Biological characteristics of the red tide causing raphidophytes Heterosigma akashiwo *and* Chattonella *spp. in the coastal Sea of Japan*

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Contents

Chattonella

- 1. Taxonomy, distribution
- 2. Ecophysiology
- 3. Life cycle
- 4. Bloom dynamics

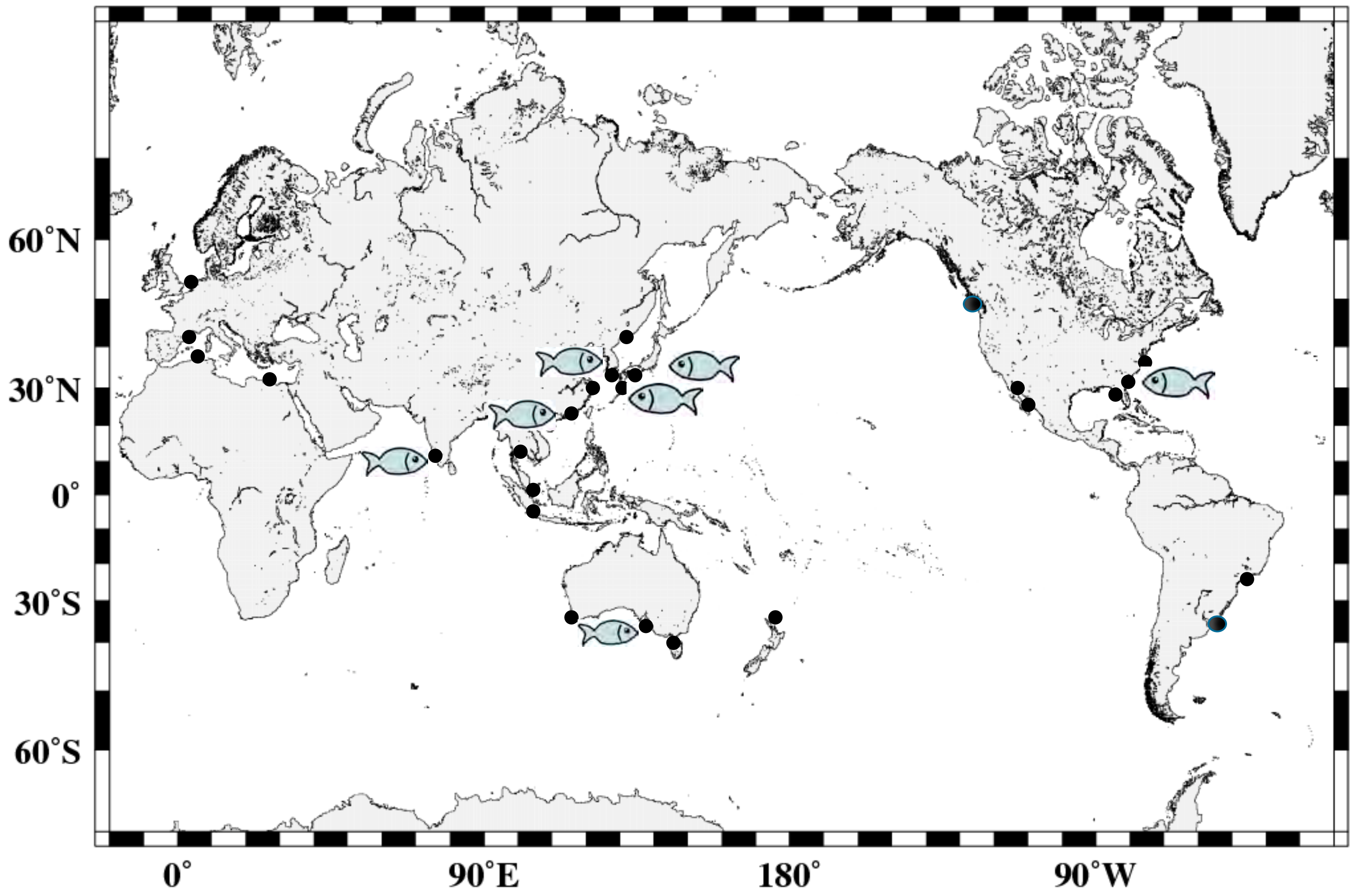
Heterosigma

- 1. Life cycle strategy
- 2. Bloom dynamics
- 3. Toxicity

ICHA Copenhagen
Ice breaker にて（Sep 2006)
With Skeleton of Little Mermaid

Global distribution of *Chattonella*

(Imai & Yamaguchi 2012)



Mass mortality of yellowtail
by *Chattonella* red tide
in Yatsushiro Sea,
(by H. Matsuo)

Former species of *Chattonella*

(Hallegraeff & Hara 1995)

1. *C. antiqua*
2. *C. ovata*
3. *C. marina*
4. *C. subsalsa*
5. *C. minima*

6. *C. verruculosa* (*Pseudochattonella verruculosa*)

7. *C. globosa* (*Vicicitus globosus*)

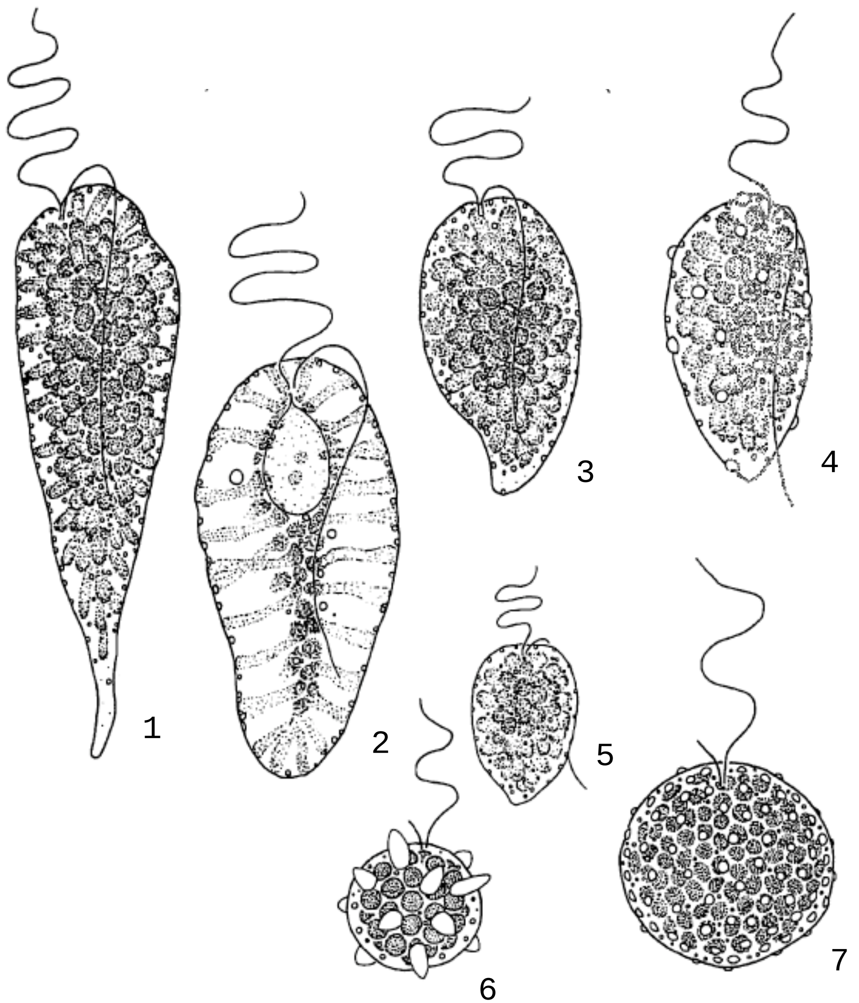
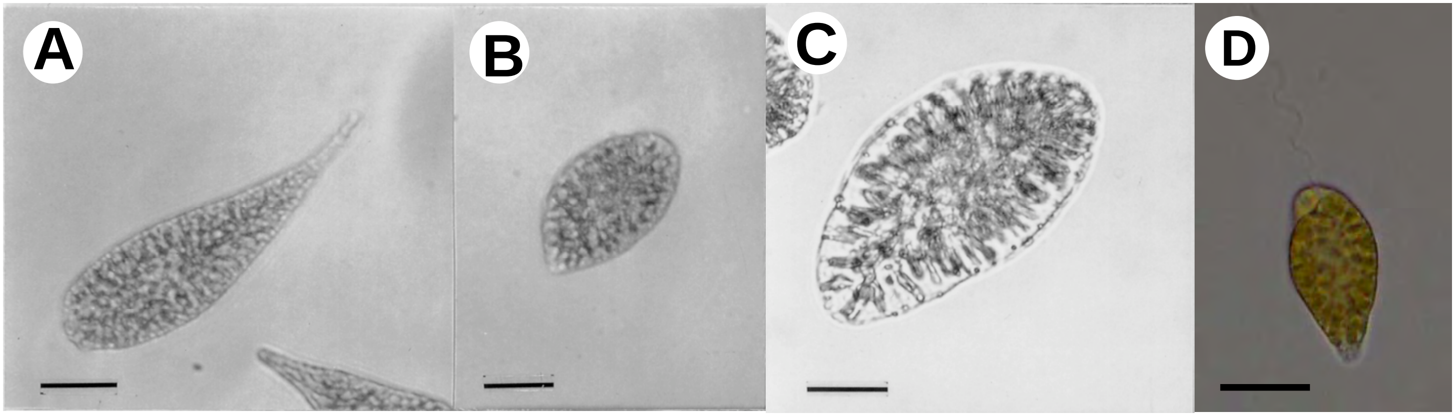


Fig. 2

Chattonella species at present
(Imai & Yamaguchi 2012)

A. Chattonella antiqua
B. C. marina
C. C. ovata
D. C. subsalsa



Demura et al. (2009) proposed a taxonomic revision of *Chattonella antiqua*, *C. marina* and *C. ovata.* These species are the varieties of *Chattonella marina.*

Phylogeny of raphidophytes (Yamaguchi et al. 2010)

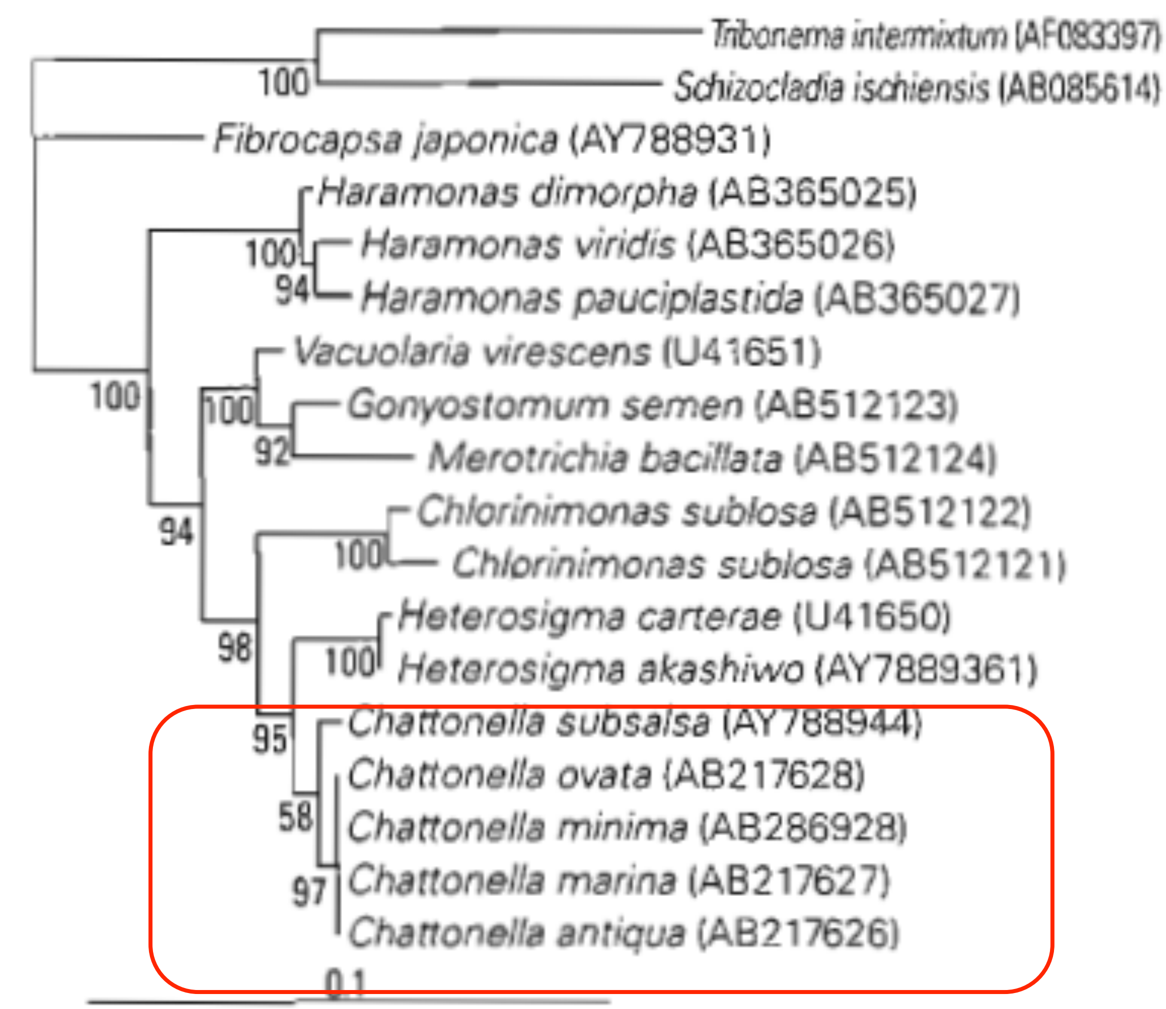


図4　SSU rDNA解析により最尤法で描かれたラフィド藻の分子系統樹[26)]

Effects of irradiance on the growth.

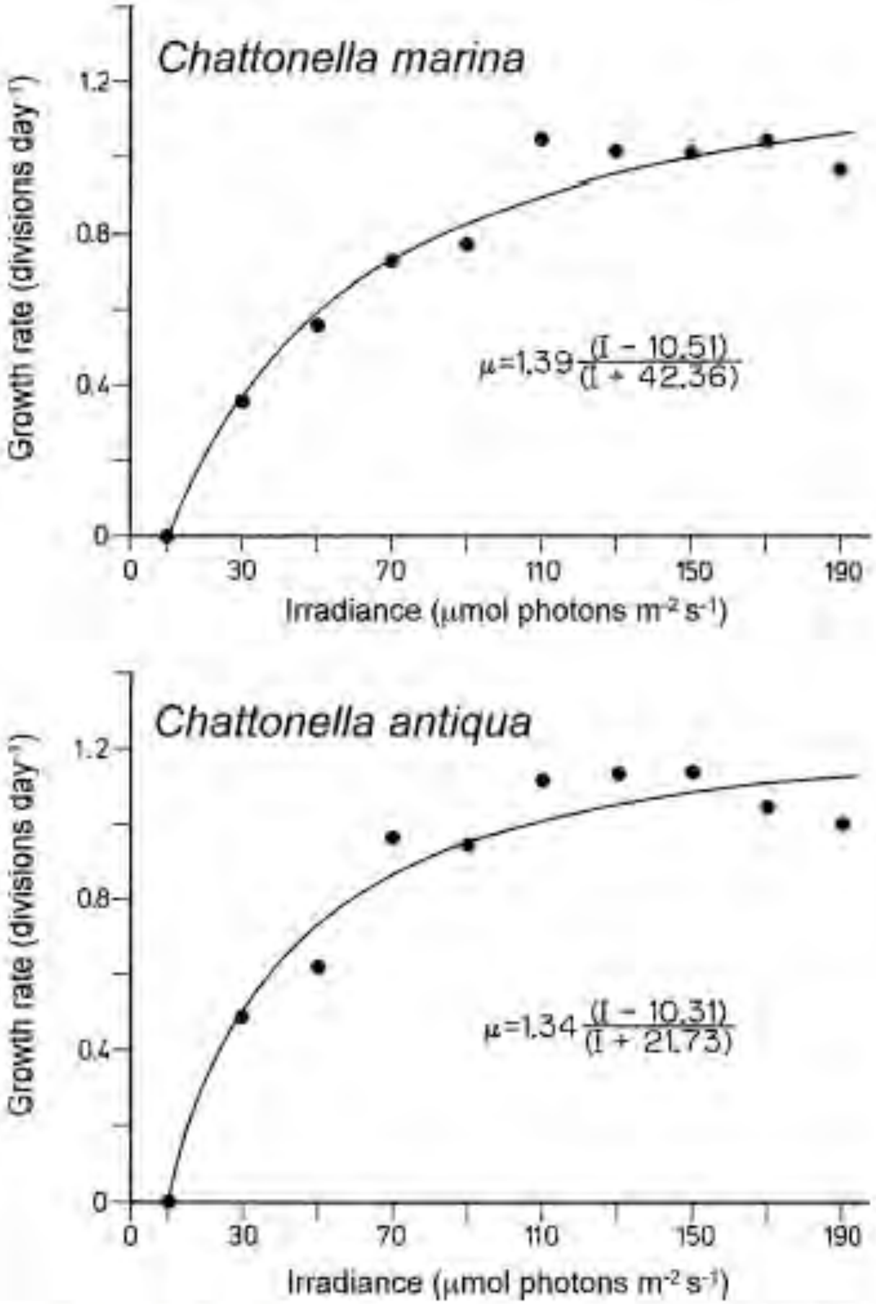


Fig. 4. Growth rates of *Chattonella marina* and *C. antiqua* as a function of irradiance. After Yamaguchi et al. (1991).

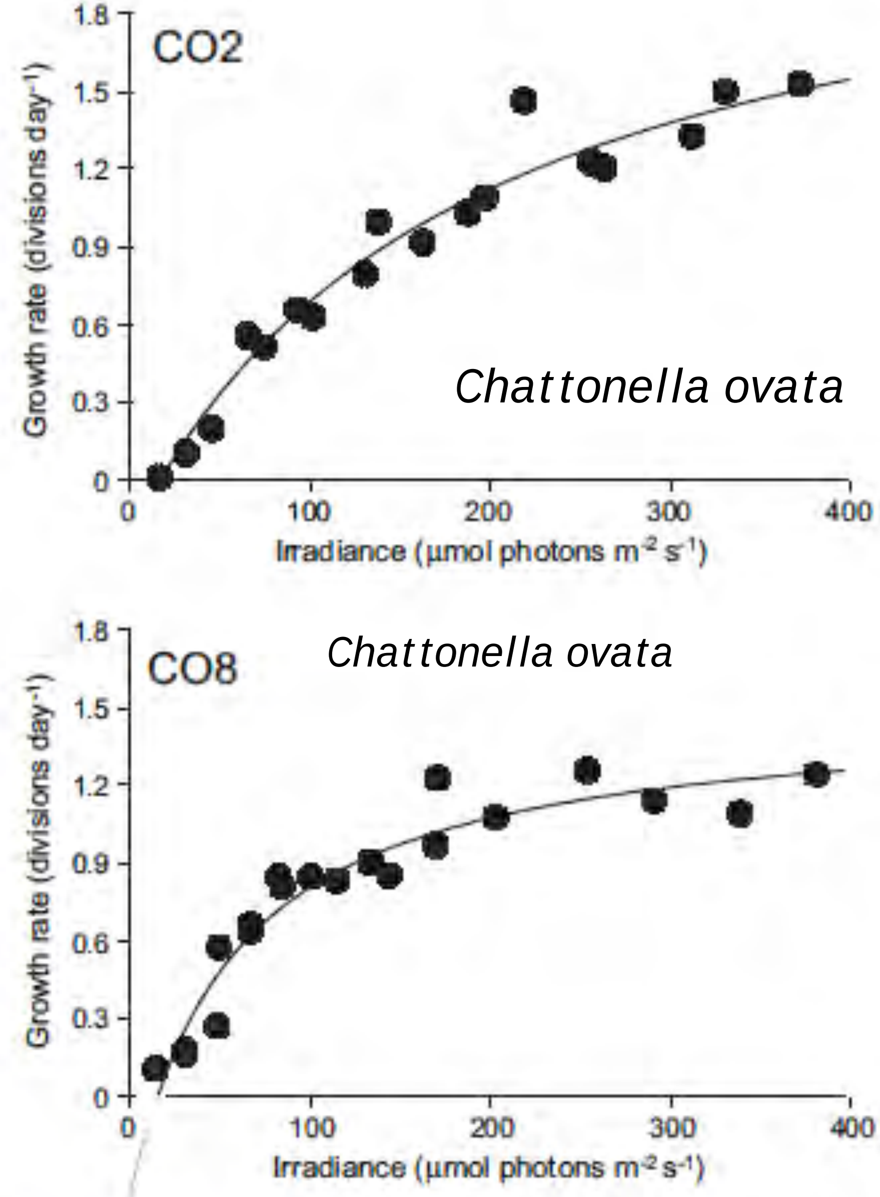
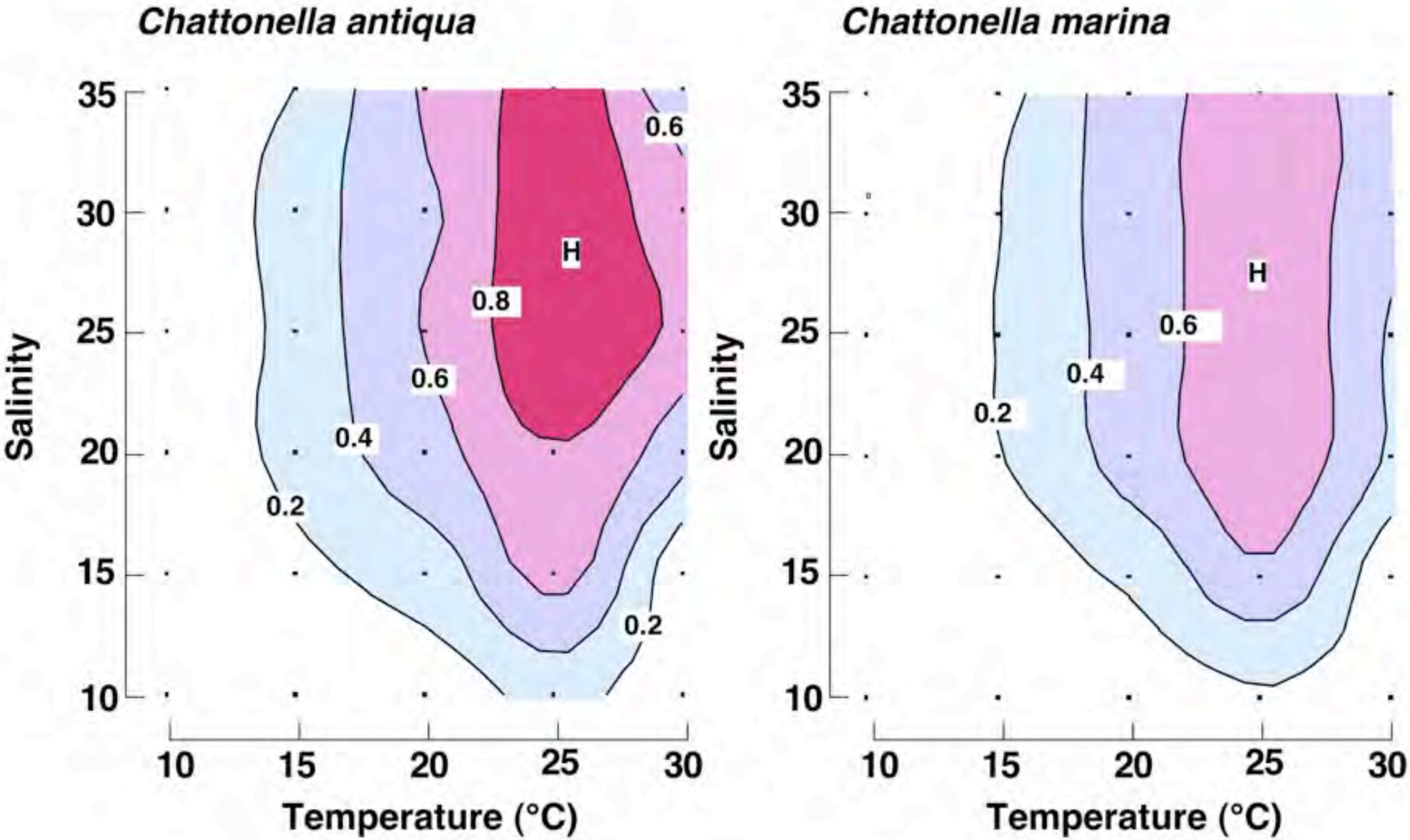


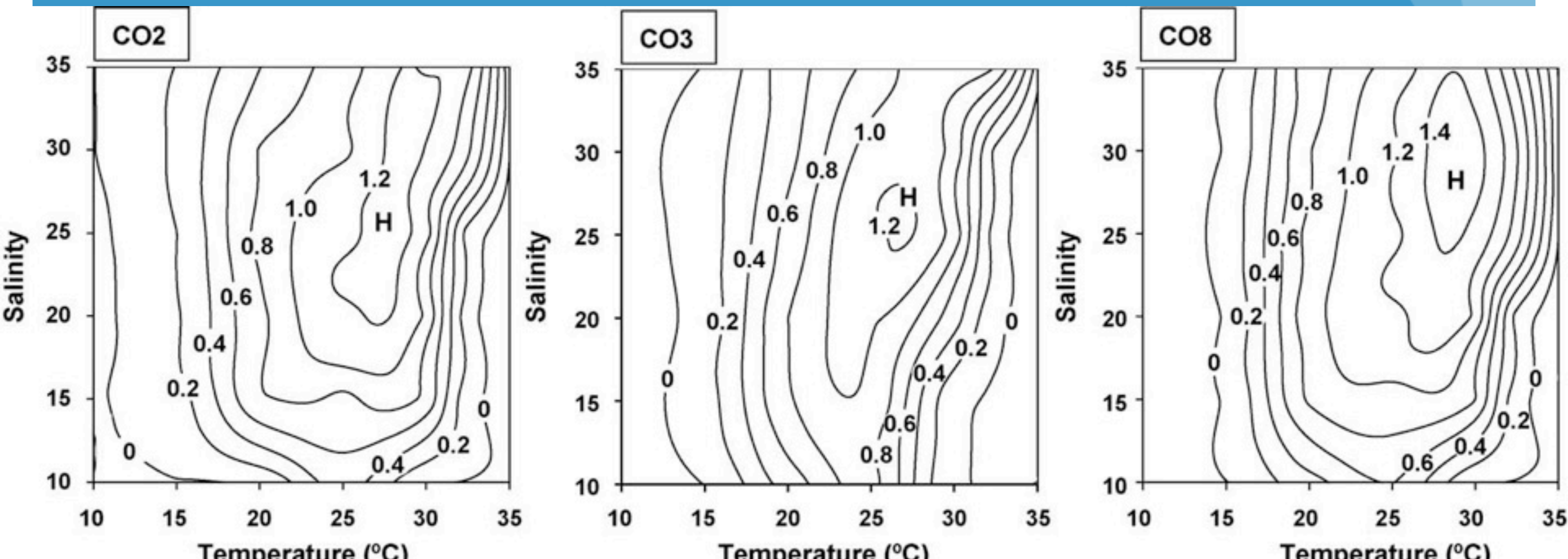
Fig. 5. Effect of irradiance on growth of *Chattonella ovata* (strains CO2 and CO8). After Yamaguchi et al. (2010).

Effects of temperature and salinity on the growth of *C. antiqua* and *C. marina* (Yamagchi et al 1991)



Effects of temperature and salinity on the growth of *Chattonella ovata* (Yamaguchi H et al. 2010)

Optimum temperature of 27.5°C for *C. ovata* was higher than that of 25°C for *C. antiqua* and *C. marina* の 25 °C.



Parameters of nutrients for *Chattonella*

Table 2
Kinetic constants for growth of *Chattonella antiqua*, *C. ovata* and *C. subsalasa*. Data are from Nakamura (1985), Nakamura et al. (1988), Zhang et al. (2006), and Yamaguchi et al. (2008a). μ_{max}, maximal growth rate; K_s, half saturation constant; q_0, minimum cell quota; ND, no data.

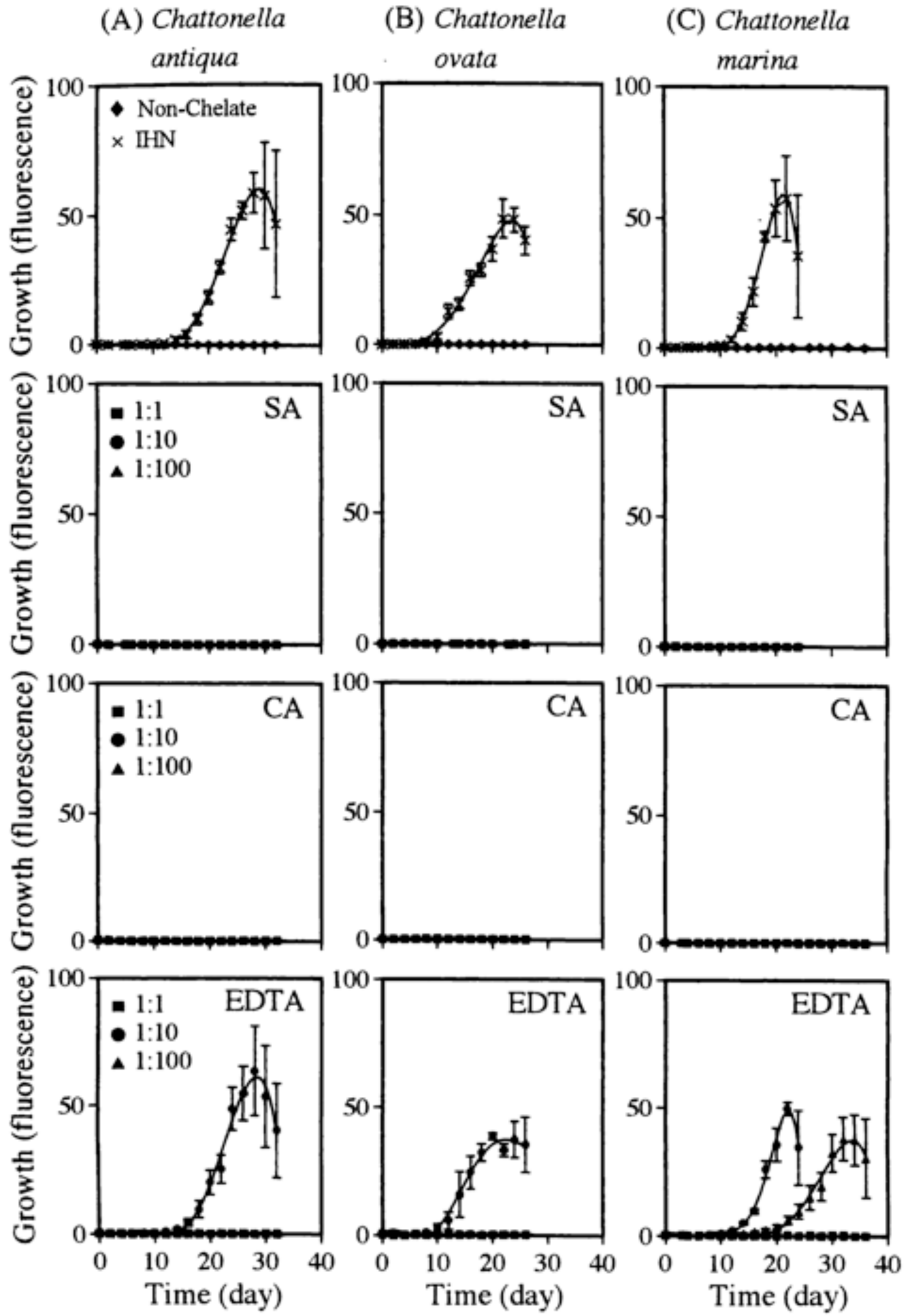
	PO_4^{3-}	NO_3^-	NH_4^+
C. antiqua			
μ_{max} (divisions day^{-1})	1.41	1.41	1.07
K_s (μM)	0.11	1.00	0.23
q_0 (pmol)	0.62	7.8	7.7
C. ovata			
μ_{max} (divisions day^{-1})	1.25	1.14	ND
K_s (μM)	ND	ND	ND
q_0 (pmol)	0.48	5.5	ND
C. subsalsa			
μ_{max} (divisions day^{-1})	0.81	0.87	0.84
K_s (μM)	0.84	8.98	1.46
q_0 (pmol)	ND	ND	ND

Iron utilization of *Chattonella*

(Naito et al. 2005)

Investigation was done by using of a chemically defined artificial medium, IHN-Medium.

Organic matters have not been studied yet.



Diurnal vertical migration of *Chattonella* observed in a mesocosm in the Seto Inland Sea during the summer of 1989.

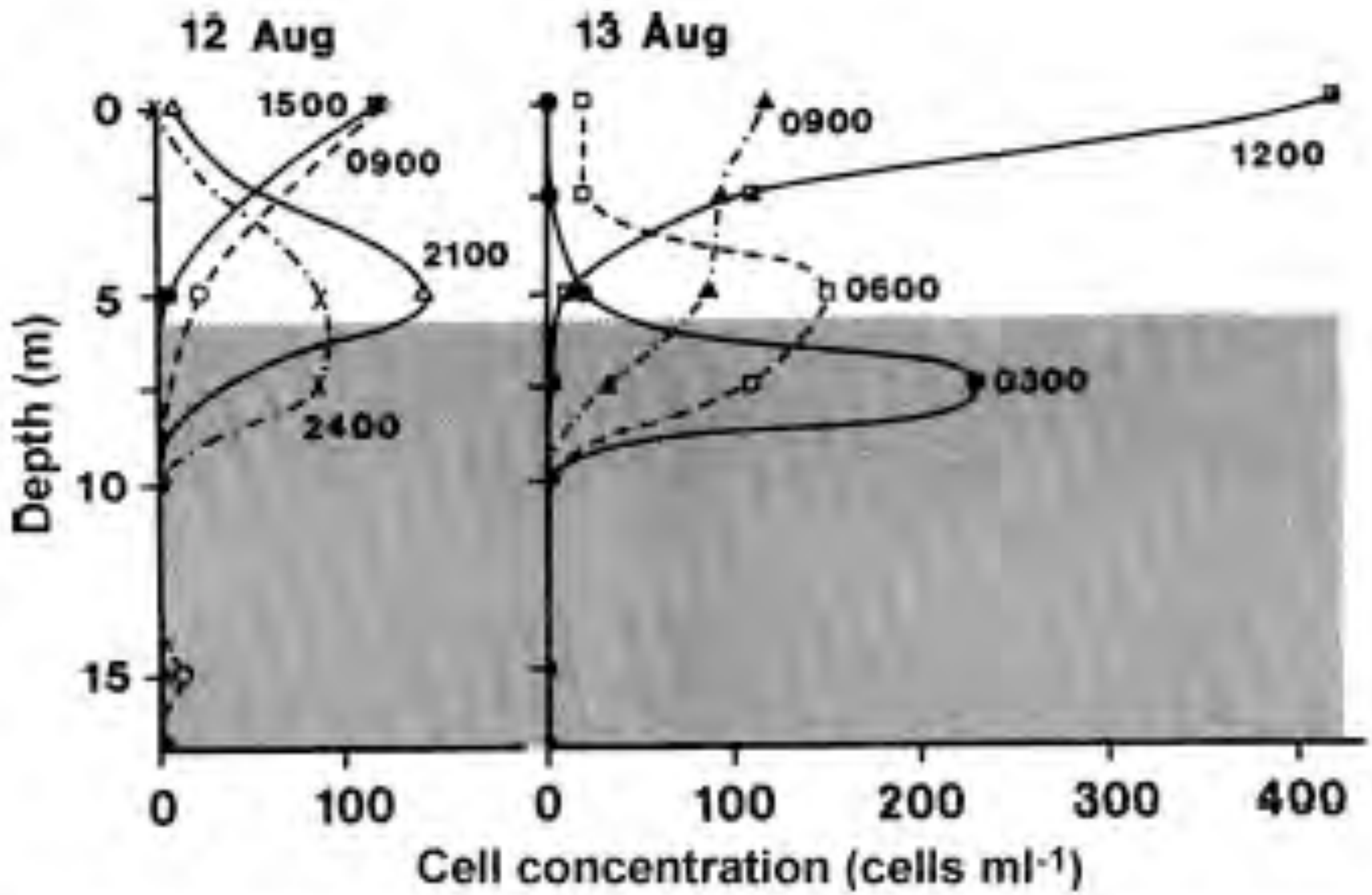


Fig. 11. Diel vertical migration of *Chattonella antiqua* observed in the mesocosm between 12 and 13 August 1989. Artificial nutrient enrichment was conducted in the shaded zone (6–18 m).
After Watanabe et al. (1995).

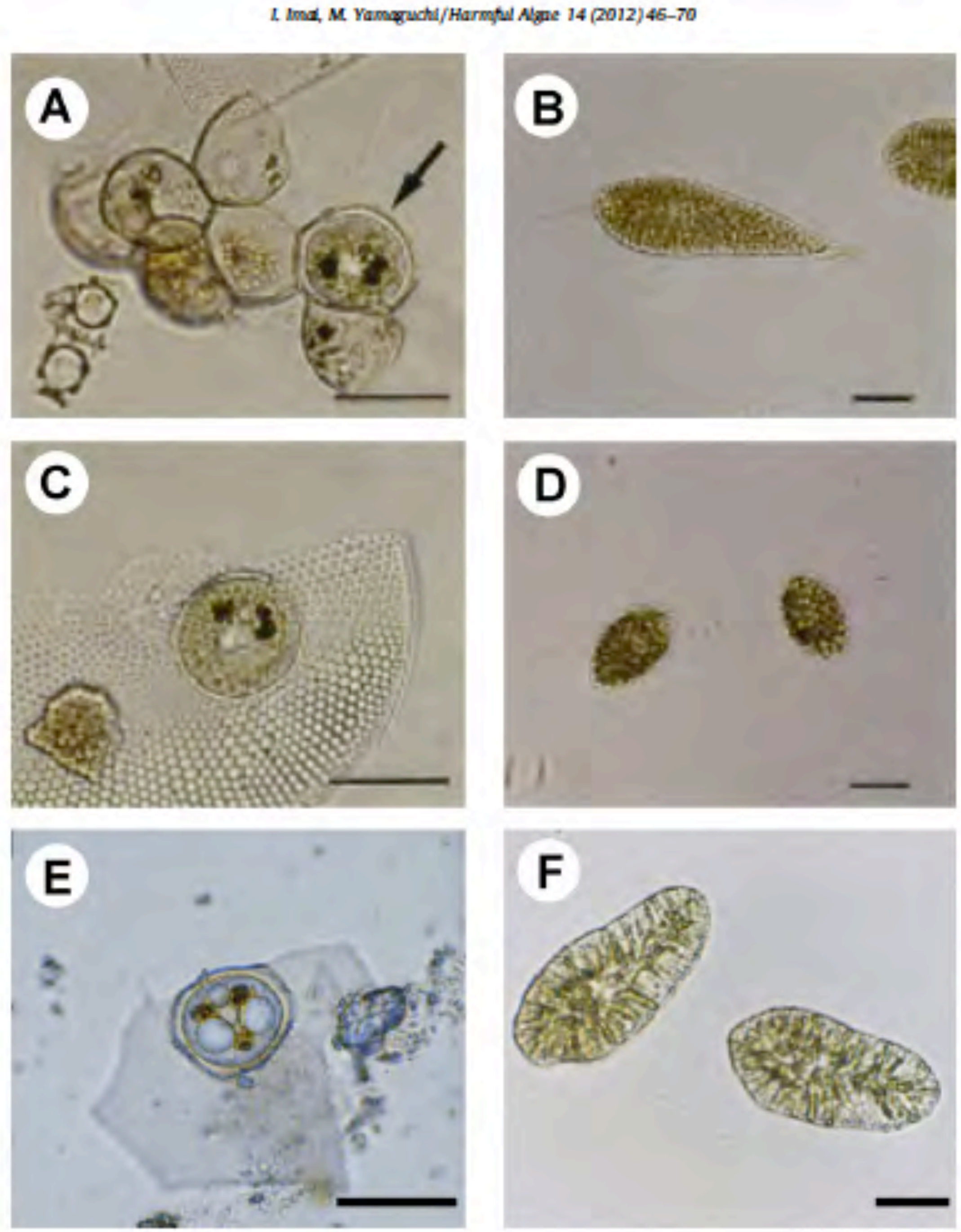
Chattonella cysts

(Imai & Yamaguchi 2012,
Imai & Itoh 1988,
Yamaguchi et al. 2008)

A, B: *C. antiqua*

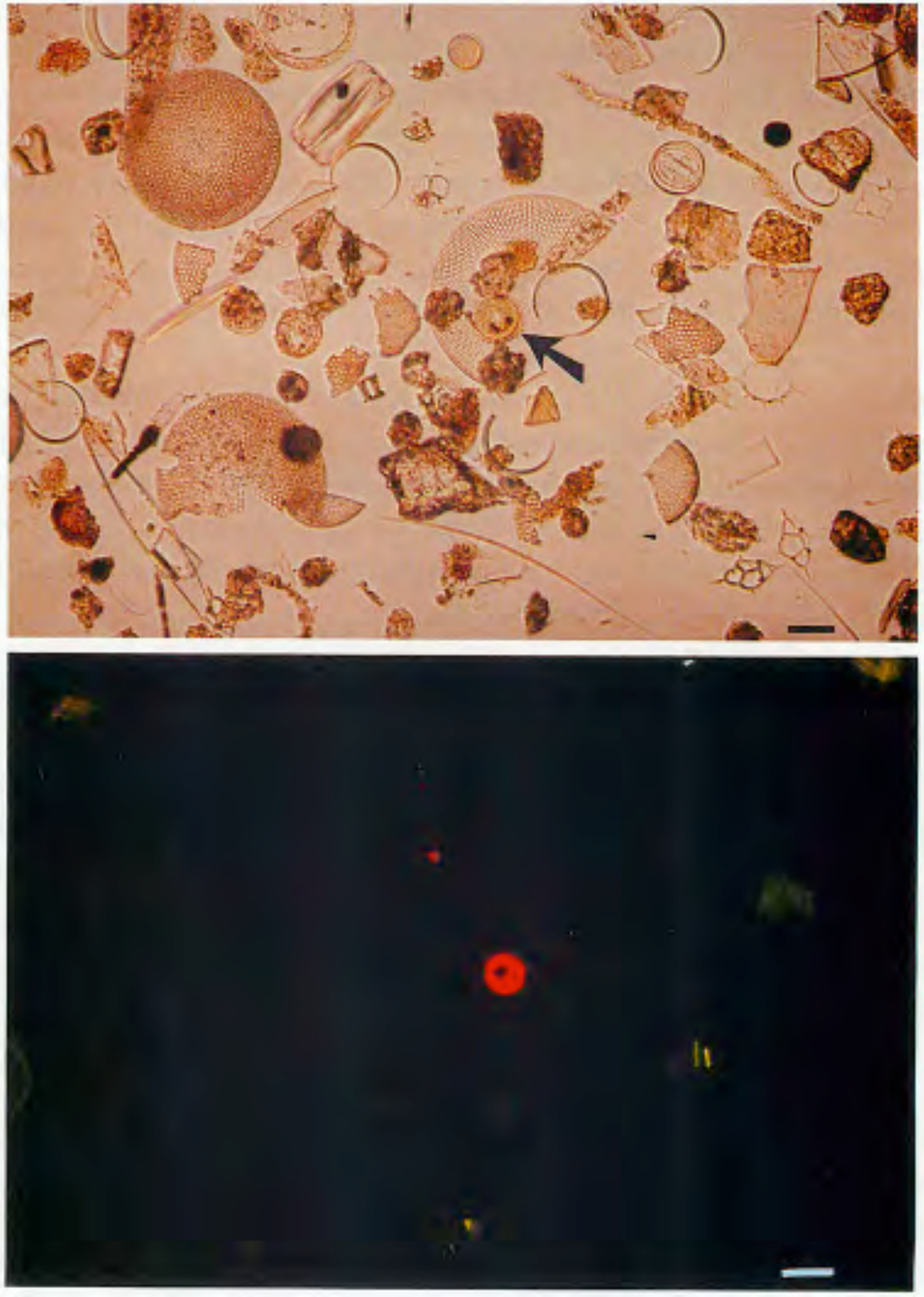
C, D: *C. marina*

E, F: *C. ovata*

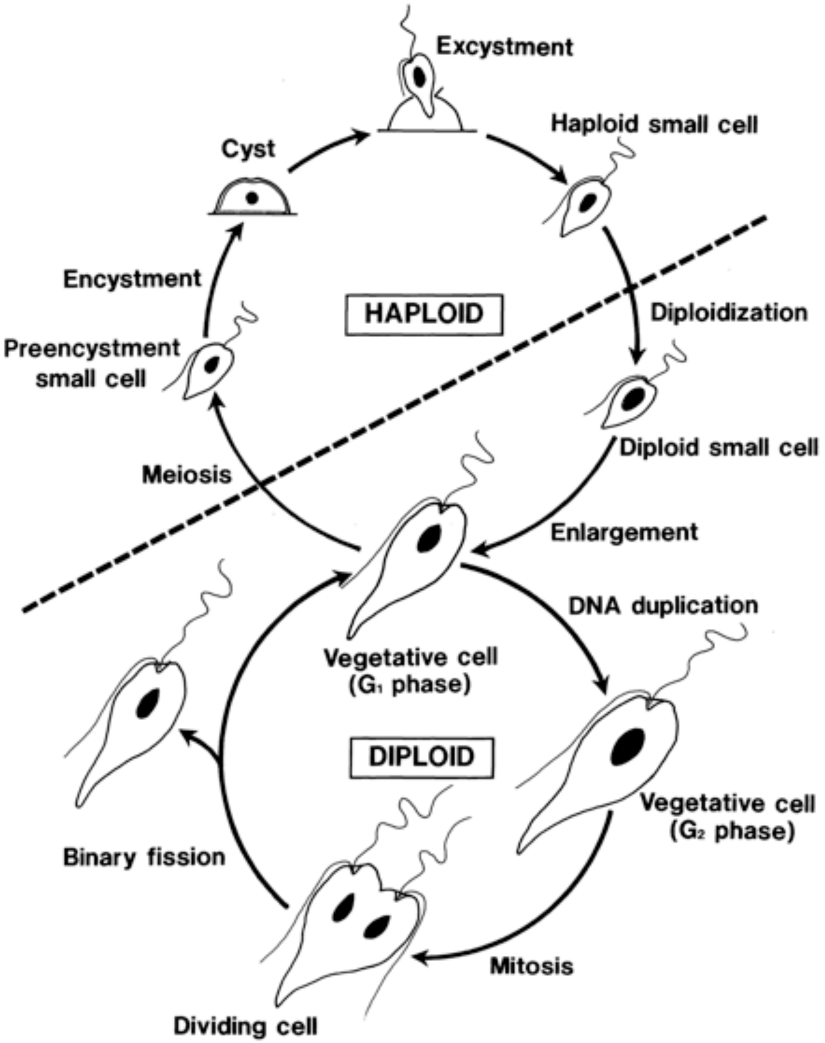


Cysts can be directly enumerated on the basis of auto fluorescence under the observation of blue light excitation using epifluorescence microscope (Imai 1990)

Cyst distribution map can be obtained for the red tide areas.



Microfluorometeric analyses were done for *Chattonella* cells at each process in the life cycle of *Chattonella*

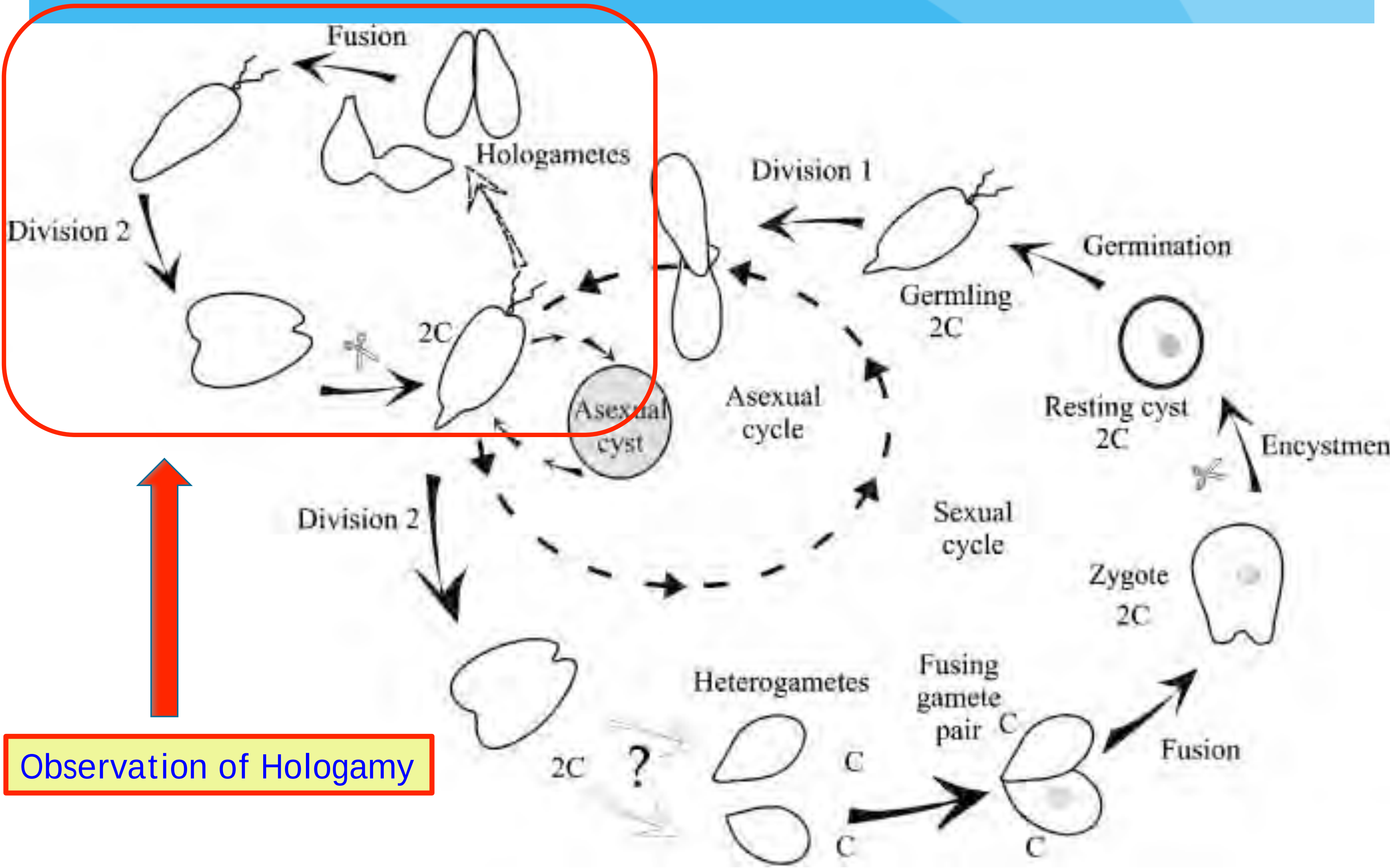


Life cycle of Chattonella

(Yamaguchi & Imai 1994)

Chattonella spp. are diplonts.

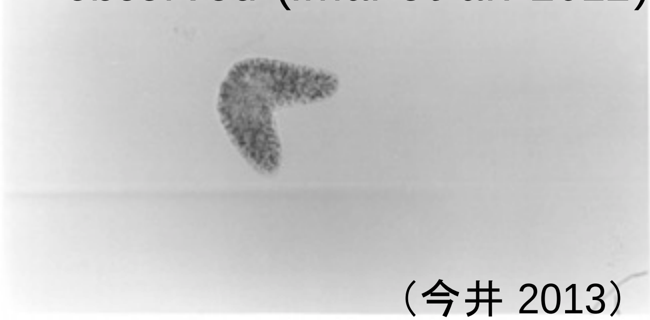
Life cycle of *Gonyostomum semen* (Figueroa & Rengefors 2006)



Observation of Hologamy

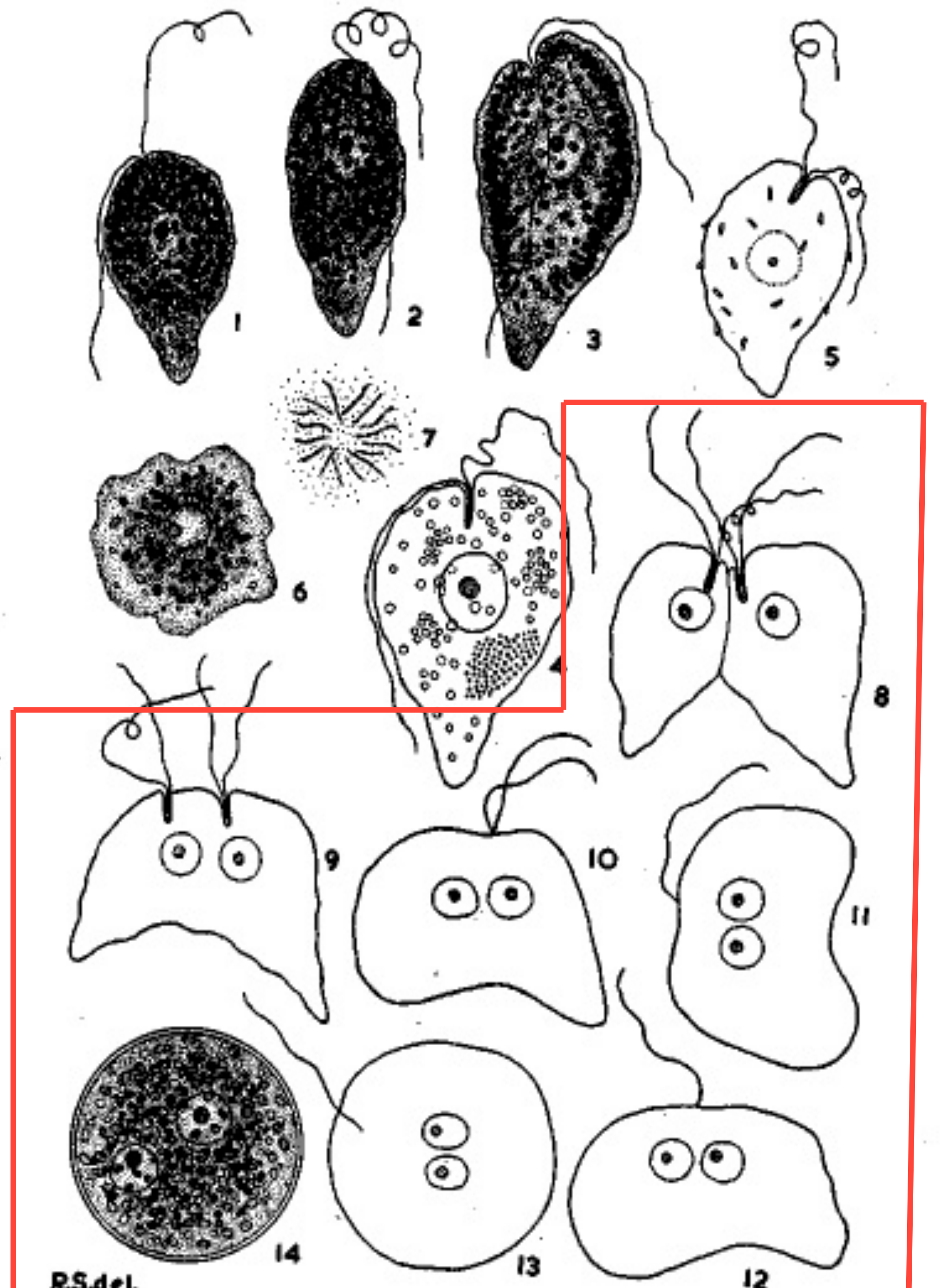
Subrahmanyan (1954) observed *C. marina in details*. Fusion of vegetative cells were observed.

Fusion of *C. marina was observed* (*Imai et al. 2012*)

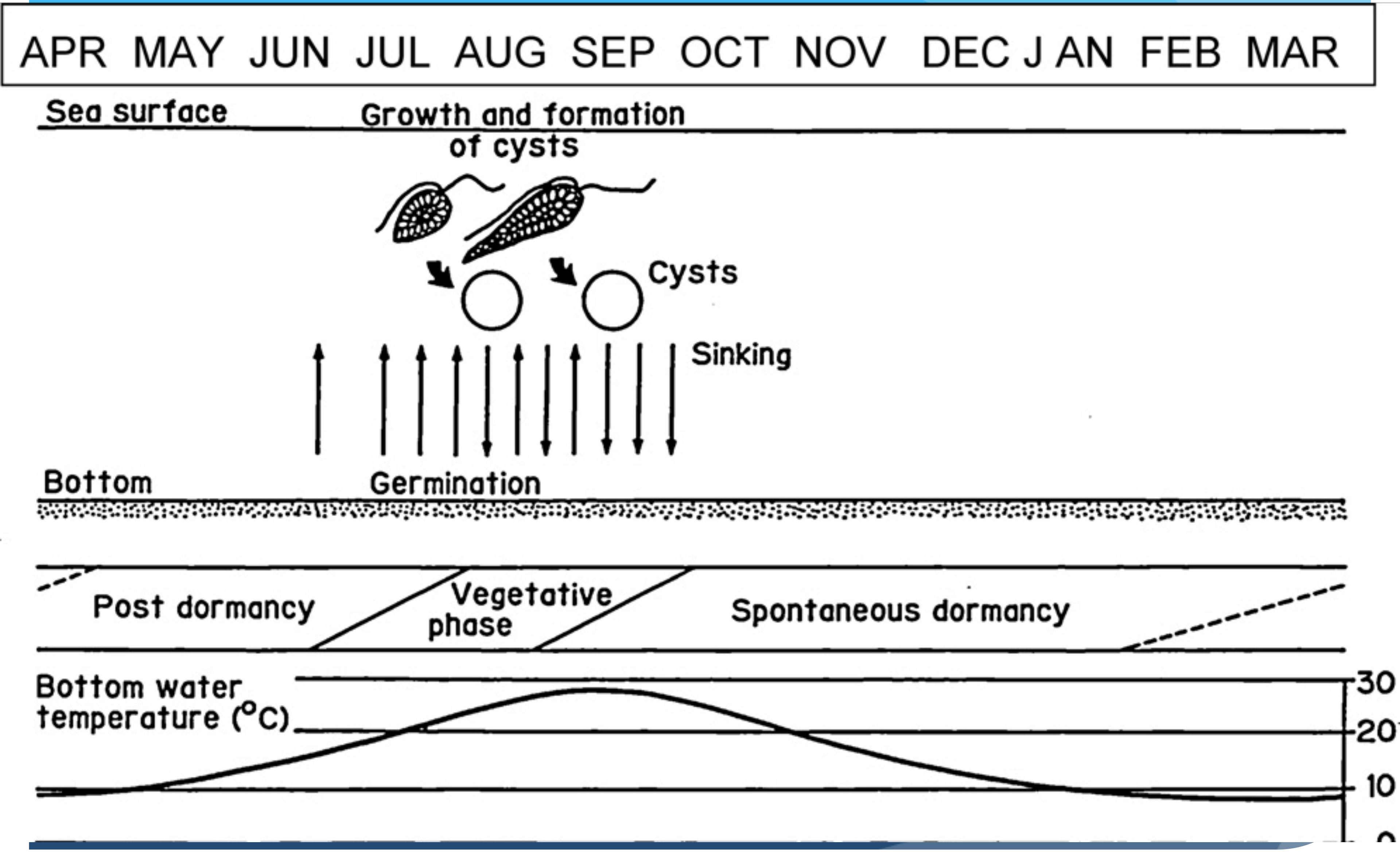


（今井 2013）

＝Sexuality would be through Hologamy

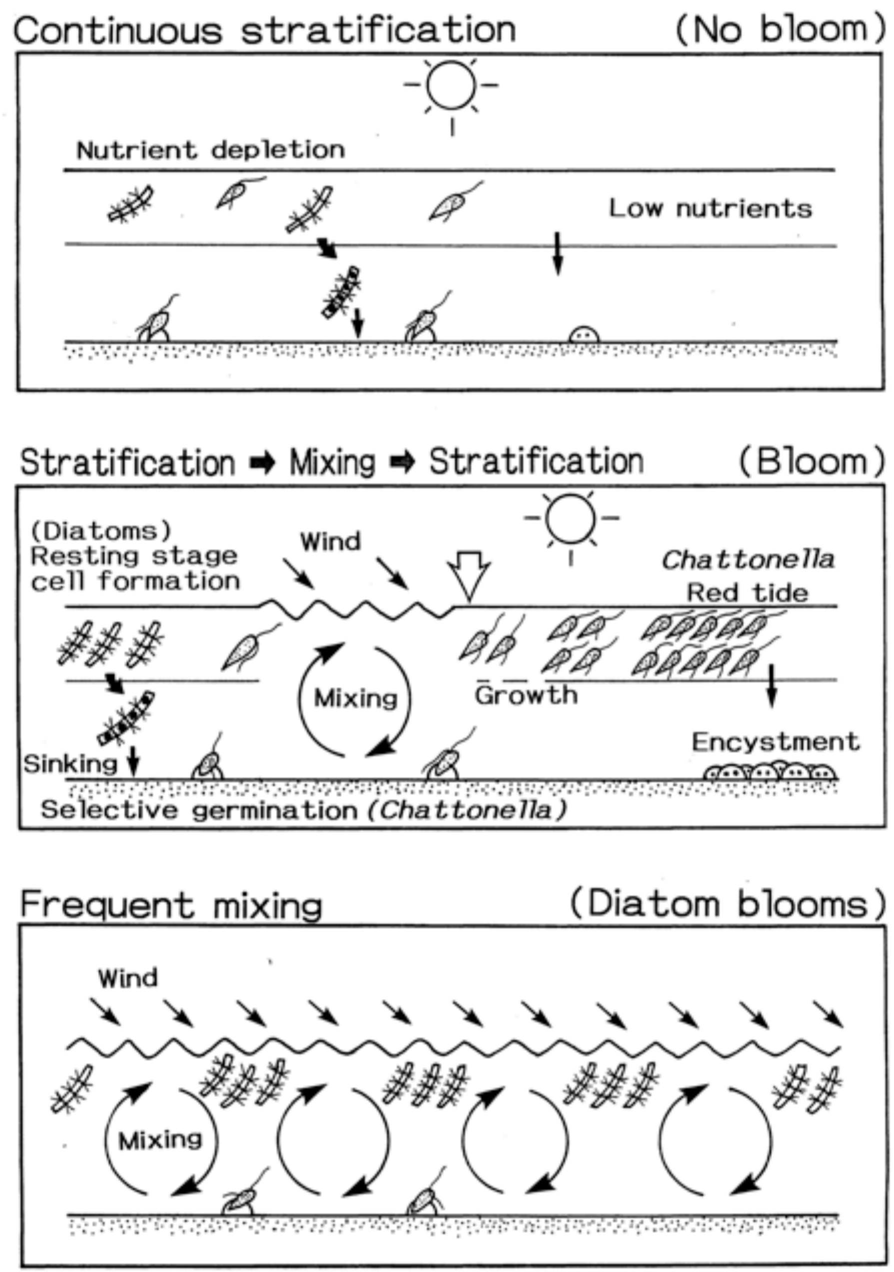


Annual life cycle of *Chattonella* in the Seto Inland Sea (Imai and Itoh 197)



“Diatom resting theory” for the bloom formation of “poorly competitive” *Chattonella* dominating over “strong” diatoms

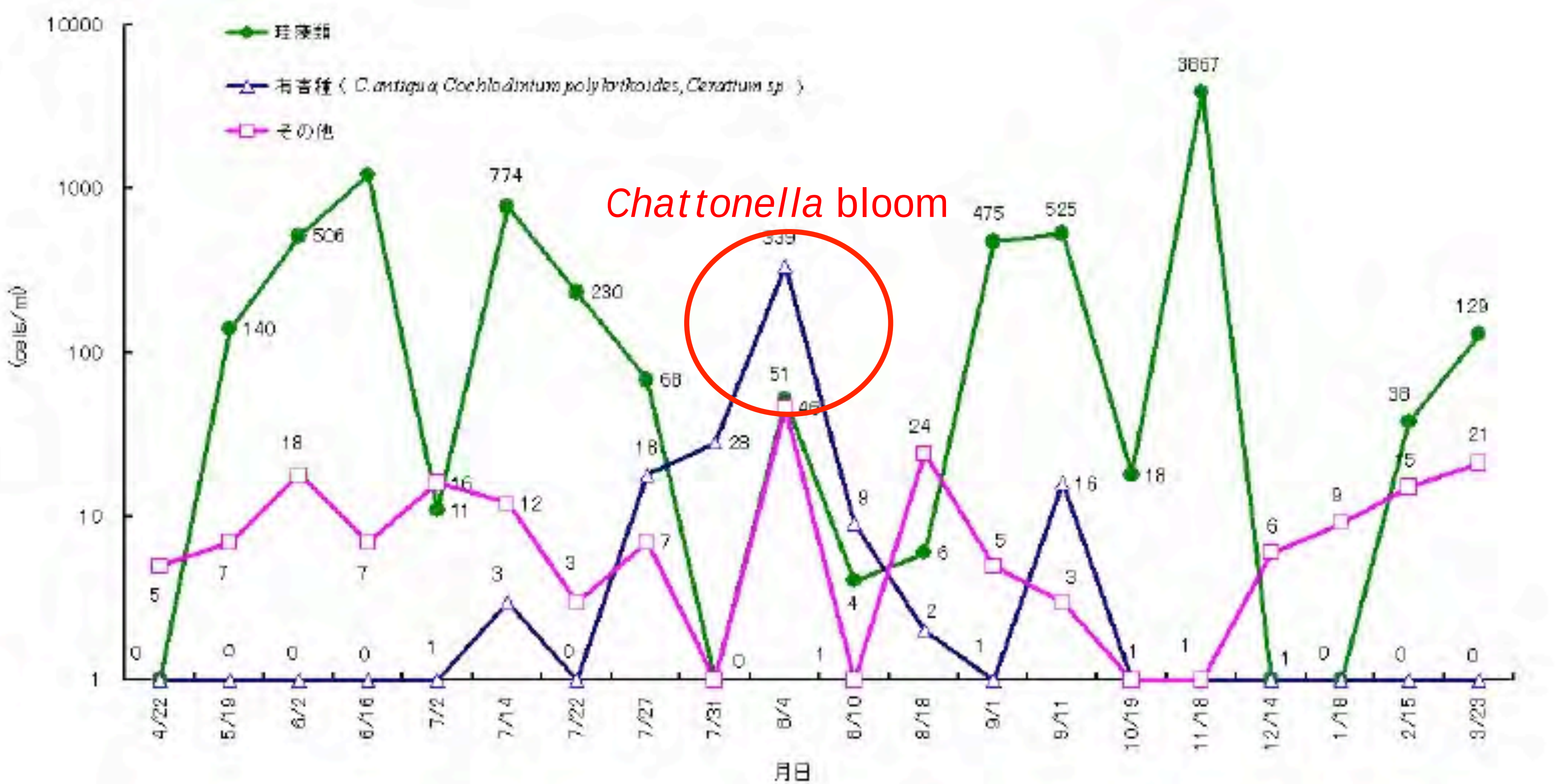
（Imai & Yamaguchi 2012）



Summary for “diatom resting theory”

- 1. Diatoms are stronger than flagellates in the growth phase.
- 2. Raphidophytes have cysts and diatoms have resting stage cells for survival strategies.
- 3. The raphidophyte cysts germinate in the dark, but diatom resting stage cells need light for germination.
- 4. Low light conditions induces selective germination of raphidophyte cysts at the sea bottom.

Chattonella bloom occurs during the period of the absence of diatoms. （Yatsushiro Sea in 2009）（Nishi et al. 2012）



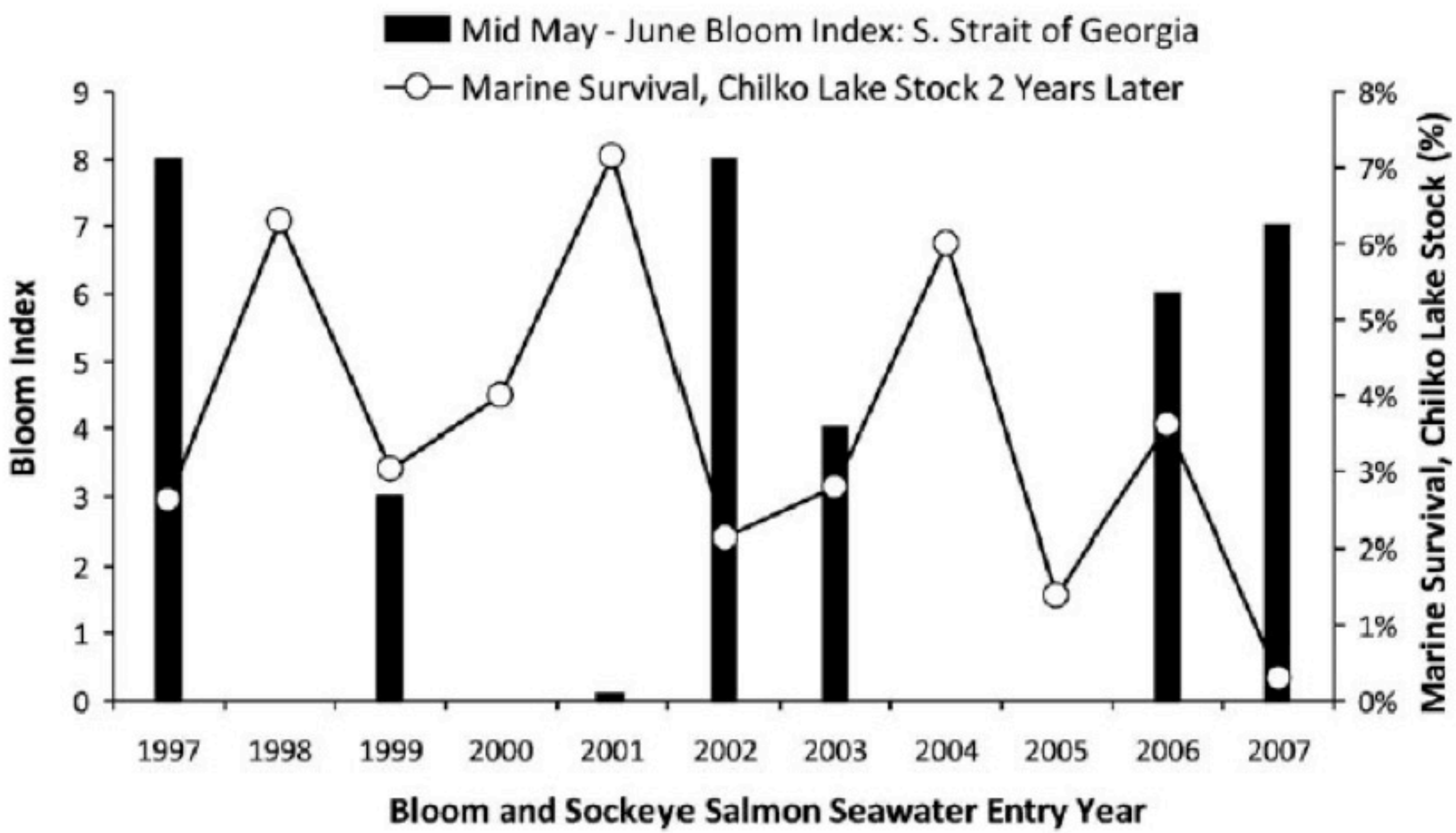
Toxicity of *Chattonella* to fish

- Super oxides contribute to the damage of gills leading to the suffocation of fish such as yellowtail.
- The strains with high production of superoxide are highly toxic strains and vice versa.
- The toxicity to fish probably depends on the toxicity of *Chattonella* strains.

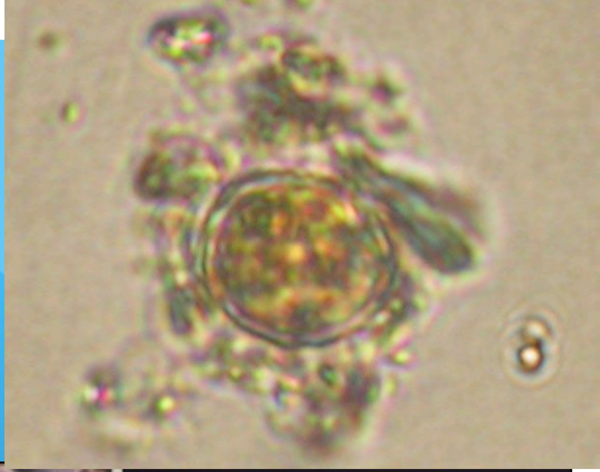
Life cycle strategy of *Heterosigma akashiwo*

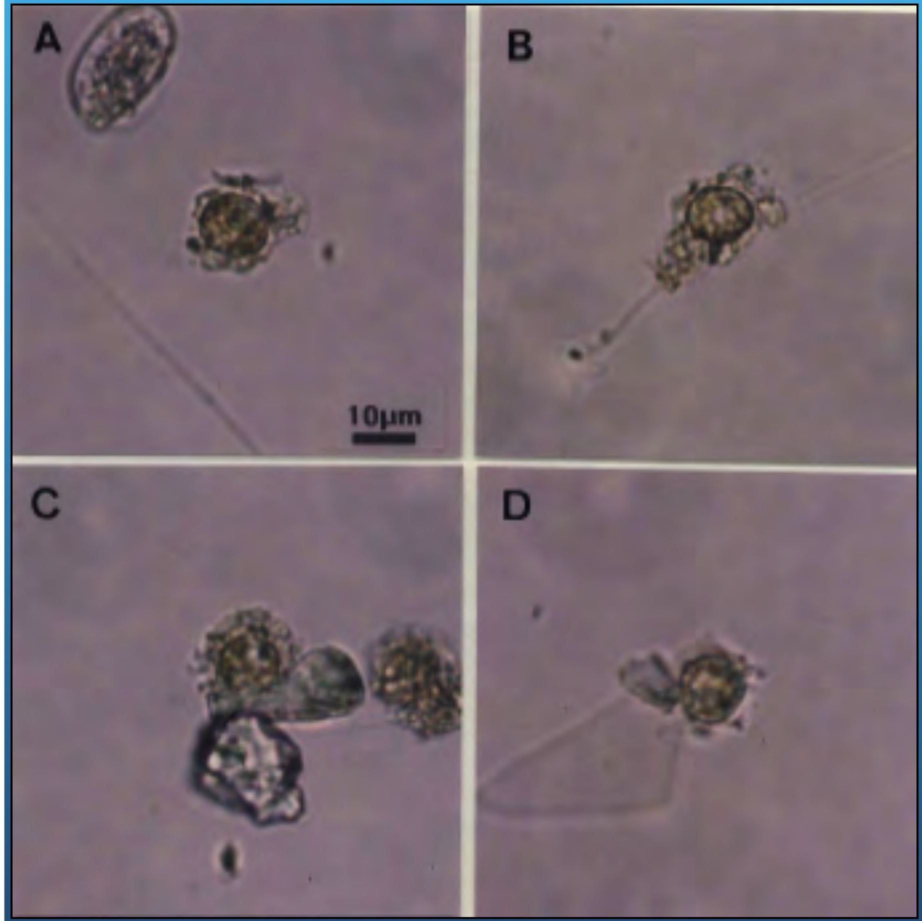
Global distribution of *Heterosigma akashiwo*

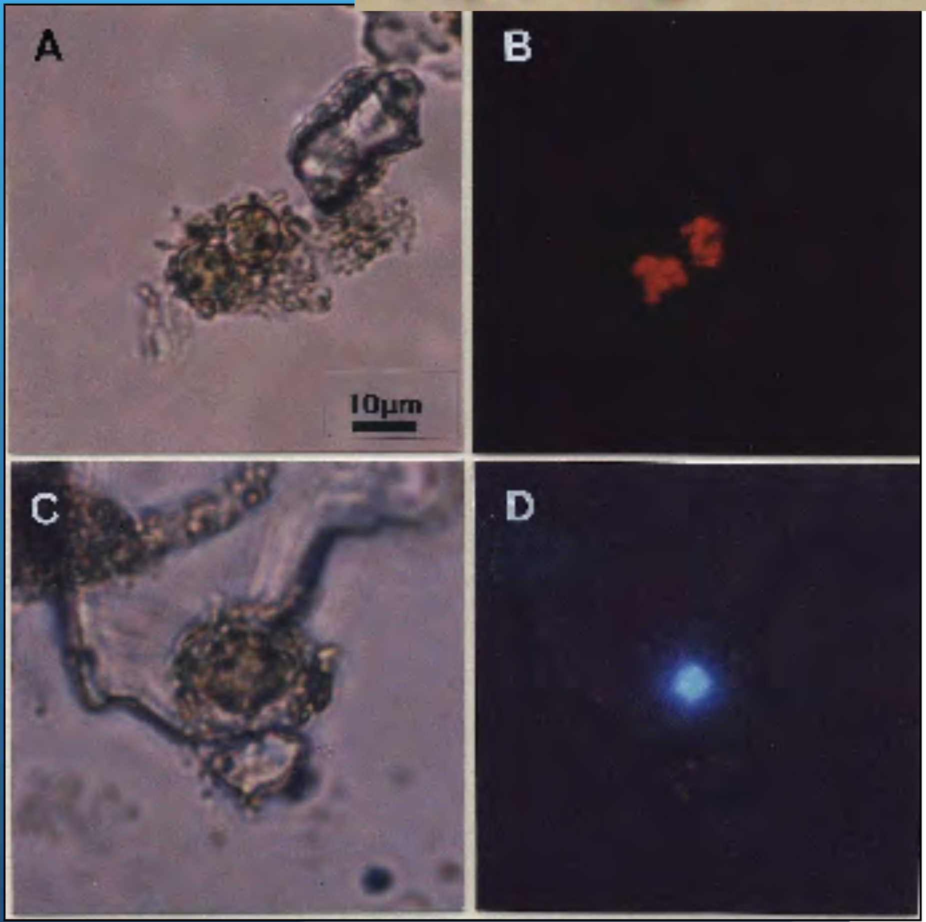
Occurrences of *Heterosigma* blooms in Georgia Strait and 2-years later coming back of Sockeye salmon into Chilko Lake, Canada (Rensel et al. 2010)



Cysts of *Heterosigma akashiwo* discovered from the sediments of the Seto Inland Sea (Imai et al. 1993)







MPN method for enumeration of *H. akashiwo* cysts having germination ability in sediments (Imai and Itakura 1991).

Feasible for the cysts without information on morphology

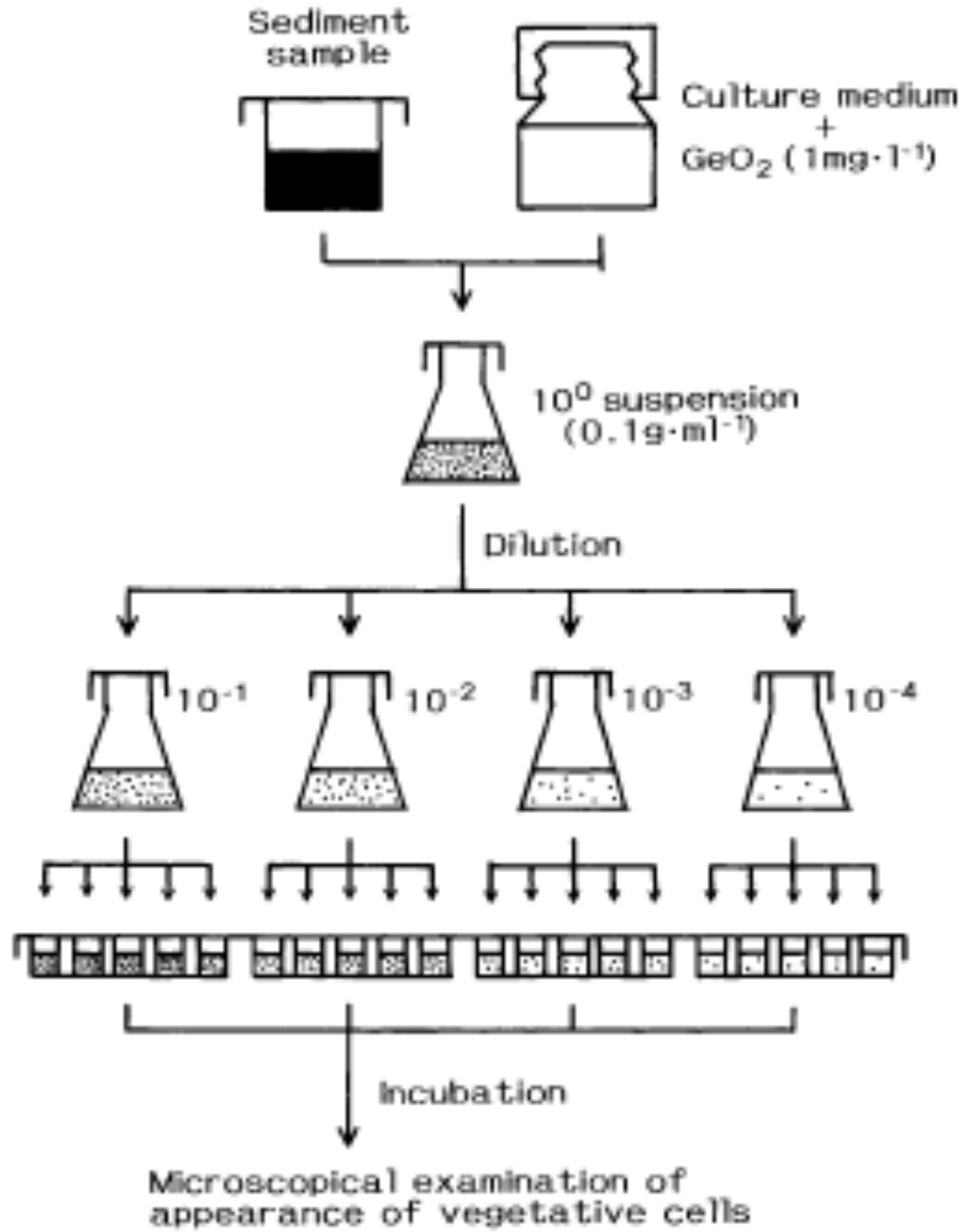


Fig. 2 *Heterosigma akashiwo*. Procedure of the extinction dilution method for enumeration of germinable cysts in sediment samples

Distribution of cysts of *Heterosigma akashiwo* in bottom sediments of Hiroshima Bay, the Seto Inland Sea (Imai and Itakura 1991).

Cysts were abundant in the coast.

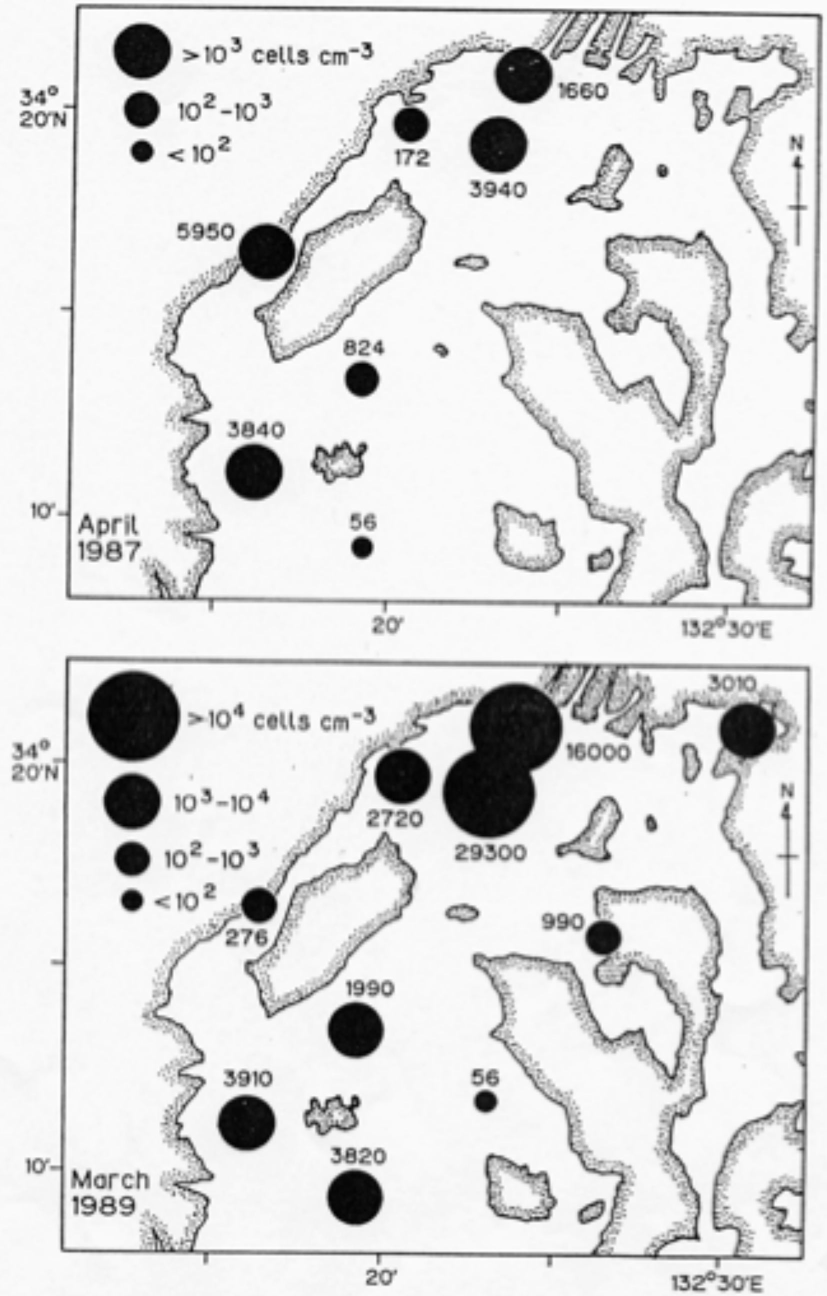
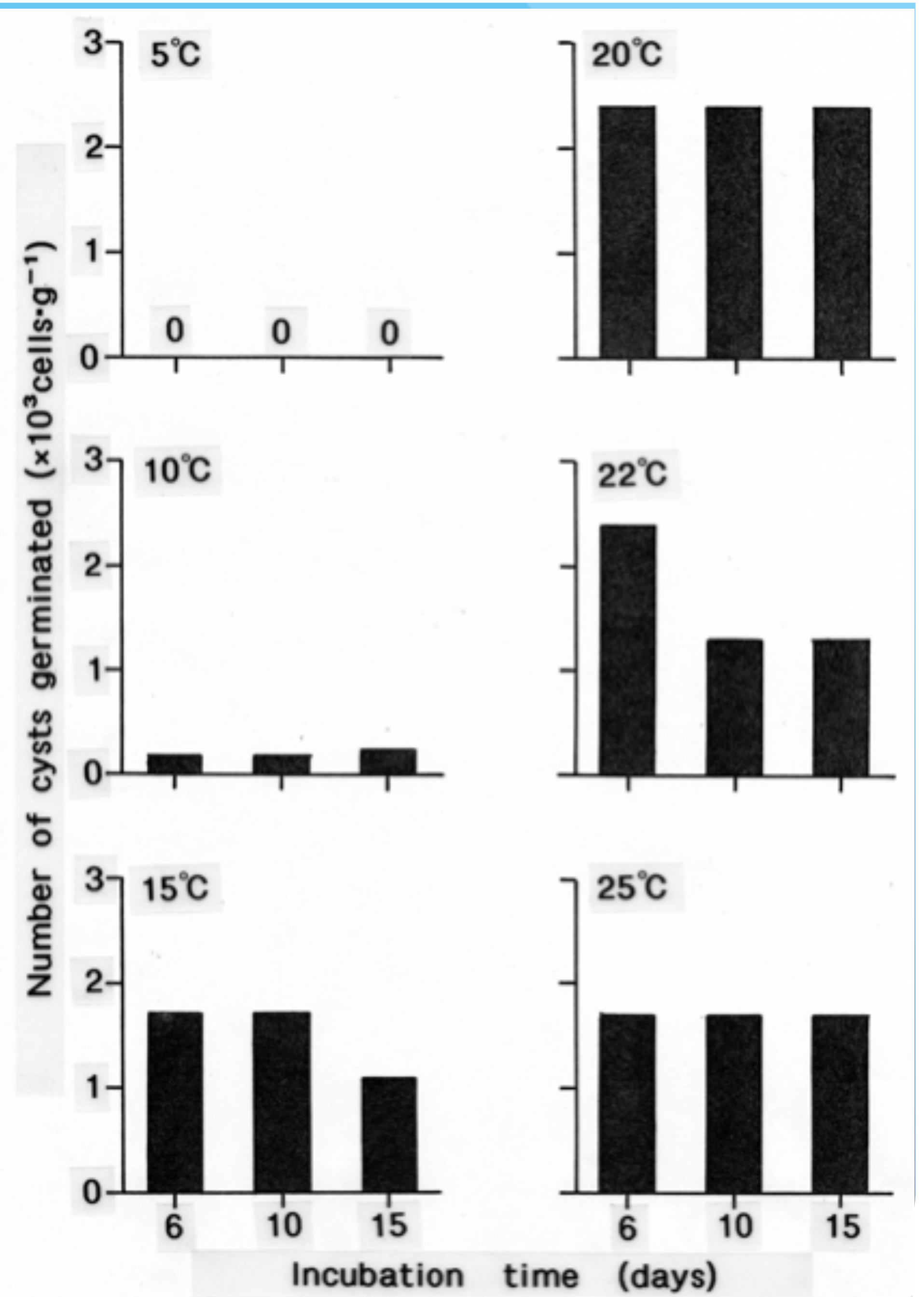


Fig. 3. Densities of dormant cells of *H. akashiwo* in bottom sediments of northern Hiroshima Bay, enumerated by the extinction dilution method. Numerals indicate the number of the dormant cells per cubic centimeter wet sediment.

Effects of temperature on the germination of Heterosigma akashiwo cysts in sediments determined by the MPN method (Imai and Itakura 1999).



Vigorous germination at 15℃ or higher temperature

Process and key factors for the occurrence of *Heterosigma akashiwo* red tide (Smayda 1998).

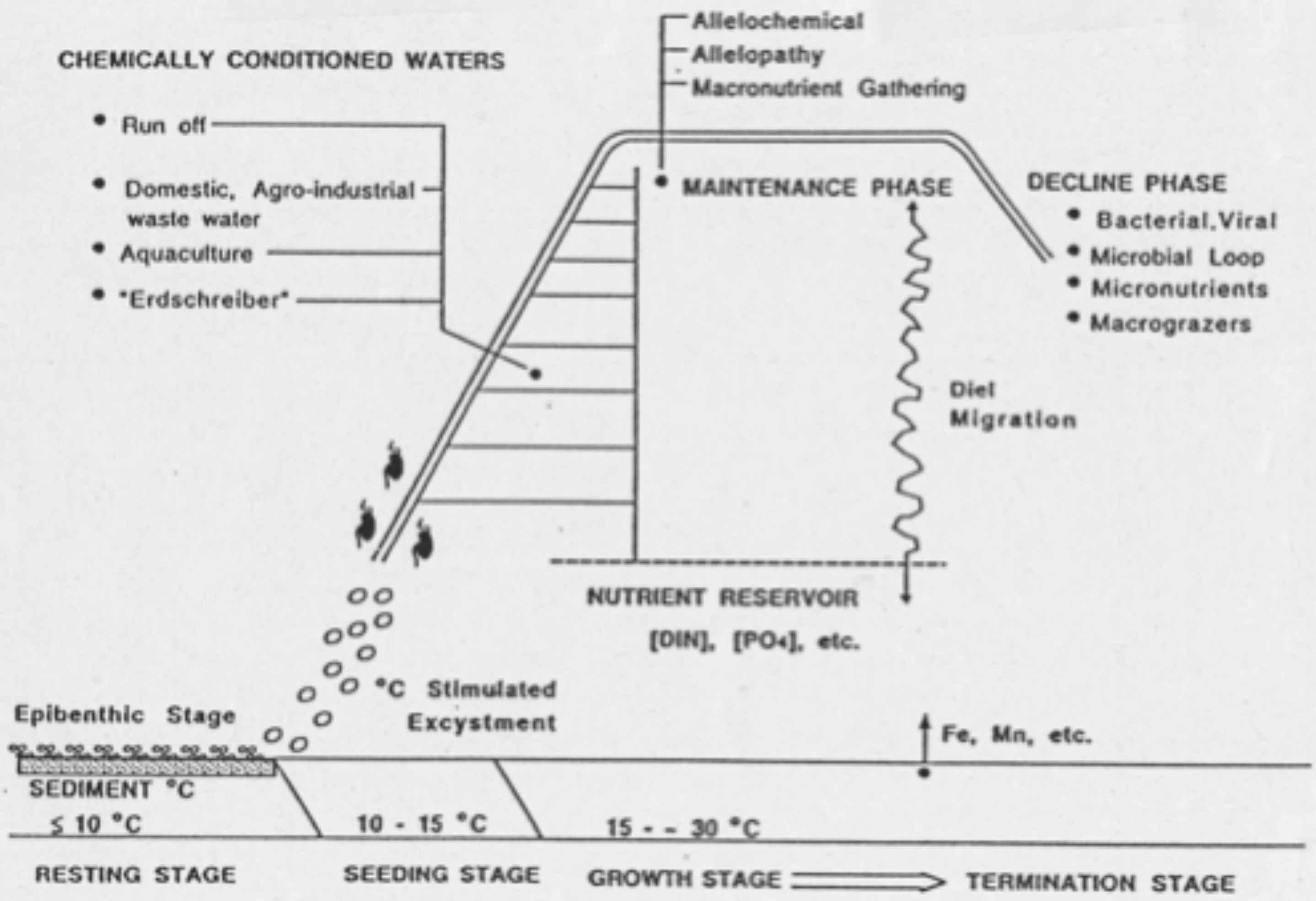


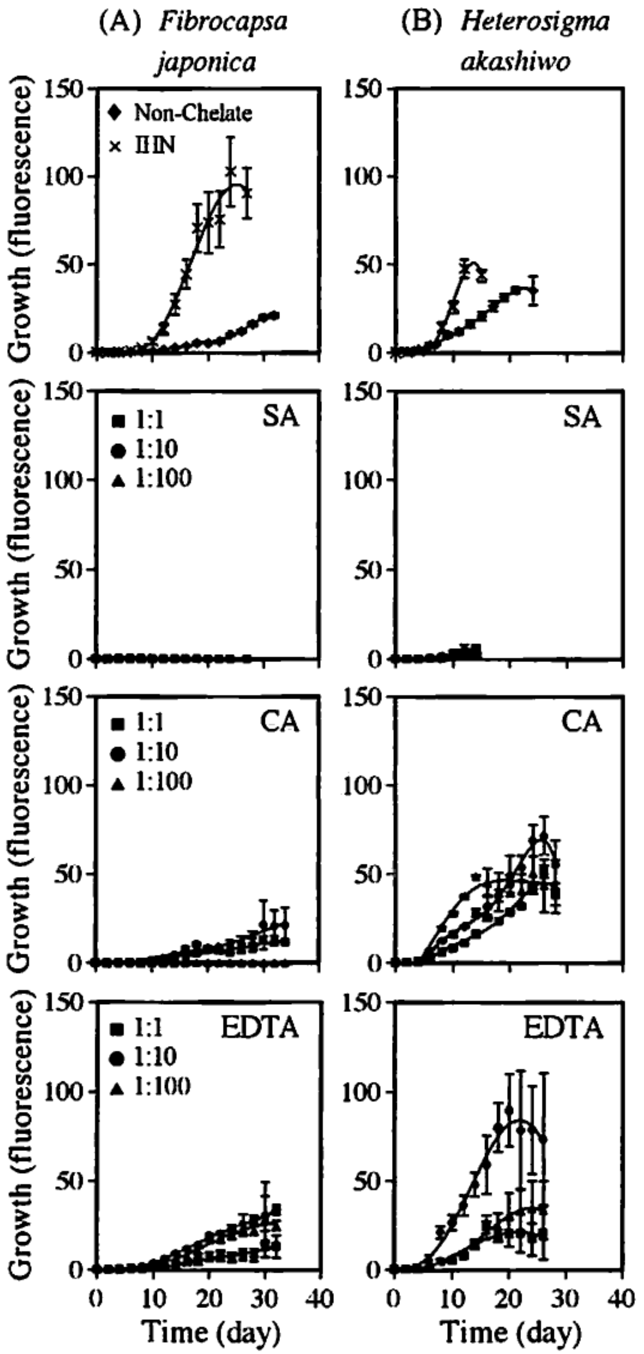
Figure 2. General model of key processes influencing bloom outbreaks of *Heterosigma akashiwo*; see text for details.

Summary for *Heterosigma akashiwo*

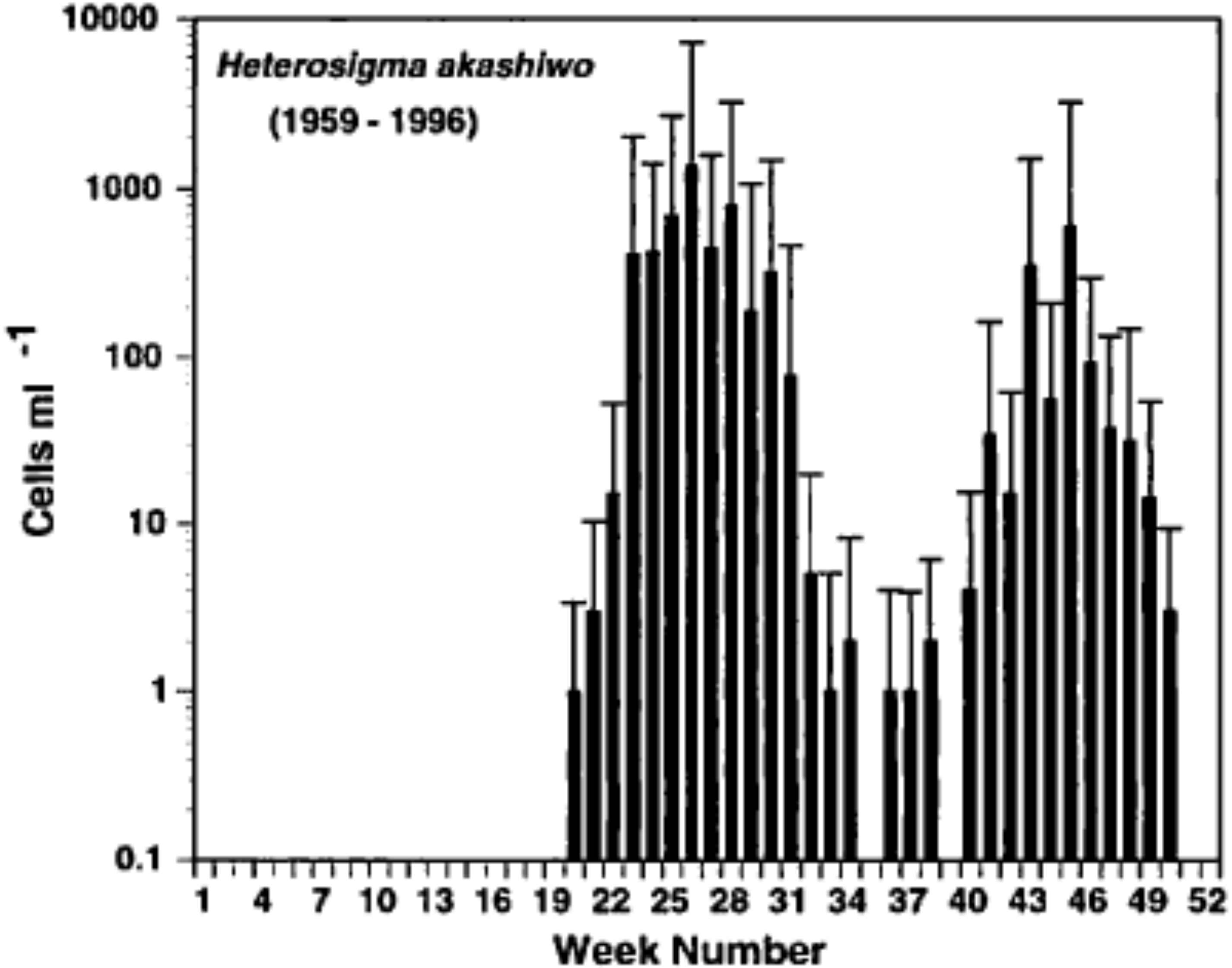
- 1. *Heterosigma akashiwo* has cyst stage for outliving such as overwintering.
- 2. Cyst formation was induced at the end of blooms and completed in the dark (Itakura et al. 1996).
- 3. New cysts need 1 week or more for maturation.
- 4. Cysts effectively germinate at 15℃ or higher.
- 5. *in situ* germination of cysts can always occur.
- 6. Red tides show great seasonality, and hence seeded by the germination of cysts in sea bottom.
- 7. Life cycle startegy of *H. akashiwo* is also well adapted to temperate shallow coastal areas; changes between cysts and vegetative cells are easy.

Heterosigma can utilize the iron chelated with rather many kinds of ligands.

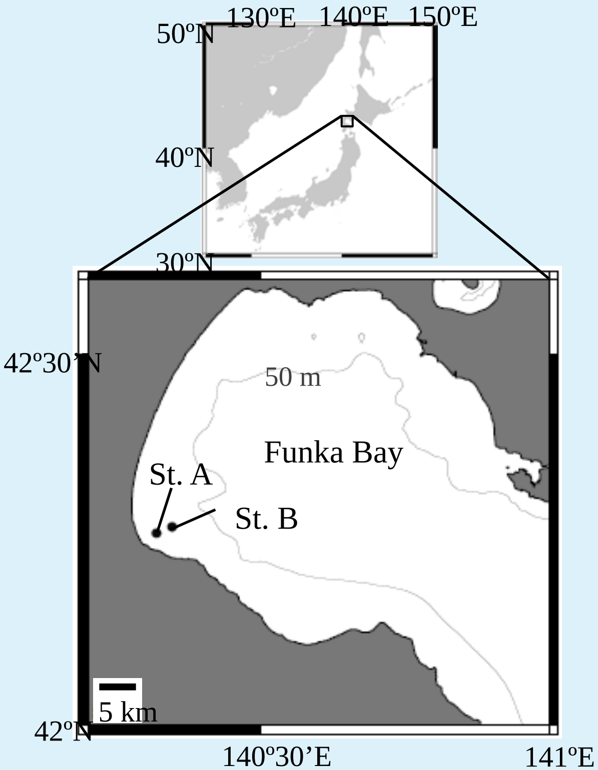
Production of chelators, resembling the production of domoic acid in the toxic *Pseudo-nitzschia* ?

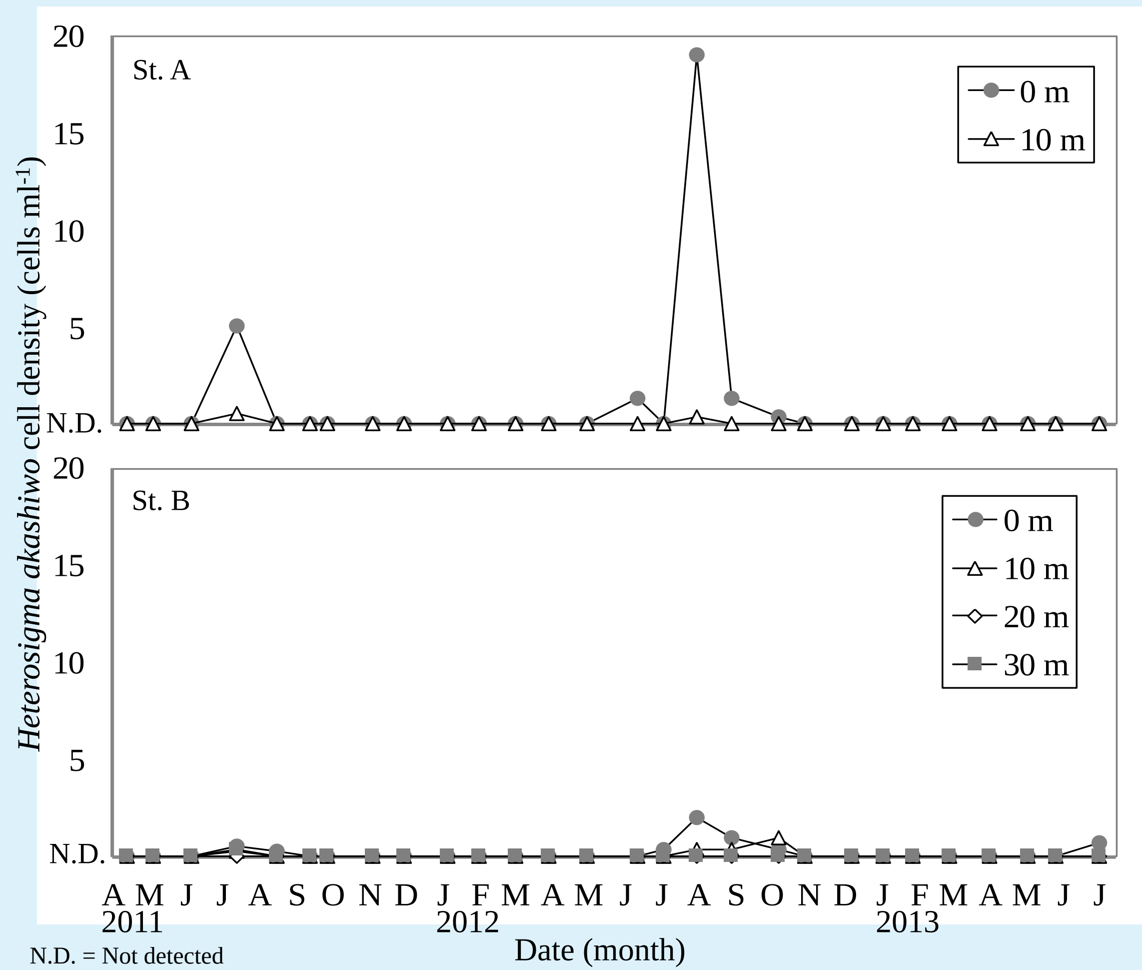


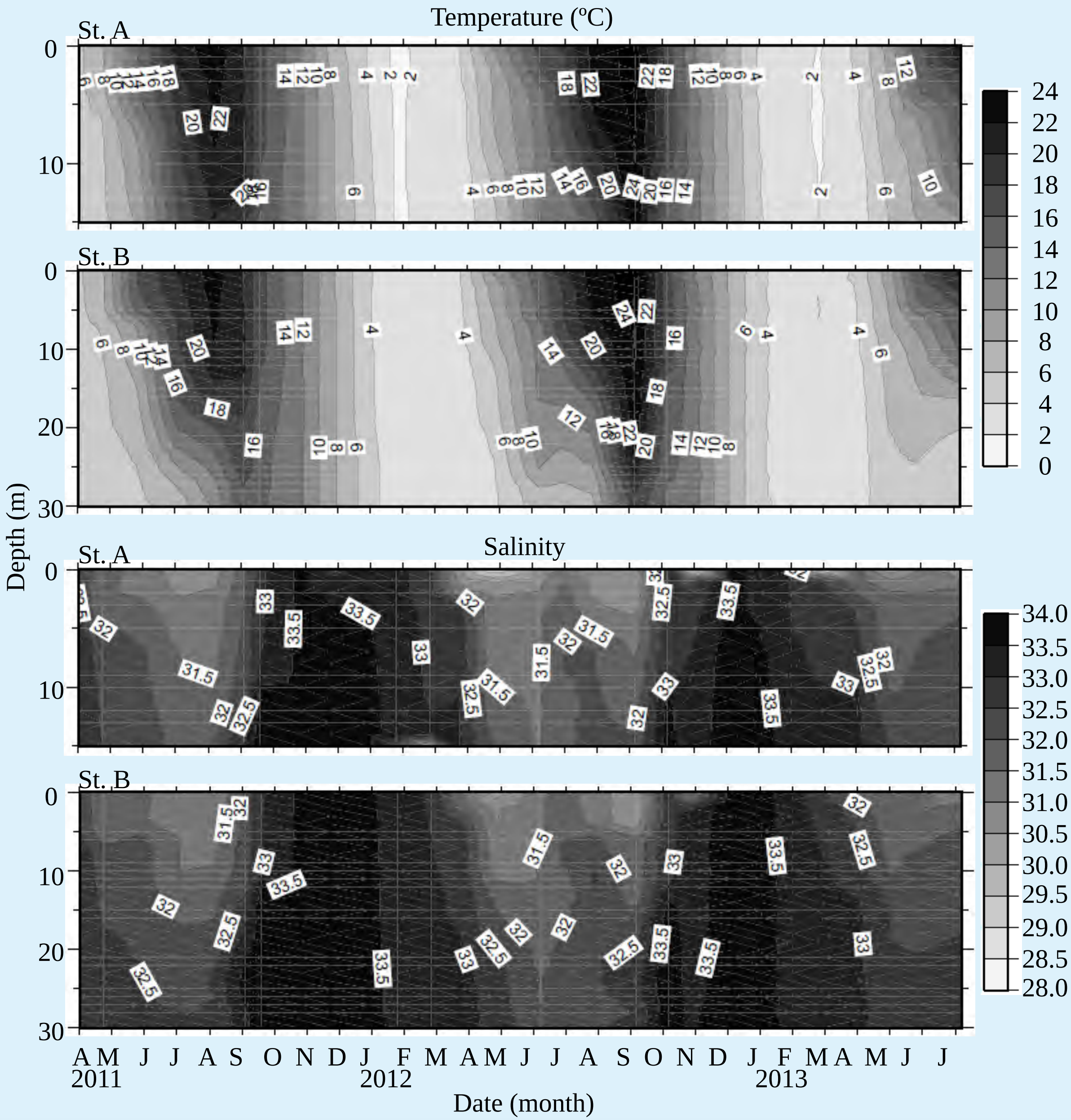
Two-peaks type of *Heterosigma* blooms in temperate waters such as Narragansett Bay (Li & Smayda 2000)



Single-peakstype of *Heterosigma* blooms in cold temperate waters such Funka Bay, Japan (Natsuike et al. 2015)







Water temperature and salinity in Funka Bay.

The highest temperature reached 24℃ in summer.

Heterosigma red tides usually occur at 20℃ or higher with wide range of salinity (Honjo 1993).

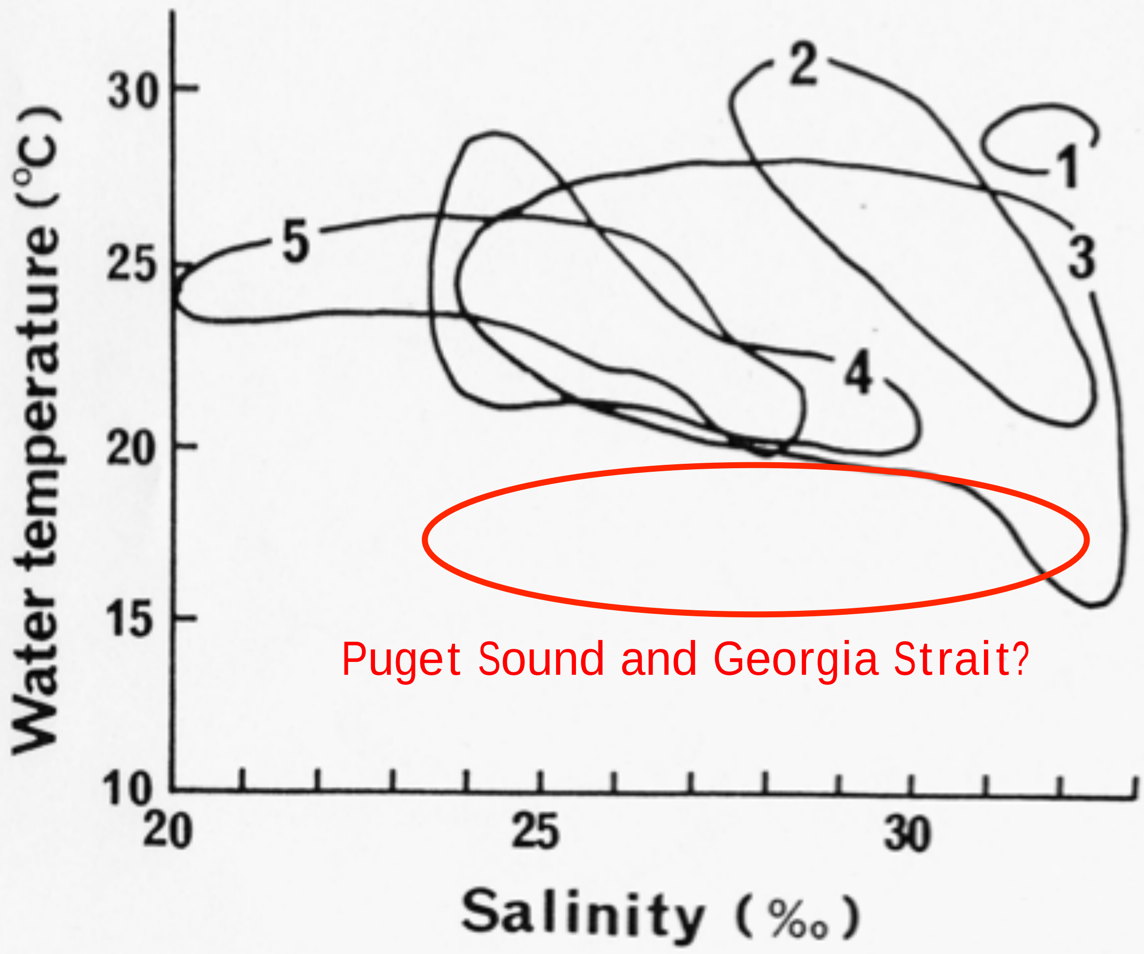


FIG. 2: The ranges of *in situ* water temperature and salinity during *H. akashiwo* red tides: 1. Nagasaki Bay, 2. Hakata Bay, 3. Seto Inland Sea, 4. Mikawa Bay, 5. Narragansett Bay.

Honjo (1993)

Toxic blooms of *Heterosigma akashiwo* in the Salish Sea: Puget Sound and Georgia Strait

Single-peak type and toxic blooms of *Heterosigma akashiwo*

- Lower temperature in the summer bloom season than Japan
- Probably lower growth rates of *Heterosigma* in the Salish Sea

^-^--^-^

- The situation is resembling the toxic blooms of *Alexandrium tamarense* in Japan: High toxicity in northern Japan, and lower toxicity in south-western Japan.
- Lower growth rates induce the more abundant production of toxins in *A. tamarense* cells.
- Comparison of toxicity is useful in USA between the *Heterosigma* blooms of northern and southern areas.

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