Eutrophication and HAB

at
CEARAC Expert Meeting
on Eutrophication Assessment

Yasuwo Fukuyo：
Tokai University,
University of Tokyo

18 October 2017

Phytoplankton (microalgae) community

Confirmation of basic concept

Once eutrophication starts, HABs, especially harmful red tides, occurrence increases.

1. Eutrophication accelerates phytoplankton blooms,
2. Various harmful red tide species prefer eutrophic nutrient level,
3. Some species can utilize organic forms of nutrients, and consequently the species have advantage to grow.

The other group of HABs, *i.e.* toxic species looks preferring low nutrients level.

Confirmation of basic concept

Eutrophication: the process by which a body of water becomes enriched in dissolved nutrients that support growth of microalgae.

In eutrophic areas often cultural eutrophication could be observed in addition to natural eutrophication.

Four eutrophic level of water according to physico-chemical properties:

- Oligotrophic
- Eutrophic
- Extremely eutrophic
- Saprobic

Microalgae often present in oligotrophic water

Blue-green alga

Trichodesmium spp.

Dinoflagellate

Amphisolenia bidentate

Ceratium arcticum

C. carriense

C. contortum

C. extensum

C. parmatum

C. pentagonum

C. sumatranum

Ceratocorys horrida

Dinophysis miles

D. fortii

Ornithocercus serratus

O. splendidus

Protoperidinium conicum

P. thorianum

Diatom

Bacteriastrum elongatum

Chaetoceros atlanticus

C. borealis

C. coarctatus

C. messanensis

C. pendulus

C. peruvianus

Climacodium concavum

Hemiaulus hauckii

Planktoniella sol

Rhizosolenia bergonii

R. castracanei

Thalassiothrix delicatula

(Based on Yamada et al. 1980)

Microalgae often present in eutrophic water

Dinoflagellate

- *Alexandrium catenella*
- *Ceratium furca*
- *C. fusus*
- *Cochlodinium polykrikoides*
- *Dinophysis acuminata*
- *D. caudata*
- *Heterocapsa circularisquama*
- *Karenia mikimotoi*
- *Noctiluca scintillans*
- *Prorocentrum micans*

Raphidoflagellate

- *Chattonella antiqua*
- *C. marina*
- *Heterosigma akashiwo*

Diatom

- *Bacillaria paradoxa*
- *Bacteriastrum varians*
- *Ceratoaulina bergonii*
- *Chaetoceros affinis*
- *C. compressus*
- *C. decipiens*
- *C. didymus*
- *C. socialis*
- *Coscinodiscus asteromphalus*
- *C. wailesii*
- *Eucampia zodiacus*
- *Leptocylindrus danicus*
- *Pseudo-nitzschia pungens*
- *Rhizosolenia fragilissima*
- *Skeletonema costatum*

(Based on Yamada et al. 1980)

Microalgae sometimes forming red tides

Dinoflagellate
- *Alexandrium catenella*
- *Ceratium furca*
- *C. fusus*
- *Cochlodinium polykrikoides*
- *Dinophysis acuminata*
- *D. caudata*
- *Heterocapsa circularisquama*
- *Karenia mikimotoi*
- *Noctiluca scintillans*
- *Prorocentrum micans*

Raphidoflagellate
- *Chattonella antiqua*
- *C. marina*
- *Heterosigma akashiwo*

Diatom
- *Bacillaria paradoxa*
- *Bacteriastrum varians*
- *Ceratoaulina bergonii*
- *Chaetoceros affinis*
- *C. compressus*
- *C. decipiens*
- *C. didymus*
- *C. socialis*
- *Coscinodiscus asteromphalus*
- *C. wailesii*
- *Eucampia zodiacus*
- *Leptocylindrus danicus*
- *Pseudo-nitzschia pungens*
- *Rhizosolenia fragilissima*
- *Skeletonema costatum*

(Based on Yamada et al. 1980)

Microalgae sometimes forming harmful red tides

Dinoflagellate

Alexandrium catenella
Ceratium furca
C. fusus
Cochlodinium polykrikoides
Dinophysis acuminata
D. caudata
Heterocapsa circularisquama
Karenia mikimotoi
Noctiluca scintillans
Prorocentrum micans

Raphidoflagellate

Chattonella antiqua
C. marina
Heterosigma akashiwo

Diatom

Bacillaria paradoxa
Bacteriastrum varians
Ceratoaulina bergonii
Chaetoceros affinis
C. compressus
C. decipiens
C. didymus
C. socialis
Coscinodiscus asteromphalus
C. wailesii
Eucampia zodiacus
Leptocylindrus danicus
Pseudo-nitzschia pungens
Rhizosolenia fragilissima
Skeletonema costatum

(Based on Yamada et al. 1980)

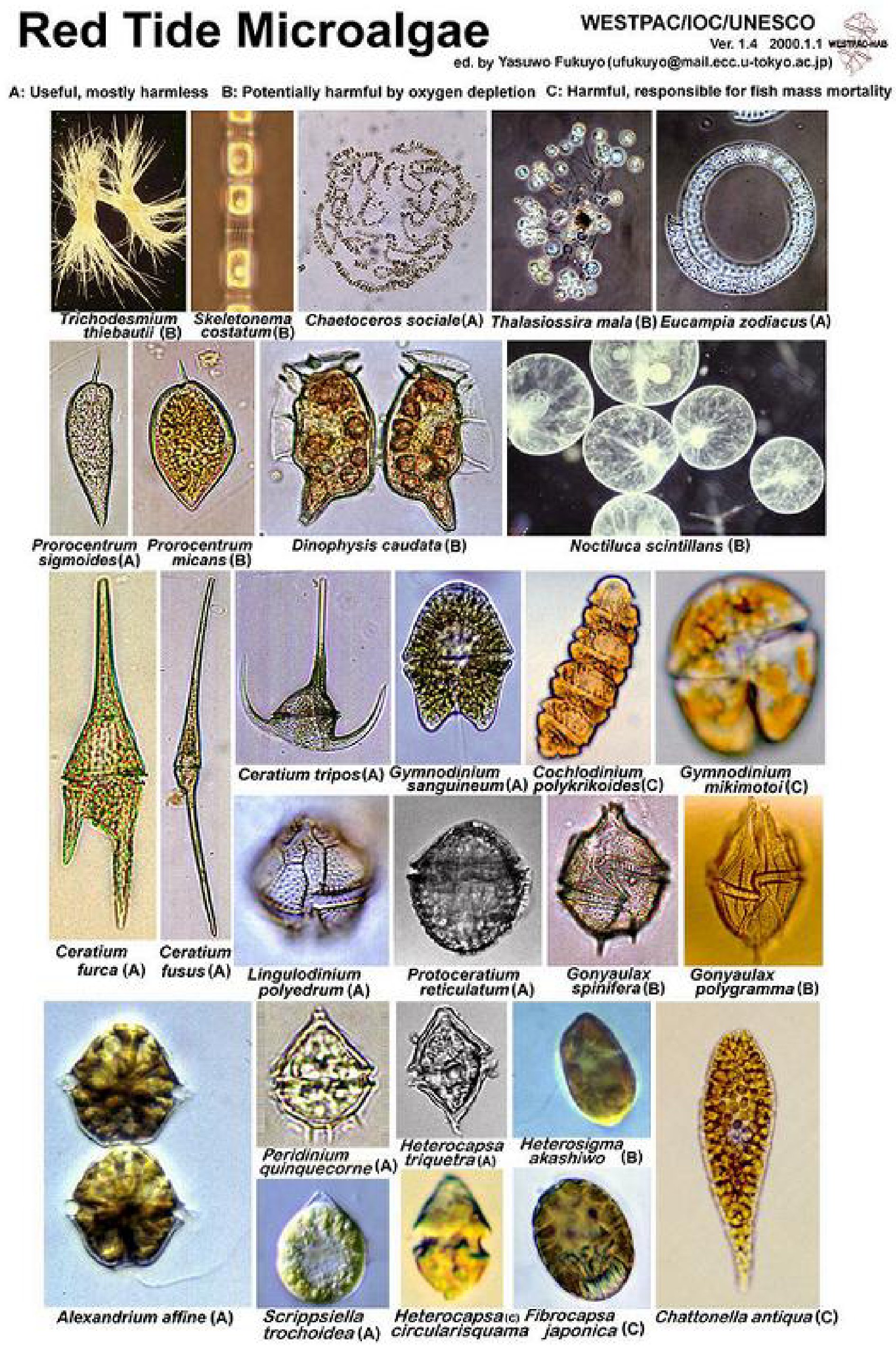
Red tide species

Very few toxin-producers make red tides.

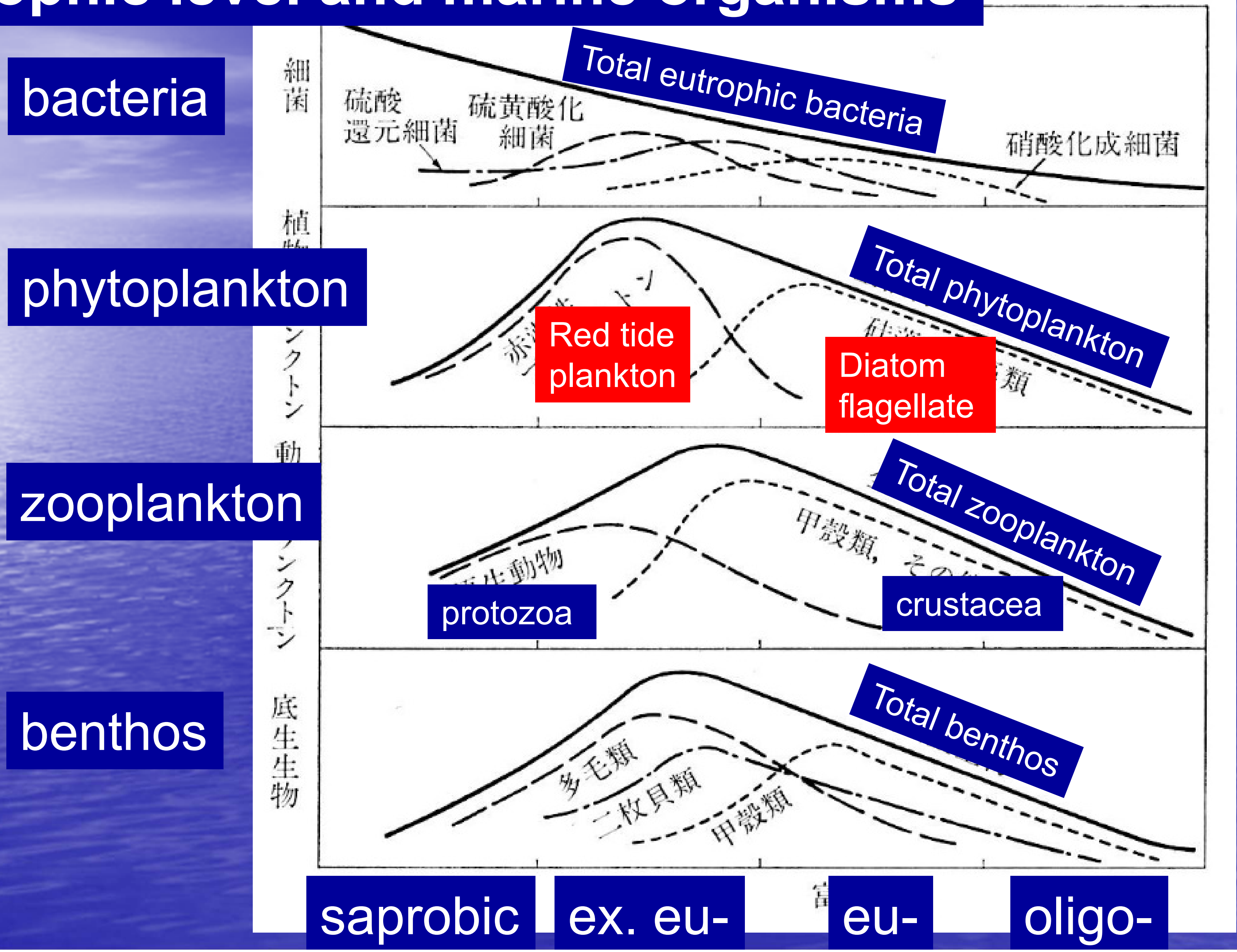
Alexandrium catenella

Pyrodinium bahamese

Pyrodinium bahamense



Trophic level and marine organisms



Perspectives on future red tides

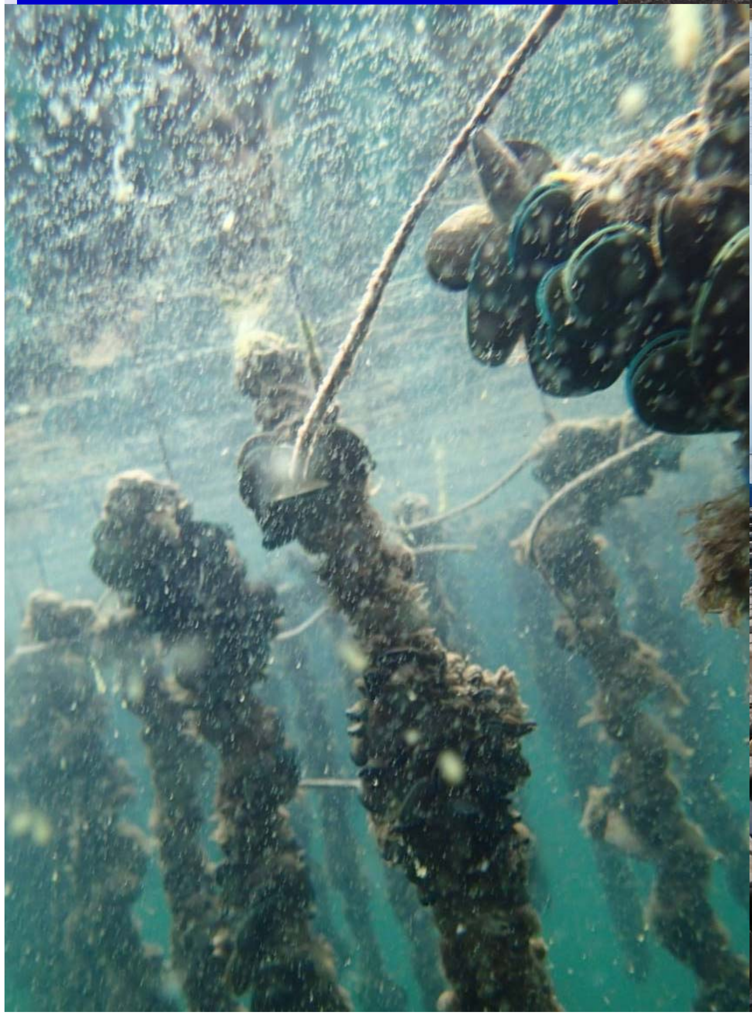
Case number will increase more,
as eutrophication in coastal water will be more serious.

Harmful consequences will occur more,
as fish and shellfish aquaculture will be operated in wider areas.

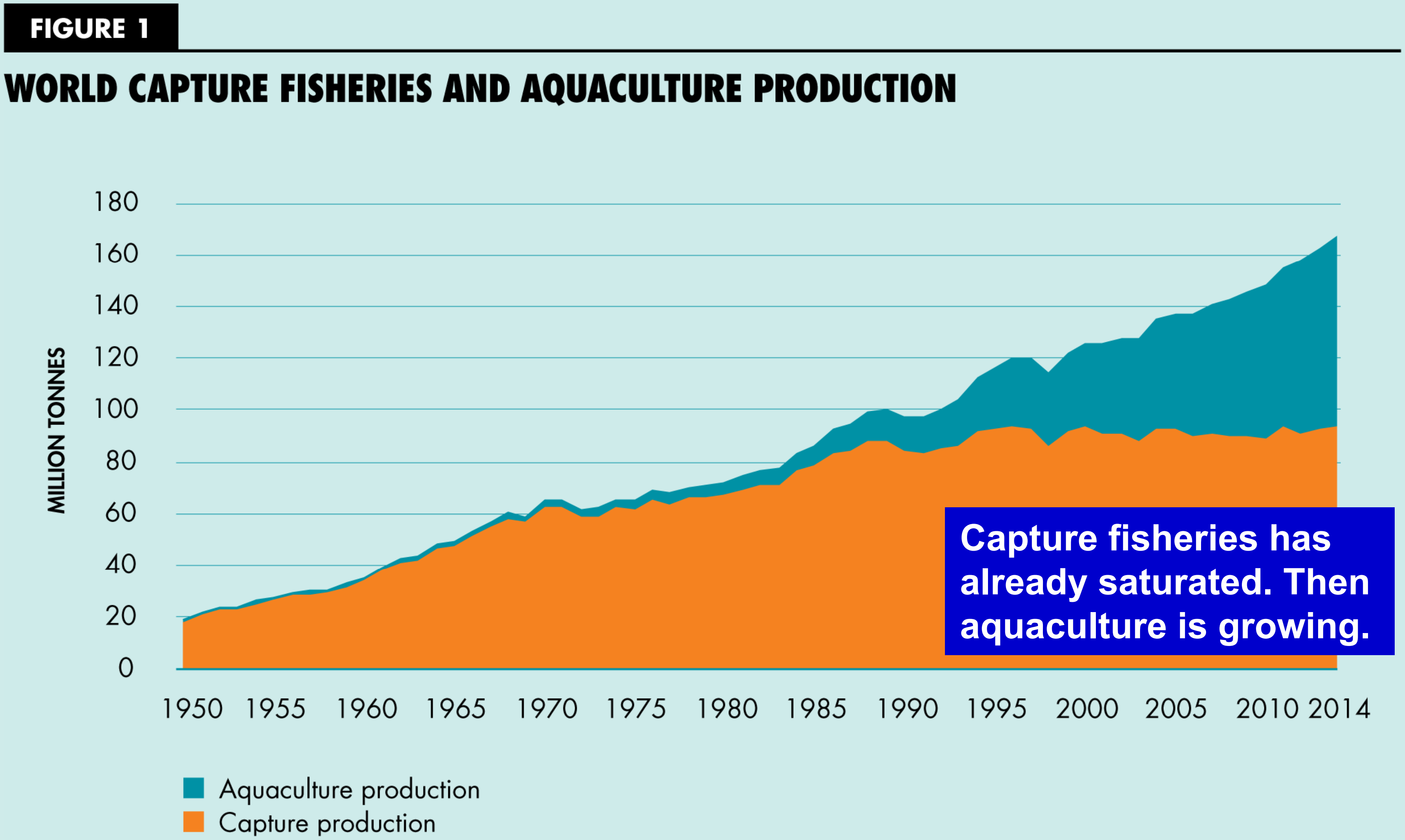
It means that, along with eutrophication more serious, red tides become harmful ones.

Observation of trophic level and its trend will be more and more important.

Coastal area utilization for tourism, and fisheries



Coastal area utilization; in case of Fisheries



Capture fisheries has already saturated. Then aquaculture is growing.

FAO 2016

TOP 25 PRODUCERS AND MAIN GROUPS OF FARMED SPECIES IN 2014

MAJOR PRODUCERS	FINFISH: INLAND AQUACULTURE	FINFISH: MARINE/ COASTAL AQUACULTURE	MOLLUSCS	CRUSTACEANS	OTHER AQUATIC ANIMALS	TOTAL AQUATIC ANIMALS	AQUATIC PLANTS	TOTAL AQUACULTURE PRODUCTION
	(Thousand tonnes)							
China	26 029.7	1 189.7	13 418.7	3 993.5	839.5	**45 469.0**	13 326.3	**58 795.3**
Indonesia	2 857.6	782.3	44.4	613.9	0.1	**4 253.9**	10 077.0	**14 330.9**
India	4 391.1	90.0	14.2	385.7	...	**4 881.0**	3.0	**4 884.0**
Viet Nam	2 478.5	208.5	198.9	506.2	4.9	**3 397.1**	14.3	**3 411.4**
Philippines	299.3	373.0	41.1	74.6	...	**788.0**	1 549.6	**2 337.6**
Bangladesh	1 733.1	93.7	...	130.2	...	**1 956.9**	...	**1 956.9**
Republic of Korea	17.2	83.4	359.3	4.5	15.9	**480.4**	1 087.0	**1 567.4**
Norway	0.1	1 330.4	2.0	...	...	**1 332.5**	...	**1 332.5**
Chile	68.7	899.4	246.4	...	...	**1 214.5**	12.8	**1 227.4**
Egypt	1 129.9	...	...	7.2	...	**1 137.1**	...	**1 137.1**
Japan	33.8	238.7	376.8	1.6	6.1	**657.0**	363.4	**1 020.4**
Myanmar	901.9	1.8	...	42.8	15.6	**962.2**	2.1	**964.3**
Thailand	401.0	19.6	209.6	300.4	4.1	**934.8**	...	**934.8**
Brazil	474.3	...	22.1	65.1	0.3	**561.8**	0.7	**562.5**
Malaysia	106.3	64.3	42.6	61.9	0.6	**275.7**	245.3	**521.0**
Democratic People's Republic of Korea	3.8	0.1	60.2	...	0.1	**64.2**	444.3	**508.5**
United States of America	178.3	21.2	160.5	65.9	...	**425.9**	...	**425.9**
Ecuador	28.2	0.0	...	340.0	...	**368.2**	...	**368.2**
Taiwan Province of China	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Iran (Islamic Republic of)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Nigeria	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Spain	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Turkey	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
United Kingdom	13.5	167.3	23.8	...	...	**204.6**	...	**204.6**
France	43.5	6.0	154.5	0.0	...	**204.0**	0.3	**204.3**

East Asia

SEast Asia

Asian countries utilize aquatic bio-resources for growing society and population

FAO 2016

Comparison between 2004 and 2014

Top ten aquaculture producers of food fish supply: quantity and emerging growth

Producer	2002 (Tonnes)	2004 (Tonnes)	APR (Percentage)
Top ten producers in terms of quantity, 2004			
China	27 767 251	30 614 968	5.0
India	2 187 189	2 472 335	6.3
Viet Nam	703 041	1 198 617	30.6
Thailand	954 567	1 172 866	10.8
Indonesia	914 071	1 045 051	6.9
Bangladesh	786 604	914 752	7.8
Japan	826 715	776 421	-3.1
Chile	545 655	674 979	11.2
Norway	550 209	637 993	7.7
United States of America	497 346	606 549	10.4
TOP TEN SUBTOTAL	35 732 648	40 114 531	6.0
REST OF THE WORLD	4 650 830	5 353 825	7.3
TOTAL	**40 383 478**	**45 468 356**	**6.1**
Top ten pro			
Myanmar			
Viet Nam			
Turkey			
Netherland			
Republic of			
Iran (Islami			
Egypt			
Chile			
Thailand			

East Asia

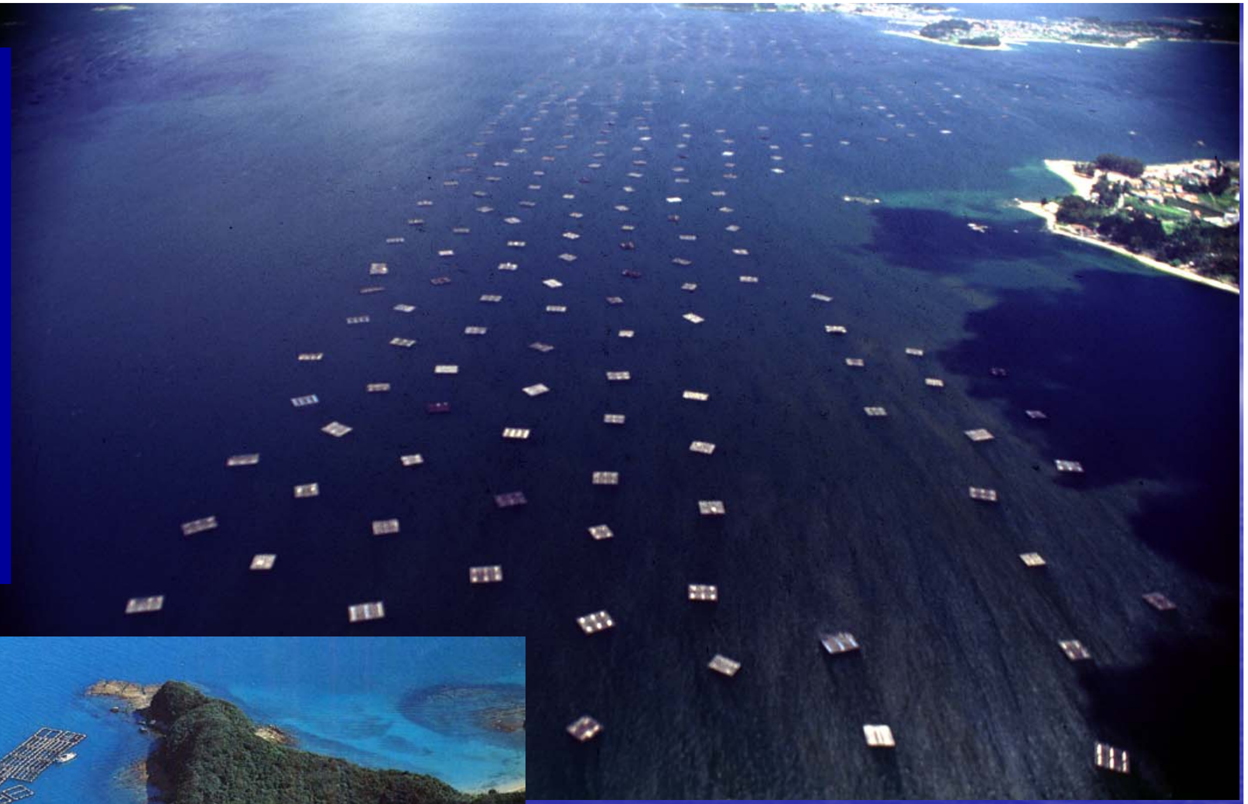
SEast Asia

Both China and Japan increased production about 1.6 and 1.3 times, respectively in 10 yrs. Korea more maybe 3 times.

FAO 2007

We need aquaculture.

But sometimes it causes problem.

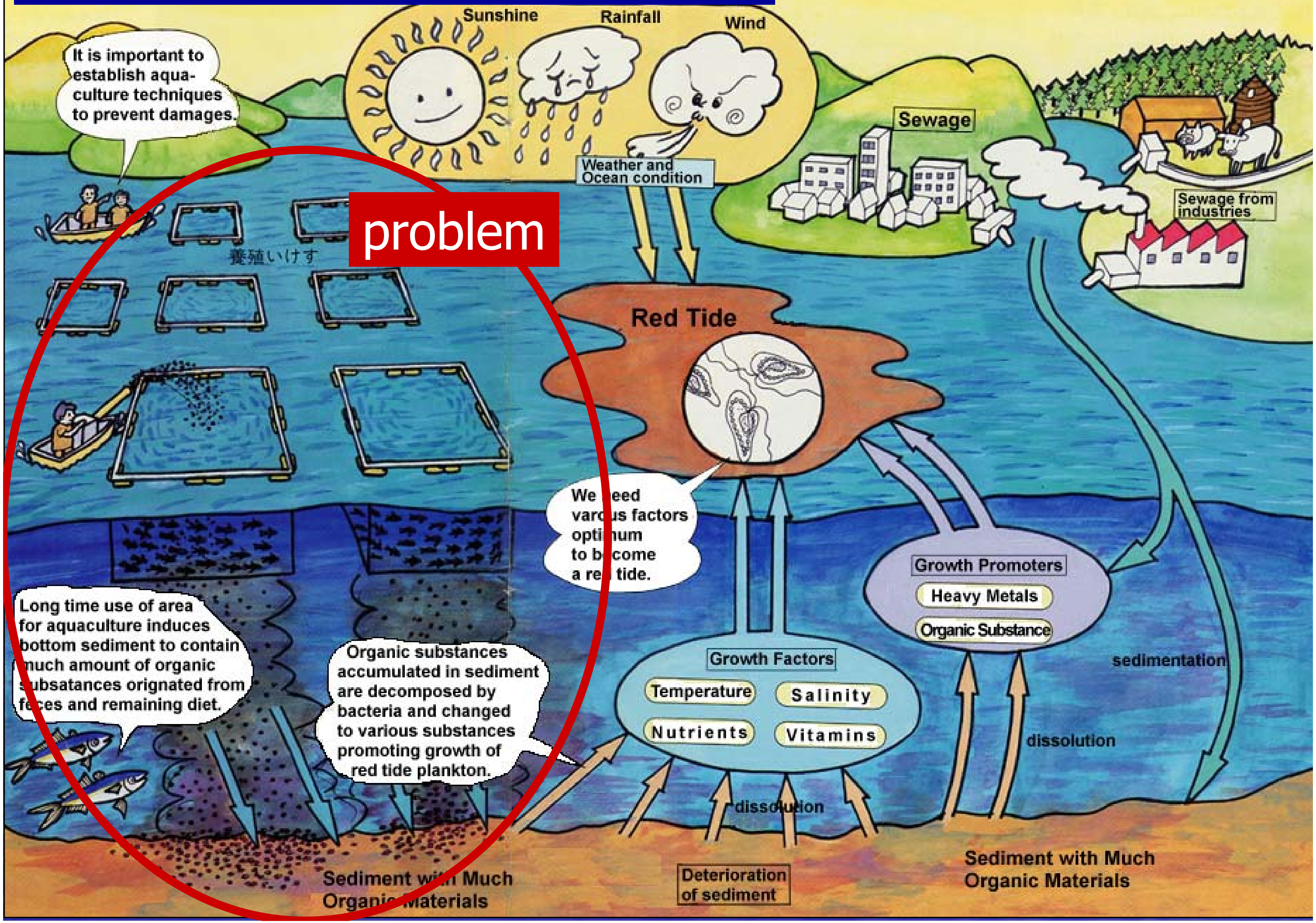


Coastal area environment of Asian countries

Exploitation and utilization of coastal area for various industries leads change of water environment.

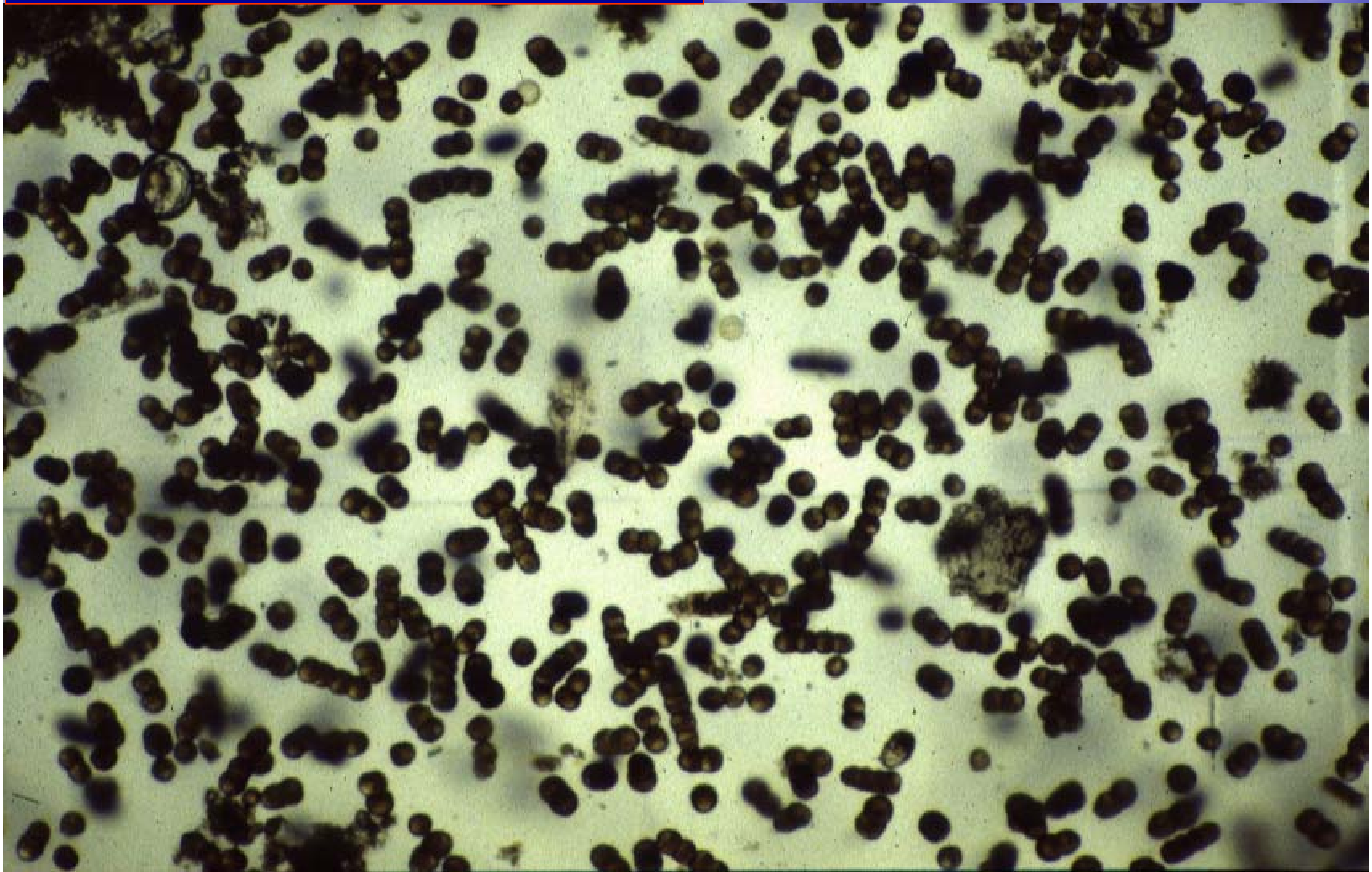
- physical change: construction of ports and installation of cages make water movement, stagnation and stratification different.
- chemical change: amount of organic substances, including those containing nitrogen and phosphorus, increases makes water eutrophic.
- biological change: along with change of physical and chemical environment, organisms respond in drastic way, e.g. simplification of biodiversity and bloom of single species.

Mechanism: factors related to red tide

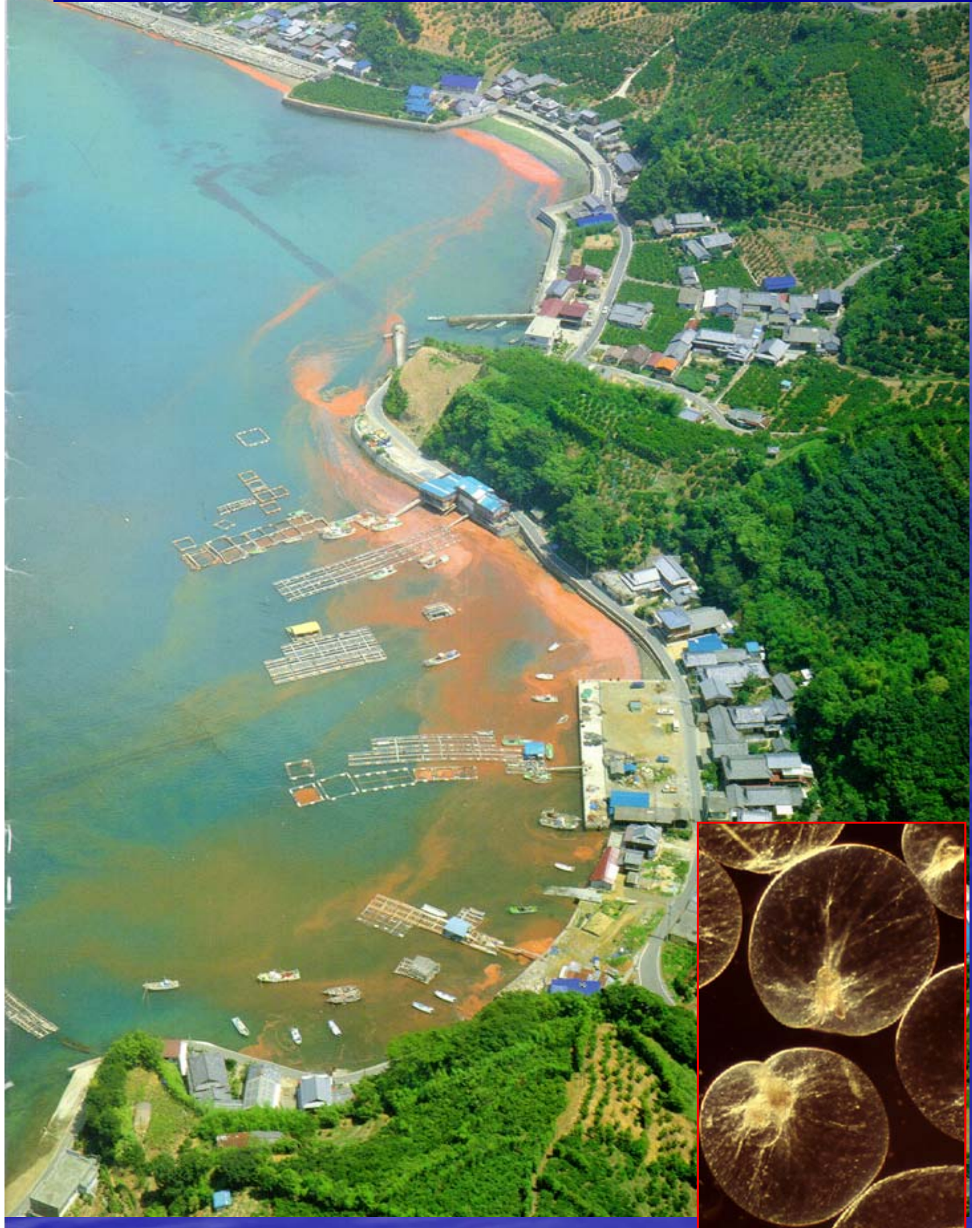


Phytoplankton (microalgae) community: Harmful microalgae exist in the community

Microalgae in Red tide water



Red tide occurring near shore



Noctiluca in Japan

Gymnodinium in Japan

by *Chattonella* in Japan

Red tides attaching aquaculture area: fish mortality

by *Cochlodinium* in Korea

by *Chattonella* in Japan

by *Karenia* in Hong Kong

Red Tide is sometimes harmful to shellfish also

Mass mortalities of clam and oyster

Mitigation against red tide

Indirect methods to improve environmental condition to have less number of red tides

1. Enforcement of regulations to improve water and sediment quality
2. Operation of rehabilitation projects to improve water and sediment
3. Improvement of aquaculture technology
4. Establishment of red tide occurrence information exchange network

Direct method to terminate red tide plankton

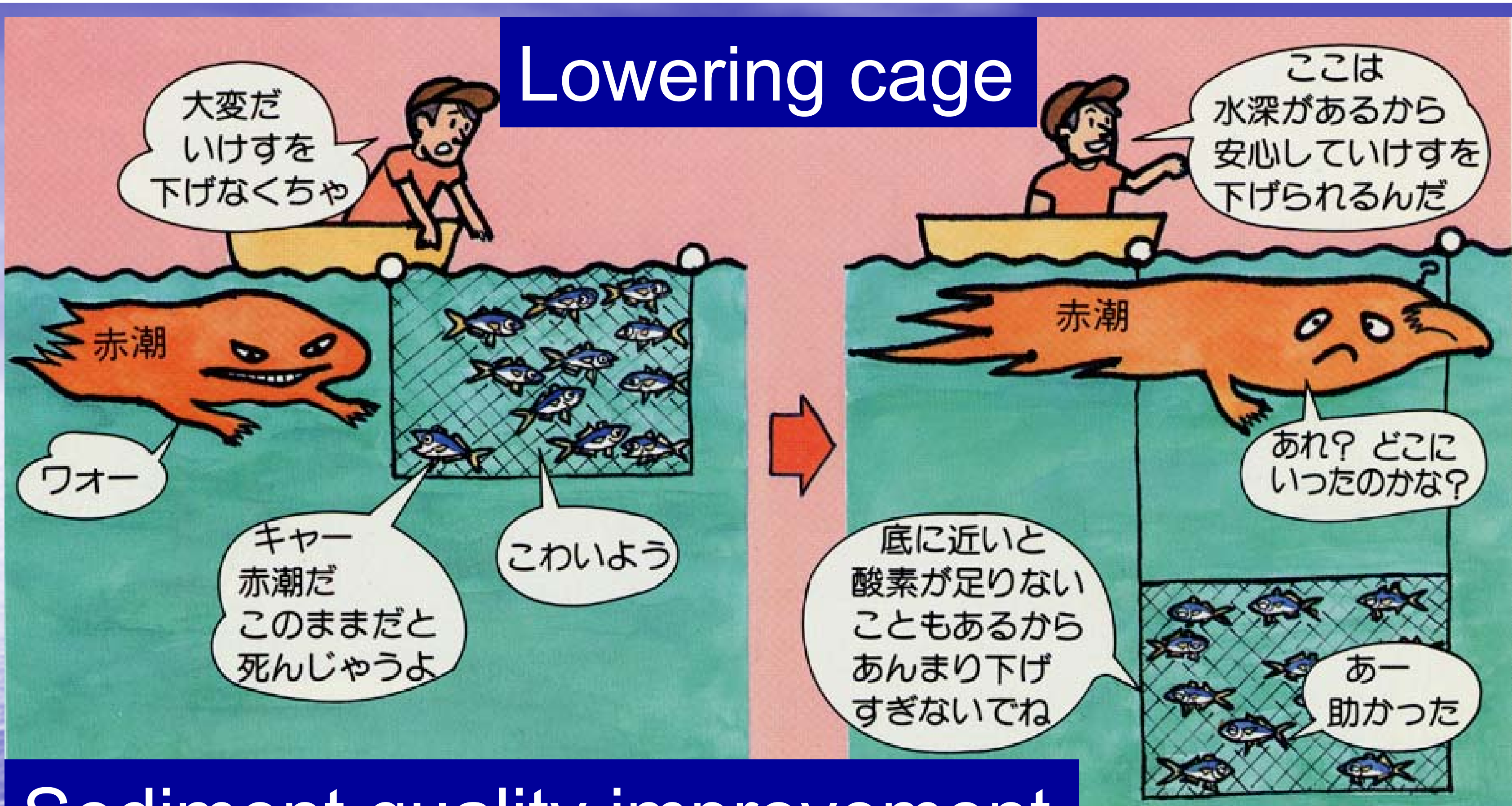
1. Spray of clay
2. Filtration
3. Chemicals etc.

Regulations aiming environment conservation in Japan

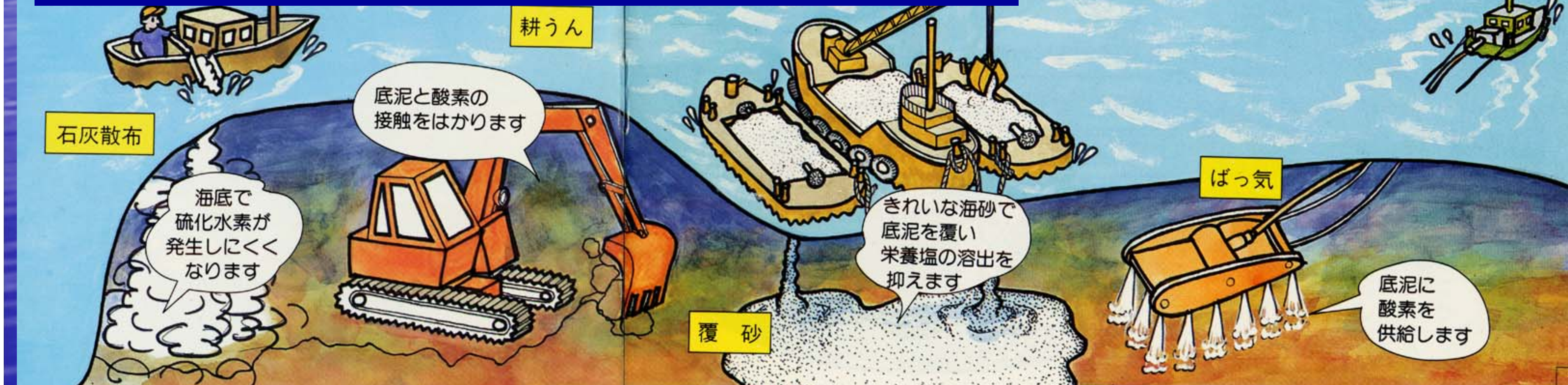
- Environment Basic Law
- Natural Conservation Law
- Natural Parks Law
- Environmental Impact Assessment Law
- Water Pollution Control Law
- Sewage Water Law
- Law concerning Provisional Measures for Conservation of the Environment of the Seto Inland Sea
- Law regulating the Commercial Transactions in Endangered Species of Wild Fauna and Flora
- Wildlife Protection and Hunting Law

Through development of these laws and regulations, environmental condition of Seto Inland Sea becomes better.

Lowering cage



Sediment quality improvement



Still most of mitigation activity have limited effect, and ill consequences continue recurring.

July – Sept. 2017: Red tide of *Karenia mikimotoi*
In Imari Bay in northwest Kyushu, Japan

Dead fish	519,000 fish	540M Yen loss
Puffer fish	439,000 fish (85%)	
Tuna	3,839 fish	
Yellow tail	26,000 fish	
others	76,500 fish	

From The New 2017 Aug 31

NCC 長崎文化放送 Aug.18 2017

Perspectives on future red tides

Case number will increase more,
as eutrophication in coastal water will be more serious.

Harmful consequences will occur more,
as fish and shellfish aquaculture will be operated in wider areas.

Mitigation against red tides will be designed more,
but reduction of eutrophication takes time.

Therefore observation of trophic level and its trend will be more and more important.

Perspectives on future red tides

Case number will increase more,

as eutrophication in coastal water will be

The importance is

what parameter we need to monitor

how to monitor

using conventional and

new sophisticated methods

more,

but reduction of eutrophication takes time.

Therefore observation of trophic level and its trend will be more and more important.

Comment to the current project,
Eutrophication Assessment and its web-page

Data to be used at the assessment

- COD value and trend
- Red tide
- Hypoxia
- Satellite Chl-*a*

Expression of assessment result in web-page

COD:

1. It is clear that COD increases with eutrophication becomes serious.

2. Contents of COD is not clear. And separation of natural source from man-made one is impossible.

3. Evaluation of natural COD is not easy, but it is basis for trend analysis.

4. It is observed that COD does not decrease, even eutrophication become light in Seto Inland Sea.

5. There is no other good indicator.

Red tide:

1. Total case number of red tide is a good indicator of phytoplankton reaction against eutrophication.
2. Association of harmful consequences often occur in eutrophic areas. Therefore number of harmful red tide may be a good indicator.
3. Causative species vary depending on trophic level (N,P, and their ratio).

Hypoxia:

1. Definition of hypoxia is not easy. Usually marine organisms cannot survive in water mass of DO <3 mL/L (4.3mg/L).

Lethal concentration of DO

demersal fish	1.5 mL/L
crab and shrimp	2.5 mL/L

Conc. limit giving physiological damage

fish, crustacean	3.0 mL/L
shellfish	2.5 mL/L

Lowest conc. giving ecological change

survival of most benthos	2.0 mL/L
distribution change (facilitation of relocation)	3.0 mL/L

Hypoxia:

2. Symbol of hypoxia in web-page is misleading. It looks like occurrence of fish mortality from any reason, incl. red tide.

3. Hypoxia occurs by stratification of water and anoxic bottom sediment.

4. Blue tide is visible anoxic water.

5. Seaweed aquaculture accelerate bottom anoxia.

Blue tide in Tokyo Bay

Satellite chl-*a*

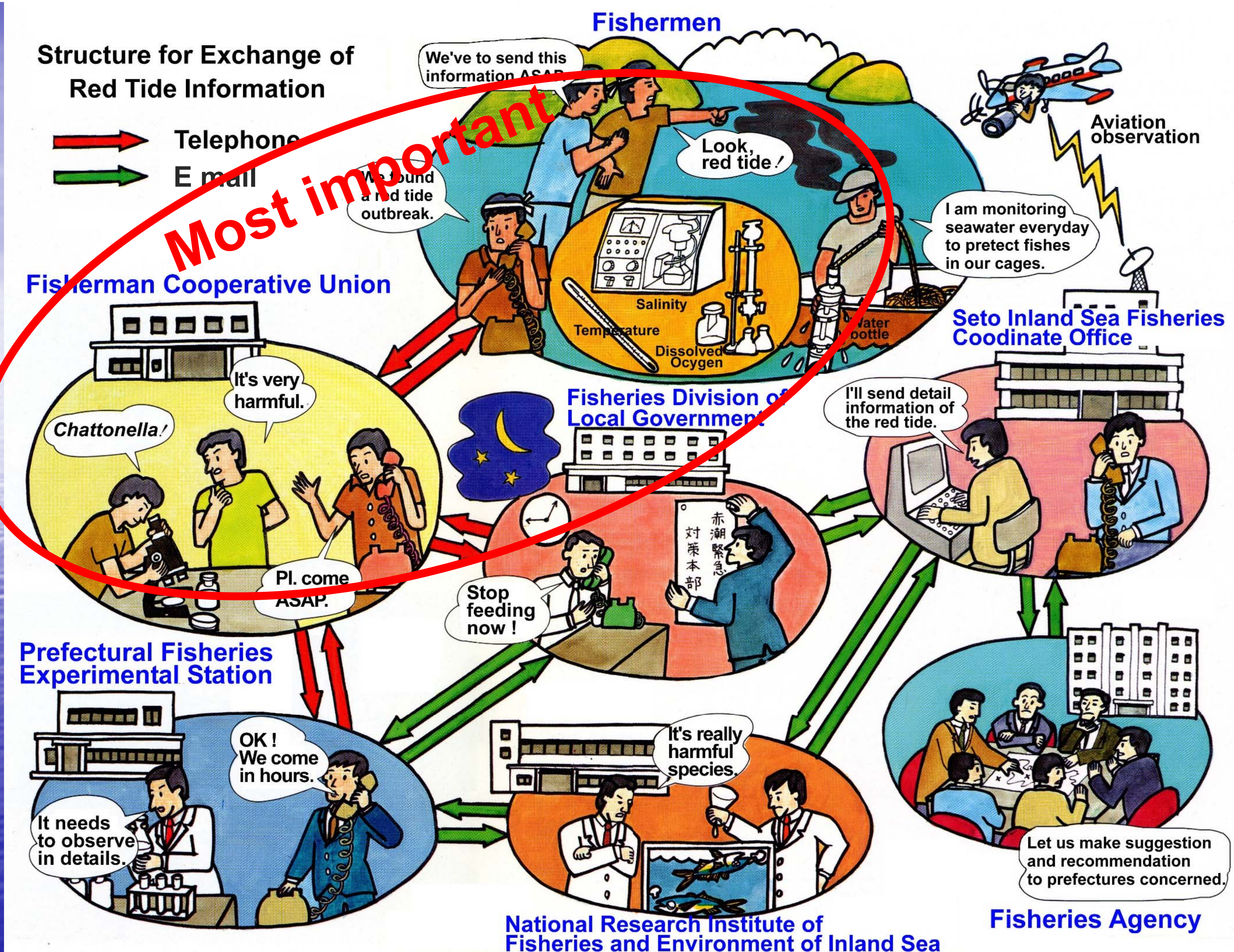
1. Good indicator, although calculation might not be easy.

Expression of web-page

1. Need to develop ways to avoid misunderstanding on frequency of occurrence and observation. For example, many marks do not always mean frequent occurrence of red tide.
2. Ratio of occurrence/observation is one of the ways to standardize.
3. Mark for hypoxia is misleading.

Thank you for your audience and patience.

We can discuss ways to improve web-page.



Structure for Exchange of Red Tide Information
Telephone
E mail
Most important
Fishermen
We've to send this information ASAP.
Look, red tide!
We found a red tide outbreak.
I am monitoring seawater everyday to pretect fishes in our cages.
Salinity
Temperature
Dissolved Ocygen
Water bottle
Aviation observation
Fisherman Cooperative Union
It's very harmful.
Chattonella!
Pl. come ASAP.
Fisheries Division of Local Government
赤潮緊急対策本部
Stop feeding now !
Seto Inland Sea Fisheries Coodinate Office
I'll send detail information of the red tide.
Prefectural Fisheries Experimental Station
OK ! We come in hours.
It needs to observe in details.
It's really harmful species.
National Research Institute of Fisheries and Environment of Inland Sea
Let us make suggestion and recommendation to prefectures concerned.
Fisheries Agency

Mitigation against red tide

Indirect methods to improve environmental condition to have less number of red tides

1. Enforcement of regulations to improve water and sediment quality
2. Operation of rehabilitation projects to improve water and sediment
3. Improvement of aquaculture technology
4. Establishment of red tide occurrence information exchange network

Direct method to terminate red tide plankton

1. Spray of clay
2. Filtration
3. Chemicals etc.

Main 5-1

ホルネリア赤潮に対する粘土散布

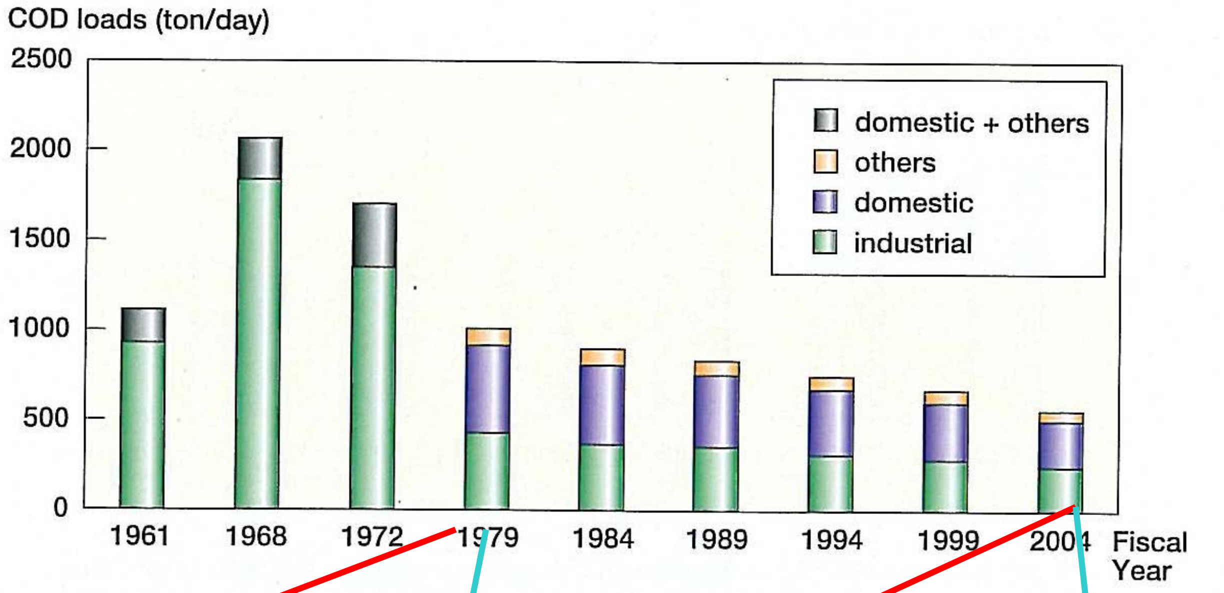
Bird's-eye View of Seto Inland Sea (courtesy of Asia Air Su

east – west: 450 km, north – south: 15-55 km
area: 23,203 km^2, average depth: 38.0 m
shoreline: 6,868 km, 700 islands

Fish aquaculture industry became active since 1960s.

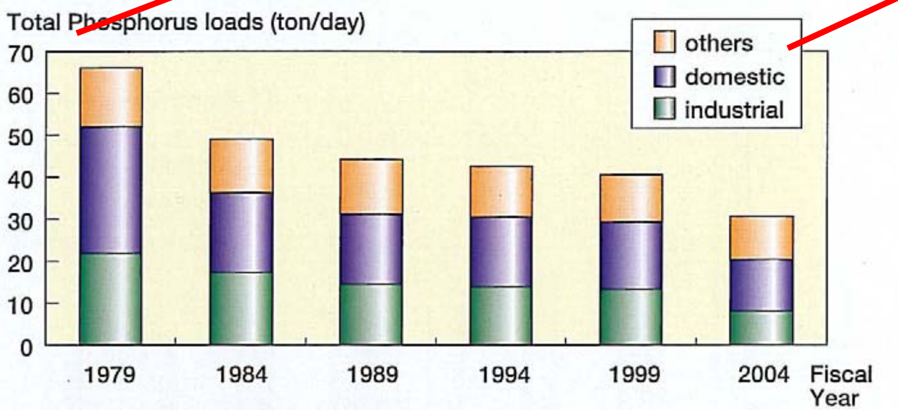
Change of load to Seto Inland Sea

Rem: duration of the upper and lower figures are different.



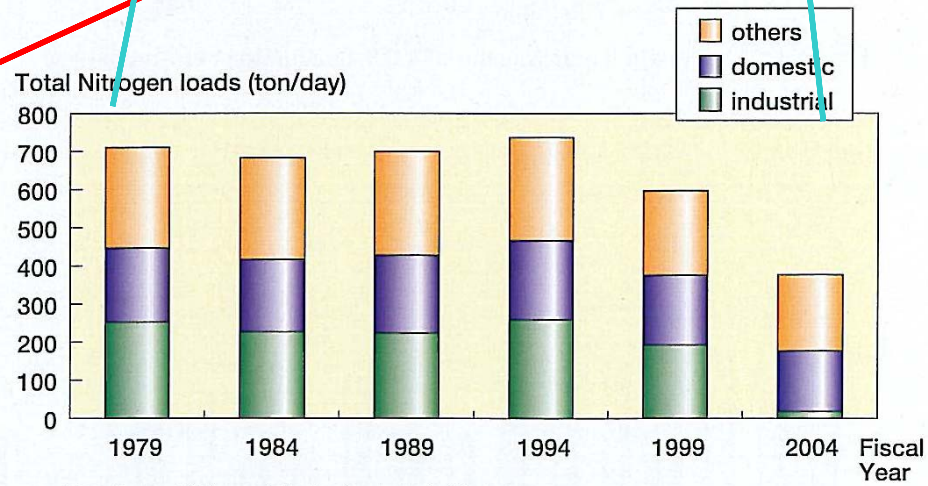
Note: Sources; Ministry of the Environment of Japan, and the Association for the Environmental Conservation of the Seto Inland Sea

Figure 3-2 Changes in Total Amount of COD Load in the Seto Inland Sea



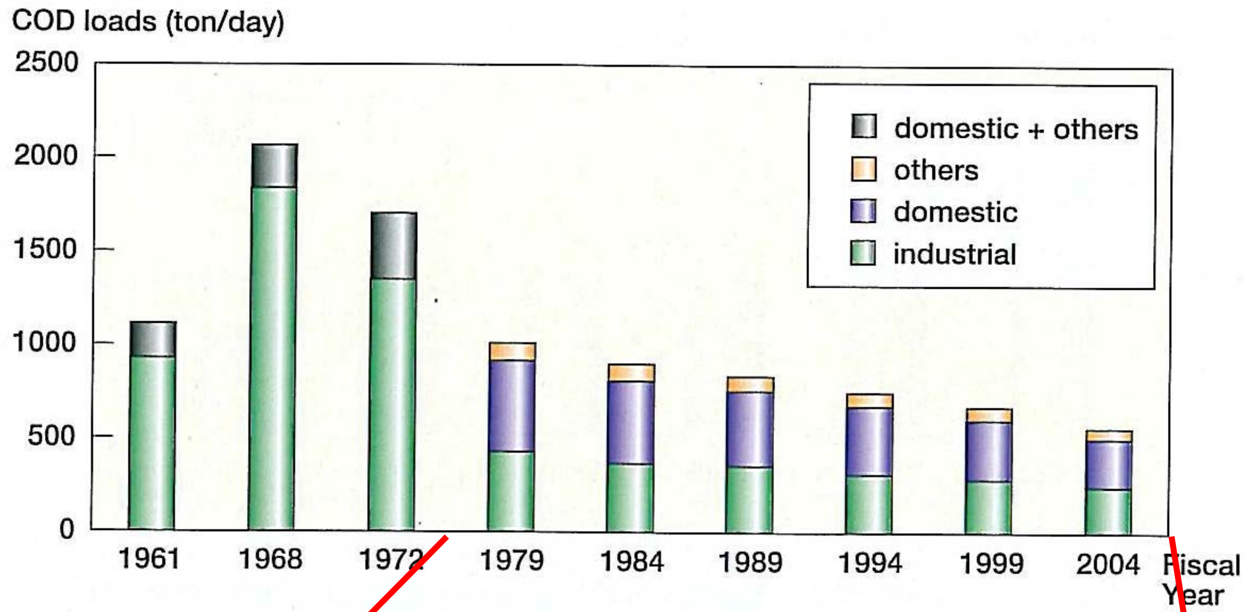
Note: Source; Ministry of the Environment of Japan

Figure 3-4 Changes in the Total Amount of Phosphorus Load in the Seto Inland Sea



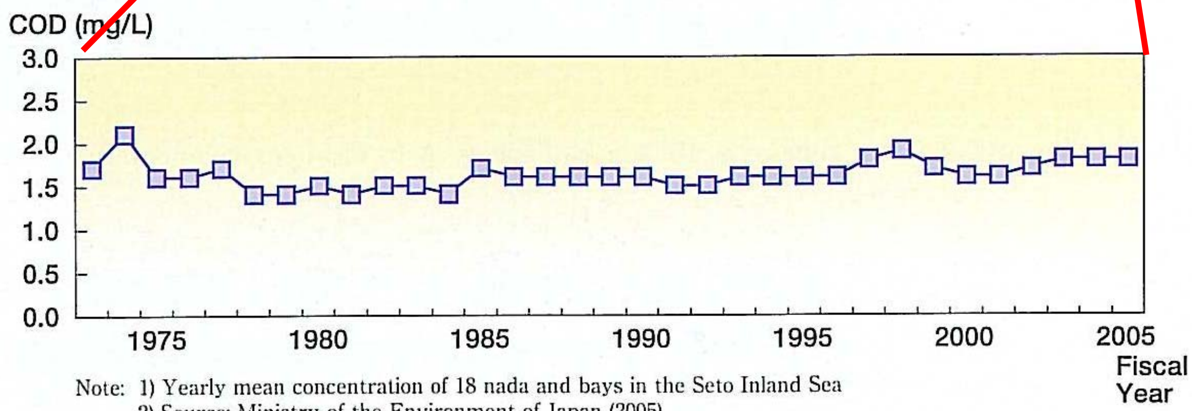
Note: Source; Ministry of the Environmental of Japan

Figure 3-5 Changes in the Total Amount of Nitrogen Load in the Seto Inland Sea



Note: Sources; Ministry of the Environment of Japan, and the Association for the Environmental Conservation of the Seto Inland Sea

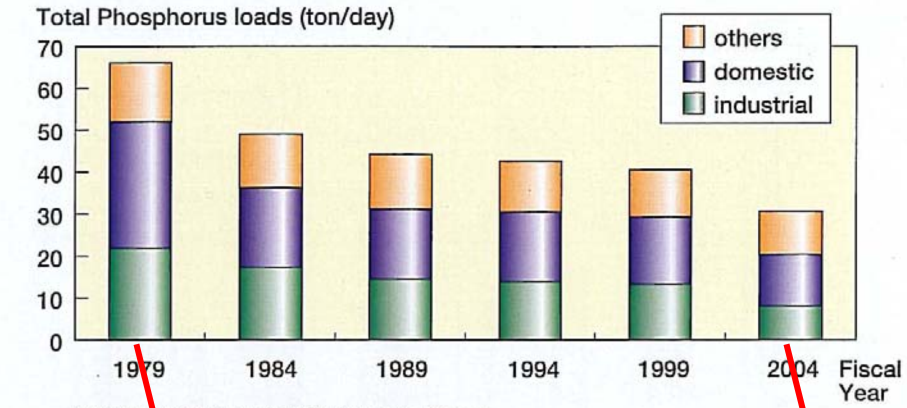
Figure 8-2 Changes in Total Amount of COD Load in the Seto Inland Sea



Note: 1) Yearly mean concentration of 18 nada and bays in the Seto Inland Sea
2) Source; Ministry of the Environment of Japan (2005).

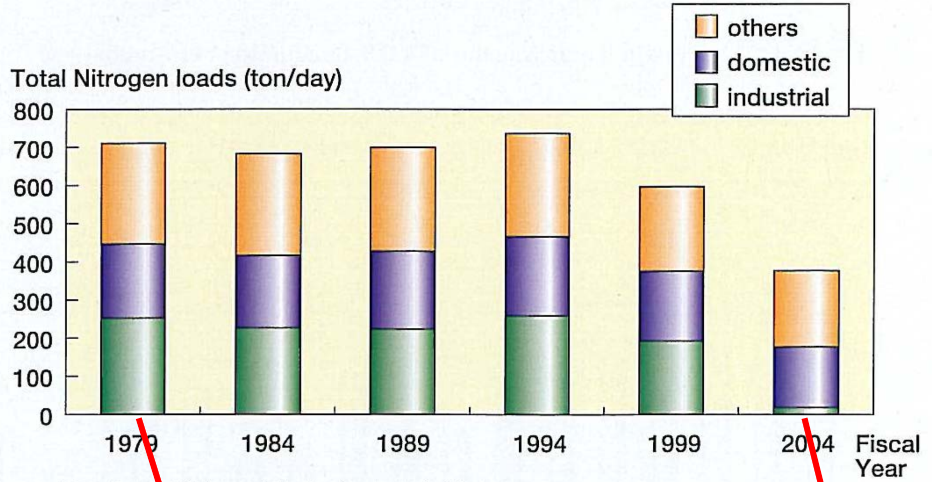
Figure 2-24 Change in COD concentration in the Seto Inland Sea

Reduction of the load has not directly related to water quality.



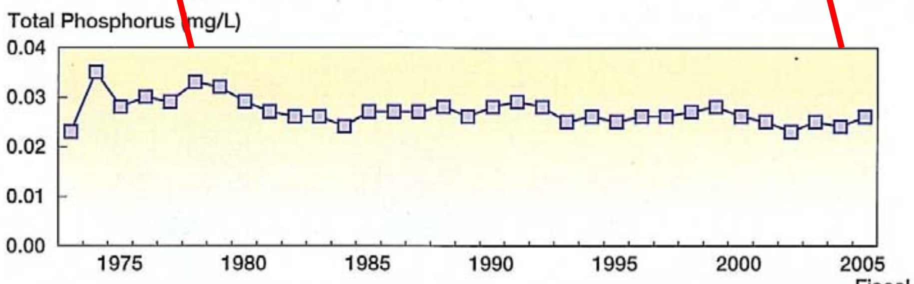
Note: Source; Ministry of the Environment of Japan

Figure 3-4 Changes in the Total Amount of Phosphorus Load in the Seto Inland Sea



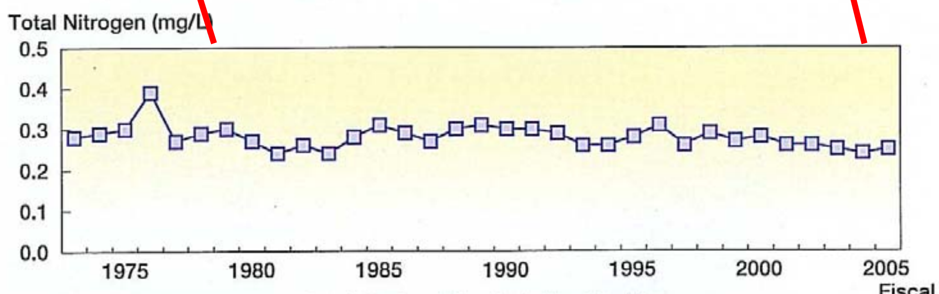
Note: Source; Ministry of the Environmental of Japan

Figure 3-5 Changes in the Total Amount of Nitrogen Load in the Seto Inland Sea



Note: 1) Yearly mean concentration of 18 nada and bays in the Seto Inland Sea
2) Source; Ministry of the Environment of Japan (2005)

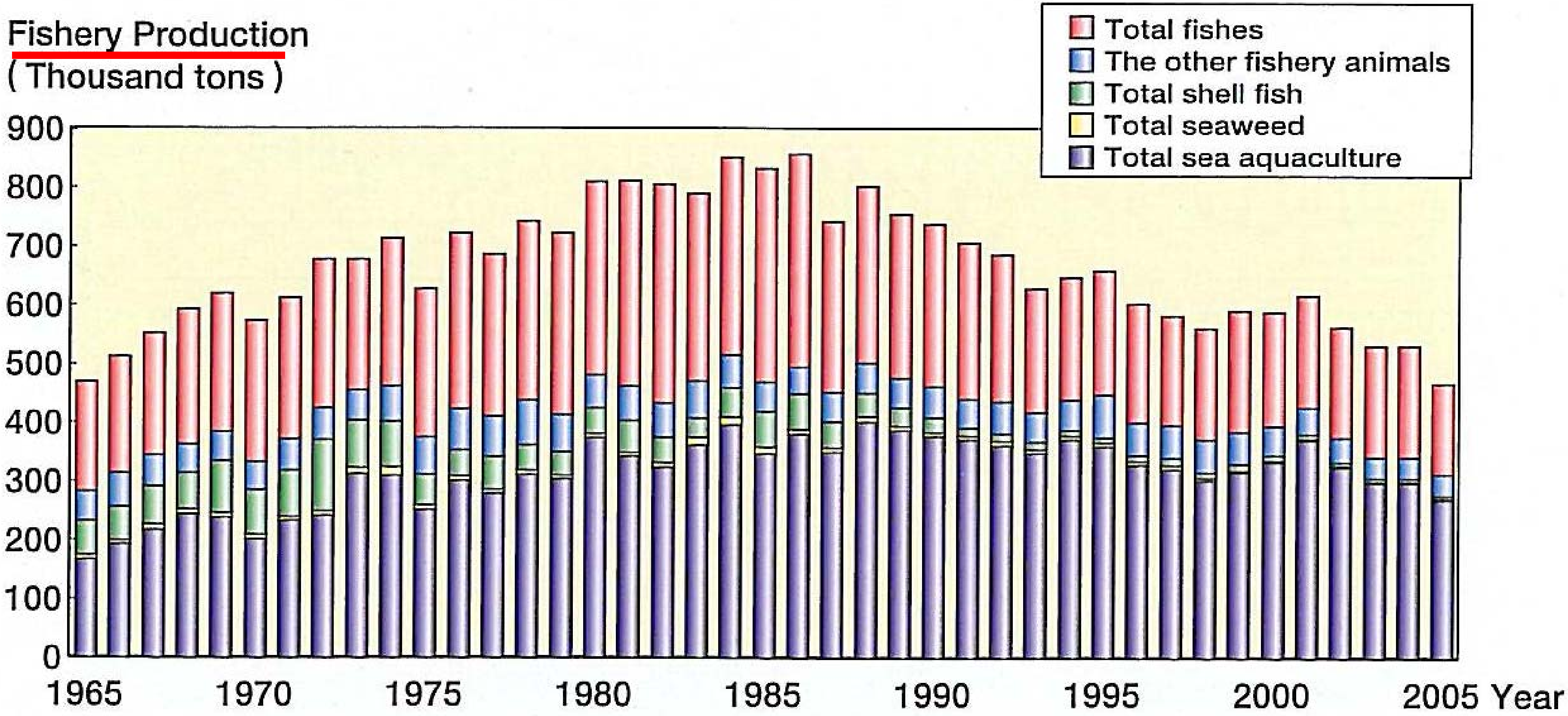
Figure 2-26 Change in TP concentration in the Seto Inland Sea



Note: 1) Yearly mean concentration of 18 nada and bays in the Seto Inland Sea
2) Source; Ministry of the Environment of Japan (2005).

Figure 2-25 Change in TN concentration in the Seto Inland Sea

Reduction of the load has not directly related to water quality.



Note: Source; Ministry of Agriculture, Forestry and Fisheries

Figure 2-6 Trends in fishery production in the Seto Inland Sea

Fisheries production decreased simultaneously with reduction of nutrient loads

TMA Bloom: Different type of problem from Red Tide

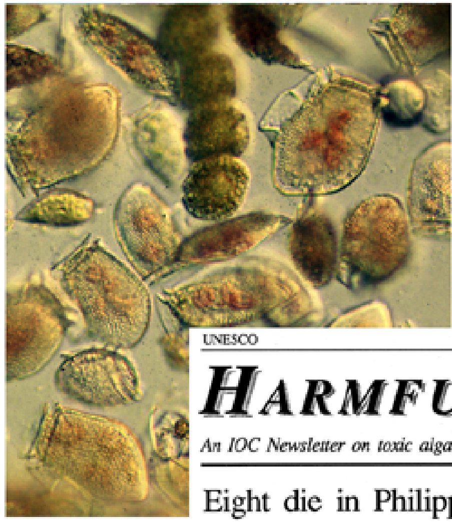
Problems caused by Toxin Producing Speceis

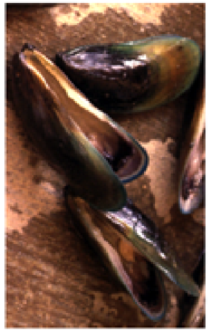
Shellfish become toxic;
People got sick, sometime died, after eating shellfish.

Occur more in
low-nutrient waters
than in eutrophic waters.

Seafood Safety problem;
It will be more and more important in SEAsia.

'oxin contamination in shellfish and fish: toxin accumulation by feeding toxic unicellular plankton; plankton number is often very low (>1 cell in 1 ml) ; toxin is harmful to people, but not to shellfish & fish





UNESCO 1992

HARMFUL ALGAE NEWS

An IOC Newsletter on toxic algae and algal blooms No. 3

Eight die in Philippines from red-tide molluscs

A state of emergency has been declared by Philippine President Fidel Ramos in Manila and four other provinces, due to the presence of red tides in various coastal regions and as a consequence of eight deaths caused by eating contaminated mussels.

Since June of this year, Philippine health authorities have banned the after eating products contaminated with this microorganism.

The red tide covered about 90% of Manila Bay along the coasts of Batán, Papanga, Bulacan and Cavite.

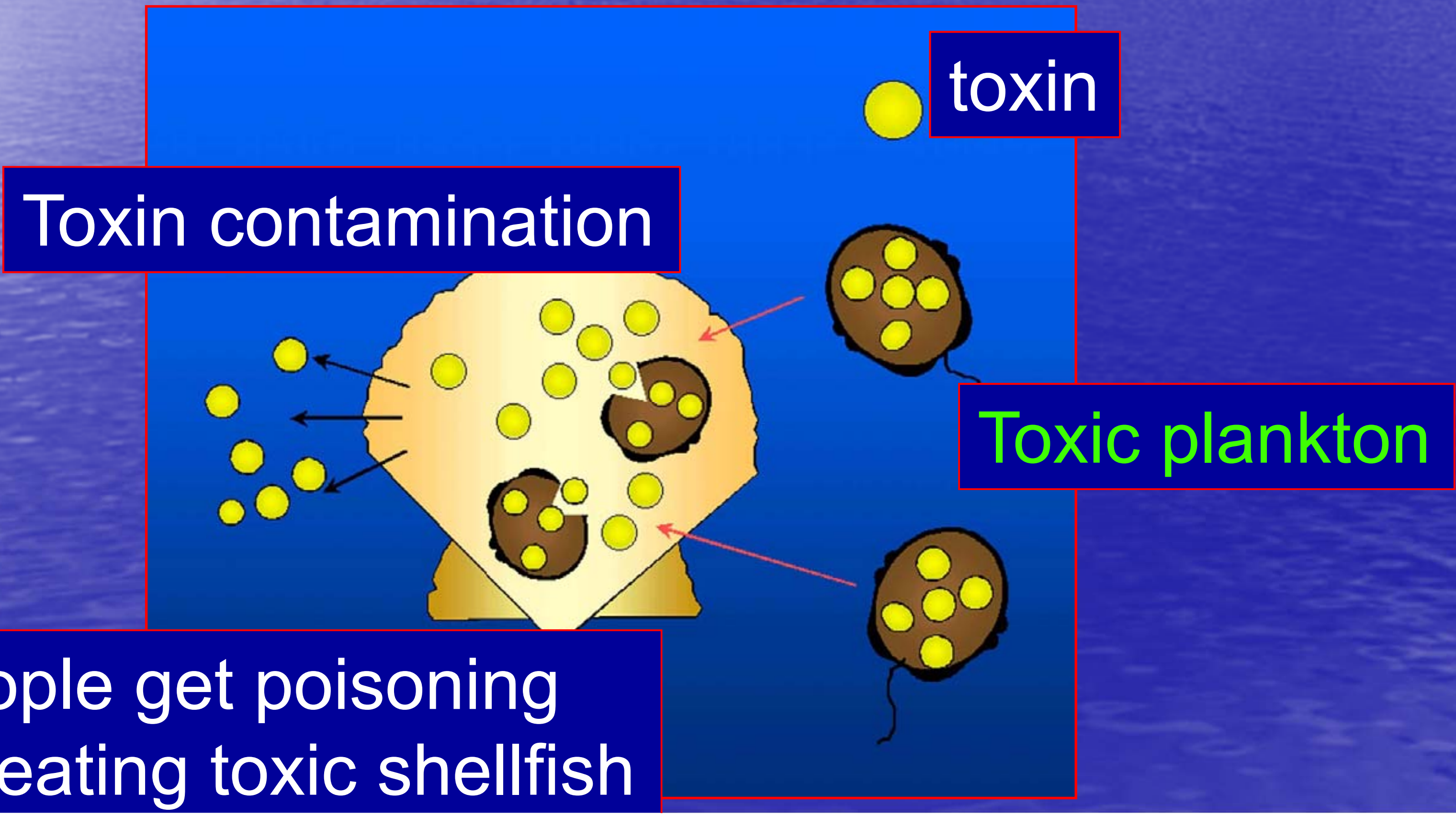
The authorities state that fishermen in the zones where the consumption of mussels is prohibited are undergoing hardship due to a sudden fall in fish

Editor's note:
The dinoflagellate *Pyrodinium bahamense* has caused paralytic poisoning in Papua New Guinea, Brunei Darussalam, Sabah, and Guatemala, as well as in the Philippines, most commonly via shellfish but also via plankton-eating fish. Cases of PSP elsewhere in the western Pacific may be

Toxic plankton is the alga that produce (or keep after uptake) toxins inside cell.

The toxins cause illness in vertebrates, including mankind.

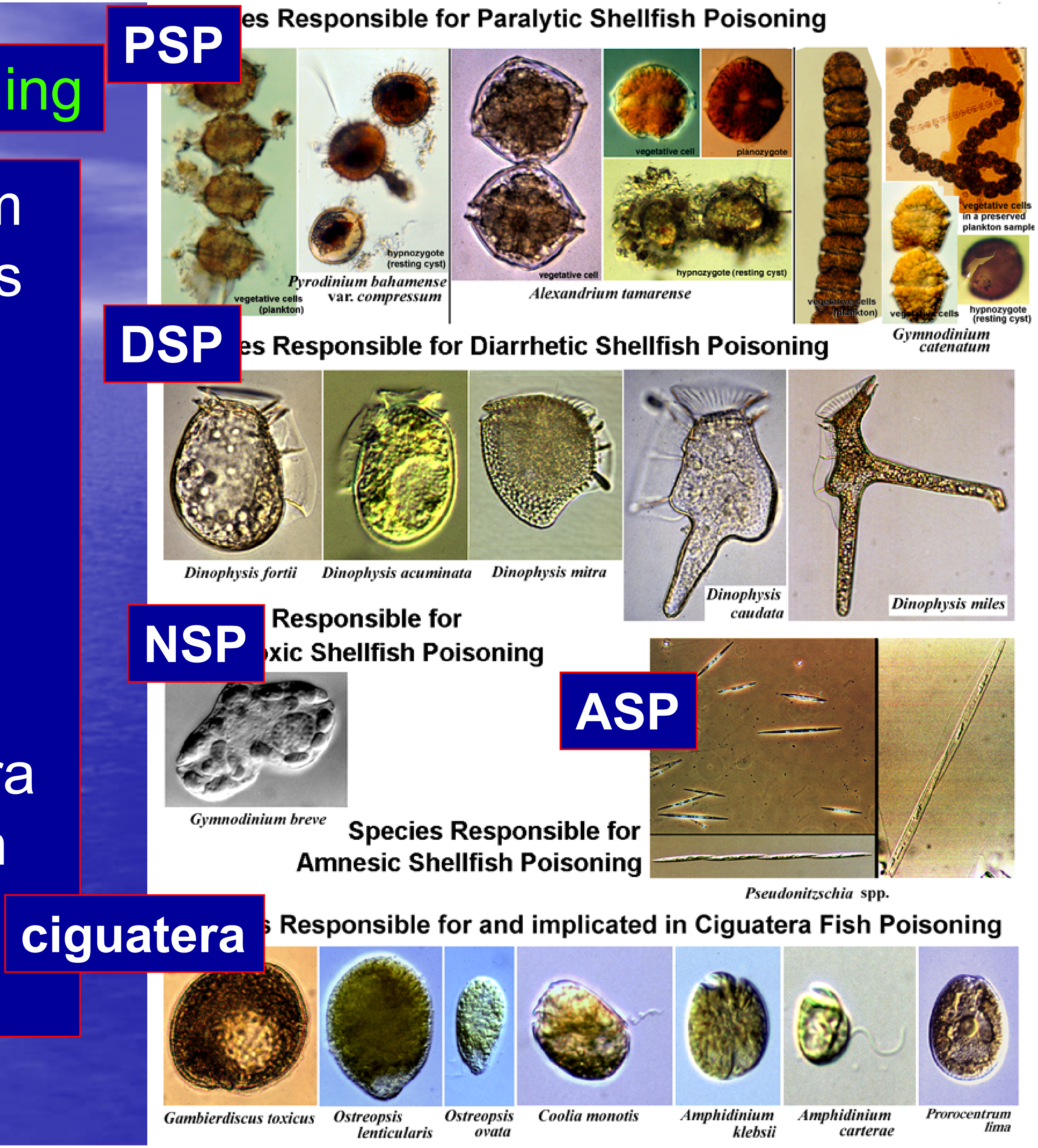
Symptom varies depending on toxins, i.e. PSP, DSP, NSP, ASP and ciguatera.



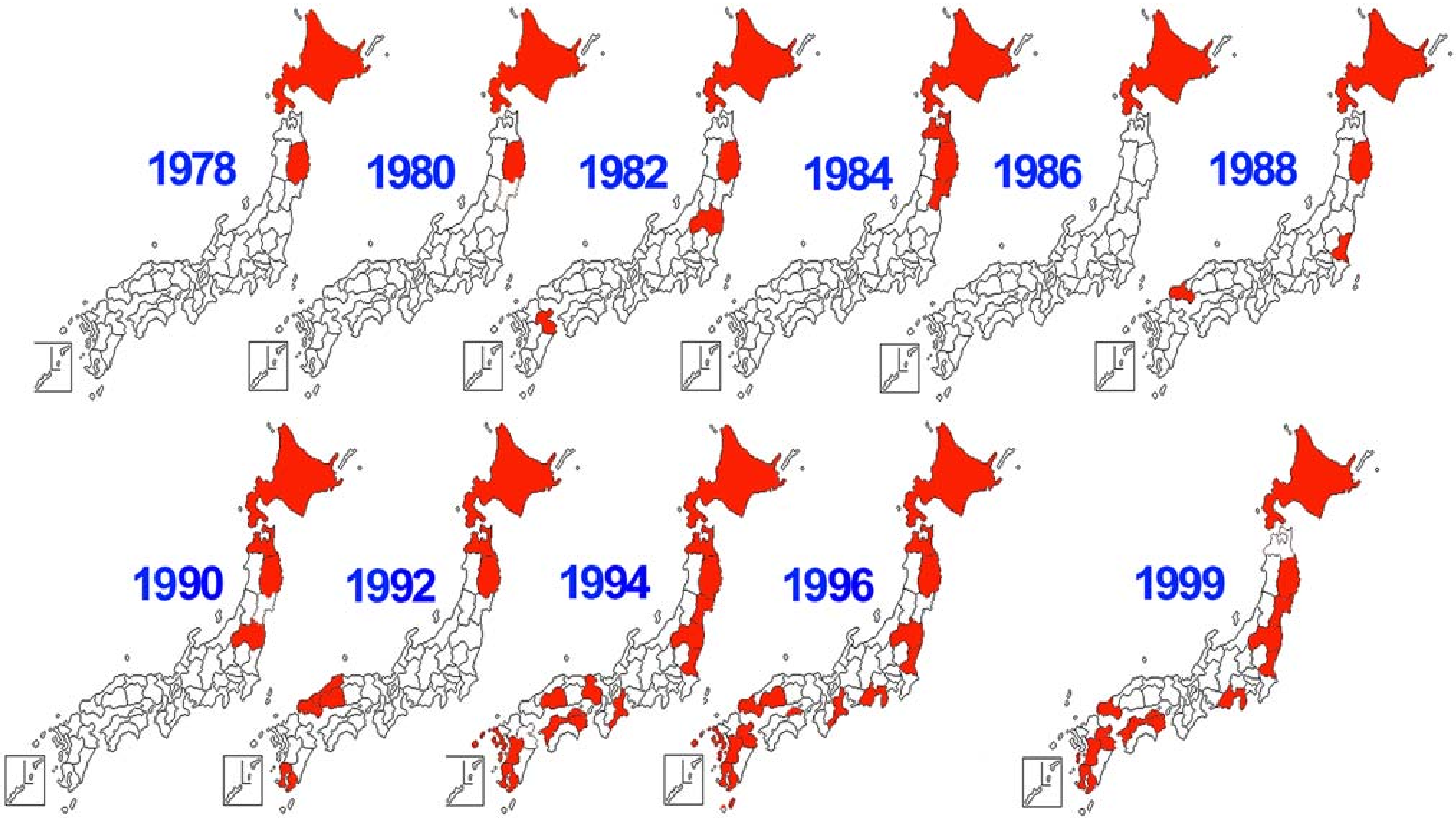
Five types poisoning

Different symptom by different toxins which are produced by different microalgae

In Vietnam, PSP, ASP and ciguatera have been known to occur sometimes.



Expansion of area affected by PSP toxin contamination in cultured shellfish in Japan (red color shows prefectures where harvesting and marketing of shellfish are banned)



Serious economic loss, but no poisoning cas

In order to prevent harmful consequences from red tide and toxic microalgae, maintenance of healthy environment, and establishment of continuous cost- and load-effective monitoring system are very basic.

Thank you for your audience

Poisoning Problems in the Western Pacific

PSP: Serious 1980s and 1990s, but
few cases after 2000;
causative species increases;
area increases

DSP: Toxic dinoflagellates are detected,
but no monitoring on toxicity in shellfish

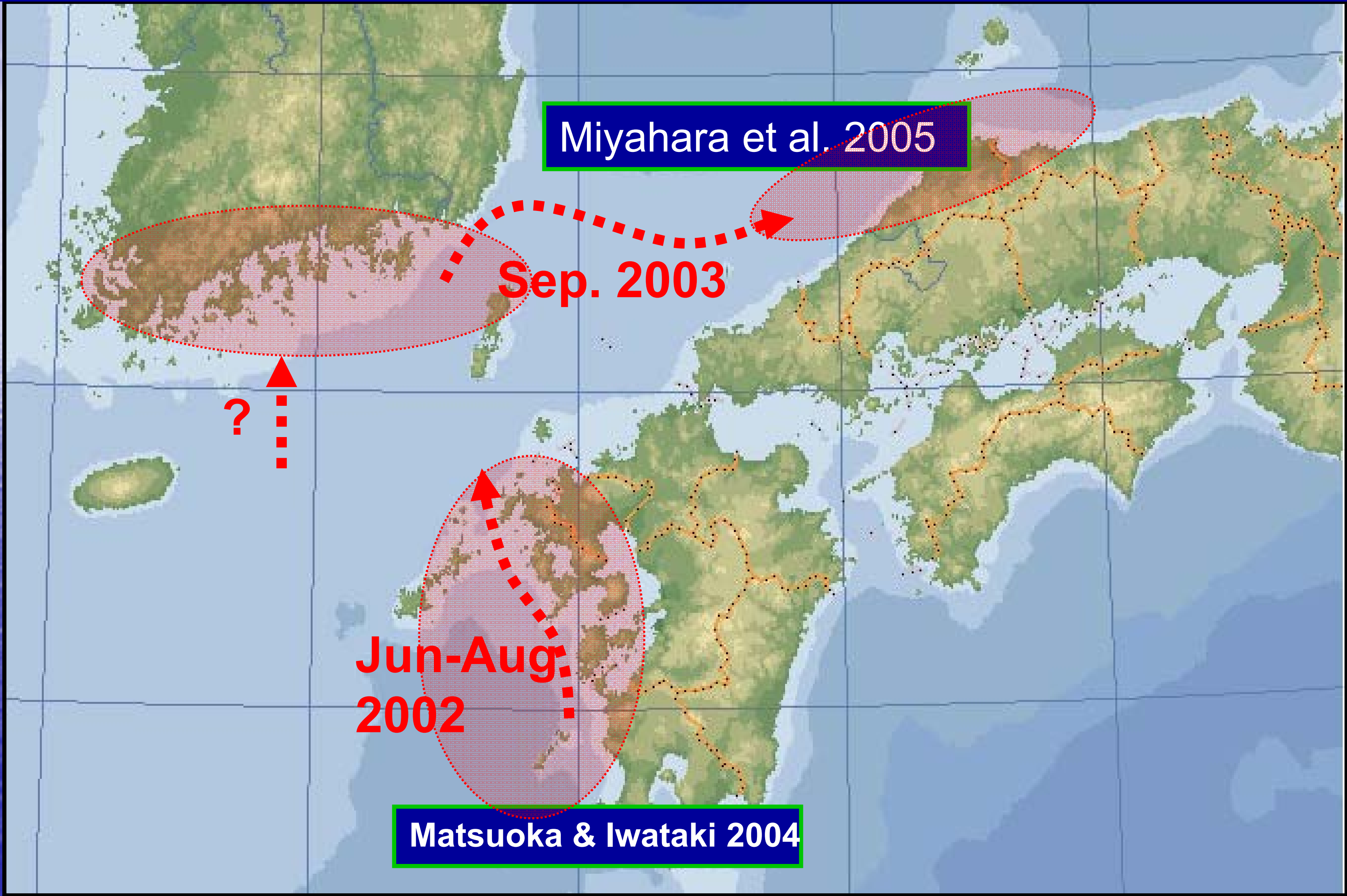
ASP: Toxic diatoms are detected,
but no monitoring on toxicity in shellfish

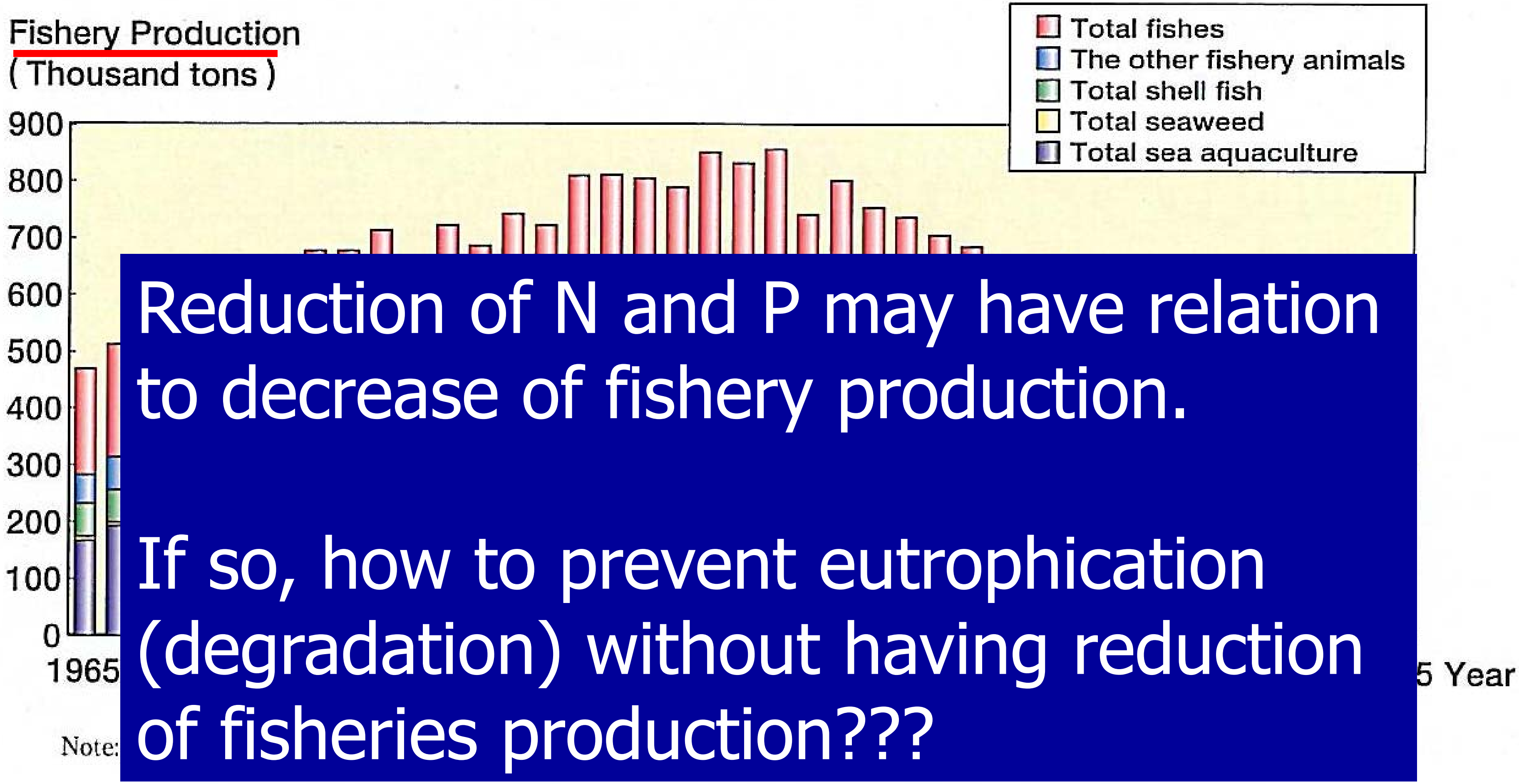
NSP: Few studies

Ciguatera: 1997- Philippines and Hong Kong;
several studies on benthic dinoflagellates,
but few on toxicity of fishes

Occurrences of *C. polykrikoides* in Japan and Korea

Red tides of *C. polykrikoides* have continuously occurred along coastal waters, does this imply that the Japanese and Korean population are identical?





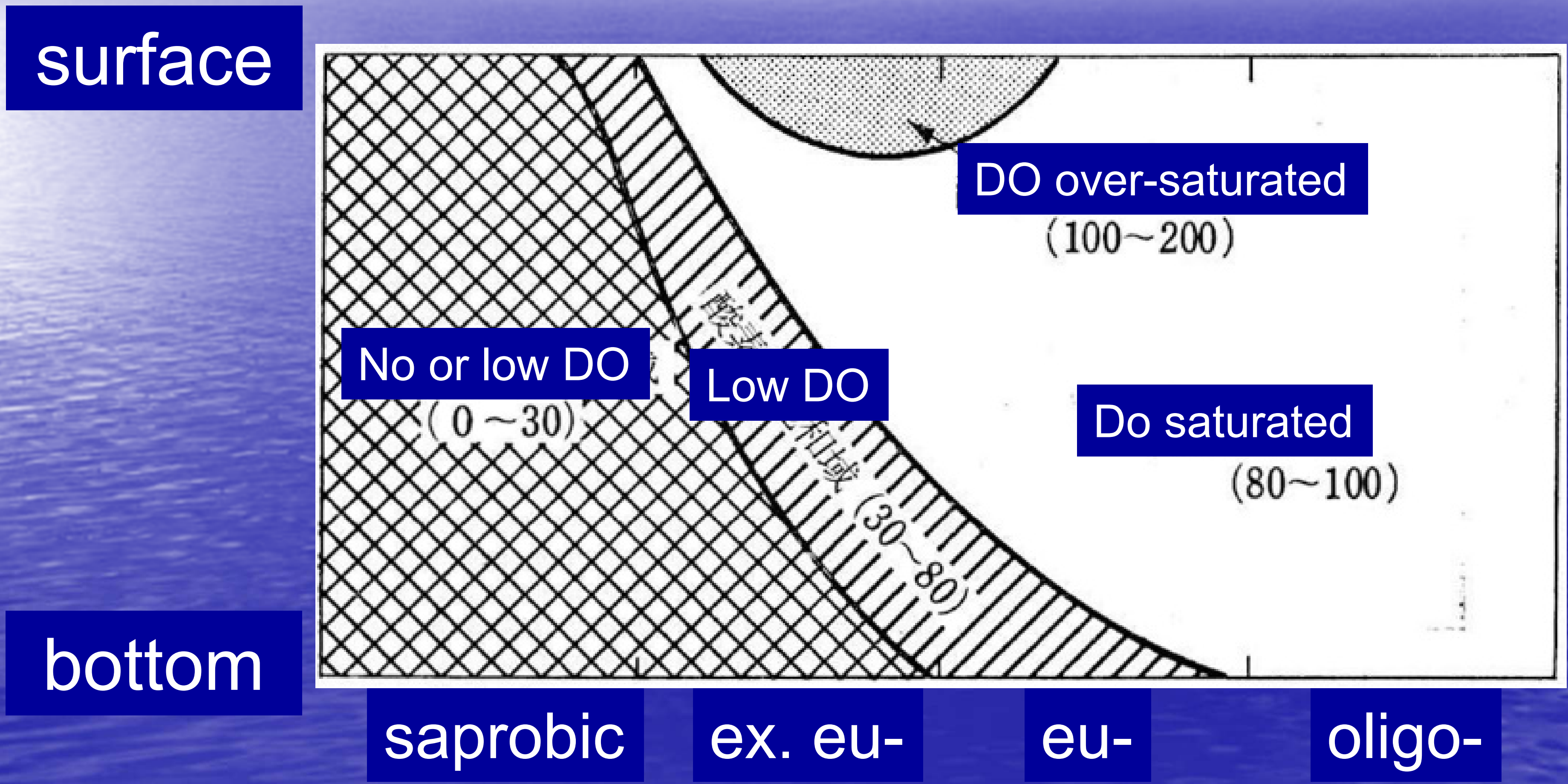
Reduction of N and P may have relation to decrease of fishery production.

If so, how to prevent eutrophication (degradation) without having reduction of fisheries production???

Figure 2-6 Trends in fishery production in the Seto Inland Sea

Fisheries production decreased simultaneously with reduction of nutrient loads

Trophic level and DO (%)



Trophic level and DO (%)