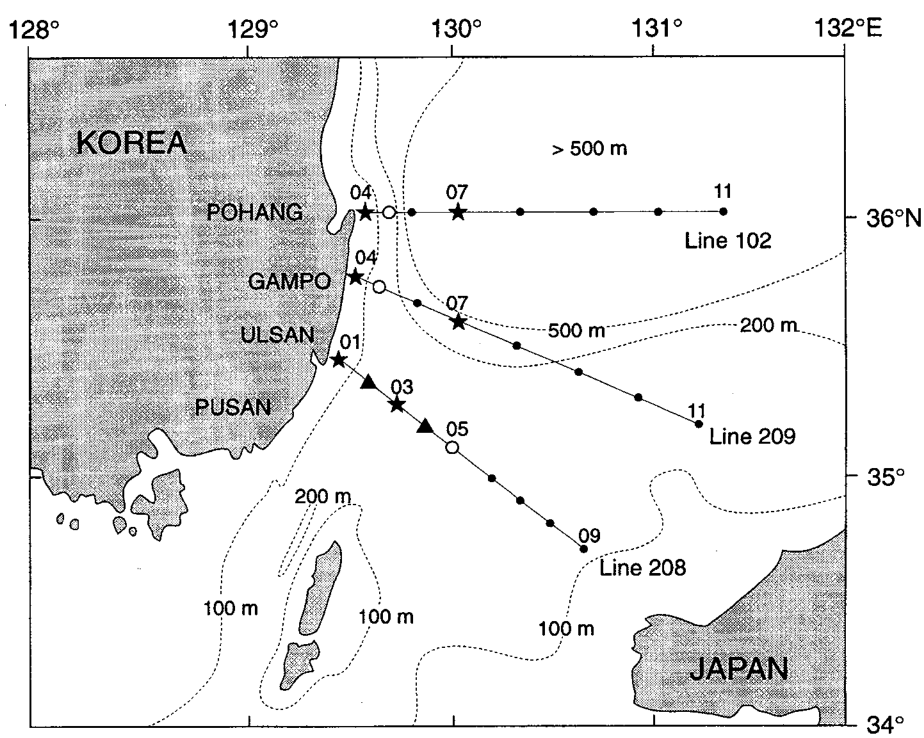

Fig. 1. Map showing sampling stations in the southwestern region of the East Sea in August and October 1995. Symbols ○ indicate the stations occupied in August, ▲ in October and ★ in both August and October.

RESULTS AND DISCUSSION

Water temperature and salinity

The sea surface temperature (SST) in this study showed a strong horizontal gradient from the Gampo coast (Fig. 2). In August, the SST was 13.5°C off Gampo coast and increased to *ca.* 24°C offshore. In October, the SST increased to *ca.* 19°C near Gampo coast and decreased by 1—2°C at offshore area, compared to that observed in August (Fig. 2). These results agree well with previous observations by Shim *et al.* (1985) and Lee (1978), who indicated that the SST near the Gampo coast was relatively low in summer and became high in autumn.

Vertical distributions of water temperature and salinity for 3 transections in August and October 1995 are shown in Fig. 3 and Fig. 4, respectively. In August, the relatively cold water with temperatures ranging from 4 to 14°C existed in the whole water column near the coast on 3 transections and extended offshore to the depth of 100—150 m on Line 209. A strong thermocline occurred offshore at about 50 m deep on Line 208, while it did not occur at the stations of Line 102. In October, the temperature increased by *ca.* 2°C at onshore stations, but decreased by 1—2°C at offshore stations compared with the values in August. However, its distribution pattern was similar to that observed in August. Salinity at onshore stations ranged from 32.84 to 34.32 psu, and relatively high salinity (≧ 34.30 psu) occurred in the intermediate or bottom waters of offshore stations. Salinity in the surface water increased more or less in October, but its distribution pattern was similar to that observed in August.

There are two hypotheses on the origin of the cold water mass along the eastern coast of Korean Peninsula. First, the cold water mass may be formed by upwelling of the sunken NKCW from the north, judging from the σ_T-O_2 diagram (Park, 1978) and relatively high oxygen contents (Kim and Kim, 1983). Yang *et al.* (1994) pointed out that the cold water mass originated probably from NKCW by measurements of Ra-228/Ra-226 activity. Another hypothesis is the formation of cold water by upward movement of ESPW in the Ulleung Basin (Lee and Na, 1985). However, this postulation has not been properly tested yet.

Distributions of particulate organic carbon and nitrogen

Vertical profiles of POC and PON in August and October are shown together with those of dissolved inorganic nutrients in Fig. 5 and Fig. 6, respectively. At most of the onshore stations, POC and PON concentrations were relatively high in the upper 20-m layer, but were constantly low below 30-m depth. Their concentration differences between the surface and bottom layers were greater in August than in October. At the offshore stations, the concentrations were relatively low and nearly constant through the whole water column in both August and October.

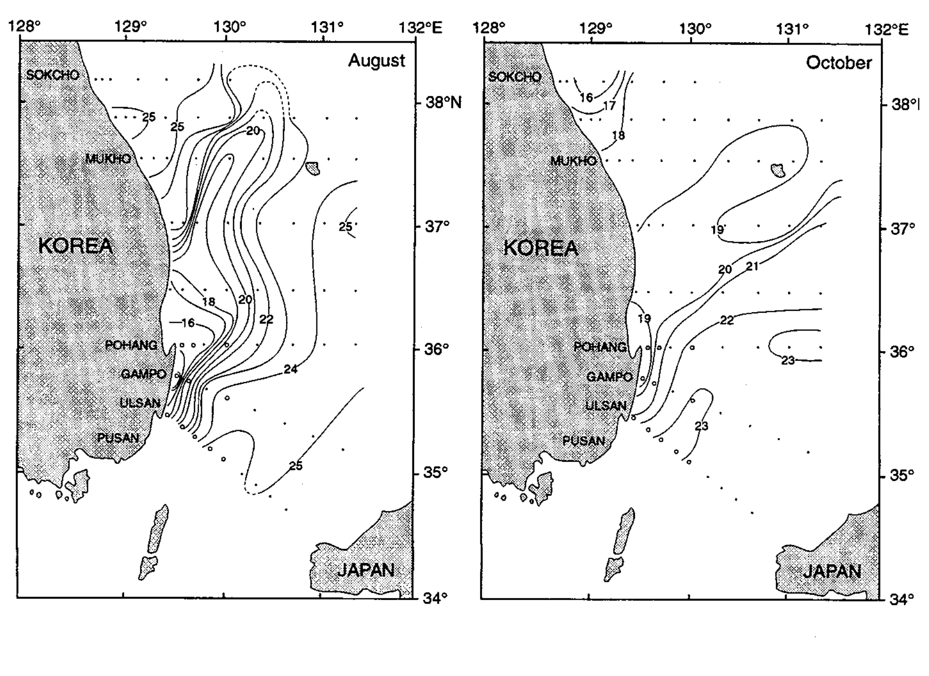

Fig. 2. Horizontal distribution of sea surface temperature (°C) in August and October 1995.

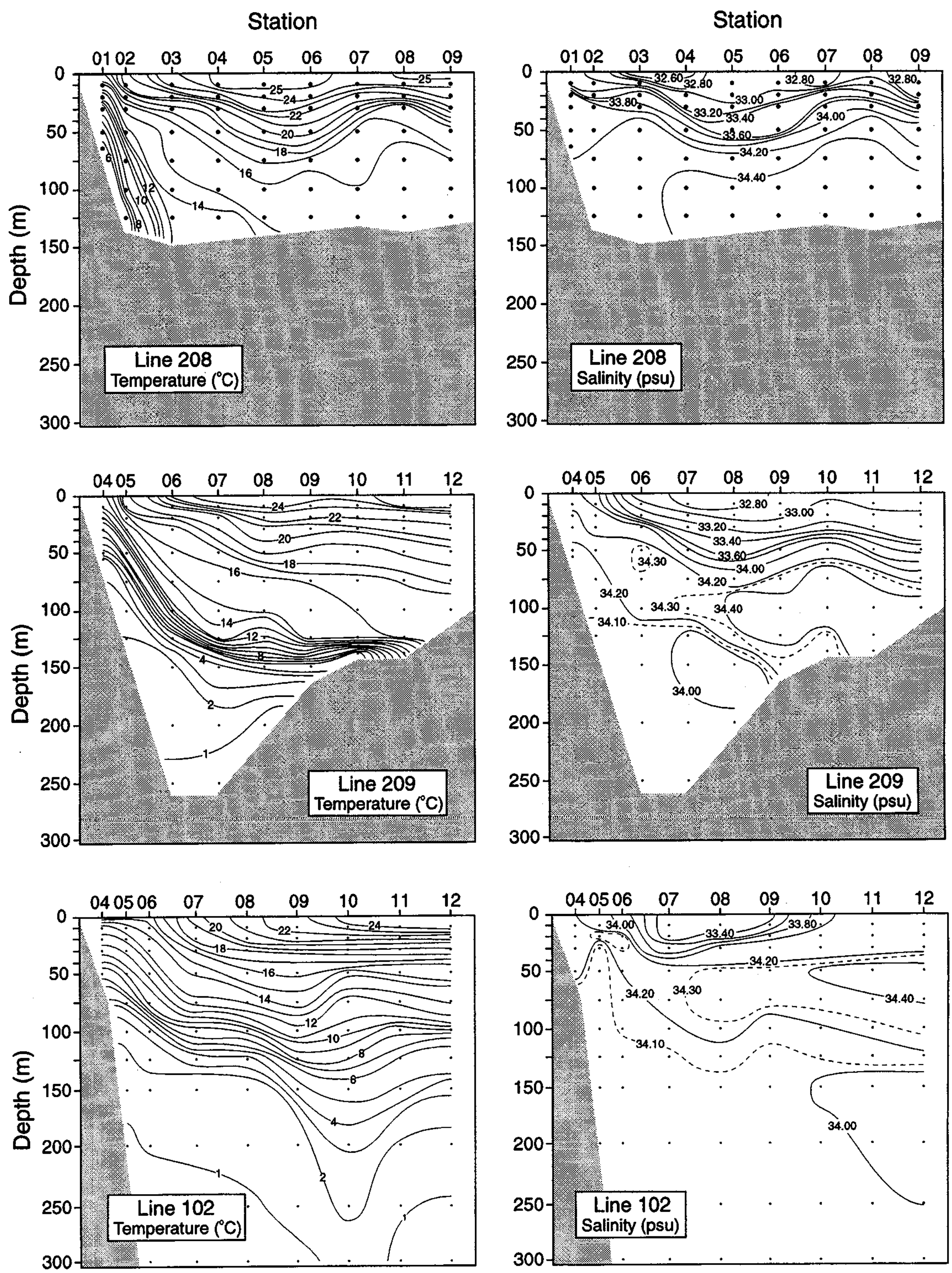

Fig. 3. Vertical distributions of water temperature and salinity along each transect in August 1995.

The vertically integrated inventories of POC and PON in the mixed layer at each station are shown in Table 1. In August, mean values of the POC and PON inventories were about 4 times higher at onshore stations than offshore stations. The PON inventory was one order of magnitude lower than that of POC. In October, the mean inventories of POC and PON at onshore stations were about half of those observed in August, and there were relatively small differences in these inventories at each

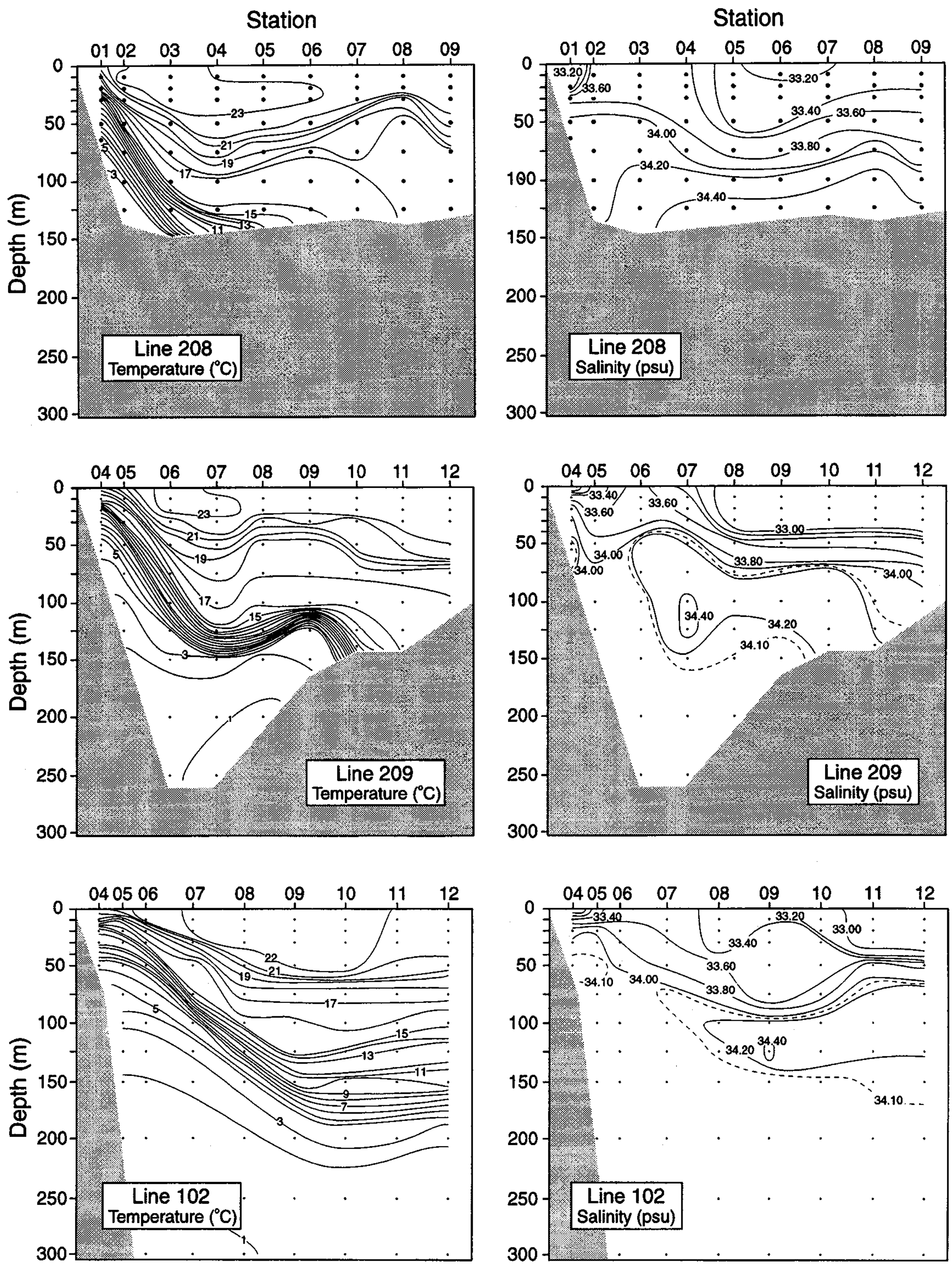

Fig. 4. Vertical distributions of water temperature and salinity along each transect in October 1995.

station. It was characteristic that the inventories of POC or PON at offshore stations were higher in October rather than in August. The highest inventories of POC and PON occurred at onshore stations in August when cold water mass was strongly present (Table 1). The inventories of POC and PON in this study are comparable to the values reported in the upper 30-m layer of Namibian upwelling area (Barange *et al.*, 1991). However, these inventories are lower than the values in

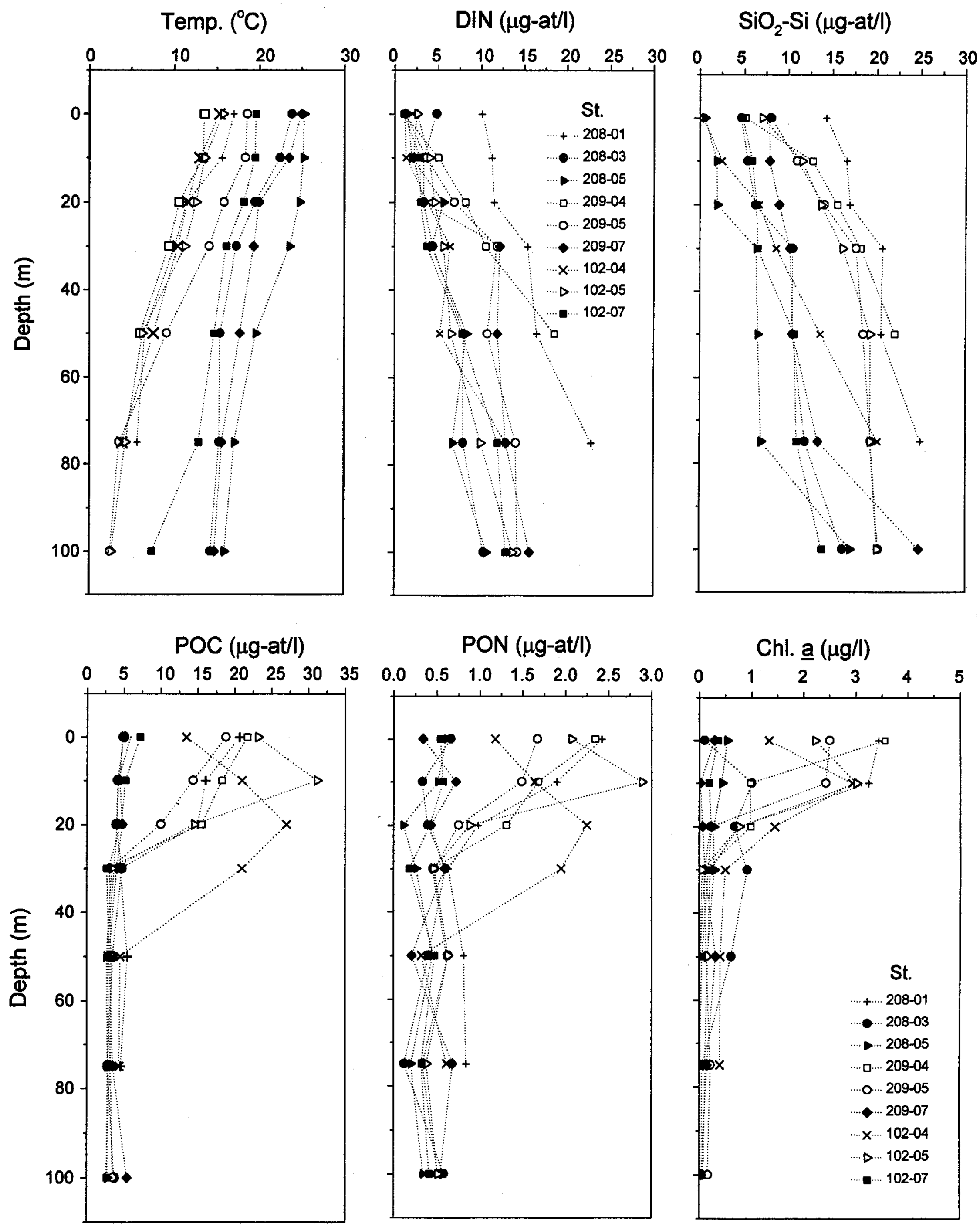

Fig. 5. Vertical profiles of water temperature, inorganic nutrients, POC, PON and chlorophyll *a* in August 1995. Onshore stations are Stations 208-01, 209-04, 209-05, 102-04, 102-05 and offshore stations are the others.

surface water of Chinhae Bay (Lee *et al.*, 1994), while they are higher than those at offshore region of the East Sea (Chester and Stoner, 1974).

The concentrations of POC were well correlated with PON in both August ($r=0.91$, $n=59$) and October ($r=0.83$, $n=56$). The POC/PON weight ratio was 8.9 in August and 6.3 in October. The C/N ratio of living phytoplankton in the mixed layer was about 5.7. The ratio of detrital matter became larger with time because proteins are more readily decomposed than carbohydrates (Duursma and Dawson, 1981). The relatively high C/N ratio in August was probably due to relatively high inventory of detritus in summer, which is discussed below.

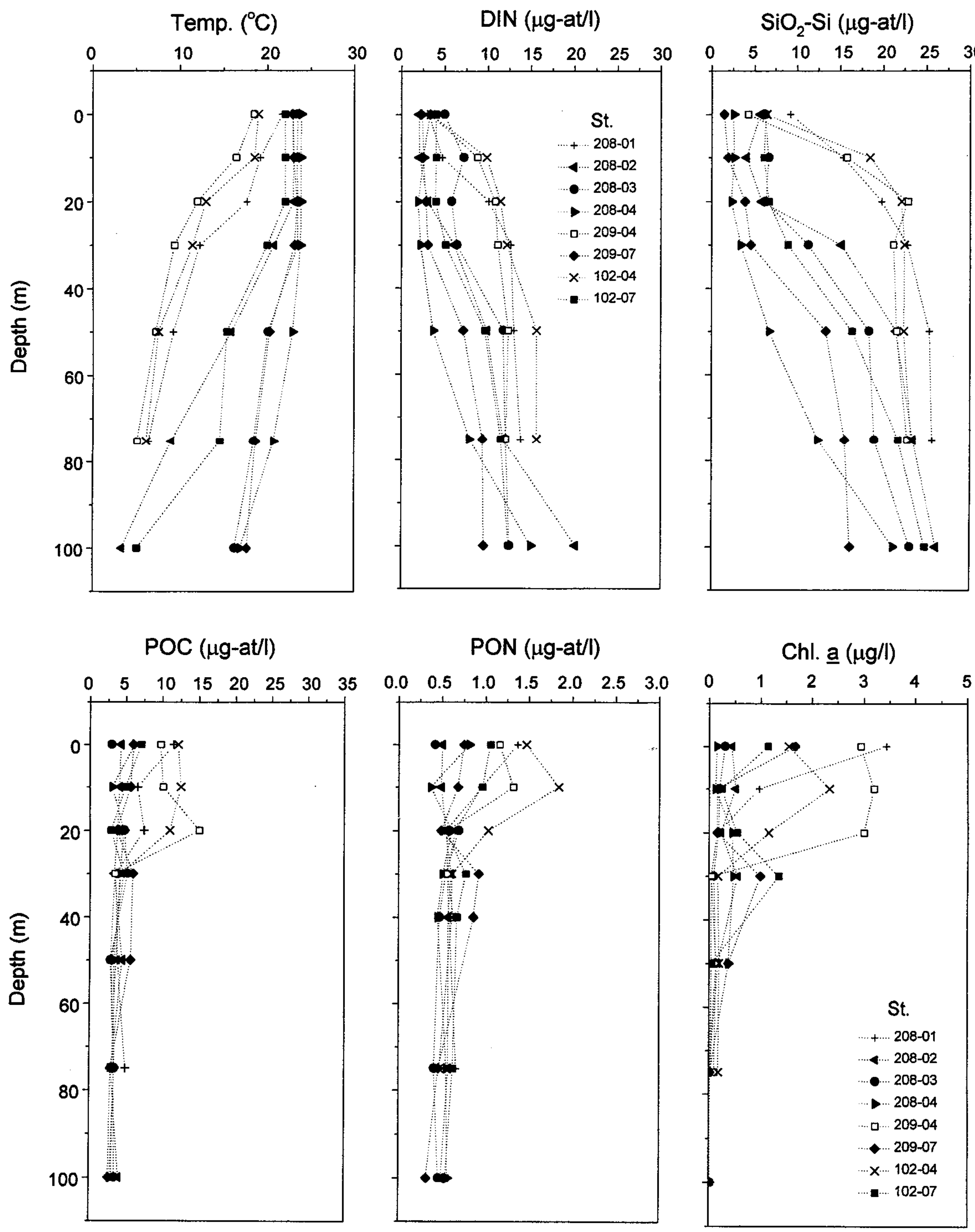

Fig. 6. Vertical profiles of water temperature, inorganic nutrients, POC, PON and chlorophyll *a* in October 1995. Onshore stations are 208-01, 208-02, 209-04, 102-04 and offshore stations are the others.

Estimation of phytoplanktonic carbon and detritus contents

The contents of POC, PON and chlorophyll *a* in TSM are shown in Table 2. In August, POC content in TSM at onshore stations was much higher in the mixed layer than in bottom layer. At offshore stations, POC contents were relatively low and constant throughout the whole water column. PON and chlorophyll *a* contents in TSM also showed a similar trend to that of POC. In October, POC, PON and chlorophyll *a* contents in TSM were much

Table 1. Vertically integrated inventories of POC and PON in the mixed layer of the southwestern East Sea in 1995

Month	Region	Station	POC (mg C/m^2)	PON (mg N/m^2)	POC/PON (weight ratio)
August	Onshore	208—01	4200	480	8.75
		209—04	4500	530	8.49
		209—05	2700	340	7.94
		102—04	7800	697	11.19
		102—05	7100	663	10.71
		average	5260±2127	542±144	9.42±1.44
		208—03	1040	112	9.29
		208—05	1650	139	11.87
		209—07	1120	155	7.23
		102—07	1450	150	9.67
		average	1315±285	139±19	9.52±1.90
	Onshore	208—01	1875	280	6.70
		208—02	1400	224	6.25
		209—04	4220	390	10.82
		102—04	3200	419	7.64
		average	2674±1282	328±92	7.85±2.06
		208—03	1690	257	6.58
		208—04	2440	357	6.83
		209—07	3040	595	5.11
		102—07	1200	245	4.90
		average	2093±812	364±162	5.86±0.99

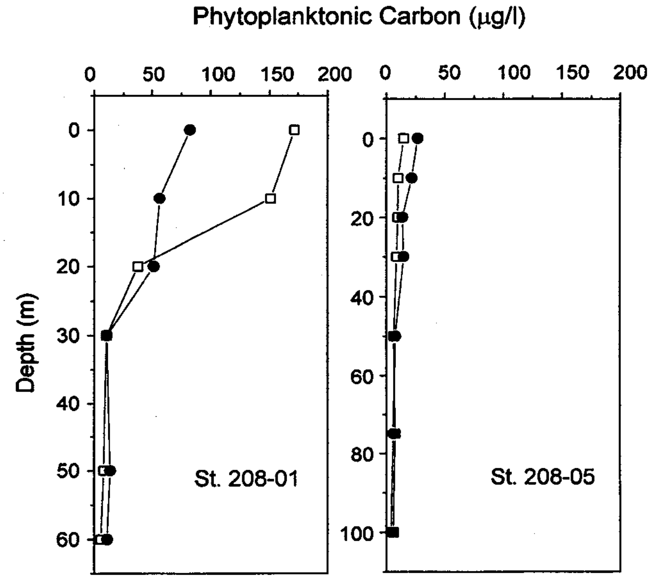

Fig. 7. Vertical profiles of phytoplanktonic carbon in August 1995. Filled circles indicate values estimated from Equation 1 (phytoplanktonic C (μg/l)=0.158POC+0.0007POC^2; Eppley *et al.*, 1977) and open squares from Equation 2 (phytoplanktonic C (μg/l)=Chl. $a\times50$; Cho and Azam, 1990). Stations 208-01 and 208-05 belong to the onshore and offshore stations, respectively.

lower than those of August and there was little difference between the values of onshore and offshore stations. The highest content of POC, PON and chlorophyll *a* in TSM occurred obviously in the mixed layer of onshore stations in August (Table 2).

Phytoplanktonic carbon concentrations were calculated by the following equation of Eppley *et al.* (1997):

$$\text{Phytoplanktonic C } (\mu g/l) = 0.158\text{POC} + 0.0007\text{POC}^2 \quad (1)$$

then, the results were compared with those determined by the following equation of Cho and Azam (1990):

$$\text{Phytoplanktonic C } (\mu g/l) = \text{Chlorophyll } a \times 50 \quad (2)$$

The concentrations calculated by Equation 1 were different from the concentrations calculated by Equation 2 as shown in Fig. 7 and this discrepancy was relatively high at surface layers of onshore stations. There was little difference between the concentrations calculated from the two equations at offshore stations. The discrepancy between the concentrations estimated from the two equations was probably due to the variations of the POC/Chl. *a* ratio. When POC/Chl. *a* was below 150, the phytoplanktonic carbon concentrations calculated by the Equation 2 became larger compared to those calculat-

Table 2. POC, PON, chlorophyll *a* and total suspended matter (TSM) concentrations in the southwestern East Sea in 1995 (Percentages of TSM are in parenthesis)

Month	Station	Depth	TSM (mg/l)	POC (μg/1)	PON (μg/1)	Chl. *a* (μg/1)	POC/Chl. *a* (weight ratio)
August	Onshore	[1]Mixed layer	2.14±0.66	215.28 (10.06)	22.95 (1.07)	1.90 (0.09)	113.31
		Bottom layer	1.53±0.87	44.01 (2.88)	7.72 (0.50)	0.15 (0.01)	293.40
	Offshore	Mixed layer	0.91±0.26	57.75 (6.35)	6.34 (0.70)	0.34 (0.04)	169.85
		Bottom layer	0.65±0.26	41.08 (6.32)	5.69 (0.88)	0.19 (0.03)	216.21
October	Onshore	Mixed layer	3.08±1.32	100.42 (3.26)	13.34 (0.43)	1.47 (0.05)	68.31
		Bottom layer	2.05±0.60	45.09 (2.20)	8.04 (0.39)	0.10 (0.00)	450.90
	Offshore	Mixed layer	1.60±0.57	57.79 (3.62)	9.35 (0.58)	0.48 (0.03)	120.40
		Bottom layer	2.18±1.48	40.40 (1.85)	7.61 (0.35)	0.16 (0.01)	252.50

[1]Mixed layer indicates the layer above the thermocline.

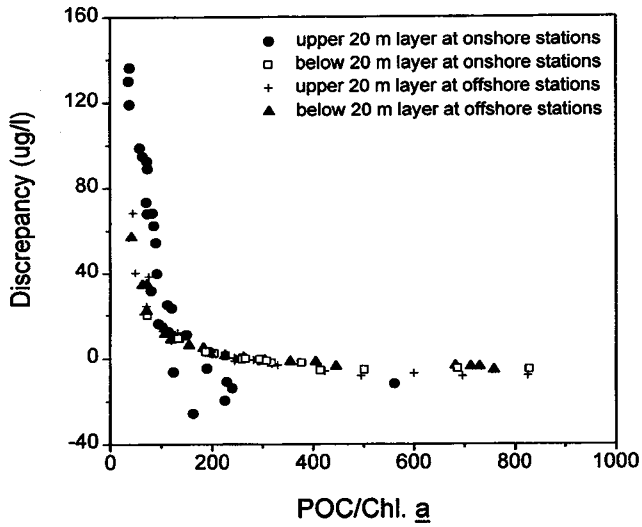

Fig. 8. Plots of phytoplanktonic carbon discrepancy vs. POC/Chl. *a* ratio in August and October 1995. The discrepancy means differences between the inventories estimated from Equations 1 and 2.

ed by Equation 1 (Fig. 8). In this study, the weight ratios of POC to chlorophyll *a* at mixed layer of onshore stations were 142 in August and 94 in October. According to Eppley *et al.* (1977), the ratio was 42 for the diatom blooms and 78—209 for the dinoflagellate blooms. Redalje (1983) and Shim and Shin (1989) mentioned that the use of a direct conversion of chlorophyll *a* to phytoplanktonic carbon might lead to an erroneous estimation, because C/Chl. *a* ratio fluctuates greatly in different marine ecosystems. Phytoplanktonic carbon contents calculated by Equation 2 at the surface layer might have been overestimated. Therefore, the phytoplanktonic carbon contents calculated from Equation 1 were used in this study.

In the vertical profiles of phytoplanktonic carbon (Fig. 7), the phytoplanktonic carbon was relatively high at surface layer and decreased with depth down to 20—30 m layer and then remained low and constant at onshore stations in August, while phytoplanktonic carbon at offshore stations was relatively low and almost constant throughout the water column. The vertically integrated inventories of phytoplanktonic carbon in the mixed layer at each station are shown in Table 3. In August, phytoplanktonic carbon inventories calculated were *ca.* 7 times higher at onshore stations than offshore stations. In October, the mean inventories for phytoplanktonic carbon were also higher at onshore stations than offshore stations, but there were relatively small differences in these inventories between onshore and offshore stations. It was characteristic that the inventories of phytoplanktonic carbon at offshore stations were higher in October rather than August like as the inventories of POC and PON. These results indicate that the major portion of POC at onshore stations was derived from primary production in August when cold water developed strongly.

Table 3. Vertically integrated inventories of phytoplanktonic carbon and detritus carbon in the mixed layer of the southwestern East Sea in 1995

Month	Region	Station	Phytoplanktonic C[1] (mg C/m^2)	Detritus C[2] (mg C/m^2)
August	Onshore	208—01	1300	2900
		209—04	1300	3200
		209—05	1000	1700
		102—04	2700	5100
		102—05	2700	4400
		average	1800±831	3460±1328
	Offshore	208—03	200	840
		208—05	300	1350
		209—07	220	900
		102—07	270	1180
		average	248±46	1068±240
October	Onshore	208—01	448	1428
		208—02	270	1130
		209—04	910	3310
		102—04	840	2360
		average	617±308	2057±986
	Offshore	208—03	270	1420
		208—04	490	1950
		209—07	1050	1990
		102—07	240	960
		average	513±375	1580±488

[1]Values estimated from Equation 1 (phytoplanktonic C=0.158POC +0.0007POC^2; Eppley *et al.*, 1977).
[2]Detritus C=POC−phytoplanktonic C (calculated by Equation 1).

The vertically integrated inventories of detritus in the mixed layer (Table 3), which were calculated by subtracting phytoplanktonic carbon from POC, were almost 3 times greater at onshore stations than offshore stations in August. Detritus inventories at onshore stations were 2 times higher in August than October, while the inventories at offshore stations were higher in October rather than August.

In addition, to estimate the living and non-living fractions of the POC, the regression analysis between POC and chlorophyll *a* was also attempted, in which the slope and the intercept of the regression line could give the POC/Chl. *a* ratio and the content of detritus with minor portion of non-photosynthetic organisms, respectively. As shown in Table 4, the detritus content in POC was 44% at

Table 4. Correlation of POC with chlorophyll *a* and the detritus contents in POC (The number of samples is in parenthesis)

Month	Station	Regression equation	r^2 (n)	Detritus in POC (%)
	Whole	POC=78.33Chl. a+42.94	0.721 (59)	44.9
August	Onshore	POC=72.11Chl. a+60.50	0.688 (31)	43.9
	Offshore	POC=11.68Chl. a+44.46	0.080 (28)	93.7
	Whole	POC=33.26Chl. a+41.36	0.699 (56)	68.1
October	Onshore	POC=34.51Chl. a+46.45	0.731 (25)	60.0
	Offshore	POC=21.67Chl. a+42.02	0.375 (31)	86.1

onshore stations and 94% at offshore stations in August. It is also strongly suggested that the POC in the cold water mass consists of phytoplanktonic organic matter to a larger extent rather than detrital organic matter.

In conclusion, onshore stations, where cold water mass occurred by upwelling, showed relatively low detritus percentage, high values of vertically integrated inventories of phytoplanktonic carbon, high percentages of POC and PON in the TSM, low ratio of POC to chlorophyll *a*, when compared with offshore stations. These phenomena were more obvious in August, when cold water mass developed strongly, than in October. This result is in good agreement with the report from Han *et al.* (1998) who noted that the primary production in August in the same area was 4—5 times higher at onshore stations than offshore stations and that the primary production was higher in August than October.

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REFERENCES

Barange, M., E. Gutierrez and J. Flos, 1991. Variability of particulate organic carbon and nitrogen in the Namibian upwelling system. *Mar. Biol.*, **110**: 309–418.

Chester, R. and J.H. Stoner, 1974. The distribution of particulate organic carbon and nitrogen in some surface water of the world ocean. *Mar. Chem.*, **2**: 263–276.

Cho, B.C. and F. Azam, 1990. Biogeochemical significance of bacterial biomass in the ocean's euphotic zone. *Mar. Ecol. Prog. Ser.*, **63**: 253–259.

Duursma, E.K. and R. Dawson, 1981. Non-living particulate matter. In: Marine Organic Chemistry, edited by Cauwet, G., Elsevier Scientific Publishing, Amsterdam, pp. 71–89.

Eppley, R.W., W.G. Harrison, S.W. Chisholm and E. Stewart, 1977. Particulate organic matter in surface water off southern California and its relationship to phytoplankton. *J. Mar. Res.*, **35**: 671–696.

Han, M.S., D.H. Jang and H.S. Yang, 1998. The ecosystem of the southern coastal waters of the East Sea, Korea. II. Primary productivity in and around cold water mass. *J. Korean Soc. Oceanogr.*, **33**: 196–204.

Holm-Hansen, O.C., 1973. Determination of total microbial biomass by measurement of adenosine triphosphate. In: Estuaries Microbial Ecology, edited by Stevenson, L.H. and R. R. Colwell, University of South Carolina Press, Columbia (South Carolina), pp. 75–89.

Holm-Hansen, O.C., C.J. Lorenzen, R.W. Holms and J.D.H. Strickland, 1965. Fluorometric determination of chlorophyll. *J. Cons. Perm. Int. Explor. Mer.*, **30**: 3–15.

Kang, C.K., P.Y. Lee, P.J. Kim and H.G. Choi, 1993. Daily variation of particulate organic carbon in Wonmun Bay on the south coast of Korea in late summer. *J. Korean Fish. Soc.*, **26**: 279–287.

Kim, C.H. and K. Kim, 1983. Characteristics and origin of the cold water mass along in the east coast of Korea. *J. Oceanol. Soc. Korea*, **18**: 73–83. (in Korean).

Lee, K.B., 1978. Study on the coastal cold water near Ulsan. *J. Oceanol. Soc. Korea*, **13**: 5–10.

Lee, J.C. and J.Y. Na, 1985. Structure of upwelling off the southeast coast of Korea. *J. Oceanol. Soc. Korea*, **20**: 6–19.

Lee, P.Y., C.K. Kang, J.S. Park and J.S. Park, 1994. Annual change and C:N:P ratio in particulate organic matter in Chinhae Bay, Korea. *J. Korean Soc. Oceanogr.*, **29**: 107–118.

Lim, D.B. and S. Chang, 1969. On the cold water mass in the Korea Strait. *J. Oceanol. Soc. Korea*, **4**: 71–82.

Moon, C.H., C. Park and S.Y. Lee, 1993. Seasonal variations of nutrient and particulate organic matter in Asan Bay. *J. Korean Fish. Soc.*, **26**: 173–181. (in Korean).

Moon, C.H., H.S. Yang and K.W. Lee, 1996. Regeneration processes of nutrients in the polar front area of the East Sea. I. Relationships between water mass and nutrient distribution pattern in autumn. *J. Korean Fish. Soc.*, **29**: 503–526. (in Korean).

NFRDA (National Fisheries Research and Development Agency), 1987. Comprehensive Studies of the Cold Water Phenomena in the Southeastern Waters of Korea. Technical Report of NFRDA, Vol. 70, 201 pp. (in Korean).

Park, C.K., 1978. Chemical oceanographic aspect of the cold water mass in offshore of the east coast of Korea. *J. Korean Fish. Soc.*, **11**: 49–54. (in Korean).

Redalje, D.G., 1983. Phytoplankton carbon biomass and specific growth rates determined with the labeled chlorophyll *a* technique. *Mar. Ecol. Prog. Ser.*, **11**: 217–225.

Riley, J.P. and R. Chester, 1971. Dissolved and particulate organic compounds in the sea. In: Introduction of Marine Chemistry, edited by Riley, J.P., Academic Press, London, pp. 182–218.

Shim, J.H. and Y.K. Shin, 1989. Biomass of primary producer in the Chŏnsu Bay: Relationship between phytoplankton carbon, cell number and chlorophyll. *J. Oceanol. Soc. Korea*, **24**: 194–205.

Shim, J.H., W.H. Lee and S.Y. Bak, 1985. Studies on the plankton in the southwestern waters of the East Sea (Sea of Japan) (II): Phytoplankton-standing crop, nanofraction, and primary production. *J. Oceanol. Soc. Korea*, **20**: 37–54.

Smayda, T.J., 1978. From phytoplankters to biomass. In: Phytoplankton Manual, edited by Sournia, A., UNESCO, Paris, pp. 273–282.

Strathmann, R.R., 1967. Estimating the organic carbon content of phytoplankton from cell volume or plasma volume. *Limnol. Oceanogr.*, **12**: 411–418.

Strickland, J.D.H. and T.R. Parsons, 1972. A Practical Handbook of Seawater Analysis (2nd edn.), Bulletin of Fisheries Research Board of Canada, Vol. 167, 310 pp.

Telek, G. and N. Marshall, 1974. Using a CHN analyzer to reduce carbonate interference in particulate organic carbon analyses. *Mar. Biol.*, **24**: 219–221.

Yang, H.S., P.J. Kim, J.C. Lee and C.H. Moon, 1994. Origin of the cold water below 10°C occurring in the southern coastal region of the Korean East Sea in summer by Ra isotope distribution. *J. Korean Fish. Soc.*, **27**: 404–412. (in Korean).

Yang, H.S., C.H. Moon, S.J. Oh and H.P. Lee, 1997. Regeneration processes of nutrients in the polar front area of the East Sea: II. Distribution of particulate organic carbon and nitrogen in winter, 1995. *J. Korean Fish. Soc.*, **30**: 442–450. (in Korean).

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