HAB occurrences and eutrophication in the Seto Inland Sea

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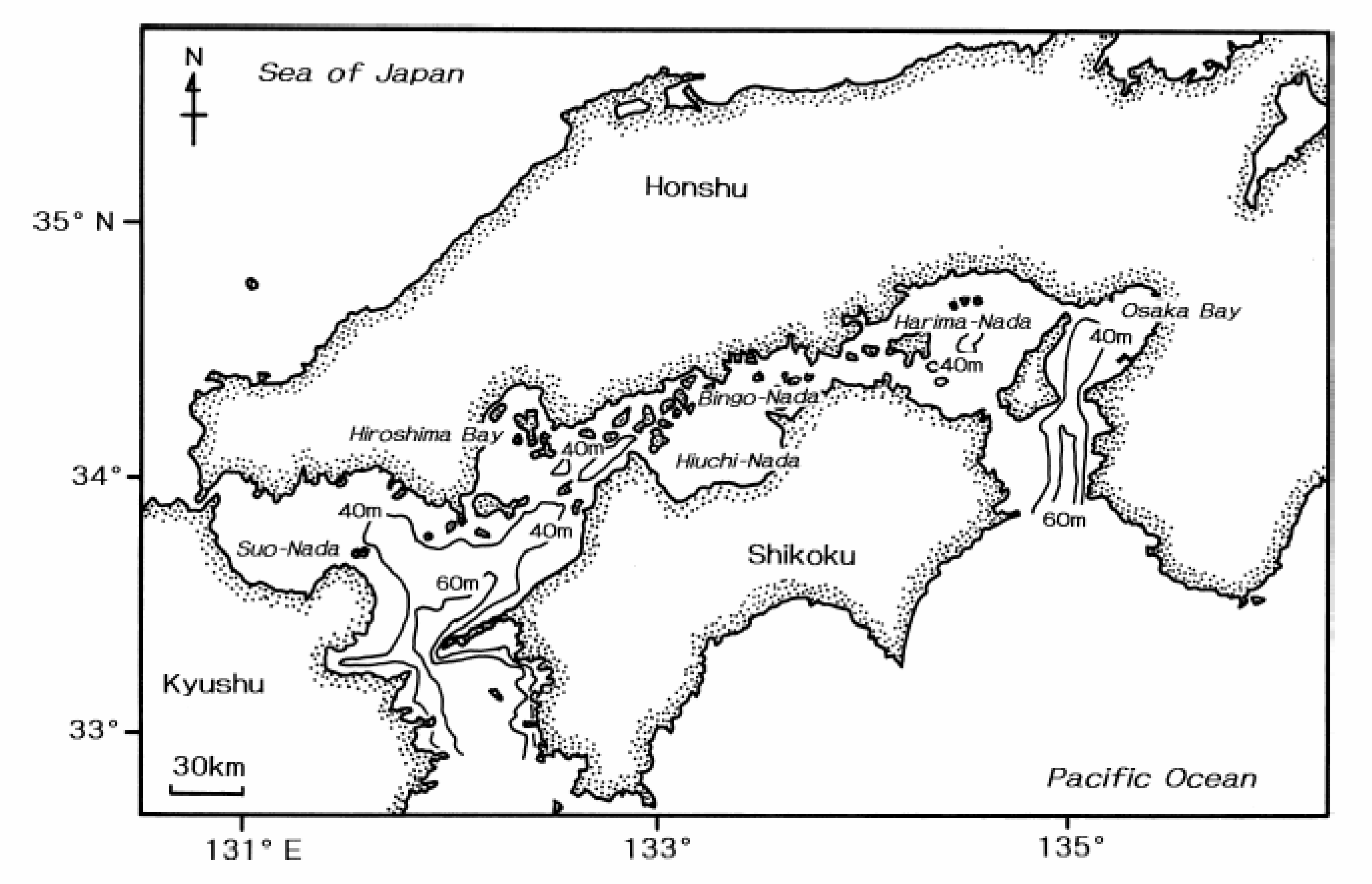
The Seto Inland Sea



Characteristics of the Seto Inland Sea, Japan

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

Pollutant loads of COD, P and N to the Seto Inland Sea

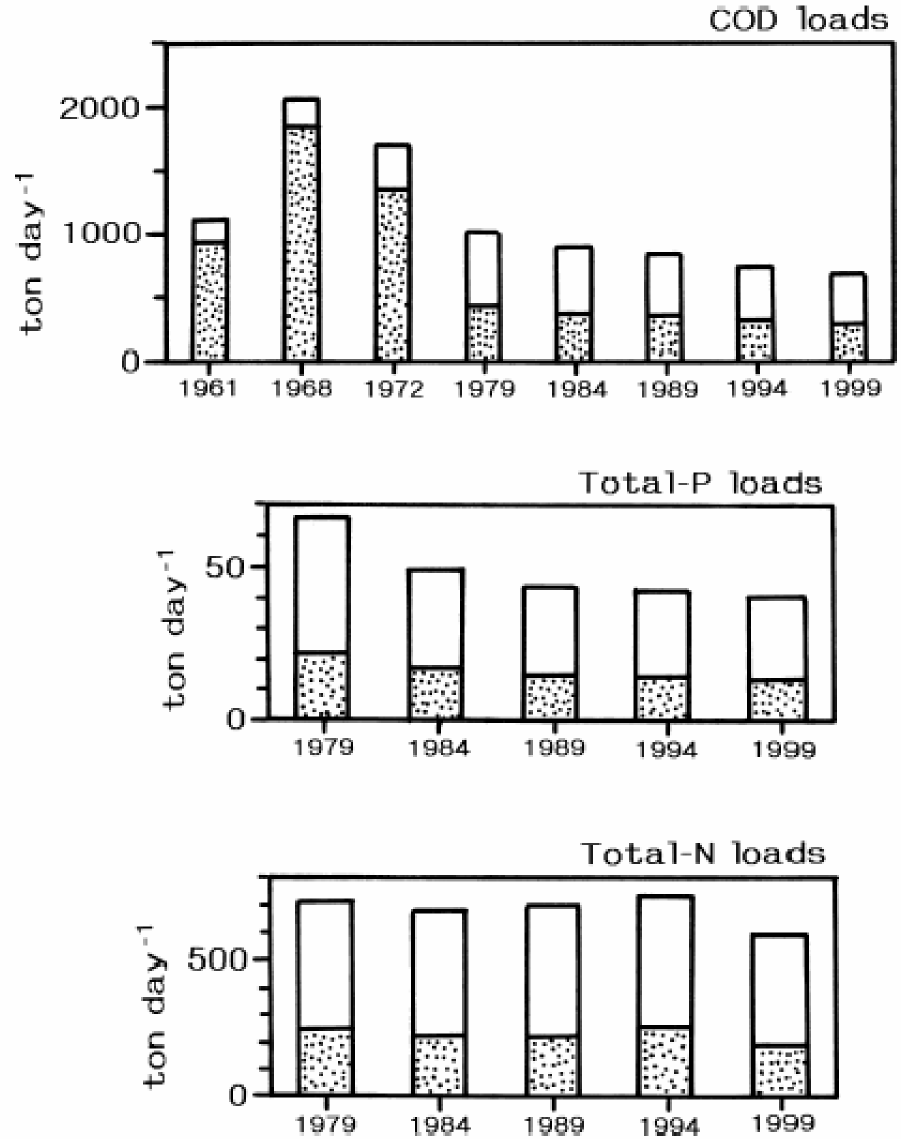


Fig. 2. Pollutant loads of COD, phosphorus, and nitrogen in the Seto Inland Sea. Open columns show the loads from households and others, and dotted columns show the industrial loads (from the Ministry of the Environment Government of Japan & the Association for the Environmental Conservation of the Seto Inland Sea 2001).

The law concerning special measures for conservation of the environment of the Seto Inland Sea (1973)

- Total pollutant load control

- COD loading:
  - 1700 tons/day in 1972

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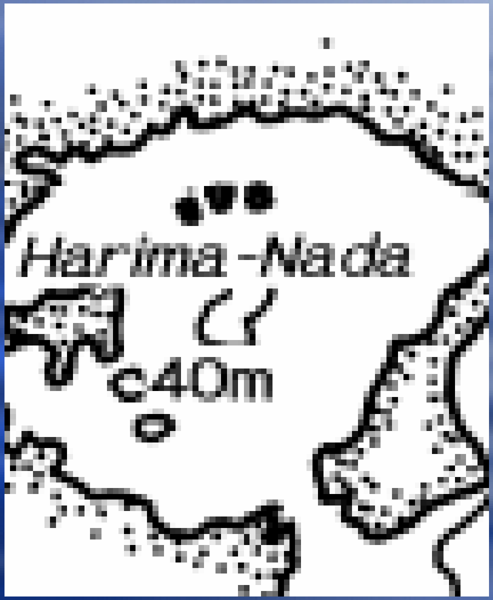
  - 717 tons/day in 1999

Long-term changes of water quality in Harima-Nada



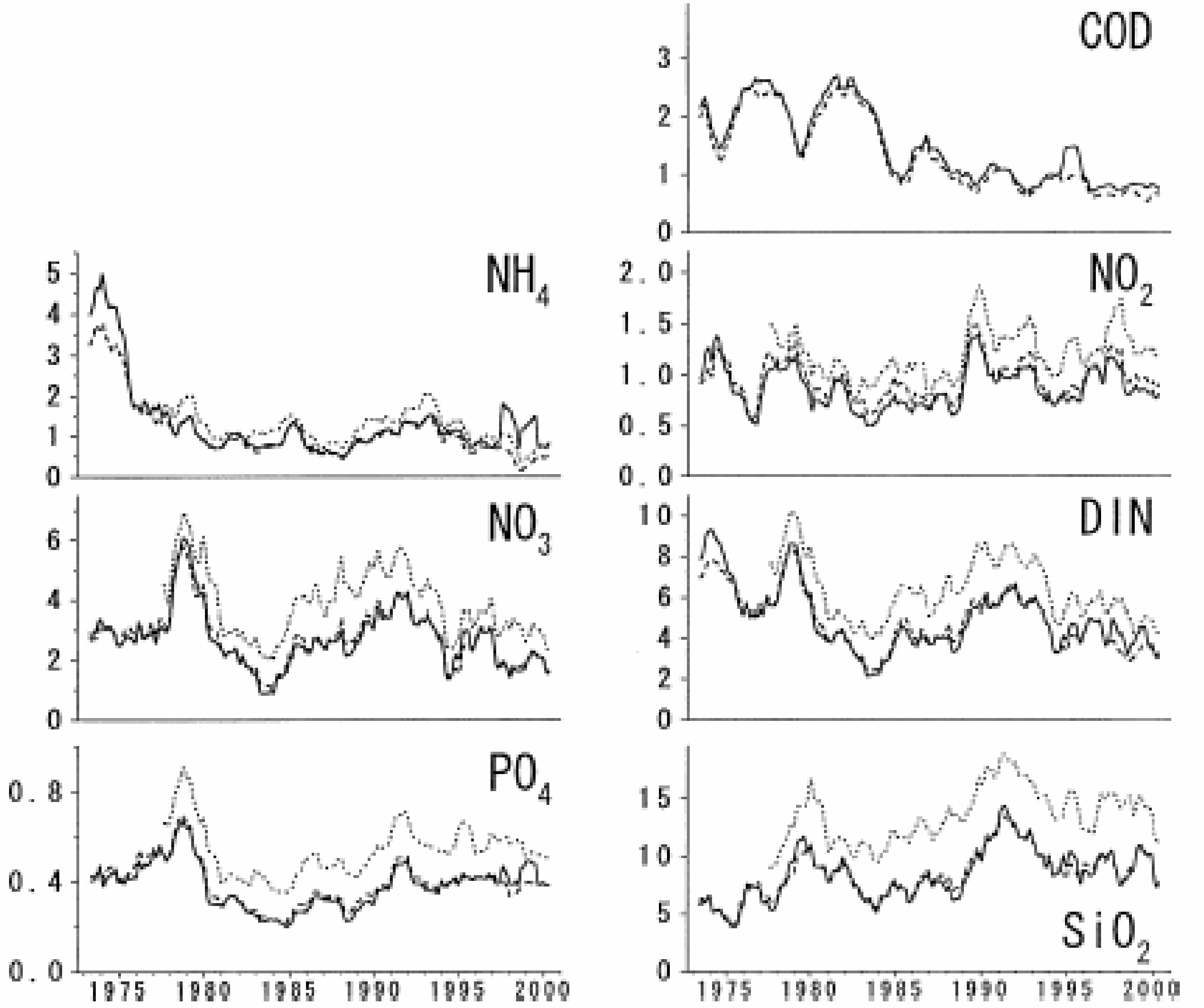
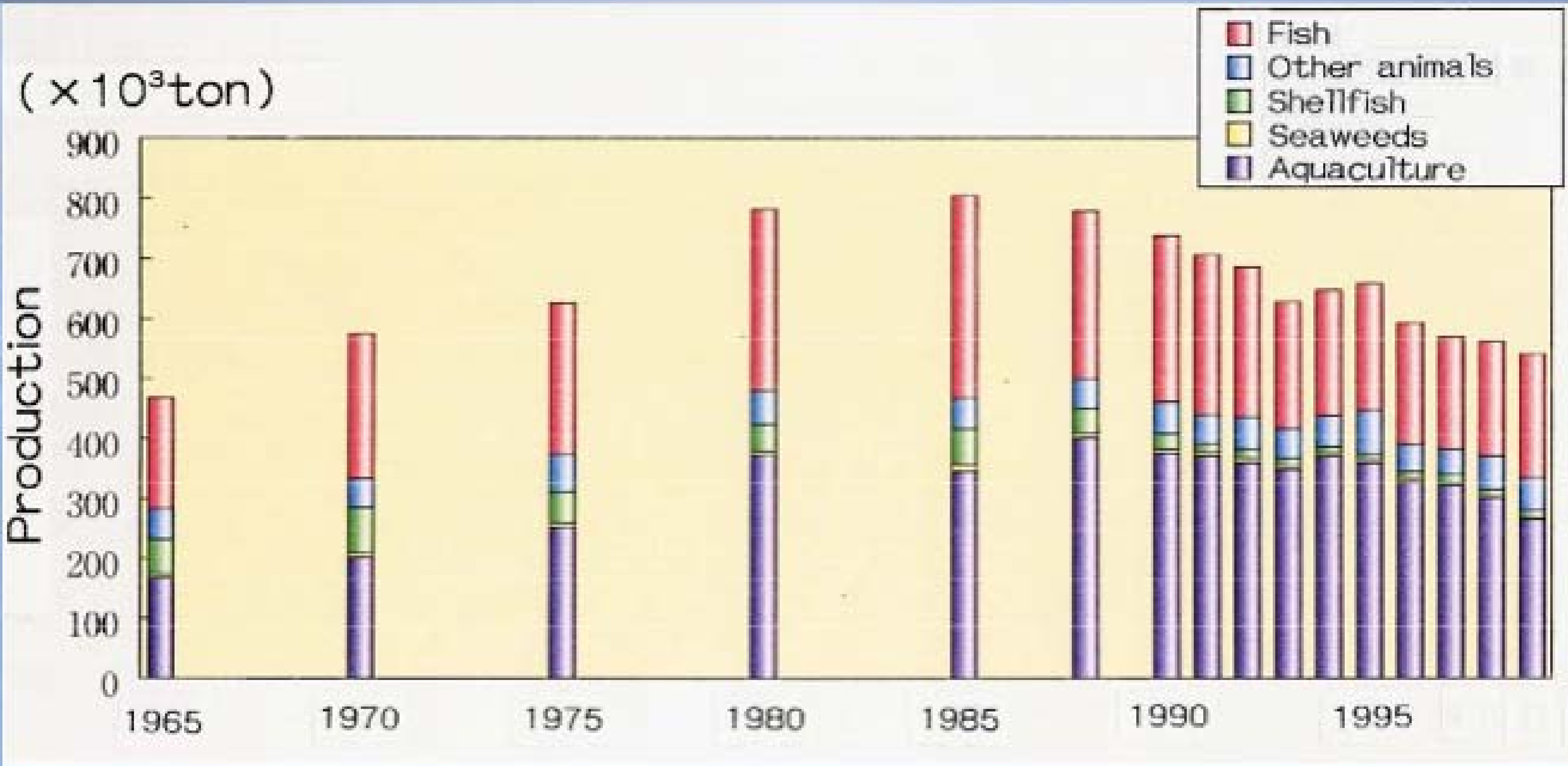


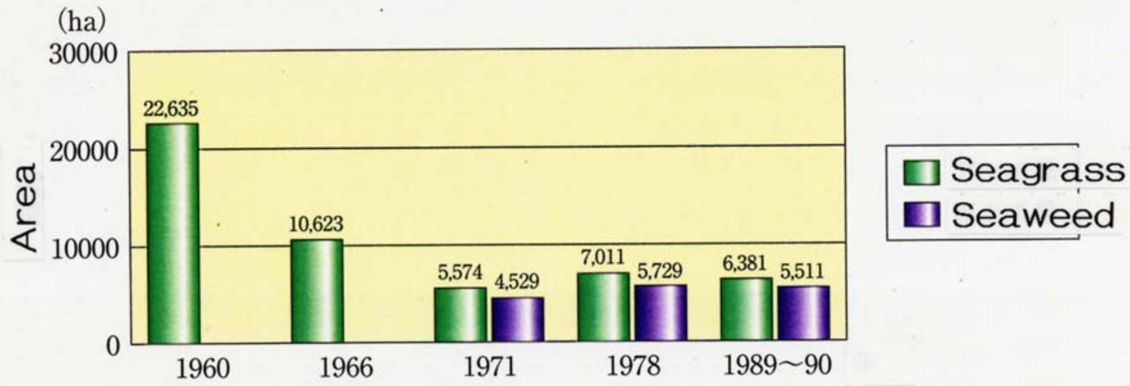
Fig. 3. Long-term changes in COD (mg L^{-1}) and nutrients (μM) in the north-eastern part of Harima-Nada, the Seto Inland Sea (solid lines: surface, dashed lines: 10 m, dotted lines: bottom) from April 1973 to March 2000. Data were treated by 12-month moving average process.

Fisheries production in the Seto Inland Sea

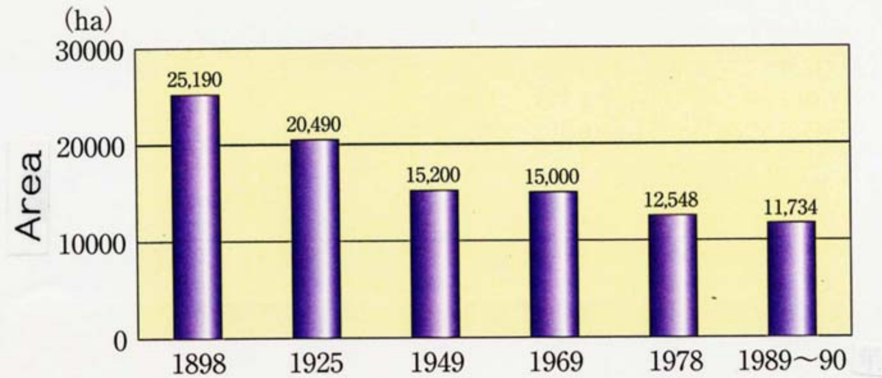


Decrease of seaweed and seagrass beds, and intertidal flats in the Seto Inland Sea

Large scale reclamations have been conducted in shallow area of the Seto Inland Sea.

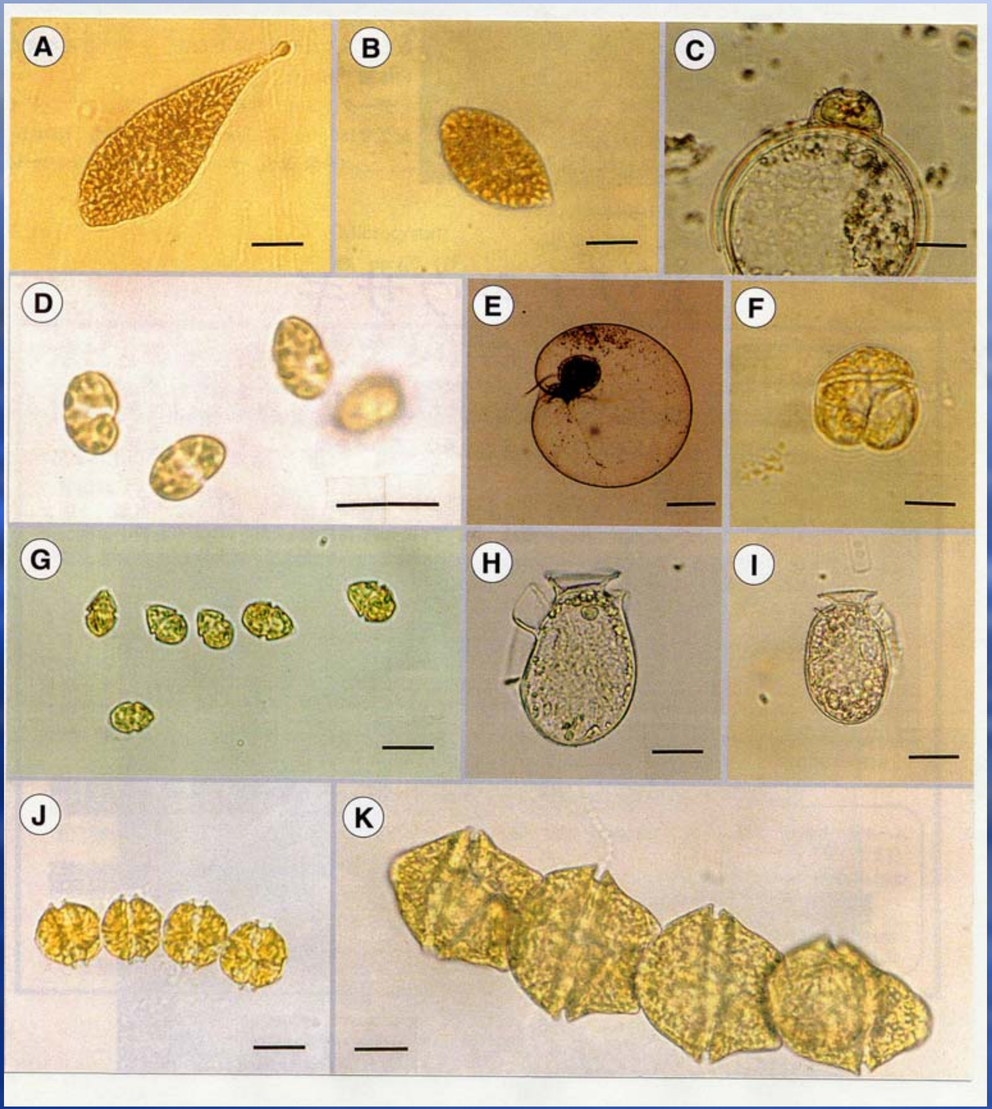


Changes in seaweed and seagrass beds in the Seto Inland Sea



Changes in intertidal flats in the Seto Inland Sea

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*

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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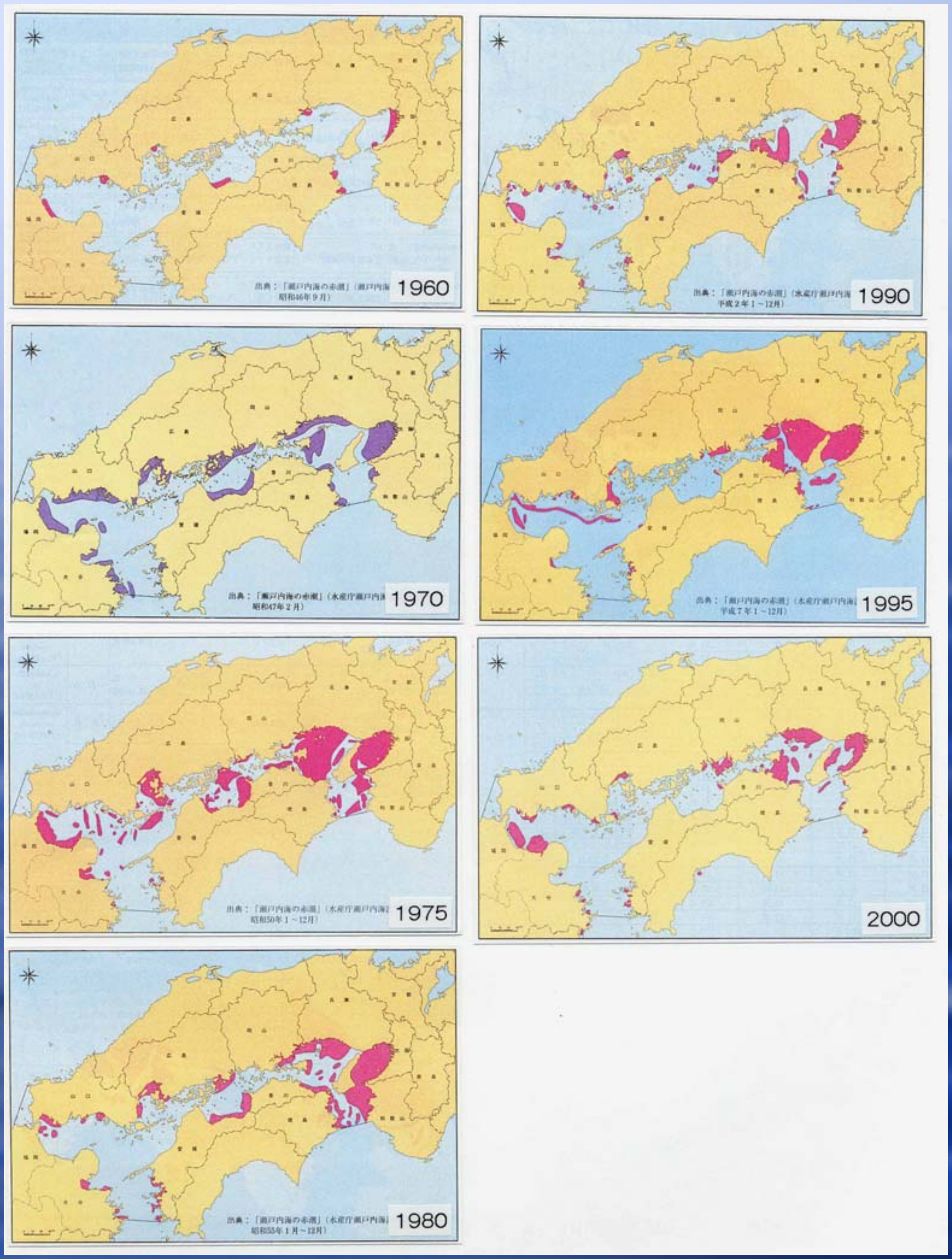
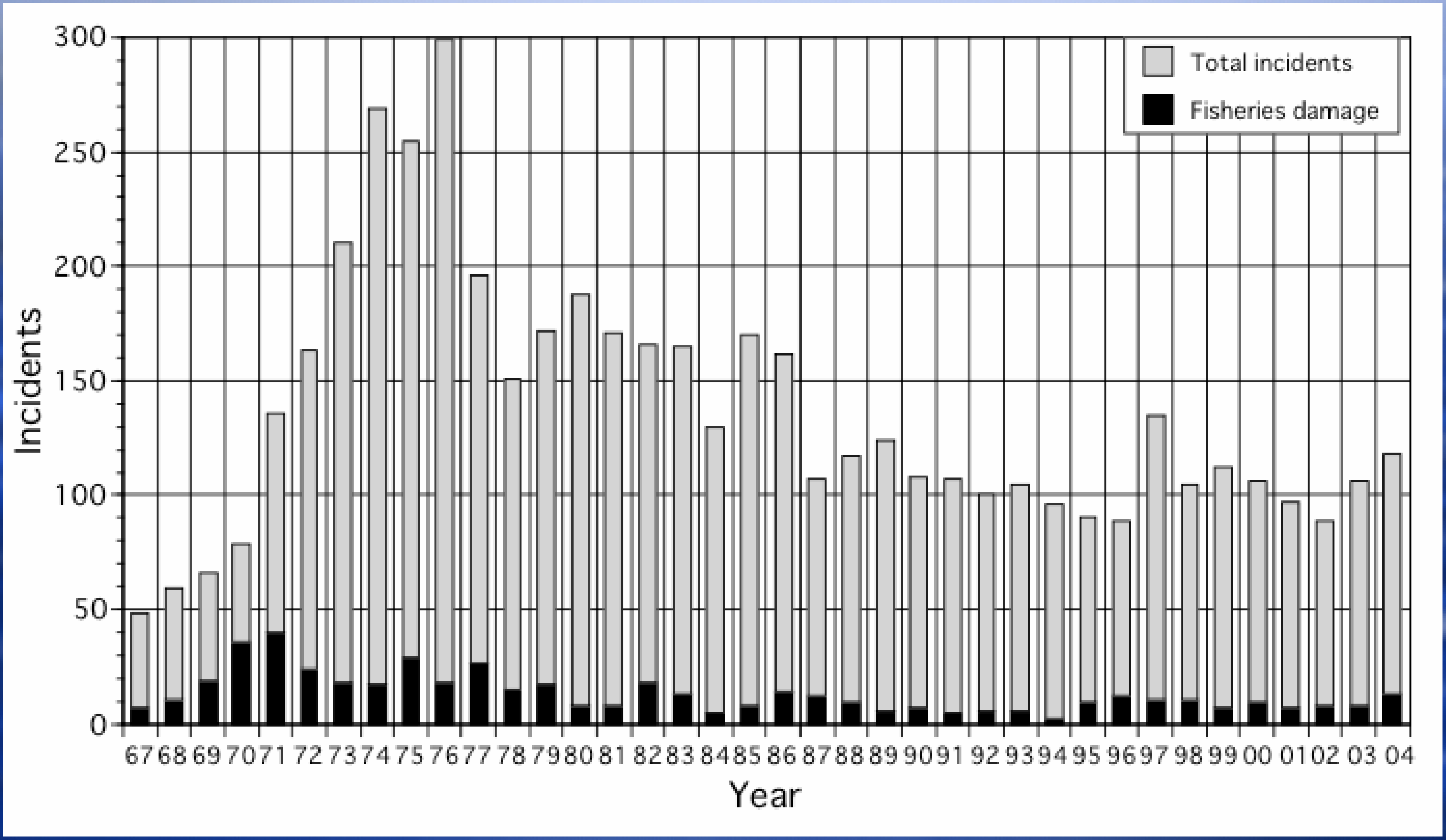
Changes in the red tide areas



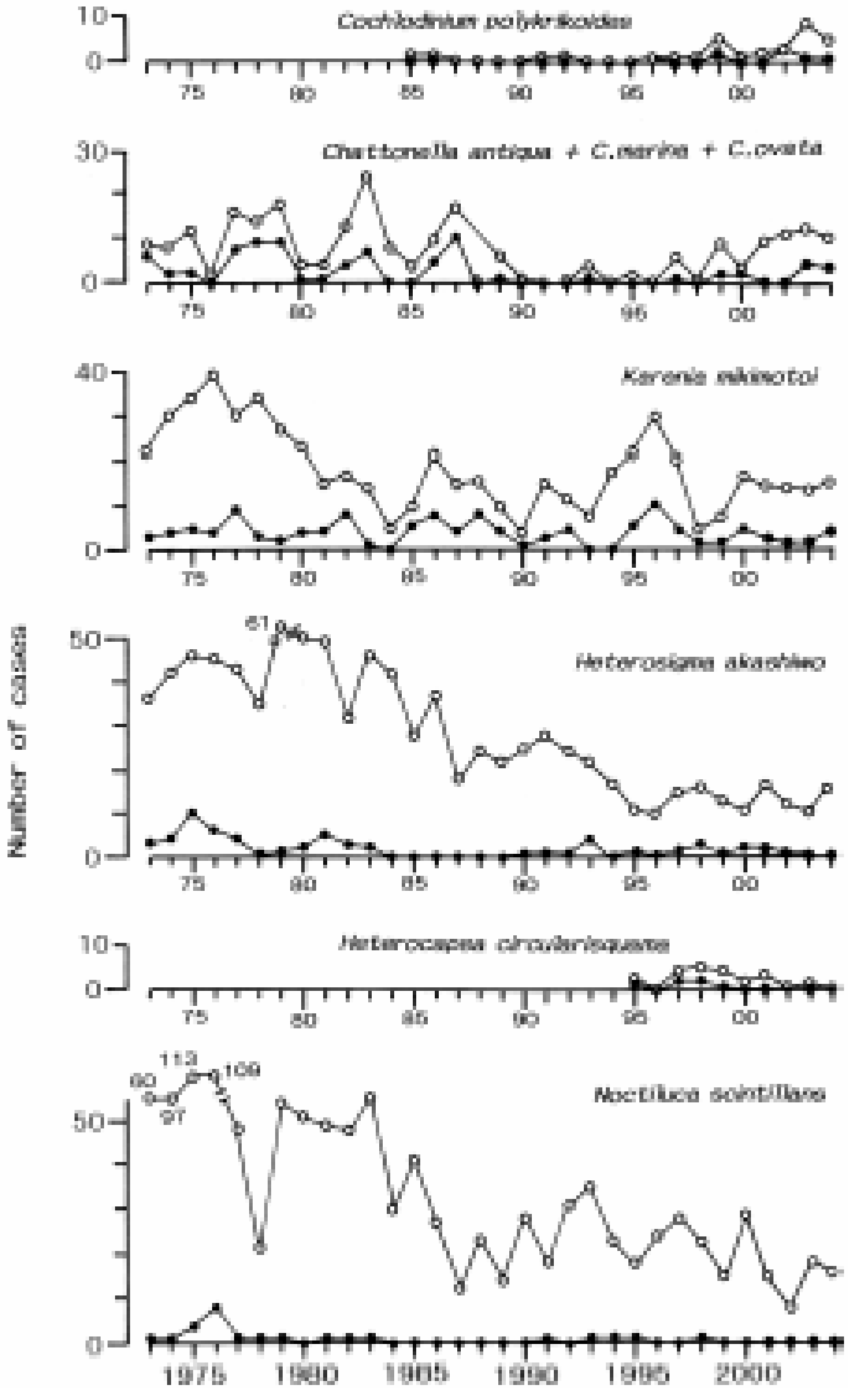
- Large scale red tides had been frequent in 1970's and 1980's

Incidents of red tides in the Seto Inland Sea



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

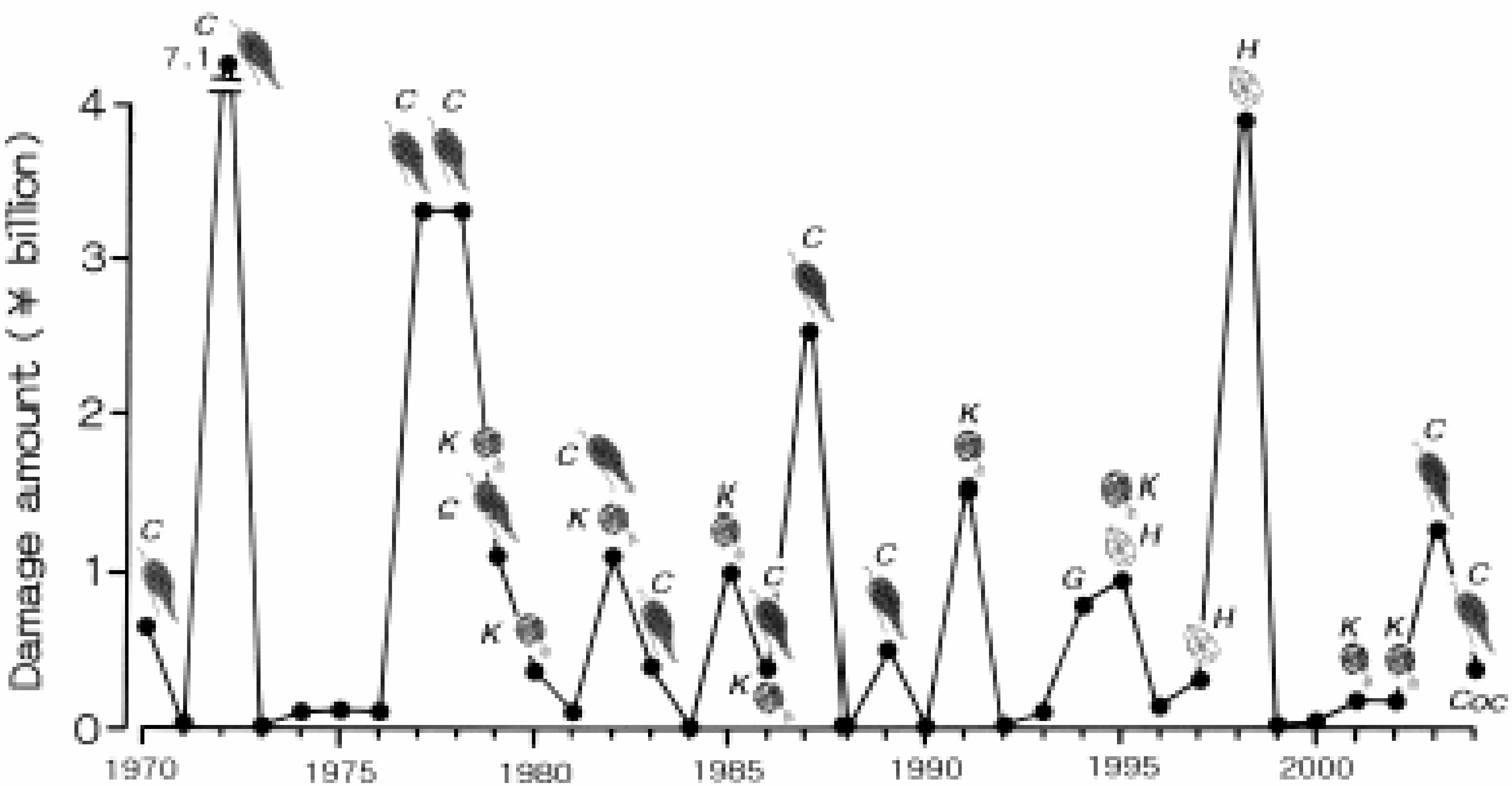


Fig. 7. Fishery damage to aquaculture caused by noxious red tides in the Seto Inland Sea from 1970 to 2004. Illustrations indicate causative microalgae responsible for >80% of total damage of each year. *C*: *Chattonella* spp. (*C. antiqua*, *C. marina* and *C. ovata*), *K*: *Karenia mikimotoi*, *H*: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

- Table 3. 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).

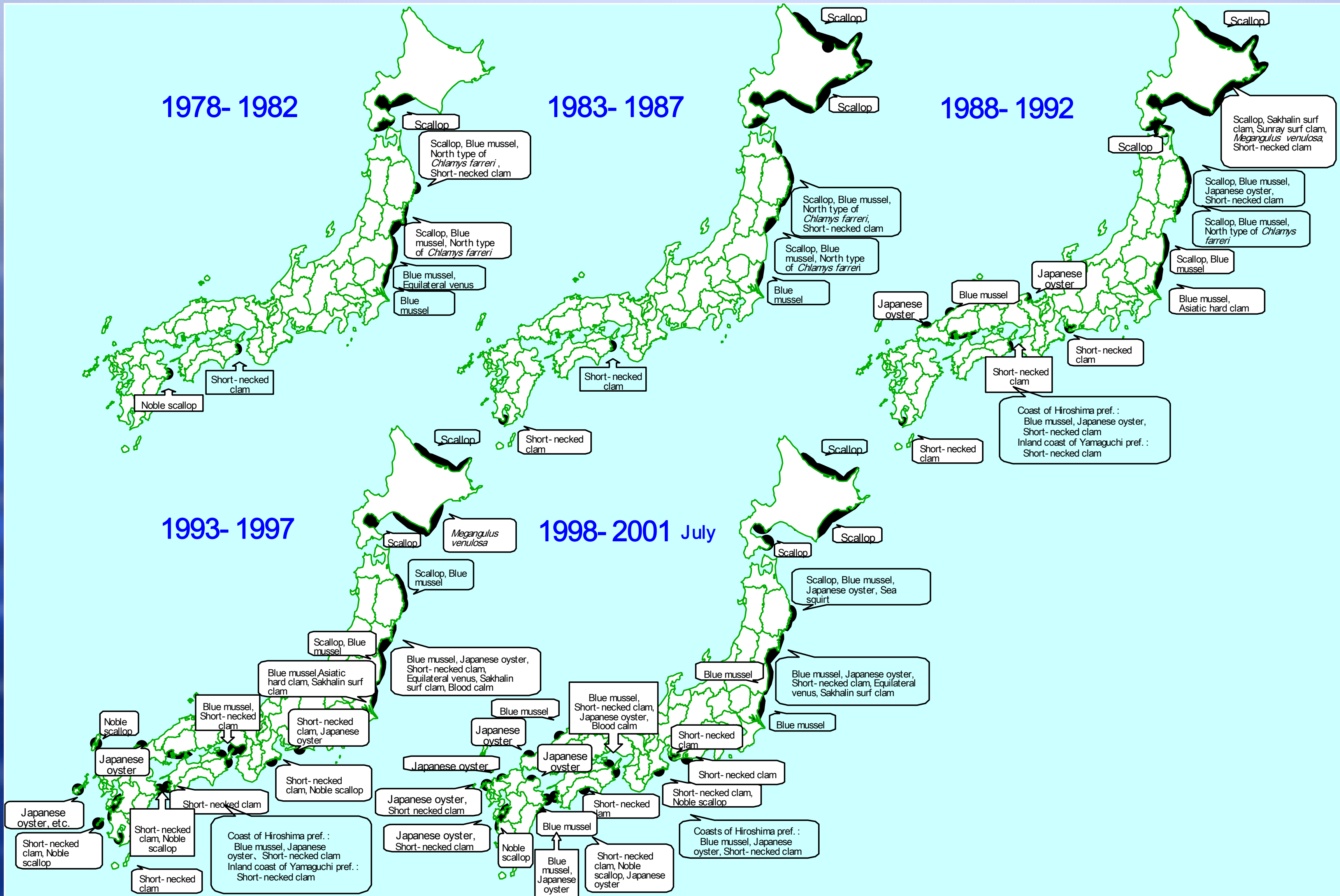
Warning levels of main red tide species in Hiroshima Prefecture, Seto Inland Sea

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



Every five years changes in the restricted sea areas and shellfish species for shipping and marketing, due to PSP outbreakes.

Summary

- Total incidents of red tides in recent years have been about 100/yr and stable.
- *Heterosigma akashiwo* and *Noctiluca scintillans* have decreased in long-term trend.
- *Cochlodinium polykrikoides* and *Chattonella* spp. are in increasing trend. *C. ovata* is new.
- PSP problems have been established in the Seto Inland Sea by *Alexandrium tamarense* from about 1990