Coastal Environmental and Ecosystem Issues of the East China Sea,
Eds., A. Ishimatsu and H.-J. Lie, pp. 111–120.

Environmental Changes in the Inner Part of Ariake Sound, West Japan Recorded in Dinoflagellate Cyst Assemblages

Kazumi MATSUOKA[1] and Hyeon Ho SHIN[2]

[1]*Institute for East China Sea Research, Nagasaki University, 1551-7 Taira-machi, Nagasaki 851-2213, Japan*
[2]*Graduate School of Science and Technology, Nagasaki University, 1-14 Bunkyo-machi, Nagasaki 852-8521, Japan*

Abstract—For understanding the paleoenvironmental change in Ariake Sound, dinoflagellate cyst assemblages preserved in two sediment cores, the JA1 and JA2 collected from the inner part of the Sound were analyzed using palynological technique. Based on ^{210}Pb dating, the JA 1 core approximately covered the past 150 years. The dinoflagellate cyst assemblages in this core were characterized by abundance of autotrophic *Lingulodinium macaherophorum*, *Spiniferites bulloideus*, and *Spin. hyperacanthus*, and increased at the late1960s and the mid 1980s in cyst density. In the JA 2 core, a sand layer inserted with at 60–71 cm depth from the sediment surface was artificially speared at 1987 AD. The dominat taxa of the dinoflagellate cyst were hterotrophic *Brigantedinium* spp., and autotrophic *Spin. bulloideus*. *Spin. hyteracanthus*, *L. machaerophorum*, and ellipsoidal cysts of *Alexandrium*. The cyst density above the sand layer was almost twice that of the lower part. These data suggest that the nutrients in the inner part of Ariake Sound increased in the late 1960s and the mid of 1980s.

Keywords: dinoflagellate cyst, autotroph, heterotroph, eutrophication, paleoenvironment, Ariake Sound

1. INTRODUCTION

Dinoflagellates, one of the important phytoplankton groups, have been used for the study of spatio-temporal changes in coastal marine environments. A number of dinoflagellates are also well known as causative organisms for harmful algal blooms, and some of them produce resting cysts that can be preserved in sediments for a long time. Since encystment and excystment of cyst-producing dinoflagellates are mainly controlled by water temperature, salinity and nutrient availability (Meier and Willems, 2003), dinoflagellate cyst assemblages preserved in sediments can be utilized to reconstruct environmental conditions of a certain area (Dale et al., 1999; Matsuoka, 1999).

Ariake Sound located in the western part of Japan is ca. 90 km long, ca. 20 km wide, and ca. 20 m in average depth (Kamada, 1985). The innermost part of this bay is strongly affected by the intrusion of freshwater from several rivers, mainly the

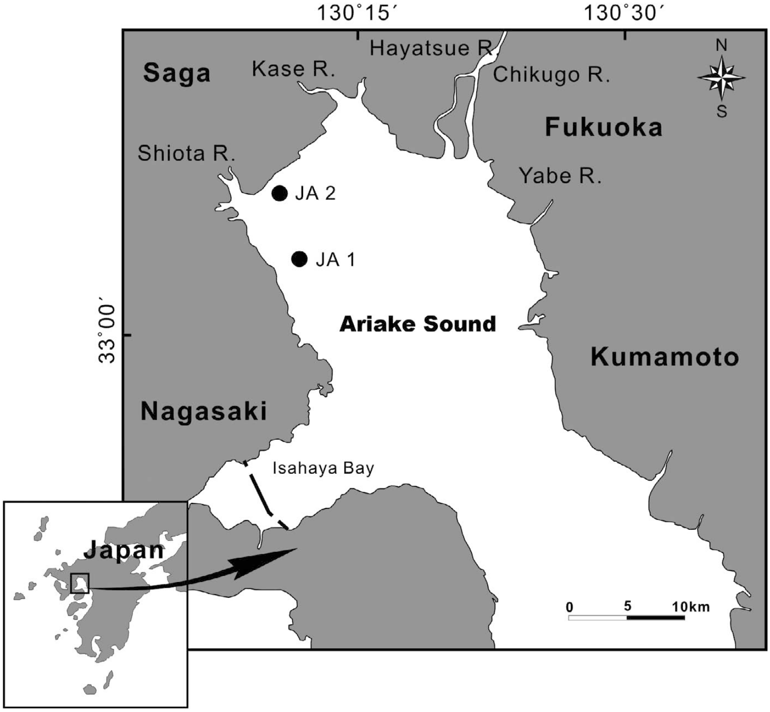

Fig. 1. Sampling locations of two cores in Ariake Sound.

Chikugo River (Fig. 1). Ariake Sound is also one of the major enclosed bays in Japan, with various and rich fishery resources. In particular, Ariake Sound also produces the edible laver "Nori" that is well known for its high quality and accounts for approximately 40% of the total production in Japan (e.g. Fujita, 2006). However, Nori culture industries were seriously damaged from the autumn of 2000 to the winter of 2001 by diatom blooms of *Rhizosolenia imbricata* Brightwell (The Ministry of Agriculture, Forestry and Fisheries of Japan, 2001). In addition, other marine products including fish and shellfish, such as little necked clam, pen shell and subcrenated ark shell, also saw a decrease from the 1980s to the recent years (The Ministry of Agriculture, Forestry and Fisheries of Japan, 2001; Kim et al., 2007). The decreases in these marine products are possibly related to environmental changes in the area, including an increase in the reclamation of tidal flats and the construction of a sea-dyke in Isahaya Bay; one of the small inlets of Ariake Sound. These anthropogenic activities brought severe environmental deterioration, changing the tidal current, causing eutrophication, oxygen depletion and an increase in transparency (e.g. Nakata, 2006; Tsutsumi, 2006). Societal concern about these environmental problems has become stronger during the 2000s in Japan.

In Isahaya Bay, Matsuoka (2004) studied the relationship between environmental changes and dinoflagellate cyst assemblages preserved in sediments as a way of clarifying the environmental history. According to the results of Matsuoka (2004, 2006), the dinoflagellate cyst assemblages in Isahaya Bay have been changing since the end of the 1960s, which may indicate eutrophication. However, environmental changes of the most inner part of this sound are still unclear. Therefore, we attempted to reconstruct the past environmental changes around this part using dinoflagellate cyst assemblages recorded in sediments.

2. MATERIALS AND METHODS

Two cores, JA1 and JA2, were collected using a "Geo-Slicer" in September 2005 and October 2006, respectively (Fig. 1). The JA1 core was 190 cm in length, and mostly consisted of dark brown homogeneous mud sediment, whereas the JA2 core was 111 cm in length, and mostly consisted of brownish mud, except between 60–71 cm depth where a sand layer was reported, including many shell fragments (NPO Organization for Ariake Bay Rehabilitation, 2007). The JA1 subsamples provided for dinoflagellate cyst analyses were taken at 1 cm intervals from the top to a depth of 31 cm and then at 5 cm intervals to the bottom of the core. The JA2 core was analyzed at 5 cm intervals throughout. These subsamples were stored in the dark and in cool conditions at ca. 4°C prior to dinoflagellate cyst extraction. The subsamples were processed using the palynological method suggested by Matsuoka and Fukuyo (2000).

The depositional ages of each subsample were estimated by ^{210}Pb dating method. According to the result given by Momoshima (in NPO Organization for Ariake Bay Rehabilitation, 2007), the sedimentation rate in the JA1 core was 0.75 cm/year. Consequently, the age at –3 cm of the JA1 core was estimated as 2000 AD, and then, at –11 cm 1990 AD, at –18 cm 1980 AD, at –29 cm 1965 AD, at –111 cm 1855 AD, at –151 cm 1800 AD, the core covering approximately the past 150 years. Since the concentration of ^{210}Pb for the upper part of the JA2 core did not change with depth, it was impossible to determine the sedimentation rate. However, the depositional age of the sandy layer at 60–71 cm depth speared out artificially for reconstruction of mollusk-fishing grounds was determined as 1987 AD according to the literature preserved in Saga Prefecture (NPO Organization for Ariake Bay Rehabilitation, 2007). Consequently, the depositional ages above this sandy layer were not given due to mixing of the sediment. However, below this depth, the sedimentation rate was estimated as 0.676 cm^2/y (Momoshima in NPO Organization for Ariake Bay Rehabilitation), the depositional age of the bottom of the JA2 core was therefore estimated as the 1940s.

3. RESULTS

A total of 37 dinoflagellate cyst taxa were identified at JA1 (Figs. 2, 3). The autotrophic group mainly consisted of *Lingulodinium macaherophorum* Deflandre et Cookson, *Spiniferites bulloideus* (Deflandre et Cookson) Sarjeant, and *Spiniferites hyperacanthus* (Deflandre et Cookson) Sarjeant. In the heterotrophic group, cysts of

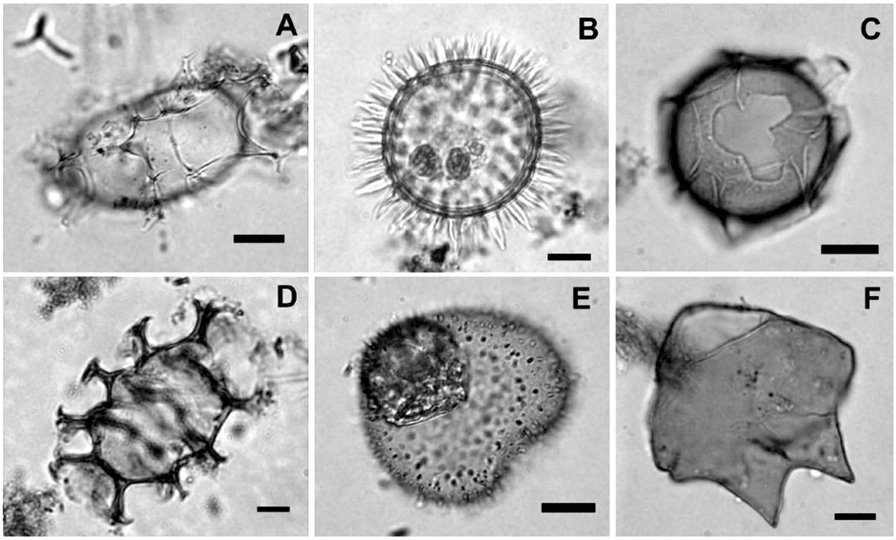

Fig. 2. Dinoflagellate cysts observed in the cores. A; *Spiniferites elongates* Reid, B; *Lingulodinium machaerophorum* (Deflandre et Cookson), C; Cyst of *Protoperidinium americanum* (Gran & Braarud), D; Cyst of *Polykrikos schwartzii* Bütschli, E: *Votadinium spinosum* Reid, F: Cyst of *Protoperidinium lassisinum*? A–B; autotrophic species, C–F; hetrotrophic species. Scale bar = 10 μm.

Protoperidinium americanum (Gran et Braarud) Balech, *Brigantedinium* spp. (round brown cysts of *Protoperidinium* and diplopsalids) were the most abundant, followed by *Dubridinium caperatum* Reid. The total concentration of dinoflagellate cysts ranged from 189 to 1526 cysts/g. The highest cyst concentration was recorded at the surface and the lowest was at 20 to 23 cm depth. The cyst concentration gradually increased at 28 to 29 cm (late 1960s), and then the second higest cyst concentration including the surface sample was observed at 13 to 14 cm (mid 1980s). Cyst concentrations including both autotrophic and heterotrophic groups were generally coincident with an increase in the autotrophic *L. machaerophorum* and *Spin. bulloideus* toward the upper part of the core.

A total of 36 dinoflagellate cyst taxa were identified in the JA2 core, and the dominant taxa were *Brigantedinium* spp. and *Spin. bulloideus*. *Spiniferites hyteracanthus*, *L. machaerophorum*, and ellipsoidal cysts of *Alexandrium* also abundantly occurred. The total cyst concentration was different between the upper and lower part of the core, with a distinct boundary at the sandy layer at 60–71 cm depth (1987AD). The cyst concentration recorded in the upper part was almost twice that of the lower part. In particular heterotrophic taxa *Brigantedinium* spp. increased. Other autotrophic taxa including *Spin. bulloideus*, *Spiniterites* spp., *L. machaerophorum* and ellipsoidal cysts of *Alexandrium* also abundantly occurred.

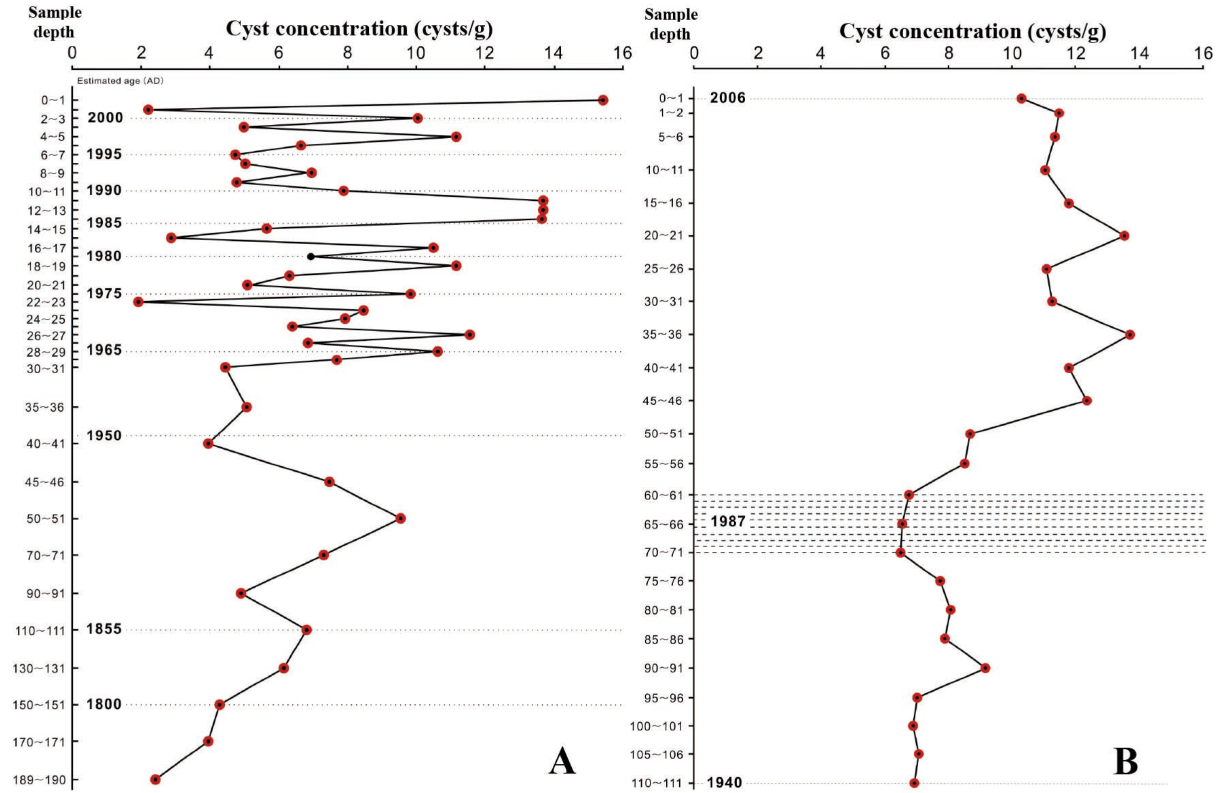

Fig. 3. Vertical distribution of dinoflagellate cyst densities in the JA1 (A) and JA2 cores (B). Dashed lines between 60–61 cm and 70–71 cm depth indicate the sand layer artificially spreaded.

In general, the dominant species and species composition of dinoflagellate cysts in JA2 were similar to those in JA1. The JA1 and JA2 cores were characterized by high cyst concentrations of autotrophic species. The total concentration of dinoflagellate cysts at JA2 ranged from 661 to 1367 cysts/g, the highest concentration was recorded at 35 to 36 cm and the lowest concentration was at 65 to 66 cm depth. The number of all dinoflagellate cysts gradually increased at 60 to 61 cm (mid 1980s) towards the surface of the core (Fig. 3).

4. DISCUSSION

The concept for an explanation between the environmental conditions and the number of dinoflagellate cysts was given by Matsuoka (1999) as follows; nutrient enrichment with phosphate, nitrogen and silicate enhances active reproduction of various phytoplankton groups. At the initial stage (Fig. 5-I) diatoms and autotrophic flagellates, including dinoflagellates and raphydophycean algae, in coastal waters may form large blooms. According to this, the dinoflagellate cyst concentrations can increase. In addition, these phytoplankton groups are prey for heterotrophic dinoflagellates. This increase may reflect an abundant occurrence of heterotrophic dinoflagellate cysts (Fig. 5-II). For example, the dinoflagellate cyst concentrations together with the relative proportion of heterotrophic dinoflagellate cysts increased from the late 1960s, which was also suggestive of environmental change , especially nutrient level, in Isahaya Bay (Matsuoka, 2004, 2006; as in Fig. 5-II).

The total cyst concentration in the most inner part of Ariake Sound (JA1) also increased from the late 1960s (as in Fig. 4-I). In the JA2 core, the dinoflagellate cyst concentration (more than 1000 cysts/g) of the upper part from the sand layer artificially superadded at 1987 increased in comparison with the lower part (ca. 800 cysts/g). However, the species responsible for this increase was autotrophic *L. machaerophorum* and *Spin. bulloideus*, not heterotrophic dinoflagellate cysts. The signal of eutrophication encoded in dinoflagellate cyst assemblages may vary with different estuarine types like those in Tokyo Bay of Japan and the Oslo fjord of Norway (Dale et al., 1999; Matsuoka, 2001; Pospelova et al., 2002). For example, *L. machaerophorum* has been utilized as an indicator of low salinities, and this species is also abundant in high nutrient conditions in the Oslo fjord (Dale et al., 1999). Pospelova et al. (2002) also suggested that *Spiniferites* spp. are the most abundant cyst assemblages in low salinities (5–15 PSU). The most inner part of Ariake Sound is strongly influenced by the intrusion of freshwater from rivers, and the freshwater input might load large amount of nutrients such as nitrogen and phosphate into the sound.

Consequently, the dominance of these species suggests that the most inner part of Ariake Sound is lower in salinity and a more eutrophicated environment than other coastal regions such as Omura Bay and Nagasaki Bay. The change in dinoflagellate cyst assemblages in these two cores suggests different environmental stages in the inner part of Ariake Sound. Since the mid 1960s, eutrophication in the inner part of Ariake Sound was indicated by an increase in the total dinoflagellate cyst densities. However, two different eutrophication stages can be considered. The early stage of

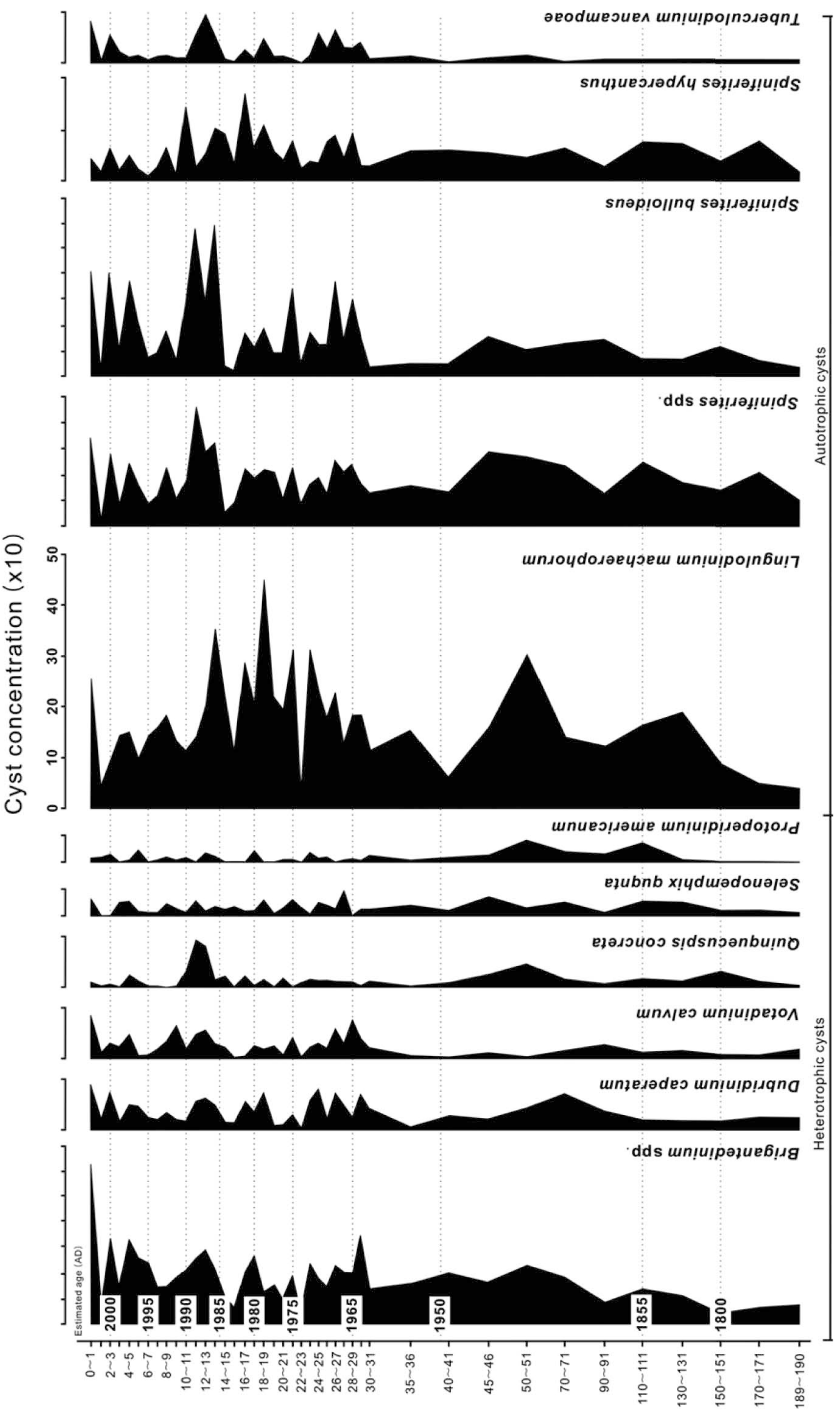

Fig. 4. Occurrence diagram of main taxa of dinoflagellate cysts observed in the JA1 core.

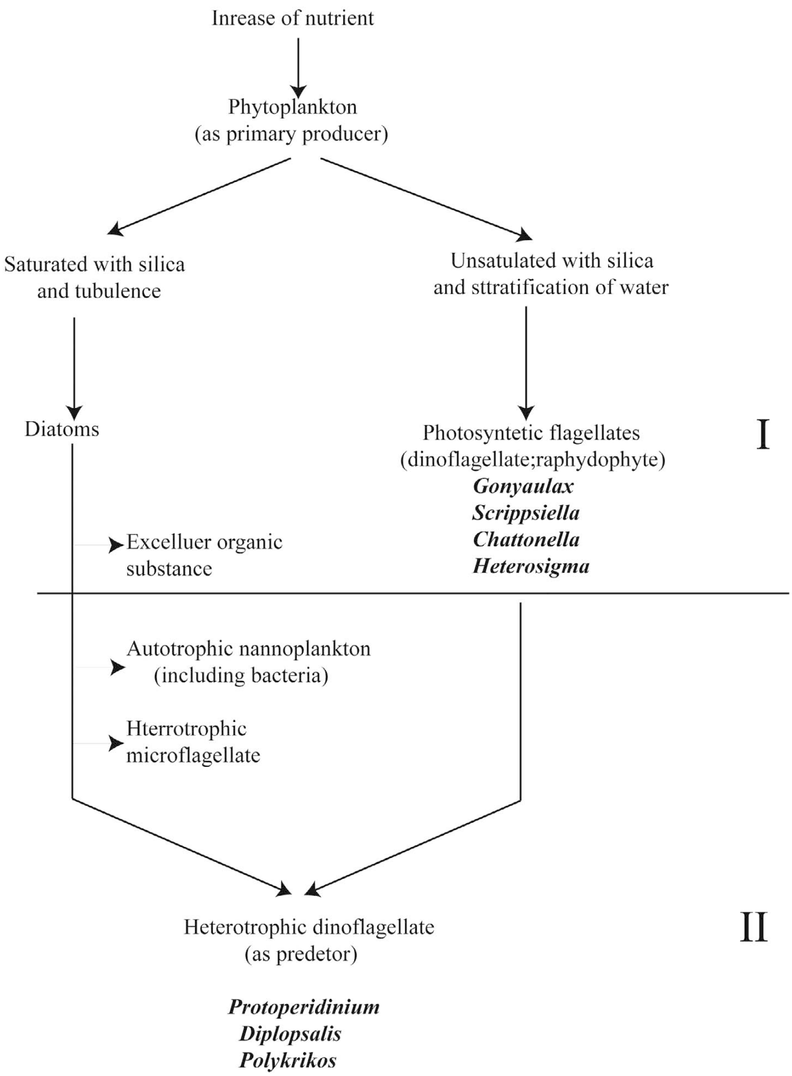

Fig. 5. Schematic diagram explaining the relationship between nutrient flow and autrotrophic and heterotrophic dinoflagellates. (Reprinted with modification from *The Science of the Total Environment*, **231**, Matsuoka, Eutrophication process recorded in dinoflagellate cyst assemblages—a case of Yokohama Port, Tokyo Bay, Japan, 1999, with permission from Elsevier.)

this eutrophication is suggested by an increase in the cyst of *Protoperidinium americanum* since the mid 1960s, and the late stage is reflected by the increase in the autotrophic taxa. The increase in the heterotrophic cyst *Protop. americanum* suggests the increase of prey organisms such as diatoms, of which reproduction is enhanced in well-circulated waters. In contrast, the increase of total cyst concentration coinciding with a decrease in the heterotrophic group since the mid 1980s suggests that the nutrients in the inner part of Ariake Sound increased more in the mid 1960s and the earlier 1960–1970s accompanied with further development of the water stratifications, because reproduction of photosynthetic flagellates is enhanced by more nutrients under more stratified condition (Margalef 1978). Chemical oxygen demand (COD) and dissolved inorganic nitrogen (DIN) concentrations in the innermost part of Ariake Sound were also rapidly increased from the 1980s according to Yokouchi et al. (2005). According to the NPO Organization for Ariake Bay Rehabilitation (2007), this increase in nutrients, in particular nitrogen, was due to the spreading of artificial nitrogen fertilizers for Nori culture in the inner part of Ariake Sound.

In conclusion two different eutrophication stages can be suggested by the dinoflagellate cyst analyses; 1) Eutrophication has progressed since the mid 1960s, 2) Further eutrophication due to the input of nitrogen fertilizers and stratified waters has developed since the early 1980s.

Acknowledgments—The core samples analyzed in this study were provided by NPO Organization for Ariake Bay Rehabilitation. This work was supported by Juten Kenkyu Kadai “Restoration of Marine Environment and Resources in East Asia”.

REFERENCES

Dale, B., T.A. Thorsen and A. Fjellsa. 1999. Dinoflagellate cysts as indicators of cultural eutrophication in the Oslofjord, Norway. *Estuarine Coastal and Shelf Science* **48**: 371–382.

Fujita, Y. 2006. Changes in seaweed vegetation and laver production. In: *Integrated Study on the Effect of Environmental Changes on the Fisheries Resources in Ariake Sound*, H. Nakata (Ed.), Report of Grant-in Aid for Scientific Research (S) (2001–2005), Nagasaki University, pp. 187–193.

Kamada, Y. 1985. Geology of Ariake Sea. In: *The Oceanographical Society of Japan*, Coastal Oceanography Research Committee, Tokai University Press, pp. 815–830.

Kim, Y.S., H.S. Eun, T. Katase and H. Fujiwara. 2007. Vertical distributions of persistent organic pollutants (POPs) caused from organochlorine pesticides in a sediment core taken from Ariake Bay, Japan. *Chemosphere* **67**: 456–463.

Margalef, R. 1978. Life-forms of phytoplankton as survival alternatives in an unstable environment. *Oceanology Acta* **1**: 493–509.

Matsuoka, K. and Y. Fukuyo. 2000. Technical guide for modern dinoflagellate cyst study. WESTPAC-HAB/WESTPAC/IOC, Japan Society for the Promotion of Science, 29 pp.

Matsuoka, K. 1999. Eutrophication process recorded in dinoflagellate cyst assemblages—a case of Yokohama Port, Tokyo Bay, Japan. *The Science of the Total Environment* **231**: 17–35.

Matsuoka, K. 2001. Further evidence for a marine dinoflagellate cyst as an indicator of eutrophication in Yokohama Port, Tokyo Bay, Japan. *The Science of the Total Environment* **264**: 221–233.

Matsuoka, K. 2004. Change in the aquatic environment of Isahaya Bay, Ariake Sound, West Japan: From the view point of dinoflagellate cyst assemblage. *Bulletin on Coastal Oceanography* **42**: 55–59.

Matsuoka, K. 2006. Mid and long term environmental change recorded in sediments-Environmental change of the inner part of Ariake Sound. In: *Integrated study on the effect of environmental changes on the fisheries resources in Ariake Sound*. H. Nakata (Ed.). Report of Grant-in Aid for Scientific Research (S) (2001–2005), Nagasaki University, pp. 65–93.

Meier, K.J.S. and Willems, H. 2003. Calcareous dinoflagellate cysts in surface sediments from the Mediterranean Sea: distribution patterns and influence of main environmental gradients. *Marine Micropaleontology* **48**: 321–354.

Momoshima, N. 2008. Sediment ages given by radiometric measurements. In: *Report of the Open Symposium for Tidal Flats*, NPO Organization for Ariake Bay Rehabilitation, pp. 34–42.

Nakata, H. (ed.) 2006. Change in transparency and its causal factors. In: *Integrated study on the effect of environmental changes on the fisheries resources in Ariake Sound*. H. Nakata (Ed.), Report of Grant-in Aid for Scientific Research (S) (2001–2005), Nagasaki University, pp. 27–31.

NPO Organization for Ariake Bay Rehabilitation (Ed.). 2007. *Abstract for the Tidal-Flat Sub-commettee*, 53 pp.

Pospelova, V., G.L. Chmura, W.S. Boothman and J.S. Latimer. 2002. Dinoflagellate cyst records and human disturbance in two neighboring estuaries, New Bedford Harbor and Apponagansett Bay, Massachusetts (USA). *The Science of the Total Environment* 298: 81–102.

The Ministry of Agriculture, Forestry and Fisheries of Japan. 2001. *The Material of the Investigative Committee for the Measures to Address the Poor Harvest of nori in the Ministry of Agriculture, Forestry and Fisheries in FY 2001 (1) and (2)*, 968 + 776 pp.

Tsutsumi, H. 2006. Critical events in the Ariake Bay ecosystem: Clam population collapse, red tides, and hypoxic bottom water. *Plankton and Benthos Research* **1**: 3–25.

Yokouchi, K., T. Handa, Y. Kawamura, Y. Yoshida, K. Yamamoto, Y. Kiyomoto, K. Okamura and G. Fujiwara. 2005. Horizontal distributions and temporal variations of environments in Ariake Bay. *Umi to Sora* **80**(4): 141–162.

K. Matsuoka (e-mail: kazu-mtk@nagasaki-u.ac.jp) and H. H. Shin (present address: Laboratory of Bio-environmental Sciences, College of Fisheries and Ocean Science, Chonnam National University, San 197, Dundeok-dong, Yeosu 550-749, Korea)