Long-term changes in eutrophication and harmful algal blooms in the Seto Inland Sea of Japan

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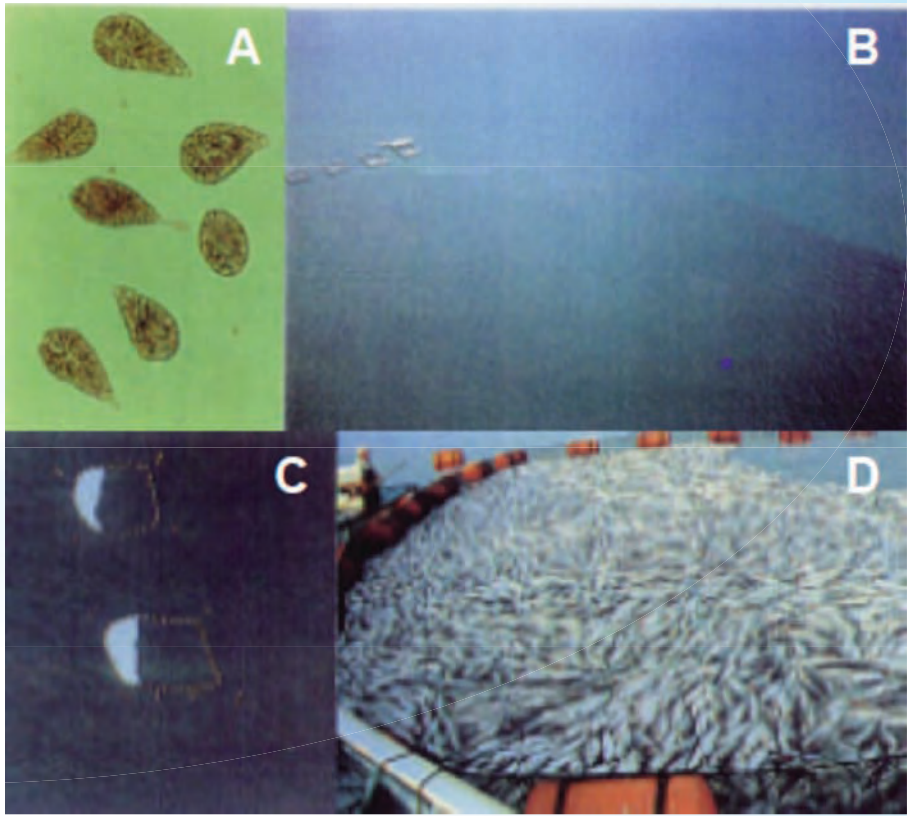


The Seto Inland Sea sea has experienced extreme eutrophication during the period of high speed economic growth.

Strong human impacts were given to the Seto Inland Sea, such as large scale reclamation, heavy inputs of nutrients, etc.

Harmful algal blooms have occurred causing mass mortalities of cultured fishes and bivalves.□

Atada Island, Hiroshima Bay, the Seto Inland Sea□

Contents

1) General trends

2) Changes in water quality

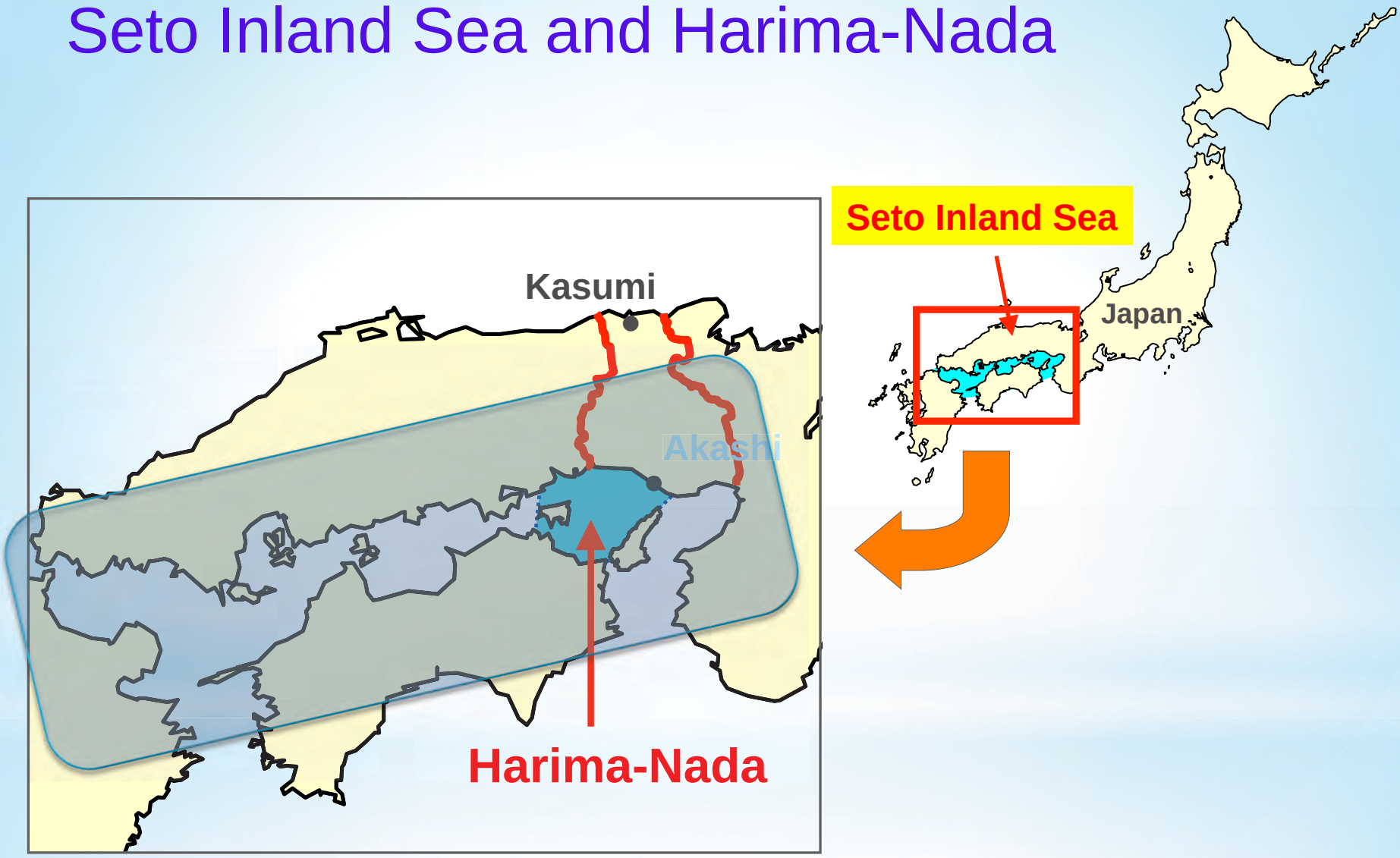
3) Harmful algal blooms

□

9/10/2009

Hime-shima Island, Seto Inland Sea □

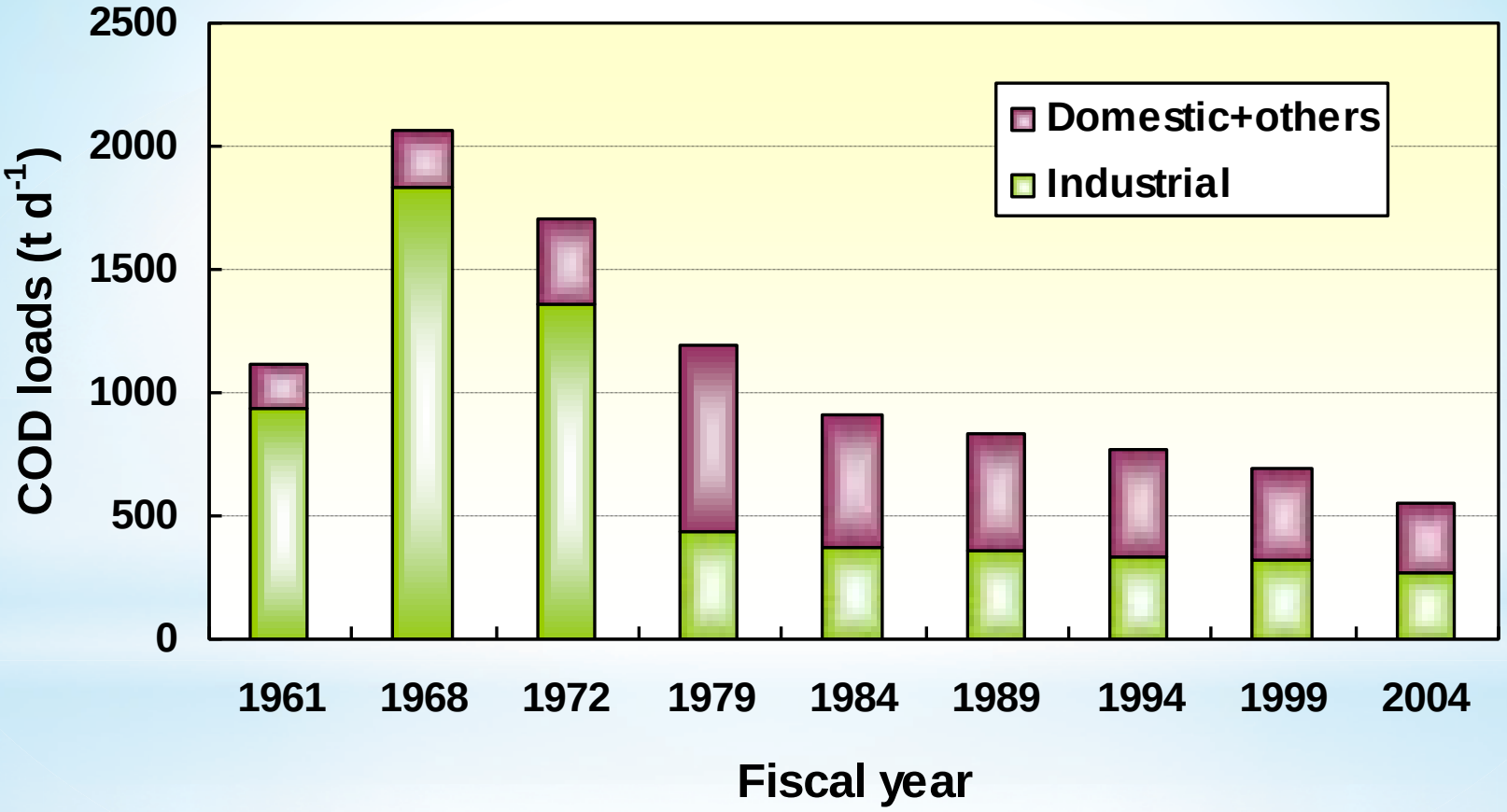
Seto Inland Sea and Harima-Nada



*Characteristics of the Seto Inland Sea, Japan

Area	23 203 km^2
Mean depth	38 m
Volume	8.8×10^{11} m^3
Islands	1015
Precipitation	1000 ~ 1 600 mm /yr
River (class A and B)	664
Run off	5.0 x 1010 m^3 /yr
Water temperature	8 ~ 26 ˚C
Population	3.0×10^7
Fishery production	6×10^5 ton /yr
Aquaculture production	3×10^5 ton /yr

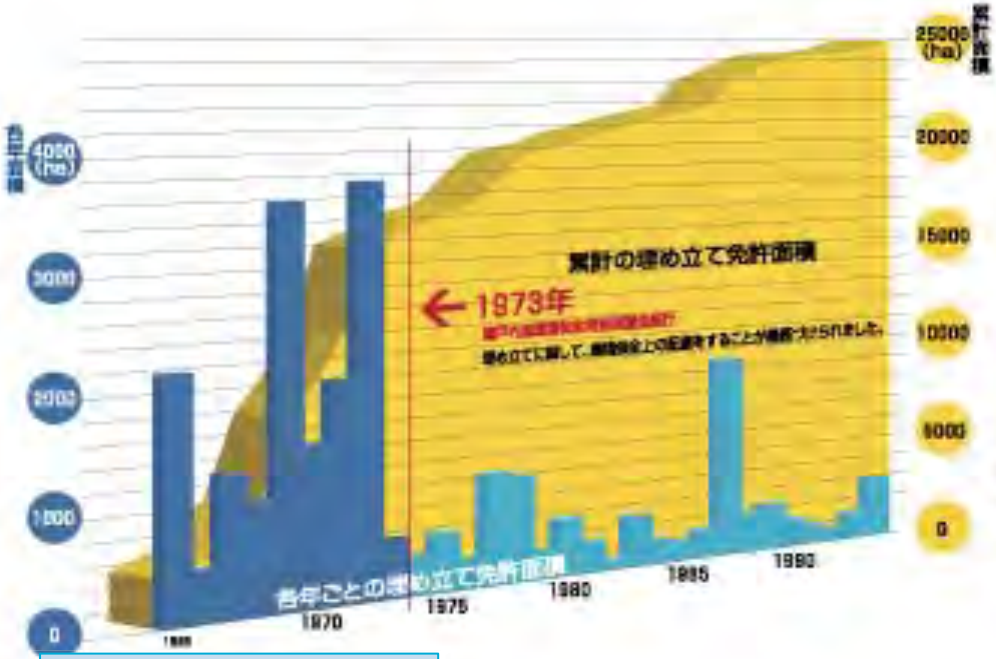
Changes in total amount of COD load in the Seto Inland Sea



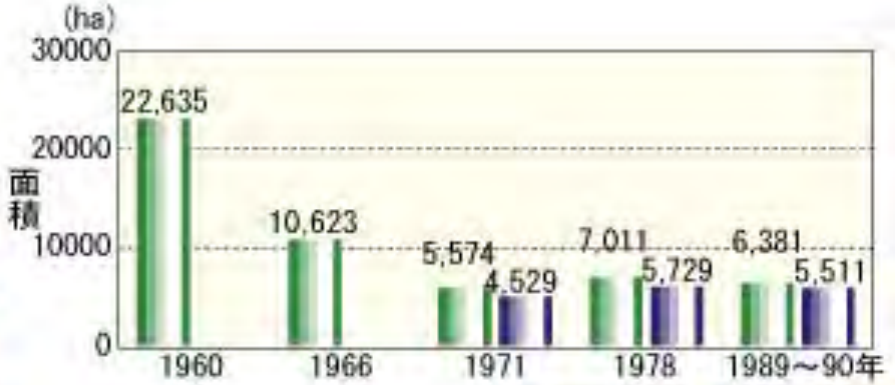
from the Ministry of the Environment Government of Japan &
the Association for the Environmental Conservation of Seto Inland Sea

*Reclamation and decrease of intertidal flats and seagrass beds in the Seto Inland Sea

Red tide occurrences

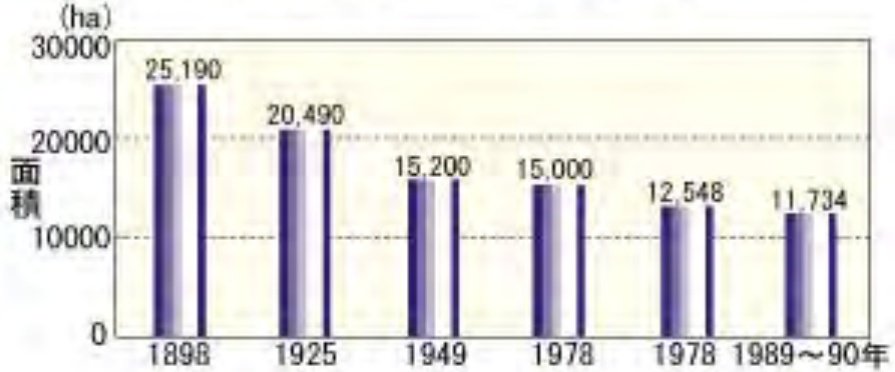


Reclamation□



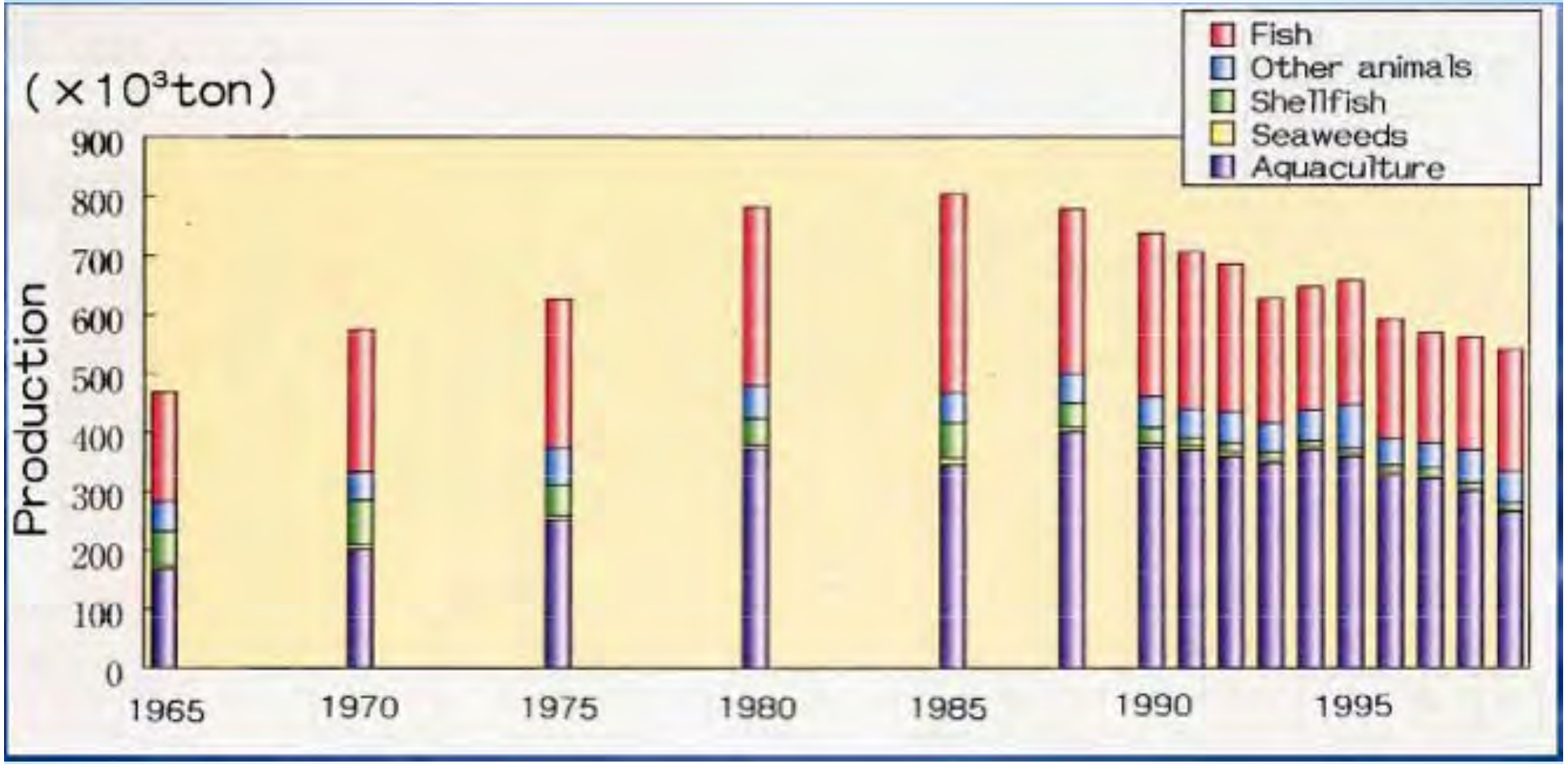
Decrease of seagrass bed

瀬戸内海における藻場の推移



Decrease of intertidal flats

*Fisheries production in the Seto Inland Sea



Serious eutrophication of the Seto Inland Sea

A: Red tide (Noctiluca)
B: Bloom of *Skeletonema* spp.
C: Mass mortality of cultured yellowtails in pen cage by HAB

Measures for eutrophication

Special law

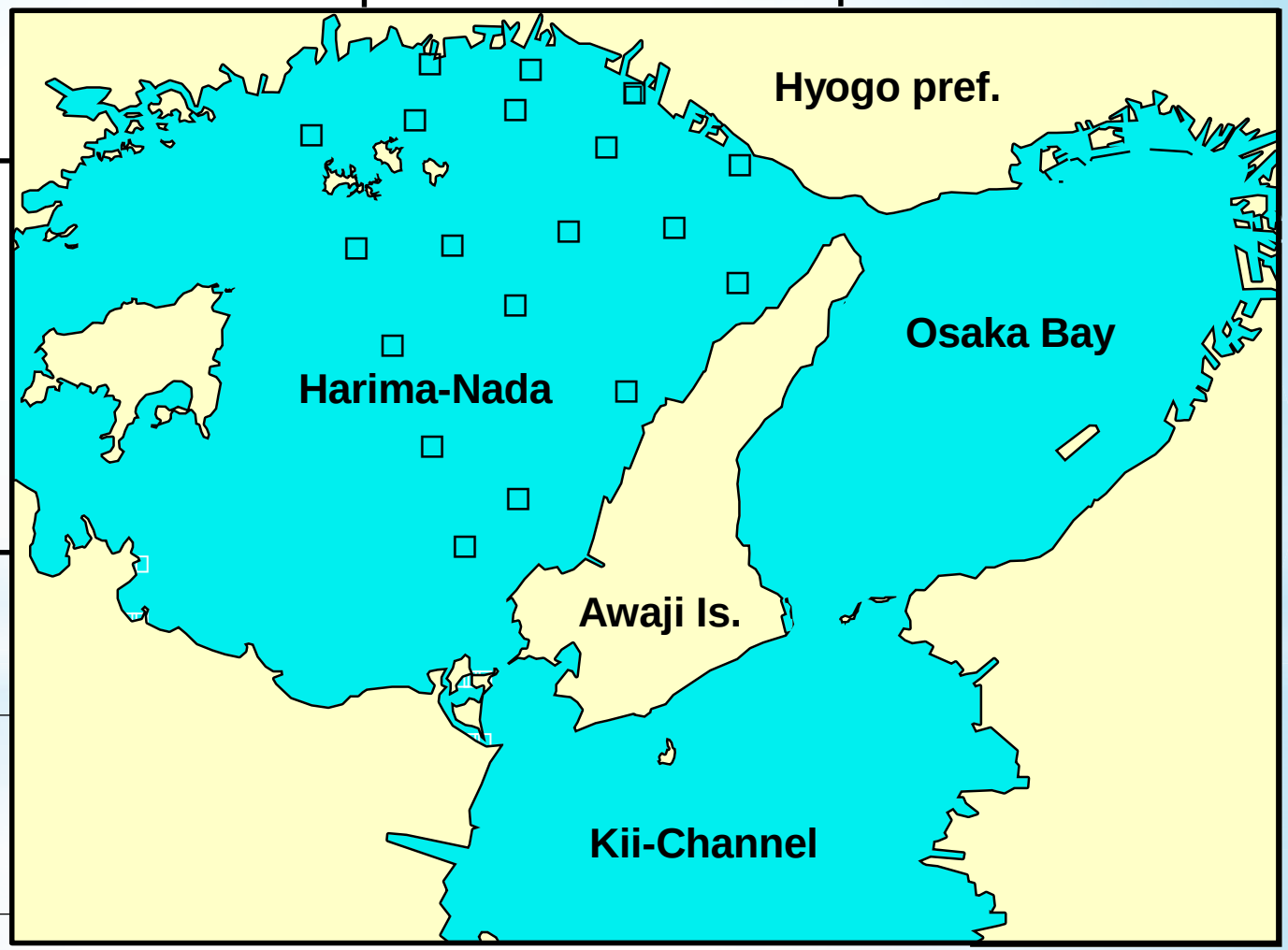
Law Concerning Special Measures for Conservation of the Environment of the Seto Inland Sea (enacted in 1973)

→ Total Pollutant Load Control
Reduce the total quantity of organic pollutants in term of COD

Controls of total P (from 1979)

Controls of total N (from 1996)

Sampling stations in Harima-Nada in the Seto Inland Sea



Harima-Nada

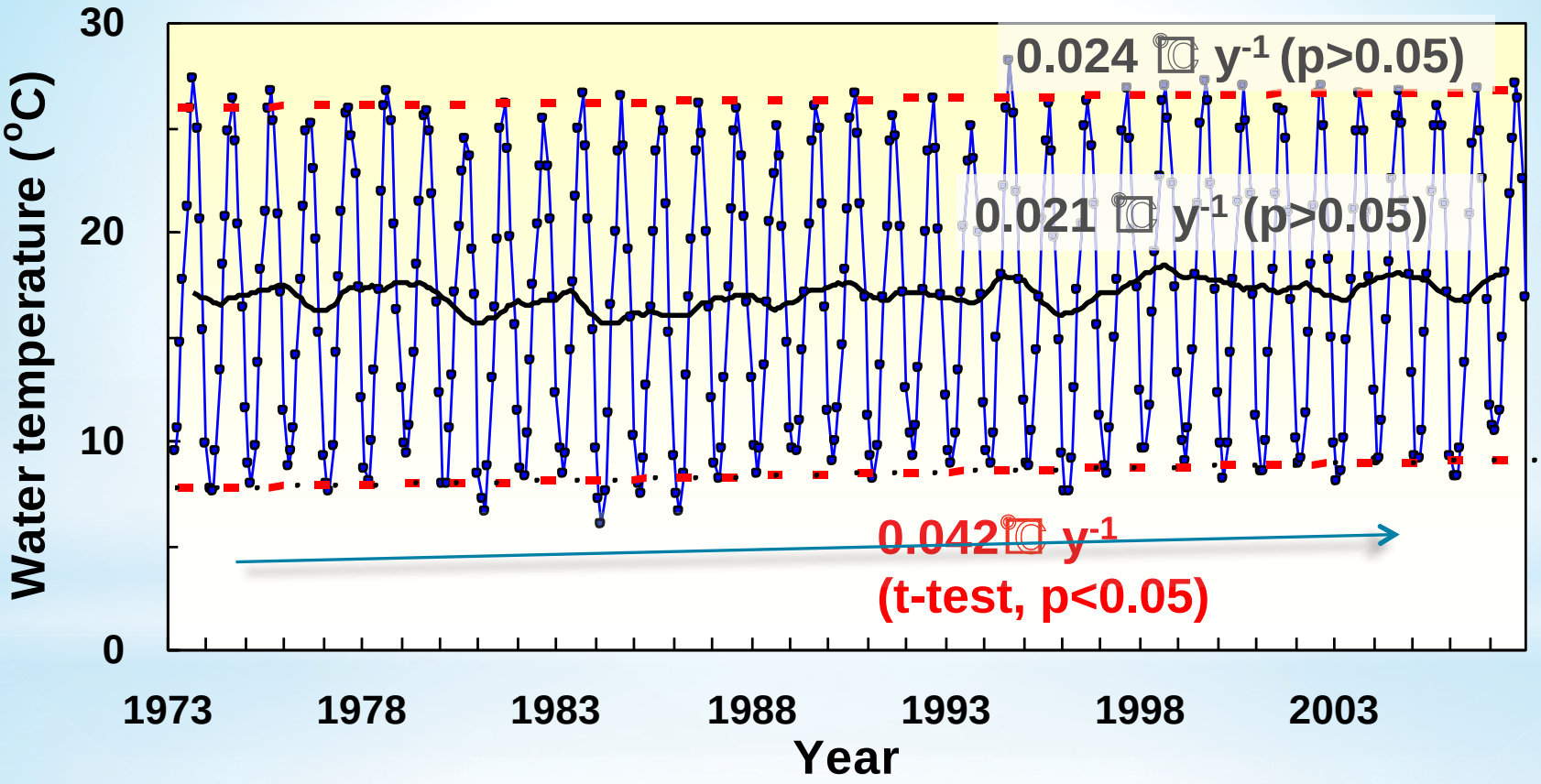
- Area: 3,400 km^2
- Mean depth: 25.9 m

Sampling

- Period: Apr. 1973- Dec. 2007 (35-years)
- Frequency: Once a month
- Sampling station:19
- Sampling layer: Surface, 5 or 10 m, B-1 m
- Measurement items
  1) Water temperature, Salinity
  2) Nutrients (DIN, PO_4-P, SiO_2-Si)
  3) Cell density of phytoplankton (surface)

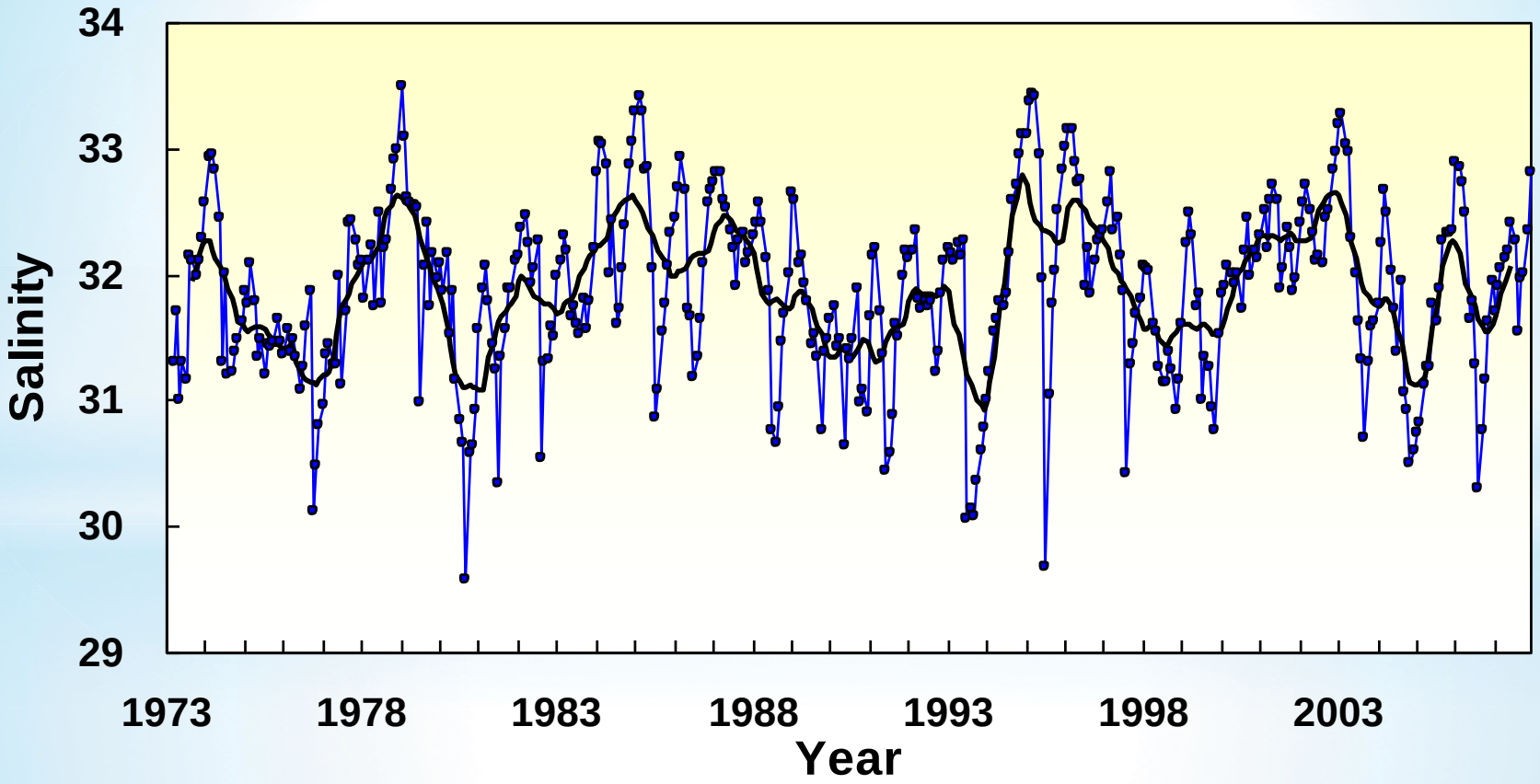
Long-term variations in water temperature

(April 1973-Dec 2007, mean of 3 depth at 19 sampling stations)



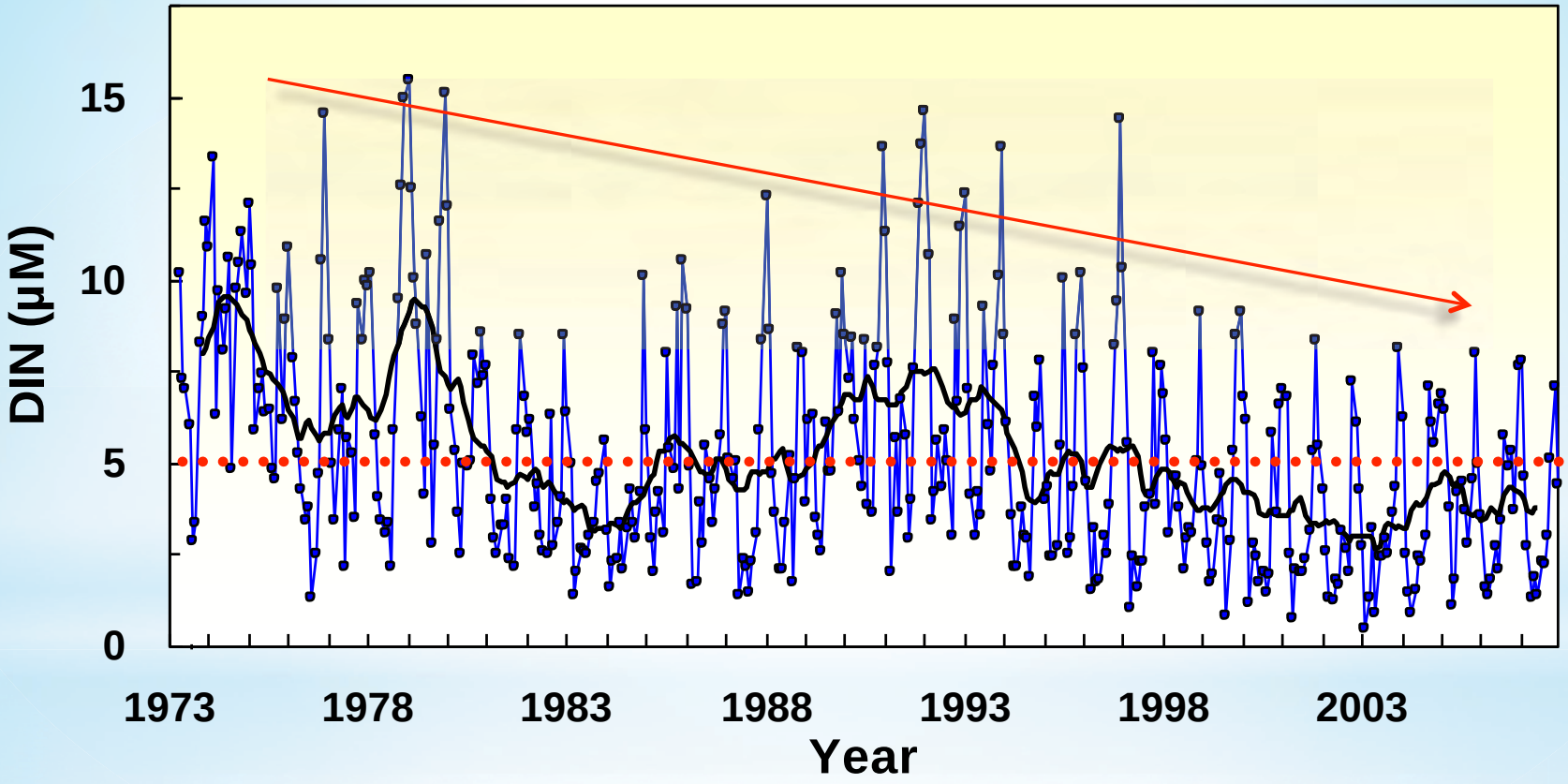
Long-term variations in salinity

(April 1973-Dec 2007, mean of 3 depth at 19 sampling stations)



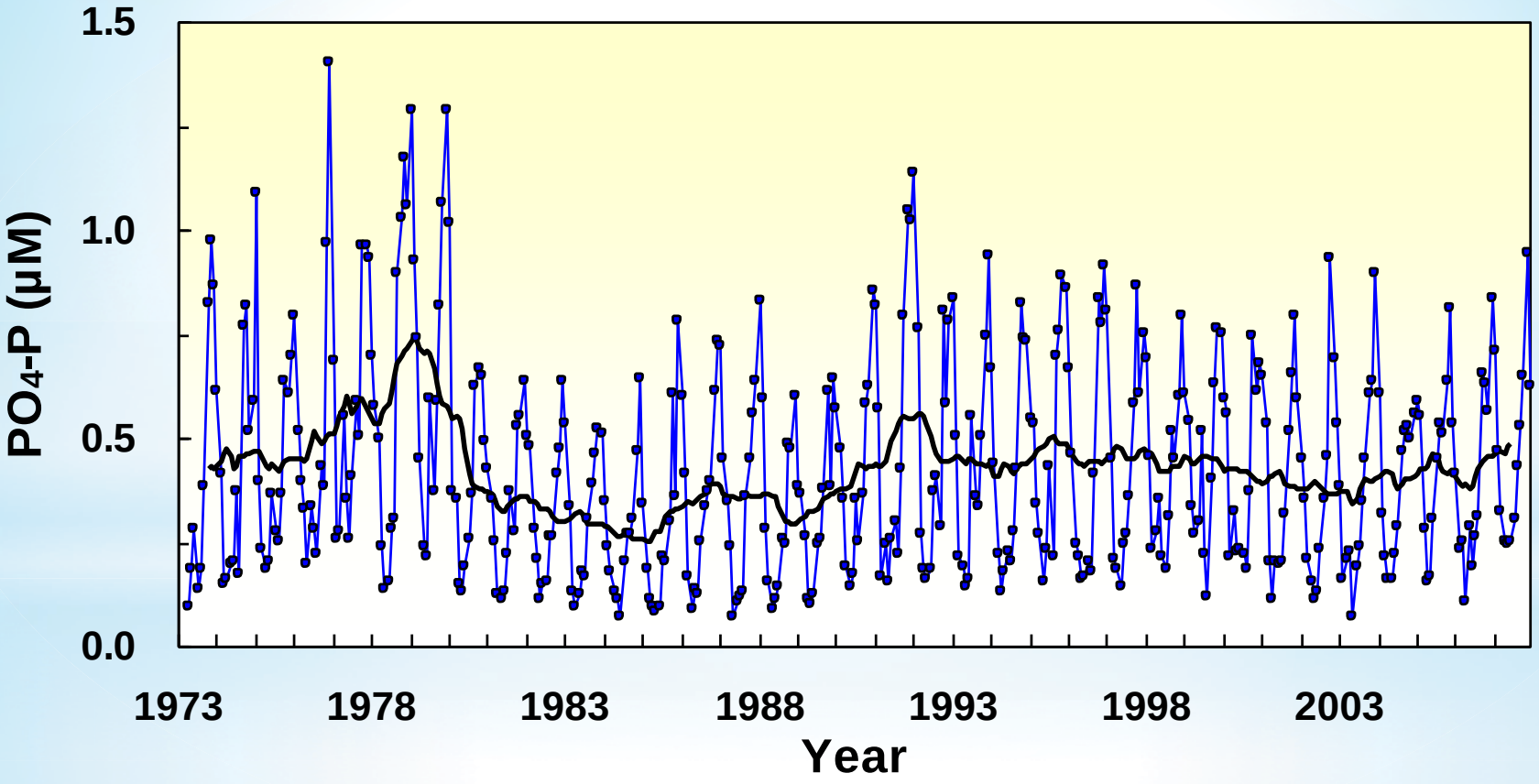
Long-term variations in DIN

(April 1973-Dec 2007, mean of 3 depth at 19 sampling stations)



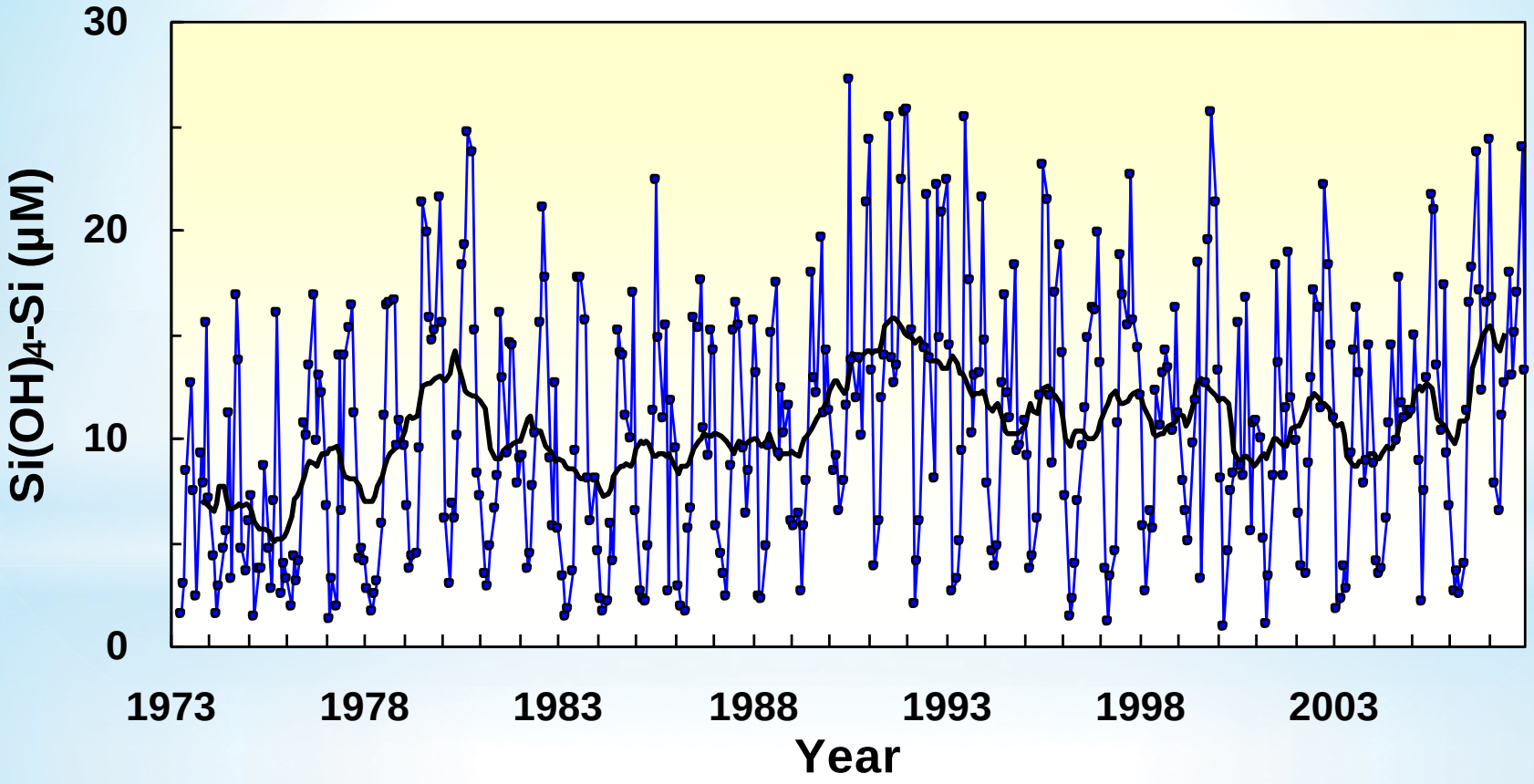
Long-term variations in phosphate

(April 1973-Dec 2007, mean of 3 depth at 19 sampling stations)



Long-term variations in silicic acid

(April 1973-Dec 2007, mean of 3 depth at 19 sampling stations)



Summary of water quality changes

Significant long-term changes:

□1) Rise in winter water temperature (0.042□ y^{-1})

□2) Decrease in dissolved inorganic nitrogen (DIN)
□ (10 µM in the 1970s to □5µM in the 1990s and thereafter)

* Mass mortality of yellowtail by a *Chattonella* red tide

Mass mortality of yellowtail, *Seriola quinqueradiata*, cultured in cages by a red tide of raphidoflagellate *Chattonella antiqua* (Seto Inland Sea, Aug.1977)

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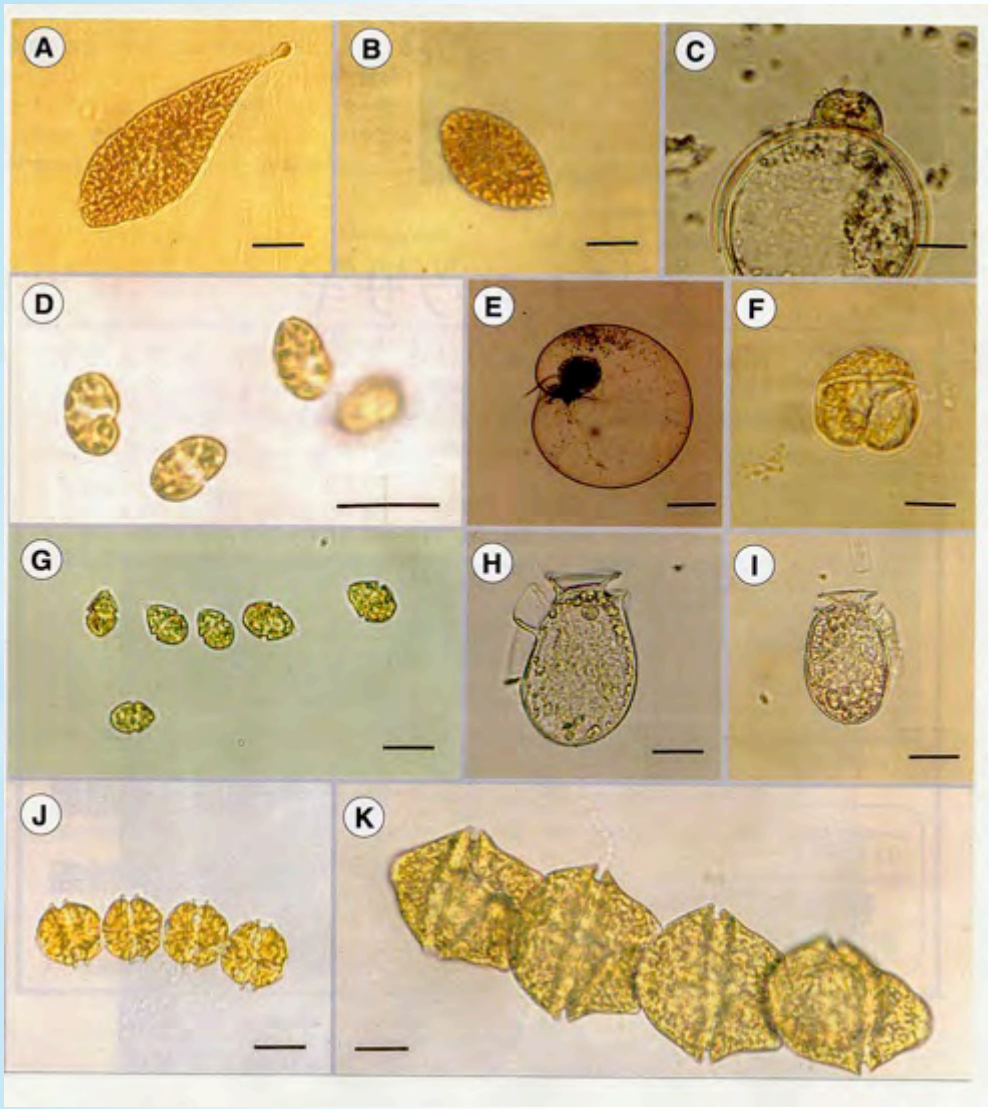
Harmful algae in the Seto Inland Sea



Bars=20μm, E=100μm

A-G: Red tide algae

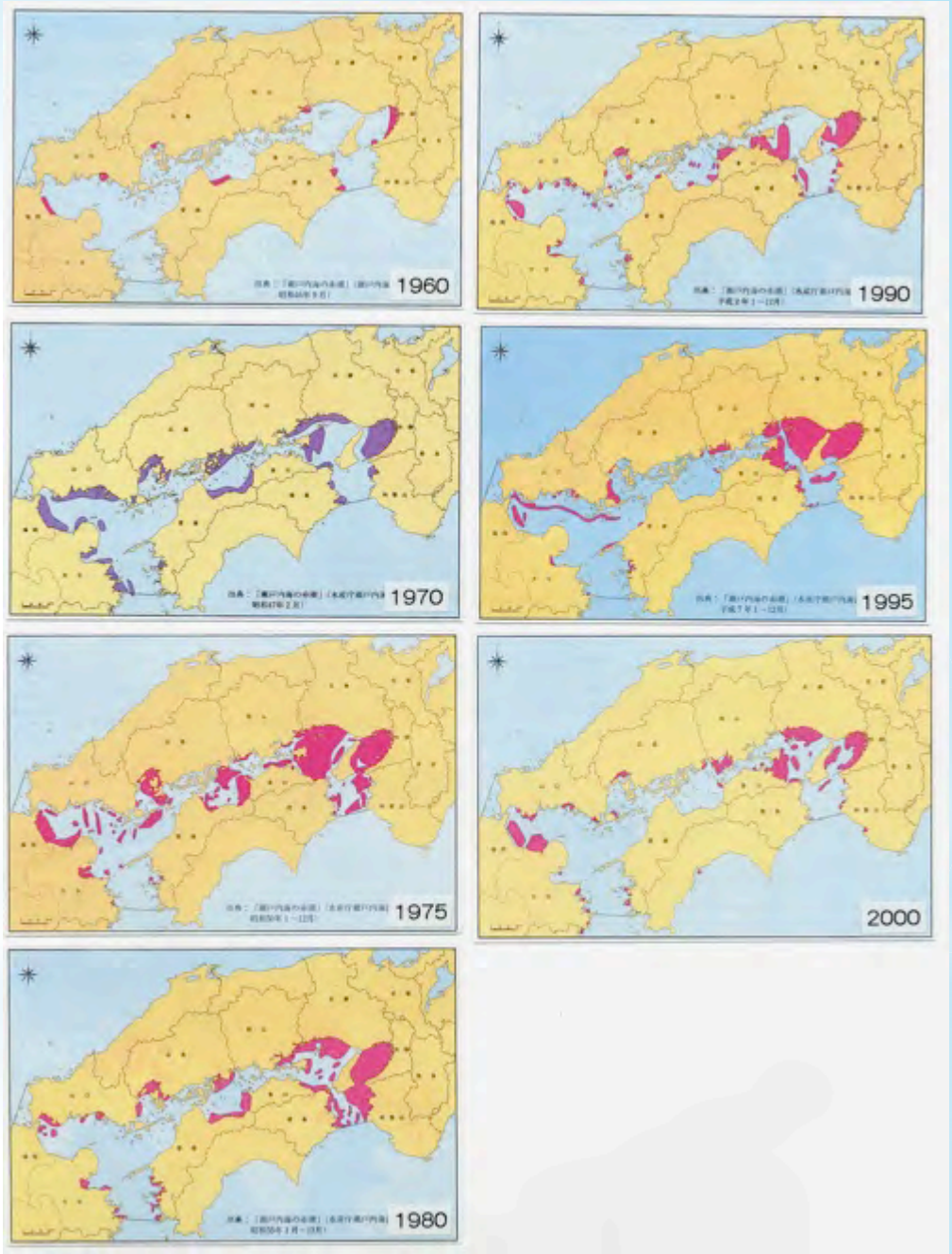
- **A: *Chattonella antiqua***
- **B: *Chattonella marina***
- **C: A cyst of *Chattonella***
- **D: *Heterosigma akashiwo***
- **E: *Noctiluca scintillans***
- **F: *Karenia mikimotoi***
- **G: *Heterocapsa circularisquama***

H-K: Toxic algae

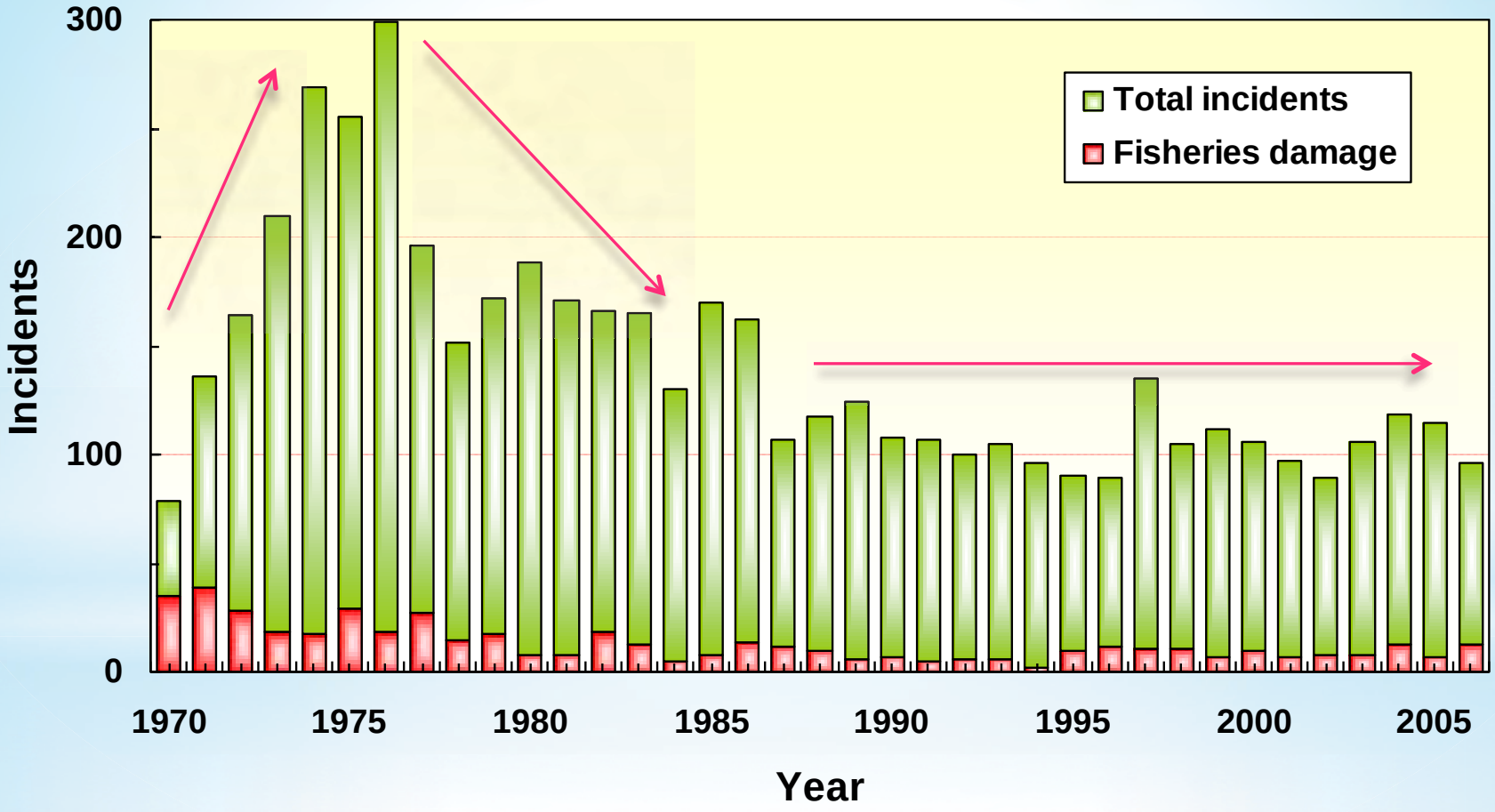
- **H: *Dinophysis fortii***
- **I: *Dinophysis acuminata***
- **J: *Alexandrium catenella***
- **K: *Gymnodinium catenatum***

*Changes in the red tide areas

*Large scale red tides had been frequent in 1970□s and 1980

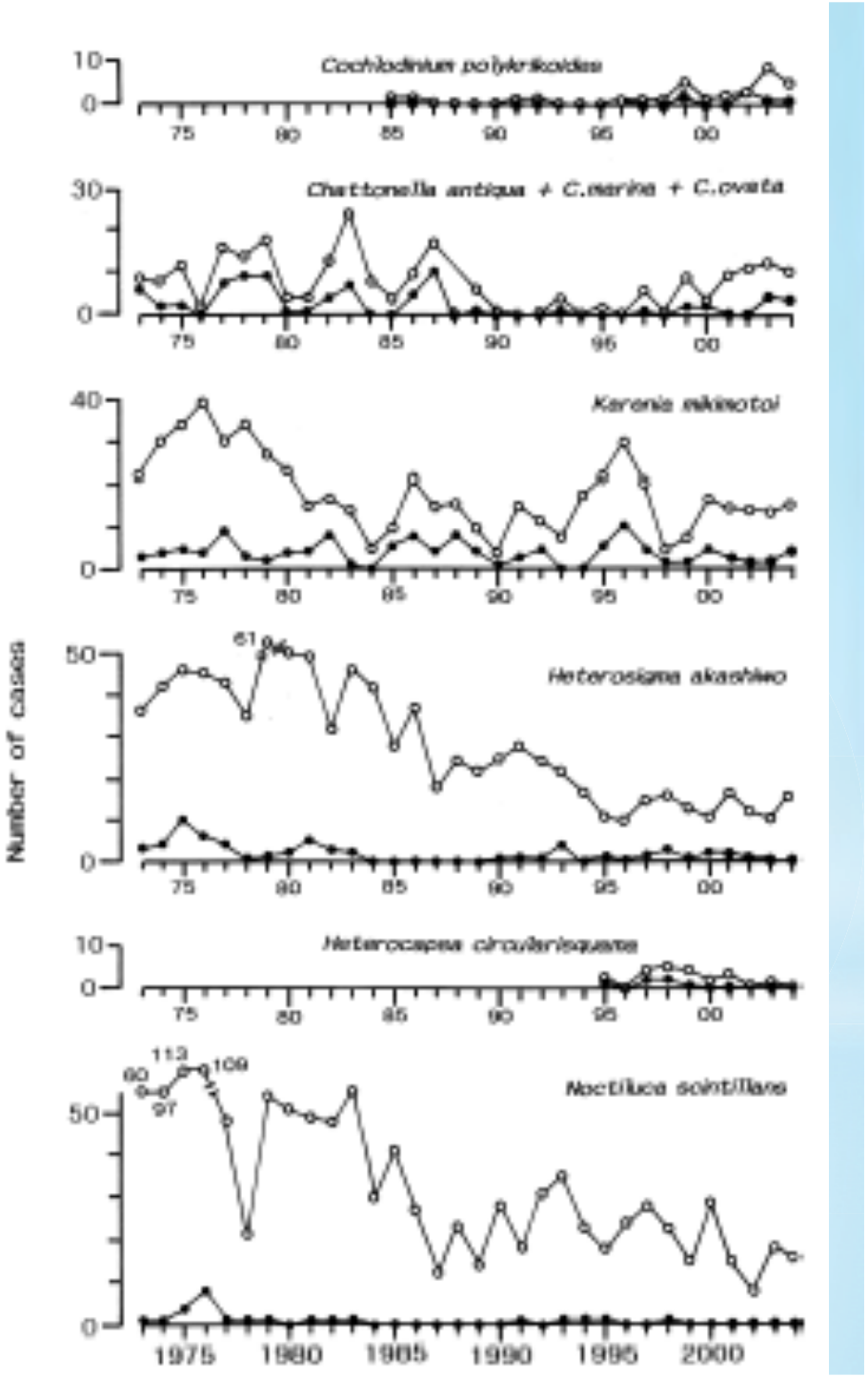


Occurrence of red tides in the Seto Inland Sea from 1970 to 2006



* Incidents of red tides caused by main species

* Recent increase of *Cochlodinium polykrikoides*
* Revival of *Chattonella* and increase of *C. ovata*
* Long-term decrease of *Heterosigma akashiwo* and *Noctiluca scintillans*



* Fishery damage amounts (yen) given by main red tide species in the Seto Inland Sea

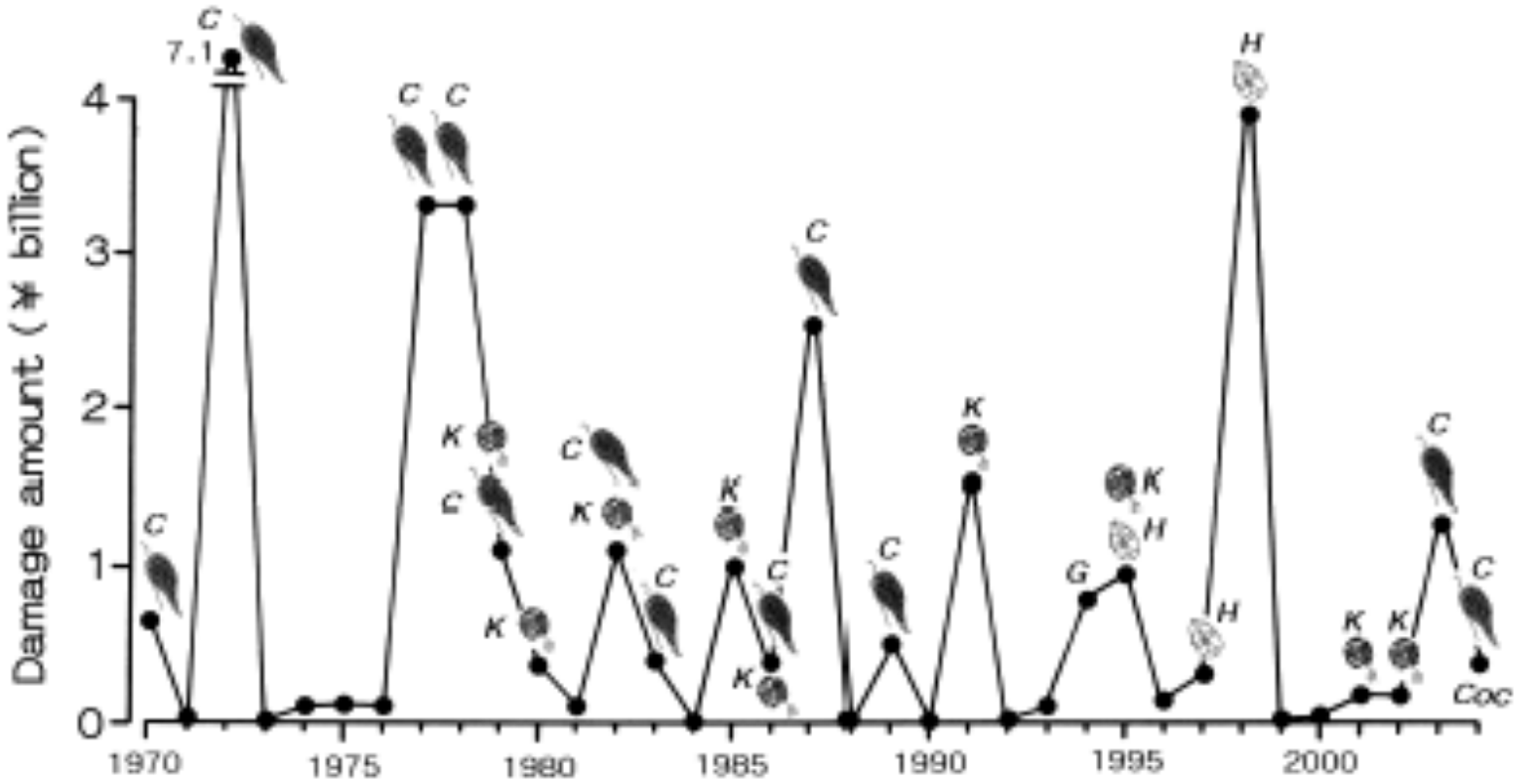


Fig. 7. Fishery damage to aquaculture caused by noxious red tides in the Seto Inland Sea from 1970 to 2004. Illustrations indicate causative microalgae responsible for >80% of total damage of each year. *C*: *Chattonella* spp. (*C. antiqua*, *C. marina* and *C. ovata*), *K*: *Karenia mikimotoi*, *H*: *Heterocapsa circularisquama*, *G*: *Gonyaulax polygramma*, *Coc*: *Cochlodinium polykrikoides*.

First occurrences of red tides and notes on the origin of the representative red-tide organisms in the Japanese coastal sea.

* Speceis	First red tide (year)	Notes
Chattonella antiqua	Hiroshima Bay (1969)	Hidden flora *
Karenia mikimotoi	Ago Bay, Gokasho Bay (1933) Tokuyama Bay (1957)	Inherent red-tide species
Heterosigma akashiwo	Bingo-Nada (1966)	Hidden flora
Heterocapsa circularisquama	Uranouchi Inlet (1988)	Introduced species (?)
* *Cochlodinium polykrikoides*	Yatsushiro Sea (1975)	Hidden flora and/or transported species by Tsushima Current

* These species have inhabited at low cell densities before the occurrence of red tide (Smayda 2002).

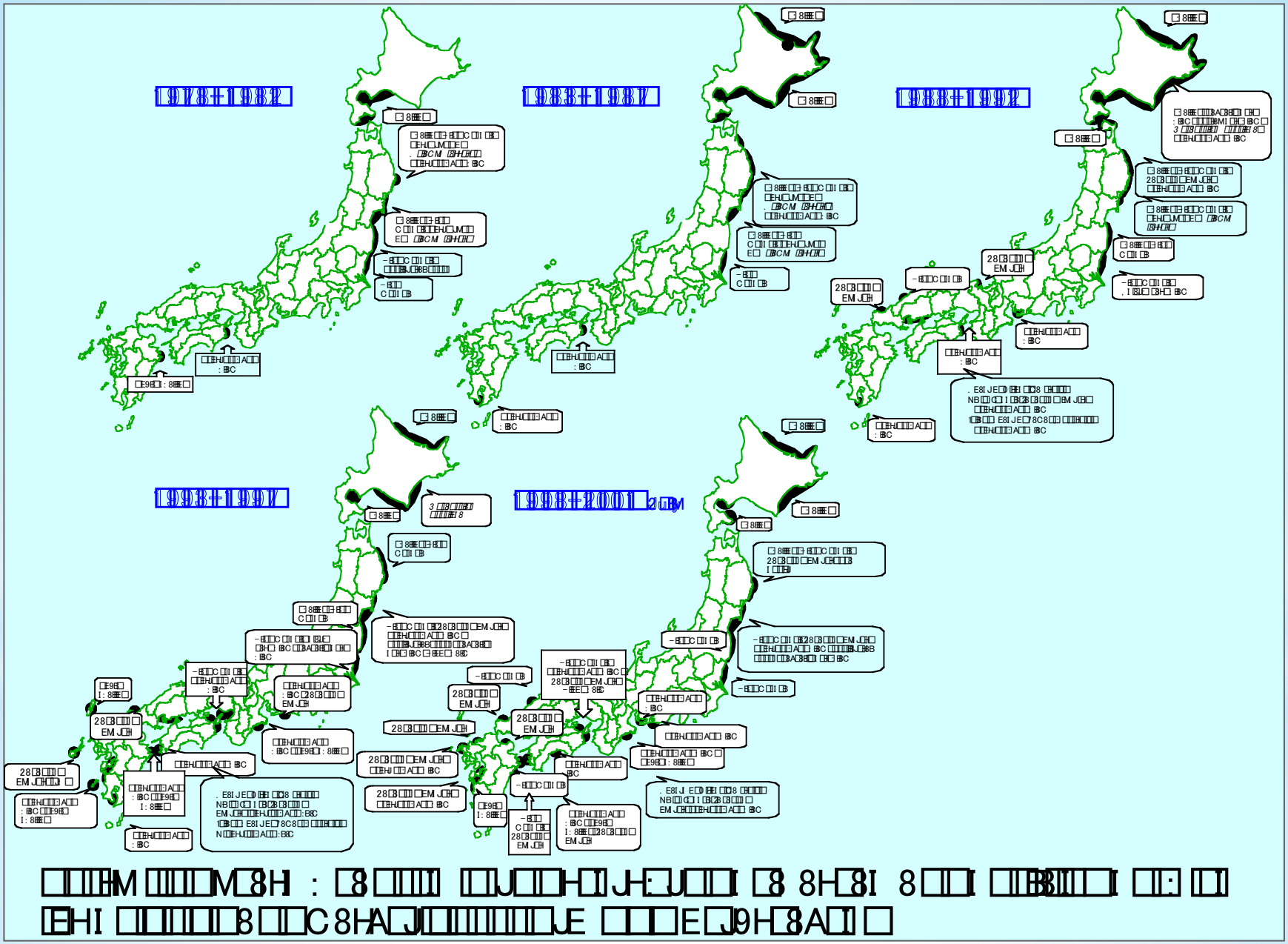
* Warning levels of main red tide species in Hiroshima Prefecture, Seto Inland Sea

Table 4. Warning level of cell densities of five representative red-tide organisms, minimum cell quota, and equivalent nutrient level to warning.

Species	Warning level (cells ml^{-1})	Minimum cell quota (fmol cell^{-1}) Nitrogen	Phosphorus	N (μM) equivalent to warning level	P (μM) equivalent to warning level
Chattonella antiqua	100	7800	620	0.78	0.062
Karenia mikimotoi	5000	3130	250	15.7	1.25
Heterosigma akashiwo	50000	1440	95	72.0	4.75
Heterocapsa circularisquama	500	1100	89.4	0.55	0.045+
Cochlodinium polykrikoides	500	5250	370	2.63	0.185

Chattonella antiqua, *Heterocapsa circularisquama* and *Cochlodinium polykrikoidea* are extremely dangerous red tide organisms.

* Distribution of PSP affected areas



Summary

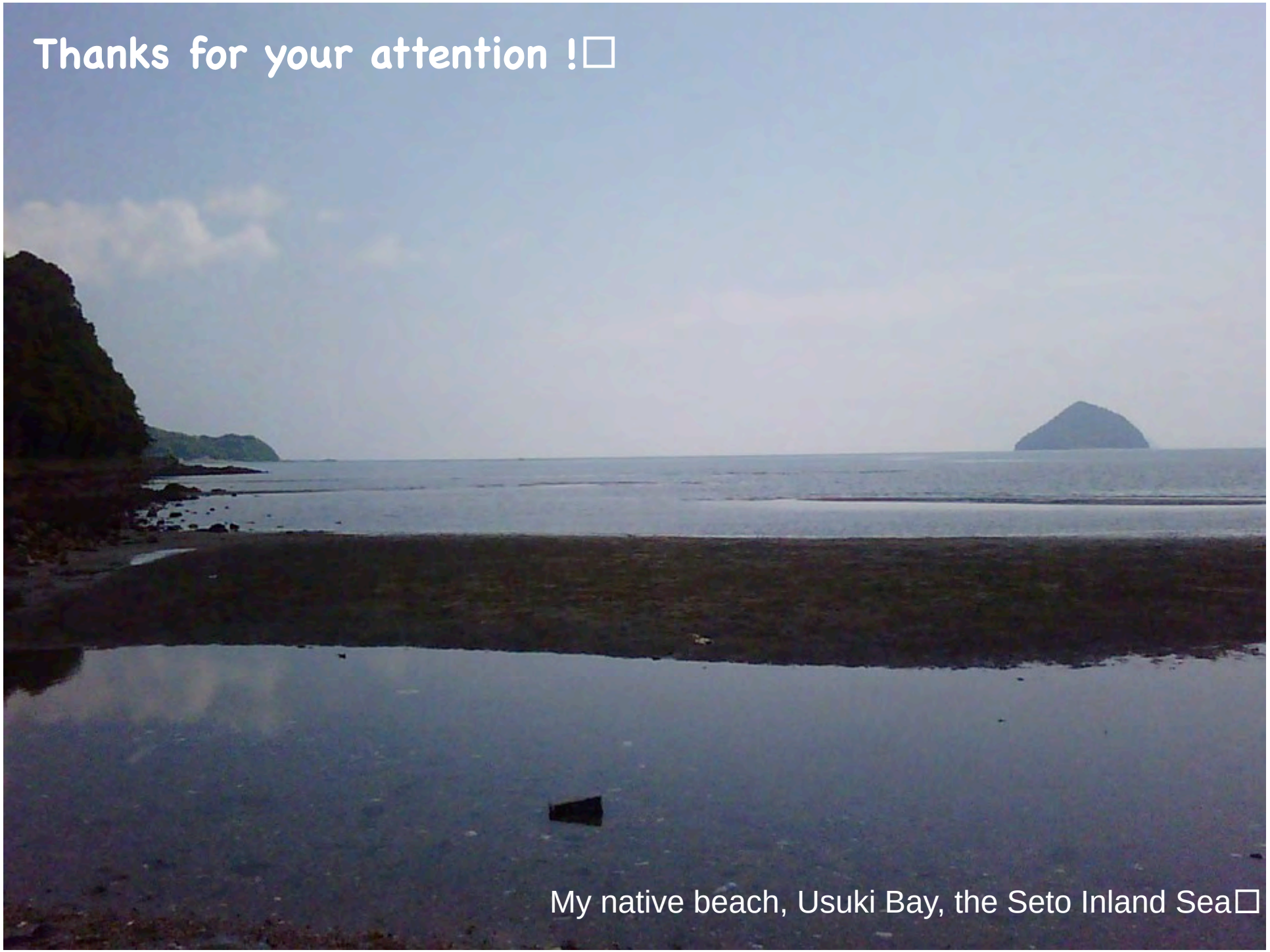
1 Total incidents of red tides were high during 1970s, decreased thereafter, and those have been about 100/yr and stable after 1990s and recent years

(no more decrease: WHY?).

2 *Heterosigma akashiwo* and *Noctiluca scintillans* have decreased in long-term trend.

3 *Cochlodinium polykrikoides* and *Chattonella* spp. are in increasing trend. *C. ovata* is new.

4 PSP problems started in the Seto Inland Sea by *Alexandrium tamarense* from about 1990


Thanks for your attention !☐
My native beach, Usuki Bay, the Seto Inland Sea☐