BASIC STUDY ON CYST FORMATION OF *CHATTONELLA ANTIQUA* IN THE ARIAKE SEA

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The Ariake Sea is semi-closed shallow sea in Japan. The typical species of red tide in the Ariake Sea is *Chattonella antiqua* which cause main damage in fish. Moreover, it is known that *Chattonella antiqua* has the cyst stage for overwintering. The purposes of this study are to investigate the *Chattonella antiqua* cyst formation and to simulate its blooming event using water quality model. The simulation results indicate that resuspended solids from mud bed is the primary cause of *Chattonella antiqua* blooming events in the Ariake Sea. Through sensitive analysis, it can be concluded that *Chattonella antiqua* cysts in the Ariake Sea are formed during winter when water temperature is lower than 11 °C.

Key Words : *Red tide, Chattonella antiqua, Cyst formation, Water quality model, Ariake Sea*

1. INTRODUCTION

The semi-closed Ariake Sea is located in the west of Kyushu Island, Japan. The total area of the Ariake Sea is about 1,700 km^2 with the length of 100 km, the average width of 15 km, and the average water depth of 20 m. The tidal flat area of the Ariake Sea is about 40 percent of the total tidal flat in Japan. The total watershed area of the Ariake Sea is about 8,400 km^2 composed of 5 prefectures, which are Fukuoka, Saga, Kumamoto, Oita and Nagasaki. As shown in **Fig.1**, there are eight major river systems located in the catchment of the Ariake Sea, namely, the Chikugo River, the Midori River, the Shira River, the Kikuchi River, the Yabe River, the Kase River, the Rokkaku River and the Honmyo River.

The Ariake Sea is a major seaweed producing region in Japan. During the winter of 2000, the *Rhizosolenia* appeared in wide area of the Ariake Sea causing the seaweed damage. It was pointed out that *Rhizosolenia* was transported from the open sea during 2000. Therefore, it can be said that *Rhizosolenia* is the atypical species of red tide in the Ariake Sea. It is well-known that *Chattonella* *antiqua* is the typical species of the red tide which damaged fish in the Ariake Sea[1]. As a result, this study aims to investigate the *Chattonella antiqua* cysts formation and its bloom event in the Ariake Sea.

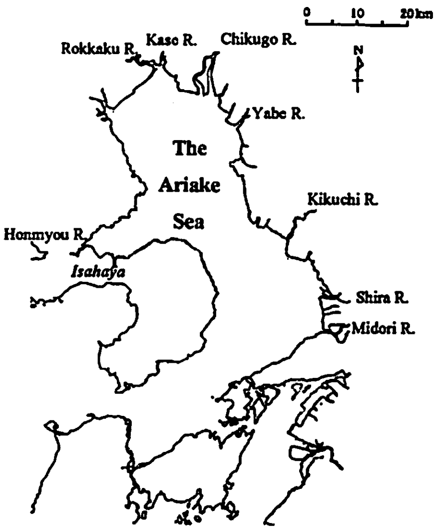

Fig.1 The Ariake Sea and the rivers flowing into the Ariake sea.

2. *CHATTONELLA ANTIQUA* LIFE CYCLE AND CYST FORMATION

Chattonella antiqua first appeared in Hiroshima Bay in 1969[2]. *Chattonella* is classified under *Heterokontophyta* division and *Raphidophyceae* class[3]. *Chattonella* forms the red tide in coastal eutrophicated waters associated with the mass mortality of fish and some species product cysts[4]. *Chattonella antiqua* grows in the temperature range from 15 to 28 °C[5]. From laboratory test using *Chattonella antiqua* sampled in the Usuka Bay in Nagasaki, the growth rate of 0.5 (1/day) is measured at the temperature range from 21 to 28.3 °C while the salinity range from 27.50 to 33.95 psu[6] (the practical salinity units). However, the maximum growth rate of 0.8 (1/day) with maximum cell of 100 cells/cm^3 is measured at the temperature range from 24.9 to 26.6 °C at the salinity range from 27.90 to 31.40 psu. Nevertheless, the optimum temperature for photosynthesis of *Chattonella antiqua* is observed at temperature 25 °C[6]. Many dinoflagellate species are known to have cyst stage in their life cycle[7]. It is known that *Chattonella antiqua* has the cyst stage for overwintering in low water temperature[4]. It was first noticed that the vegetative cells of *Chattonella antiqua* and *Chattonella marina* appeared from the sediments after several incubation days in the culture medium[8]. This result indicates that *Chattonella antiqua* and *Chattonella marina* have a benthic dormant stage such as a cyst in the sediment during a certain period of their life cycle. In general, the *Chattonella antiqua* and *Chattonella marina* cysts usually adhere to the bottom mud. This experimental result suggests that *Chattonella antiqua* completes the cyst formation after sinking to the sea bottom[9]. The germination of *Chattonella antiqua* cyst occurs when the water temperature is less than 11 °C for more than 4 months[10, 11]. When resuspension process of SS by tidal current and wind waves occurs, *Chattonella antiqua* cysts in the mud bed are resuspended to water column. The basic life cycle of *Chattonella antiqua* is demonstrated in **Fig.2**. When the water temperature is lower than the critical temperature for cyst fomation, *Chattonella antiqua* forms cyst and germinates. When water temperature is higher than the critical temperature, cyst formation process cannot occur and finally there is no *Chattonella antiqua* blooming. *Chattonella antiqua* intakes the nutrients and usually floats at the surface water in day time. However, at night, it sinks down from the water surface to the lower layer and intakes the nutrients needed[4].

3. WATER QUALITY MODEL

In this study, the two-dimensional water quality model in the Ariake Sea is applied based on the finite volume model[12, 13]. In this model, the Ariake Sea is divided into 11 elements as shown in **Fig.3**. Each divided element is considered to be in the complete mixing state. According to the salinity level, the Ariake Sea is divided into three parts, namely, the innermost part, the central part, and the gulf mouth. In addition, the water quality constituents in this model are salinity, chemical oxygen demand (COD), suspended solids (SS), dissolved inorganic nitrogen (DIN), orthophosphate phosphorus (PO_4-P), and chlorophyll-*a* (Chl-*a*). In this study, there are 4 kinds of algae concerned, namely, diatom, green algae, blue green algae and *Chattonella antiqua*.

With the given boundary conditions, a net flow rate between two adjacent elements can be obtained from the continuity equation in equation (1). The basic equation in each element of the finite volume model[11] is described in equation (2).

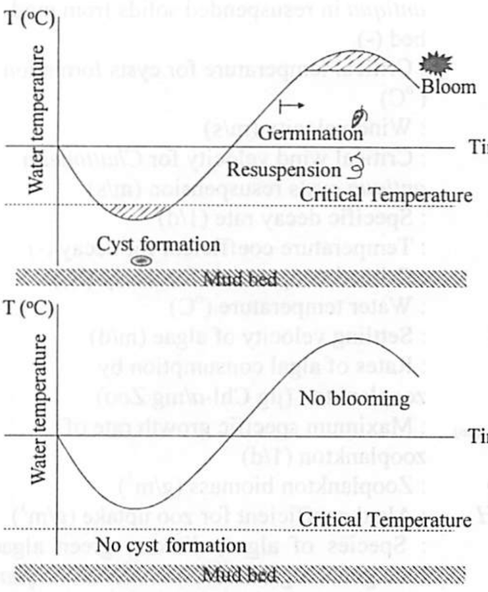

Fig.2 Basic life cycle of *Chattonella antiqua*.

$$\frac{dV_n}{dt} = \sum Q_{nm} + Q_{B(n)} \quad (1)$$

$$\frac{dc_{(n)} \cdot V_{(n)}}{dt} = \sum \{Q_{nm}[\delta_{nm} \cdot c_{(m)} + (1-\delta_{nm})c_{(n)}] + E'_{nm}(c_{(m)} - c_{(n)})\} \pm S_{(n)} \quad (2)$$

Where

V	: Water volume of element (m^3)
Q_{nm}	: Net flow rate between element n and m (m^3/s)
Q_B	: Boundary condition of flow rate to the element (m^3/s)
c	: Average concentration in the element (g/m^3)
δ_{nm}	:Net advection factor between element n and m (-)
E'_{nm}	: Mixing coefficient between element n and m (m^3/s)
S	: Reaction term (g/s)

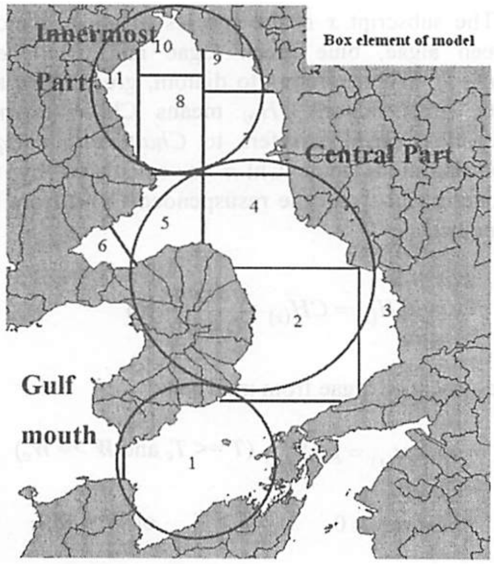

Fig.3 Divided elements and divided parts of the Ariake Sea.

The reaction terms of DIN and PO_4-P of element n are described as S_N and S_P in equations (3) and (4).

$$S_N = -\sum_{x=1}^{4} Y_{N(x)} \cdot AG_{(x)} + K_{RN} \cdot DIN_B \cdot R_M \cdot A \quad (3)$$

$$S_P = -\sum_{x=1}^{4} Y_{P(x)} \cdot AG_{(x)} + K_{RP} \cdot PO4_B \cdot R_M \cdot A \quad (4)$$

The substantial biomass change of algae (AG) is expressed in equation (5).

$$AG_{(x)} = AGgrw_{(x)} - AGdcy_{(x)} - AGsed_{(x)} - AGcon_{(x)} \quad (5)$$

Where as

Algal growth:

$$AGgrw_{(x)} = \mu_{MAX_{(x)}} \cdot T_{G_{(x)}} \cdot S_{G_{(Chat)}} \cdot \frac{DIN}{(K_{N(x)} + DIN)} \frac{PO4}{(K_{P(x)} + PO4)} \frac{I}{K_{L(x)} + I} \cdot CH_{(x)} \cdot V \quad (6)$$

The subscript x is the species of algae: diatom, green algae, blue green algae and *Chattonella antiqua*. When x refers to diatom, green algae and blue green algae, $CH_{(x)}$ means Chl-*a* (mg/m^3). However, when x refers to *Chattonella antiqua* concentration, total Chl-*a* is calculated by the existing Chl-*a* and the resuspended Chl-*a* from the mud bed as:

$$CH_{(x)} = CH_{(x)} + (\frac{AGres_{(x)}}{V}) \tag{7}$$

Resuspended algae from mud bed:

$$AGres_{(x)} = \beta \cdot SS_{RS} \quad (T =< T_c \text{ and } W >= W_c)$$

$$AGres_{(x)} = 0 \qquad (T > T_c \quad \text{or } W < W_c) \tag{8}$$

Algae decay:

$$AGdcy_{(x)} = K_{D_{(x)}} \cdot \theta_{(x)}^{(T - T_D(x))} \cdot CH_{(x)} \cdot V \tag{9}$$

Algal sedimentation:

$$AGsed_{(x)} = K_{SA(x)} \cdot CH_{(x)} \cdot V \tag{10}$$

Algal consumption by zooplankton:

$$AGcon_{(x)} = Y_{Z(x)} \cdot Zgrw \tag{11}$$

$$Zgrw = \mu_{\max(zoo)} \cdot (\frac{CH_{(x)}}{SCH_{(x)} + CH_{(x)}}) \cdot Zoo \cdot V \tag{12}$$

When

CH	: Chlorophyll-*a* (mg/m^3)
Y_N	: DIN: Chl-*a* (mg DIN/μg Chl-*a*)
Y_P	: PO_4-P: Chl-*a* (mg PO_4-P /μg Chl-*a*)
K_{RN}	: Release rate of DIN (m/d)
K_{RP}	: Release rate of PO_4-P (m/d)
DIN_B	: DIN in mud bed (g/m^3)
$PO4_B$	: PO_4-P in mud bed (g/m^3)
μ_{MAX}	: Maximum specific growth rate (1/d)
T_G	: The temperature coefficient (-)
S_G	: The salinity coefficient (-)
DIN	: Dissolved inorganic nitrogen (g/m^3)
$PO4$	: Orthophosphate phosphorus (g/m^3)
I	: Light intensity (J/cm^2-d)
K_N	: Saturation constant of DIN (g/m^3)
K_P	: Saturation constant of PO_4-P (g/m^3)
K_L	: Saturation constant light (J/cm^2-d)
β	: Coefficient regarding *Chattonella antiqua* in resuspended solids from mud bed (-)
T_c	: Critical temperature for cysts formation (°C)
W	: Wind velocity (m/s)
W_c	: Critical wind velocity for *Chattonella antiqua* cysts resuspension (m/s)
K_D	: Specific decay rate (1/d)
θ	: Temperature coefficient for decay (-)
T_D	: Critical temperature for decay (°C)
T	: Water temperature (°C)
K_{SA}	: Settling velocity of algae (m/d)
Y_Z	: Rates of algal consumption by zooplankton (μg Chl-*a*/mg Zoo)
$\mu_{max(zoo)}$	: Maximum specific growth rate of zooplankton (1/d)
Zoo	: Zooplankton biomass (g/m^3)
SCH	: Algal coefficient for zoo uptake (g/m^3)
x	: Species of algae, diatom, green algae, blue green algae and *Chattonella antiqua*

The transported term of the suspended solids (S_S) in element n is expressed in equation (13).

$$S_S = SS_{RS} - K_{SS} \cdot B_S \cdot SS \cdot A \tag{13}$$

$$SS_{RS} = (R_T \cdot K_{RT} + K_{RW}) \frac{R_M \cdot A}{D} \tag{14}$$

Where

SS	: Suspended solids (g/m^3)
SS_{RS}	: Resuspension rate (g/d)
K_{SS}	: Settling velocity of SS (m/d)
B_S	: Settling coefficient (-)
A	: Element area (m^2)
R_T	: Resuspension coefficient due to tidal movement (-)
K_{RT}	: Resuspension rate due to tidal movement (g/m-d)
K_{RW}	: Resuspension rate due to wind (g/m-d)
R_M	: Ration of mud bed area in the element (-)
D	: Water depth of the element (m)

The simulation period is from 1991 to 2004 and the time step of the model is one day. The parameters used in the developed finite volume model obtained from the calibration are listed in **Table 1**.

Table 1 Parameters used in the two-dimensional finite volume model of the Ariake Sea.

	parameter	unit
μ_{max}	0.34/ 0.3/ 0.32/ 0.95*	1/d
K_N	0.07/ 0.05/ 0.05/0.03*	g/m^3
K_P	0.01/0.01/0.02/0.006*	g/m^3
K_D	0.01/0.005/0.005/0.003*	1/d
θ	0.014/0.014/0.016/0.014 *	-
T_D	19/ 24/ 30/ 27.5*	°C
K_{SS}	0.1	m/d
K_{SA}	0.1/ 0.1/ 0.1/ 0.85*	m/d
K_{RN}	0.05	m/d
K_{RP}	0.02	m/d
Y_N	0.02/0.02/0.02/0.035*	mg DIN/µg Chl-*a*
Y_P	0.0012	mg PO4-P/µg Chl-*a*
$\mu_{max(zoo)}$	0.1	1/d
Y_Z	0.05/0.05/0.05/0.05*	µg Chl-*a*/mg Zoo
SCH	0.2/0.2/0.2/0.2*	g/m^3
K_L	419/ 419/419/ 419*	J/cm^2-day
β	0.05	(-)

Note: * Diatom/ Green algae/ Blue green algae/ *Chattonella antiqua*

4. SENSITIVITY ANALYSIS

The conditions for *Chattonella antiqua* cysts formation is analyzed through sensitive analysis. In this sensitivity analysis, the developed model regarding to the effect of temperature on the cysts formation is taken into account. In order to get the suitable temperature for the cysts formation, various critical water temperatures are examined. The sensitivity analysis reveals that *Chattonella antiqua* cysts in the Ariake Sea are formed during winter when water temperature is lower than 11 °C.

Figure 4 shows an outline of an effect of critical temperature on cyst formation. When the critical temperature is higher than 11 °C, *Chattonella antiqua* cyst can be formed, and blooming of *Chattonella antiqua* can occur in every year because temperature already reaches the critical. On the other hand, when the critical temperature is lower than 11 °C, *Chattonella antiqua* cannot form the cyst and finally blooming of *Chattonella antiqua* does not occur.

These results verify that the developed water model have an efficiency to evaluate the critical temperature for the *Chattonella antiqua* cysts formation. In **Fig.4**, *Chattonella antiqua* simulation results occur during 1992 and 1998. However, during 1991, 1997, 2002 and 2004, the simulated results of *Chattonella antiqua* appear although there are no *Chattonella antiqua* bloom events in the observed data. To improve the model, other parameters for algal growth should be examined more in detail.

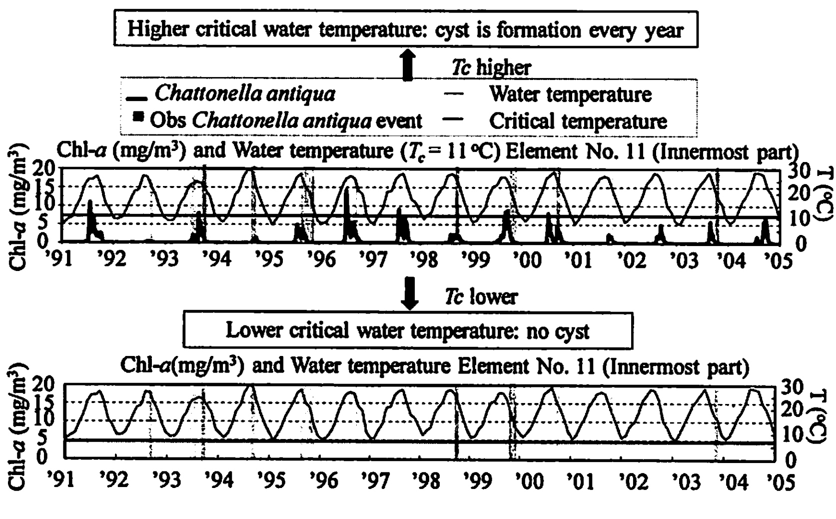

Fig.4 Simulation result of *Chattonella antiqua* in the innermost part (cysts formation in various critical temperatures).

The salinity concentrations for *Chattonella antiqua* growth are taken into consideration to simulate the better agreement with observed data. Comparison of simulated results between without and with salinity limiting factor are shown in **Fig.5.** It can be seen that during 1997 and 2002, simulated results with salinity limiting factor have better agreement with observed data.

The limiting coefficient of salinity concentration obtained from calibration results is presented in **Fig.6.** The coefficient of salinity range in the developed model for *Chattonella antiqua* growth is from 27 to 31.1 psu[14), 15)].

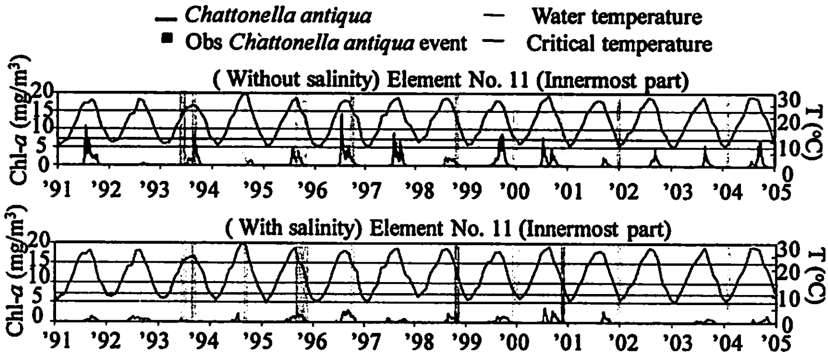

Fig.5 Simulation result of *Chattonella antiqua* without and with salinity concern.

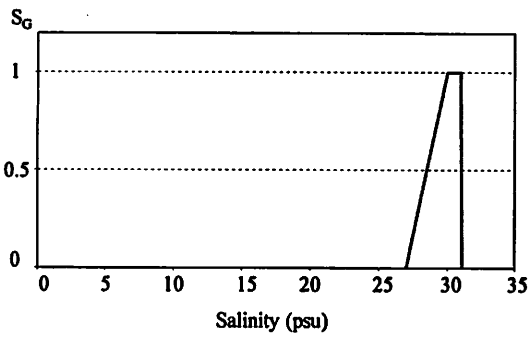

Fig.6 Coefficients of salinity for *Chattonella antiqua* growth.

The simulation results of *Chattonella antiqua* in the gulf mouth zone, the central part, and the innermost part are shown in **Fig.7**, respectively. After applying the limiting factor of the salinity for the *Chattonella antiqua* growth, the concentration of *Chattonella antiqua* is lowered because *Chattonella antiqua* growth rate is decreased by the salinity control. In fact, the observed data on the Chl-*a* concentration of *Chattonella antiqua* is not observed because only the periods of *Chattonella antiqua* bloom event are recorded[16)].

The better agreement between simulation results and observed data are obtained by considering the influence of the salinity. Specifically the simulation results of the *Chattonella antiqua* bloom events during summer 1997 and 2002 almost disappear. From these simulation results, it is suggested that the salinity concentration influences on the growth rate of *Chattonella antiqua*.

For element 1 and 5 in the gulf mouth zone and the central part, the simulation results of *Chattonella antiqua* bloom events occur in the same periods with element 11 although the field data are not observed. This phenomenon happens due to effect of the advection and the dispersion in the water quality model. The space scale of each element in this water quality model is large while numbers of the observation points are few. Therefore, the observation points do not always cover the whole area of the Ariake Sea.

The final calibration results on total Chl-*a* in the gulf mouth zone, the central part, and the innermost part are shown in **Fig.8.** The temperature coefficient for algal productivity in the Ariake Sea obtained from the developed model is illustrated in **Fig.9.** Diatoms are predominant during winter while green algae and blue green algae are predominant from spring until summer period. The temperature for *Chattonella antiqua* growth obtained from the developed model is from 20 to 27.5 °C. In **Fig.8**, the simulation results of Chl-*a* in element 11 of the innermost shows higher concentration because of high discharged nutrients from the Chikugo River watershed and mud bed. The simulation results of *Chattonella antiqua* reveal that high concentration of Chl-*a* appear at the same time when high SS concentration occurs which is shown in **Fig.10.** Consequently, the occurrences of *Chattonella antiqua* can be triggered by the high SS concentration after the high resuspended period. Furthermore, the simulated Chl-*a* are happened at almost the same time with the observed periods of *Chattonella antiqua* bloom.

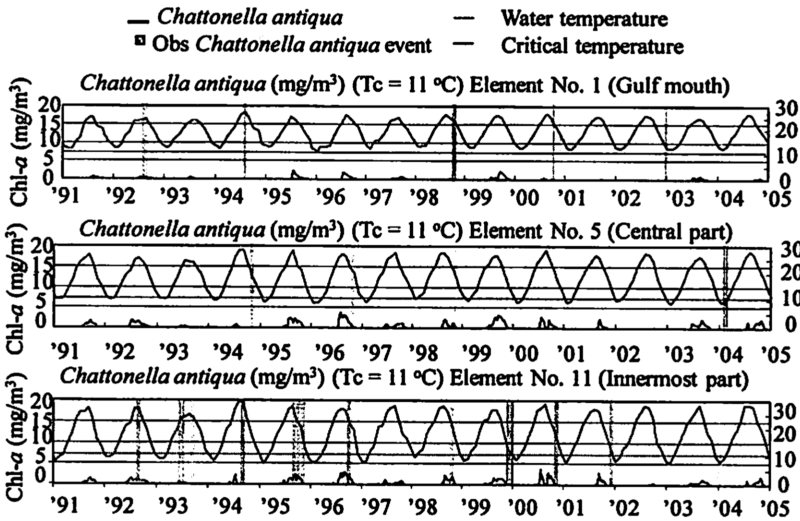

Fig.7 Simulation result of *Chattonella antiqua* in the gulf mouth zone, the central part, and the innermost part after the salinity concentration is taken into account for the *Chattonella antiqua* growth.

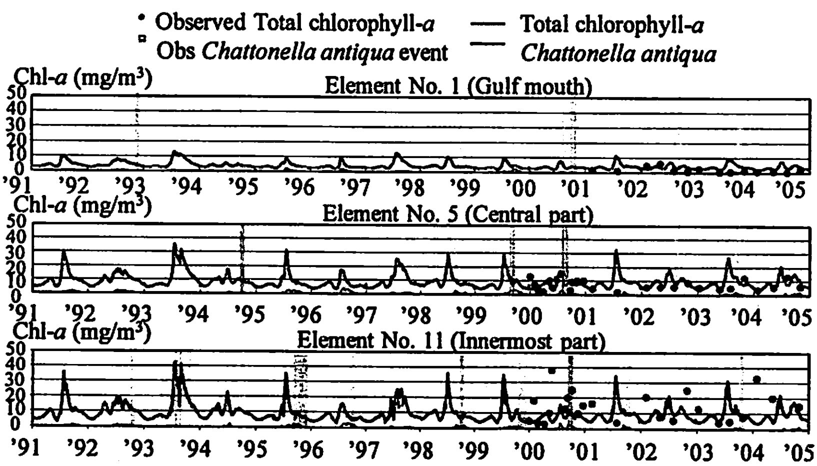

Fig.8 Chlorophyll-*a* concentration in the gulf mouth, the central part, and the innermost part of the Ariake Sea.

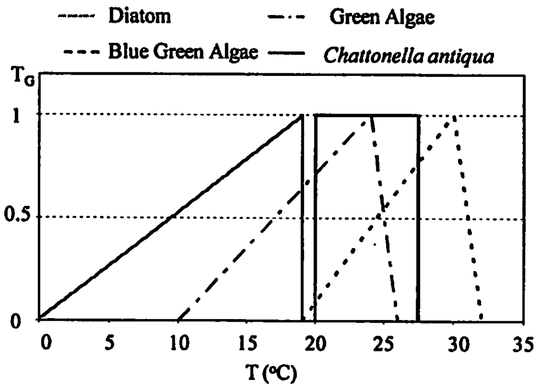

Fig.9 Coefficients of temperature for each algae growth.

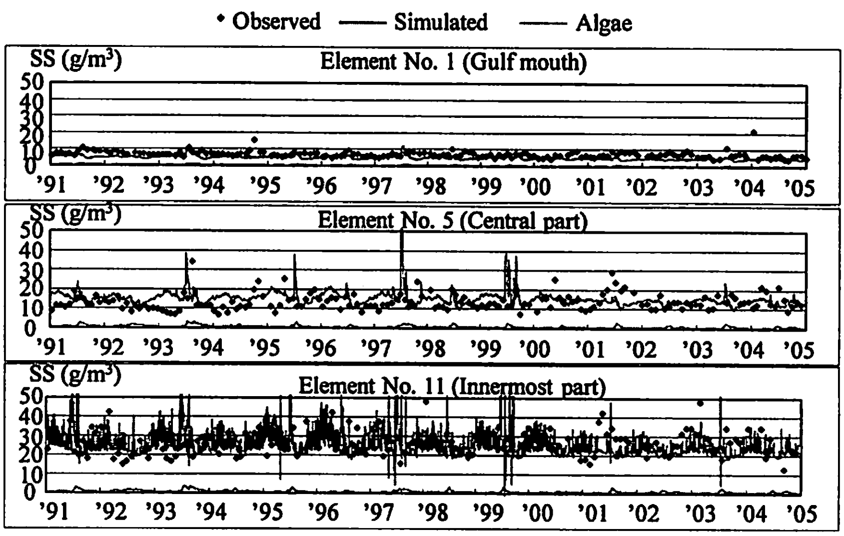

Fig.10 Suspended solids concentration in the gulf mouth, the central part, and the innermost part of the Ariake Sea.

Concentration of DIN and PO_4-P in gulf mouth, central part and innermost part are shown in **Figs.11** and **12**, respectively. Both of DIN and PO_4-P are lower in gulf mouth zone because nutrients in this area are diluted by seawater from the open sea. Simulation results of DIN in the innermost part are higher than in the central part because of high discharged loading from the Chikugo River watershed and other watersheds. Low concentration of simulated DIN and observed data in the central part mean the discharged loading from the surround watersheds slightly affects on DIN in the Ariake Sea except rainy season. For PO_4-P, simulation results in central part and innermost part are high in rainy period because of discharge loading from watershed. However, during summer and period of low discharge loading from land area, PO_4-P is still high. It is caused by the release process from the mud bed. It can be said that orthophosphate for algal production is rich. As the result, it is found that inorganic nitrogen is the growth-limiting factor for algae in the Ariake Sea. During summer season, nutrients are released from mud bed at high rate.

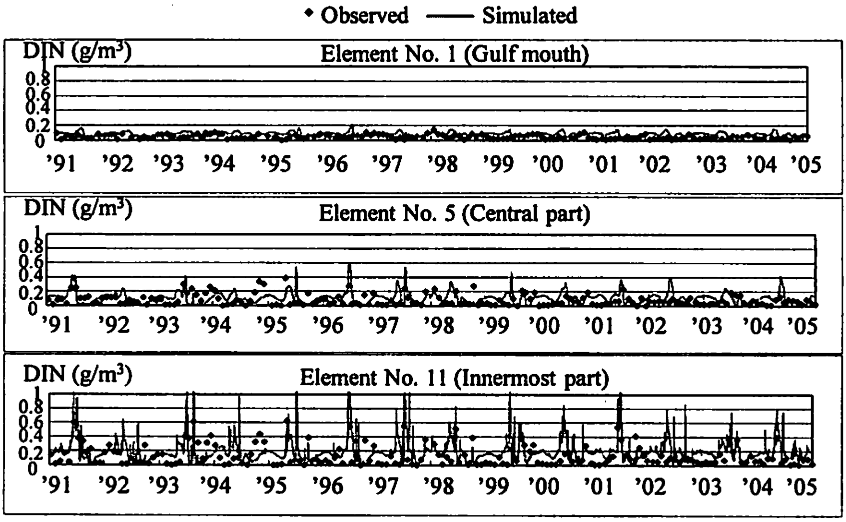

Fig.11 Dissolved inorganic nitrogen concentration in the gulf mouth, the central part, and the innermost part of the Ariake Sea.

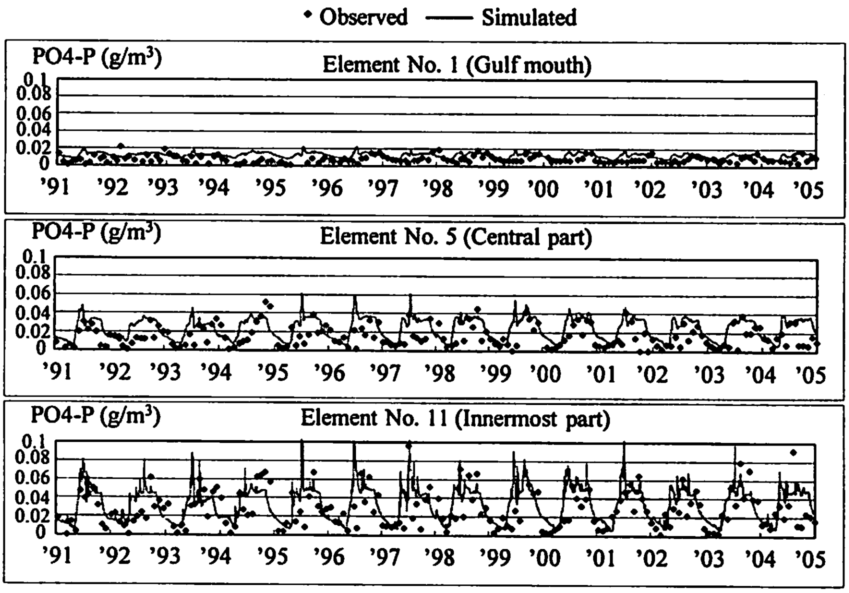

Fig.12 Orthophosphate phosphorus concentration in the gulf mouth, the central part, and the innermost part of the Ariake Sea.

5. CONCLUSION

In this study, the simulation on *Chattonella antiqua* growth is carried out. It is concluded that resuspended solids from mud bed is the primary cause of *Chattonella antiqua* blooming events in the Ariake Sea. The mechanisms for *Chattonella antiqua* cyst formation is analyzed through sensitive analysis. It can be concluded that *Chattonella antiqua* cysts in the Ariake Sea are formed during winter when water temperature is lower than 11 °C. During strong wind, *Chattonella antiqua* cysts are resuspended to water column with suspended solids. In summer when water temperature is between 20 and 27.5 °C, *Chattonella antiqua* can be germinated, and finally *Chattonella antiqua* bloom event occurs. Moreover, the developed model indicates that salinity concentration is a limiting factor for the growth of *Chattonella antiqua*. The suitable salinity range for *Chattonella antiqua* growth is from 27 to 31 psu.

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REFERENCES

1) Ittisukananth, P., Koga, K., Vongthanasunthorn, N., Liengcharernsit, W. : Study on water quality and *Chattonella* in the Ariake Sea using water quality model, *The reports of the faculty of science and engineering Saga University*, Vol. 36, No. 1, pp.53-58, 2007.
2) Okaichi, T. : Red tides, Ocean Science Research, Terra Scientific Publishing Company, Tokyo Kluwer, Academic Publishers, Dordrecht, London, Boston , Vol. 4, pp. 7-329, 2004.
3) Hoek, C. Van Den, D. G. Mann and H. M. Jahns. : Algae, an Introduction to Phycology, *Cambridge Univ. Press* . 623, 1995.
4) Yasuwo F. : Red tides, Biological character of red-tide organisms part, Ocean Science Research, Terra Scientific Publishing Company, Tokyo Kluwer Academic Publishers, Dordrecht, London, Boston, Vol. 4, pp. 61-64 , 2004.
5) Nakamura, Y. and Watanabe, M. : Growth character of *Chattonella antiqua* Part 2, Effect of nutrients on growth, *Rep. J. Oceanogr. Soc. Japan.* Vol. 39, pp. 151-155, 1983.
6) Nagasaki Prefectural Institute of Fisheries : Growth condition of harmful algae and red tide, *Chattonella ovata*, in Nagasaki Sea Area, 2008. *(in Japanese)* *http://www.marinelabo.nagasaki.nagasaki.jp/akasio%20ovata.pdf*
7) Dale, B. : Dinoflagetlate resting cysts, benthic plankton, In Fryxell, G. A. (ed.), Survival strategies of algae, Cambridge University Press, Cambridge, pp. 69-136, 1983.
8) Imai, I. : Annual life cycle of *Chattonella spp.*, causative flagellates of noxious red tides in the Inland Sea of Japan, *Journal Marine Biology*, Vol. 94, No. 2, 1987.
9) Imai, I. and Itoh, K. : Cysts of *Chattonella antiqua and C. marina* (Raphidophyceae) in sediments of the Inland Sea of Japan. Bull. *Plankton Soc. Japan*, Vol. 35, pp. 35-44, 1988.
10) Yamaguchi M., and Honjo, T. : Effects of temperature, salinity and irradiance on the growth of the noxious red tide flagellate Gymnodinium nagasakiense (Dinophyceae), *Nippon Suisan Gakkaishi*, Vol. 55, pp. 2029-2036, 1989. (*in Japanese, with English abstract*).
11) Imai, I. and Itoh, K. : Annual life cycle of *Chattonella spp.*, causative flagellates of noxious red tides in the Inland Sea of Japan. *Mar Biol*, Vol. 94, pp. 287-292, 1987.
12)Rich, L.G. : Environmental system engineering, McGraw-Hill, pp.113-114, pp. 139-141, 1973.
13) Vongthanasunthorn, N. : Integrated water quality analysis for water management in the Chikugo basin and the Ariake Sea. Graduated School of Science and Engineering Saga University, 2004.
14) Mary, A. Tiffany, Steven B. Barlow, Victoria E. Matey and Stuart H. Hurlbert : *Chattonella marina* (raphidophyceae), a potentially toxic alga in the Salton Sea, California, *Hydrobiologia*, Vol. 466, No.1-3, pp. 187-194, 2001.
15) Kagoshima Prefectural Institute of Fisheries : Red tides information, 2002. *(in Japanese)* http://www.minc.ne.jp/suishi/page059.html
16) Fisheries Agency : The red tide in Kyushu area. 2006. *(in Japanese)*