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Modern Dinoflagellate Cysts Distribution off the Eastern Part of Geoje Island, Korea

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Abstract – Distributional characteristics of dinoflagellate cysts in surface sediments were investigated in relation to environmental factors in the eastern part of Geoje Island, Korea. Samples were collected from 10 stations in February of 2004 and water temperature and salinity were measured in February, May, September and November of 2004. Total 30 taxa of dinoflagellate cysts were identified representing 19 genera, 28 species and 2 unidentified species. Among these dinoflagellate cysts, *Brigantedinium* spp. of which relative proportion in the total dinoflagellate cysts was 23.5%, was the most abundant at all stations except St. 1, and was followed by *Spiniferites bulloideus* (8.6%), *Lingulodinium machaerophorum* (8.2%) and *Diplopsalis lenticula* (6.7%). In addition, ellipsoidal cysts of the genus *Alexandrium* (*Alexandrium catenella - tamarense* type) and *Gymnodinium catenatum,* known to be causative organisms for PSP, occurred with high concentrations. *Scrippsiella trochoidea* was also found; however, its cyst concentration was low. Generally, species composition in the study area was similar to these reported from Jinhae Bay and Busan Harbor and several dinoflagellate cysts reflected the eutrophic condition. Cyst distribution in the eastern part of Geoje Island seems to be influenced by the Tsushima Warm Current flowing from the southwest. The mean water temperature was 12.0°C in February, 14.7°C in May, 20.9°C in September and 17.2°C in November, which was most favorable for *Alexandrium* spp. growth. The abundances of dinoflagellate cysts ranged from 528 to 2,834 cysts/g dry sediment. Higher concentrations were recognized in sediments of west area of the Jisimdo than at other stations. The cyst composition of this area was closely related to these of Jinhae Bay and Busan Harbor from which currents flow into this area. Higher cyst concentration in the west area of Jisimdo might be due to formation of the gyre.

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Key words – dinoflagellate cyst, Geoje Island, Jinhae Bay, *Alexandrium*, gyre

1. Introduction

Dinoflagellates for marine phytoplankton are utilized to study spatio-temporal change of marine environment and are well known as causative organisms for outbreak of harmful algae blooms. 200 of the approximate 2000 exsisting species of marine dinoflagellates are known to form resting cysts in a part of their life cycle, and some of them are typically preserved in sediments (Head 1996). These cysts may contribute to phytoplankton assemblages in the water column through germination and may play an important role in dinoflagellate species dispersal, bloom initiation and termination, and provide places where blooms will break out in the future. Therefore, cyst surveys provide a history of harmful species in a certain study area.

The encystment and excystment of dinoflagellate cysts in the sea is mostly controlled by water temperature, salinity and the availability of nutrients (Sebastian and Willems 2003), while the geographical distribution of cysts is influenced by primary production, sediment grain sizes and sedimentation rates (Cho and Matsuoka 2001). Also, interpretation of physical and chemical change of water mass and information on current patterns can help our understanding of distributional characteristics as cysts are transported from the original places by water movements.

Geoje Island is the second largest island in Korea and the coastal area around this island is very important for the fishing industry, as many marine farms culturing oysters, ark-shells and sea mustards are developed (Han and Kim 1985), and coastal industrial complexes are also located in Okpo. Moreover, this area is influenced by the Tsushima Warm Current (TWC) and is dominated by an outstanding semidiurnal tide producing periodical and strong tidal movement (Chang *et al.* 1993), and is connected with Jinhae Bay at the north-east side where many nutrients from the Nakdong River in Busan flow into coastal waters around the island. In Korea, toxic blooms have frequently occurred mainly in Jinhae Bay and its surroundings since 1982 (Kim 1990; Han *et al.* 1992, 1993; Kim *et al.* 2002; Lee *et al.* 2003), and the first paralytic shellfish poisoning (PSP) outbreak was reported in 1986 at Busan (Chang *et al.* 1987; Lee *et al.* 1992; Choi *et al.* 1999). Since then, an accident caused by PSP also was reported in 1996 at Geoje Island (Lee *et al.* 1997) and red tides frequently occurred in this area (Kim *et al.* 2000). For these reasons, various oceanographic studies have been carried out in this area and adjacent areas (Lee *et al.* 1997; Jeon and Han, 1998; Lee *et al.* 1998; Choi *et al.* 1999; Lee *et al.* 2000; Kim *et al.* 2002). However, studies concerning dinoflagellate cysts have been carried out mainly in Jinhae Bay; these concentrated on toxic species such as *Alexandrium tamarense* (Lee and Yoo 1991; Lee *et al.* 1998; Kim *et al.* 2002; Park *et al.* 2004).

Therefore, the present study will provide the species composition, distribution and abundance of dinoflagellate cysts on surface sediments in the eastern sea of the Geoje Island, Korea. Also, we will discuss the relationship between distributional characteristics of dinoflagellate cyst assemblages and oceanographic conditions.

2. Materials and Methods

To examine the species composition, distribution and abundance of dinoflagellate cysts, surface sediments were collected from 10 stations of the eastern sea of Geoje Island in February of 2004 and environmental parameters such as water temperature and salinity were measured in February, May, September and November of 2004 (Fig. 1).

Surface sediments provided for dinoflagellate cyst analysis were collected with a gravity corer. A top 2 cm of the cores was stored in the dark at 4°C in order to prevent cyst germination until the start of the analysis. Samples were processed as described by Matsuoka and Fukuyo (2000). One gram of samples was put into a beaker with pure water and processed with an ultrasonic probe for 30 seconds, and then the samples were sieved with 125 μm and 20 μm mesh stainless steel screen. The residues on 20 μm mesh stainless steel screen were made up to 10 ml aliquots with pure water. Observation was carried out on

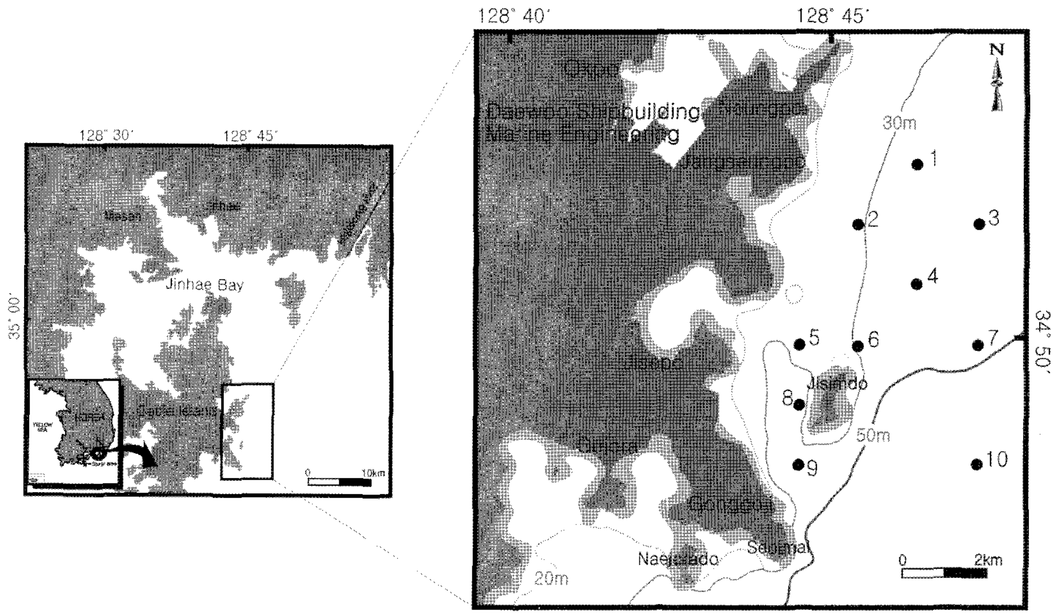

Fig. 1. Sampling stations in the eastern part of Geoje Island.

a 1 ml sub-sample of the 10 ml aliquots in Sedgwick-Rafter counting chamber under an optical microscope (Nikon, Eclipse E600). A part of another sample was weighed in wet condition and then dried in an oven to 110°C for 1 day to measure the water content, and cyst concentrations in this study were estimated by the sum of living and empty cysts, which were presented as number of cysts per grams dry sediment.

Water temperature and salinity were measured from

Table 1. Species compositions, abundances (cysts/g dry) and dominance in the eastern part of Geoje Island.

Dinoflagellate cysts	Stations										Dominanace (%)
	1	2	3	4	5	6	7	8	9	10	
AUTOTROPHIC SPECIES											
Gonyaulacoid group											
Spiniferites bulloideus	72	69	22	23	280		72	72	390	66	8.6
Spiniferites hypercanthus							48				0.4
Spiniferites mirabilis						24					0.2
Spiniferites ramous	48		66	69	140	48	120	72	78	44	5.5
Spiniferites spp.		46	22	46	168	72	216	120	130		6.6
Alexandrium affine type cyst		23			56	24					0.8
Alexandrium catenella/tamarense type cyst	72	69	22	46	56	24	96	96	234		5.8
Lingulodinium machaerophorum					168	24	384	48	390		8.2
Operculodinium centrocarpum	24	92	22		56		72	72			2.7
Operculodinium israelianum									26		0.2
Tuberculodinioid group											
Tuberculodinium vancampoae	24				28						0.4
Calciodinellid group											
Scrippsiella trochoidea		23	22		28				78		1.2
Gymnodinioid group											
Gymnodinium catenatum	96	69	66	184		24	24	48	78	66	5.3
Pheopolykrikos hartmanii					112		48	48	78		2.3
HETEROTROPHIC SPECIES											
Peridinioid group											
Brigantedinium irregular		23	22					72		44	1.3
Brigantedinium simplex	24			23		24				110	1.5
Brigantedinium spp.	24	261	154	207	448	192	360	384	702	176	23.5
Selenopemphix nephroides			22	23		24			52		1.0
Selenopemphix quanta	24		132		168	48	48	48	52	44	4.6
Stelladinium reidii			22				24		52		0.8
Trinovantedinium capitatum	24	23	66	23	56	24	120	72	78	66	4.5
Quinquescuspis concreta	24										0.2
Votadinium calvum		46		23	56			48	104		2.2
Protoperidinium americanum		23		23		24			26		0.8
Protoperidinium latissium							24				0.2
Diplopsalid group											
Diplopsalis lenticula	24	115	22	39	196	48		144	182	66	6.7
Diplopelta parva								24			0.2
Dubridinium caperatum								24	26		0.4
Gymnodinioid group											
Polykrikos kofoidii		46		23	28			48	78	44	2.2
Polykrikos schwartzii	48		88		28	48		48			2.1
TOTAL	528	851	814	752	2,072	672	1,656	1,488	2,834	726	100

surface to bottom layers with Submersible Fluorometer (Alec Co., ACL 1151-D).

3. Results

Dinoflagellate cyst compositions

A total of 30 taxa of dinoflagellate cysts representing 19 genera, 28 species and 2 unidentified forms were identified from all stations (Table 1). These dinoflagellate assemblages comprised 9 species of the gonyaulacoid (38.9% in total dinoflagellate cysts of all samples), 10 species of the peridinioid (40.3%), 4 species of the gymnodinioid (11.9%), 3 species of the diplopsalid (7.3%), 1 species of the calciodinellid (1.2%) and 1 species of the tuberculodinioid (0.4%), respectively (Fig. 2). The gonyaulacoid and peridinioid groups were dominant. *Brigantedinium* spp. (23.5%) were most abundant in all stations except St. 1 and were followed by *Spiniferites bulloideus* (Deflance *et* Cookson) Sarjeant (8.6%), *Lingulodinium machaerophorum* (Deflandre *et* Cookson) Wall (8.2%) and *Diplopsalis lenticula* Bergh (6.7%). Moreover, ellipsoidal cysts of *Alexandrium catenella* (Whedon *et* Kofoid) Balech - *tamarense* (Lebour) Balech type (5.8%) and cysts of *Gymnodinium catenatum* Graham (5.3%) known to be a PSP causative organism appeared in high concentrations. Cysts of *Scrippsiella trochoidea* (Stein) Loeblich were also found; however, the cyst concentration was low (1.2%). In general, cysts belonging to the heterotrophic group showed a higher proportion (51.8%) of the cyst abundance than the autotrophic group (48.2%).

Distribution of dinoflagellate cysts

The species number of dinoflagellate cysts ranged between 9 and 17 with an average of 13 species. Higher numbers of cysts were recorded at Sts. 5, 8 and 9 located in the west area of Jisimdo. The horizontal distribution of the cyst concentrations is shown in Figure 3. The cyst concentrations ranged from 528 to 2,834 cysts/g. The highest concentration was recorded at St.9, and the lowest was recorded at St. 1. As described below, higher cyst concentrations were observed at the west area of Jisimdo than in other areas.

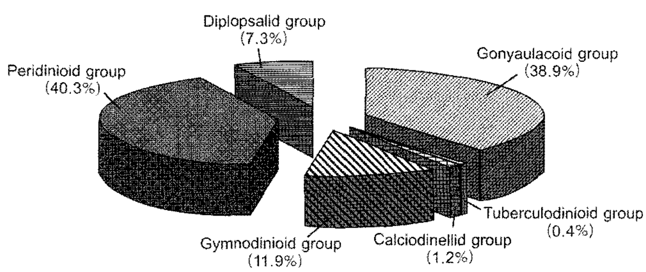

Fig. 2. Relative abundance of dinoflagellate cysts occurred at all stations of the eastern part of Geoje Island.

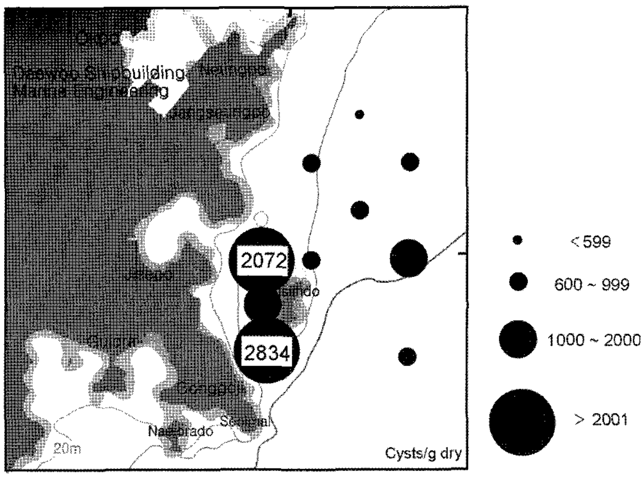

Fig. 3. Abundance of dinoflagellate cysts in surface sediments of the eastern part of Geoje Island.

Oceanographic conditions of the study area

Water temperature and salinity were measured to understand the relationship between distributional characteristics of dinoflagellate cyst and oceanographic condition in the eastern part of the Geoje Island (Fig. 4). In result, the water

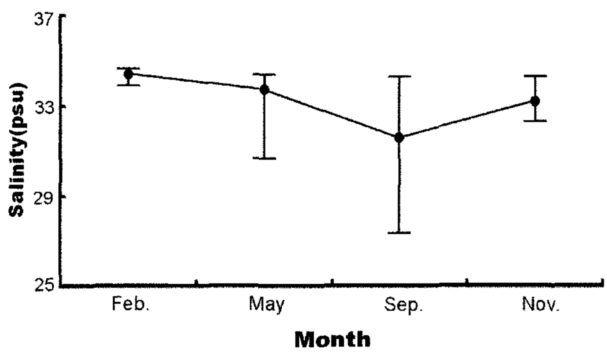

Fig. 4. Temporal variation of water temperature and salinity in the eastern part of Geoje Island.

temperature ranged from 11.7°C in February to 25.0°C in September, the mean water temperatures were 12.0°C in February, 14.7°C in May, 20.9°C in September and 17.2°C in November, and bottom water temperature was low in all periods. In particular, the mean water temperature of May was lower than that of November. The salinity ranged from 27.4 psu in September to 34.5 psu in February, and the mean salinities were 34.4 psu in February, 33.7 psu in May, 31.6 psu in September and 33.2 psu in November. The highest salinity was in February and gradually decreased toward May. The lowest salinity was in September, and then increased from November.

4. Discussion

Characteristics of dinoflagellate cyst assemblage

In surface sediments of the coastal area around Geoje Island, the gonyaulacoid and peridinioid cysts dominated, and these are also abundant groups in coastal waters of the southern part of Korea (Lee *et al.* 1998; Kim *et al.* 2003; Park and Yoon 2003). *Brigantedinium* spp. and *Spiniferites bulloideus* belonging to these groups were most abundant in this area. According to Marret and Zonneveld (2003), *Brigantedinium* spp. are not restricted to any range of temperature, salinity, phosphate and/or nitrate concentrations, and dominated in all studied environments. McMinn (1992) suggested that the peridinioid cysts including *Brigantedinium* spp. are associated with high nutrients. Recently, since many heavy industrial plants are constructed in this area, water quality becomes more eutrophicated and polluted due to rapid increase of waste water flowing through these plants (Han and Kim 1985). Therefore, the high concentration of *Brigantedinium* spp. in this area is concordant with more polluted and eutrophicated waters probably flowing from coastal industrial complexes. *Lingulodinium machaerophorum* is also often used as a proxy for eutrophication (Dale *et al.* 1999; Harland *et al.* 2004); it was the third-most abundant species in this study area. In addition, Matsuoka (1999) concluded that an increase of heterotrophic cyst groups is probably a good indicator for eutrophication. Accordingly, the proportion of heterotrophic species such as *Diplopsalis lenticula* observed in this area seems to reflect eutrophic conditions. *Spiniferites bulloideus* is known to be dominant species in the central parts of the South Sea of Korea (Park *et al.* 2005), Southwest Sea of Korea (Shin 2005), Yellow Sea and the East China Sea (Cho and Matsuoka 2001) where influenced by TWC. Cysts attributable to the genus *Gonyaulax* dominated in the Southern Japanese waters (Matsuoka 1985). In comparison with these reports, the study area is also influenced by the TWC as well as is West Kyushu, Japan.

The study area is indirectly influenced by Jinhae Bay and Nakdong River at the north-east side. The Jinhae Bay is well known as a place with high concentration of *Alexandrium* cysts (An 1998), of which species have been recorded as a red tide organism in the late spring and fall from 1990 to 1995 (Kim *et al.* 1997). *Scrippsiella trochoidea* have been also reported as a red tide causative species in Jinhae Bay during early spring (Park and Kim 1991). These also appeared in this area. A general species composition in this study area was similar to these reported in Jinhae Bay (Lee and Yoo 1991; Lee and Matsuoka, 1994; Lee *et al.* 1998) and Busan Harbor (Kim *et al.* 2005). These results suggest that environmental characteristics of this area have a close relation to Jinhae Bay and the coastal area of Busan, which will be discussed in more detail later.

Cyst distribution and environmental condition

The cyst abundance of this study area was also similar to these of Gamak Bay, Gwangyang Bay and the Saemangeum area of Korea; however, it was different from these of Korea Strait and Jeju waters and the Southwest Sea of Korea (Table 2). This is probably due to different nutrient

Table 2. Total abundances of dinoflagellate cyst reported in the coastal waters of Korea.

Study areas	Abundances (cysts/g dry)	References
Gamak Bay	21 ~ 4,322	Park *et al.*, 2003
Gwangyang Bay	15 ~ 2,188	Kim *et al.*, 2003
Saemangeum area	6 ~ 1,618	Park *et al.*, 2004
Korea Strait and Jeju waters	36 ~ 962	Lee and Matsuoka, 1994
Southwest sea of Korea	13 ~ 527	Shin, 2005
Eastern part of the Geoje Island	528 ~ 2,834	This study

levels, which in open seas are generally lower than that of the coastal waters (Shin 2005). In this area, high cyst concentrations were in the west area of Jisimdo and low concentrations were in other stations in offshore areas except for St. 7 and the west area of Jisimdo.

The distribution of cysts is controlled by several factors, including motile stage, biological and ecological controls over encystment, and the behavior of cysts as sediment particles in the hydrographic regime (Goodman 1987). It is also closely related to the physical parameters of the surface water masses, in particular the strong influence of hydrological fronts (Marret *et al.* 2001). The hydrographic condition of this area was characterized by low temperature and high salinity in February, May and November, except in September which had high temperature and low salinity. In other words, this area appears to be affected by freshwater run-off in summer rainy season and by the bottom cold waters flowing from the East Sea (the Sea of Japan) until May. According to Suh *et al.* (2001), the bottom cold waters that flow from around the East Sea expand through coastal area of Busan to Seoimal of Geoje Island. This environmental characteristic in the coastal area of Geoje Island is favorable for *Alexandrium* cysts growth as *Alexandrium tamarense* frequently grows at low water temperature (Ichimi *et al.* 2001). Moreover, *A. tamarense* cysts isolated in Jinhae Bay have maximum growth rate at around 15°C in culture (Park *et al.* 2004). Therefore, *Alexandrium* cysts in this area may be germinated with the stimulus of low water temperature in May and cold bottom water.

The dynamics of dinoflagllate cysts are affected by water movement as sediments including dinoflagellate cysts are transported from the original area by tidal currents (Matsuoka and Fukuyo 2000). Moreover, the currents, with environmental conditions such as water temperature, salinity and nutrients are closely related to geographical distribution of cysts (Marret and Zonneveld 2003); the currents can also control the cyst horizontal distribution and abundance of cysts (Joyce *et al.* 2005). Therefore, the current patterns as well as other environmental parameters are important for understanding the distributional characteristics of dinoflagellate cysts. The coastal area of Geoje Island is connected with Jinhae Bay and the coastal area of Busan at the north-east side. In these areas, tidal currents flow from the coastal area of Busan to Geoje Island and Jinhae

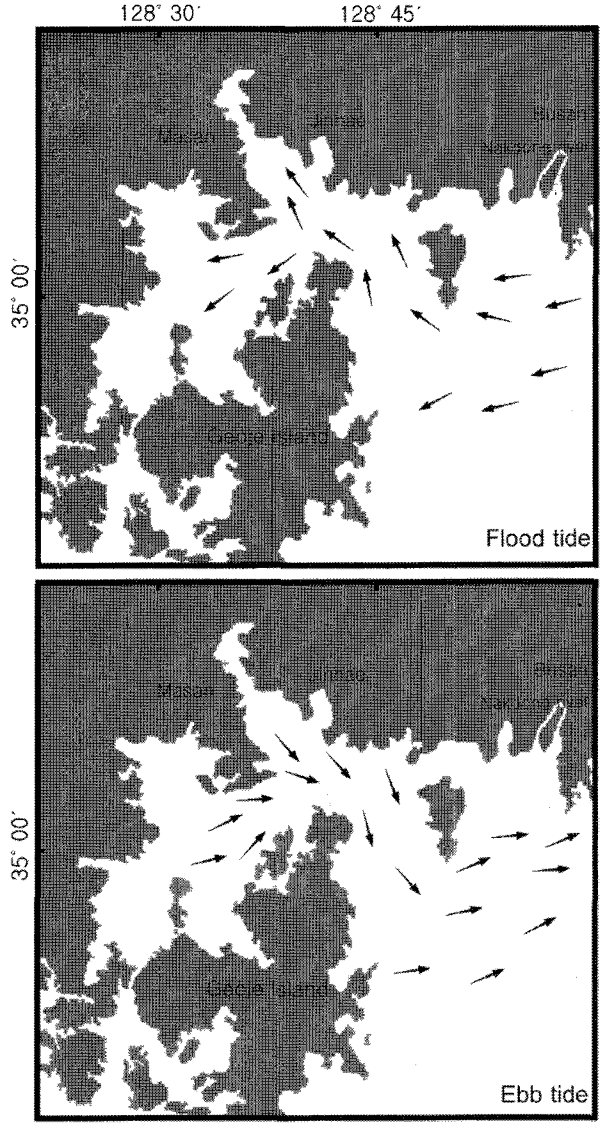

Fig. 5. The direction of flood and ebb tidal currents in the coastal area of Geoje Island and adjacent areas (Korea Hydrographic Office 1982).

Bay during flood tide, sediments from Nakdong River near Busan simultaneously flow into this area, and the current flows out to the coastal area of Geoje Island and Busan during ebb tide (Kim *et al.* 1986; Hwang *et al.* 2002) (Fig. 5). At this time, the dinoflagellate cysts produced in the coastal area of Busan and Jinhae Bay can be transported to the coastal area of Geoje Island along the flood and ebb tides that run in these areas, and then (the cysts) sink down in this area. This explains why the species composition in this study area is similar to these of Jinhae Bay and Busan Harbor. Therefore, the appearance of ellipsoidal *Alexandrium* cysts in this area

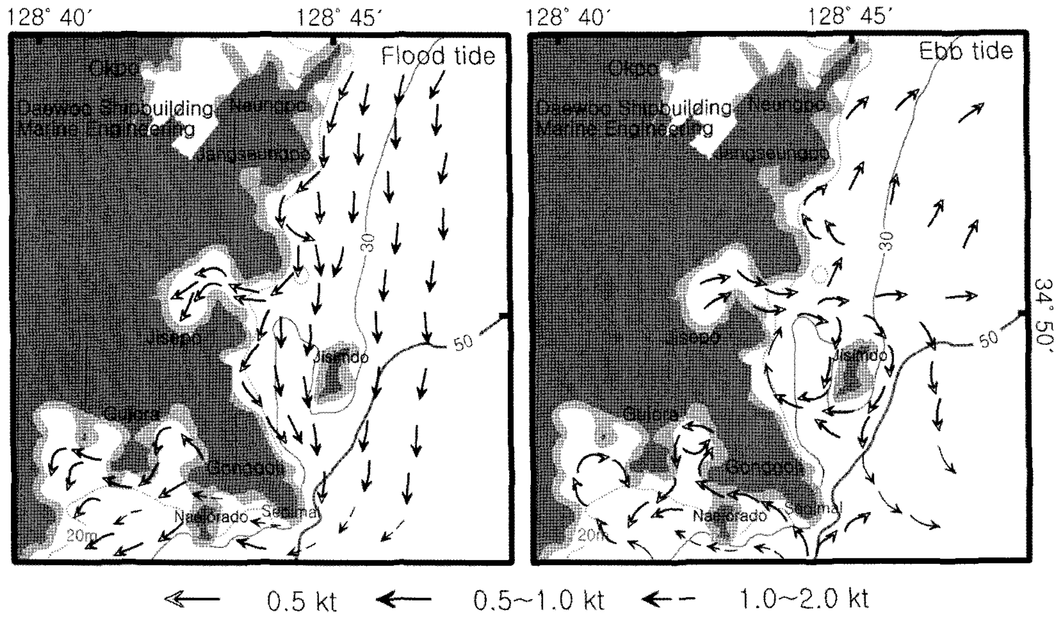

Fig. 6. The current patterns (Han and Kim 1985).

seems to be a natural occurrence.

In addition, the current in the coastal area of Geoje Island flows from the east side of Jangseungpo to east-west side of Jisimdo during flood tide. As the current around the coast is of slower (speed of less than 0.5 knot) than the east side of Jisimdo (speed from 0.5 to 1.0 knot), dinoflagellate cysts may be deposited near shore. In particular, the current during ebb tide develop the gyre in the west area of Jisimdo, of which the center is a favorable condition for dinoflagellate cysts deposition and thereby allows the dinoflagellate cysts to easily accumulate at the west area of Jisimdo (Fig. 6). In other words, the weak currents and gyre in this area seem to be certainly responsible for distribution of dinoflagellate cysts. Nevertheless, the result of St. 7 (the third highest abundance of dinoflagellate cysts in this area) could not be explained by these factors; this abundance might be affected by several other factors (mentioned above) that control the cyst distribution and abundance. As the cysts dynamics in oceanic conditions are complex phenomena, the understanding of environmental characteristics in a certain study area is essential. It is inevitable that the coastal area of Geoje Island accepts the dinoflagellate cysts from the coastal area of Busan and Jinhae Bay due to continuously running current in this area. Therefore, occurring red tides and harmful algal blooms caused by dinoflagellate such as *Alexandrium* spp. at inshore areas may probably be correlated with dinoflagellate cysts derived from the coastal area of Busan and Jinhae Bay.

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