An overview on the species succession of HABs in Korean coastal waters for the last three decades

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Major topics of this presentation

I. Methodologies

II. General trends of HABs in Korea

III. Species succession in HABs

IV. Discussion and conclusions

I. Methodologies

Materials and Methods

□ Stations and samples collection

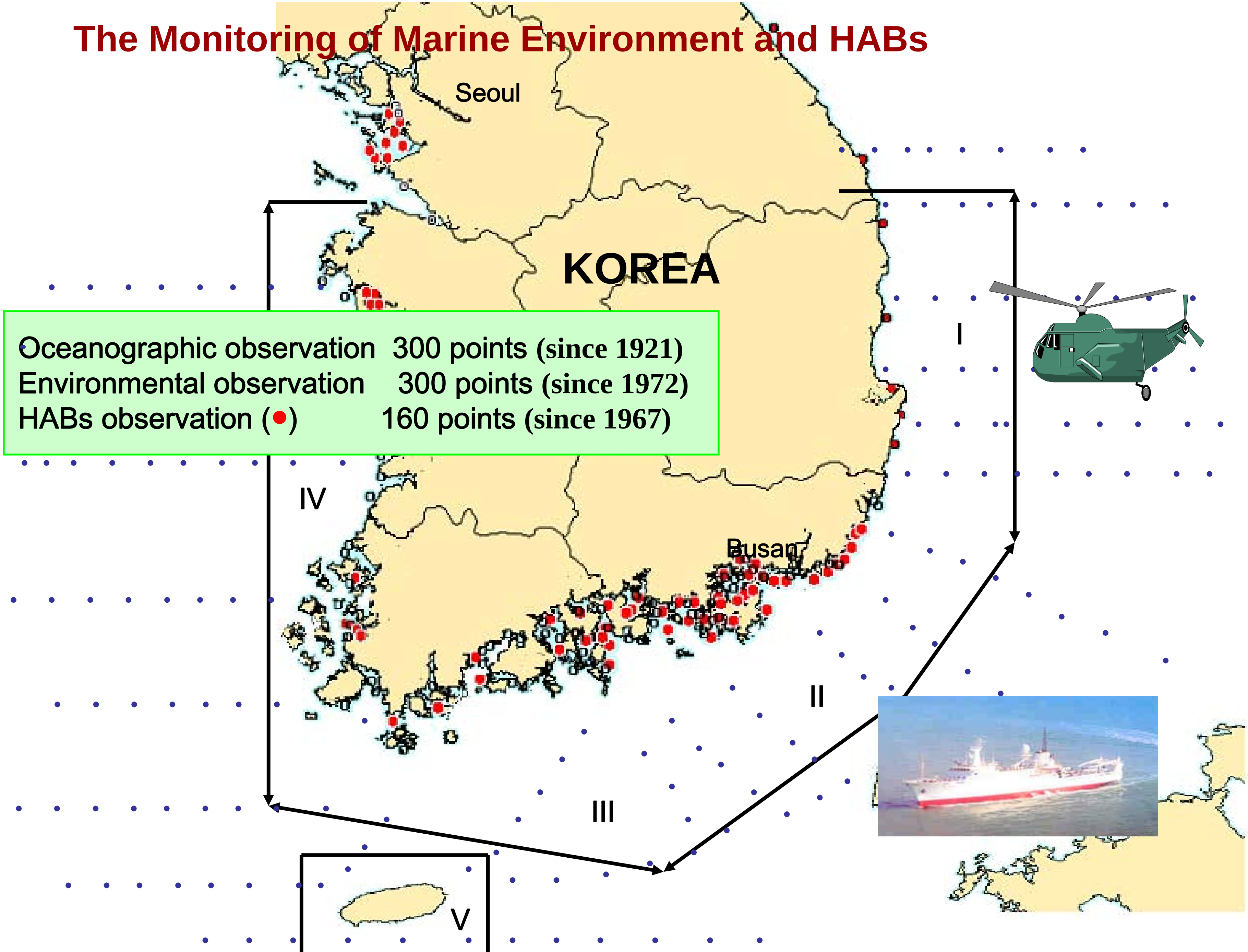
- **Environmental parameters assessing coastal pollution**
  - collect samples 6 times/yr since 1972
  - number of stations : 265 sts./45 areas
  - chemical parameters : nutrients, heavy metals, COD, DO, PON, POP, DON, DOP
- **HABs/toxic algae monitoring : daily or weekly**
  - biological parameters : phytoplankton abundance, chlorophyll
  - chemical parameters : COD, DIN, DIP, POC

□ Identification and Analysis

- **Microscopy : Nikon LM and JEOL SEM**
  - Phytoplankkton manual : UNESCO, 1978
  - Red tide organisms : Fukuyo et sl., 1990
- **Analytical methods and standards**
  - Manual of methods for research and monitoring of marine pollution and red tide (Park et al., 1985)
  - Organic nitrogen & carbon contents in sediment : CHN analyzer-Perkin Elmer 2400

The Monitoring of Marine Environment and HABs

Oceanographic observation 300 points (since 1921)
Environmental observation 300 points (since 1972)
HABs observation (●) 160 points (since 1967)



Monitor components for Korean marine environment

Monitoring requirement		Required monitoring components
SEAWATER (21factors)	General items	SST, Salinity, pH, DO, COD, TN, TP, NO2 - N, NO3 - N, NH4 - N, PO4 - P, SS, Oil & Grease, Clearness
	Trace metal	Cu, Pb, Zn, Cd, Cr^{+6}, total Hg, As, CN
	Organic contaminants	PCBs, TBT
SEDIMENT (12factors)	General items	Particle size, IL, AVS, COD
	Trace metal	Cu, Pb, Zn, Cd, Cr^{+6}, total Hg, As, CN
	Organic contaminants	PCBs, TBT, Pesticides, PAHs, PCDDs/DFs
ORGANISM (15factors)	General items	Chl *a*
	Trace metal	Cu, Pb, Zn, Cd, Cr^{+6}, total Hg, As, CN
	Organic contaminants	PCBs, TBT, Pesticides, PAHs, PCDDs/DFs

II. General trends of HABs in Korea

Nature and history of HAB

- **Historical record**

HABs in 639 in the Silla dynasty

東海水赤且熱魚鼈死(三國史記卷第5號)

: The seawater, from Kijang Kaulpo in August in 1403, discolored as yellow and red, the water was viscous just as gruel and a lot of dead finfish were found in the surface.

- The first scientific report : Park & Kim; 1967

1369 years ago, red tide had broken in Korea.

三國時代, 李朝
水赤, 水血色

Since 1967, 赤潮

Since 1990s, HABs

Cochlodinium patches
- peak stage

Cochlodinium patches
- in developing stage

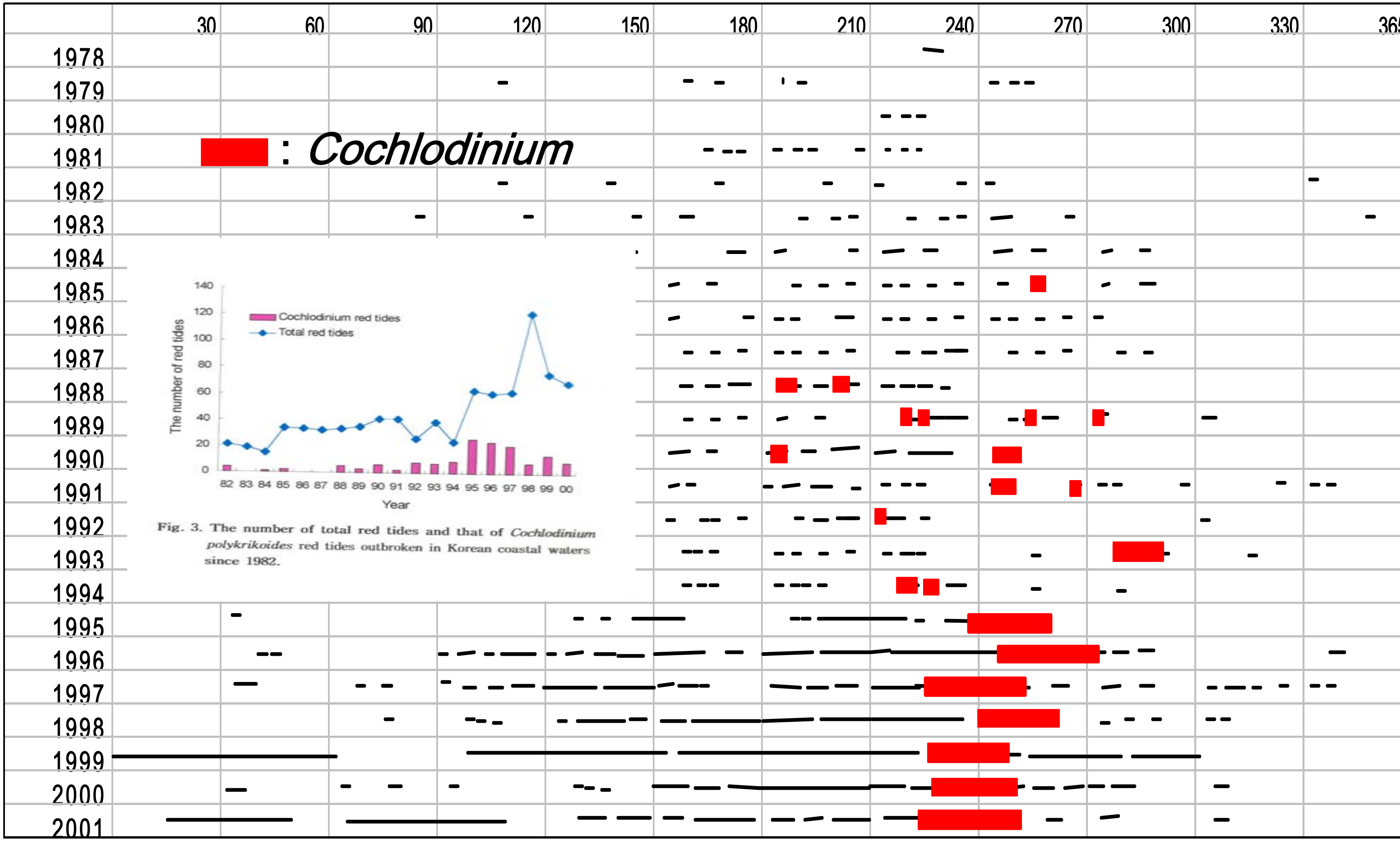


Fig. Temporal distribution of HABs plotted on monthly basis in Korean coastal waters since 1978.

Recent HABs in Korean Coastal Waters

Terms	Till 1980	1981-1994	Since 1995
Species	Harmless Diatoms	Harmful *Kare. Hete. Pro.*	Hamful & fishkilling *Cochlodinium*
Spatial distribution	Partial area	Widespread in South Sea	Widespread overall coast
Highest density(cell/ml)	≥ 1,000	1,000-10,000	1,000-30,000
Persistency	1-2 weeks	3 weeks	1-2 months

Summary 1

- **Even there found historical records of red tides in Korean waters.**
- **Recent HABs become widespread spatio-temporally, persistent, high density, and changes in the dominant species of HABs,**

III. Species succession in HABs

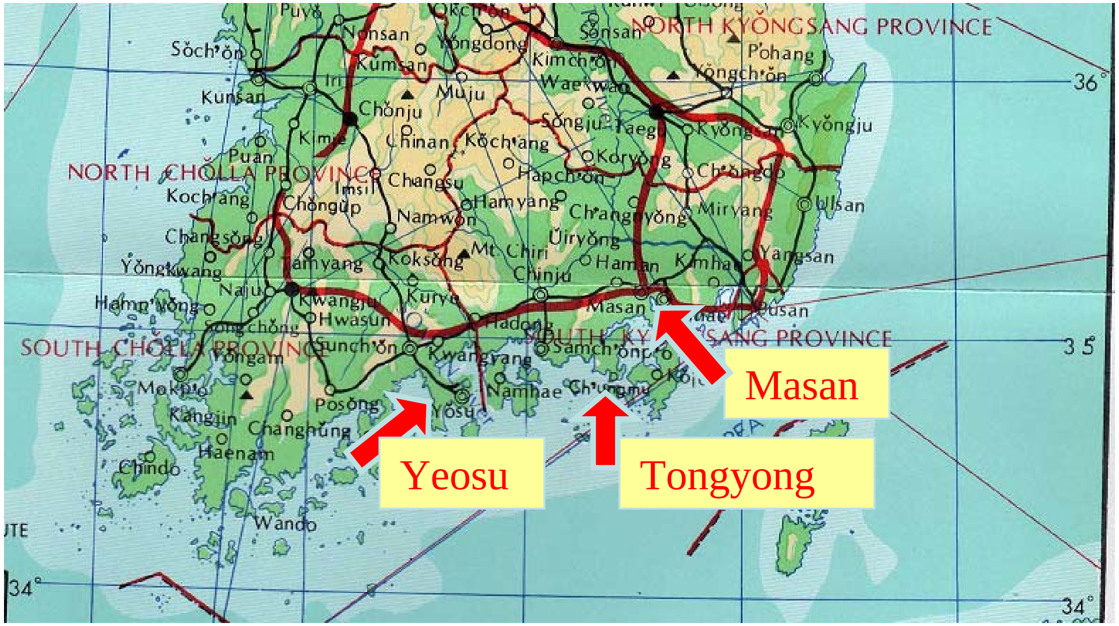
The species responsible for HABs in Korean waters since 1978

Class (*classis*)	**Order** (*ordo*)	**Red tide Organisms** (*Genus*)
Cyanophyceae	*Chroococcales*	*Anabaina, Microcystis*
Cryptophyceae	*Cryptomonadales*	*Chroomonas*
Dinophyceae	*Prorocenrales*	*Prorocentrum,Cochlodinium, Karenia*
	Noctilucales	*Noctiluca*
	Peridiniales	*Alexandrium, Ceratium, Lingulodinium*
Bicillariophceae	*Centrales*	*Chaetoceros, Skeletonema,*
	Pennales	*Asterionella, Pseudonitzschia*
Raphidophyceae	*Raphidomonadales*	*Chattonella, Fibrocapsa, Heterosigma*
Chrysophyceae	*Dictyochales*	*Dictyocha*
Euglenophyceae	*Eutreptiales*	*Eutreptiella*
Protozoa	*Ciliophora*	*Mesodinium rubrum*

For comparative analysis of species succession, select 3 points among 70stations

- **Masan : haunting area of HABs**
- **Tongyong : important mariculture bed**
- **Yeosu : bordering offshore waters**

Representative 3 points



Year \ Month	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.
1980 ~ 1988			Skele.	Thala.	Skele. Hetero Proro.	Proro.		
1989 ~ 1992	Skele. Hetero.		Eutrep. Proro.	Hetero. Proro.	Hetero Proro.	Chaeto. Proro.	Skele.	Gym.
1993 ~ 1997		Eutrep.	Eutrep. Hetero Proro.	Eutrep. Hetero Proro.	Others. Hetero Proro.	Others. Hetero Proro.	Cera.	
1998 ~ 2001	Hetero capsa	Eutrep Hetero Proro	Hetero Hetero Gym	Cera Hetero Proro	Cera Proro Proro	Proro Gym Skele	Skele	
2001-2008		Skele. Hetero. Proro.	Hetero. Proro. Meso.	Eucam. Proro. Hetero. A. san.	Thalo. Skele. Proro. Hetero. Eutrep.	Thalo. Skele. Proro. Hetero. Eutrep.	Skele. Proro	

Skeletonema.
Thalassiosira
Chaetoceros
Eutreptiella
Heterosigma
Prorocentrum
Gymnodinium
Ceratium
Alexandrium
Cochlodinium
Noctiluca
Others

Fig. Species succession in HABs in Masan Bay since 1980

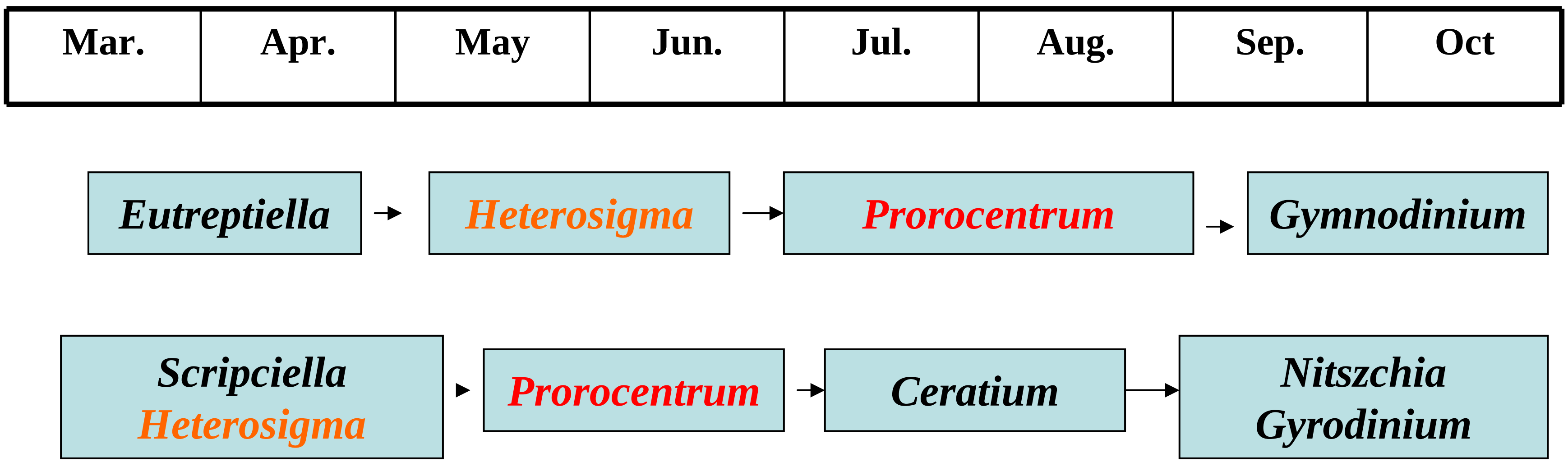


Fig. Species succession of phytoplankton community in Masan Bay representing Chinhae Bay

Year \ Month	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.
1980 ~ 1988					Skele. Gym.			
1989 ~ 1992		Noctil.	Proro.	Hetero. Proro. Other	Skele. Proro. Proro.	Cochl.	Cochl. Gym. Other.	
1993 ~ 1997		Hetero. Gym.	Hetero Proro.	Gym. Proro.	Cera. Proro.	Gym. Proro.	Cochl.	Cochl. Gym.
1998 ~ 2001		Noctil	Hetero Hetero Cera	Hetero Proro	Cera Proro Cochl	Skel Cochl Cochl	Gym Cochl	
2001-2008			Proro. A. sang.	Proro. Skele. Cochlo.	Proro. A.sang. Protope.	Cochlo. Proro.		

Skeletonema.
Thalassiosira
Chaetoceros
Eutreptiella
Heterosigma
Prorocentrum
Gymnodinium
Ceratium
Alexandrium
Cochlodinium
Noctiluca
Others

Fig. Species succession in HABs in Tongyoung Bay since 1980

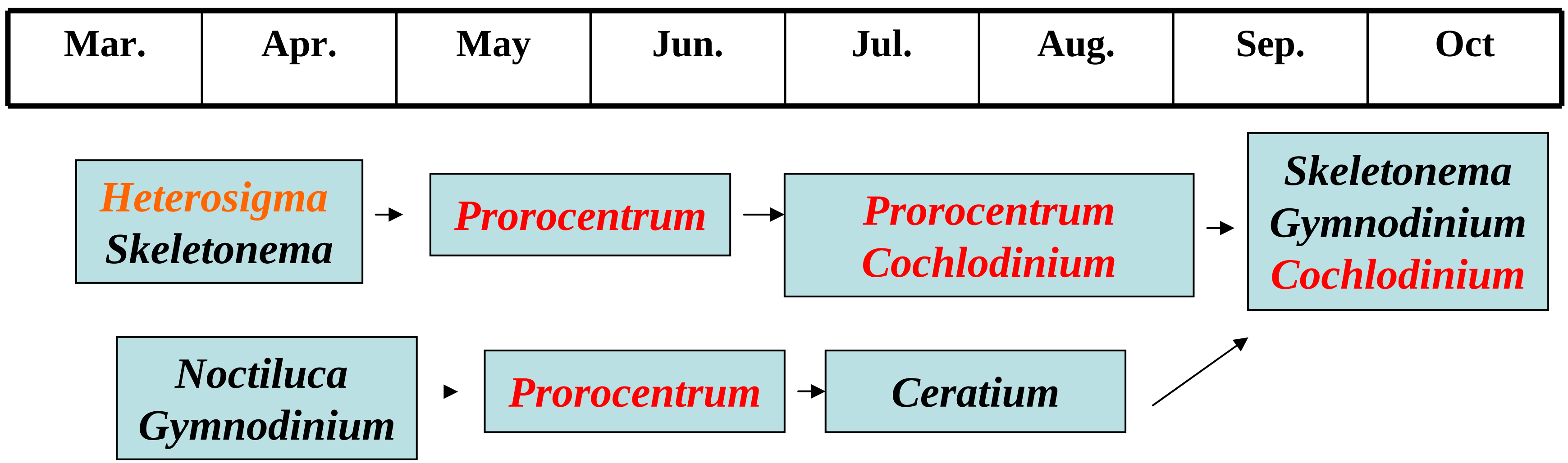


Fig. Species succession of phytoplankton community in Tongyoung areas representing marine culture farm

Month / Year	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.
1980~1988					Skele. Others			
1989~1992			Hetero.	Skele.	Skele. Proro. Alex.	Gym		
1993~1997		Noctil	Skele. Hetero Noctil.	Proro Hetero Alex.	Skele. Hetero Cera.	Skele. Hetero Cera.	Cochl.	Cochl
1998~2001			Skele Hetero	Cera Hetero Proro	Skele Hetero Chaeto	Skele Cochl Cochl	Cochl.	
2001-2008				Proro. Skele.	Chaeto. Skele. Cochlo	Notillu. Skele. Cochlo.	Cochlo. Protope.	

Skeletonema.	Thalassiosira	Chaetoceros
Eutreptiella	Heterosigma	Prorocentrum
Gymnodinium	Ceratium	Alexandrium
Cochlodinium	Noctiluca	Others

Fig. Species succession in HABs in Yeosu Bay since 1980

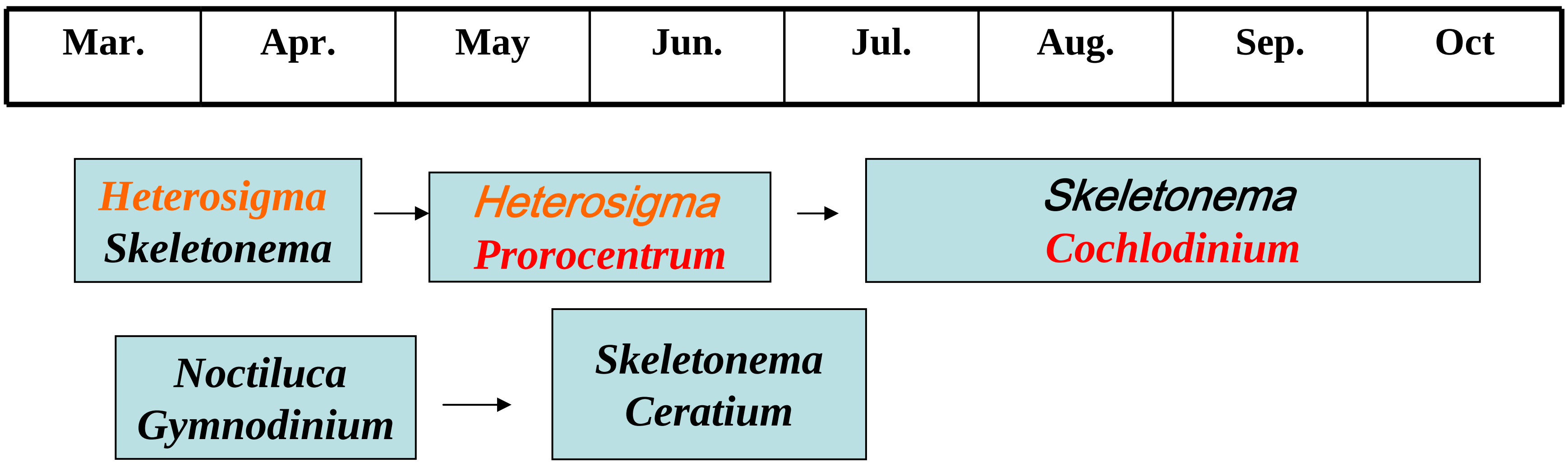
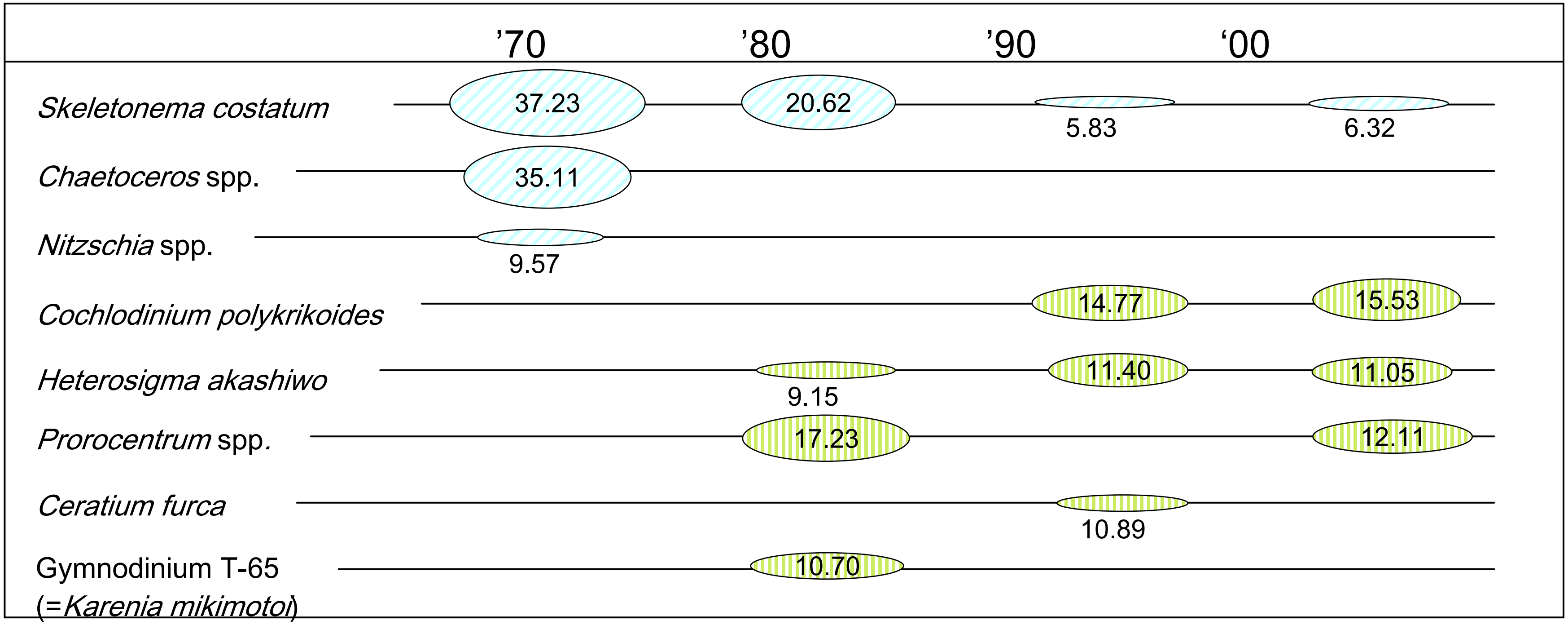


Fig. Species succession of phytoplankton community in Yeosu areas representing marine culture farm

Species fluctuation for the last three decades since 1970



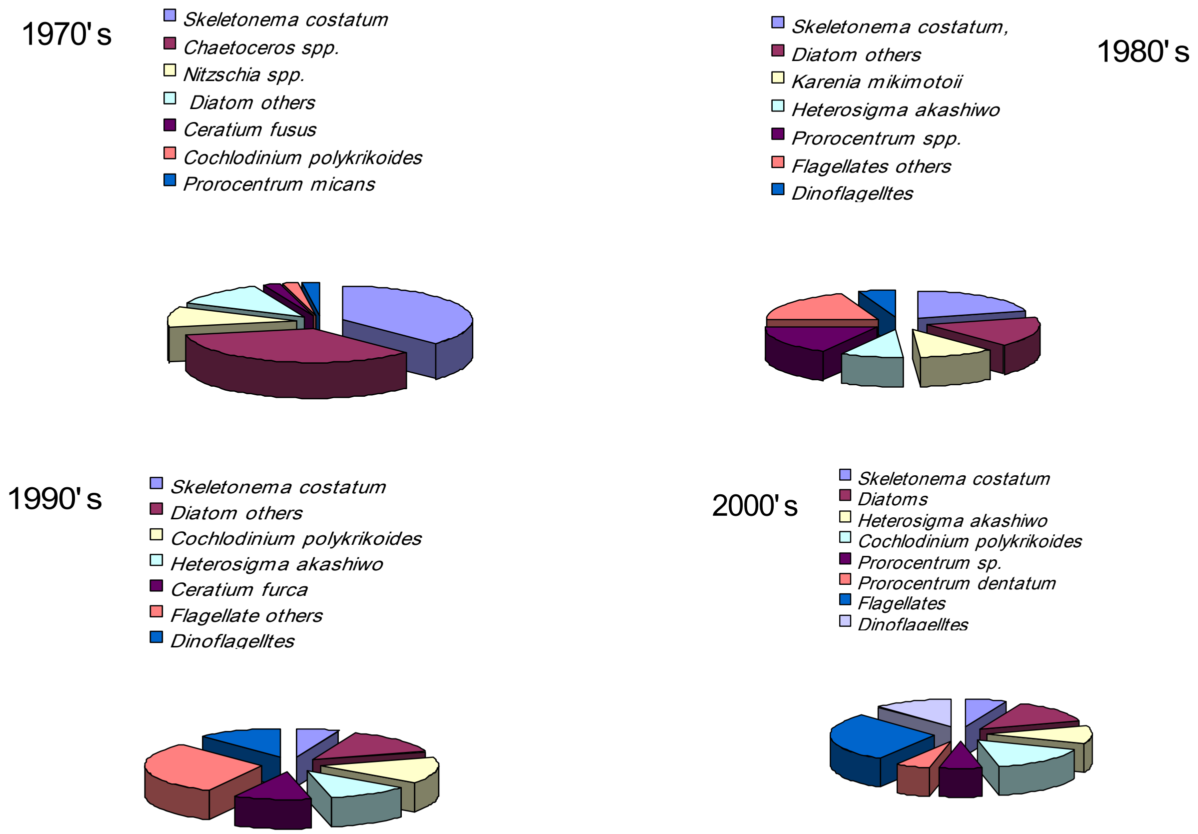


Fig. Percentage composition of the dominant HABs species since 1970s.

Cell size and cell volume of 13 selected species to compare to find the directionality in species succession

Species name	cell size	cell volume
Diatoms	µm	μm^3
Skeletonema costatum	5 - 18	
Chaetoceros spp.	15 - 50	
Thalassiosira allenii	8 - 18	
Nitzschia spp.	70 -140	
Leptocylindrus danicus	6 - 12	

Flagellates	Length	width	cell volume
Heterosigma akashiwo	5 – 20	6 - 15	1,031
Eutreptiella gymnastica	13 - 38	6 - 10	1,099
Prorocentrum spp.	10 - 40	20 - 50	1,460
Gymnodinium mikimotoi	22 - 38	15 - 35	4,786
Cochlodinium polykrikoides	30 - 40	20 - 30	5,754
Ceratium fusus	300 - 500	15 - 28	34,540
Gymnodinium sanguineum	55 - 60	35 - 58	47,372
Noctiluca scintillans	150 - 2000		2.9×10^6

Favorable conditions

Species	W.T.( )	Sal.(‰)	pH
Skeletonema	~12	Euryhaline	7.9 ~ 8.4
Eutreptiella	~15	14 ~ 31	6.5 ~ 8.5
Gymnodinium	15 ~ 20	9 ~ 33	7.4 ~ 8.8
Heterosigma	15 ~ 25	13 ~18	6.9 ~ 8.5
Prorocentrum	20 ~ 29	27 ~31	7.9 ~ 8.3
Cochlodinium	22 ~ 29	29 ~33	7.9 ~ 8.3
Nitzschia	~25	Euryhaline	7.5 ~ 8.5

Species-specific essential nutrients & their half saturation constant(Ks)

Species	DIN (uM)	DIP (uM)	VB_{12} (ng/l)	Thia-min	Bio-thin
Skeletonema	0.4 ~ 0.8	0.5 ~ 9.3	1 ~ 2	Ex	Ex
Eutreptiella	0.12	-	0.2 ~ 1.07		R
Gymnodinium	0.1 ~ 10	0.2 ~ 2.40	R	R	R
Heterosihgma	0.1 ~ 10	.2 ~ 2.4	0.39 ~ 0.6	R	R
Prorocentrum	-	-	R	R	R
Cochlodidnium	0.1 ~ 0.5	0.1 ~ 2.0	R	R	R
Nitzschia	0.5	0.5	R	R	R

DIN : Dissolved inorganic nitrogen   DIP : Dissolved inorganic phosphate
R. : Require   Ex. : Excrete
Ks : Half Saturation Constant ,   (the substrate conc. at Which V= Vm/2)

Succession directionality

Skeletonema Mar.-Apr.	LT ,	Euryhaline,	High Ks ,	Vitamin produce ,	Enable OM
Heterosigma May-Jun.	HT	Lsal,	Low ks	consume	uptake
Prorocentrum Cochlodinium Jun.-Aug.	HT	Lsal,	Low ks	consume	uptake
Nitzschia Sep. -Oct.	HT ,	Euryhaline,	High Ks ,	Vitamin produce ,	Enable OM

Directionality of species succession in HABs

■ **Small size & cell volume (High A/V)) → Large size(Low A/V)**

Species	*Ske.*	*Hetero.*	*Proro.*	*Cochlo.*	*Nitz.*
Cell size(㎛)	5-18	5-20	10-40	30-40	6-8
Cell volume(㎛^{3})		1,031	1,460	5,754	

■ **Low growth → High growth – doubling time(day)**

Species	*Ske.*	*Hetero.*	*Proro.*	*Cochlo.*	*Nitz.*
Cell size(㎛)	0.43	0.63-1.04	2.31	1.8	

■ **Non-motile (Diatoms) → Motile dinoflagellate species(5-240㎛/sec)**

■ **r-selection → k-Selection**

High growth *Low growth*
Low density *High density*
Temporary *Persistent*

Summary 2

- **HABs have developed into monospecific blooms, and accompanied short-term (seasonal) and long-term (coastal warming) species succession,**

- **Direction of species succession are;**

  - short-term : diatom ⇨ motile flagellate ⇨ diatom
  - long-term : mixotrophic/heterotrophic dinoflagellates


IV. Discussion and conclusion

Why such different species succession at three areas ?

☐ Masan Bay (highly-eutrophic, COD *c.a.*, 3ppm)

Mar. Apr. May Jun. Jul. Aug. Sep. Oct.

Skeletonema
Eutreptiella
Heterocapsa → Eutreptiella
Heterosigma
Prorocentrum → Heterosigma
Prorocentrum
Ceratium → Skeletonema
Ceratium

☐ Yeosu Coast (eutrophic, COD *c.a.*, 2ppm)

Mar. Apr. May Jun. Jul. Aug. Sep. Oct.

Noctiluca → SkeletonemaH
eterosigma
Prorocentrum → Skeletonema
Heterosigma
Ceratium
Cochlodinium → **Cochlodinium**

☐ Tongyoung Coast (eutrophic, COD *c.a.*, 1ppm)

Mar. Apr. May Jun. Jul. Aug. Sep. Oct.

Noctiluca
Heterosigma
Gymnodinium → Skeletonema
Chaetocerosa
Heterosigma
Ceratium
Cochlodinium → Gymnodinium
Cochlodinium

Influencing parameters are ;

- Smayda (1970 ~ 1975)
  - Activity of regulating factors
- Cassie (1960)
  - Water temperature, Salinity
- Powell (1975) : Circulation
- Hutchinson (1961), Richerson (1970)
  - Temporal environmental variability

◆ Petersen (1975) : Competence equilibrium
◆ Riely (1973) : Co-evolution-little competition

Regulating Factors

Allogenic	Autogenic	Sequential
Salinity	Life cycle	Sinking rate
Temperature	Nutrients (Micronutr.,Trace etc.)	Suspension
Light	Ectocrines	
Turbulence	Predation	
Anthropogenic substances		

Transition of eutrophic state in Masan Bay

Terms	~ 1988	1989 ~ 1992	1993 ~ 1997
COD(mg/l)	0.5 ~ 2	2 ~ 3	2 ~ 4
DIN(uM)	0.4 ~ 0.8	0.8 ~ 2.5	0.8 ~ 4.5
DIP(uM)	0.01 ~ 0.05	0.01 ~ 0.80	0.01 ~ 1.50
DO (mg/l)			
-hot season	5 ~ 6	4 ~ 5	0 ~ 4
-cold season	5 ~ 6	4 ~ 5	4 ~ 5
HABs	Diatom	Multi-species	Monospecies

Assessment by Liebman,s saprobien system

~ 1988 : oligosaprobic state

1989 ~ 1992 : β - mesosaprobic state

1989 ~ 1997 : α - mesosaprobic state

Comparison of eutrophic state between Masan Bay and Yosu coastal area

Terms	Yeosu	Masan Bay
COD(mg/l)	1 ~ 2	2 ~ 4
DIN(uM)	0.4 ~ 0.8	0.8 ~ 4.5
DIP(uM)	0.01 ~ 0.50	0.01 ~ 1.50
DO (mg/l)		
-hot season	4 ~ 6	0 ~ 4
-cold season	5 ~ 6	4 ~ 5
HABs	Multispecies	Monospecies

◆ Assessment by Liebman,s saprobien system

Yeosu : β - mesosaprobic state

Masan : α - mesosaprobic state

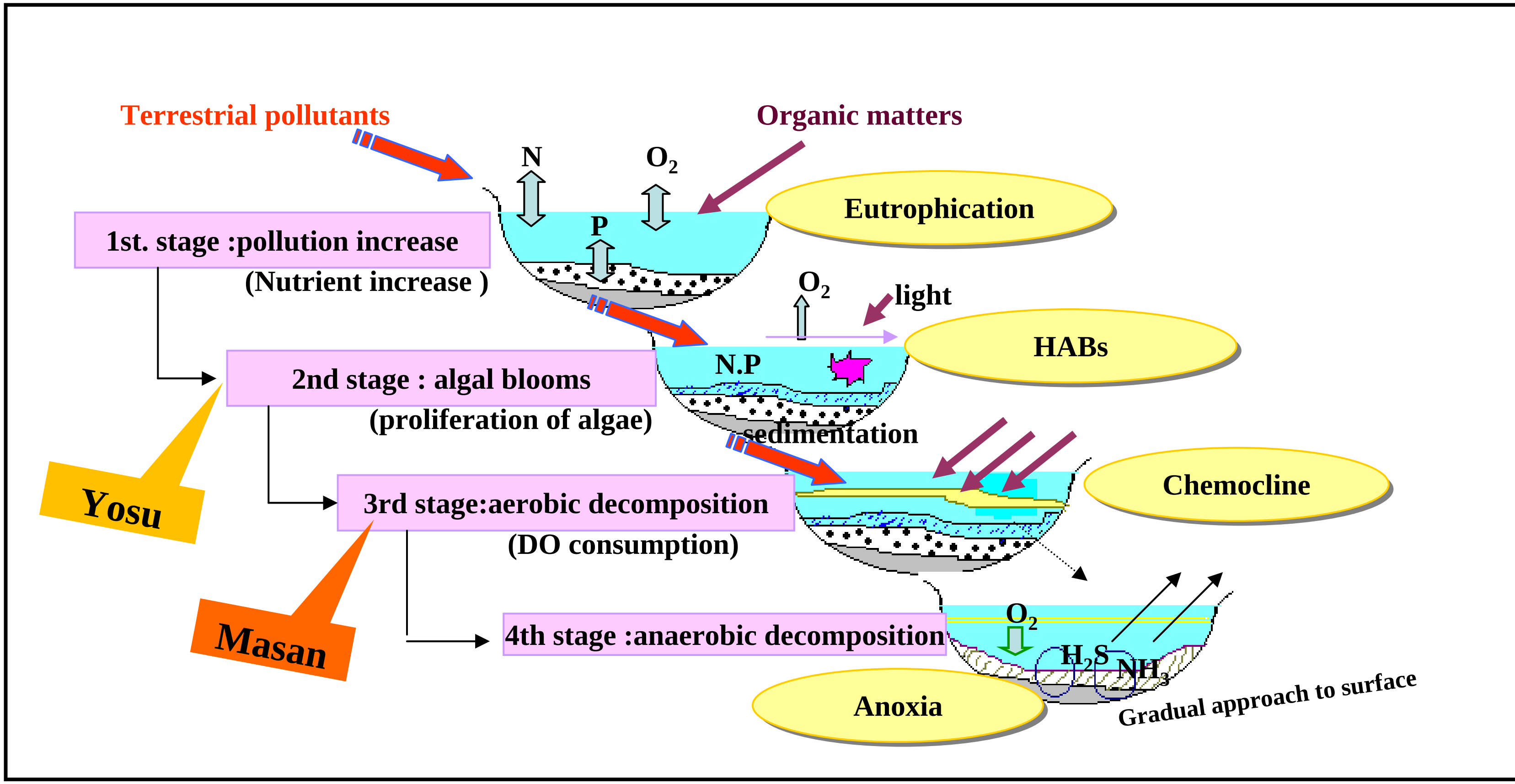


Fig. Schematic illustration of the progressive eutrophication in embayment system By François Ramade, 1978.

Coastal eutrophication and HABs

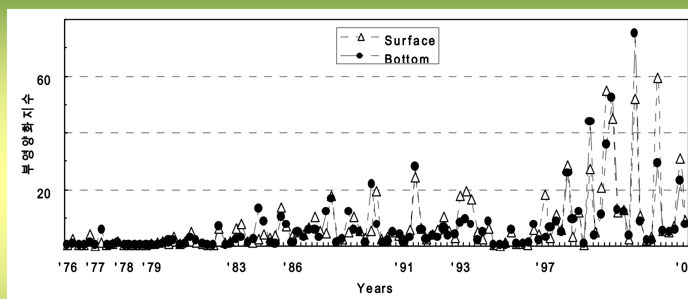
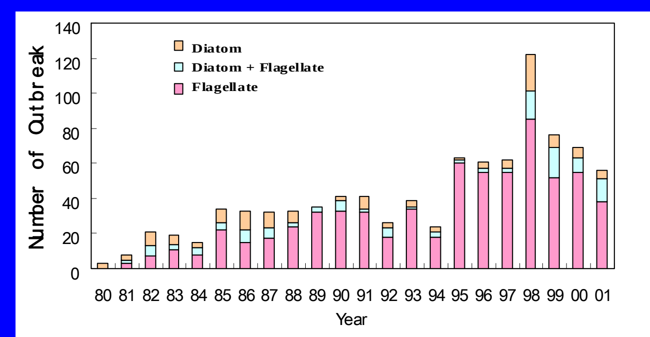


Fig. Annual changes of eutrophic index in the seawater collected from Jinhae

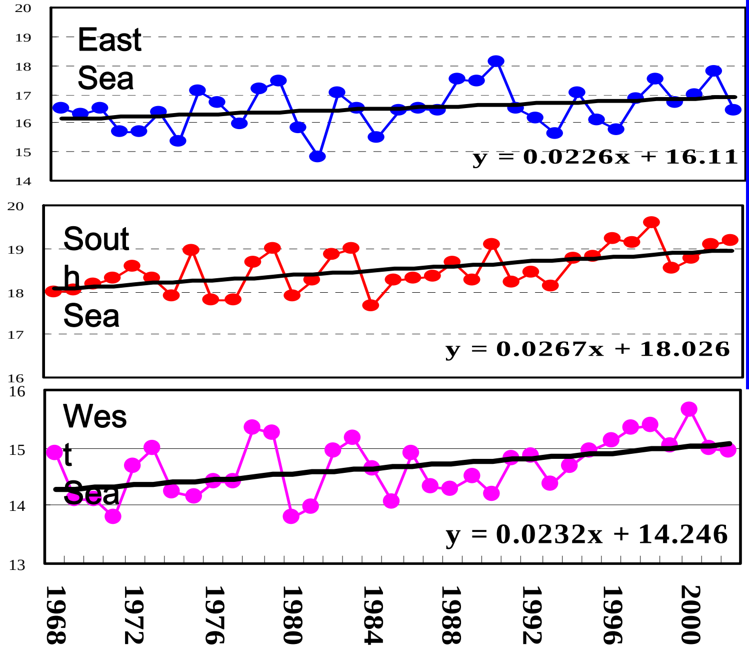
Okaichi Eutrophic index = ($COD_{(mg/l)}$x$DIN_{(ug\text{-}at/l)}$xPO_4-$P_{(ug\text{-}at/l)}$)/3.43

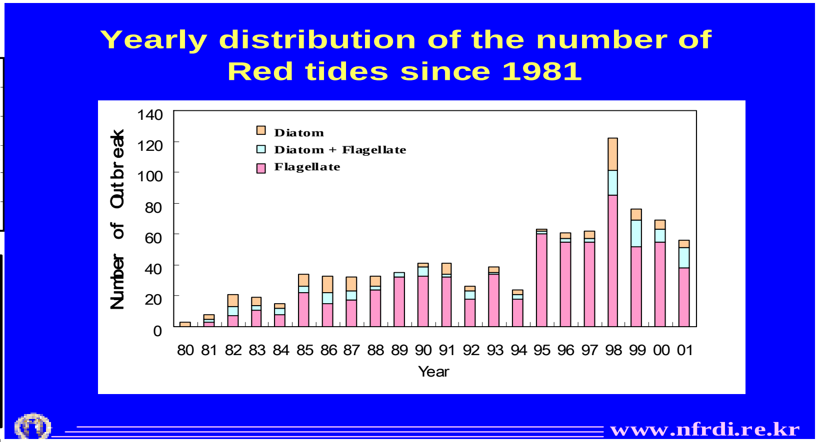
Yearly distribution of the number of Red tides since 1981



www.nfrdi.re.kr

Coastal warming and HABs





- **Increase of temperature(1℃/36yrs)**

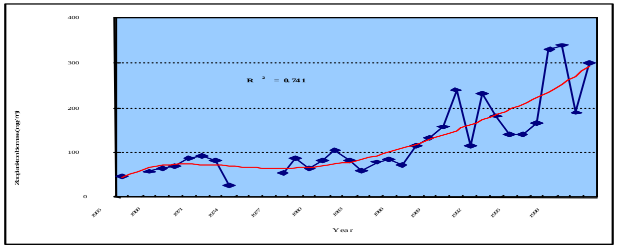
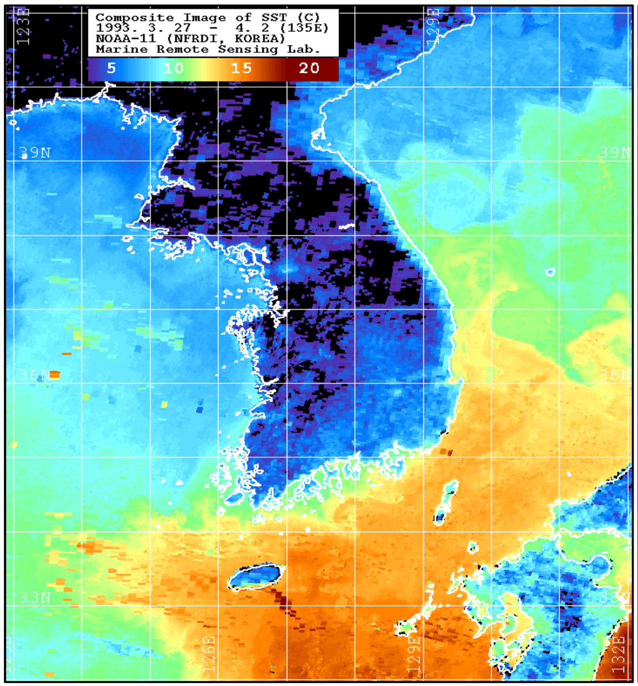
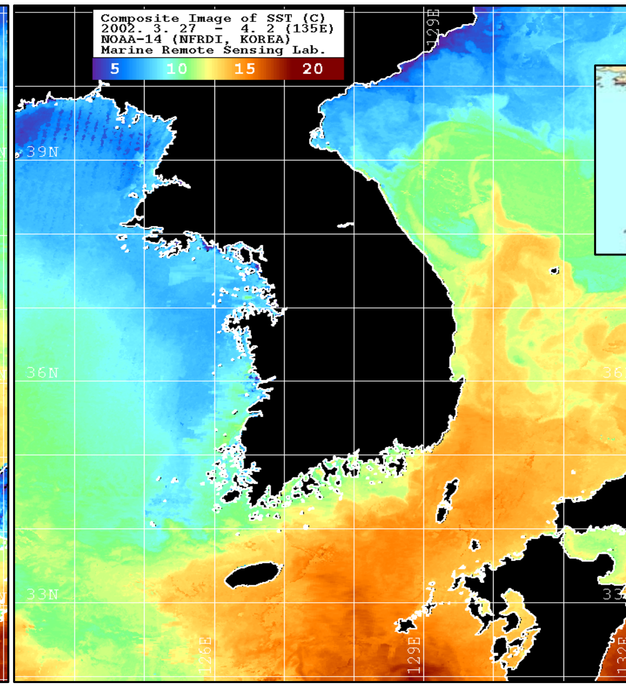


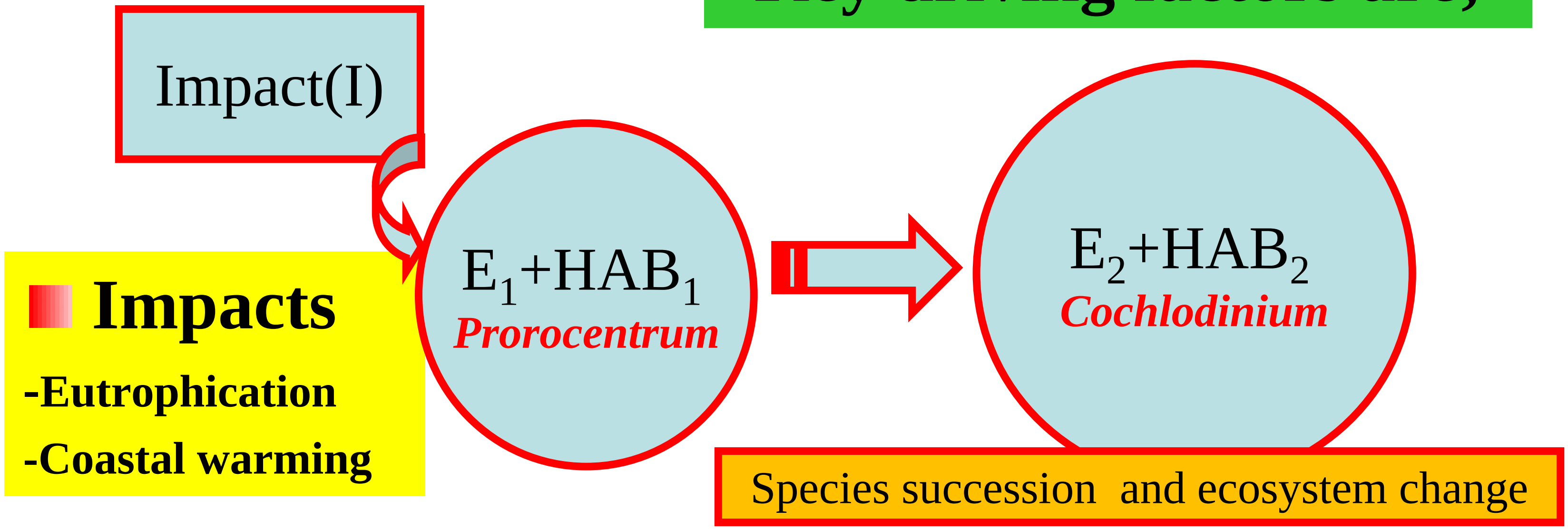
Fig. Long-term changes in annual mean biomass of the zooplankton in Korean waters, 1965-1998

The Kuroshio go further to the north





Key driving factors are;

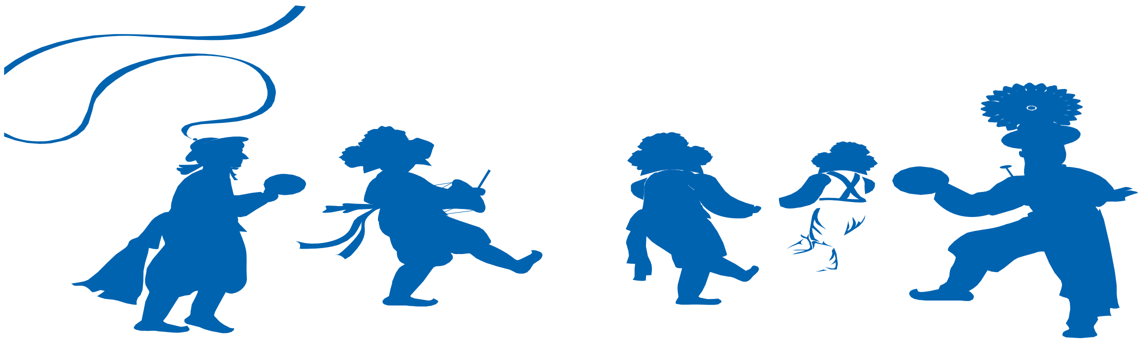


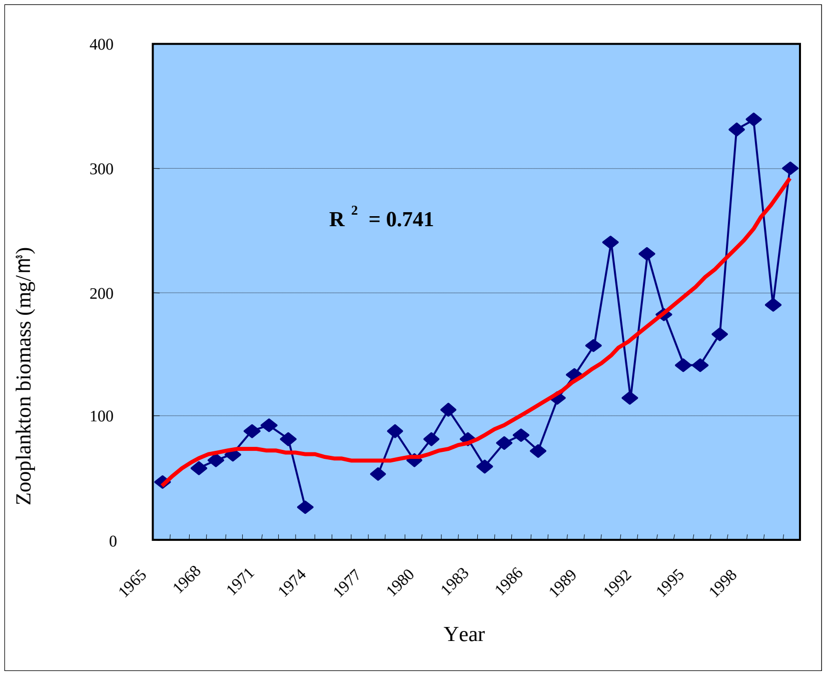
$I(E_1+HAB_1)= E_2+HAB_2$

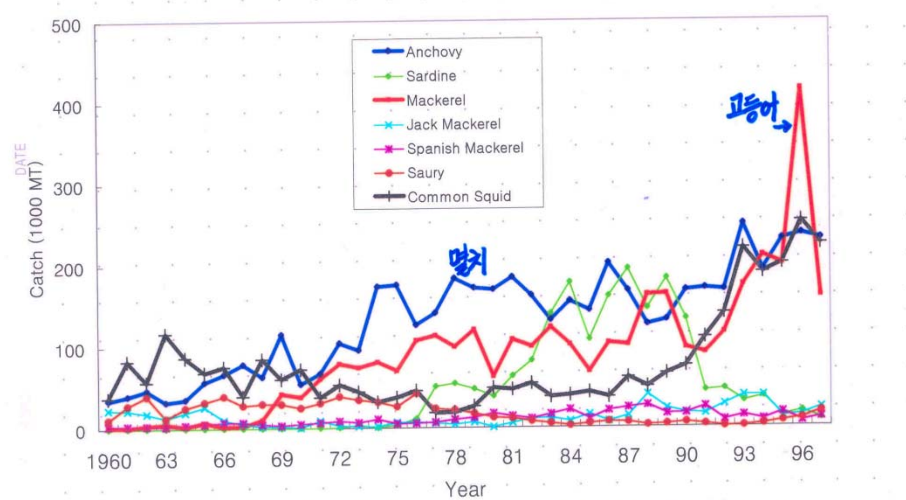
- Higher biomass
- Lower diversity
- Species succession

Thank you

For your attention







Yearly catch statistics of pelagic fish in the Korean waters

Fig. Long-term changes in annual mean biomass of the zooplankton and pelagic fish catch in Korean waters, 1965-1998

2001-2008	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.
2001		Skele. Eutrep.	Hetero.		Thala. Proro. Hetero.			
2002			Hetero	Thala. Eutrep.	Lepto. Hetero. Proro.	Proro. Thala. Eutre.	Skele.	
2003		Proro. Hetero	Eucam.				Proro.	
2004		Proro. Hetero	Hetero	Proro. A.Sangui. B.Eutrep.	Skele. Thala.	Hetero		
2005			Mesod.	Hetero. Proro.	Eutre. Hetero.	Pseudo-nit.		

Fig. Species succession in HABs in Masan Bay since 2001