Influence of Discontinuous Layer on Plankton Community Structure and Distribution in Masan Bay, Korea

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마산만에서 관찰된 불연속층과 플랑크톤 군집구조와의 관계

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The community structure and micro-scale distribution of plankton in relation to hydrography were investigated in Masan Bay, Korea in October 1989. Warmer and less saline waters with stratification was located in the inner part of the Pudo Strait, and chlorophyll-*a* and nutrients were higher. Both phytoplankton biomass and nutrients was changed dramatically around the Strait. Offshore/oceanic species in phytoplankton i.e., *Chaetoceros decipiens, Rhizosolenia stolterforthii, Rhizosolenia styliformis* and *Ceratium trichoceros* and zooplankton i.e., *Sagitta enflata, Oncaea venusta* and *Oikopluera longicaudata* occurred mainly in well mixed waters of the outer part. This suggests that discontinuous layer seems to play an important role as an approximate border for the plankton population. This layer was located between Station 3 and Station 4 near the Pudo Strait, since the layer consisted of a series of micro-scale discontinuties of salinity and dissolved inorganic nutrients gradient. Phytoplankton patchs of more than 80$\mu g/l$ were found only in the inner part of the bay. Depletion of silicate caused by a rapid assimilation of phytoplankton in the inner part of the bay seemed to be responsible for the decline of blooms.

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Introduction

Coastal ecosystem consisted of various kind of systems with complexity, viz., estuarine system, nearshore system and offshore system, etc. The offshore boundary of the nearshore zone often consists of a front, then is sometimes defined by a steep density change (discontinuous layer) and is closely related with the distribution of plankton community and transport of organic and inorganic matter (Pingree et al., 1975; Simpson et al., 1979; Han et al., 1989). Therefore, investigation on mechanisms and causes of biomass concentration, changes in productivity and impact on the structure of the ecosystem in relation to discontinuous layer must be added to an understanding of ecological process in the coastal and offshore ecosystem (Loder and Platt, 1984; UNESCO, 1986).

Semi-enclosed Masan Bay is located in south-eastern part of Korea and its water circulation is restricted because of its narrow mouth and many islands adjacent to the bay. Historically, the bay has been a important breeding and nursing ground for anchovy and cod and many shellfish culture farms have been estabilished (Yang and Hong, 1988). Since the 1970's, eutrophication in the inner part of Masan Bay has been accelerated due to the effluents of large amounts of domestic and industrial wastes (Lee et al., 1981; Lee and Yoo 1990; Yang 1989). In the last decade, red tide and anoxic condition frequently occurred in the bay, therfore, intensive investigations in various fields have been conducted since then (Han et al., 1983a, b; Yoo and Kim, 1987; Kim, 1989; Pae and Yoo, 1991; Hong et al., 1991). In the aspect of plankton study, however, our knowledge is still rather limited to micro-scale distribution. Futhermore, investigations on plankton community structure in costal offshore ecosystem in relation to hydrographic condition are scare.

The objectives of the present study are to clarify the reason why different structure of plankton community occurred in the bay, and to explain the micro-scale distribution of phytoplankton in relation to hydrographic condition and zooplankton distribution of Masan Bay, Korea in October 1989.

Materials and Methods

Intensive survey on plankton communities and physico-chemical factors, i.e., water temperature, salinity, chlorophyll-*a* and nutrients, was conducted in Masan Bay from 27 to 28 October 1989 based on preliminary survey on water temperature and salinity made on 26 October(Fig. 1) (KORDI, 1990).

For the horizontal mapping of above factors, sampling was pumped up continuously from a 1 meter depth while cruising at a constant speed of 10 knots in Pudo Strait during 5 hours of neap tide on 27 October. Temperature and salinity were recorded with a portable S-C-T meter(YSI, Model 33) on board. These values were also calibrated against discrete samples with reading of a thermometer and salinometer(Guidline, Autosal 8400A), respectively. Chlorophyll-*a* was measured for particles collected on Whatmann GF/F filters with extraction in 90% acetone using a UV-VIS Spectrophotometer(Shimadsu, UV-150-02). Dissoved inorganic nutrients(nitrate, nitrite, ammonia, phosphate and silicate) were determined with a UV-VIS Spectrophotometer(Parsons et al., 1984). Phytoplankton samples were collected and fixed with 1% glutaraldehyde for microscopy.

Vertical sampling for 4 selected stations have been made at 5 depths(0 *m*, 2 *m*, 5 *m*, 8 *m*, 12 *m*) with van-Dorn water sampler. Temperature, salinity, and chlorophyll-*a* were measured, and phytoplankton samples were also collected and fixed with 1% glutaraldehyde.

Fixed phytoplankton samples were concentrated by settling, and species identification and cell counting were made. Quantitative zooplankton samples, collected by vertical hauls of a conical plankton net equipped with a flowmeter(mouth diameter: 30 *cm*; mesh size: 100 μm) from near the bottom to the surface, were fixed with 5% neutralized formalin.

Primary productivity was measured by uptake of ^{14}C at 4 selected stations simultanuously(Steemann Nielsen, 1952) on 28 October 1989. Subsamples in 2 light and 1 dark bottles(250 *ml*) were incubated with 10 μCi $NaH^{14}CO_3$. After 1~3 hours of incubation *in situ*, subsamples are harvested on Whatmann GF/F filters under a vacuum pressure of 250 *mm* Hg and transferred to scintillation vials. Phytoplankton was acidified directly with 0.5N HCl in the scintillation vials(20 *ml* in capacity volume) to remove inorganic ^{14}C and then open vials were placed overnight in dark room. Ten milliliters of scintillation cocktail(Instagel) was added to each vial and the activity was assayed with a LKB Wallack (Rackbeta 1215) liquid scintillation counter with quench correction by the external standard ^{14}C method.

Results

Horizontal Mapping

Contour of environmental factors was made along the Pudo Strait with a zig-zag course(Figs. 2, 3). Water temperature and salinity variations were similar to those observed in the preliminary survey (cf. KORDI, 1990)(Fig. 2). Salinity increased as

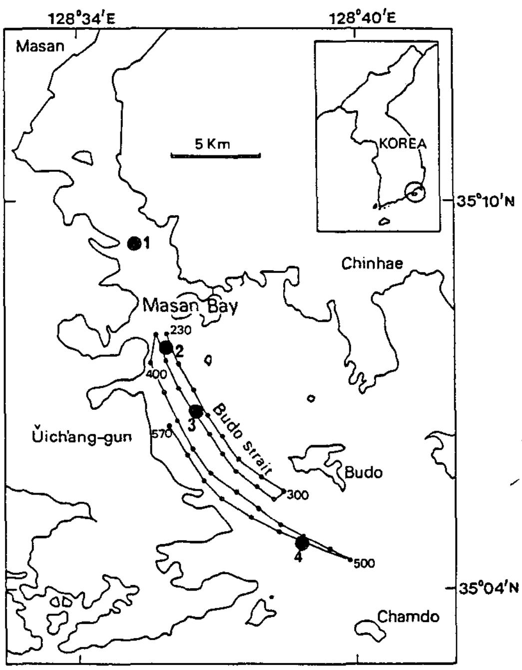

Fig. 1. Sampling stations in Masan Bay on 27 October 1989
(——: cruise track, ●: cruise track numbers, ●: vertical sampling stations)

going from inner to outer part of the bay and ranged from 31.0 to 32.5 ppt. Namely, relatively colder and saline waters was located in the outer part of the bay.

Chlorophyll-*a* and total cell number of phytoplankton changed dramatically between the inner part (Stations 1~3) and the outer part(Station 4) of the bay from more than 90 to 5μg/l, 20×10^7 to <1 $\times10^6$ cells/l, respectively(Fig. 2). Cell numbers of the inner stations were more than 20 times higher than that of the outer part. Three patchs of phytoplankton more than 80μg/l were also detected around the Pudo Strait.

Obvious decrease in dissolved inorganic nutrients was shown in outer part of the bay: ammonia, nitrite, nitrate and phosphate varied from 10 μg-atm/l to 0.1 μg-atm/l, 1.5 μg-atm/l to no detect, 20 μg-atm/l to 0.5 μg-atm/l and 1.3 μg-atm/l to 0.1 μg-atm/l, respectively(Fig. 3). Nitrite was not detected in Station 4. Distributional patterns of the nitrogenous nutrients were similar to that of phosphate. Silicate was distributed abundantly in the outer waters where it was more than 15 μg-atm/l, while it was nearly depleted in the inside waters of stations 1 and 2. Dense nutrient concentrations for the ammonia(8.0 μg-atm/l to 10 μg-atm/l), phosphate(1.0 μg-atm/l to 1.3 μg-atm/l) and silicate(40 μg-atm/l) distributed around the Pudo Strait.

Vertical Distribution

Vertical distributions of the water temperature, salinity, chlorophyll-*a* and cell number of phytoplankton at selected stations were shown in Figure 4. Water temperature of the upper layer was slightly higher than that of the bottom one. The upper layer was less saline than the bottom ones in the inner part, while the outer part was homogeneous.

As going down to the bottom layer in water column of the inner part, abundant surface chlorophyll-*a* and total cell numbers of phytoplankton remarkably decreased from >35 to <5μg/l, 20×10^6 to <1×10^6 cells/l, respectively. They were, however, in homogeneous state in the outer part.

The vertical distribution of nutrients in the bay was shown in Figure 5. In the inner part, ammonia (<1.0μg-atm/l to >20.0μg-atm/l), nitrite(<0.1μg-atm/l to >2.0μg-atm/l) and nitrate(<1.0μg-atm/l to >17.0μg-atm/l) were distributed more abundantly in the surface layer than the bottom. While phosphate of bottom layer was relatively abundant(>1.0 μg-atm/l) when comparison with that of the upper layer in the inner stations. Silicate showed higher value in the bottom as more than 100μg-atm/l at Stations 1 and 2. Distribution of each nutrient in the water column of Station 4 was homogeneous.

These results revealed that the inner part of the bay was stratified, and the outer part well-mixed.

Species Composition of Phytoplankton

Phytoplankton community consisted of a total of 85 species, representing 55 species of diatom, 25 species of dinoflagellate and 5 species of microflagellate. Most of the diatoms were centrales, then 14 species of *Chaetoceros* and 11 species of *Rizosolenia* showed high abundance. Pennales were few, and consisted of *Navicula, Nitzschia* and *Thalassionema* spp. Eleven species of *Protoperidinium* was identified with lower density. Despite few species number of the species of *Prorocentrum, Gymnodinium* and *Protogonyaulax,* their abundance occupied most of dinoflagellate abundace. *Chaetoceros decipiens, Rhizosolenia stolterforthii, Rhizosolenia styliformis* and *Ceratium trichoceros,* which have been known as offshore/oceanic species(Cupp, 1943),

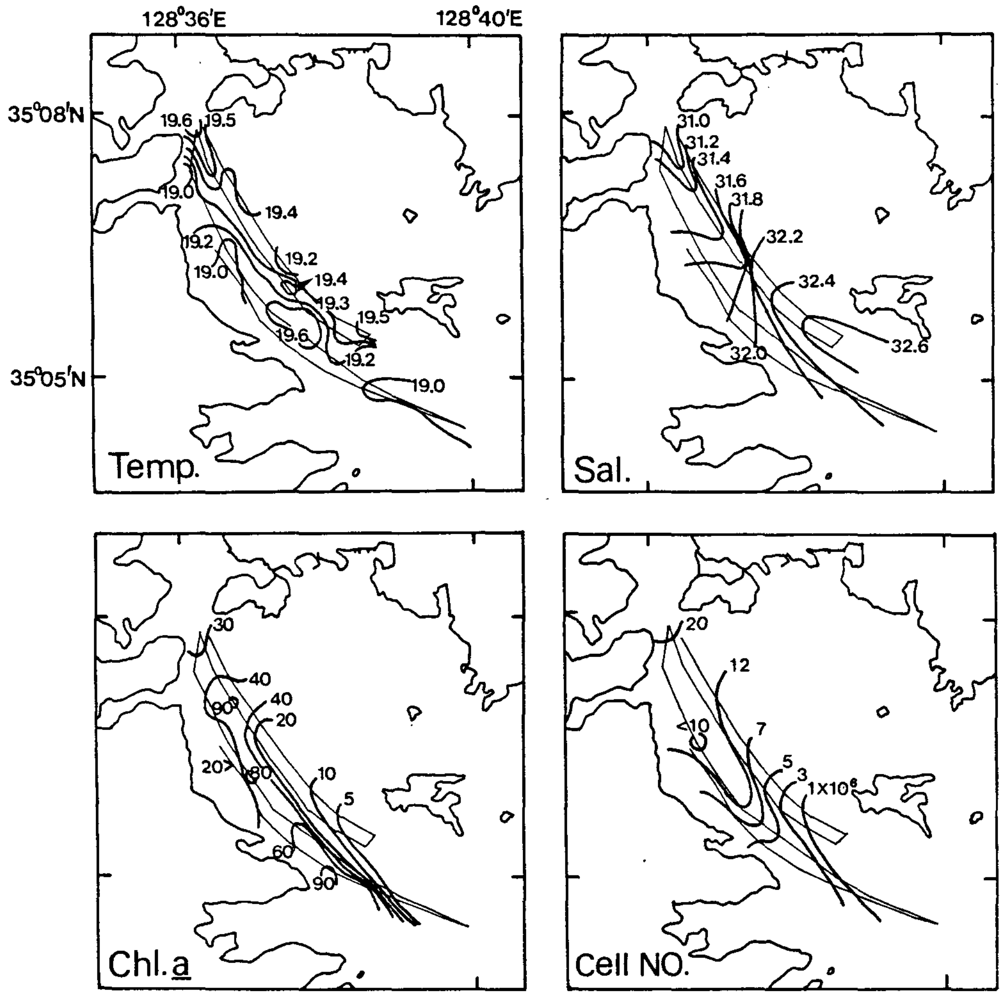

Fig. 2. Horizontal distribution of temperature(℃), salinity(‰), chlorophyll-a(μg/l) and total phytoplankton cell number(cells/l) in Masan Bay on 27 October 1989

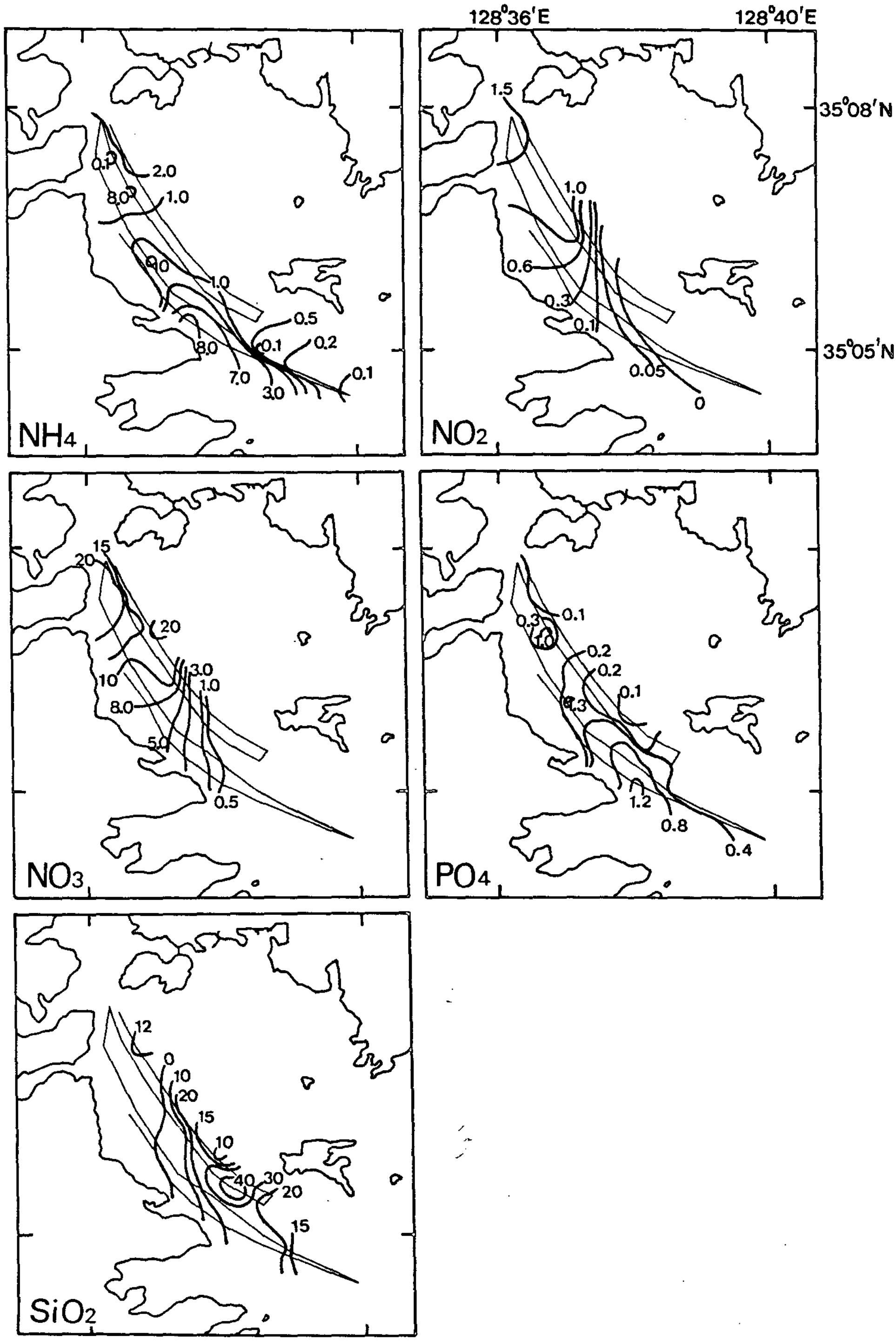

Fig. 3. Horizontal distribution of nutrients(μg-atm/l) in Masan Bay on 27 October 1989: NH_4, NO_2, NO_3, PO_4 and SiO_2

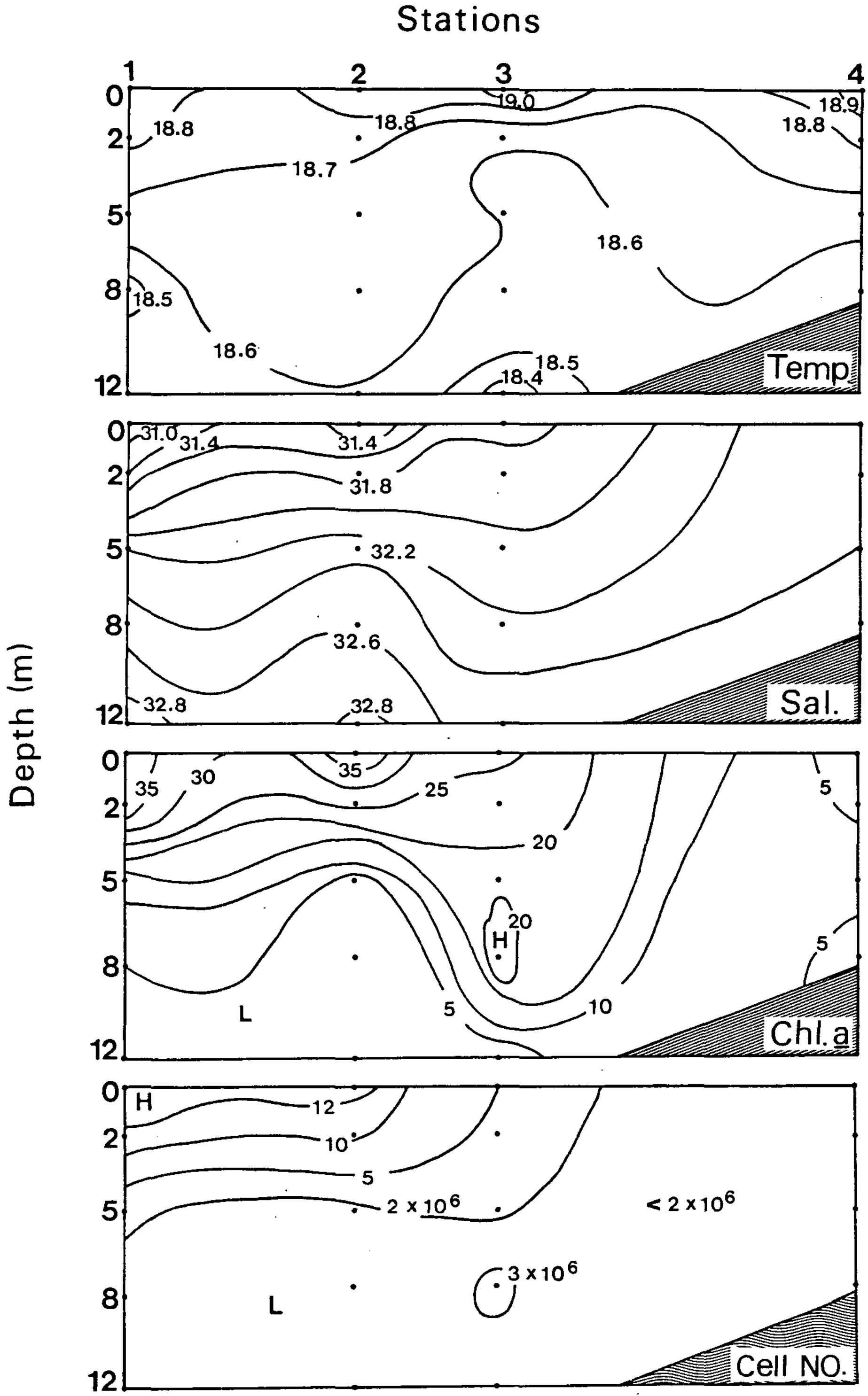

Fig. 4. Vertical distribution of temperature(℃), salinity(‰), chlorophyll-*a*(μg/*l*) and total phytoplankton cell number(cells/*l*) in Masan Bay on 27 October 1989

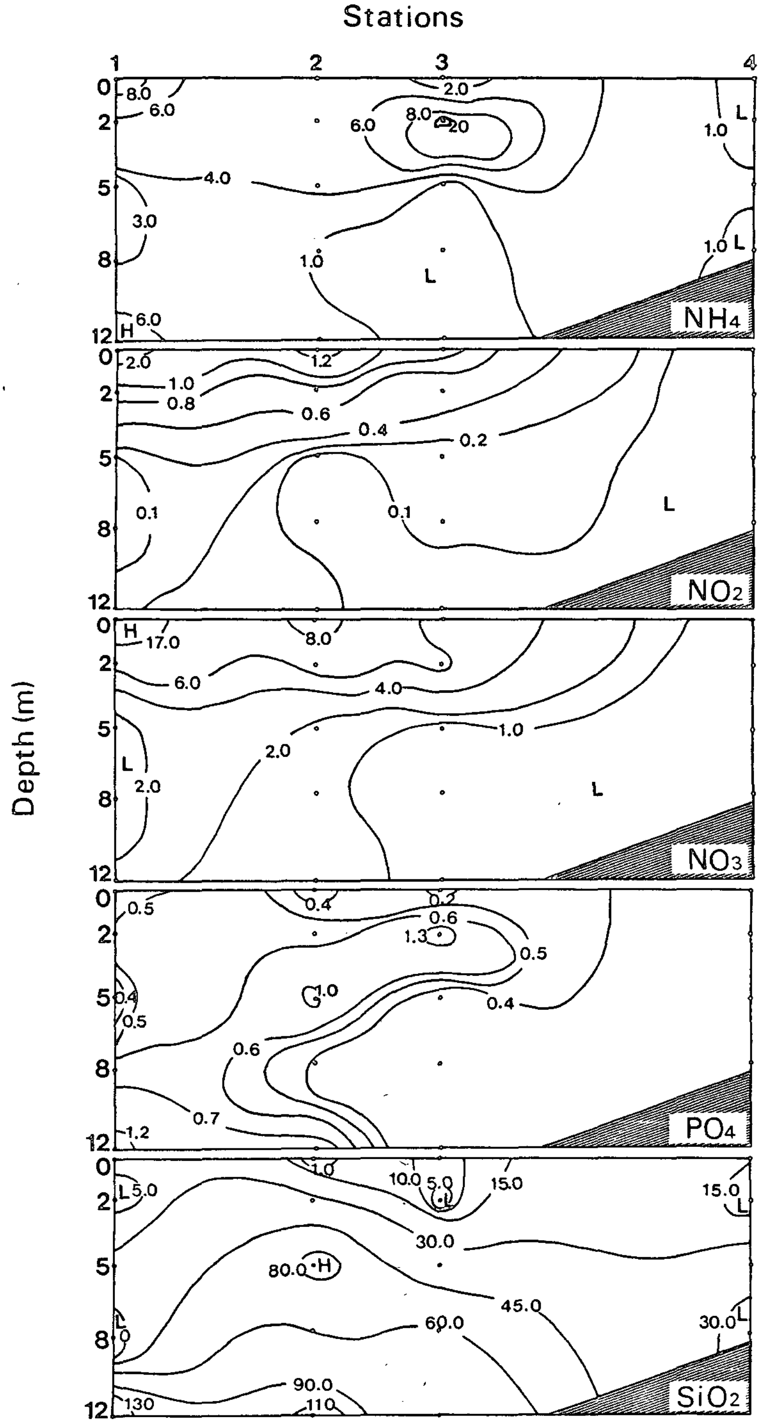

Fig. 5. Vertical distribution of nutrients(μg-atm/l) in Masan Bay on 27 October 1989: NH_4, NO_2, NO_3, PO_4 and SiO_2

were occurred only in the outer part(Table 1).

Productivity

Chlorophyll-*a* content, primary productivity and assimilation number for 4 stations on 28 October 1989 were indicated in Table 2. Primary productivity was recorded in the maximum value of 549.9 μgC/*l*/hr at Station 4. Station 1 also showed high primary productivity of 345.1μgC/*l*/hr and Station 2 and 3 were relatively low in 137.5 and 106.7μgC/*l*/hr, respectively. Chlorophyll-*a* decreased in 0.3 to 0.6 times through October 27 and 28 in the inner part, however, was observed to increase 6.5 times in the outer part(from 3.0 to 19.6μg/*l*). The highest assimilation number was also recorded in the outer part as 28.1μgC/μg chl*a*/hr. While, these of the inner stations were remarkably low compared with that of the outer part.

Zooplankton

Zooplankton community consisted of a total of 20 species, representing 14 species of copepod, 2 species of chaetognath, 2 species of appedicularian, and 1 species of protozoan and cladoceran(Table 3). Six species including *Noctiluca scintillans, Podon polyphemoides, Acartia omorii, Oithona davisae, Paracalanus indicus* and *Oikopluera dioika* occurred at all stations in the bay. Despite the occurrence of

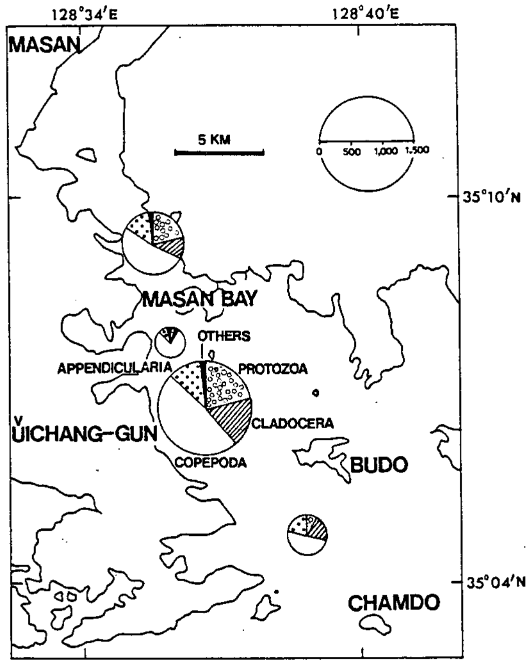

Fig. 6. Zooplankton abundance(indiv./m^3) in four selected stations in Masan Bay on 27 October 1989
(▒: Apendicularia, □: Copepoda, ▨: Cladocera, ░: Protozoa, ■: Others)

Table 1. Distribution and abundance(cells/*l*) of offshore/oceanic species in Masan Bay in October 1989(CTN indicates the cruise track number shown in Fig. 1)

	CTN 300	CTN 310	CTN 320	CTN 330
Chaetoceros decipiens	30682	-	5492	-
Rhizosolenia stolterforthii	-	3586	-	6574
Rhizosolenia styliformis	-	-	3068	-
Ceratium trichoceros	3586	-	-	-

Table 2. Primary productivity, chlorophyll-*a* and assimilation number in Masan Bay in October 1989

Date	October 27	October 28		
Station	Chlorophyll-*a* (μg/*l*)	Chlorophyll-*a* (μg/*l*)	Productivity (μg/C/*l*/hr)	Assimilation number (μg/C/μg chl*a*/hr)
1	37.6	24.3	345.1	14.2
2	39.6	16.7	137.5	8.2
3	26.2	9.7	106.7	11.0
4	3.0	19.6	549.9	28.1

Table 3. Zooplankton species composition and abundance(indiv./m^3) in Masan Bay, Korea on 27 October 1989

TAXA	St. 1	St. 2	St. 3	St. 4
PROTOZOA				
Noctiluca scintillans	110	30	270	60
Tintinnopsis sp.	120	5	55	10
CHAETOGNATHA				
Sagitta crassa				*
Sagitta enflata				*
CLADOCERA				
Podon polyphemoides	100	10	250	100
COPEPODA				
Paracalanus indicus	55	30	20	15
Acartia omorii	*	*	*	*
Acartia pacifica				*
Centropaghes abdominalis		*		
Oithona brevicornis			*	
Oithona davisae	50	60	80	25
Oithona similis		*		
Oncea venusta				*
Corycaeus affinis				*
Corycaeus speciosus				*
Euterpina acutifrons	10	5	10	
Microsetella norvegica		*	*	*
Saphirella sp.	*	5	*	
Copepodid	160	180	230	120
Copepod nauplii	270	50	290	120
APPENDICULARIA				
Oikopluera dioika	140	40	200	100
Oikopluera longicaudata				20
Polychaeta larvae	10	*	20	*
Barnacle cyprid		*	*	
Fish egg & larvae	25	15	20	*
TOTAL	1,030	430	1,440	570

* indicates the abundance less than 5 indiv./m^3

neritic species in the bay, some neritic-oceanic species, i.e. *Sagitta enflata, Onceae venusta* and *Oikopluera longicaudata,* were distributed in the outer part. Highest abundance of 1,440 indiv./m^3 was recorded at Station 3(Fig. 6). *N. scintillans* took up more than 10% of zooplankton abundance at the entire stations, and *P. polyphemoides* occurred predominantly with 18% in Station 4. Copepodite and copepod nauplii occurred in high proportion of more than 40% of total zooplankton abundance in the bay. In Station 4, *Oikopluera dioika* also occurred abundantly and occupied 20%. Typical neritic copepods such as *Acartia omorii, Oithona davisae* and *Paracalanus indicus* occurred in low abundance.

Discussion

Although no distinct variation in water temperature was recorded, salinity, chlorophyll-*a*, nutrients and biological abundance showed that the outer part is characterized by well mixed waters in contrast with the inner part where stratified waters occurred. Offshore/oceanic species of phytoplankton and zooplankton were also observed in the well-mixed waters of the outer part. While neritic species mainly occurred in the inner part. Spatial distribution of phytoplankton and zooplankton was well combined with hydrographic characteristics. This discontinuity of physico-chemical and biological factors has often been recorded in waters where a front in formed. The typical aspect of a front which is formed at the place where two different water masses with different properties meet is well defined by Simpson and Hunter(1974), Fever(1986) and Yanagi(1987). However, we have no available data to know which kind of a front being formed in the bay. Although a series of micro-scale discontinuties of salinity and dissolved inorganic nutrients gradient is less defined a steep density change in the bay, the present result suggests that discontinuous layer was located between Station 3 and Station 4 near the Pudo Strait. This layer seems to play an important role as an approximate border form the distribution of palnkton population.

Three phytoplankton patchs were detected around the Pudo Strait. The best known feature is the peak of standing crops of phytoplankton which is usually found on the stratified side of the front (Savidge, 1976; Pingree et al., 1978). This accumulation of phytoplankton may be explained as the result of recently stabilized nutrient-rich mixed water at the front providing particularly favourable conditions of, 1) passive advection of phytoplankton cells into the frontal region(Okubo, 1978), or 2) nutrients complementation between the abutting water masses(Beardall et al., 1982). The first one is not likely because we cannot found floating materials which are usually accumulated at the surface of the front by converging flow(Uda, 1938). To examine the second possibility and to another explanation, information on growth rate or photosynthetic activity is a prerequisite. Phytoplankton patchs were also located far away from the discontinuous layer. We found that phytoplankton patchs were well combined with the distribution of ammonia and phosphate(Fig. 2 and 3). Phytoplankton patchiness, therefore, may be explained in terms of nutrient availability to phytoplankton in the surface waters.

Phytoplankton bloom occurred in the inner part of the bay on 27 October 1989. Next day, sudden decrease in chlorophyll-*a* was observed in the inner part which seems to be due to sillicate deficiency (Table 2 and Fig. 3). It was reported that a diatom growth is often limited by low silicate concentration in this bay(Hong et al., 1991; Pae and Yoo, 1991). Low assimilation number in the inner part of the bay when compared with that in the outer part agrees well with above mentioned assumption(Table 3). Depletion of silicate caused by a rapid assimilation of phytoplnakton in the inner part of the bay seemed to be responsible to the succession of phytoplankton community and decline of blooms, since the diatoms i.e., *Skeletonema costatum*, *Chaetoceros* spp. and *Fragilaria* sp. occurred dominantly on October 27(KORDI, 1990).

In this report we doccument close relationship between plankton distribution and discontinuous layer in Masan Bay in the limited observation period. A subsequent research program is necessary to examine the detailed physical characteristics of discontinuous layer suggested here and spatial and temporal variations of plankton.

Acknowledgements

We are very grateful to Prof. Kwang-Il Yoo, Hanyang University and Dr. Hyung-teck Huh of Korea Ocean Research & Development Institute for their helpful advice and encouragement. Anonymous reviewers have provided invaluable suggestions resulting in improvement on an earlier version of this manuscript. This work was supported in part by the Ministry of Science and Technology through the grant to Korea Ocean Research and Development Institute(BSPE 00146-263-3).

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Received October 5, 1991
Accepted November 11, 1991

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1989년 10월, 진해만에서 수괴의 물리화학적 요인과 관련된 플랑크톤의 미세분포와 군집구조를 micro-scale 관측을 통하여 분석하였다. 부도수도 내측에는 비교적 온난, 저염의 성층화된 수괴(stratified waters)가 존재하였으며, 풍부한 클로로필양과 영양염류가 관찰되었다. 식물플랑크톤의 생물량과 영양염류는 부도수도의 내측과 외측에서 현저한 변화를 보였다. 외만성 혹은 해양성의 식물플랑크톤(*Chaetoceros decipiens, Rhizosolenia stolterforthii, Rhizosolenia styliformis,* and *Ceratium trichoceros*)과 동물플랑크톤(*Sagitta enflata, Oncaea venusta* and *Oikopluera longicaudata*)은 부도수도 외측의 혼합된 수괴(mixed water)에서만 관찰되었다.이는 부도수도해역의 정점 3과 4 사이에서 염분과 영양염류의 구배에 따른 불연속층(discontinuous layer)이 존재하고 있음을 암시하며, 이 불연속층이 플랑크톤 군집분포에 중요한 영향을 미치는 것으로 생각된다. 부도수도 내측에서는 클로로필양이 80$\mu g/l$ 이상인 식물플랑크톤 patchs가 관찰되었다. 이와같은 식물플랑크톤 bloom시, 높은 동화율에 의한 silicate 고갈은 이 지역에서의 식물플랑크톤 bloom 소멸의 원인으로 추정된다.