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Community Dynamics and Distribution of Dinoflagellates and Their Cysts in Masan-Chinhae Bay, Korea

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The community dynamics and distribution of dinoflagellates and their cysts were monitored monthly from June 1996 to May 1997 at six stations in Masan-Chinhae Bay, one of the famous bays for red-tide occurrence in Korea. The dinoflagellate standing crops ranged from the minimum of 306 cells $m\ell^{-1}$ in February to the maximum of 37,959 cells $m\ell^{-1}$ in May. The species causing massive blooms were *Prorocentrum micans* Ehrenberg and *Ceratium furca* (Ehrenberg) Claparede & Lachmann in July, *Gymnodinium sanguineum* Hirasaka in October, *Alexandrium tamarense* (Lebour) Balech in April and *Prorocentrum minimum* (Pavillard) Schiller in May.

Twenty-seven taxa of dinoflagellate cysts were isolated, including 20 identified species and 7 unidentified species. The mean cyst abundance ranged from the minimum of 556 cysts cm^{-3} in June to the maximum of 5,727 cysts cm^{-3} in February. The spatial pattern of cyst distribution showed the gradual increase in abundance from offshore to inshore stations. The cyst genera of *Protoperidinium, Gymnodinium, Scrippsiella, Gyrodinium* and *Alexandrium* were abundant throughout the year. The vertical distribution of cysts showed the surface miximum at the 0~2 cm layer and the sub-surface maximum at the 2~4 cm layer. Total abundance of cysts showed the most significant relationships with water temperature, and some minor relationship with dissolved oxygen, salinity, pH, phosphate and total inorganic nitrogen of surface and bottom layer in the water column. The number of dinoflagellate species decreased, while the abundance of cysts increased 4.5 times as compared with the observation of 10 years prior to the present study at the same stations of Masan-Chinhae Bay.

Key words: dinoflagellate, dinoflagellate cyst, red tide, Masan Bay, Chinhae Bay

Introduction

Many dinoflagellates produce resting cysts (dinoflagellate cyst below here) as part of their sexual life cycle (Anderson and Wall, 1978; Walker and Steidinger, 1979). After a dormancy period, these cysts germinate into vegetative cells that can act as potential seed populations for initial red tide events (Steidinger, 1975; Anderson and Wall, 1978). Dinoflagellate cysts might cause the transfer and expansion of red-tide from place to place (Steidinger and Haddad, 1981; Ishikawa and Taniguchi, 1994; Nehring, 1995). The red-tide expansion has been recently paid attention to a global scale by ballast water of tankers or big commercial ships, which could cause the harmful algal bloom in coastal area worldwide (Hallegraeff, 1993). Some of the harmful algal blooms have a very close relationship with the cyst abundance, which indicates a potential for the next harmful bloom.

In Korean waters, red tides has occurred frequently on the southern coast from late spring until late fall since 1970s, but it has recently tended to expand to the western and eastern coasts (Kim et al. 1997). Among them, one of the most famous bays is Masan-Chinhae Bay, which shows the characteristics of a low current speed and little exchange of seawater as enclosed bay. It have been severely eutrophicated by runoff of domestic sewage and industrial waste, leading to frequent occurrence of red tide. The red tides in this area occur in very dense blooms and continue for long periods. Recently the community composition of red tide

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organisms have a tendency to be changed from diatoms to flagellates including dinoflagellate (Lee and Yoo, 1990; Kim et al., 1997), of which the resting cyst have been paid attention as seed population in this area. Only a few reports were published on the focus of distribution and dynamics of dinoflagellate cyst from the Korean coasts so far (Lee and Yoo, 1991; Kim, 1992; Lee and Matsuoka, 1996; Kim, 1997; An, 1998). Additionally some works have been done about cyst germination ability on the basis of *Alexandrium* (Kim, 1994) and some red tide organisms (Kim et al., 1990). We, however, need more information in order to understand properly the occurrence and transfer of red-tide organisms in this area. Thus this study was carried out to clarify the abundance and distribution of dinoflagellate in the motile phase and the resting cyst in the surface sediments in Masan-Chinhae Bay.

Material and Methods

Sampling has been done in Masan-Chinhae Bay from June 1996 to May 1997. Stations 1, 2, 3 were selected as offshore station and stations 4, 5, 6 as inshore station with an interval of 4~4.5 km between each station. The depths were 25~35 m in the offshore station, and 8~12 m in the inshore station (Fig. 1).

For plankton analysis, water samples were collected using a Niskin water sampler and a van Dorn sampler, and then fixed with Lugol solution. After concentration, subsamples were used for quantitative and qualitative analysis.

TFO hand core sampler (diameter 1.4 cm) was used for cyst collection. The cysts were isolated and collected after a modified method of Matsuoka et al. (1989). The upper 3 cm of each sediment was used for cyst analysis at each station after sieving in the range of 26~100 μm size fraction, and the 2 cm or 1 cm interval subsamples were also analyzed for vertical distribution at station 4. Only living cysts were counted with a Sedgwick-Rafter chamber using an inverted microscope and calculated the average of triplicate counts by the unit of dinoflagellate cysts per 1 cm^3 wet sediment. For the sediment type, Lewis's sediment classification was applied: station 1 was composed of sandy mud, station 2 and 3 shell sandy mud, station 4 mud, and station 5 and 6 reduced mud (Fig. 1). For the environmental factors, water temperature, salinity, dissolved oxygen, pH, phosphate phosphorus, total inorganic nitrogen were measured from the surface and bottom layer at each station.

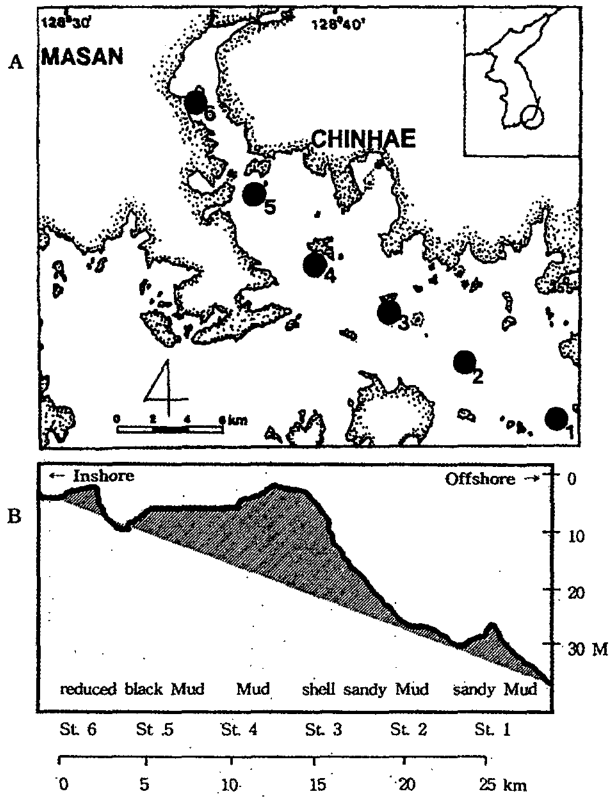

Fig. 1. The map showing the sampling stations in Masan-Chinhae Bay (A) and the bottom topography of the stations and the sediment type (B).

Results and Discussion

Dynamics of motile dinoflagellates

A total of 42 dinoflagellates were identified, representing 5 orders, 13 families, 19 genera (Table 1). In terms of frequency, ten species occurred throughout the year; *Prorocentrum micans, Gymnodinium sanguineum, Gyrodinium spirale, G. fissum, Pheopolykrikos hartmanii, Katodinium glaucum, Ceratium fusus, Alexandrium tamarense, A. affine, Protoperidinium pellucidum.* The species more than 50% of relative abundance were *Prorocentrum minimum, P. micans, Gymnodinium sanguineum, Ceratium fusus, Alexandrium tamarense*, and those with the range of 30~50% *Ceratium furca, Protoperidinium pellucidum, Oxyphysis oxytoxoides.* These species are included in the so-called endemic species of dinoflagellate in this area, which was recorded in

Table 1. Monthly variation of relative abundance (%) of motile dinoflagellates in Masan-Chinhae Bay

Species Name / Month	1996 J	J	A	S	O	N	D	1997 J	F	M	A	M
Alexandrium affine (In. & Fu.) Balech	1.2	–	0.6	0.5	0.9	0.2	0.5	10.1	3.3	1.9	2.9	0.2
Alexandrium catenella (Wh. & Ko.) Balech	1.6	–	0.1	0.5	0.9	–	–	9.7	1.3	–	0.2	–
Alexandrium fraterculus (Balech) Balech	0.8	–	0.3	–	0.4	0.2	0.5	2.8	1.3	0.6	0.3	–
Alexandrium tamarense (Lebour) Balech	0.8	–	0.6	52.9	2.9	0.8	2.2	25.6	3.3	2.6	65.1	0.4
Amphidinium acutum Conrad	0.4	–	–	–	–	–	–	–	0.7	0.6	0.5	–
Amphidinium glaucum Conrad	–	–	–	–	0.1	0.2	–	0.5	0.7	1.9	0.9	–
Ceratium furca (Eh.) Clap. & Lach.	0.4	42.9	29.7	0.5	0.3	1.3	6.6	–	–	0.6	–	0.1
Ceratium fusus (Eh.) Dujardin	4.7	–	0.1	–	2.7	11.8	38.3	12.0	8.5	66.1	19.2	1.5
Ceratium tripos (O.F.Müller) Nitzsch	–	–	–	–	0.1	–	–	–	–	–	–	–
Cochlodinium polykrikoides Margaref	–	–	0.8	5.1	–	–	1.1	–	2.6	–	–	–
Dinophysis acuminata Clap. & Lach.	–	3.7	0.7	0.5	–	–	–	0.9	–	0.6	–	–
Dinophysis fortii Pavillard	0.4	–	–	–	–	–	–	–	–	–	–	–
Gonyaulax spinifera (Cla. & Lach.) Diesing	0.4	–	0.3	–	0.1	–	–	0.5	–	–	0.3	0.1
Gymnodinium breve Davis	0.4	–	0.2	6.0	–	–	1.1	–	–	–	–	–
Gymnodinium catenatum Graham	0.4	–	0.5	4.5	–	0.4	0.5	0.9	–	–	–	–
Gymnodinium sanguineum Hirasaka	–	0.5	2.3	6.5	87.4	71.8	24.6	2.3	0.7	4.5	0.2	–
Gymnodinum mikimotoi Mi.&Ko. ex Oda	1.2	–	1.2	3.0	0.1	–	1.1	1.4	1.3	–	–	–
Gyrodinium fissum (Le.) Kof. & Swezy	1.6	–	0.2	0.5	0.1	0.6	0.5	0.9	2.0	1.9	0.4	–
Gyrodinium spirale (Be.) Kof. & Swezy	2.4	0.1	1.5	1.5	0.1	1.3	3.8	3.7	11.8	1.9	0.6	0.2
Gyrodinium sp.	0.4	0.1	1.0	3.0	0.1	3.6	3.3	3.7	0.7	2.6	0.2	–
Heterocapsa triquetra (Eh.) Stein	3.9	0.2	2.0	–	0.3	0.4	0.5	4.1	3.3	–	0.9	–
Katodinium glaucum (Le.) Loeblich III	0.4	–	0.2	0.5	–	1.5	6.6	6.0	5.9	9.1	3.9	0.7
Lingulodinium polyedra (Stein) Dodge	–	–	0.3	0.5	0.1	–	0.5	–	–	–	0.2	0.1
Noctiluca scintillans (Mac.) Kof. & Swezy	0.8	–	–	0.5	–	–	–	0.9	6.5	1.3	1.8	0.1
Oxyphysis oxytoxoides Kofoid	30.4	0.3	–	–	–	–	–	–	–	–	0.2	0.4
Pheopolykrikos hartmannii (Zi.) Ma. & Fu.	0.4	–	0.4	0.5	0.1	0.6	1.1	2.3	2.0	1.3	0.5	–
Polykrikos kofoidii Chatton	–	–	0.1	0.5	0.1	0.2	0.5	0.9	1.3	1.3	0.2	–
Polykrikos schwartzii Bütschli	0.4	0.1	–	0.5	–	0.2	0.5	0.5	0.7	0.6	–	–
Prorocentrum dentatum Stein	2.0	0.1	0.4	1.0	0.1	–	1.1	1.4	0.7	–	–	–
Prorocentrum micans Ehrenberg	0.4	50.2	34.9	2.0	0.1	0.6	0.5	0.5	–	0.6	0.2	0.1
Prorocentrum minimum (Pa.) Schiller	20.1	0.2	1.0	0.5	–	–	–	–	–	–	–	95.4
Prorocentrum triestinum Schiller	3.6	0.9	2.9	2.0	0.1	–	–	–	–	–	–	0.6
Protoperidinium bipes (Paulsen) Balech	5.1	–	2.6	0.5	0.1	0.2	0.5	1.4	–	–	0.5	–
Protoperidinium conicum (Gran) Balech	0.4	0.1	0.1	1.0	–	–	–	0.5	–	–	–	–
Protoperidinium depressum (Ba.) Balech	0.4	–	0.4	–	–	–	–	0.5	–	–	–	–
Protoperidinium divaricatum (Me.) Balech	–	–	–	–	–	–	–	–	4.6	–	–	–
Protoperidinium leonis (Pavillard) Balech	0.4	–	0.5	1.5	0.1	0.8	0.5	2.3	1.3	–	–	–
Protoperidinium pellucidum Bergh	9.5	0.2	6.4	0.5	0.6	0.2	1.1	0.9	33.5	–	0.2	–
Protoperidinium pentagonum (Gran) Balech	0.4	0.1	0.6	1.0	0.1	1.1	1.1	0.9	0.7	–	–	–
Protoperidinium subinerme (Pa.) LoeblichIII	–	–	–	–	1.0	–	–	0.5	–	–	–	–
Pyrophacus steinii (Schiller) Wall & Dale	0.4	–	0.2	2.0	1.0	2.0	0.5	–	0.7	–	–	–
Scrippsiella trochoidea (Stein) LoeblichIII	3.9	0.3	6.9	–	–	–	0.5	1.4	0.6	–	0.6	0.1
Total number of species	33	16	33	29	27	22	27	30	26	18	23	14

previous studies as dominant species (Lee and Yoo, 1990).

The number of species of dinoflagellate tends to increase year by year, since a total of 18 dinoflagellates have been reported by Lee et al. (1981). Genus *Alexandrium* is known to bloom massively in winter and spring in Korean waters (Han et al., 1996). *Alexandrium tamarense, Heterocapsa triquetra, Prorocentrum minimum, P. triestinum, Gyrodinium* sp., *Heterosigma akashiwo, Gymnodinium sanguineum, G. mikimotoi, Ceratium furca, Cochlodinium polykrikoides* were recorded as red-tide organism in this area in the late spring and fall season from 1990 to 1995 (Kim et al., 1997).

Total standing crops of dinoflagellates represented low abundance from June to March except for two peaks in July with 9.4×10^3 cells $m\ell^{-1}$ and in October with 9.9×10^3 cells $m\ell^{-1}$. These standing crops increased again from April with the highest peak of 38.0×10^3 cells $m\ell^{-1}$ in May (Fig. 2). They varied especially with a very low abundance of $0.3\sim0.4\times10^3$ cells $m\ell^{-1}$ from December to March in winter.

Dinoflagellate blooms were maintained throughout the year by 1~2 dominant species showing seasonal succession. Dinoflagellate blooms above 2.0×10^3 cells $m\ell^{-1}$ were five times during the study period (Fig. 2): *Prorocentrum micans* and *Ceratium furca* were dominant with 4.7×10^3 cells $m\ell^{-1}$ and 4.0×10^3 cells $m\ell^{-1}$, respectively in July, *Gymnodinium sanguineum* with 8.9×10^3 cells $m\ell^{-1}$ in October, *Alexandrium tamarense* with 2.3×10^3 cells $m\ell^{-1}$ in April, and *Prorocentrum minimum* with 36.0×10^3 cells $m\ell^{-1}$ of the highest abundance in May. The blooms of *Prorocentrum minimum* are known to occur frequently in this area and especially at the lower saline waters of the inner bay in summer (Lee and Yoo, 1990). Kim (1989) indicated that dinoflagellate blooms took place not only as a result of anoxic phenomena in this area since 1979, but also as a result of the COD and

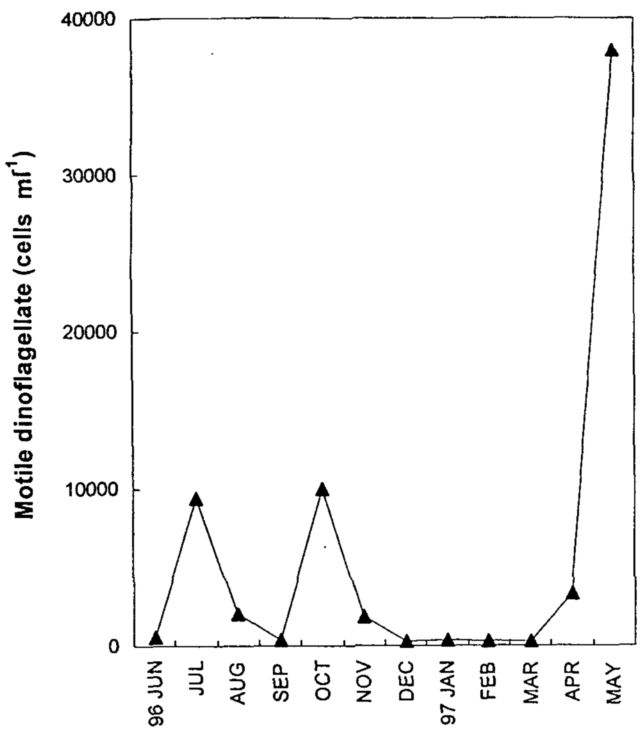

Fig. 2. Monthly variation of total standing crops of motile dinoflagellate in Masan-Chinhae Bay.

DIN increase which triggered the bloom of *Prorocentrum* sp. This species was also mainly linked to low-salinity water coming from land run-off after summer rainy season (Pae and Yoo, 1991).

Spatial-temporal distribution of dinoflagellate cysts

A total of 27 taxa of dinoflagellate cyst were identified representing 12 genera, 20 species, 7 unidentified species (Table 2). Dinoflagellate cysts mainly consisted of the Protoperidinioid cyst and the Gonyaulacoid cyst, whereas the unarmored cysts such as the genera of *Gymnodinium, Cochlodinium* and *Polykrikos* were a few. The cyst of genus *Protoperidinium* was the most dominant species in terms of the species number. The cyst of toxic *Alexandrium tamarense* occurred with a lower abundance in this area. The other cysts of toxic *Cochlodinium* sp. and *Gymnodinium* sp. were also found, but the identification was not done precisely.

To date, 17 taxa of dinoflagellate cyst were reported in Masan Bay by Lee and Yoo (1991), 20 taxa from the southern Korean waters including this study area by Lee and Matsuoka (1996), and 22 taxa from the Korean coastal area by An (1998).

The cyst abundance showed a minimum of 837 ± 197 cysts cm^{-3} in June 1996 and a maximum of $3,182 \pm 1,417$ cysts cm^{-3} in February 1997 (Table 3). Cyst counts decreased horizontally from inner shore to offshore : the annual mean abundance of dinoflagellate cyst at station 6 showed 1.9 times greater than at station 1 (Table 3), coinciding with the results obtained by Blanco (1995b) in Spanish coast. Generally dinoflagellate cysts increase in fine sediment and are diverse in eutrophicated sediment (Anderson and Keafer, 1985; Erard-Le Denn et al., 1993; Nerhring, 1994; Yamaguchi et al., 1995; Peperzak et al., 1996). The study area is composed of fine sediment due to the effect of Naktong River inflow, which has more than 12% organic matter (Park and Lee, 1996). Recently the organic matter in this area has been increased due to domestic sewage and industrial waste (Hong and Lee, 1983; Kim, 1989; Kim et al., 1993). Thus the high distribution of dinoflagellate cysts in the inner bay (station 4, 5, 6) might be closely related to the sediment distribution pattern and the eutrophication in this area. It, however, is also thought that living cysts have been accumulated without germination for long period because the anoxy condition of inner bay could prevent from germinating to vegetative cell (Rengefors and Anderson, 1998).

Table 2. Check-list of thecate-cyst names of recent dinoflagellate cyst from surface sediments collected in Masan-Chinhae Bay from June 1996 to May 1997

Motile form-based name	Cyst-based name
Gymnodiniales	
Cochlodinium sp.	---
Gymnodinium sp.	---
Gyrodinium sp.	---
Pheopolykrikos hartmannii (Zimmermann) Matsuoka & Fukuyo	Not named
Polykrikos kofoidii Chatton	Not named
Polykrikos schwartzii Bütschli	Not named
Gonyaulacales	
Alexandrium tamarense (Lebour) Balech	Not named
Alexandrium sp1.	---
Alexandrium sp2.	---
Gonyaulax digitales (Pouchet) Kofoid	*Spiniferites bentori* (Rossignol) Wall & Dale
Gonyaulax grindleyi Reinecke	*Opeculodinium centrocarpum* (Deflandre & Cookson) Wall
Gonyaulax scrippsae Kofoid	*Spiniferites bulloideus* (Deflandre & Cookson) Sarjeant
Gonyaulax spinifera (Claparede & Lachmann) Diesing	*Spiniferites elongatus* Reid
Pyrophacus steinii (Schiller) Wall & Dale	*Tuberculodinium vancampoae* (Rossignol) Wall
Peridiniales	
Diplopsalis lenticula Bergh	Not named
Preperidinium meunieri (Pavillard) Elbrächter	*Dubridinium caperatum* Reid
Protoperidinium compressum (Nie) Balech	*Stellatinium reidii* Bradford
Protoperidinium conicum (Gran) Balech	*Selenopemphix quanta* (Bradford) Harland
Protoperidinium latissimum (Kofoid) Balech	Not named
Protoperidinium leonis (Pavillard) Balech	*Lejeunecysta concreta* (Reid) Matsuoka
Protoperidinium minutum (Kofoid) Loeblich III	Not named
Protoperidinium oblongum (Aurivillius) Parke & Dodge	*Votadinium carvum* Reid
Protoperidinium pentagonum (Gran) Balech	*Brigantedinium majusculum* Reid
Protoperidinium subinerme (Paulsen) Loeblich III	*Selenopemphix nephroides* Benedex
Protoperidinium sp1.	---
Protoperidinium sp2.	---
Scrippsiella trochoidea (Stein) Loeblich III	Not named

Table 3. Temporal and spatial variation of abundance of dinoflagellate cysts in Masan-Chinhae Bay (unit: cysts cm^{-3})

Month	Range	Mean ± 1 SD
JUN 1996	627~1193	837 ± 197
JUL	885~1489	1106 ± 213
AUG	1058~2148	1510 ± 406
SEP	865~2793	1972 ± 839
OCT	1060~2143	1647 ± 417
NOV	1405~2530	2028 ± 452
DEC	1499~3133	2432 ± 676
JAN 1997	1740~3764	2806 ± 843
FEB	1759~5026	3182 ± 1417
MAR	1516~3159	2371 ± 599
APR	1297~2635	2087 ± 479
MAY	1330~2373	1906 ± 442
Station	**Range**	**Mean ± 1 SD**
1	627~1931	1334 ± 420
2	750~2270	1456 ± 475
3	797~2373	1853 ± 543
4	1019~3963	2363 ± 861
5	911~4379	2461 ± 973
6	746~5026	2475 ± 1116

Vertical distribution of dinoflagellate cysts

The vertical abundance of dinoflagellate cyst at station 4 showed the range of 932~4,372 cysts cm^{-3} at 0~2 cm, 818~4,552 cysts cm^{-3} at 2~4 cm, and 724~3,102 cysts cm^{-3} at 4~6 cm through the year (Fig. 3). The 0~2 cm layer showed mostly surface maxima, while the 2~4 cm layer sub-surface maxima in September and February (Fig. 3). Yamaguchi et al. (1995) reported that the maxima of cysts were distributed at the 3 cm surface from the Japanese coastal waters, and Kim (1992) reported that almost 70% of cysts existed at the 0~2 cm layer from the surface maxima in the Korean coastal waters.

The vertical distribution of cyst abundance from surface down to 20 cm depth based on each 1 cm interval sediment at station 4 showed the difference with depth, ranging from the highest concentration of 4,620 cysts cm^{-3} at the 1 cm layer to the lowest of 867 cysts cm^{-3} at the 18 cm layer (Fig. 4). The cyst abundance uniformly decreased from the top sediment with depth, except for small increases at the 8, 13, 16, 20 cm depth. This means that the cyst has been periodically accumulated during the last several decades. We, however, need sedimentation rates of this bay in order to understand

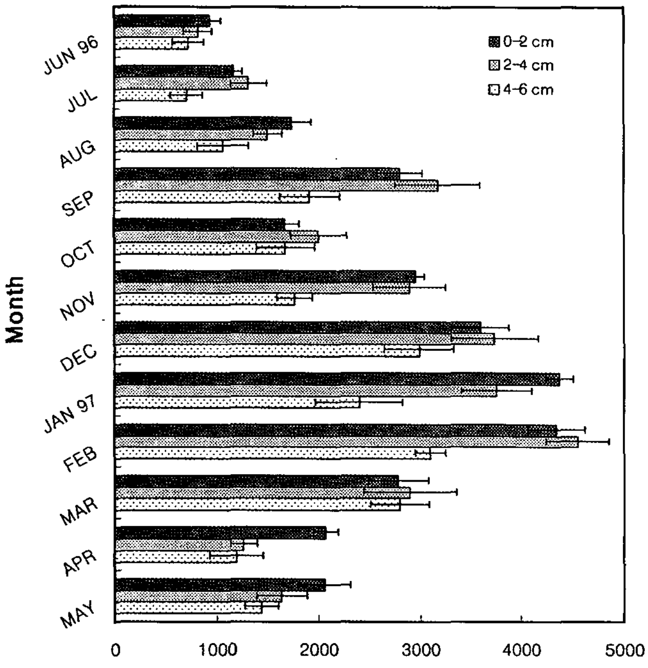

Fig. 3. Monthly variation and vertical distribution of dinoflagellate cysts at station 4 in Masan-Chinhae Bay.

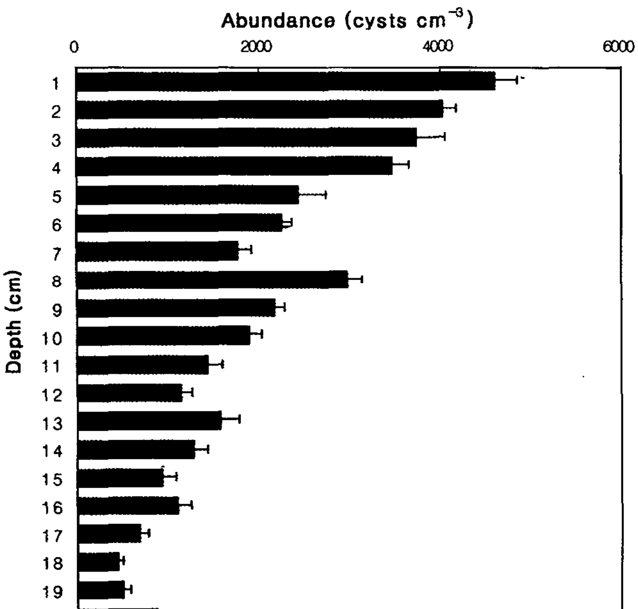

Fig. 4. Depth profile of abundance of dinoflagellate cysts in the surface sediment at st. 4 in Masan-Chinhae Bay in June 1997.

the precise period for this interval. Kim and Matsuoka (1998) represented that sedimentation rate at Omura Bay of Japan, which is a semi-enclosed bay like this study area, is the range of 2.1~2.7 mm per year. From their result, the sedimentation rate of the study area might be assumed about 2.4 mm per year, which is coincided with the range of 2~5 mm per year suggested by Park and Lee (1996). Thus the prominent increase of cyst abundance above 4 cm layer means that the cyst have been accumulated most recently from about 20 years ago. This finding reflects that the cyst production and accumulation have been made recently after acceleration of eutrophication in this area. There were few living cyst below 10 cm from this sediment, which represents a little difference from Anderson et al. (1982) showing few dinoflagellate cysts below the 8 cm layer in the Potomac River, and Kim (1992) showing few cysts below the 6 cm layer in this area.

Relations between motile cell and resting cyst

Relationships between cyst-producing dinoflagellates and their living cyst were analyzed on the focus of station 4 in terms of abundance (Fig. 5). On the whole, the seasonal variation of dinoflagellate cysts showed a little difference from the motile cell dynamics. The motile cell decreased from October to March, but the cysts increased from October to February. When the maximum abundance of motile cell was 2,759 cells $m\ell^{-1}$ in October, the cyst showed 366 cysts cm^{-3} with low abundance. That is, the motile cell abundance was low from December to March, while the cyst abundance increased with a high peak in February. The motile cell represented a small peak of 2,415 cells $m\ell^{-}$ in April, from which the cyst abundance decreased slowly until May.

This correlation study was done on the basis of cyst-producing genera of *Protoperidinium, Gymnodinium, Scrippsiella, Gyrodinium* and *Alexandrium*. However the dinoflagellate blooms were frequently observed in the water column by *Prorocentrum* and *Ceratium* genera which were not found in the cyst population. So the community dynamics of dinoflagellate is not really correlated to the cyst dynamamics of dinoflagellate in the surface sediment in terms of cyst production and motile cell dynamics. Even though the genus *Protoperidinium* was most abundant in the sediment, the species did not dominated in the water column in the study

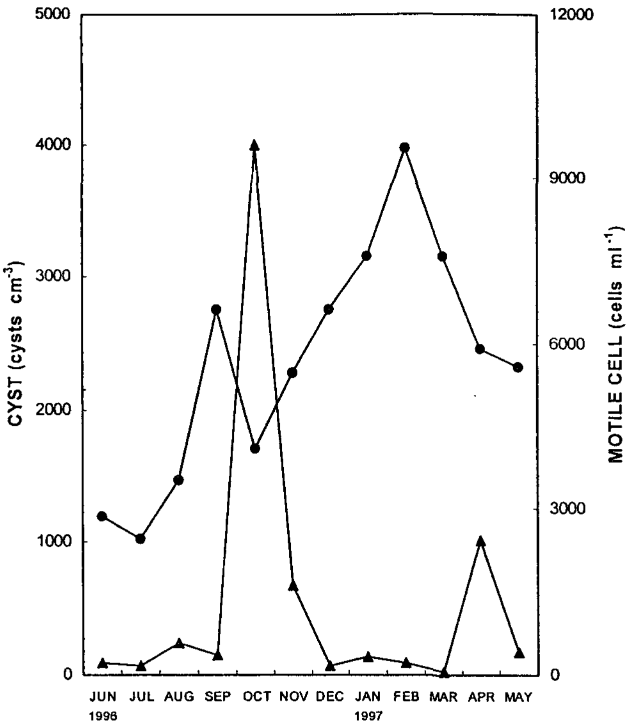

Fig. 5. Monthly variation of motile cell (▲) and cyst abundance (●) of dinoflagellates at station 4 in Masan-Chinhae Bay from June 1996 to May 1997.

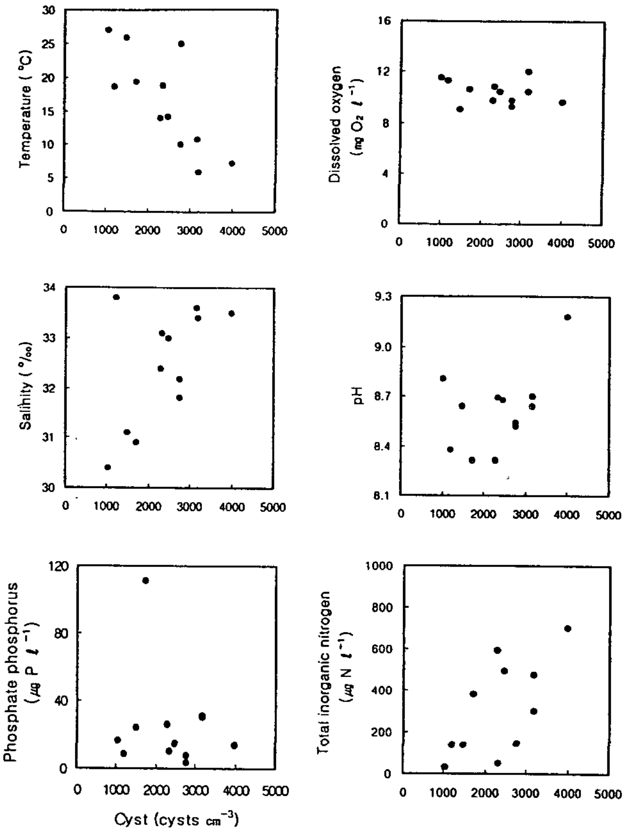

Fig. 6. Relationships between abundance of dinoflagellate cyst and environmental factors at the surface water in Masan-Chinhae Bay from June 1996 to May 1997.

area. Only *Alexandrium, Gymnodinium* and *Scrippsiella* genera showed a correlation in the cyst and motile cell dynamics in this area (unpublished data). Although many researches postulated that the cyst dynamics could influence the plankton dynamics in many places of the world, there are not enough evidences about that in this surveyed area (Tyler et al., 1982; Balch et al., 1983; Anderson and Keafer, 1985).

Correlations between cyst dynamics and environmental factors

To analyze the correlations between dinoflagellate cyst abundance and environmental factors, such as water temperature, dissolved oxygen (DO), salinity, pH, phosphate, total nitrogen, each related data to cyst abundance were plotted with emphasis of station 4 (Fig. 6, 7). The cyst abundance was related negatively to water temperature at the surface and the bottom layer. It showed positive correlation to DO, total nitrogen and salinity at the surface layer, whereas to DO and pH at the bottom layer. The DO was positively related to the cyst abundance at the both layers, but much more correlated at the bottom layer than at the surface layer.

As nutrient concentration become less, the production of resting cyst increase, while the motile form decrease (Blanco, 1995a). Although decomposition of organic sediment and exudation of inorganic matter from sediment occurred often in this bay (Yang and Hong, 1982; Yang, 1992), the concentration of nutrient in this study is not related to the cyst abundance except for total inorganic nitrogen at the surface layer. Uchida et al. (1996) discussed that only water temperature among various factors showed obviously a relationship with the seasonal dynamics of dinoflagellate, which is coincided with our result. The production and germination of dinoflagellate cyst during its sexual reproduction is controlled by water temperature and light condition (Anderson, 1980; Binder and Anderson, 1987; Pfiester and Anderson, 1987).

Dinoflagellate cysts are known to be more abundant and more diverse in a reduced environment (Anderson and Keafer, 1985; Blanco, 1995a). The bottom layer of Masan-Chinhae Bay

Table 4. A comparion of two observations in Masan-Chinhae Bay

May 1986~March 1987 (Lee, 1987)	June 1996~May 1997 (present study)
I. Motile dinoflagellate	I. Motile dinoflagellate
● Total number of species : 53 species	● Total number of species : 42 species
● Dominant species	● Dominant species
Ceratium fusus	*Prorocentrum micans*
Gyrodinium fissum	*Prorocentrum minimum*
Heterocapsa triquetra	*Ceratium furca*
Prorocentrum minimum	*Gymnodinium sanguineum*
	Alexandrium tamarense
● Standing crops :	● Standing crops :
44~2,798,900 cells ℓ^{-1}	306,000~37,959,000 cells ℓ^{-1}
II. Dinoflagellate cyst	II. Dinoflagellate cyst
● Total number of species : 17 species	● Total number of species : 27 species
	● Dominant genus
	Protoperidinium *Gymnodinium*
	Scrippsiella *Gyrodinium*
	Alexandrium *Gonyaulax*
● Abundance :	● Abundance :
48~1,402 cysts cm^{-3}	627~5,026 cysts cm^{-3}

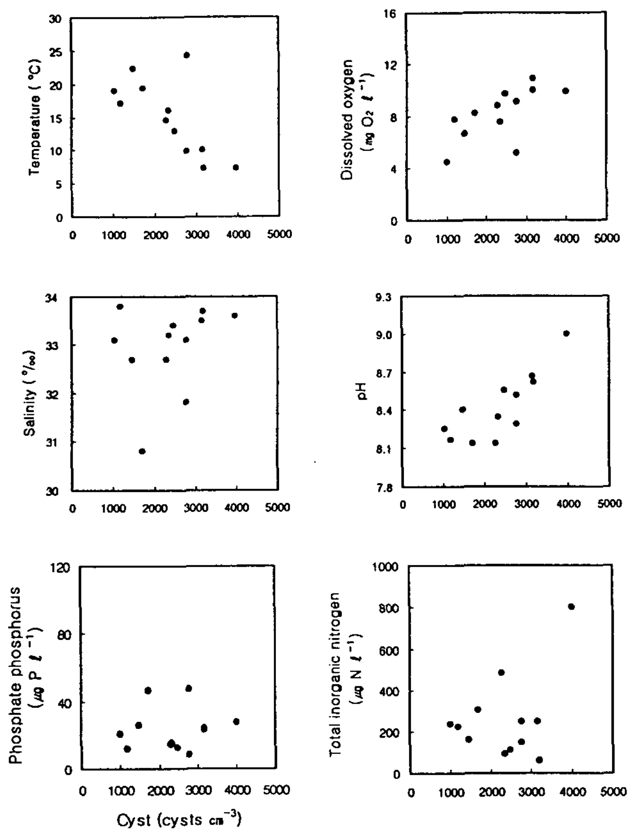

Fig. 7. Relationships between abundance of dinoflagellate cyst and environmental factors at the bottom water in Masan-Chinhae Bay from June 1996 to May 1997.

sometimes forms an anoxic condition in summer (Kim et al., 1994) and provides as much sufficient nutrients to the water column as red tide blooms throughout the year. In this study the dissolved oxygen in the bottom was 2.2~4.5 mg ℓ^{-1} in summer showing little oxygen concentration. The dinoflagellate cysts were less abundant in outer bay than in inner bay, where it was likely to be closely related with the anoxic water mass. The station 5 and 6 at the inner bay had organic compound and very fine mud type as reduced environmental condition, compared to the rest stations at the outer bay.

Comparison between two observations within the last 10 years

In comparison with Lee (1987) in the same study area, the standing crops of dinoflagellate increased after about 10 years, but the number of species decreased from 53 species to 42 species (Table 4). The dominant species were *Ceratium fusus*, *Gyrodinium fissum*, *Heterocapsa triquetra*, *Prorocentrum minimum* in 1986~1987, but *Prorocentrum micans*, *P. minimum*, *Ceratium furca*, *Gymnodinium sanguineum*, *Alexandrium tamarense* were dominant in this study. Genera *Prorocentrum* and *Ceratium* were dominant in 1986~1987 as well as in this study. Ten species of dinoflagellate cysts were added during the last decade and the abundance of cysts also increased about 4.5 times from the range of 48~1,402 cysts cm^{-3} to 556~5,727 cysts cm^{-3}. This means that the community structure of dinoflagellates have become simple, but the dominant species have been more abundant than the last ten years. Whereas the cyst abundance increased and accumulated in this study area within the last decade.

Conclusion

Dinoflagellate blooms were maintained throughout the year by 1~2 dominant species showing seasonal succession; mainly *Prorocentrum, Ceratium, Gymnodinium, Alexandrium* genera.

Dinoflagellate cysts mainly consisted of the Protoperidinioid cyst and the Gonyaulacoid cyst, while the unarmored cysts such as the genera of *Gymnodinium, Cochlodinium* and *Polykrikos* were a few. Cyst counts decreased horizontally from inner shore to offshore. In vertical distribution, the cyst abundance uniformly decreased from the top sediment with depth, except for small increases at the 8, 13, 16, 20 cm depth. This means that the cyst has been periodically accumulated during the last several decades. The community dynamics of dinoflagellate is not really correlated to the cyst dynamamics of dinoflagellate in the surface sediment in terms of cyst production and motile cell dynamics. The cyst abundance was related negatively to water temperature at the surface and the bottom layer. From the comparison within the last 10 years, the standing crops of dinoflagellate increased and the community structure have become simple, whereas the cyst abundance increased compared with the last ten years, which suggests that the eutrophication become worse with respect to environmental conditions in Masan-Chinhae Bay.

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