Long-term monitoring of the toxic dinoflagellate *Alexandrium tamarense* and environmental factors in Osaka Bay, eastern Seto Inland Sea, Japan: History of invasion and expansion of toxic blooms

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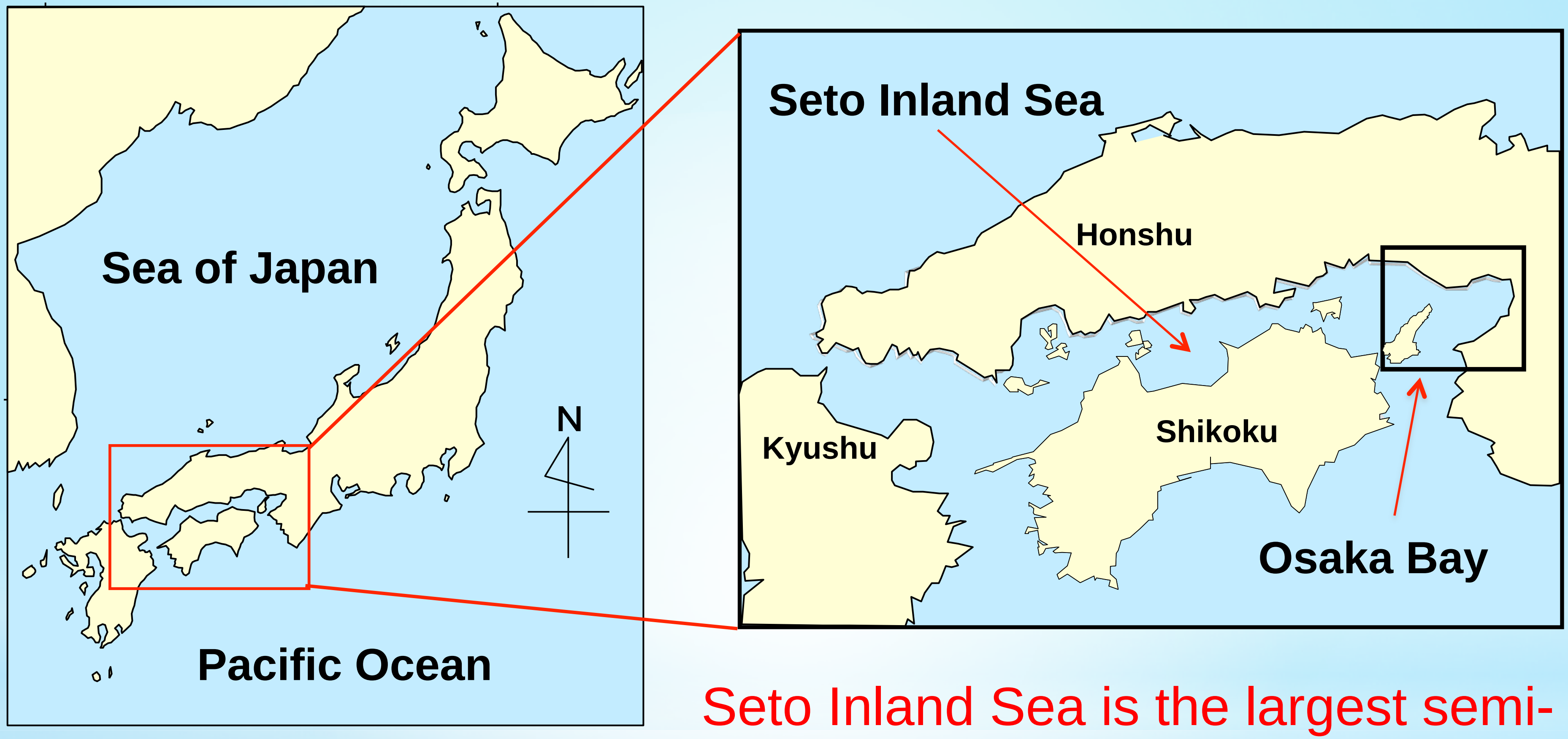
Location of Osaka Bay



Seto Inland Sea is the largest semi-enclosed coastal sea in Japan

Osaka Bay is located in eastern end of Seto Inland Sea.

Elliptical shape

Long axis：60 km
Short axis：30 km

Square measure：1,450 km^2

Average depth：28 m
About half of the bay is shallower than 20 m

From north east of the bay, large rivers through into the bay (Yodo R., Yamato R.）

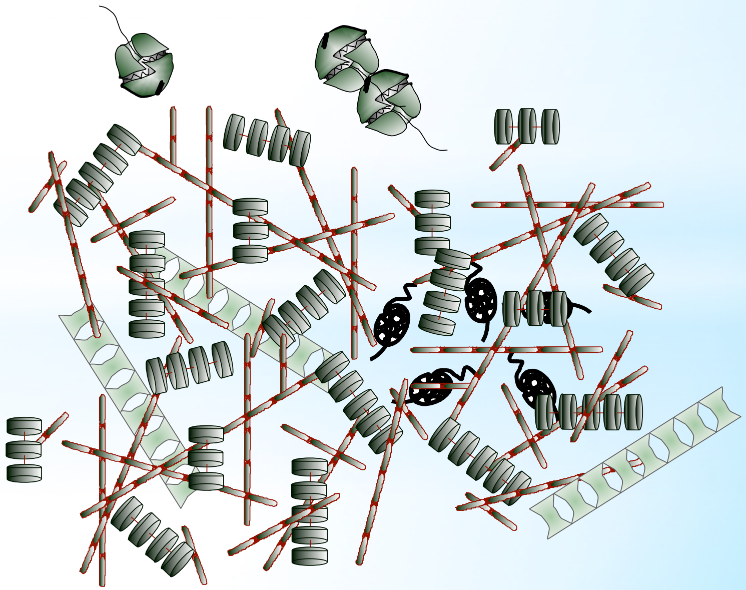
Big cities such as Osaka city, Kobe city, Sakai city and Kyoto city are located along these rivers

In former Osaka Bay（until about 1990s)

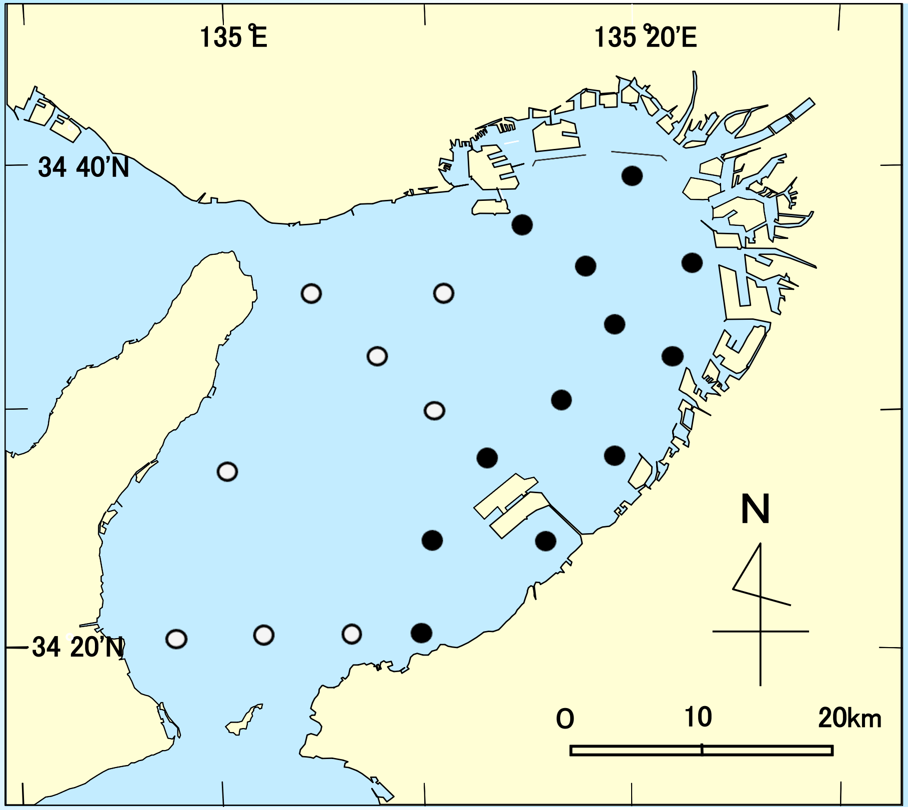
Osaka Bay is infamous for eutrophication

↓

Red tides were frequently observed and dominant group was diatoms



Plankton monitoring



Monitoring station for phytoplankton

Countermeasures for eutrophication

- Special law

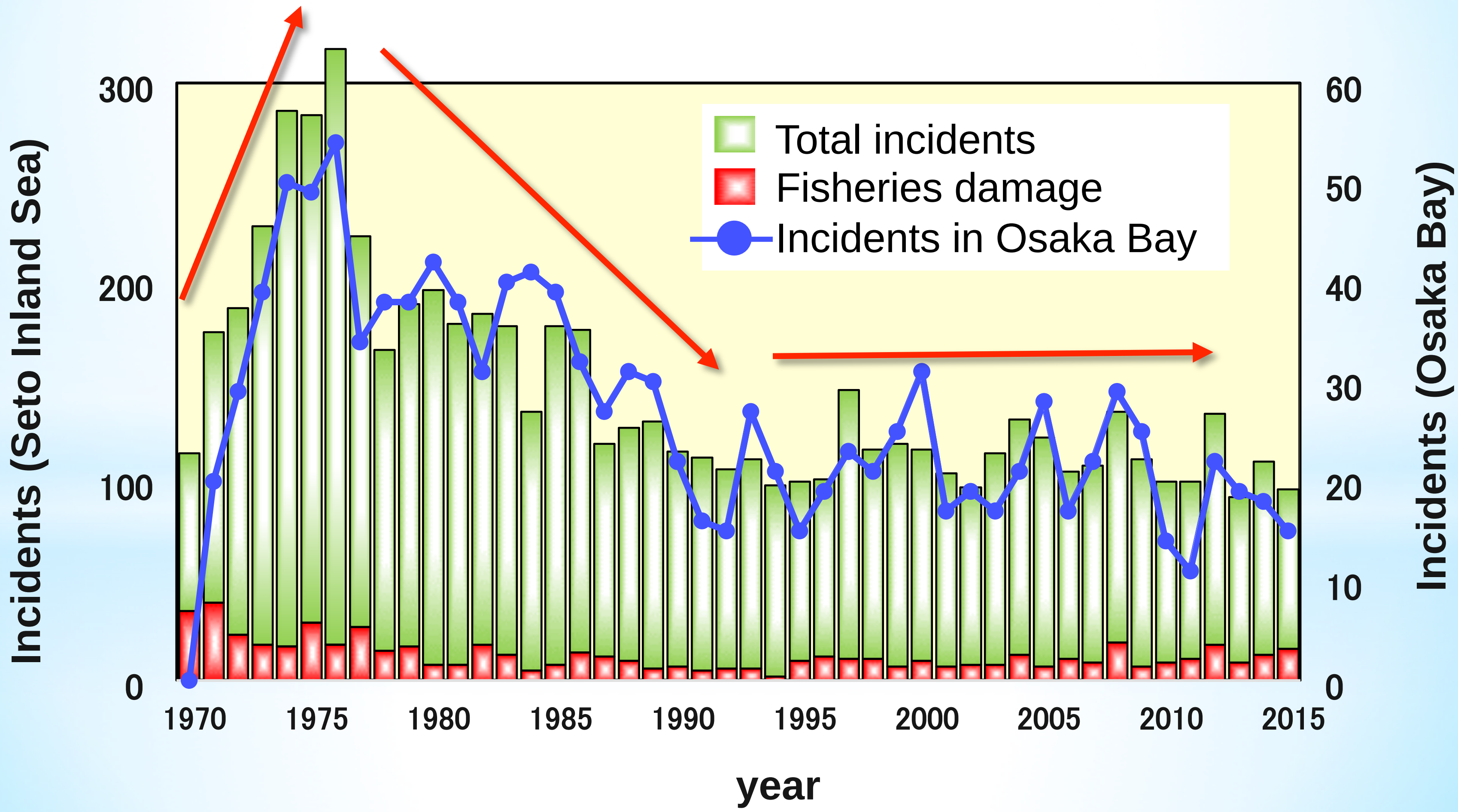
"Law Concerning Special Measures for Conservation of the Environment of the Seto Inland Sea" (enacted in 1973)

→ # Control of the total pollutant load
  # Reduction of the total quantity of organic pollutants in term of Chemical Oxygen Demand (COD)

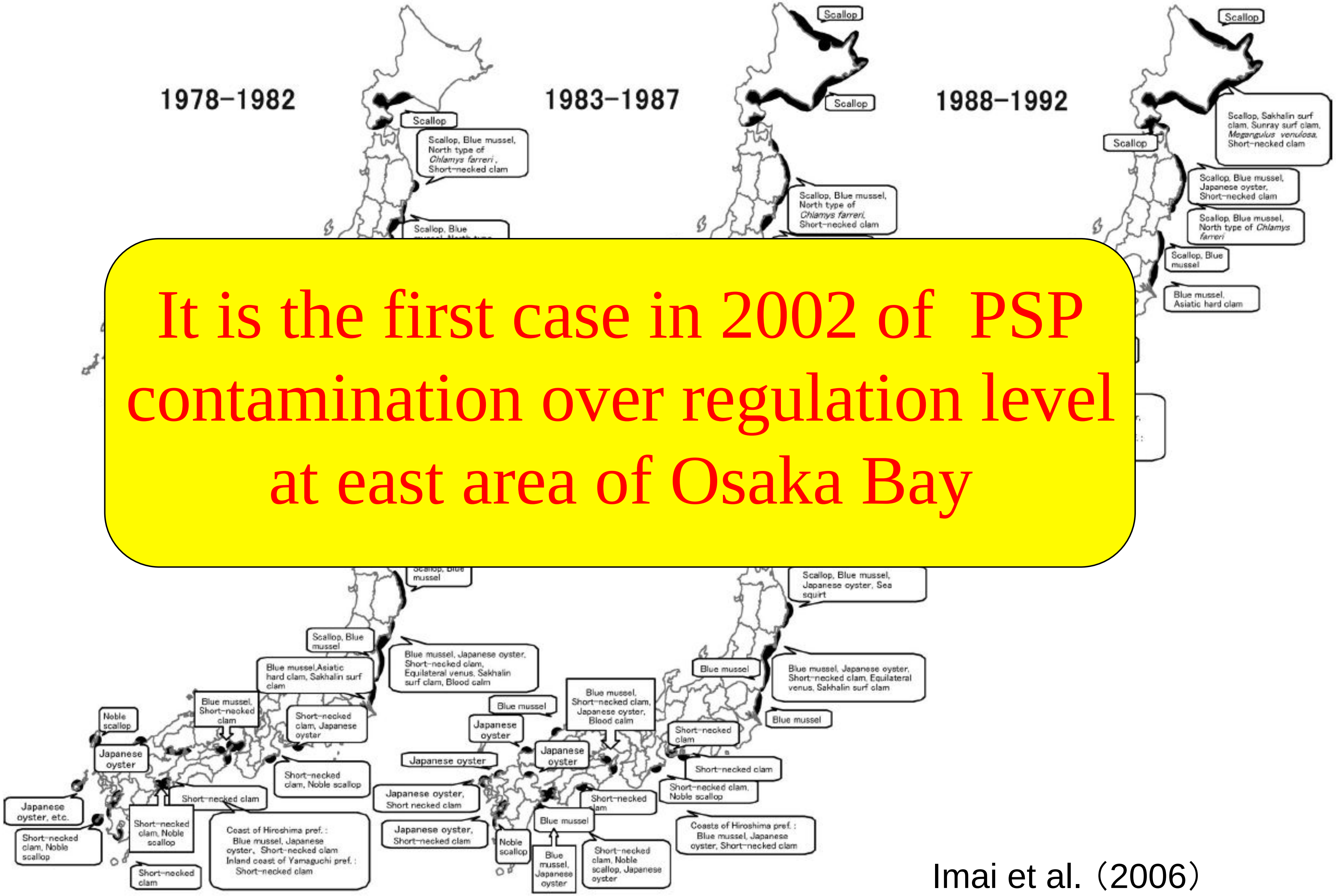
- Control of total P inputs (from 1979)

- Control of total N inputs (from 1996)

Occurrences of red tides in the Seto Inland Sea and Osaka Bay from 1970 to 2015



Expansion of PSP area in Japan



It is the first case in 2002 of PSP contamination over regulation level at east area of Osaka Bay

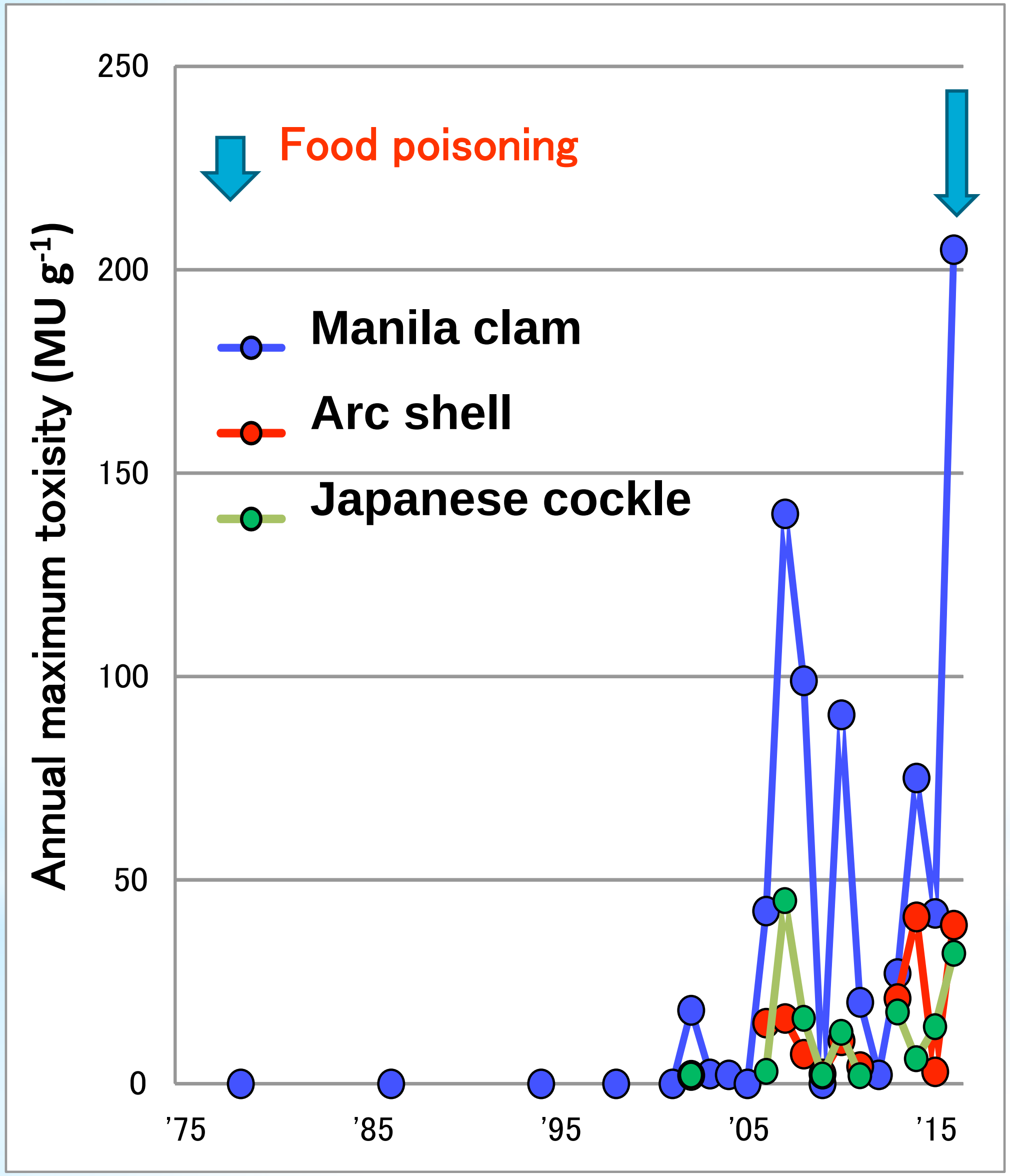
Imai et al.（2006）

These are species contaminated with PSP in Osaka Bay

Carnivorous conch

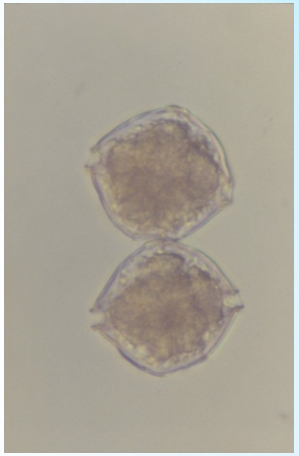
Swimming crab

Changes in annual maximum toxicity in 3 bivalves



Causative Phytoplankton of Paralytic Shellfish Poisoning

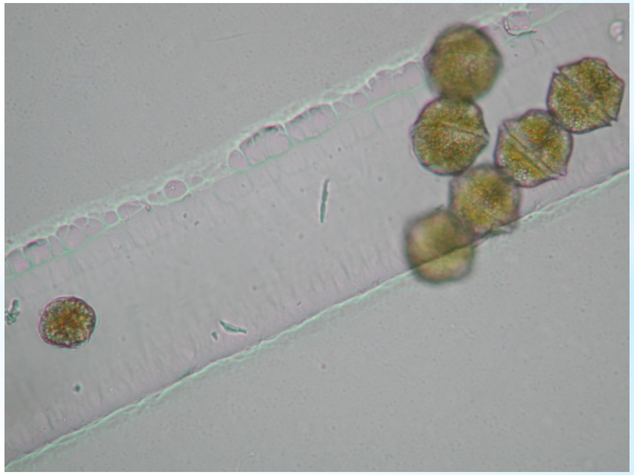
Causative species	Taxon	Growth period in Osaka bay
Alexandriuum acatenella	Dinofra.	
Alexandriuum catenella	Dinofra.	Spring to early summer
Alexandrium tamiyavanichii	Dinofra.	Autumn to winter
Alexandrium fundyense	Dinofra.	
Alexandrium minutum	Dinofra.	
Alexandrium tamarense	Dinofra.	Early spring to late spring
Gymnodinium catenatum	Dinofra.	Summer to autumn
Pyrodinium bahamense	Dinofra.	
Anabena circinalis	Ciano.	



Alexandrium tamarense

Alexandrium catenella

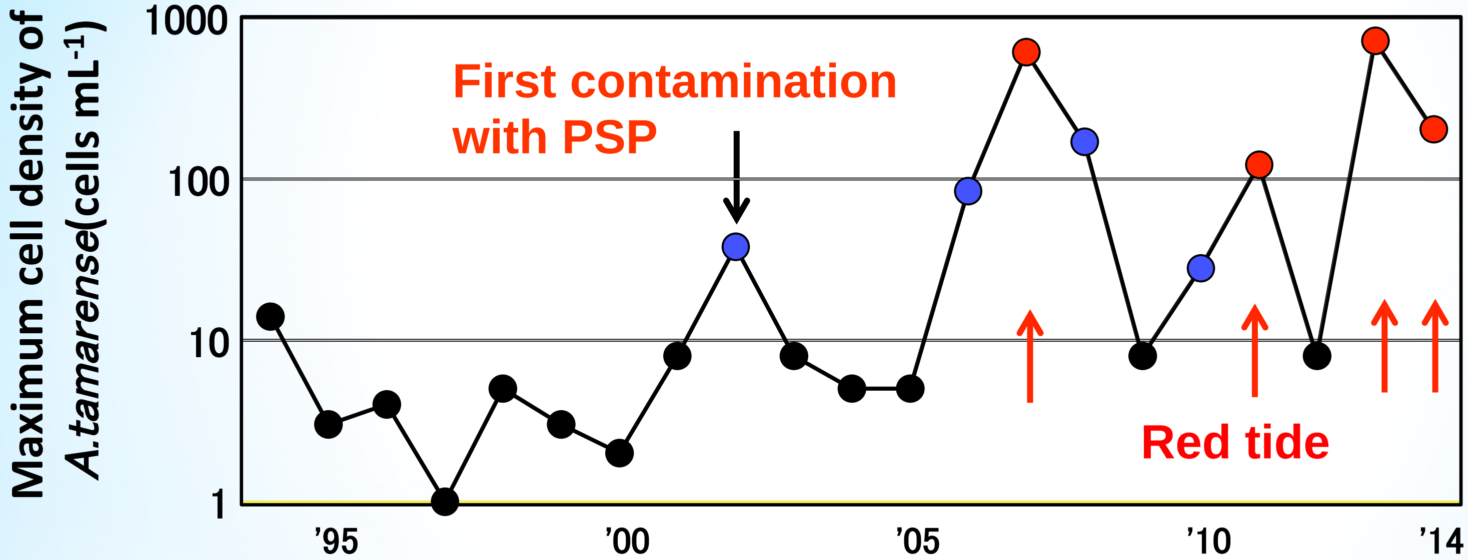
Gymnodinium catenatum
(photo by Dr. Sakamoto)

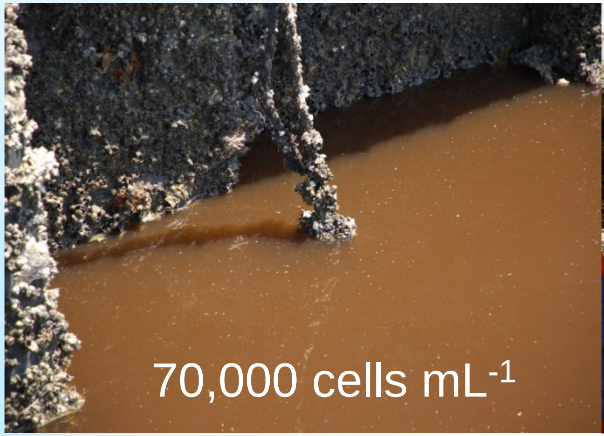


Alexandrium tamiyavanichii
(photo by Dr. Nagai)

From 2002, nearly every year bivalves in Osaka Bay contaminated with PSP in spring and furthermore red tide have been observed.

⇨ It is rare case for *A. tamarense*





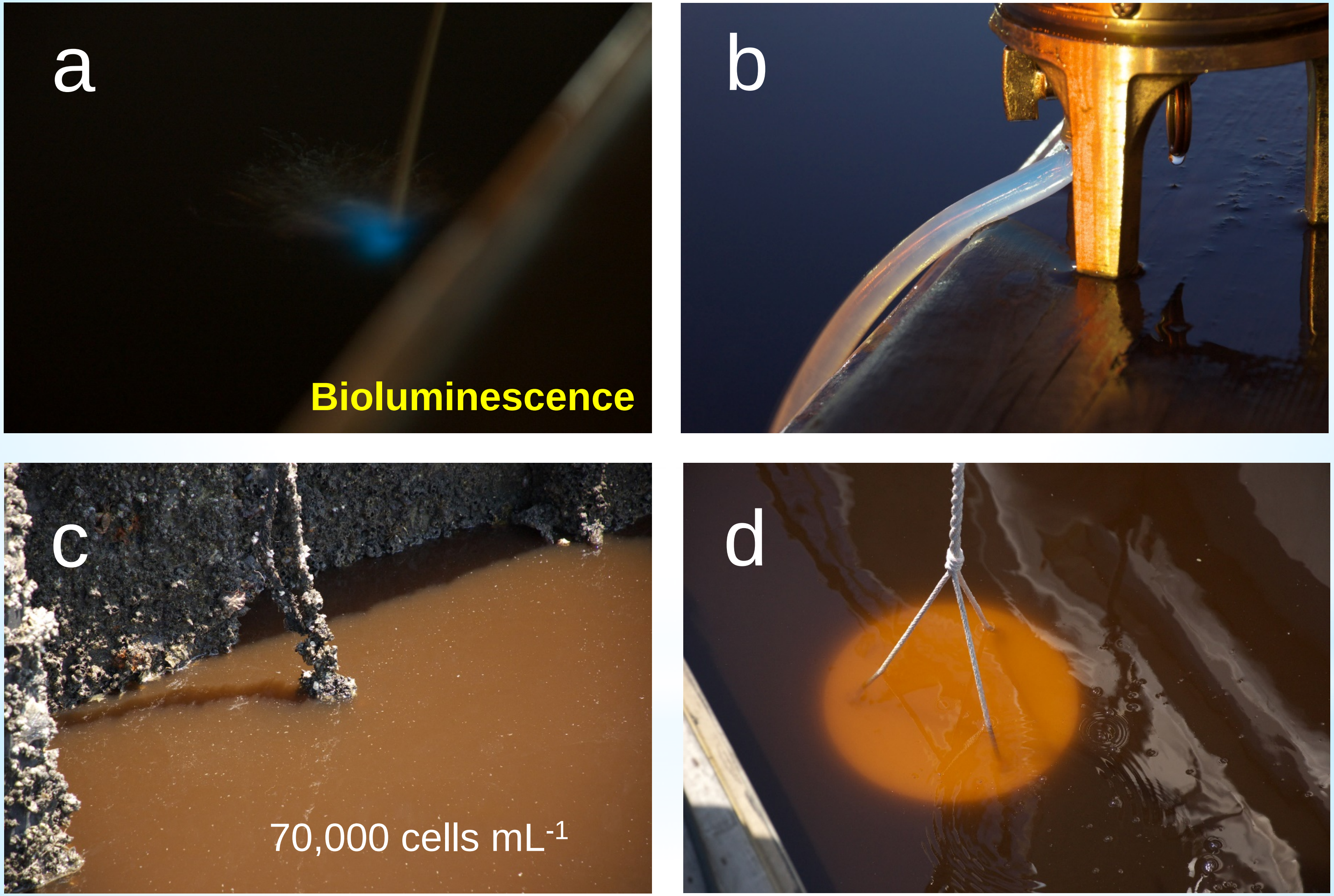
2007（Sakai. C）

2011（Yodo River）

2013（Sakai C.）

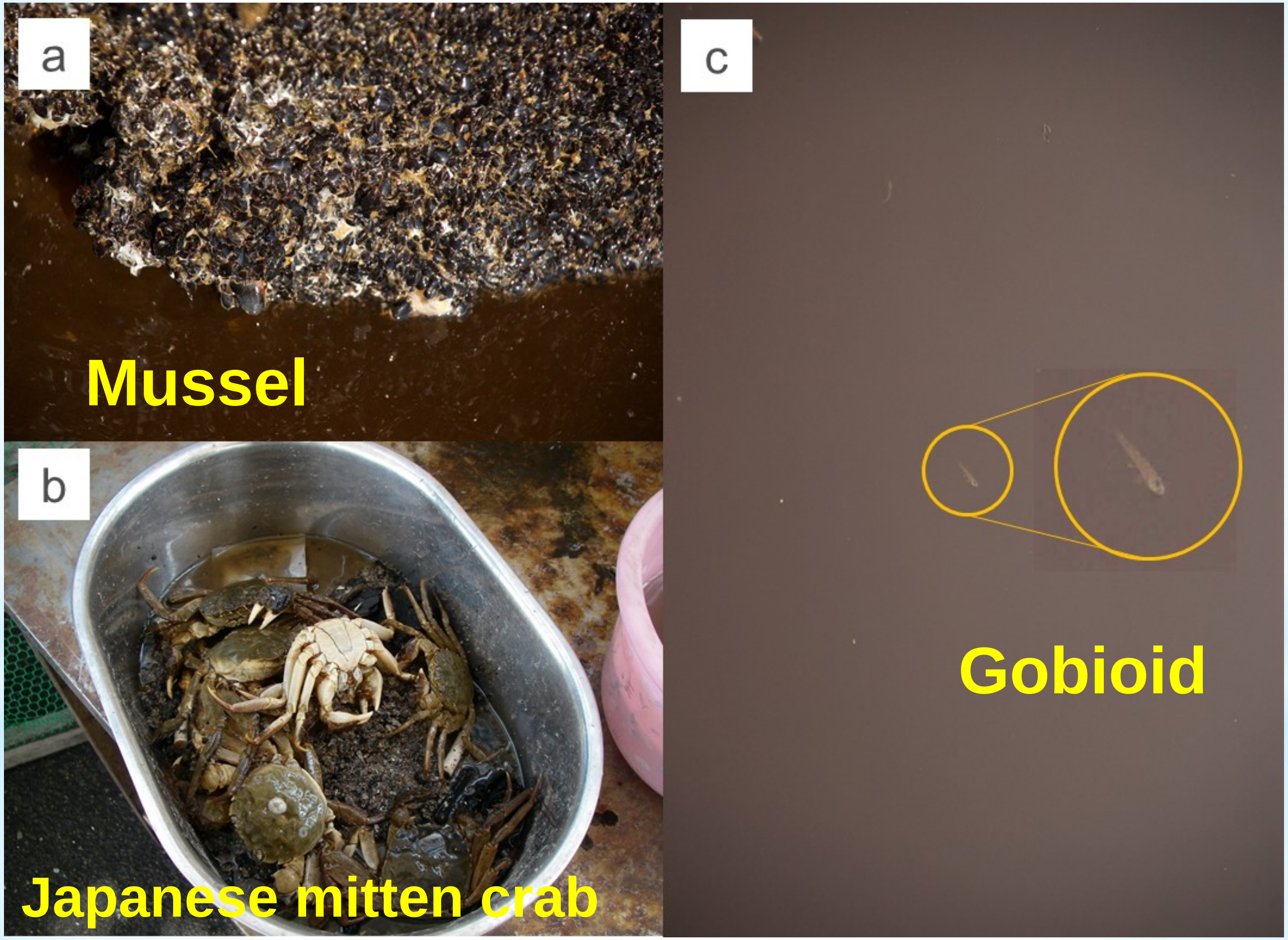
Red tide of *Alexandrium tamarense*

Bioluminescence observed in a fishing port during a red tide in 2007



(modified from Yamamot0 2010)

Aquatic animals killed by the bloom of *Alexandrium tamarense* at fishing port



Today’s contents

1. Trends of *Alexandrium tamarense* blooms in Osaka Bay in recent years

2. Long-term changes in environmental factors in Osaka Bay

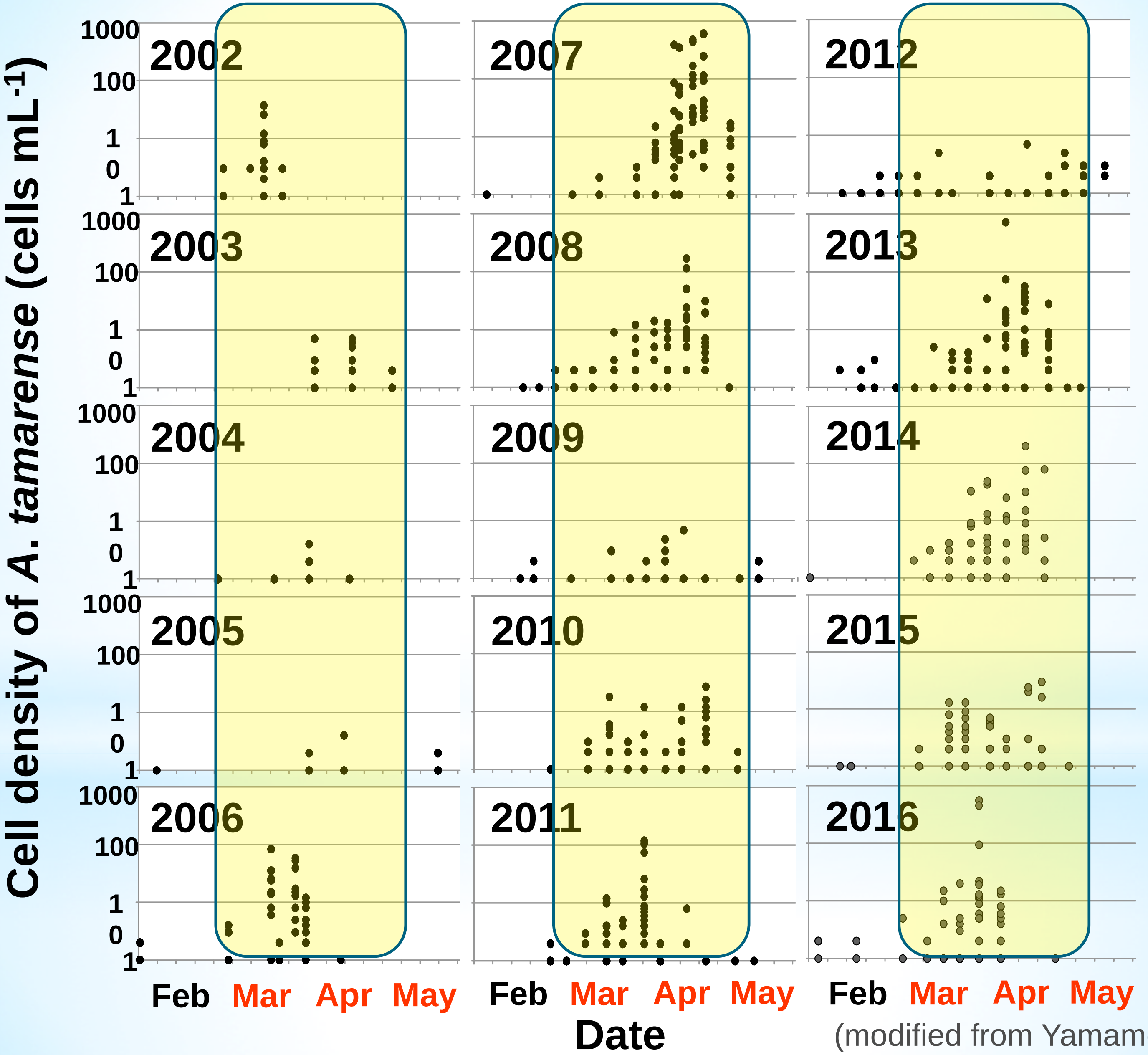
3. Why has become massive blooms in recent years?

1. Trends of *Alexandrium tamarese* blooms in Osaka Bay in recent years

2. Long-term changes in environmental factors in Osaka Bay

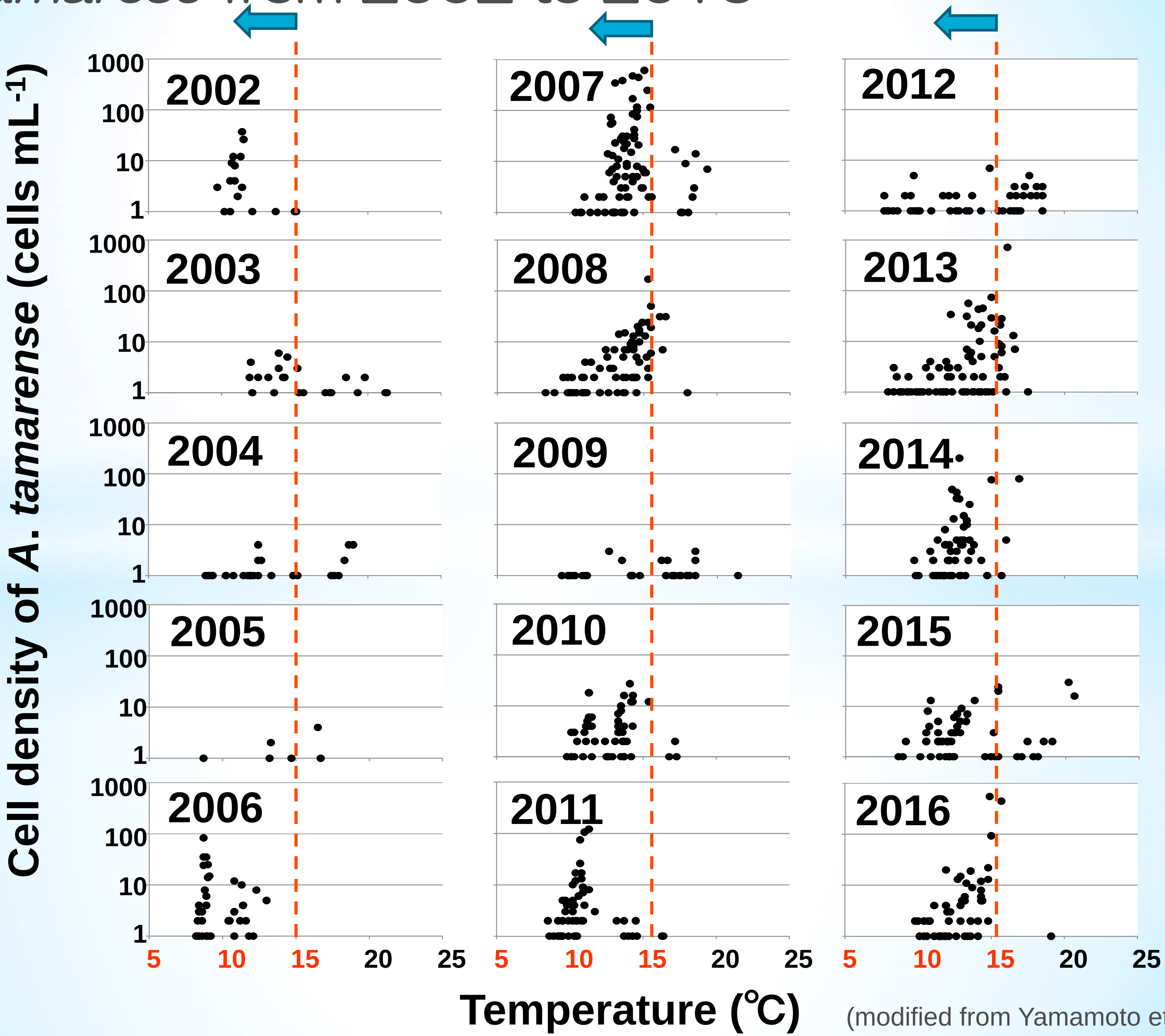
3. Why has become a massive bloom in recent years?

Temporal changes in cell densities of *A. tamarense* vegetative cells from 2002 to 2016



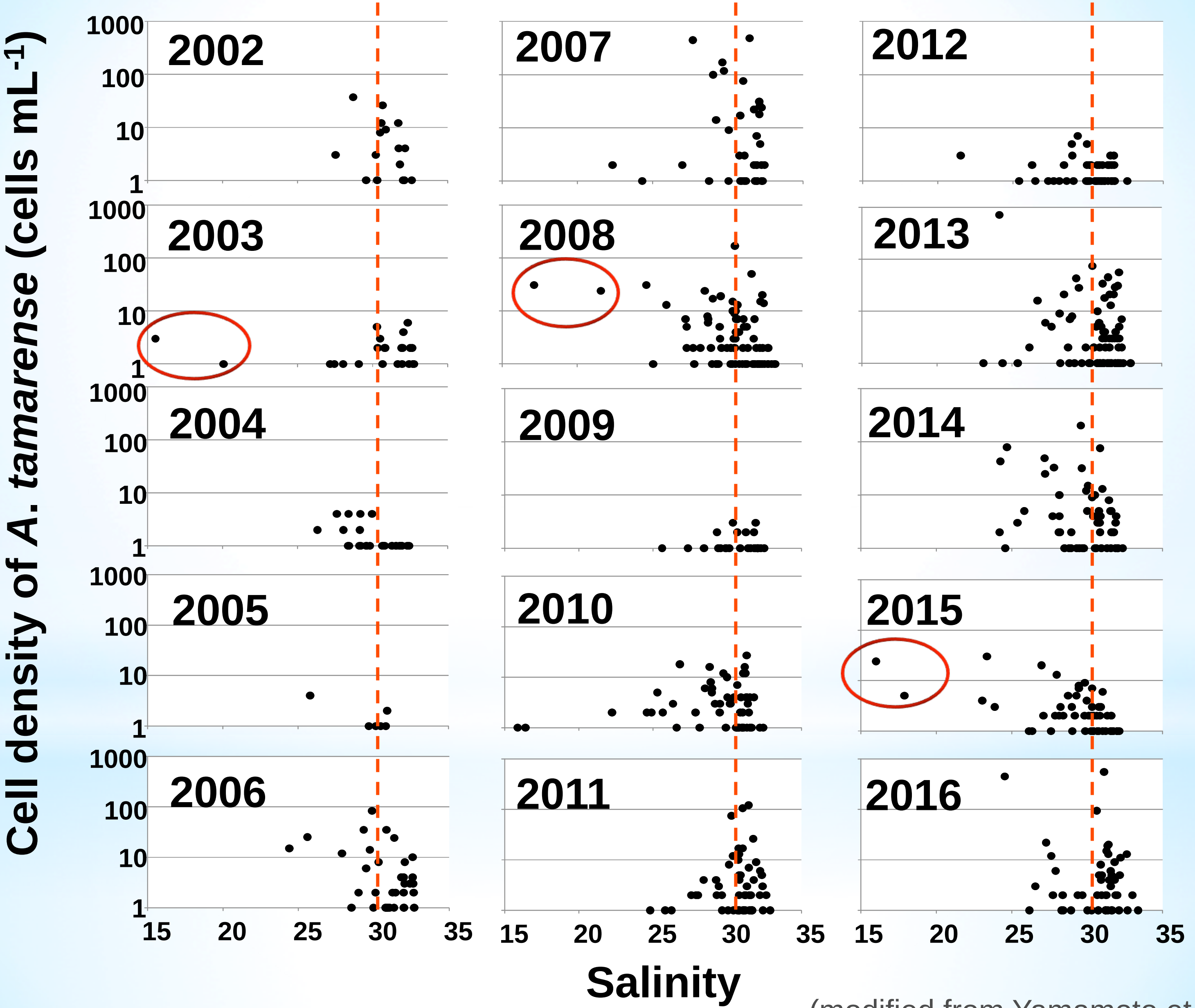
(modified from Yamamoto et al. 2017)

Relationships between temperature and cell density of *A. tamarese* from 2002 to 2016



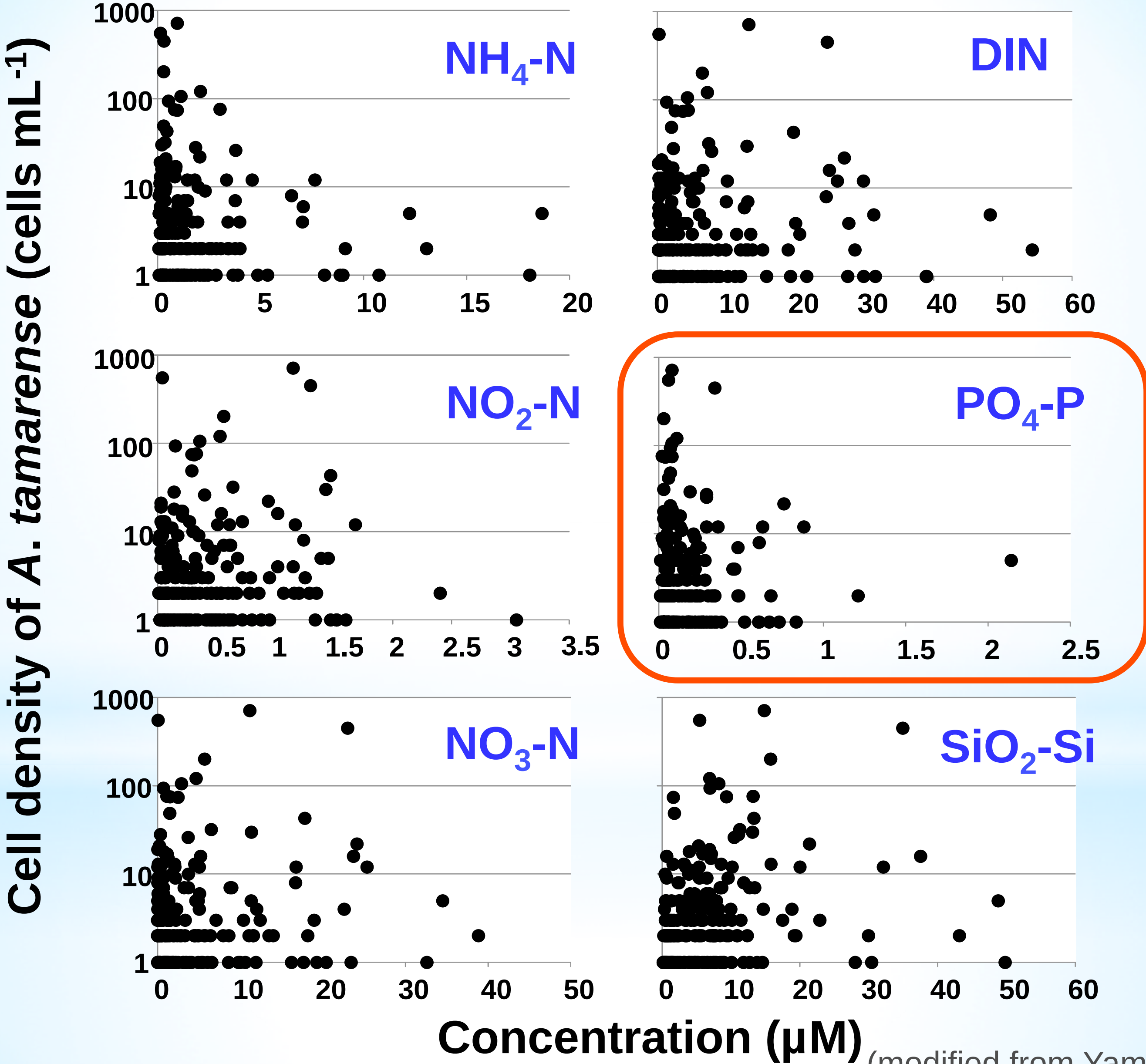
(modified from Yamamoto et al. 2017)

Relationships between salinity and cell density of *A. tamarese* from 2002 to 2016



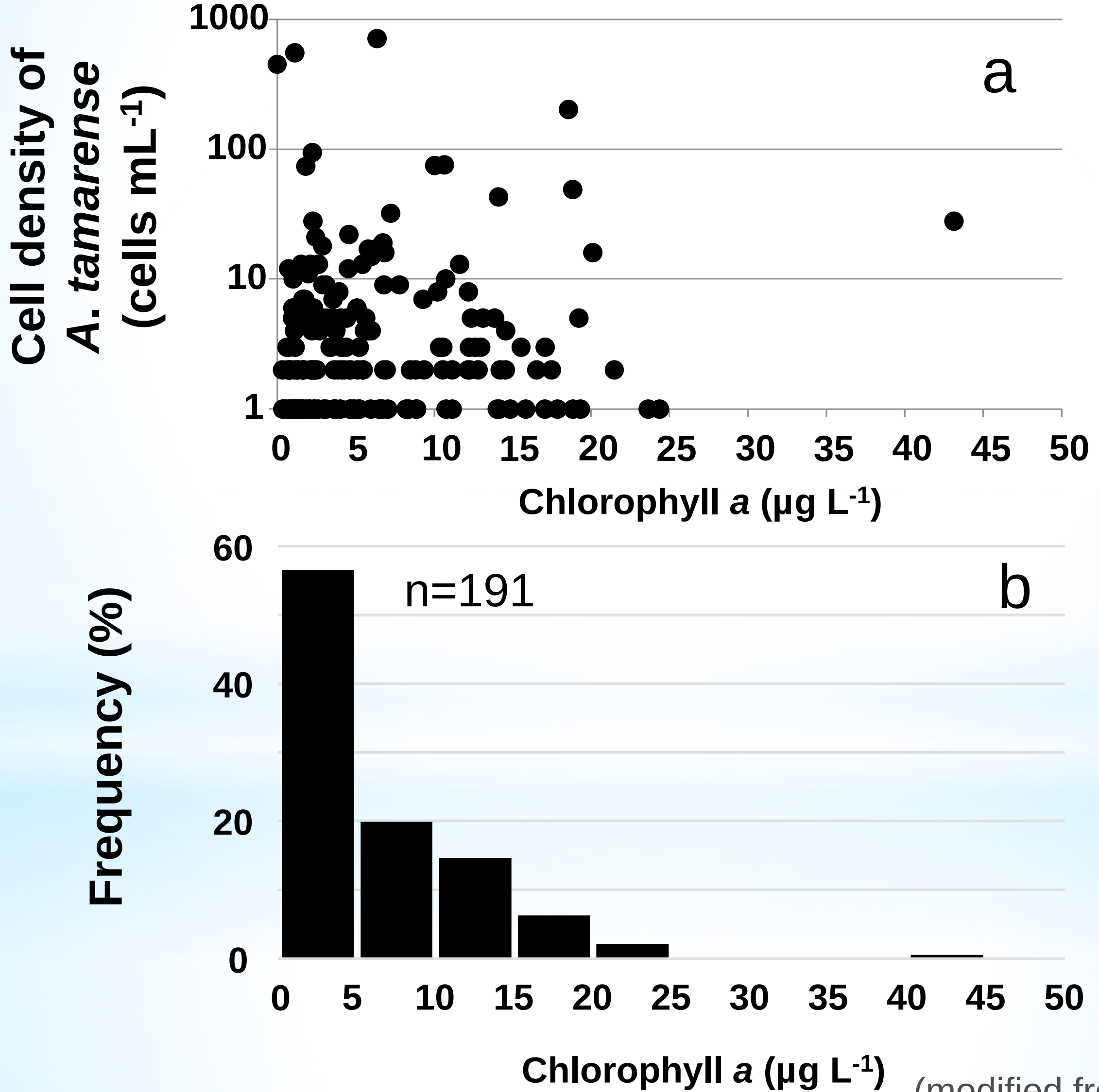
(modified from Yamamoto et al. 2017)

Relationships between nutrients concentration and cell density of *A. tamarese*



(modified from Yamamoto et al. 2017)

Relationship between chlorophyll *a* concentration and cell density of *A. tamarese* and frequency distribution



(modified from Yamamoto et al. 2017)

Conclusion 1

Alexandrium tamarense was observed in high cell density when,

1. 15 ℃ in temperature and 30 in salinity
2. Low nutrients, especially in phosphorus
3. Low chlorophyll *a* concentration

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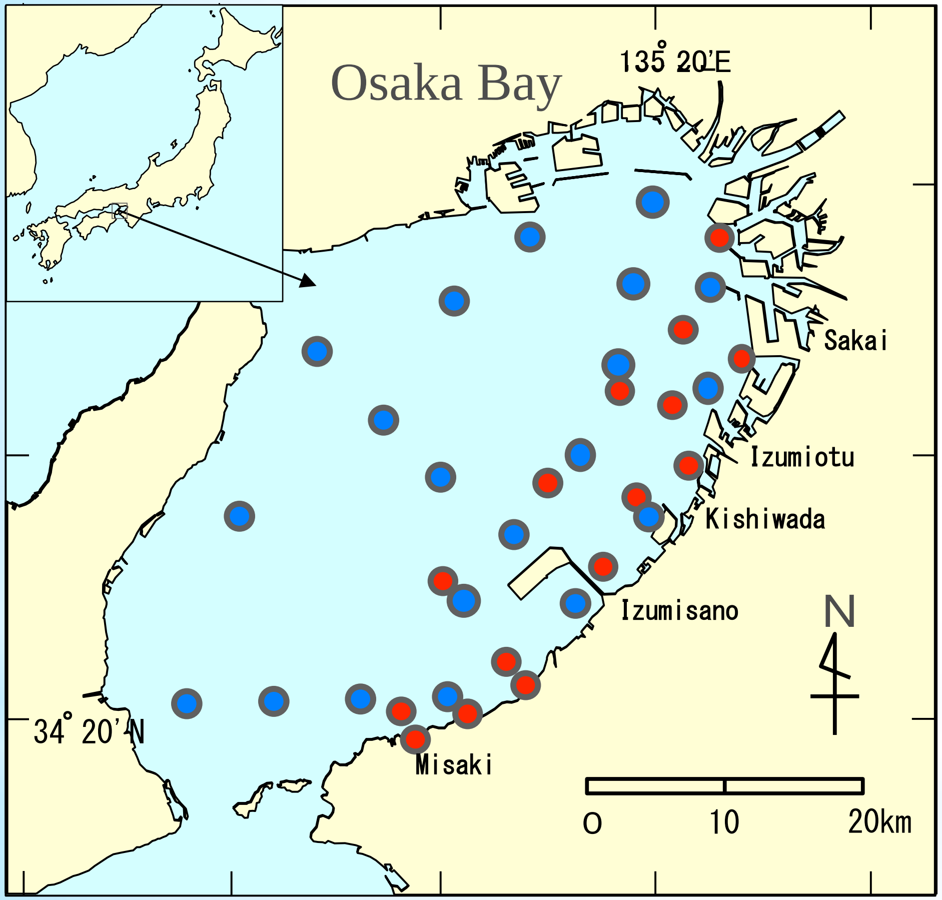
Analysis of long-term fluctuations

Study area and sampling stations



- Environmental factor
- Sampling station for phytoplankton

Material and Method

Environmental factor

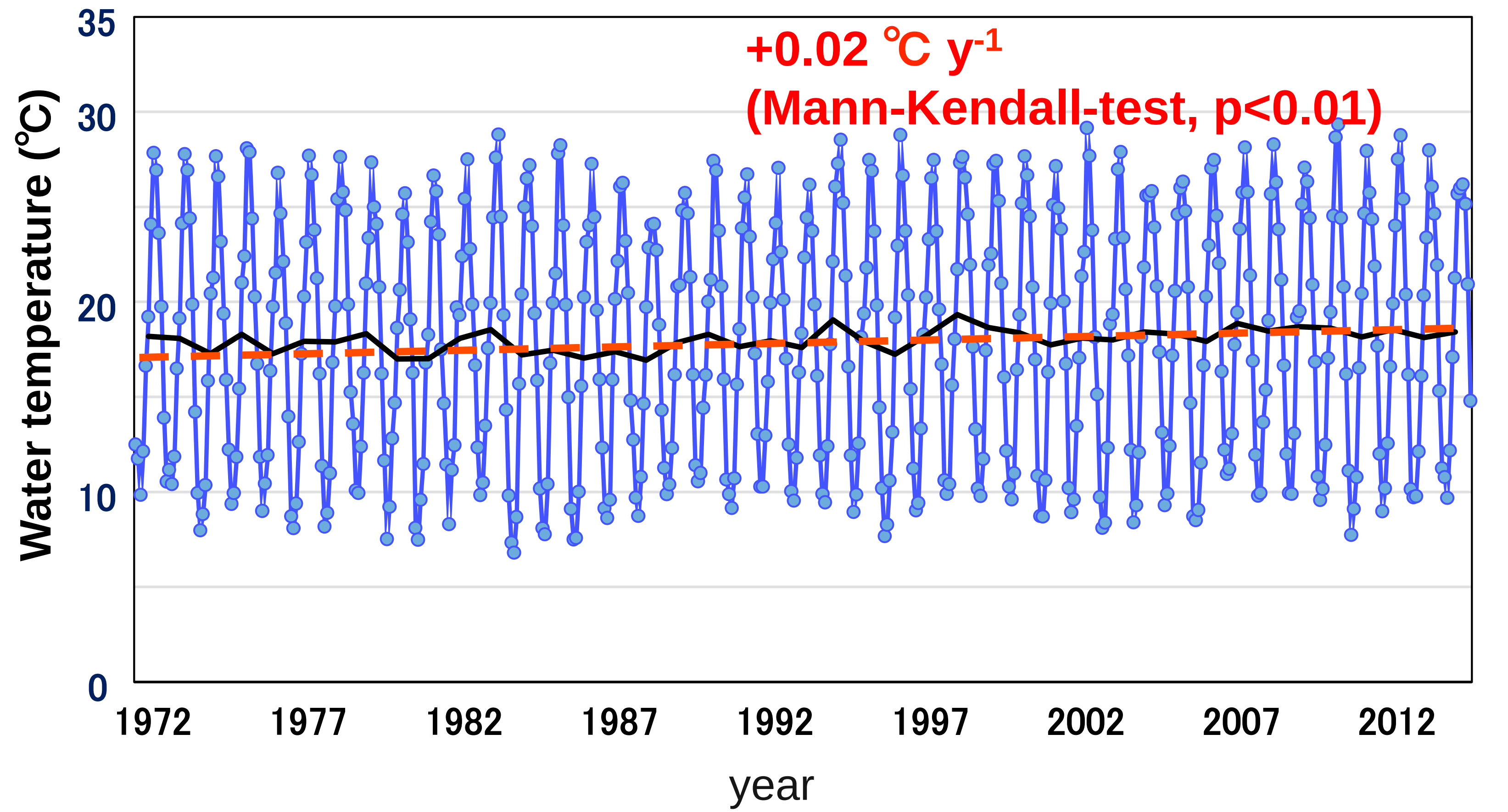
- Samples were collected 4times per year (Feb., May, Aug., Nov.) at 20 stations (blue circle)
- Water temperature, Salinity, Dissolved inorganic nitrogen (DIN), Dissolved inorganic phosphate (DIP), chlorophyll a from surface layer.

Phytoplankton data

- Use the research result surveyed by Osaka pref. government.
- Water samples were collected by Bandon water bottle from 1m layer at 15 stations (red circle)
- Every months in neap tide

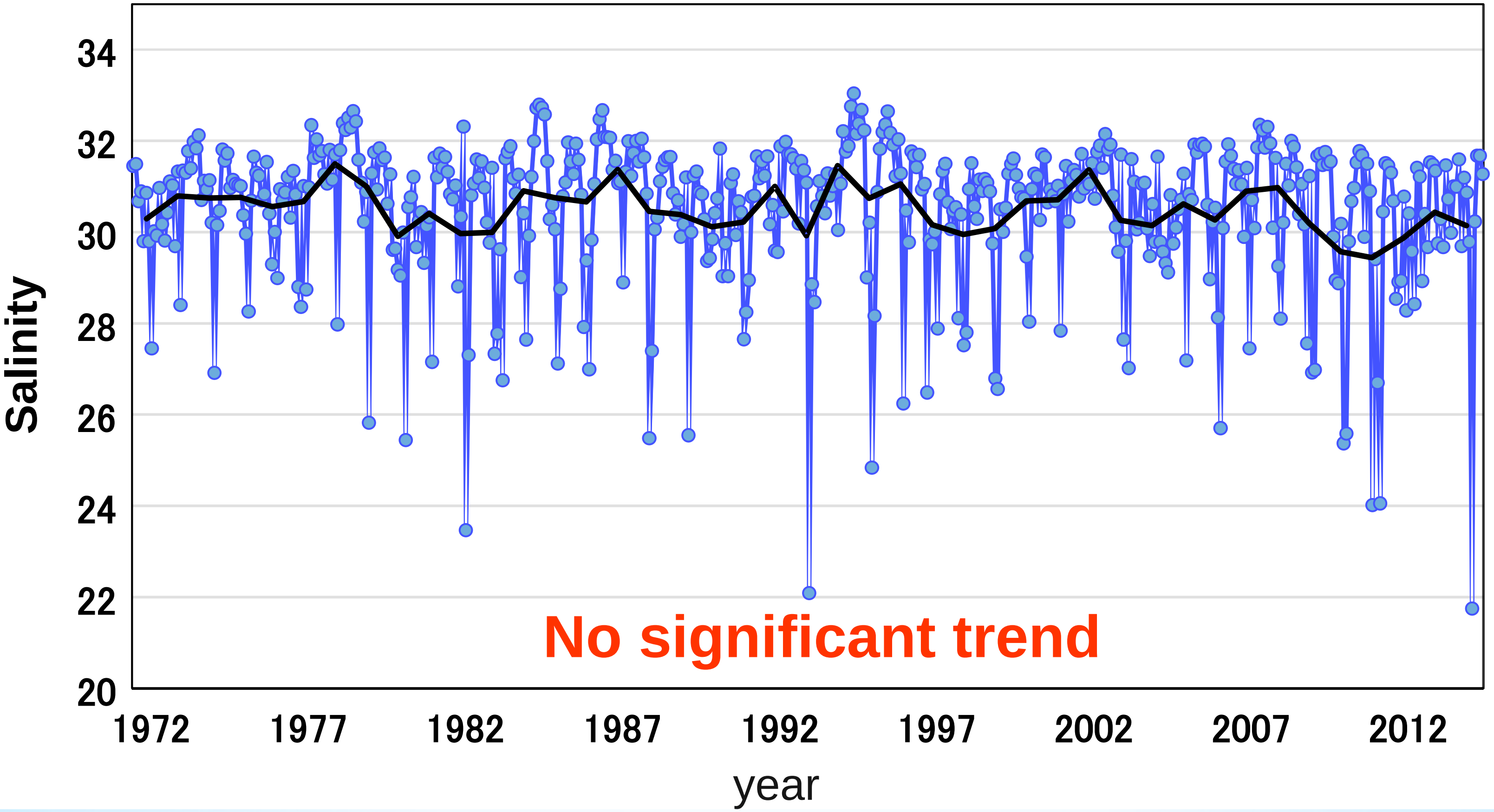
Long-term variations in water temperature

(1972-2016, surface layer at 20 sampling stations)



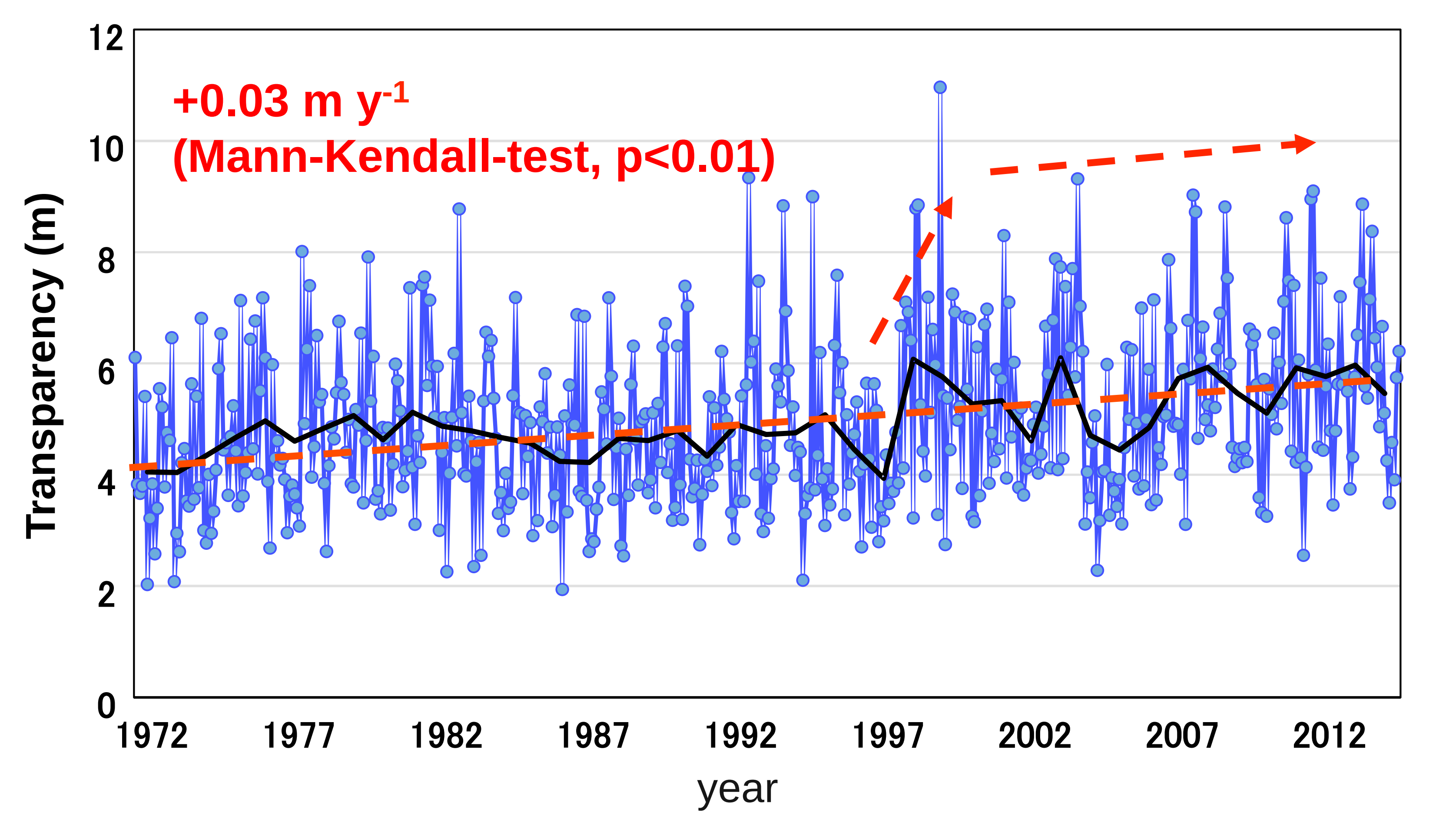
Long-term variations in salinity

(1972-2016, surface layer at 20 sampling stations)



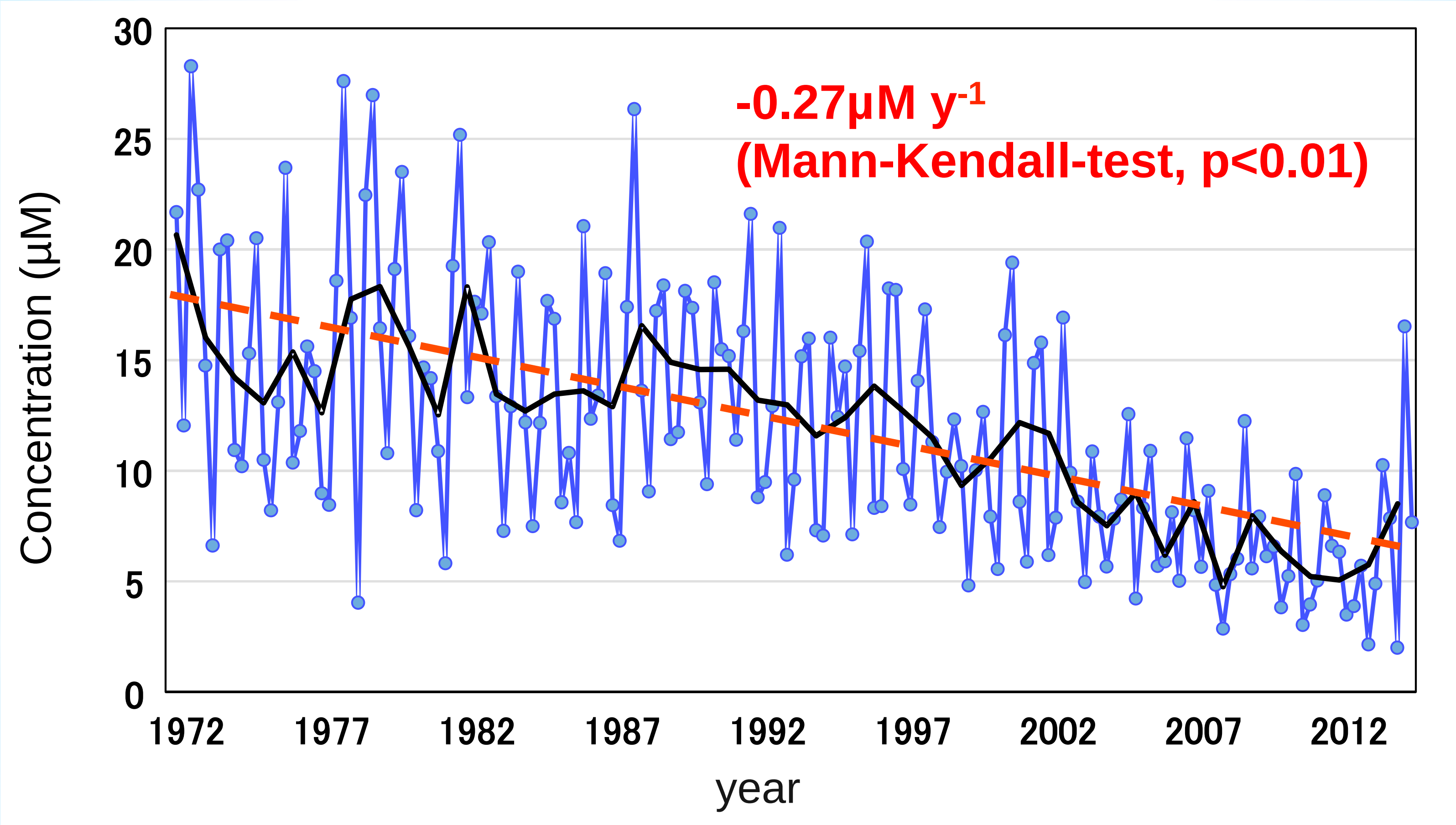
Long-term variations in transparency

(1972-2016, at 20 sampling stations)



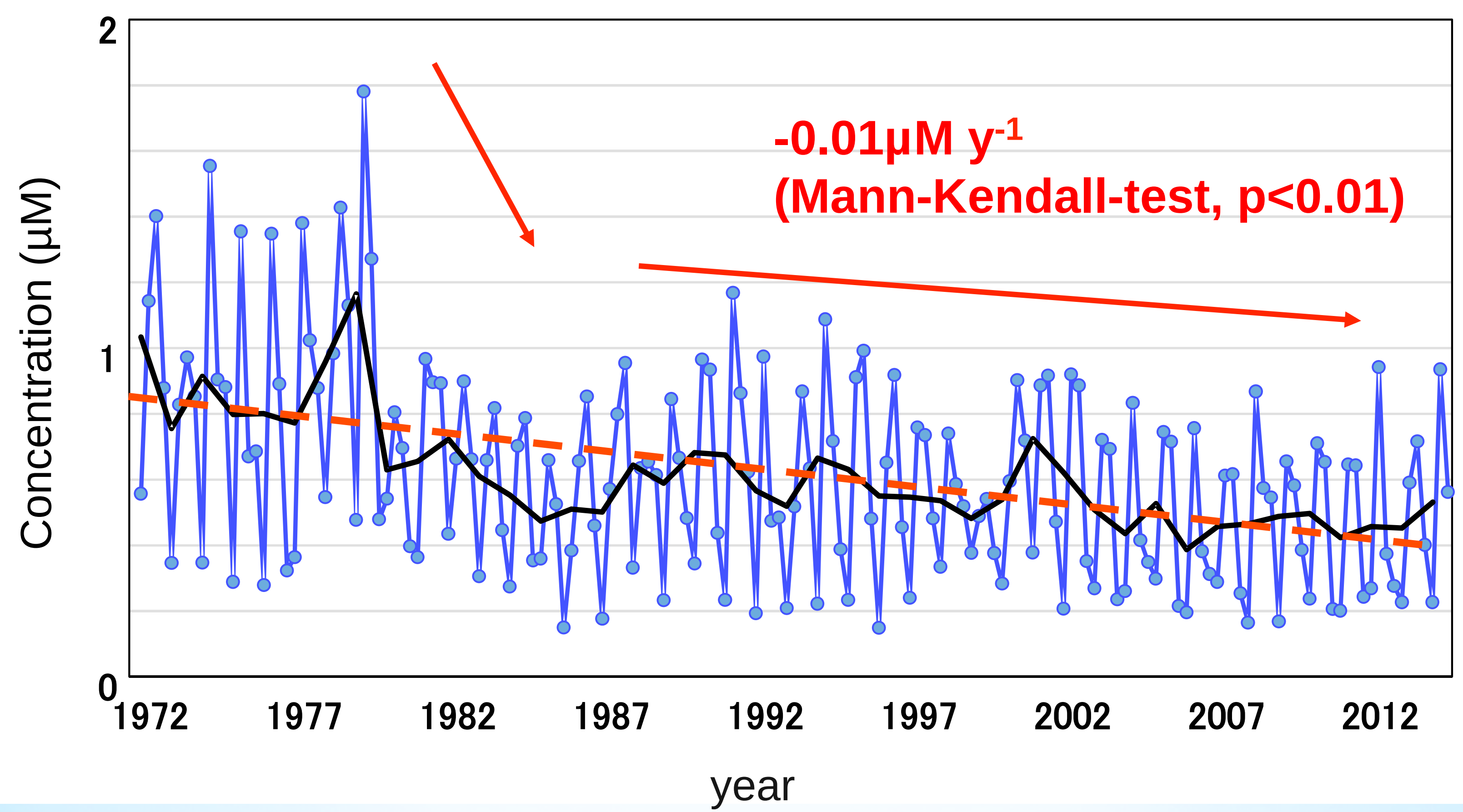
Long-term variations in DIN

(1972-2016, mean of surface layer and bottom layer at 20 sampling stations)



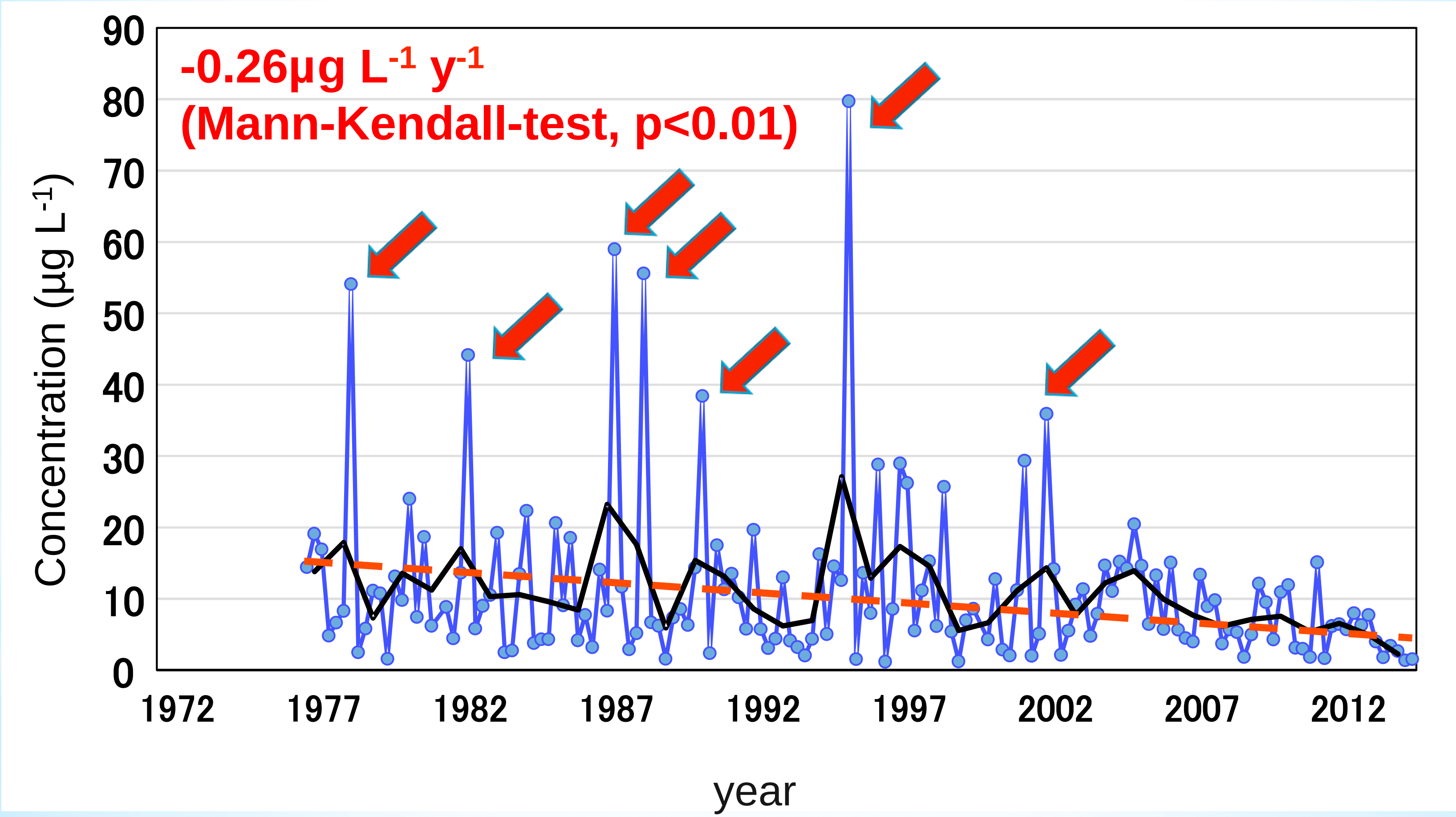
Long-term variations in phosphate

(1972-2016, mean of surface layer and bottom layer at 20 sampling stations)

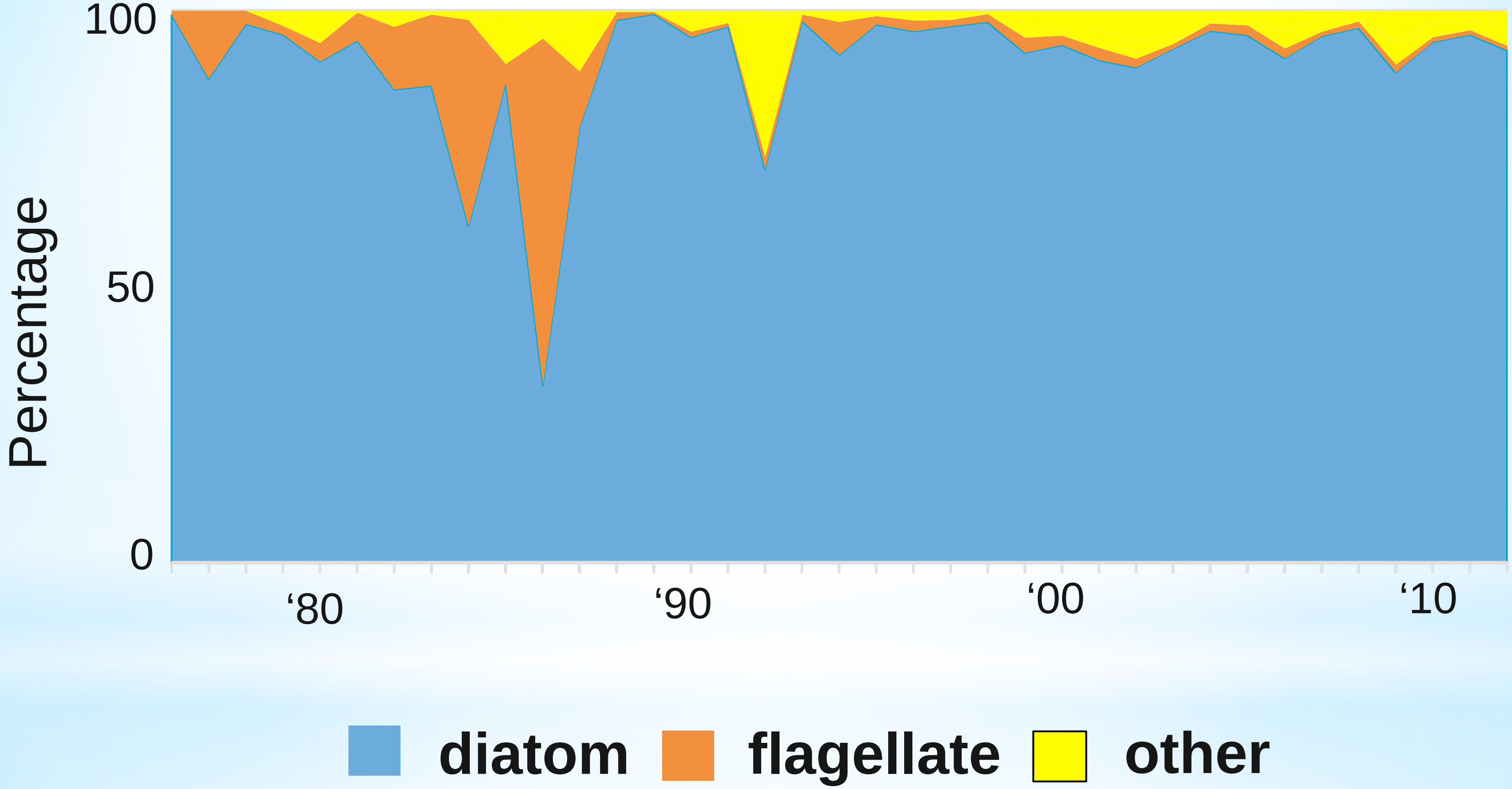


Long-term variations in chlorophyll a

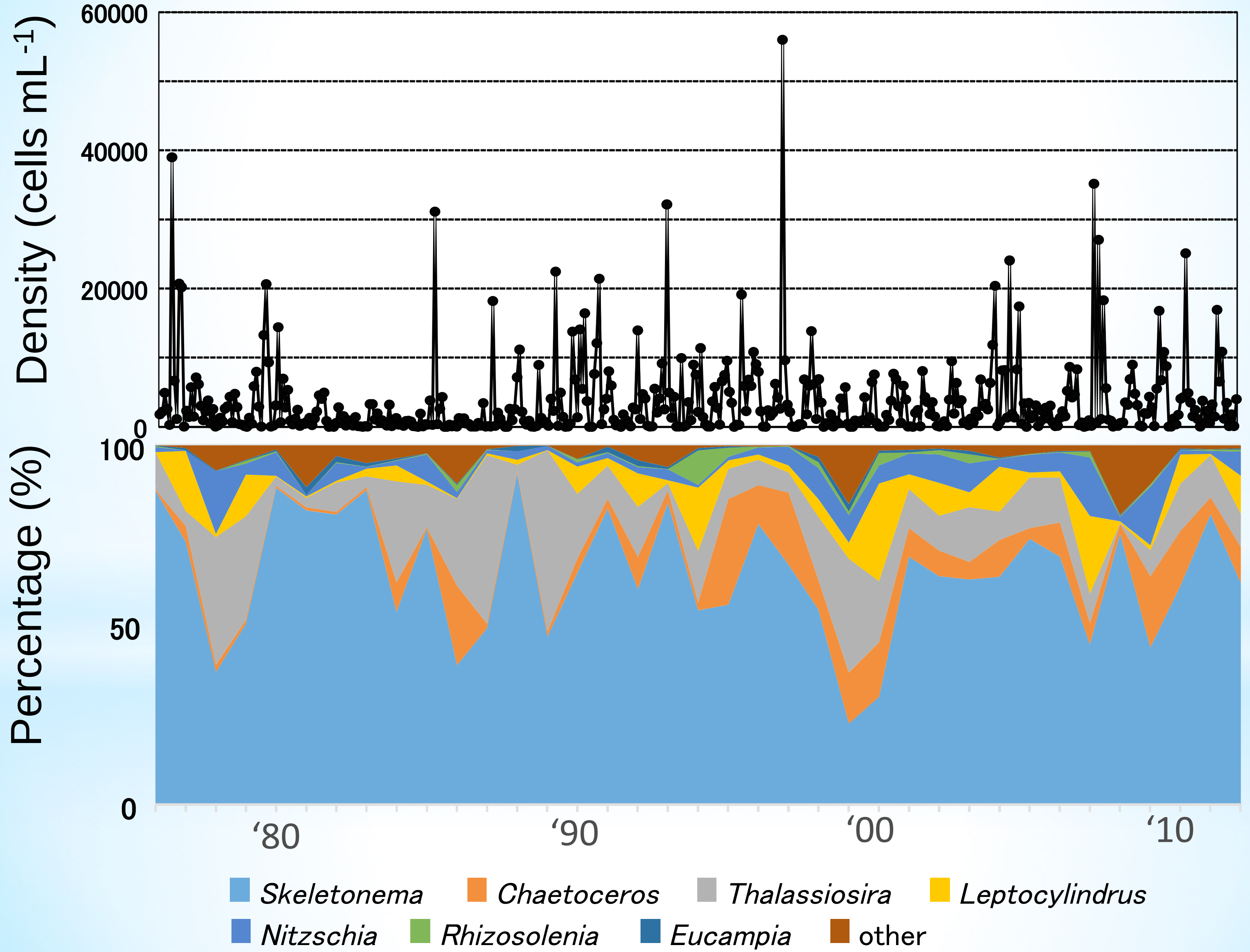
(1977-2016, in surface layer at 20 sampling stations)



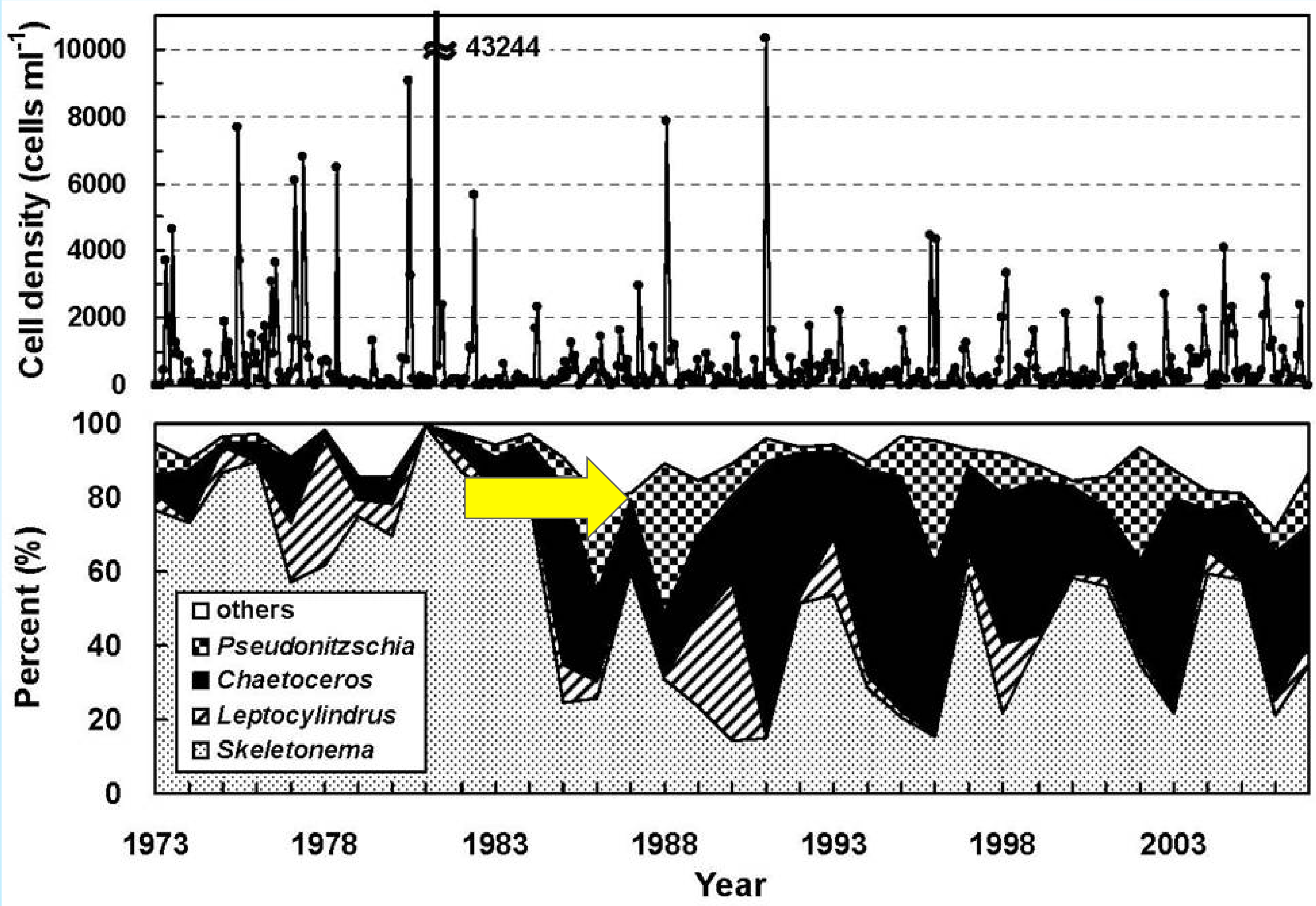
Long-term variation in yearly percent taxonomic group composition of phytoplankton from 1976 to 2012



Long-term variations in monthly total cell density and yearly percent genus composition of diatoms in Osaka Bay



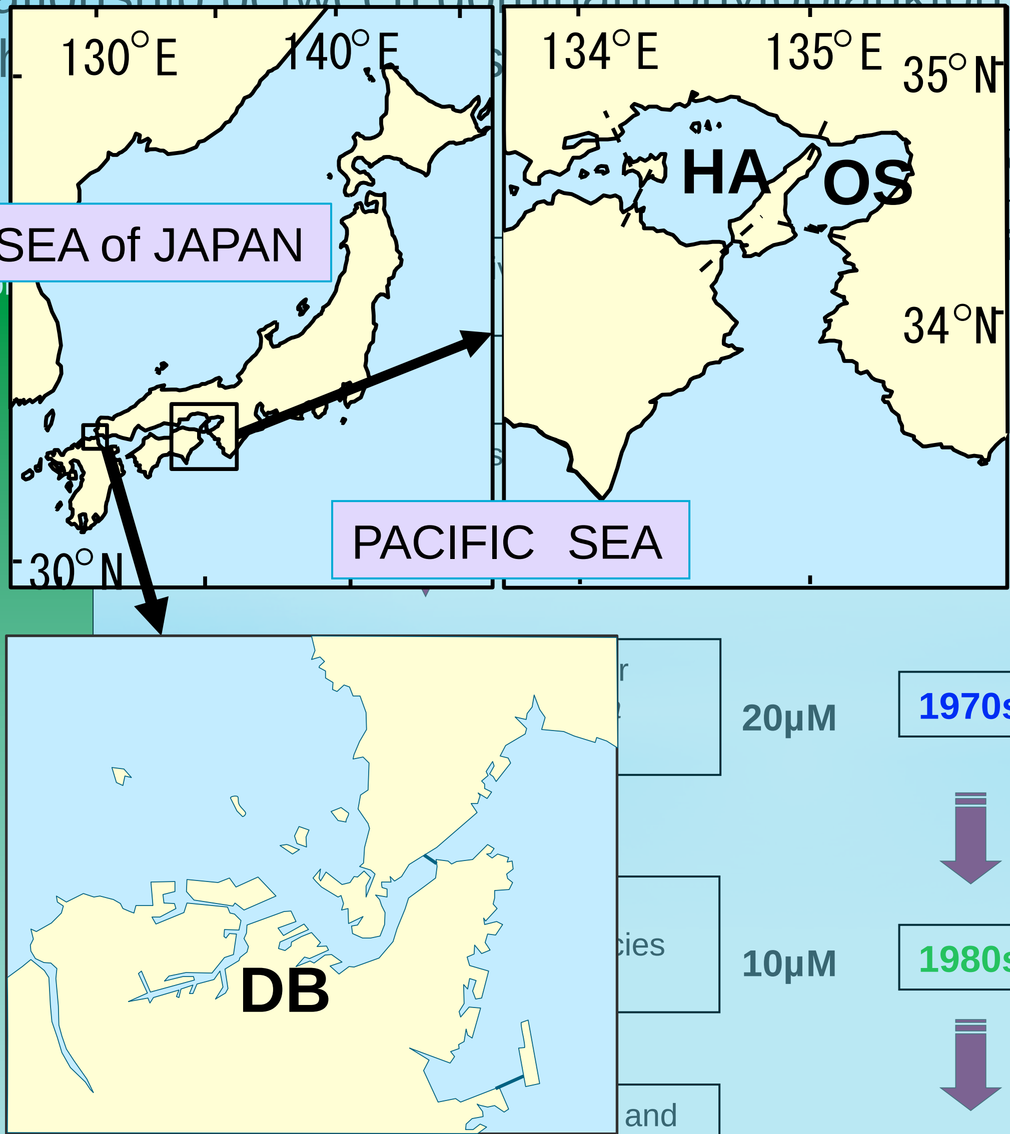
Long-term variations in monthly total cell density and yearly percent species composition of diatoms in Harima-Nada



(Nishikawa et al. 2009)

Relationship between dominant phytoplankton species and nutrient levels

in th



Eutrop

ies

and

Nori bleaching occurres.
Dominant diatom species during the winter change from *Coscinodiscus* to *Eucampia*.

Oligotrophic

ions

	Nada	Osaka Bay	Dokai Bay
			1970s
		1970s	1980s
20μM	1970s	1980s	1990s to present
10μM	1980s	1990s to present	
<5μM	Mid-1990s to present		

(modified from Tada et al. 2014)

1. Occurrence of *Alexandrium tamarese* and environmental factors in Osaka Bay in recent years

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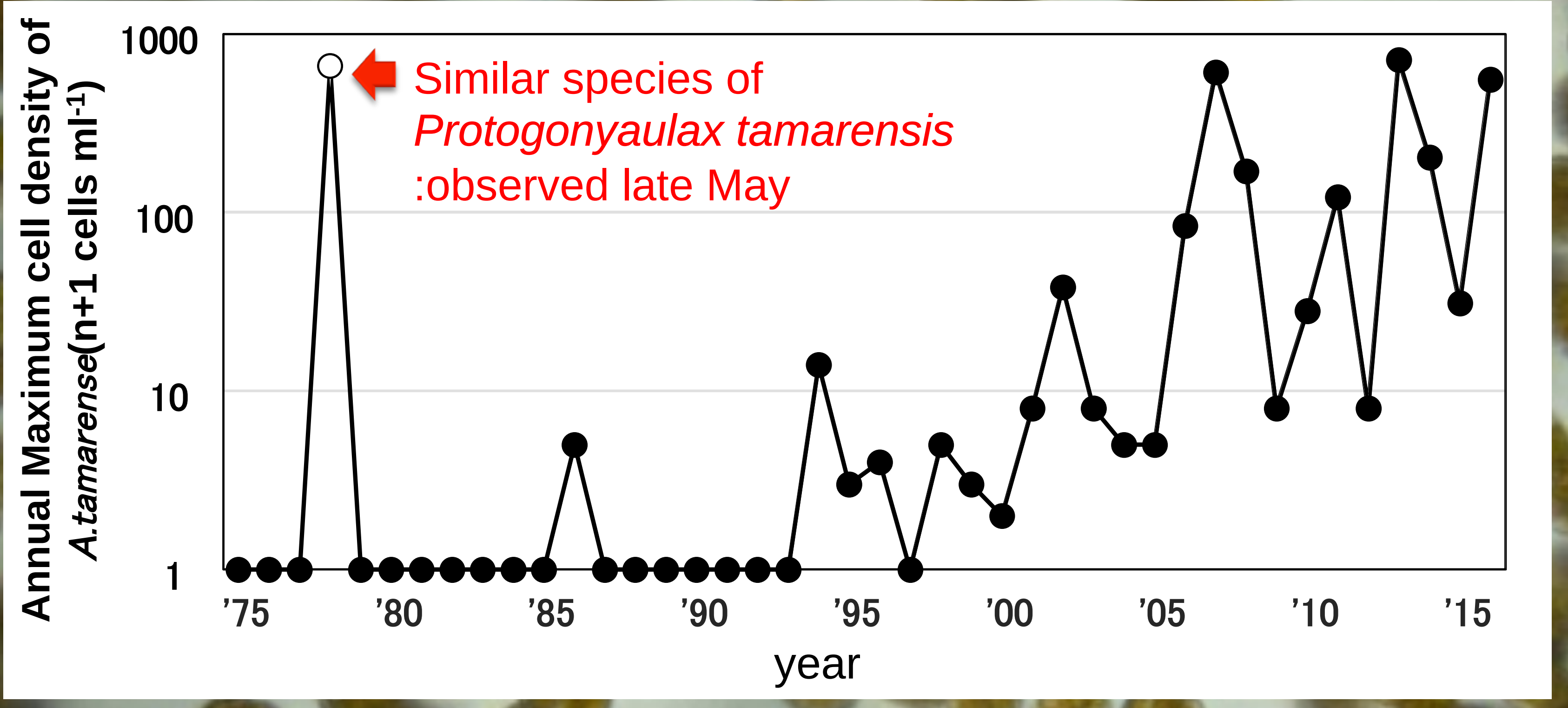
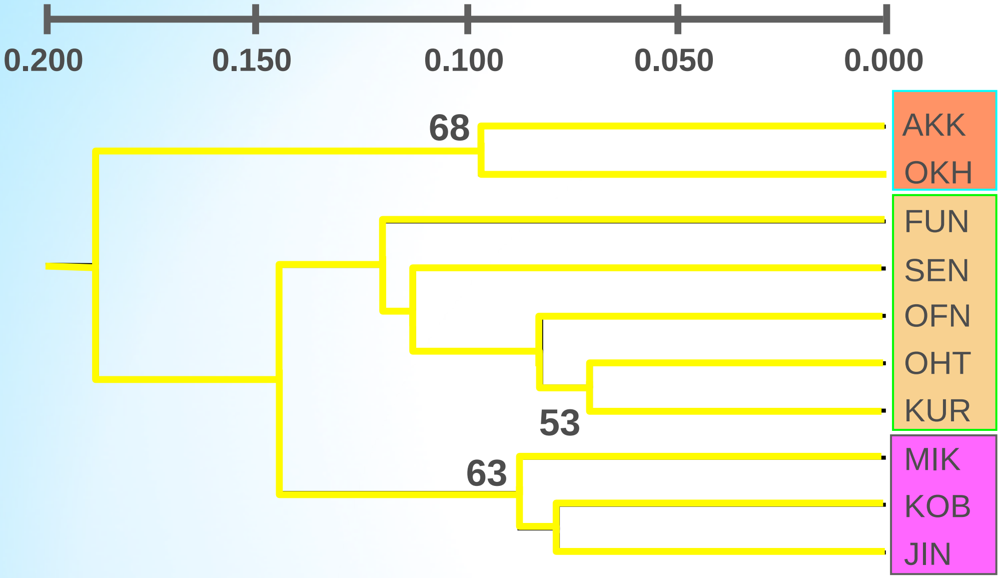
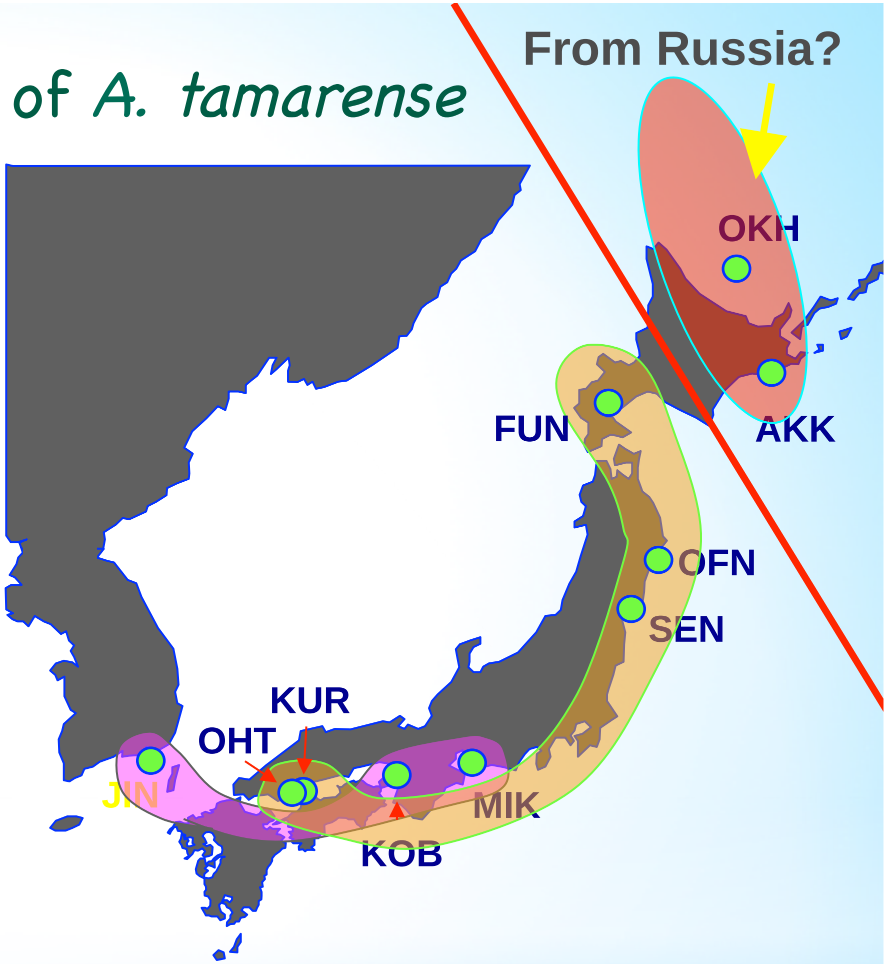
3. Why has become a massive bloom in recent years?

Long-term variations in annual maximum cell density of *A. tamarense*



Distribution of population genetics of *A. tamarense*





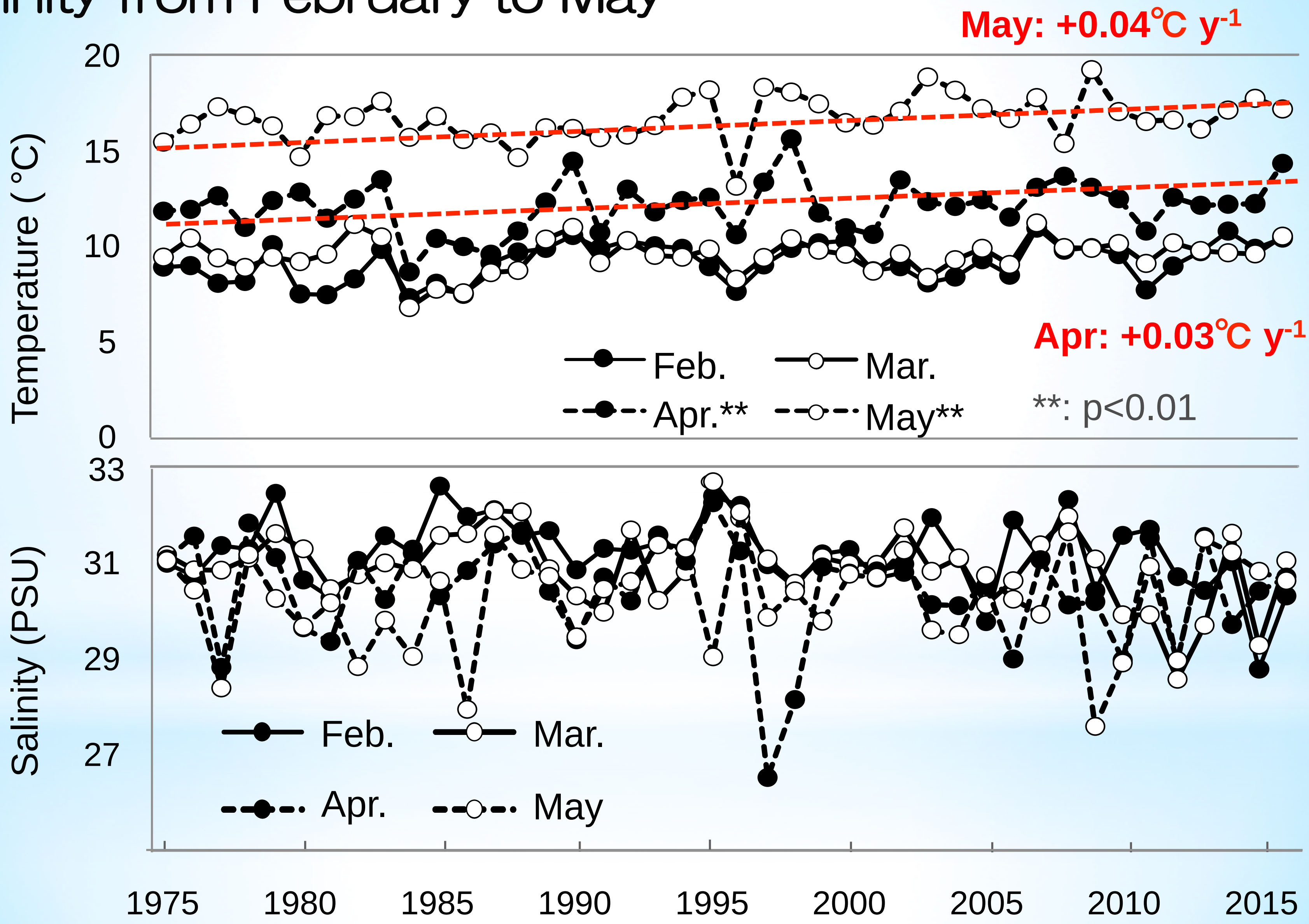
UPGMA dendrogram constructed using Nei's genetic distance among the ten localities of *A. tamarense* samples.

The dendrogram identified 3 clusters.

Transplantation from north to the Seto Inland Sea

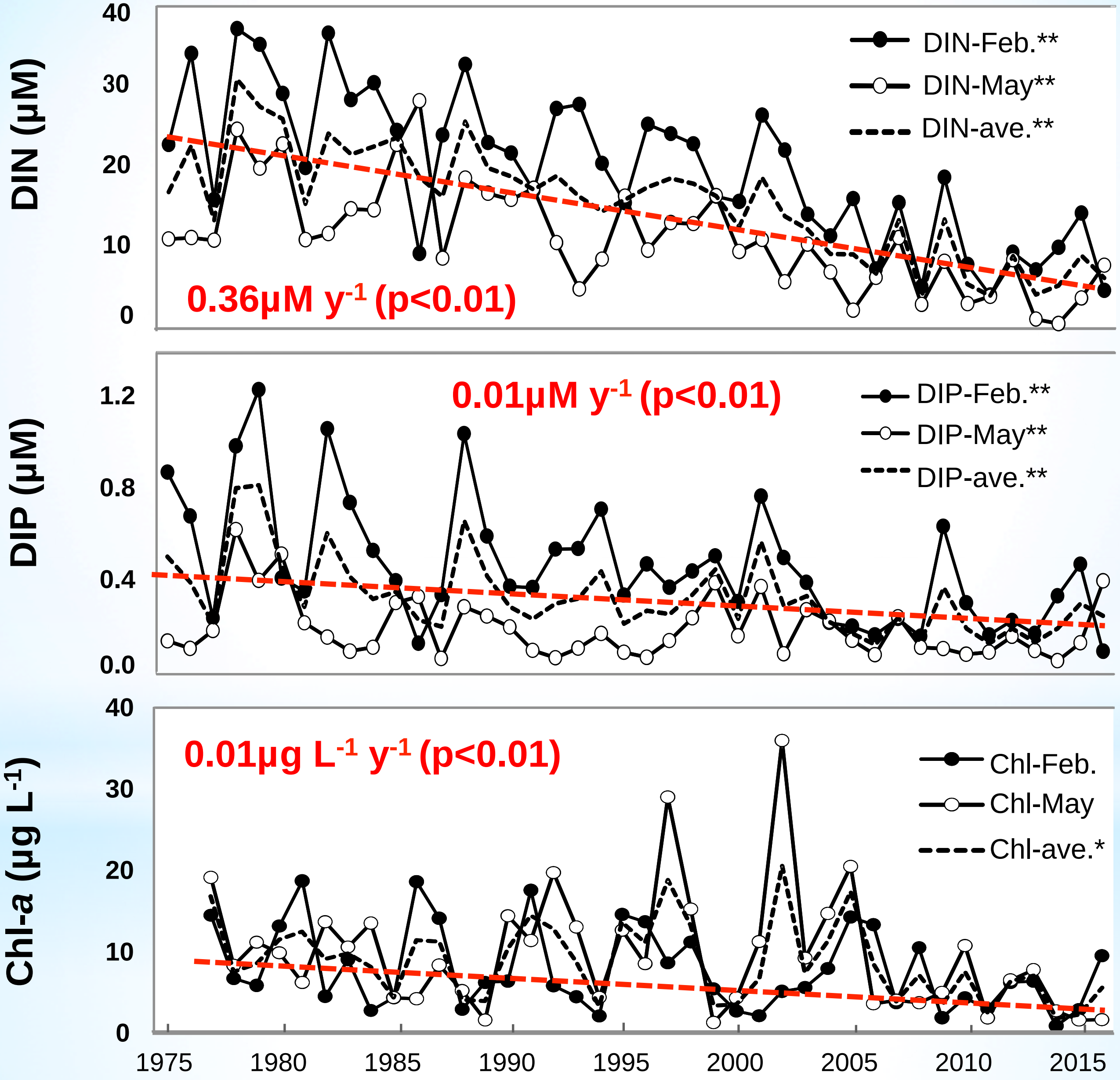
Nagai et al. (2007)

Long-term fluctuations of water temperature and salinity from February to May



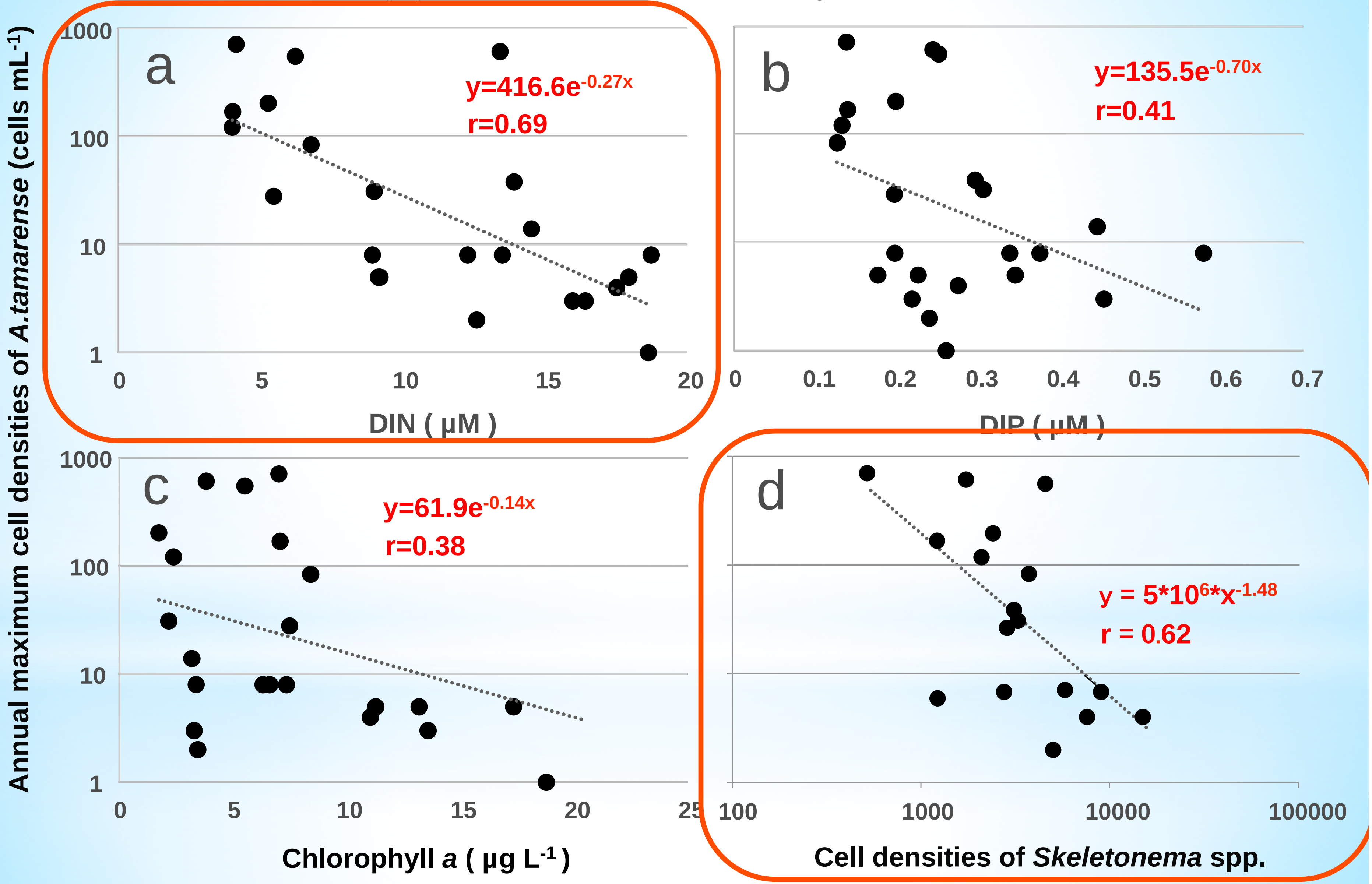
(modified from Yamamoto et al. 2017)

Long-term fluctuations of DIN, DIP and chlorophyll *a* from February to May



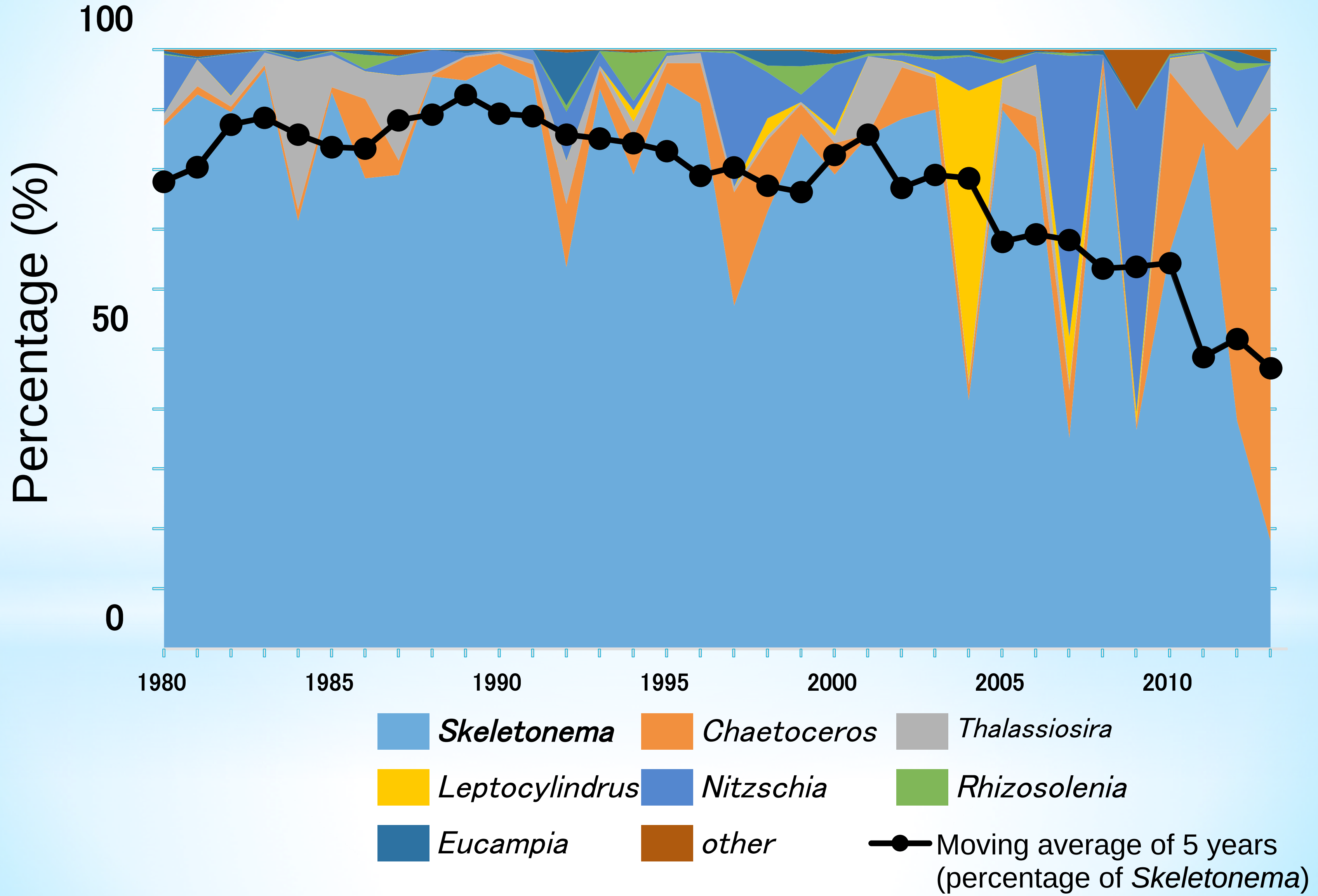
(modified from Yamamoto et al. 2017)

Relationships between DIN, DIP, chlorophyll *a*, cell density of *Skeletonema* spp. and cell density of *A. tamarense*

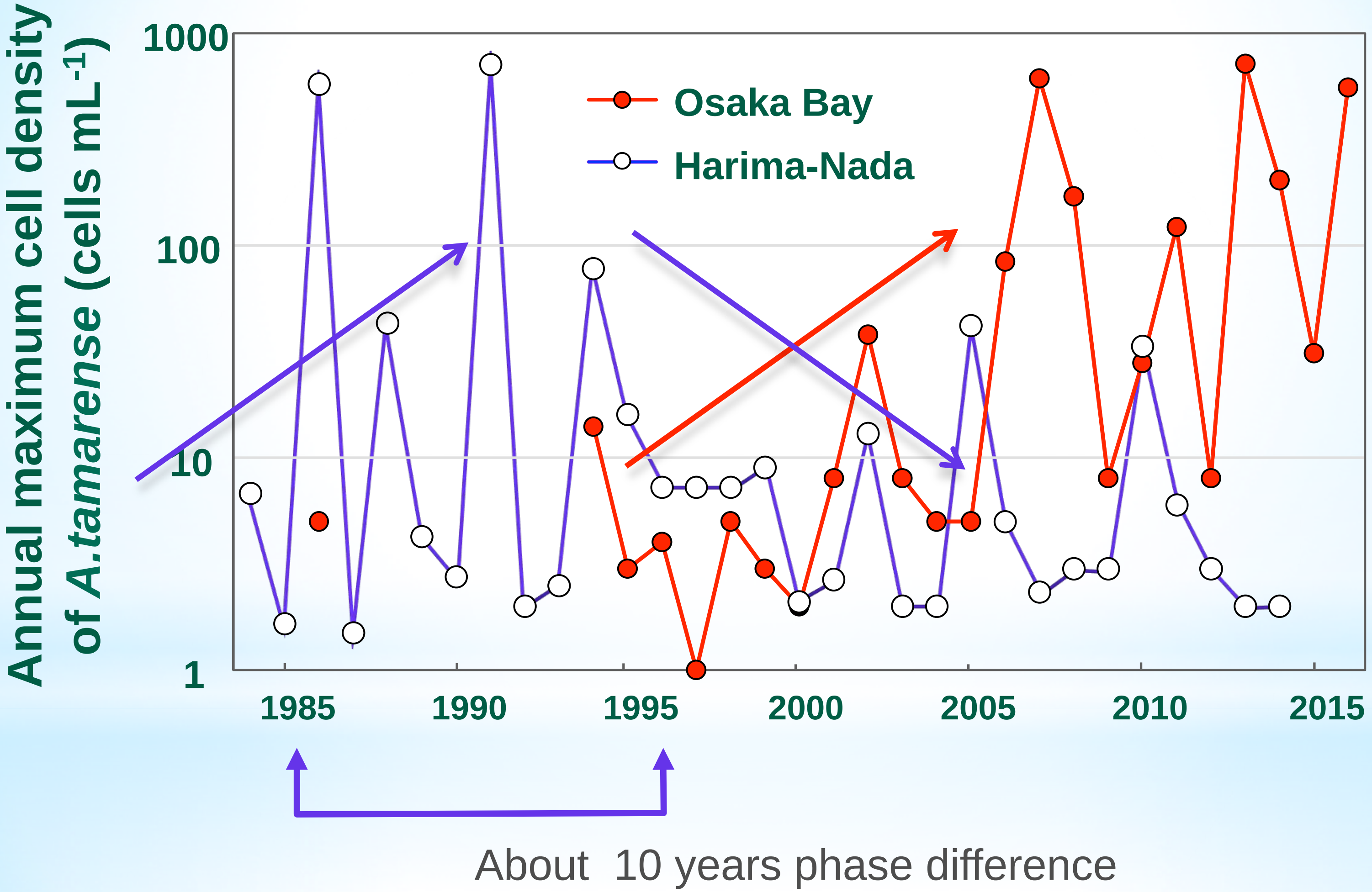


(modified from Yamamoto et al. 2017)

Long-term variation in yearly percent species composition of diatoms in the surface layer of Osaka Bay during *A. tamarense* bloom period (February To May)

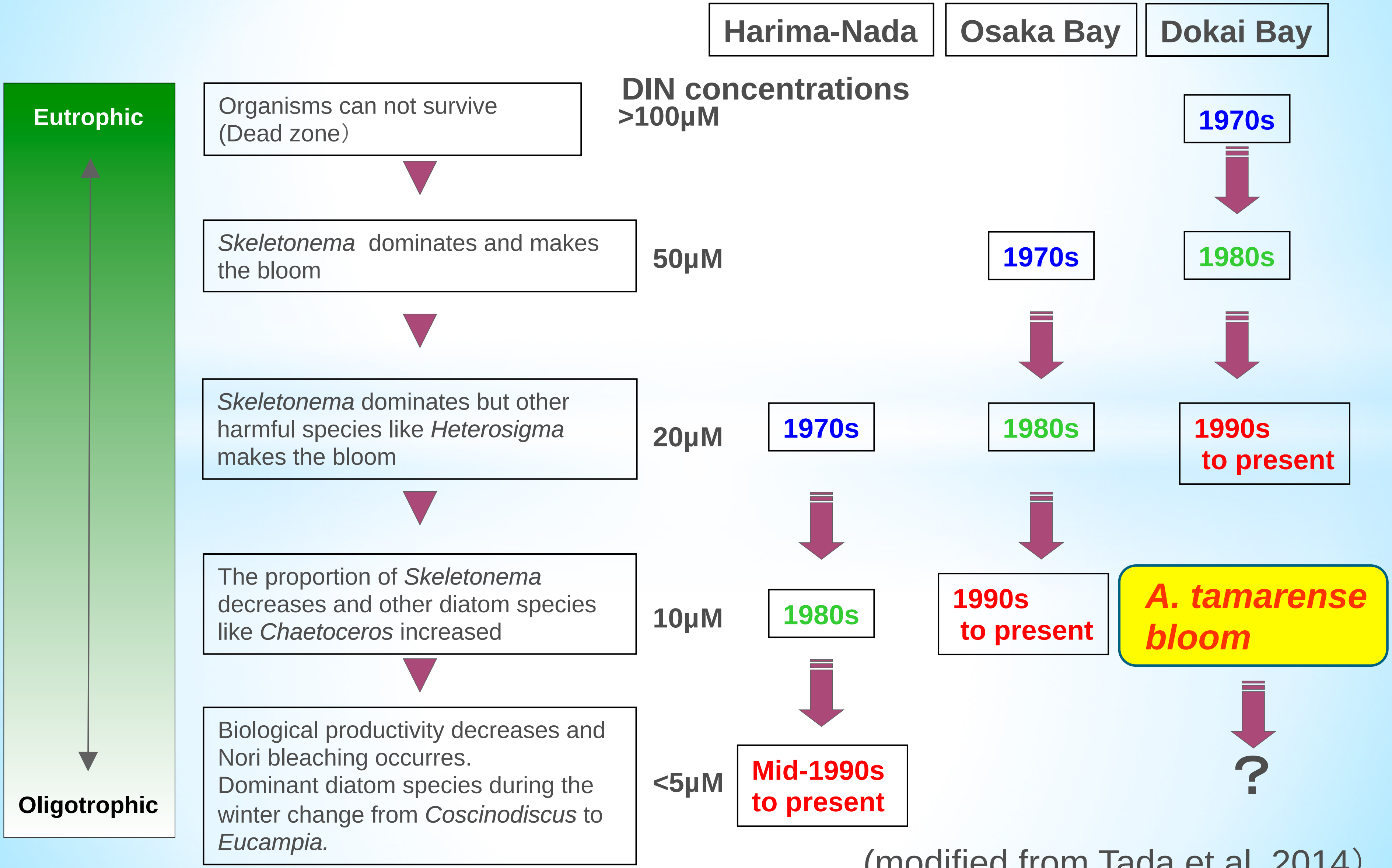


Annual fluctuation of maximum cell densities of *A. tamarense* in Harima-Nada and Osaka Bay from 1984 to 2016

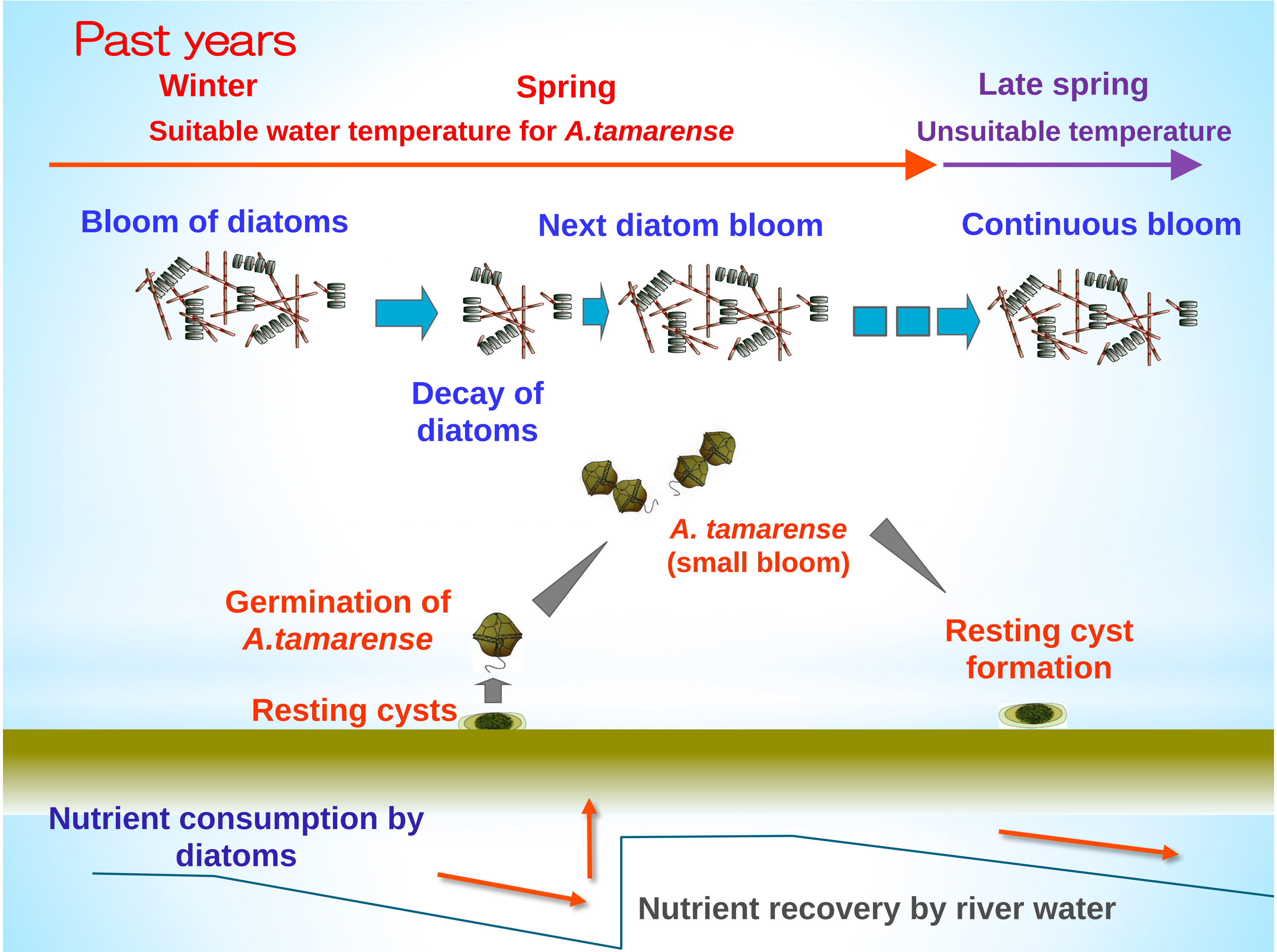


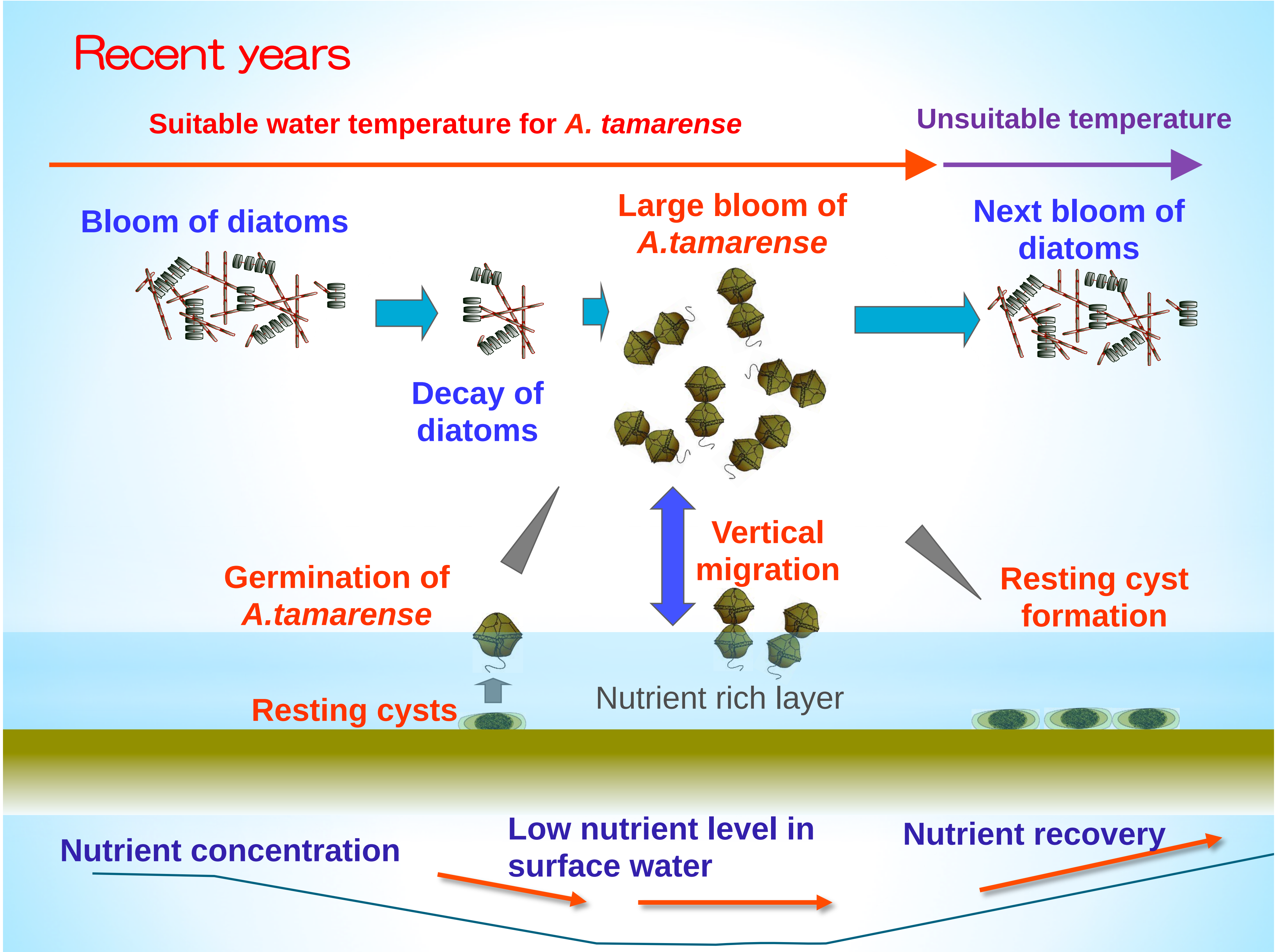
(modified from Yamamoto et al. 2017)

Relationship between dominant phytoplankton species and nutrient levels in three semi-enclosed seas of Japan



(modified from Tada et al. 2014)


Past years
Winter
Spring
Late spring
Suitable water temperature for A.tamarense
Unsuitable temperature
Bloom of diatoms
Next diatom bloom
Continuous bloom
Decay of diatoms
A. tamarense (small bloom)
Germination of A.tamarense
Resting cyst formation
Resting cysts
Nutrient consumption by diatoms
Nutrient recovery by river water



Recent years
Suitable water temperature for A. tamarense
Unsuitable temperature
Bloom of diatoms
Decay of diatoms
Large bloom of A.tamarense
Next bloom of diatoms
Vertical migration
Germination of A.tamarense
Resting cyst formation
Resting cysts
Nutrient rich layer
Nutrient concentration
Low nutrient level in surface water
Nutrient recovery

Conclusion

In Osaka Bay, the environmental condition getting well, but unexpected problems have arisen

That is,

1. *A. tamarense* has grown with the decline in nutrient levels, especially as the nitrogen declines.
2. The cause of large bloom of *A. tamarense* is related to the reduction of the competing species due to the decline of nutrients level.
3. But it is interesting to see whether the growth of *A. tamarense* will change or not, when nutrients further decreases from now on.


Thanks for your attention !!
Morning grow in Osaka Bay