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Distribution of dinoflagellate cysts in Masan Bay, Korea

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馬山灣一帶 渦鞭毛藻類 休眠胞子의 分布

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The distribution of dinoflagellate cysts have been investigated at 6 stations in Masan Bay, a well-known area of red tide in the southern coastal waters of Korea, from May 1986 to March 1987. During the study, a total of 11 species in dinoflagellate cysts were isolated from surface sediments, representing 6 genera, 9 species and 2 unidentified species. The standing crops of dinoflagellate cyst varied extensively by month and station: ranging from 48 to 1,279 cells/cm^3 and showing major peaks in July, August and February. At stations, the distribution was most abundant at st. 4 (mouth of the bay), whereas it was very low at st. 1 (inner bay), where motile cell's blooms occur throughout the year. Thus, It is speculated that the distribution between the plankton and cyst populations of dinoflagellates show the different temporal and spatial patterns in a semi-closed bay like this survey area.

1986년 5월부터 1987년 3월까지 적조가 만연하고 있는 마산만일대 6개 정점의 저질표층으로부터 와편모조류 휴면포자(시스트)를 분리하여 월별 및 정점별 분포를 조사하였다. 조사기간 중 총 11종류의 와편모조류 휴면포자가 분리되었으며 6속 9종 2 미동정종으로 구성되어 있다. 휴면포자의 현존량은 월별, 정점별로 차이를 나타내었으며 48-1,279 cells/cm^{3}의 분포범위를 보였다. 월별로 보면 7, 8월, 그리고 2월에 가장 높았으나 그외 시기에는 낮은 분포를 나타내었다. 정점별로보면 만 입구인 정점 4에서 가장 많고 만 내인 정점 1에서 가장 적게 분포하고 있으나 와편모조류 유영세포는 만 내에서 년중 가장 높은 분포를 보이고 있었다. 따라서 반폐쇄적 만의 특징을 가지고 있는 마산만에서는 와편모조류의 유영세포와 휴면포자의 분포는 시, 공간적으로 다른 분포특성을 보이고 있다고 생각된다.

INTRODUCTION

The southern part of the Korean Penninsula shows submerged topographic features and so has many bays in which shallow water is prevalent. Especially Masan Bay has been known to be an important spawning and nursing ground for fish and shellfish for many years. However it has recently become notorious for its eutrophication and frequent red-tides due to the establishment of an industrial complex around the bay since the 1970s. This red-tide sometimes causes serious damages to cultured shellfish and other living organisms therein.

Since the first investigation of red tide occurrence in this area was reported (Park and Kim, 1967), red tide organisms have been changing from diatoms to dinoflagellates or other flagellates year by year. Among these, the taxonomical and ecological studies of dinoflagellates in Masan Bay have received ever increasing attention (Han and Yoo, 1983a, b; Yoo and Lee, 1986; Lee and Kwak, 1986;

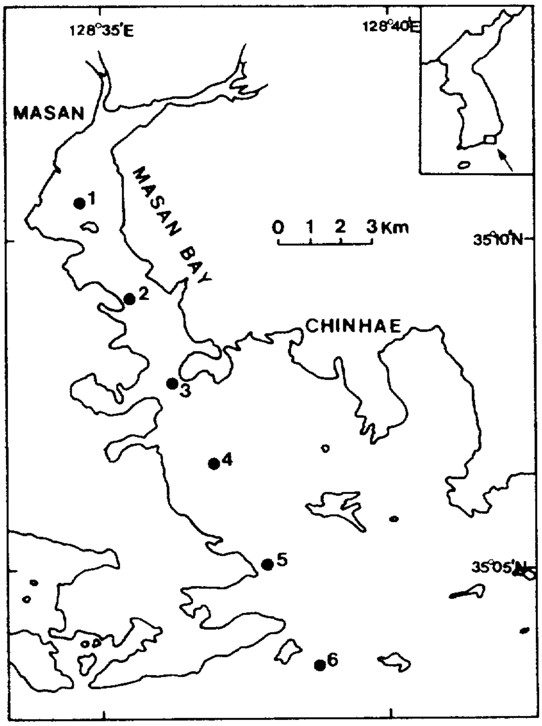

Fig. 1. Sampling stations for dinoflagellate cyst studies in Masan Bay, Korea.

Park *et al.*, 1989; Lee and Yoo, 1990). Other researchs discussed the physiological ecology of genus *Prorocentrum* (Kim, 1986a, b) and the trophical relationship between dinoflagellates and tintinnids (Yoo and Lee, 1987).

In general, the dinoflagellate is known to produce its cyst, which is called a dinoflagellate cyst, for dormancy in bad environmental conditions and/or overwintering (Steidinger, 1975; Wall, 1975; Anderson and Wall, 1978). So it is very important to investigate cyst dynamics as well as plankton dynamics, because the cyst plays a significant role as a seed populaton of dinoflatellate blooms (Reid, 1972; Lewis *et al.*, 1979; Anderson *et al.*, 1982; Tyler *et al.*, 1982; Balch *et al.*, 1983; Anderson and Keafer, 1985; Kobayash *et al.*, 1986). Since dinoflagellate cysts have recently been discovered in the surface sediments of Masan Bay, our efforts have concentrated on clarifying the distribution and dispersion of dinoflagellate cyst (Lee, 1987; Kim *et al.*, 1990). There, however, are still many gaps in our knowledge. Thus, the present study was carried out to clarify the distribution of dinoflagellate cysts and the relationship of the dynamics between the motile cell (=plankton) and its cyst in Masan Bay.

MATERIALS AND METHODS

Plankton and cyst samples of dinoflagellate were collected monthly at six stations in Masan Bay from May, 1986 to March, 1987 (Fig. 1). Plankton was sampled using Van Dorn water sampler at surface and bottom layers. Laboratory analyses of samples followed the methods as described by Yoo and Lee (1985).

For cyst study, sediment samples were collected using the core sampling method with a modified van Veen grab and hand core sampler. Cores were preserved at 4℃ on board and transfered to a laboratory for cyst isolation and germination experiments. The upper 2 cm of each core was extruded and examined to estimate total cyst abundance at each station. Cysts were isolated with in 24 hours after sampling using Fukuyo's method (1980). The isolated samples were divided into two parts. Of these, one part was refrigerated for the germination study, while the other was fixed with 5% neutral formalin for quantitative and qualitative analyses.

For qualitative study, dinoflagellate cysts were identified and classified using the systematic treatment of Matsuoka (1987). Germination experiments were also done as a part of qualitative study. Living cysts, which have markers for impending germination such as the red auto-fluorescence, were isolated and incubated with filtered sea water or F/10 medium in 14 : 10 (Light : Dark) cycle for 1-2 weeks (Anderson and Wall, 1978). For quantitative study, both living cyst and empty cyst were counted using a Sedgwick-Rafter counting chamber and calculated to [cells/cm^3], in terms of standing crops of dinoflagellate cyst.

RESULTS AND DISCUSSION

Species composition

During the survey, 11 species of dinoflagellate

Table 1. Theca-cyst correlations of dinoflagellates isolated from Masan Bay during this study period.

Theca nomenclature	Cyst nomenclature
Gymnodiniaceae	Gymnodinioid Lineage
Gyrodinium sp.?	not named
Polykrikaceae	
Polykrikos kofoidii	not named
Polykrikos schwartzii	not named
Gonyaulaceae	Gonyaulacoid Lineage
Alexandrium sp. (*tamarense*?)	not named
Pyrophacaceae	Tuberculodinioid Lineage
Pyrophacus steinii var. *vancampoae*	*Tuberculodinium vancampoae*
Peridiniaceae	Peridinioid Lineage
Protoperidinium concium	*Selenopemphix quanta*
Protoperidinium latissimum	not named
Protoperidinium leonis	*Lejeunecysta concreta*
Protoperidinium oblongum	*Votadinium carvum*
Protoperidinium pentagonum	*Trinovantedinium capitatum*
Zygabikodinium lenticulatum	*Dubridinium caperatum*

cyst were identified, representing 6 genera, 9 species, and 2 unidentified species (Table 1). These species comprised 3 unarmored dinoflagellate cysts and 8 armored dinoflagellate cysts. The cysts of *Polykrikos kofoidii*, *Polykrikos schwartzii* and *Gyrodinium* sp. belong to the unarmored group (Plate I, 1-3), and the rest to the armored group (Plate I, 4-6; Plate II, 1-6). Of these, *Protoperidinium* cysts were dominant in species composition as well as in cyst abundance (Plate II, 1-6). The cyst of toxic *Alexandrium* sp. (*tamarense*?) was also found (Plate I, 4). The *Protoperidinium oblongum* cyst was identified from motile cells germinated by single-cyst incubation experiments (Plate II, 1, 2). Two or three more species were also germinated but unidentified due to loss of the motile cells. Each dinoflagellate cyst showed the different germination rate depending on its germination ability. *Protoperidinium* cysts were generally easier to germinate than the others.

Kim *et al.* (1990) reported that eight species, producing benthic cyst and comprising 6 Dinophyceae and 2 Raphidophyceae, had caused a bloom in this study area from March to September since 1982. Among these species, the cyst of *Gyrodinium* sp. and *Alexandrium* sp. were the only ones found during this study period, but the cysts of *Scrippsiella trochoidea*, *Heterocapsa triquetra*, *Cochlodinium* sp., and *Pheopolykrikos hartmanii* were not found. Lee *et al.* (1991) observed 16 dinoflagellate cysts from surface sediment in Chinhae Bay which included this study area. We think that if the observation fields were expanded, more cyst could be isolated.

In Omura Bay of Japan, a total of 27 cyst were found, and the cysts of *Polykrikos schwartzii*, *Pheopolykrikos hartmanii* and *Pyrophacus steinii* dominated throughout the stations (Kobayashi *et al.*, 1986). However they reported that the dominant species in plankton were different from those in cysts, which is similar to our result. In our result, there were some differences between cyst assemblage and plankton assemblage in species composition and dominance ranking. It can be explained by following : all dinoflagellates cannot produce their own cysts, and additionally, cyst-producing dinoflagellate might not have readily a cyst stage in its life cycle within different environments (Kobayashi *et al.*, 1986).

Cyst distribution

The abundance of both living and empty dinoflagellate cyst fluctuated extensively by month and station, ranging from 48 to 1,279 cells/cm^3. The average of all stations was 400 cells/cm^3. Empty cysts included 60-70% of the total abundance and generally were more abundant than living cysts in all stations. On monthly distribution, it showed major quantitative peaks above 1,000 cells/cm^3 in July, August, and February at only st. 4 (Fig. 2). As shown in Fig. 2, cyst abundance was lowest at st. 1 in the inner bay and relatively lower at st. 5, 6 in the outer bay, but st. 4 at the mouth of bay showed the highest abundance. It suggests that the opening part of the bay plays a role as seeding region for cysts in the study area. The plankton dynamics, however, reveal that the inner bay showed the most abundance of dinoflagellate in all stations throughout the year (Lee and Yoo, 1990), even though it showed the lowest cyst abun-

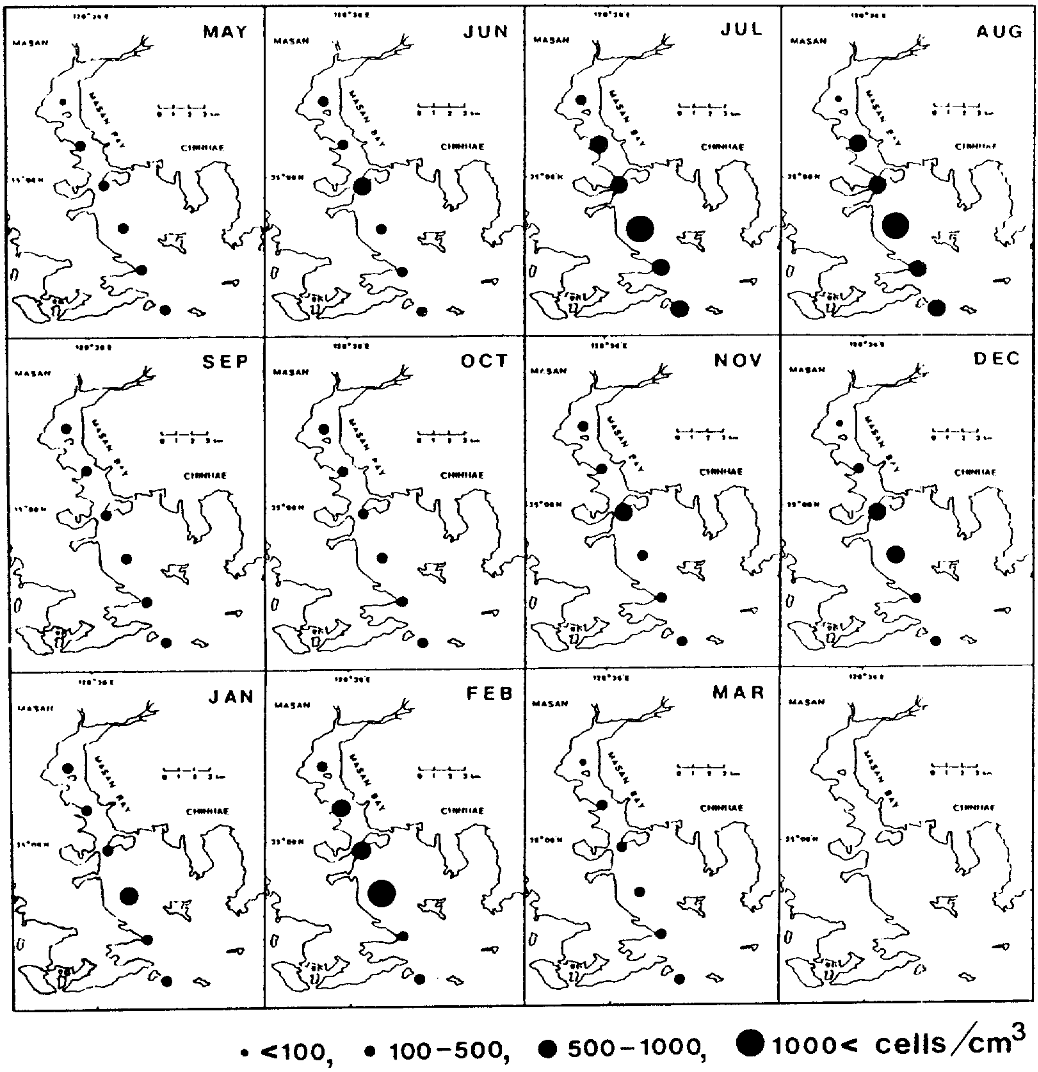

Fig. 2. Monthly distribution of dinoflagellate cysts in the surface sediments of Masan Bay from May, 1986 to March, 1987.

dance. So the inner bottom of this bay seems to provide a bad environment for cysts due to anoxy condition observed in this bottom sediments for many months from spring to summer (Anderson and Keafer, 1985; Yang and Hong, 1988).

As a result, dinoflagellate cyst was distributed more abundantly in the opening part of the bay than in the other parts of the bay. Thus the dynamics of seed population were different from that of plankton population with respect to blooming season and blooming area. It is considered that this result was attributed to the hydrographic characteristics of a semi-closed bay like Masan Bay.

Relationship between plankton and cyst dynamics

Table 2 shows the genera of dinoflagellates which can produce benthic cyst throughout their life cycles (Matsuoka *et al.*, 1989). In this survey, 7 occurred genera belonged to these, comprising mainly the marine dinoflagellates with armored and unarmored forms. Most genera were the ar-

Table 2. The genus of marine dinoflagellates producing a cyst for life cycle (after Matsuoka *et al.*, 1989).

Family Gymnodiniaceae	Family Pyrophacaceae
Cochlodinium	*Helgolandium*
Gymnodinium	*Pyrophacus*
Gyrodinium	Family Peridiniaceae
Family Polykrikaceae	*Scrippsiella*
Pheopolykrikos	*Ensiculifera*
Polykrikos	*Cachonina*
Family Gonyaulaceae	*Heterocapsa*
Gonyaulax	*Peridinium*
Protoceratium	*Protoperidinium*
Alexandrium	*Diplopelta*
Pyrodinium	*Diplopsalis*
Family Triadiniaceae	*Diplopsalopsis*
Triadinium	*Gotoius*
	Zygabikodinium

mored dinoflagellate, but the unarmored genera such as *Gyrodinium* and *Polykrikos* were also found. According to our previous observations (Yoo and Lee, 1985), dinoflagellates were generally abundant from spring to summer in this study area regardless of whether they were armored or unarmored. However unarmored species were especially abundant such as *Gyrodinium* sp. during the survey (Lee and Yoo, 1990).

We also identified a total of 18 genera of dinoflagellate in the same study area. Among these genera, the standing crops of motile cells in only 7 cyst-producing genera were estimated to be compared with cyst population dynamics. It also varied extensively by month and station: ranging from 22 to 2,713,437 cells/*l* in the surface layer and from 181 to 162,131 in the bottom layer. Motile cells were more abundant on the surface layer than on the bottom layer, especially from June to July.

Fig. 3 represents the comparison of motile cell and cyst dynamics in st. 1, where motile cells are most abundant among all stations, and st. 4, where cysts are most dominant among all sediments, in terms of standing crops. Motile cell's standing crop similary fluctuated both at st. 1 and at st. 4, which means that there is little difference in plankton dynamics between different stations. On the other hand, the monthly variations of cysts show different patterns from those of motile cells. At the mouth of the bay (st. 4) cysts fluctuated seasonally,

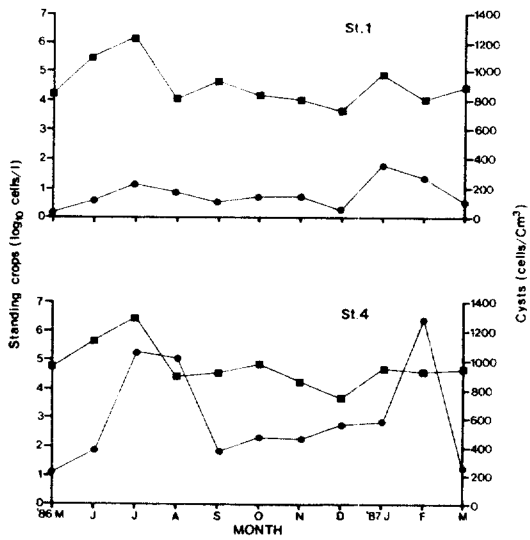

Fig. 3. Monthly variations of standing crops of cyst-producing motile cell of dinoflagellate in the surface layer and cyst abundance from the surface sediments at st. 1 and st. 4 in Masan Bay from May, 1986 to March, 1987.

but at the inner bay (st. 1) it showed little variations. It suggests that the motile cell's blooms in the inner bay could probably be originated from the cysts of other seed bed like the opening part of the bay, not from the inner cysts of sediments therein. That is, plankton dynamics in this bay might seem to be closely related to cyst dynamics in the outer bay with respect to cyst-producing dinoflagellates. There, however, aren't enough evidences about that in this survey area, even though many researchs postulated that the cyst dynamics could influence the plankton dynamics in many places of the world (Balch, *et al.*, 1983; Tyler *et al.*, 1982; Anderson and Keafer, 1985). We feel that futher study must be required so that more information can be obtained on the plankton and cyst dynamics of cyst-producing red tide organisms including dinoflagellate.

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REFERENCES

Anderson, D.M. and D. Wall, 1978. Potential importance of benthic cysts of *Gonyaulax tamarensis* and *G. excavata* in initiating toxic dinoflagellate blooms. *J. Phycol.*, **14**: 224-234.

Anderson, D.M. and B.A. Keafer, 1985. Dinoflagellate cyst dynamics in coastal and estuarine waters. In: Proc. 3rd Int. conf. on Toxic Dinoflagellates, edited by D.M. Anderson, A.W. White and D.G. Baden, Elsevier Science Publ., 219-224.

Anderson, D.M., D.G. Aubrey, M.A. Tyler and D.W. Coats, 1982. Vertical and horizontal distribution of dinoflagellate cysts in sediments. *Limnol. Oceanogr.*, **27**: 757-765.

Balch, W.M., P.C. Reid and S.C. Surrey-Gent, 1983. Spatial and temporal variability of dinoflagellate cyst abundance in a tidal estuary. *Can J. Fish. Aquat. Sci.*, **40** (sppl. 1): 244-261.

Fukuyo, Y., 1980. Dinoflagellate cyst. In: Red tide Manual I. edited by R. Adachi and H. Irie. The Working party on Taxonomy in the Akashio Kenkyukai, 40-46 (in Japanese).

Han, M.S. and K.I. Yoo, 1983a. A taxonomical study on the dinoflagellates in Jinhae Bay. I. Armored and unarmored dinoflagellates. *Bulletin of KORDI.* **5**: 37-47 (in Korean).

Han, M.S. and K.I. Yoo, 1983b. A taxonomical study on the dinoflagellates in Jinhae Bay. II. Peridiniales. *ibid.* **5**: 49-67 (in Korean).

Kobayashi, S., K. Matsuoka and S. Iizuka, 1986. Distribution of dinoflagellate cysts in surface sediments of Japanese Coastal Waters. I. Omura Bay, Kyushu. *Bull. Plankton Soc. Japan*, **33**: 81-93 (in Japanese).

Kim, H.G., 1986a. Ecological study of dinoflagellates responsible for red tide. 1. The population growth and control of *Prorocentrum triestinum* Schiller. *Bull. Fish. Res. Dev. Agency*, **39**: 1-4 (in Korean).

Kim, H.G., 1986b. Ecological study of dinoflagellate responsible for red tide. 2. The population growth of *Prorocentrum minimum* Schiller. *Korean J. Phycol.*, **1**: 103-106.

Kim, H.G., J.S. Park and S.G. Lee, 1990. Coastal algal blooms caused by the cyst-forming dinoflagellates. *Bull. Korean Fish. Soc.*, **23**: 468-474.

Lee, J.B., 1987. Studies on the Structure and Dynamics of Dinoflagellates Community in Masan Bay, Korea. Ph. D thesis. Hanyang University, 130pp.

Lee, J.B. and K.I. Yoo, 1990. Dynamics and seasonal succession of dinoflagellate community in Masan Bay, Korea. *J. Oceanol. Soc. Korea*, **25**: 106-116.

Lee, J.B., M.S. Han, J.K. Jeon and K.I. Yoo, 1991. Taxonomical study of dinoflagellate cysts in Chinhae Bay, Korea (in preparation).

Lee, J.H. and H.S. Kwak, 1986. A study on the *Gymnodinium nagasakiense* red-tide in Jinhae Bay of Korea. *Korean J. Ecol.*, **9**: 149-160.

Lewis, C.M., C.M. Yentsch and B. Dale, 1979. Distribution of *Gonyaulax excavata* resting cysts in sediments of the Gulf of Main. In: Proc. 2nd Int. Conf. on Toxic dinoflagellate blooms, edited by D.L. Taylor and H.H. Seliger, Elsevier/North-Holland, New York, 235-238.

Matsuoka, K., 1987. Organic-walled dinoflagellate cysts from surface sediments of Akkeshi Bay and Lake Saroma, North Japan. *Bull. Faculty of Liberal Arts*, Nagasaki Univ., (Natural Science), **28**: 35-123.

Matsuoka, K.Y. Fukuyo and D.M. Anderson, 1989. Methods for modern dinoflagellate cyst studies. In: Proc. 1st Int. Symp. on Red Tides, edited by T. Okaichi *et al.*, Elsevier Science Publ., 461-479.

Park, J.S. and J.D. Kim, 1967. A study on the "red-water" caused at Chinhae Bay. *Bull. Fish. Res. Dev. Agency*, **1**: 65-79 (in Korean).

Park, J.S., H.G. Kim and S.G. Lee, 1989. Studies on red tide phenomena in Korean coastal waters. In: Proc. 1st Int. Symp. on Red Tides, edited by T. Okaichi *et al.*, Elsevier Science Publ., 37-40.

Reid, P.C., 1972. Dinoflagellate cyst distribution around the British Isles. *J. Mar. Biol. Assoc. U.K.*, **52**: 939-944.

Steidinger, K.A., 1975. Basic factors influencing red tides. In: Proc. 1st Int. Conf. on Toxic Dinoflagellate Blooms, edited by V.R. LoCicero, Mass. Sci. Technol. Found. Wakefield, 153-162.

Tyler, M.A., D.W. Coats and D.M. Anderson, 1[illegible]. Encystment in a dynamics environment: dep[illegible]ation of dinoflagellate cysts by a frontal convergence. *Mar. Ecol. Prog. Ser.*, **7**: 163-178.

Wall, D., 1975. Taxonomy and cysts of red-tide dinoflagellates. In: Proc. 1st Int. conf. on Toxic Dinoflagellate Blooms, edited by V.R. LoCicero, Mass. Sci. Technol. Found. Wakefield, 249-255.

Yang, D.B. and J.S. Hong, 1988. On the biogeochemical characteristics of surface sediments in Chinhae Bay in September 1983. *Bull. Korean Fish. Soc.*, **21**: 195-205.

Yoo, K.I. and J.B. Lee, 1985. Environmental studies on Masan Bay 3. Population dynamics of dinoflagellates. *Bull. Environ. Sci.*, Hanyang Univ., **6**: 117-127 (in Korean).

Yoo, K.I. and J.B. Lee, 1986. Taxonomical studies on dinoflagellates in Masan Bay 1. Genus *Prorocentrum* Ehrenberg. *J. Oceanol. Soc. Korea*, **21**: 46-55.

Yoo, K.I. and J.B. Lee, 1987. On the trophic correlation between tinninids and dinoflagellates in Masan Bay, Korea. *Bull. Korean Fish. Soc.*, **20**: 230-236.

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Explanation of Plate

Plate I

1. *Polykrikos kofoidii* cyst
2. *Polykrikos schwartzii* cyst
3. *Gyrodinium* sp.? cyst
4. *Alexandrium* sp. (*tamarense*?) cyst
5. *Pyrophacus steinii* var. *vancampoae* cyst
6. *Zygabikodinium lenticulatum* cyst.

Plate II

1. Living cyst of *Protoperidinium oblongum*
2. Empty cyst of *Protoperidinium oblongum* after germination (An arrow is the acheopyle)
3. *Protoperidinium conicum* cyst
4. *Protoperidinium latissimum* cyst
5. *Protoperidinium leonis* cyst
6. *Protoperidinium pentagonum* cyst

(One scale bar is 10 μm.)

PLATE I

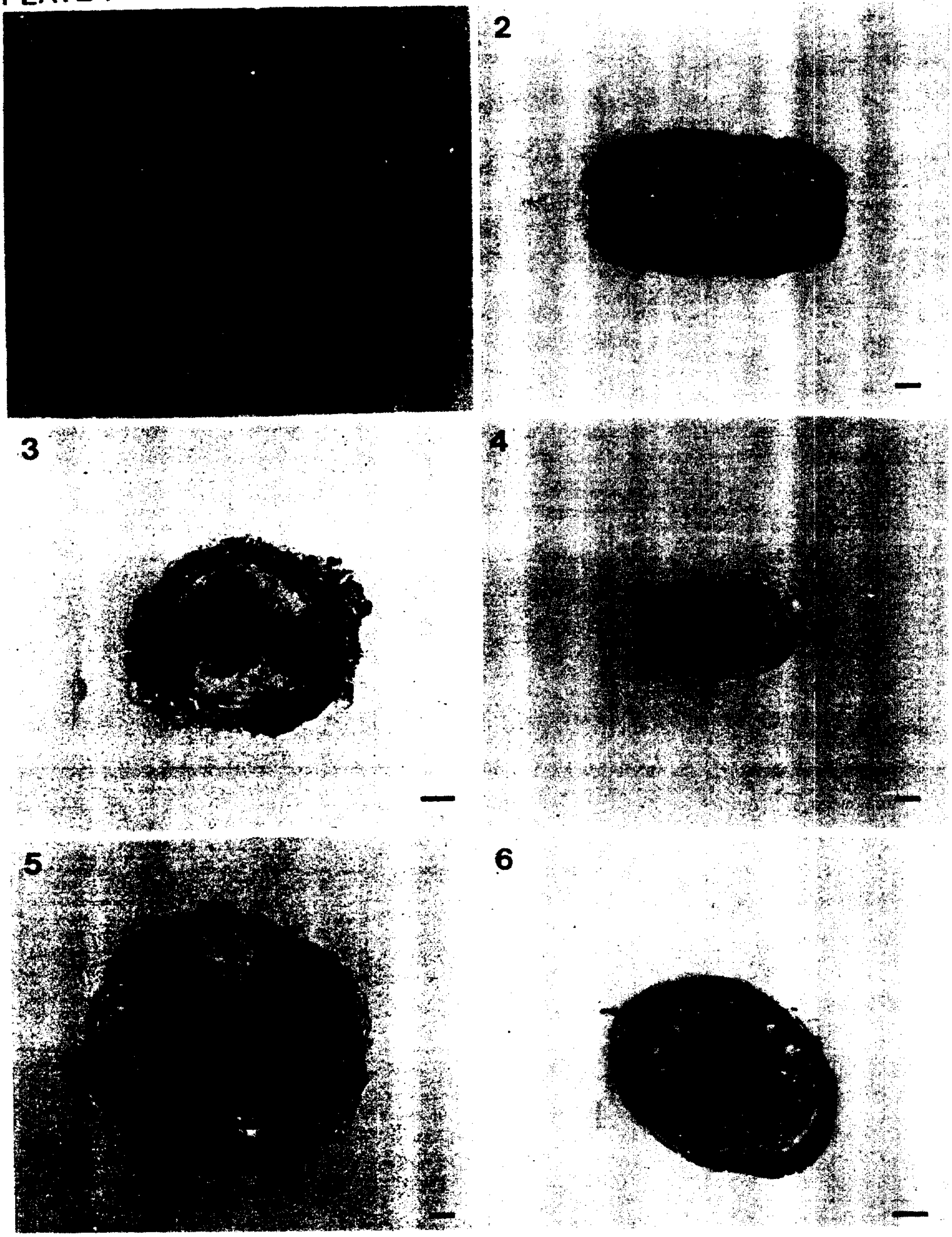

PLATE II