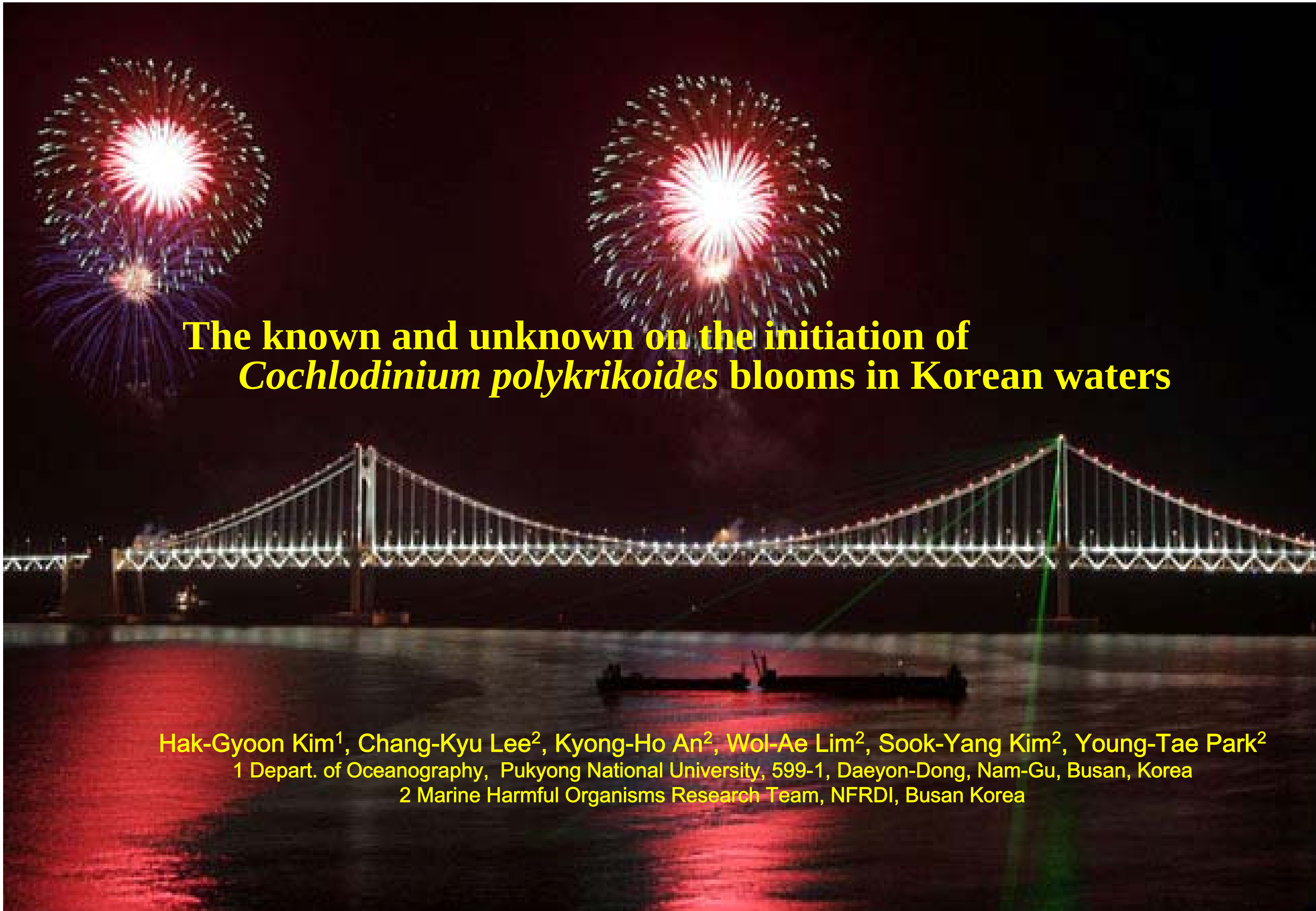

The known and unknown on the initiation of *Cochlodinium polykrikoides* blooms in Korean waters

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Major topics of this presentation

- **The known**
  - **I. Recent progress**
  - **II. Initiation of *Cochlodinium* bloom**
  - **III. Movement and dispersion**
- **The unknown**
  - **IV. Where *C. polykrikoides* comes from ?**
  - **V. What's the key factors on the increase ?**
  - **VI. Are they on the climax of the species succession ?**

■ The known

1. The recent progress of *Cochlodinium polykrikodes* blooms for the last four decades in Korean coast.

Genus *Cochlodinium*

Species	*C. polykrikoides*	*C. catenatum*	*C.* sp.
Size	30-40㎛		45-50㎛
Shape	Epicone is conical, hypocone is subspherical.	Cell is subspherical.	Cell is roundly and ellipsoidal shape.
Distribution	□ Western Pacific □ Eastern Pacific □ Atlantic	□ Western Pacific : - Japan –Mikawa Bay, Gokasho Bay	□ Western Pacific : - Tachihana Bay

Global distribution

- **Asia**
  - **Japan-Yatsushiro Bay-Kyushu Island(since 1978),**
  - **China-Quanzhou-Fujian (1993)**
  - **Malaysia & Indonesia (2004)**
  - **Korea-South-East coast(since 1982),**
- **North America**
  - **Canada-Vancouver Island (since 2000),**
  - **USA-York river, Virginia (1979)**
- **South America**
  - **Chile-south coast (since 2004)**

Scientific reports and findings on *C. polykrikoides*

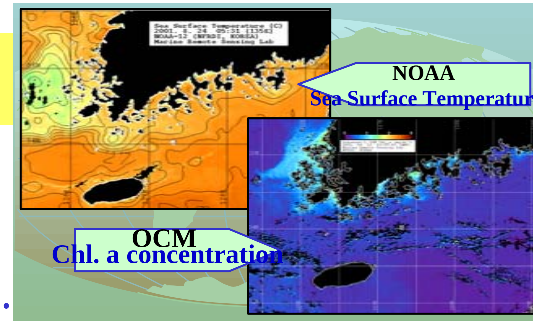
Global scientific finding

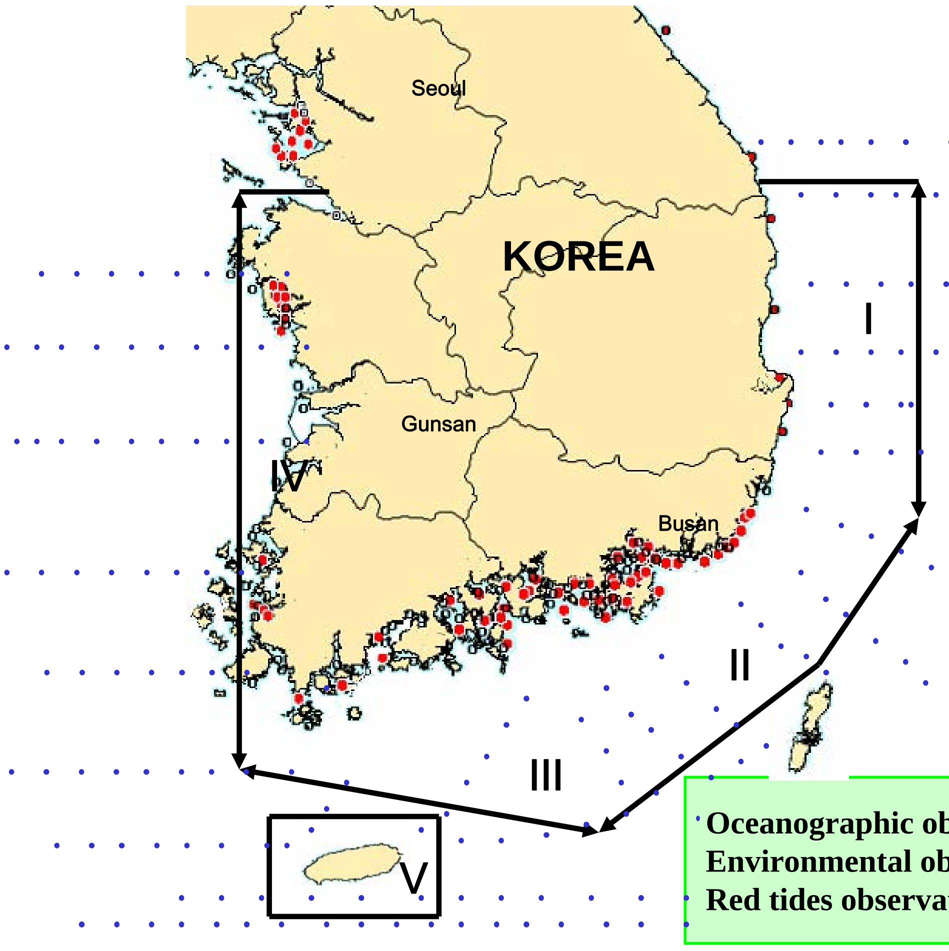
- Margalef, R., 1961 : find(Puerto Rico) and identify firstly
- Silva, E.S., 1967 : structure and cytophysiological aspects
- Seliger et al., 1978 : bloom dynamics in Cheasapeake Bay in USA
- Fukuyo & Matsuoka 1983 : cyst of *Cochlodinium* sp.
- Yuki, K & Yoshimatsu, S. 1989 : fish kill in seto Inland sea Japan caused by *C. polykrikoides*.
- Onoue & Nozawa 1989 : separation of toxins from *C. polykrikoides*.
- Du Qi et al., 1993 : bloom of *Cochlodinium* sp. in Fujian China
- Qi Yu Zao et al., 1997 : cysts of *Cochlodinium* sp. in China
- Fernando Rosales-Loessener et al., 1997 : cysts in Guatemala
- Whyte et al., 2000 : *Cochlodinium* sp. and fishkill in Canada

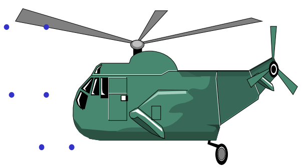
Korean scientific findings

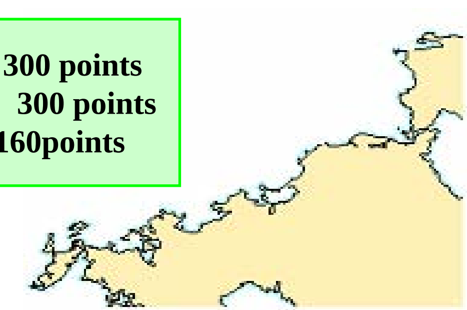
- **Park et al., 1987 : bloom of *Cochlodinium* sp.**
- **Kim et al., 1993 : cell volume and carbon contents *C. polykrikoides*.**
- **Kim 1991 : cyst of** *Cochlodinium* **sp.**
- **Kim & Matsuoka et al., 1996 : cyst of** *C. polykrikoides***.**
- **Kim et al., 1998 : *C. polykrikoides* and mitigation**
- **Na 96, Choi 98 : *C. polykrikoides* and clays**
- **Kim et al., 1999 : initiaticn of *C. polykrikoides* Blooms**
- **Kim et al., 1999 : ichthyotoxicity of *C. polykrikoides* .**
- **Lee et al., 2000 : algalytic control of *C. polykrikoides* .**
- **Cho et al., 2000 : DNA probe and *C. polykrikoides* .**

The Monitoring of Marine Environment and HABs









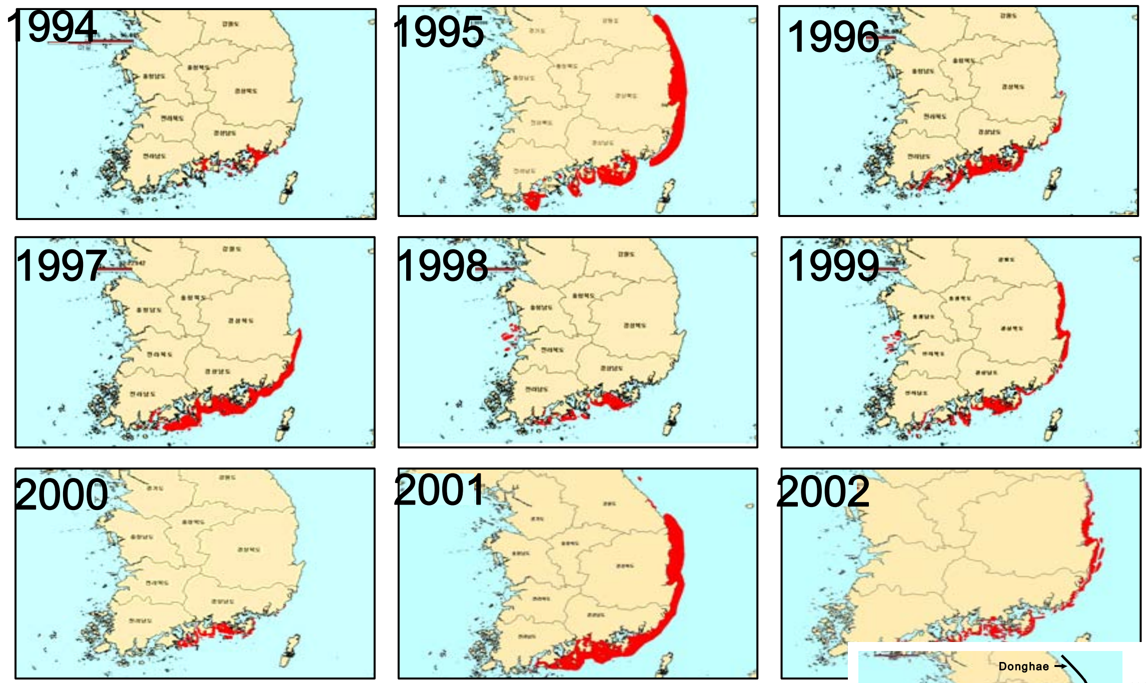
Oceanographic observation 300 points
Environmental observation 300 points
Red tides observation 160points

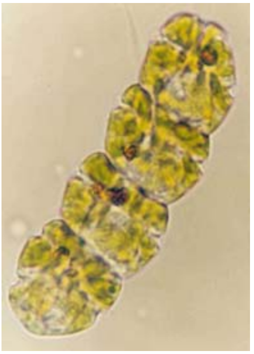
Present Korean HABs Monitoring System
- Focused on *Cochlodinium* blooms

- **Precautionary Monitoring (initiation) : Less than 300cells/ml**
  - **5 susceptible areas to initiate the bloom**
  - **To begin in June till the first bloom at the density of more than 300cells/ml**

- **Regular Monitoring (Subsequent development) : over 300cells/ml**
  - **Regular Cruise : weekly, biweekly at 70 stations from Mar. to Nov.**
  - **Emergent Cruise : daily observation in Cochlodinium blooms area**

The *Cochlodinium polykrikoides* blooms in Korean waters





Annual Changes of the Area Affected by the *C. polykrikoides* Blooms in Korean Waters

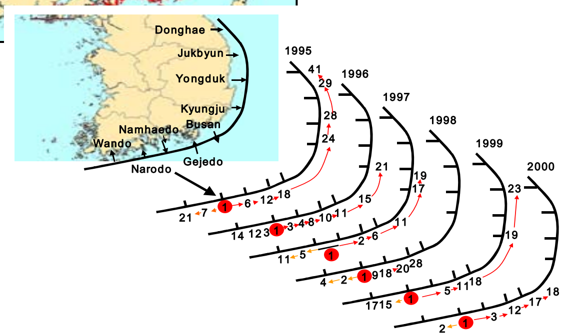


Fig. Year to year variations of the movement of HABs. Red circles and numbers denote the first outbreak area and the elapsed dates respectively.

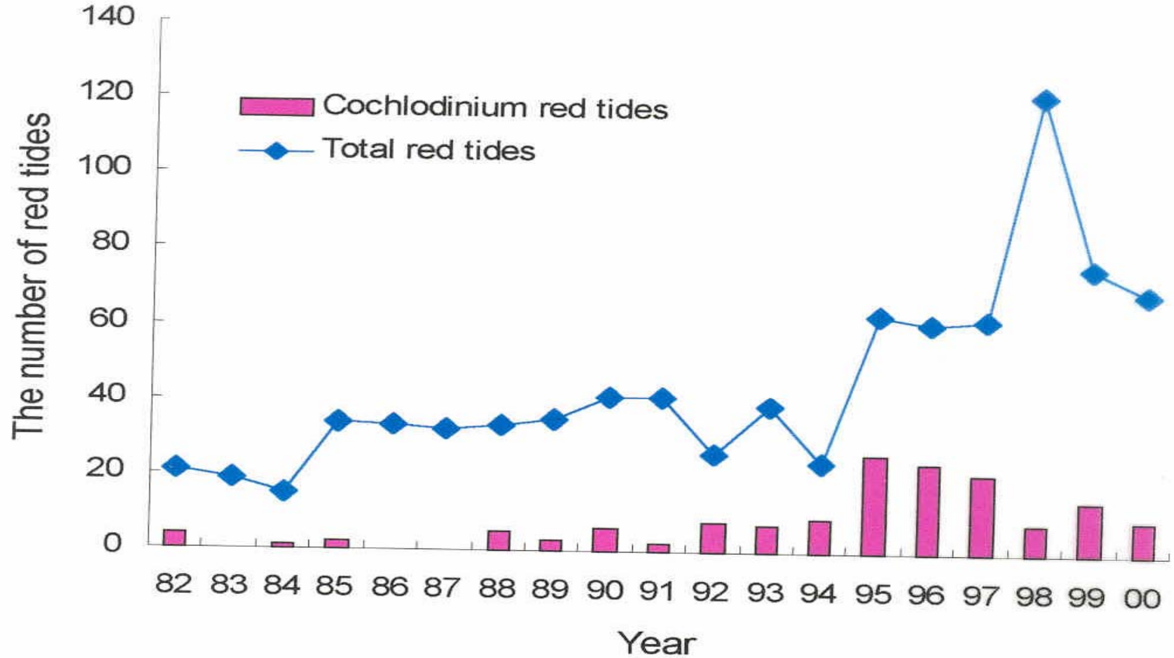


Fig. 3. The number of total red tides and that of *Cochlodinium polykrikoides* red tides outbroken in Korean coastal waters since 1982.

Two decadal progress of *Cochlodinium* blooms in Korean Waters

Terms	1982-1988	1989-1994	Since 1995
Spatial distribution	Partial area Jinhae Bay	South Sea to Kijang in East Sea	Widespread overall coast
Highest density(cell/ml)	Less than 8,700	Less than 25,000	Up to 48,000
Persistency	10days	20days	Up to 62days

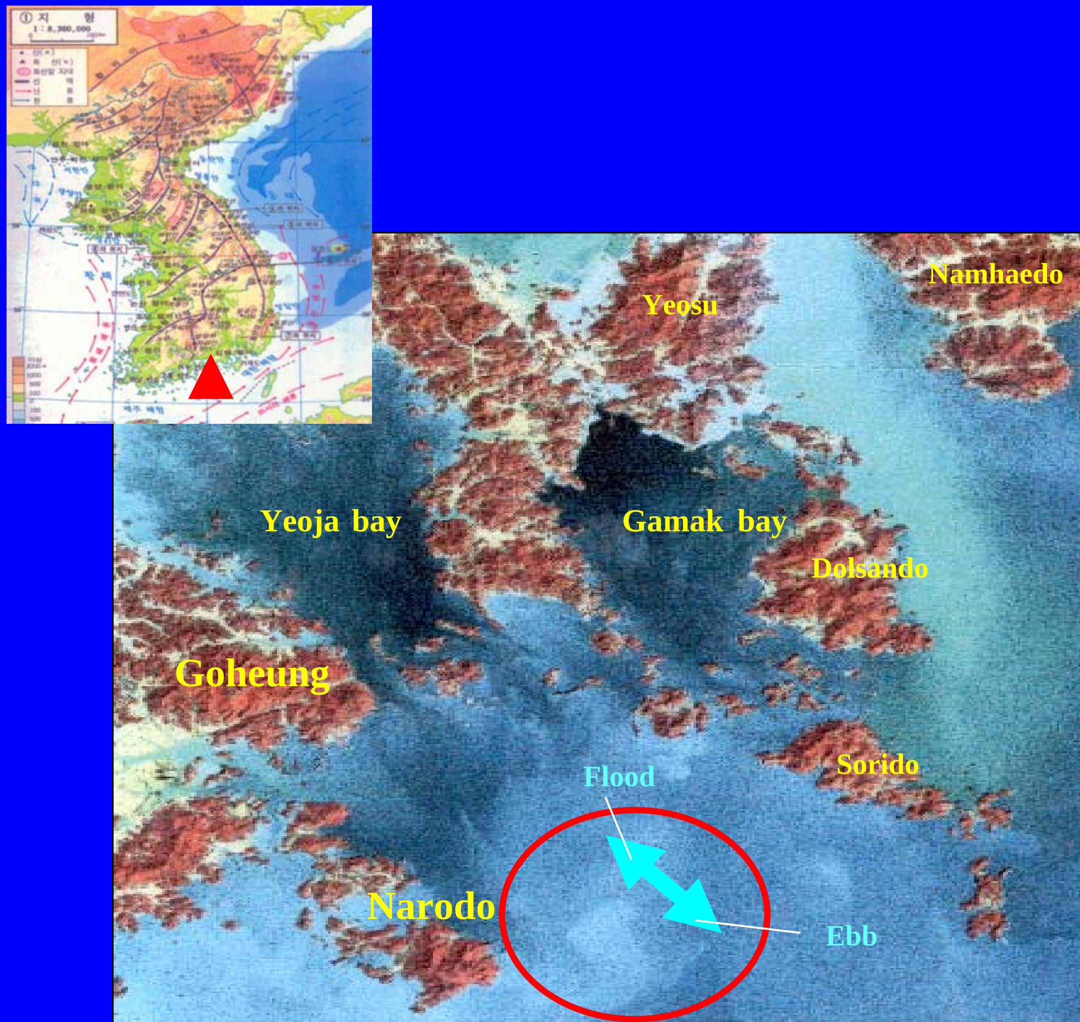
→ **Wide-spread & persistent**

Fisheries damages and economic loss by *C. polykrikoides* blooms

- **Korea**
  - **95.5 million US$ in 1995**
  - **2.3 million US$ in 1996**
  - **1.6 million US$ in 1997**
  - **133 thousand US$ in 1998**
  - **6.46 million US$ in 2001**
- **Japan**
  - **398 M Japanese Yen in 2000**

Aerial view of clay dispersion in South Sea

2. Initiation of *Cochlodinium* bloom in Korean coastal waters

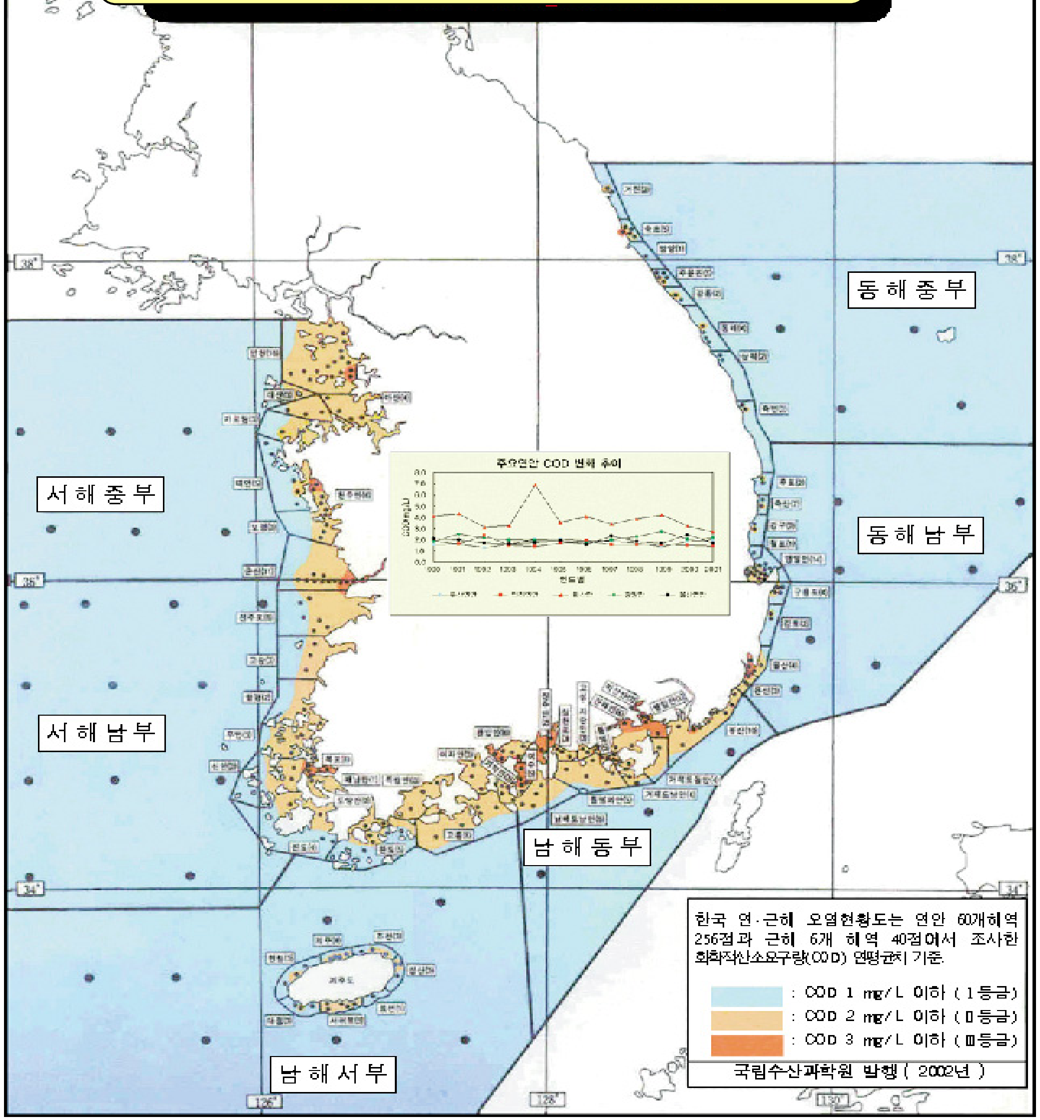


Environmental Features

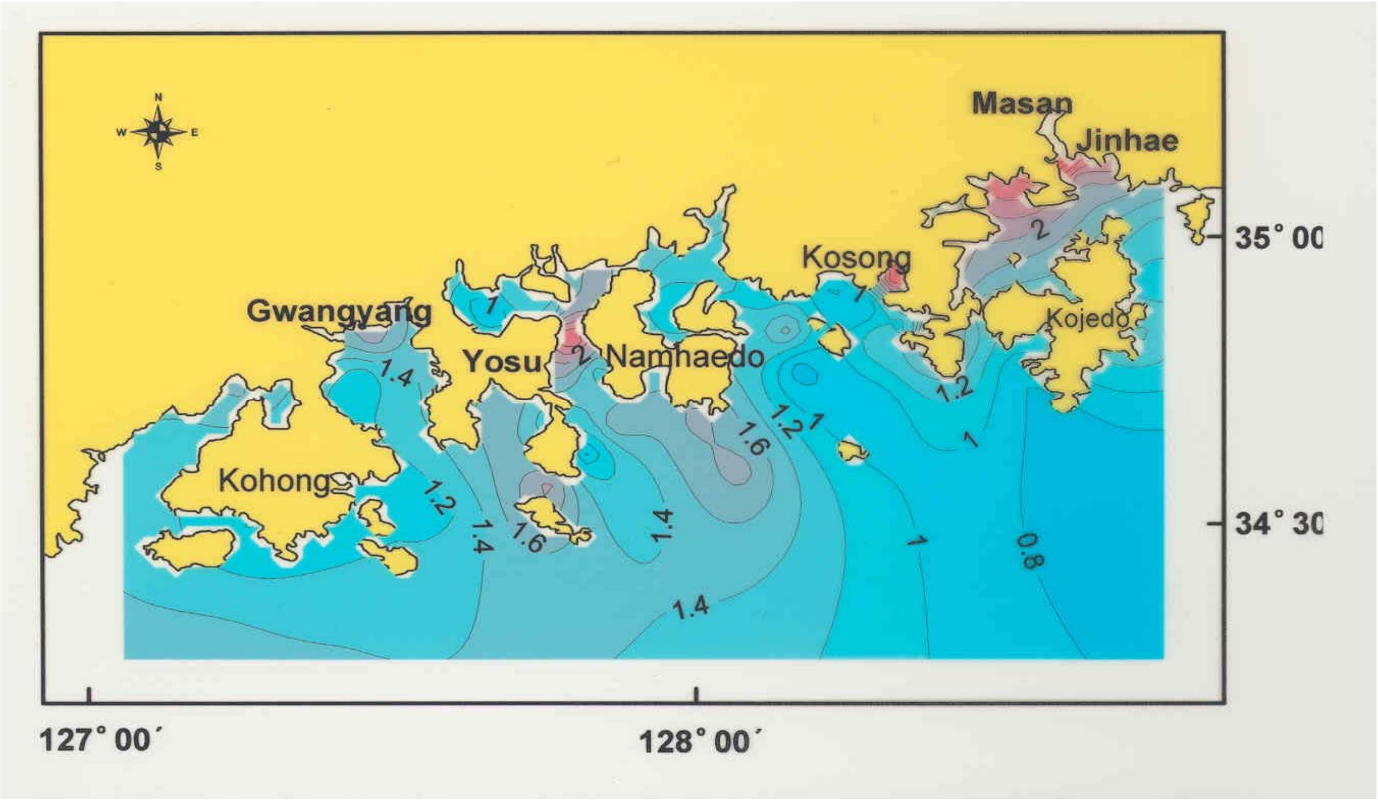
- mean SST in Aug.: 24 - -25 ℃,
- eastern boundary of tidal mixing area
- coastal front between coastal waters and warm current
- plentiful nutrients input
- tidal curr. : flood(northwestward)
  ebb(southeastward)

Fig. Landsat image around first outbreak area (red circle) of *C. polykrikoides*

Eutrophic level by COD (2002)



Eutrophic level COD in Aug. 2001



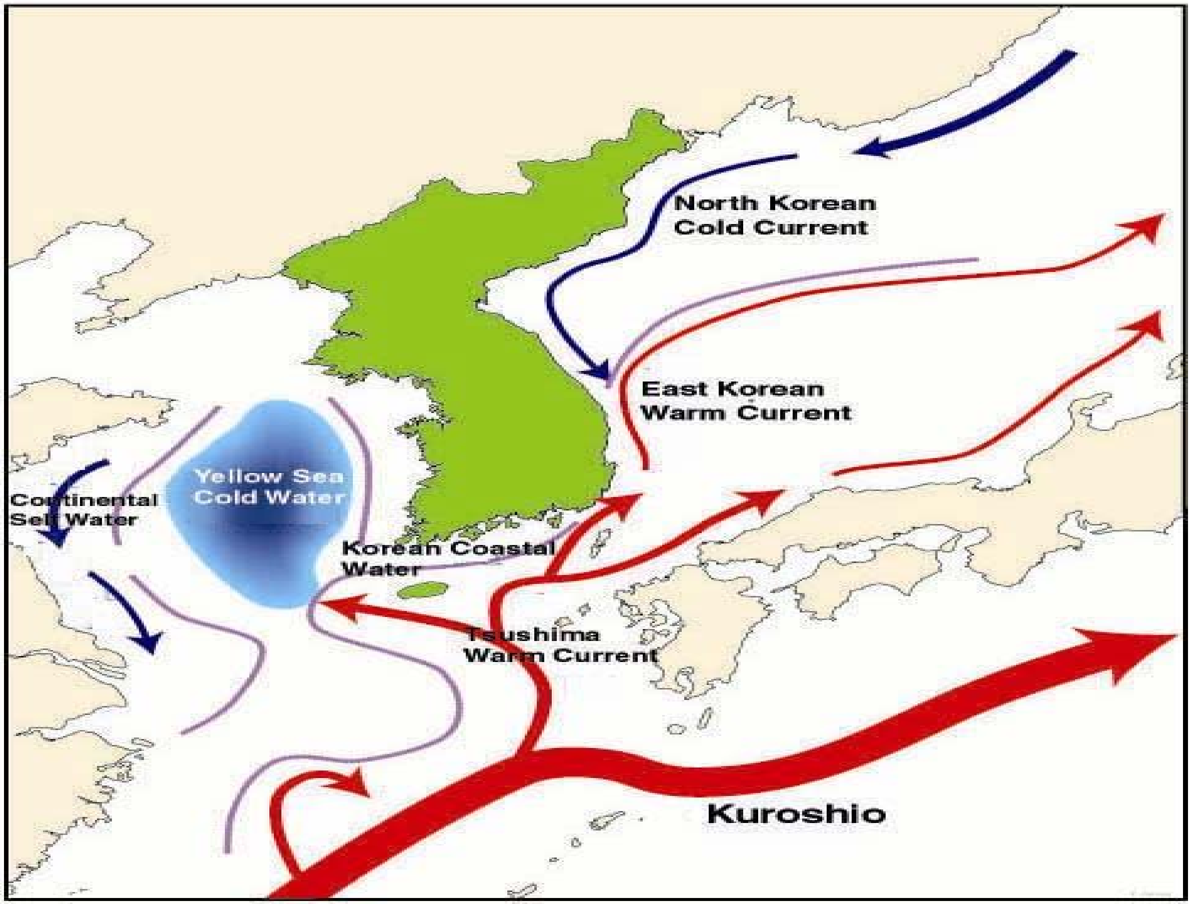
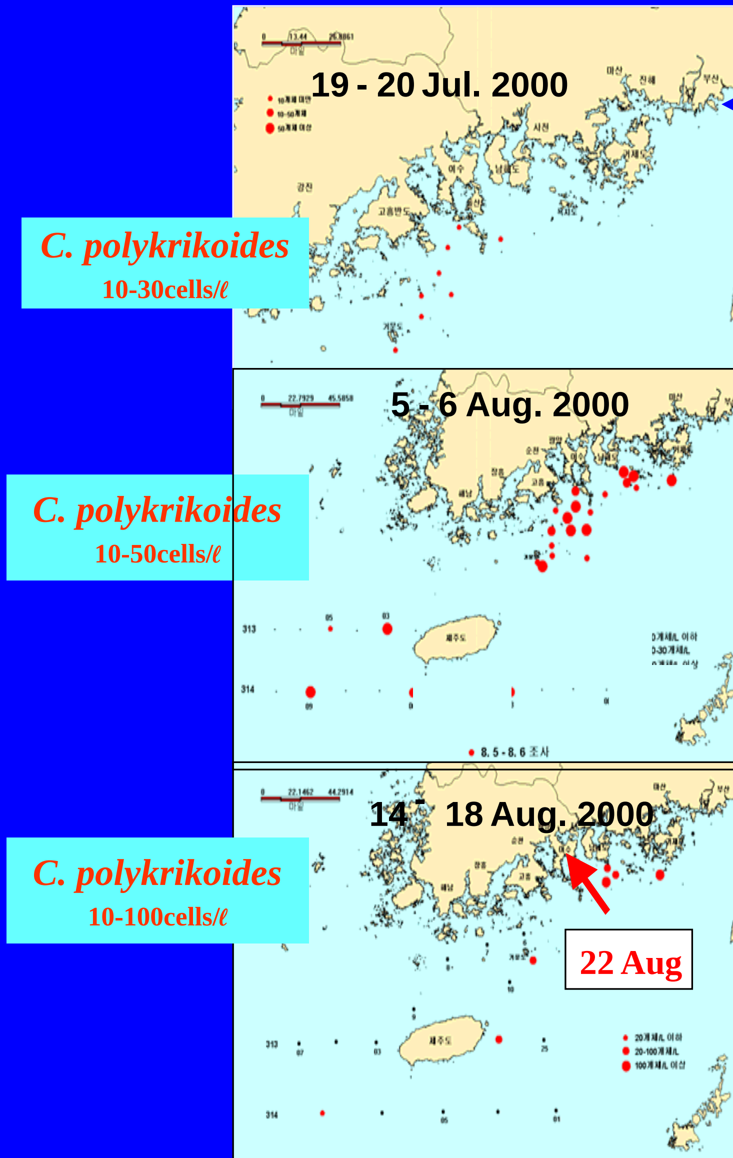
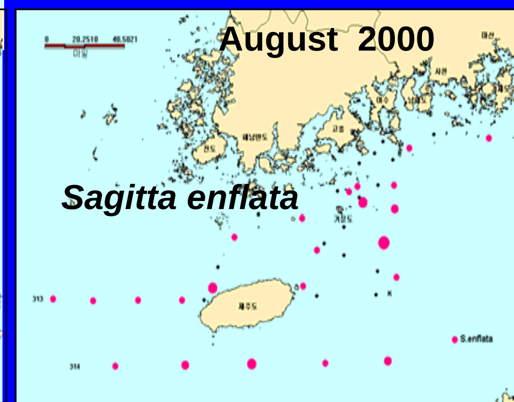


Fig. Current system around Korean peninsula(after Naganuma, 1973; Inoue, 1974).

Precautionary monitoring





Good relation on the occurrence of Cochlodinium and Sagitta at the initiation stage

Fig. The appearance C. polykrikodies and Sagitta enflata in the South Sea of Korea in 2000.

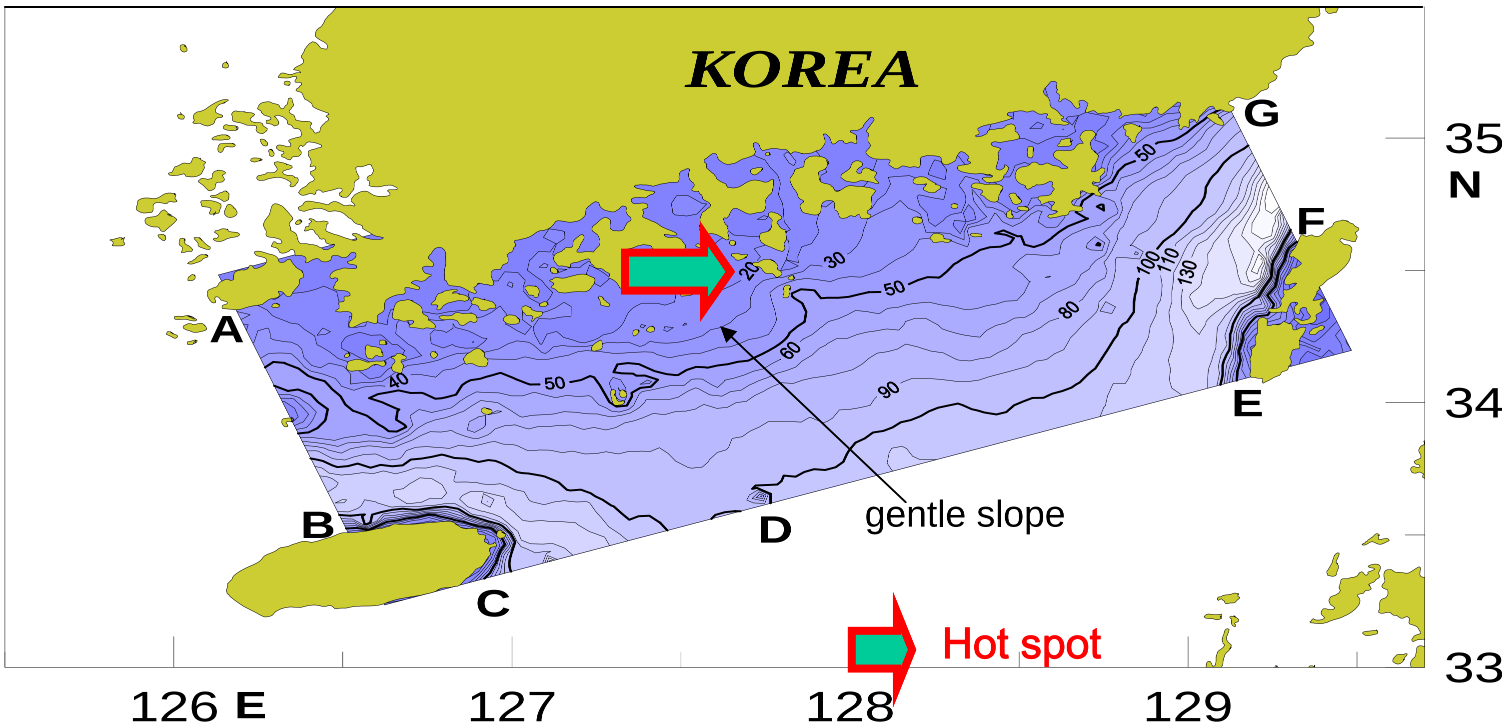
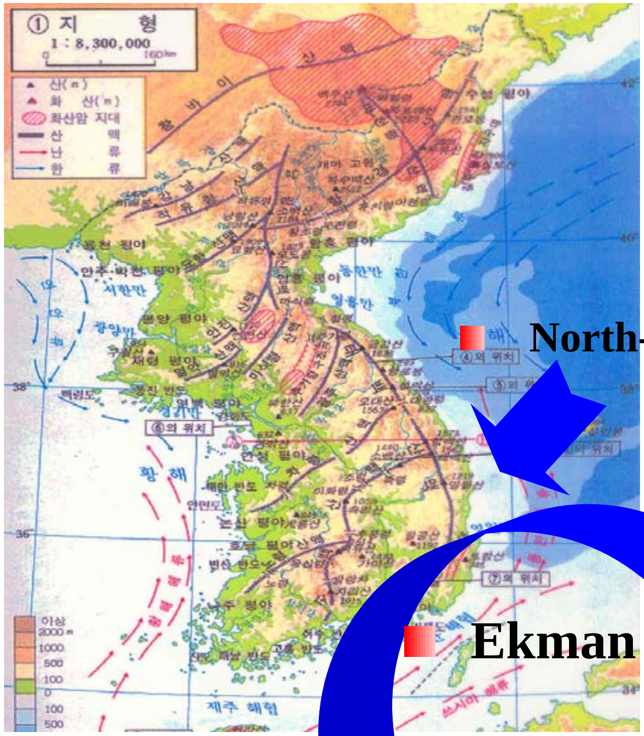


Fig. Bottom topography(in meter) in the South Sea of Korea.

Role of wind stress on the initiation



- North-eastly wind in late Aug.
- Ekman transport of open ocean water
- Induce Ekman transport
- Intrusion of warm water
- South-western wind in June and July

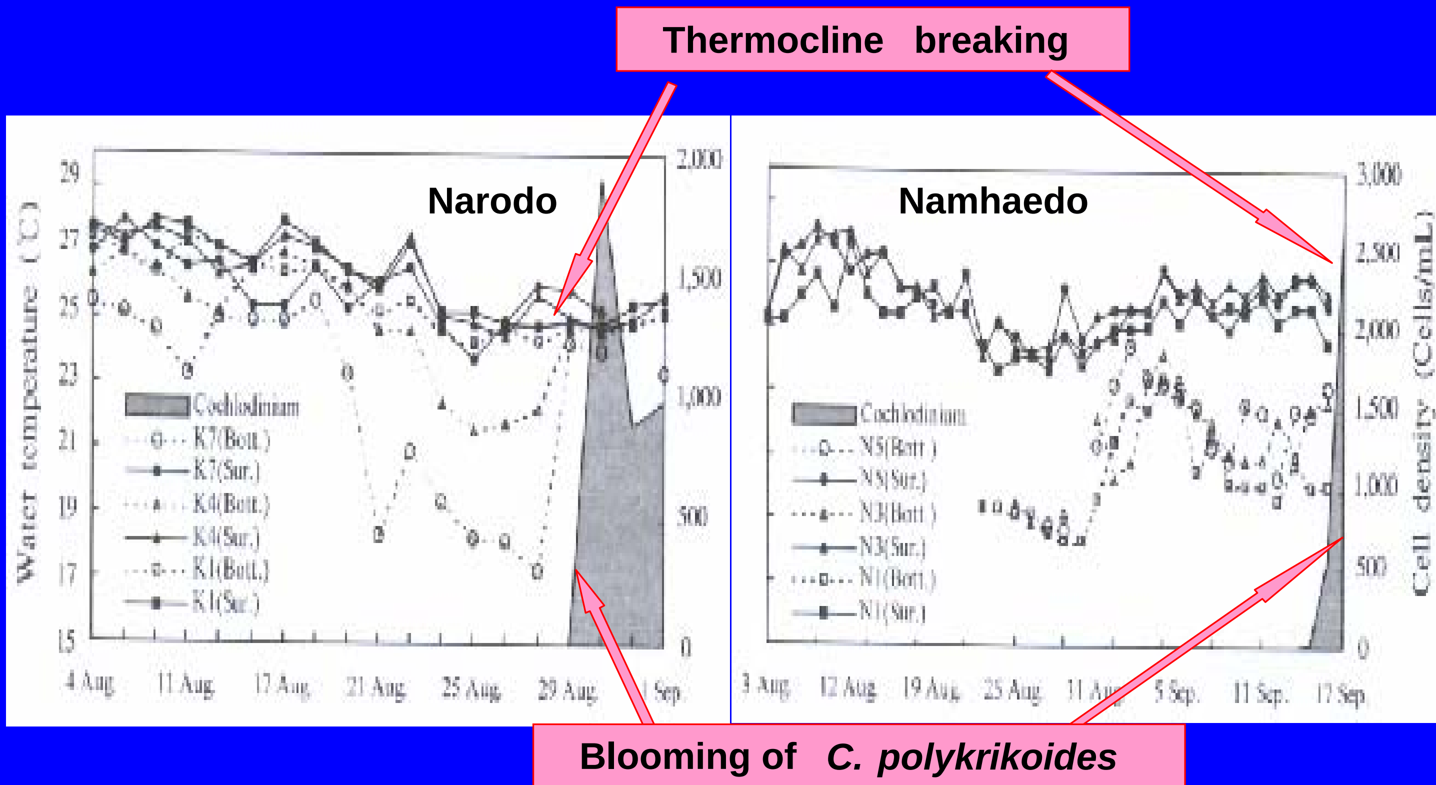
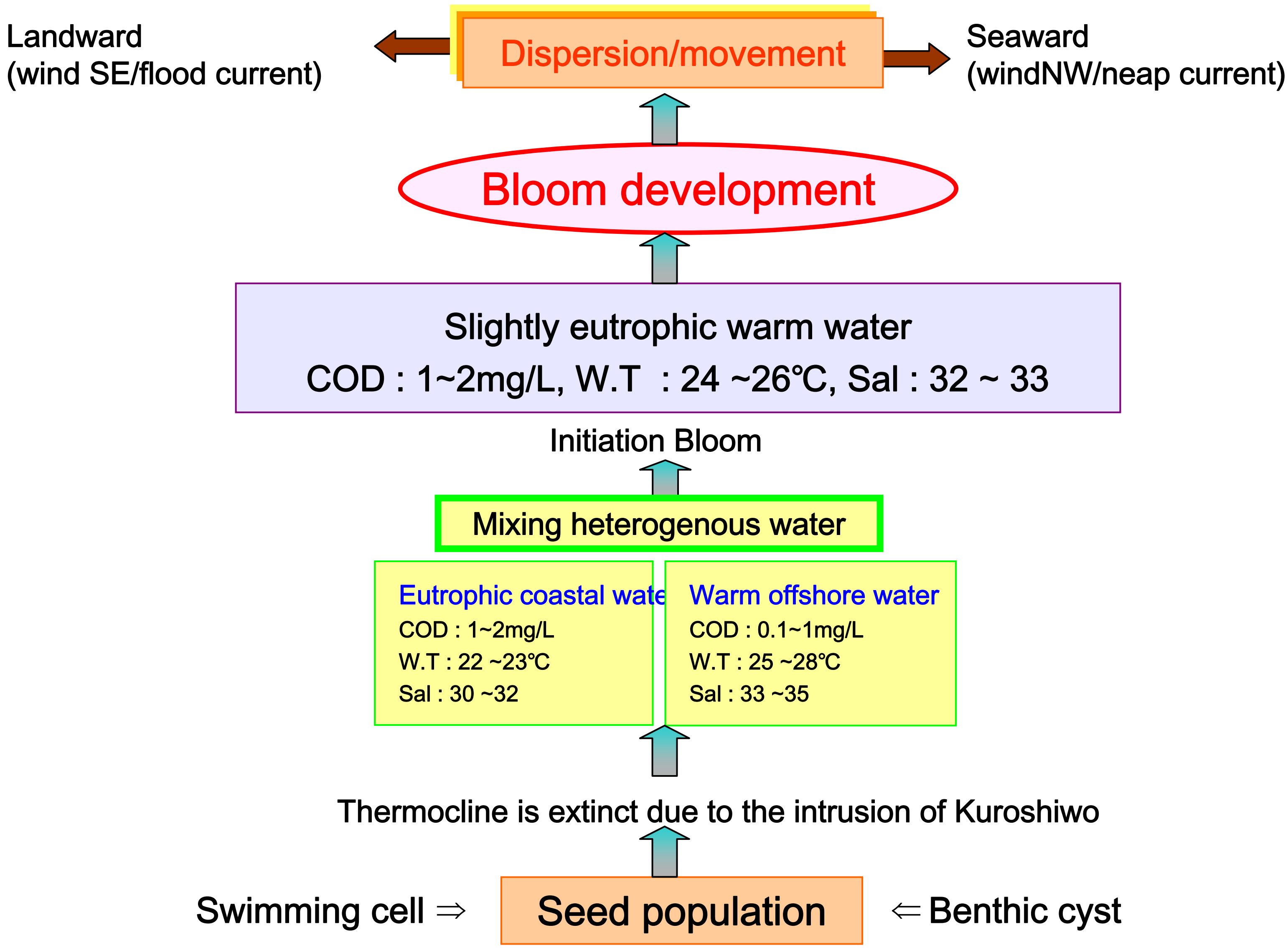


Fig. The relationship between the bloom of *C. polykrikoides* and Thermocline breaking in August 2000

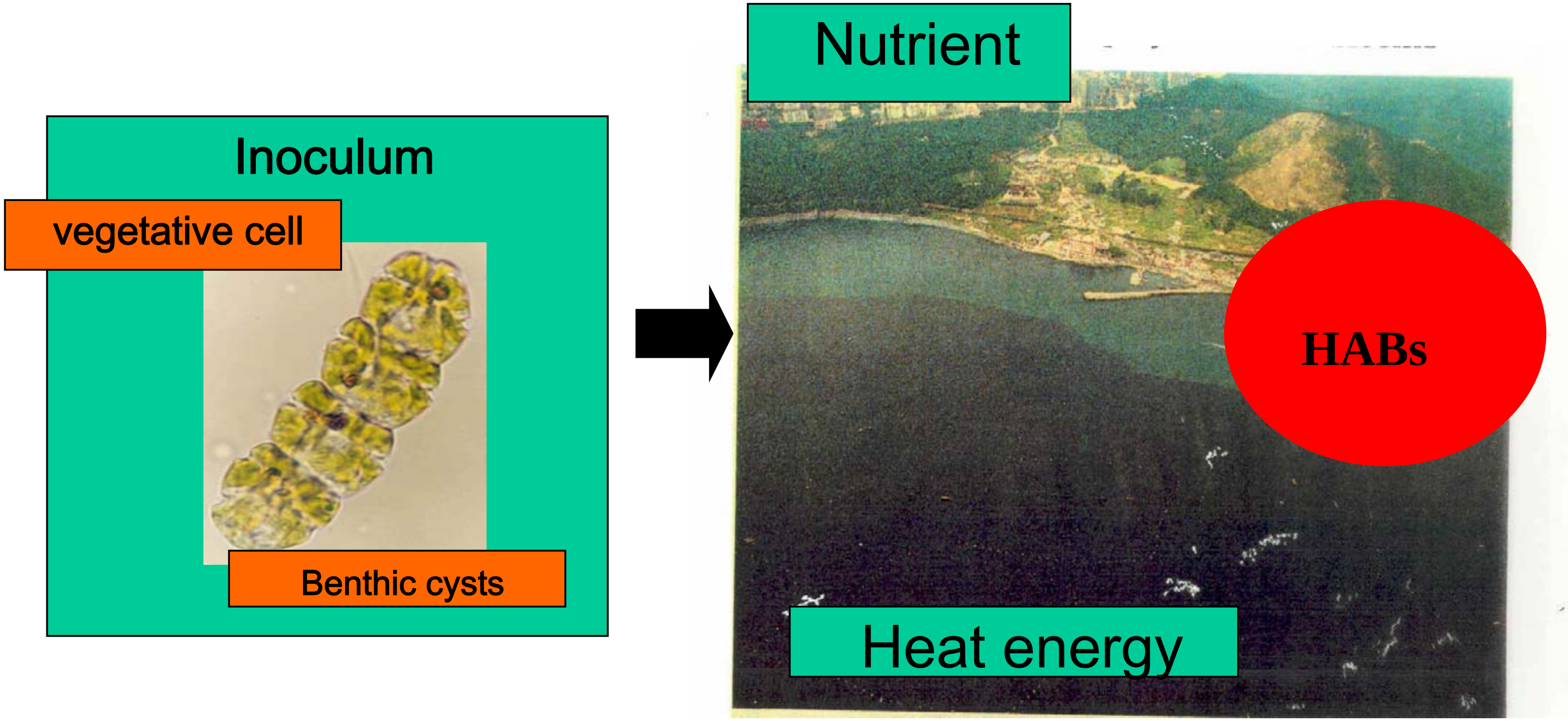
When HABs initiate the bloom ?

Initiation day (Lunar)	Tide	Julian day
1995. 8.29 (8.22)	Neap tide	241-294
1996. 9. 4 (7.22)	Neap tide	248-276
1997. 8.25 (7.22)	Neap tide	237-265
1999. 8.10 (6.29)	Neap tide	221-275
2000. 8.22 (6.29)	Neap tide	235-264



Landward
(wind SE/flood current)
Dispersion/movement
Seaward
(windNW/neap current)
Bloom development
Slightly eutrophic warm water
COD : 1~2mg/L, W.T : 24 ~26℃, Sal : 32 ~ 33
Initiation Bloom
Mixing heterogenous water
Eutrophic coastal wate
COD : 1~2mg/L
W.T : 22 ~23℃
Sal : 30 ~32
Warm offshore water
COD : 0.1~1mg/L
W.T : 25 ~28℃
Sal : 33 ~35
Thermocline is extinct due to the intrusion of Kuroshiwo
Swimming cell ⇒
Seed population
⇐ Benthic cyst

- **Hypothesis**
  1. Eutrophication is the key factors on the initiation
  2. Warm Kuroshiwo supply heat energy for the growth
  3. Inoculum from resting cysts and/or transported from offshore waters



Cochlodinium patches

- in developing stage

1995년도 적조

Cochlodinium polykrikoides blooms

미역양식장 뒤덮은 적조대 적조와 기름으로 바다가 신음하고 있는 가운데 29일 부산 青砂浦 앞바다에 검붉은 적조대가 미역양식장을 뒤덮고 있다。 <부산시 소방본부헬기=朴熙萬기자>

Cochlodinium patches

- peak stage

Initiation of HAB - Known(□) and unknown (□)

- □ Known and knownable
  - Key driving force
    - Coastal eutrophication : N. P.
    - Physical oceanographic propertities
      - Kuroshio, Upwelling, Advection
  - Limiting factors (dinoflagellates)
    - First came nitrogen, then phosphorus

- □ Unknown
  - Life cycle-reproduction system of harmful algae
  - The origin of inoculum-the role resting cysts
  - The influence of eutrophication and climate changes

3. Movement and dispersion

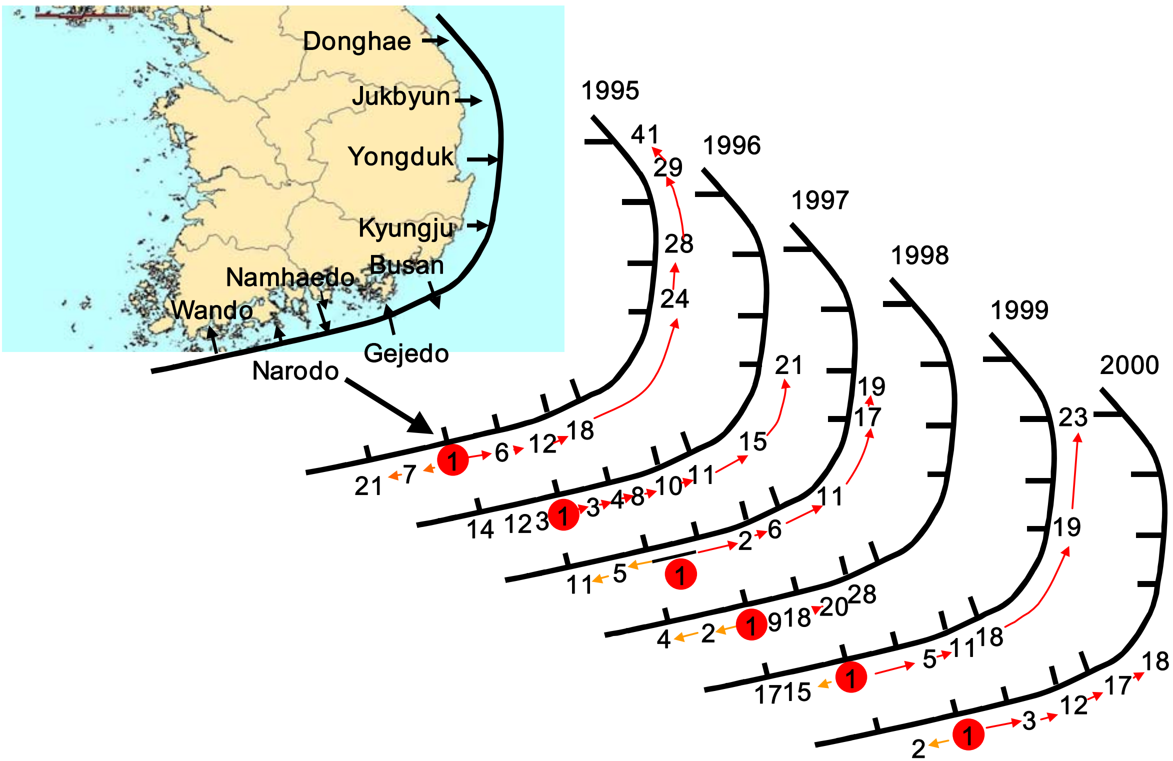


Fig. Year to year variations of the movement of HABs. Red circles and numbers denote the first outbreak area and the elapsed dates respectively.

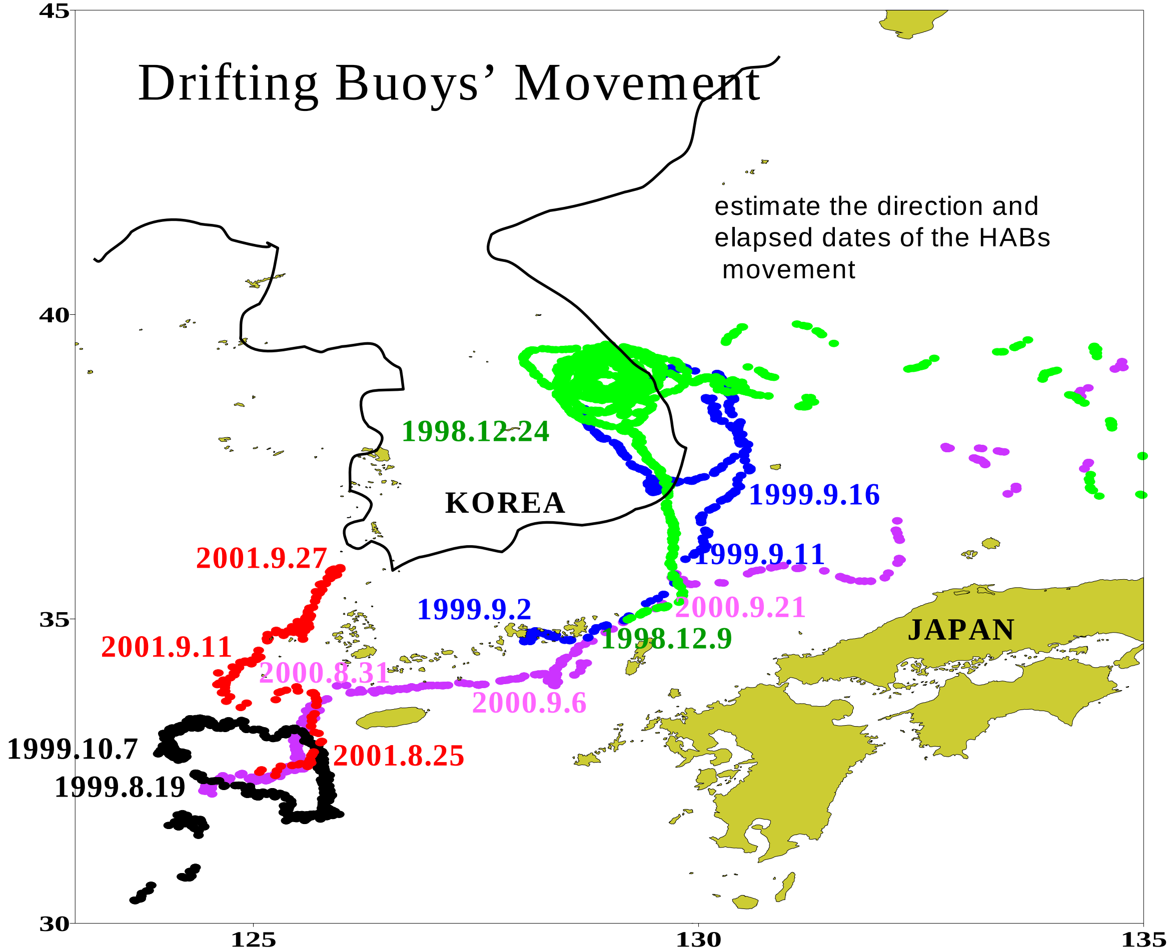


Fig. Drifting buoy trajectories in Korean Waters.

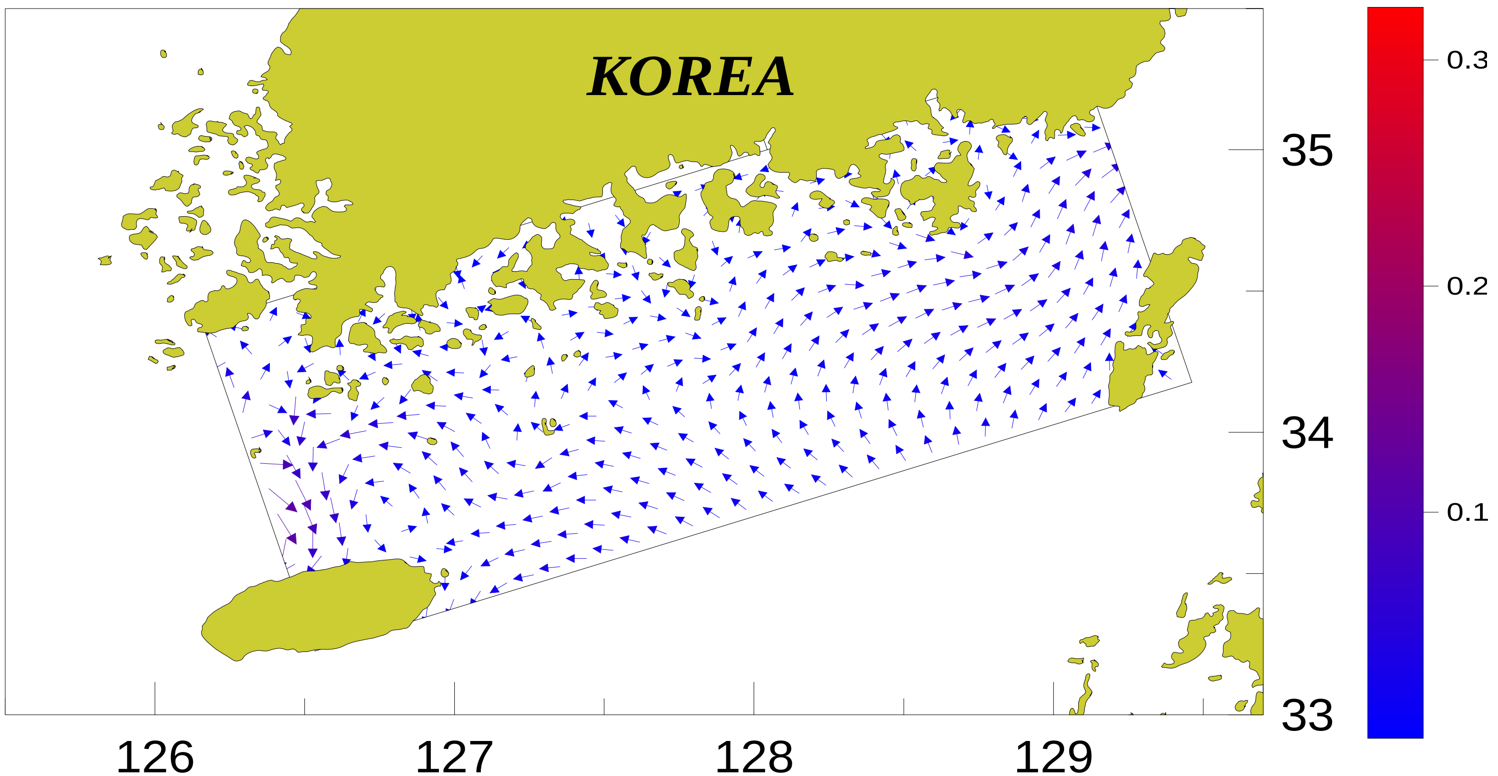


Fig. Residual currents in the model area.

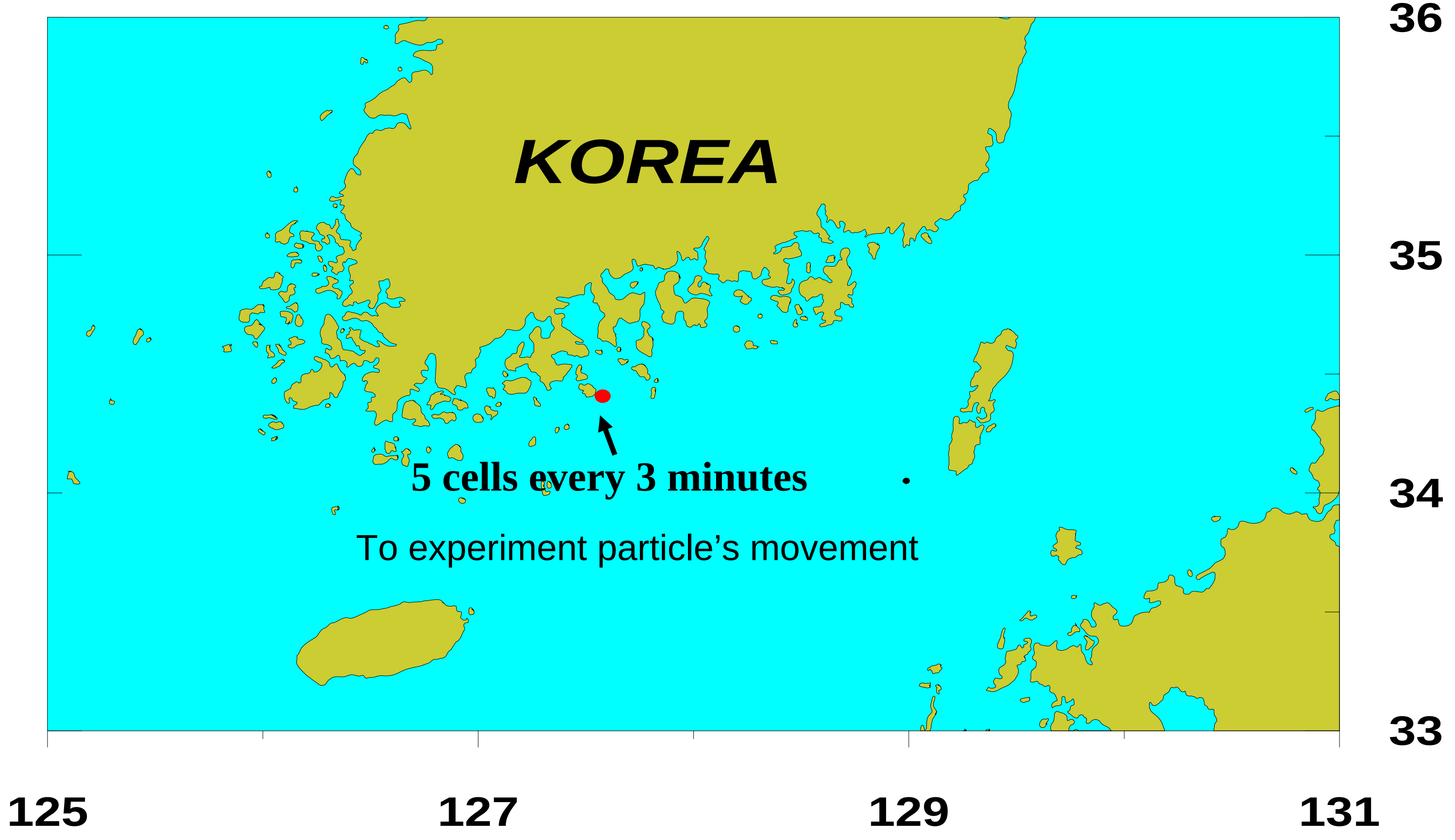


Fig. Numerical tracer release point(red point).

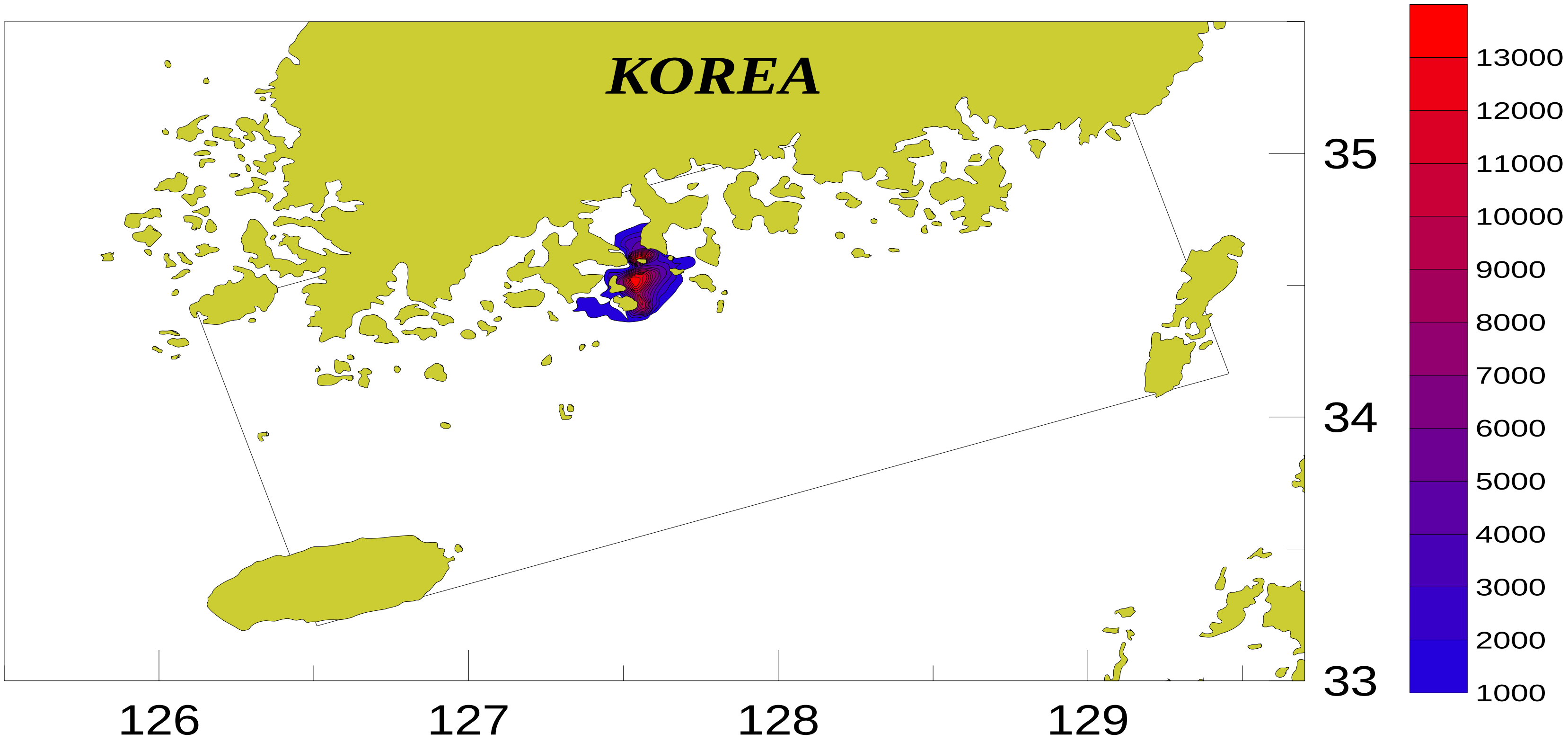


Fig. Computed area of C. polikrikoides after 5 days with windless.

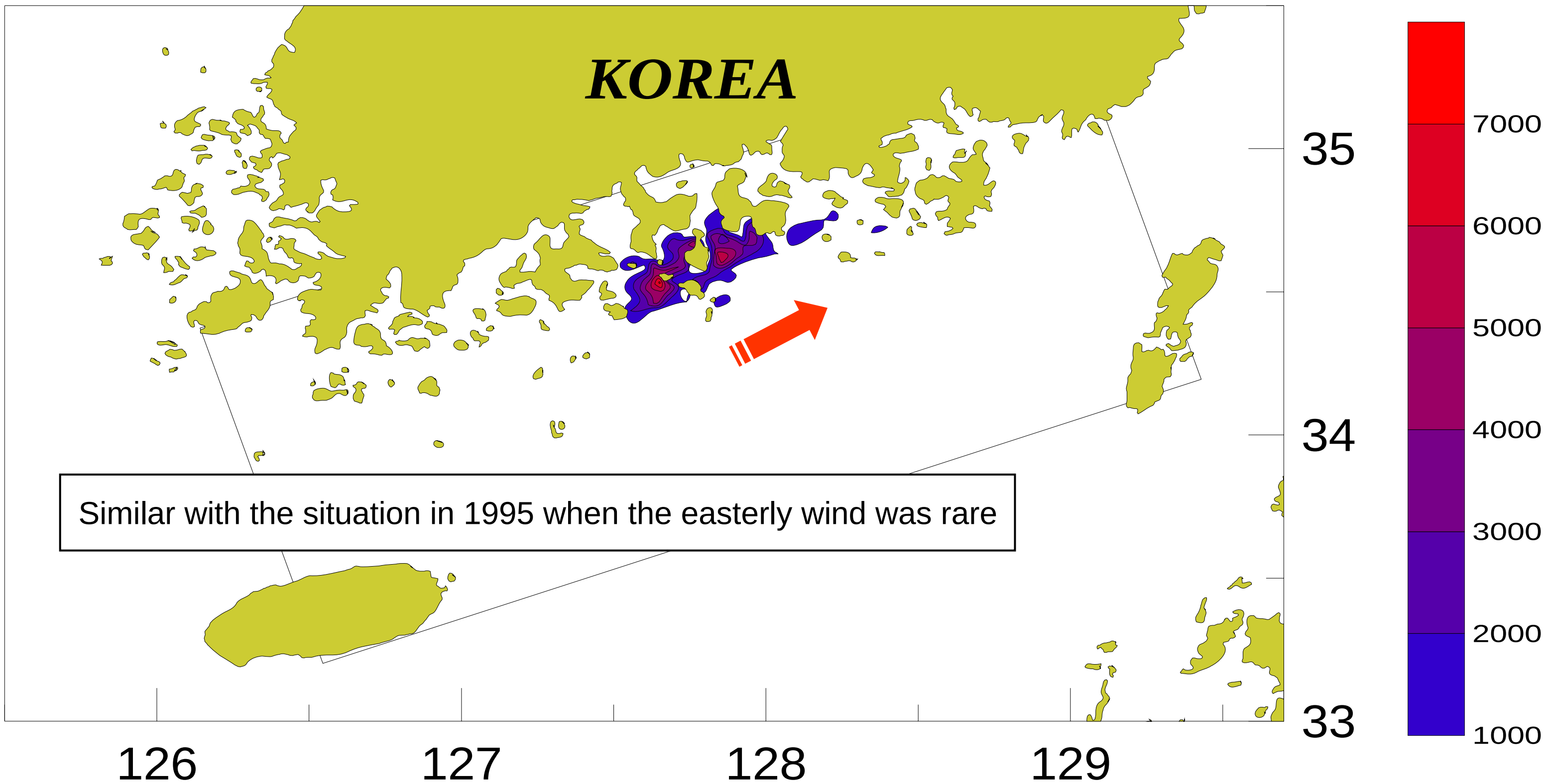


Fig. Computed area of *C. polikrikoides* after 5 days with southwesterly wind.

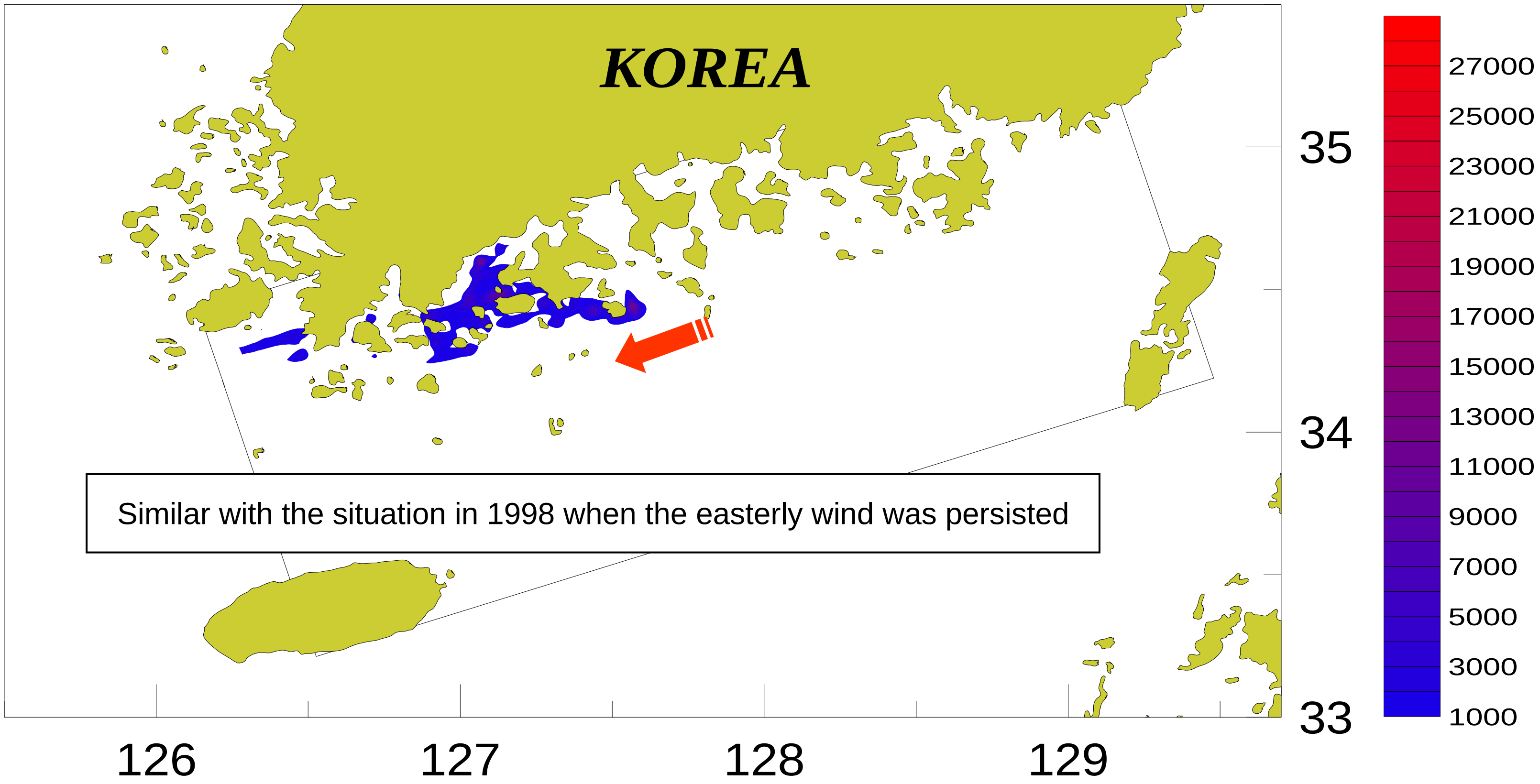


Fig. Computed area of *C. polikrikoides* after 5 days with southeasterly wind.

Where are HABs go ?

Driving forces	Direction	Magnitude
Tidal current	Come & back	Flood-NE Ebb-SE
Winds	Surface	SE-to west, landward NE-seaward
Migration	Vertical	Day-surface Night-deep

What is the velocity ?

Driving forces	Speed/hour	Travel in 4hrs
Tidal current	50cm(1kt)-100cm(2kt)	7-14km
Tsushima current	3-20kt/d	10-15days to cross south Sea
Winds	SE-NE	Variable
Migration depth	Surface to 20 m	Light dependent

Movement of HAB - Known(□) and unknown (□)

- Known and knownable
  - Key driving force on the transportation
    - Same as the direction of Kuroshiwo
    - Tidal current induce landward or seaward
    - The wind induce to the east or to the west
- Unknown
  - The prediction on the transport route to northeast
  - The fluctuation in the scale in the Northeastern coast
  - The influence of typhoon and coastal upwelling

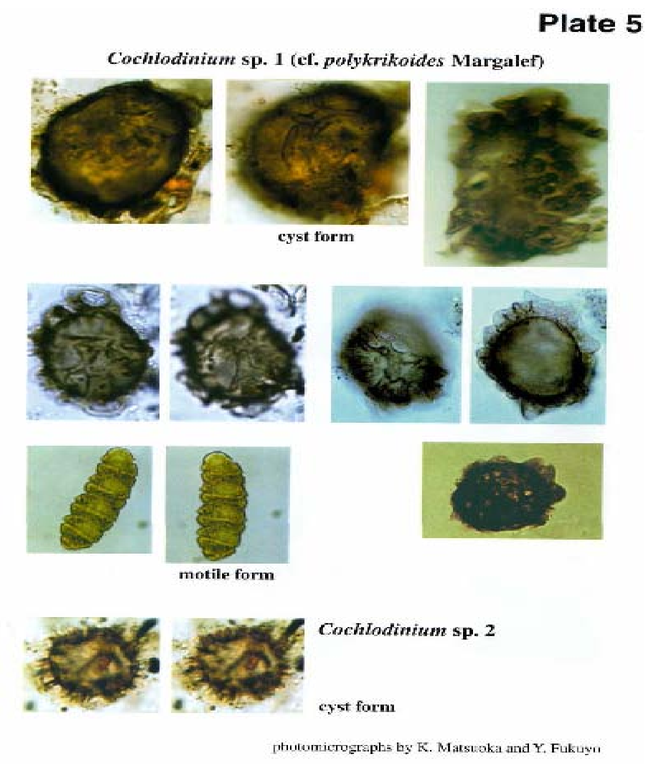
■ The unknown

1. Where *C. polykrikoides* comes from?
   Is it from benthic resting cyst or transport from offshore waters ?

■ From benthic cyst ?

C. polykrikoides can produce benthic cyst ?

- Probably Yes
  - Because, there once a bloom in the semi-enclosed Jinhae Bay in 2000.
  - There found the cyst of this species.
  - Annually same season and same locality



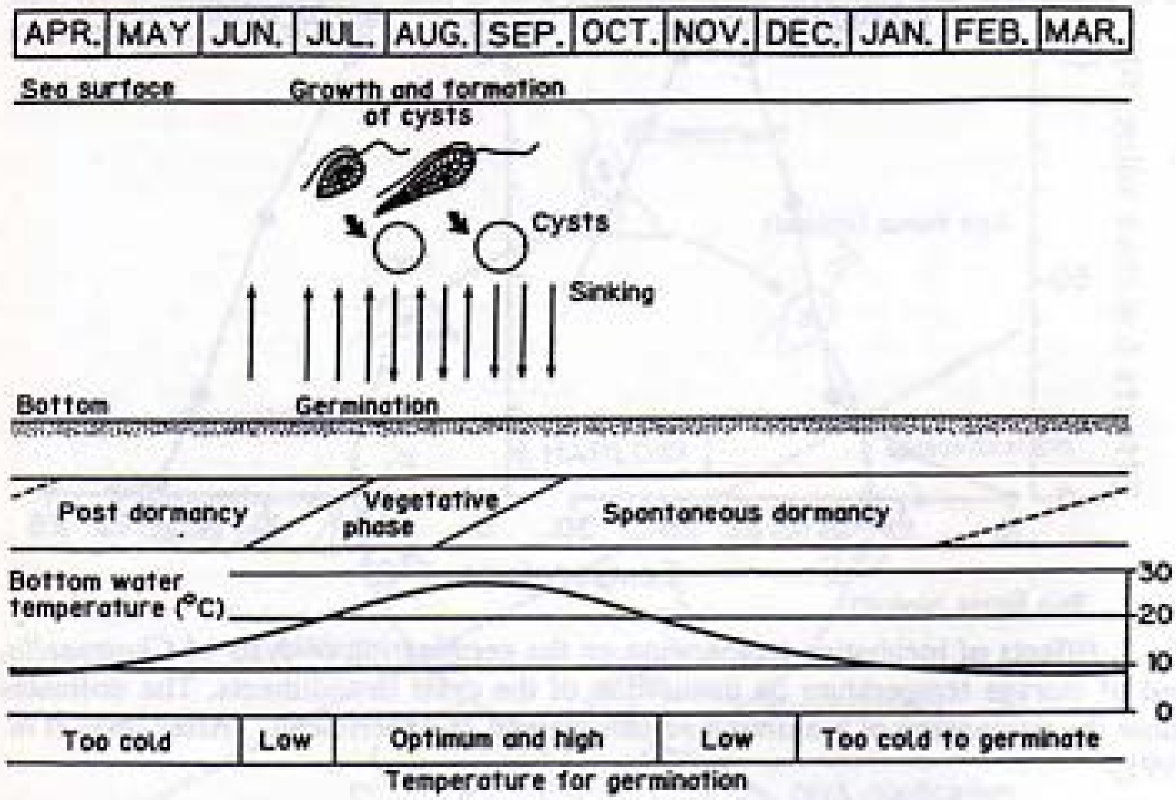


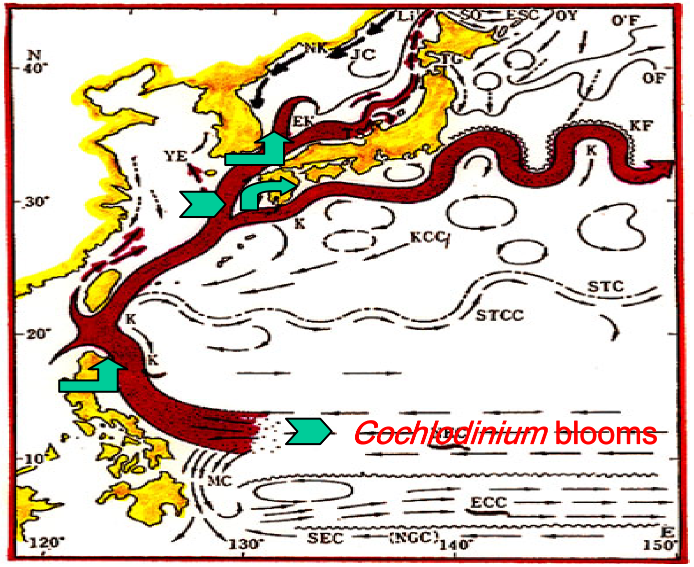
Fig.5. Schematic representation of the annual life cycle of *Chattonella* in the Seto Inland Sea, including vegetative and cyst phases. The seasonal fluctuation of bottom water temperature is also shown. (After Imai and Itoh 1987, Imai *et al.* 1991)

- **An example of the same season and locality of recurrent HABs**

■ From offshore waters, where ?

C. polykrikoides can be transported by the Kuroshiwo ?

- **Probably Yes**
  - **They recurred in summer when Kuroshio influence on the oceanographic properties of the very coastal waters.**
  - **Many observations on the transportation from offshore waters in Korea.**
  - **Recent blooms in Philippines, Malaysia, Indonesia**



Representative of the bloom influenced by the warm oceanic water

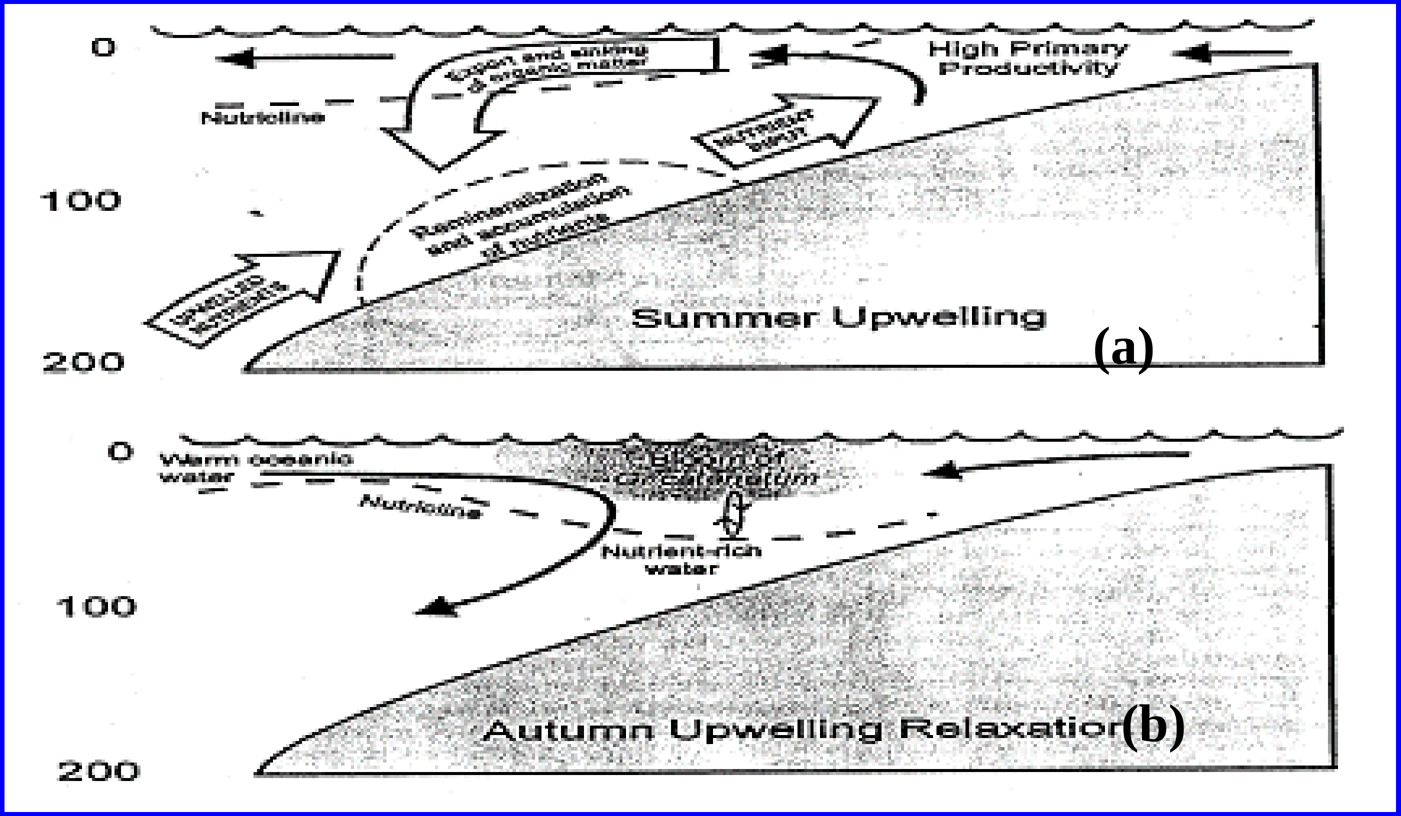
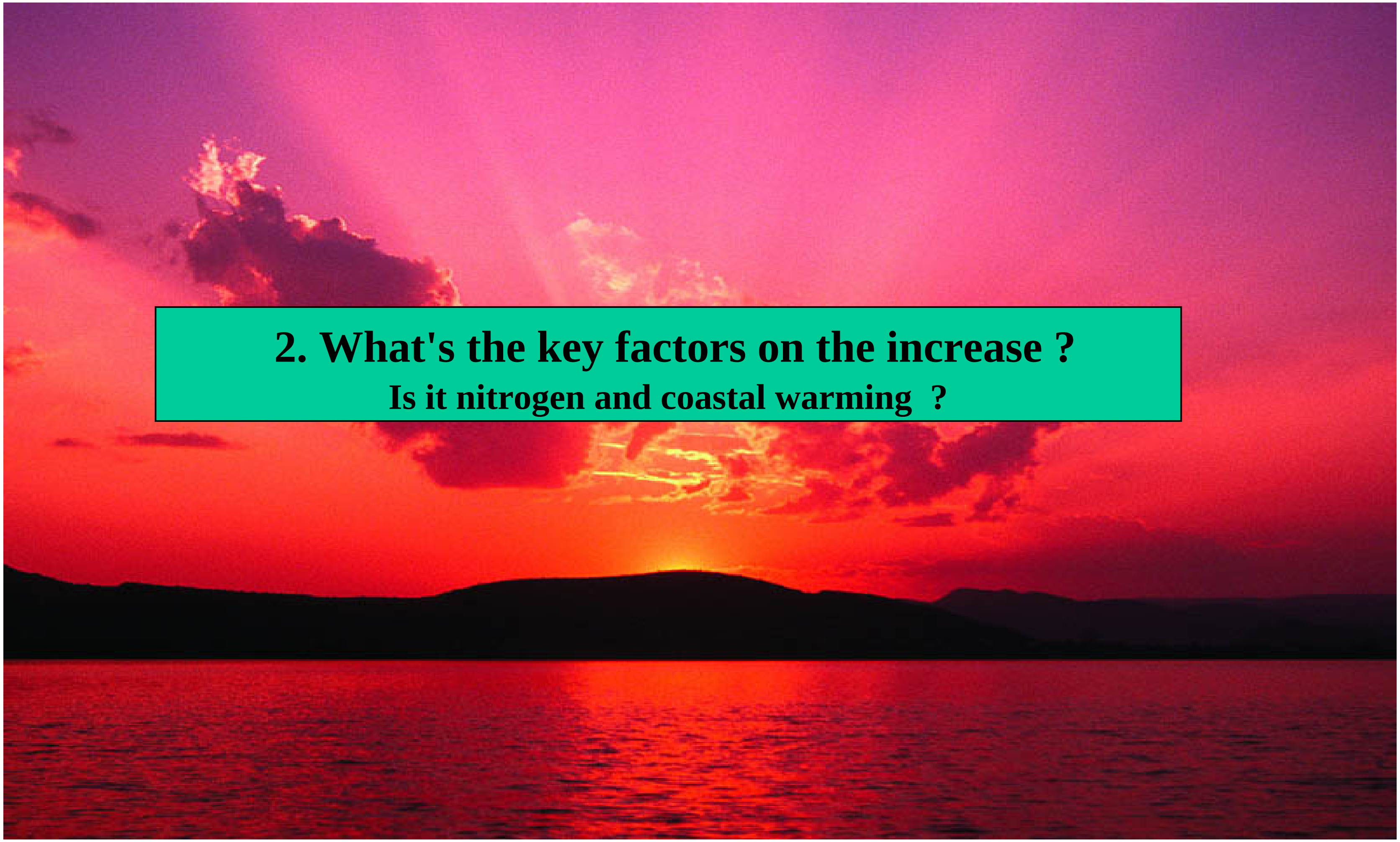


Fig. Hydrography of the Ria de Vigo during (a) summer upwelling and (b) autumn upwelling relaxation. Note the shallow nutricline in (a) allowing for diatom blooms, while the advection of warm oceanic water in (b) leads to a deepening of the nutricline, providing a competitive advantage to migrating dinoflagellates (Fraga & Bakun,1993).



2. What's the key factors on the increase ?

Is it nitrogen and coastal warming ?

Some relation between coastal eutrophication and HABs

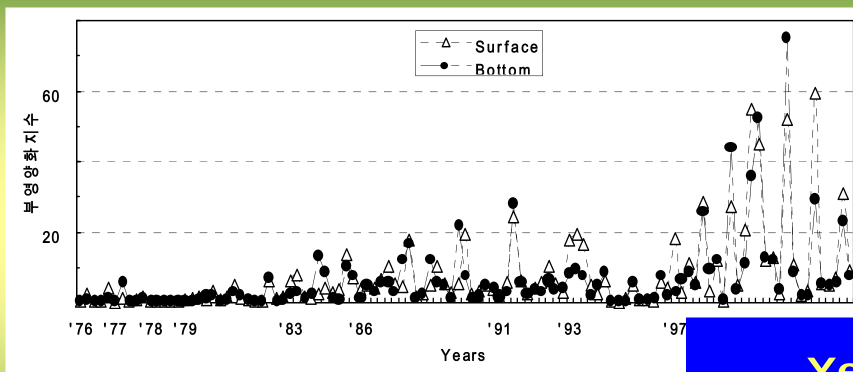
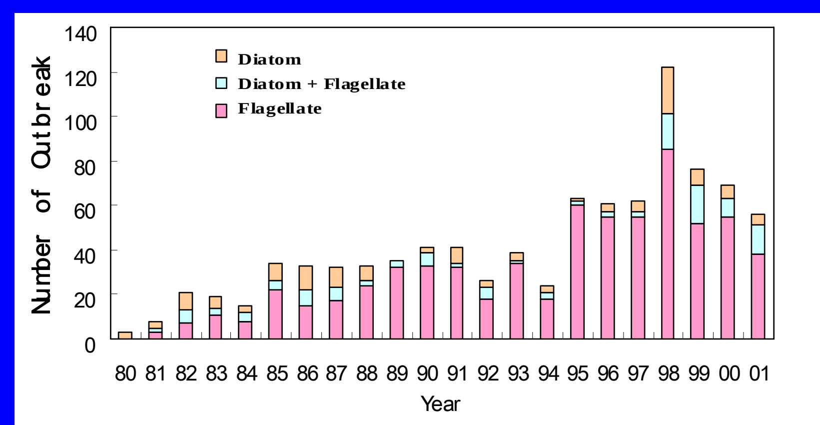


Fig. Annual changes of eutrophic index in the seawater co

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

What is the initiative nutrients ?
Is it nitrogen or phosphate ?
Inorganic and organic ?

Yearly distribution of the number of Red tides since 1981



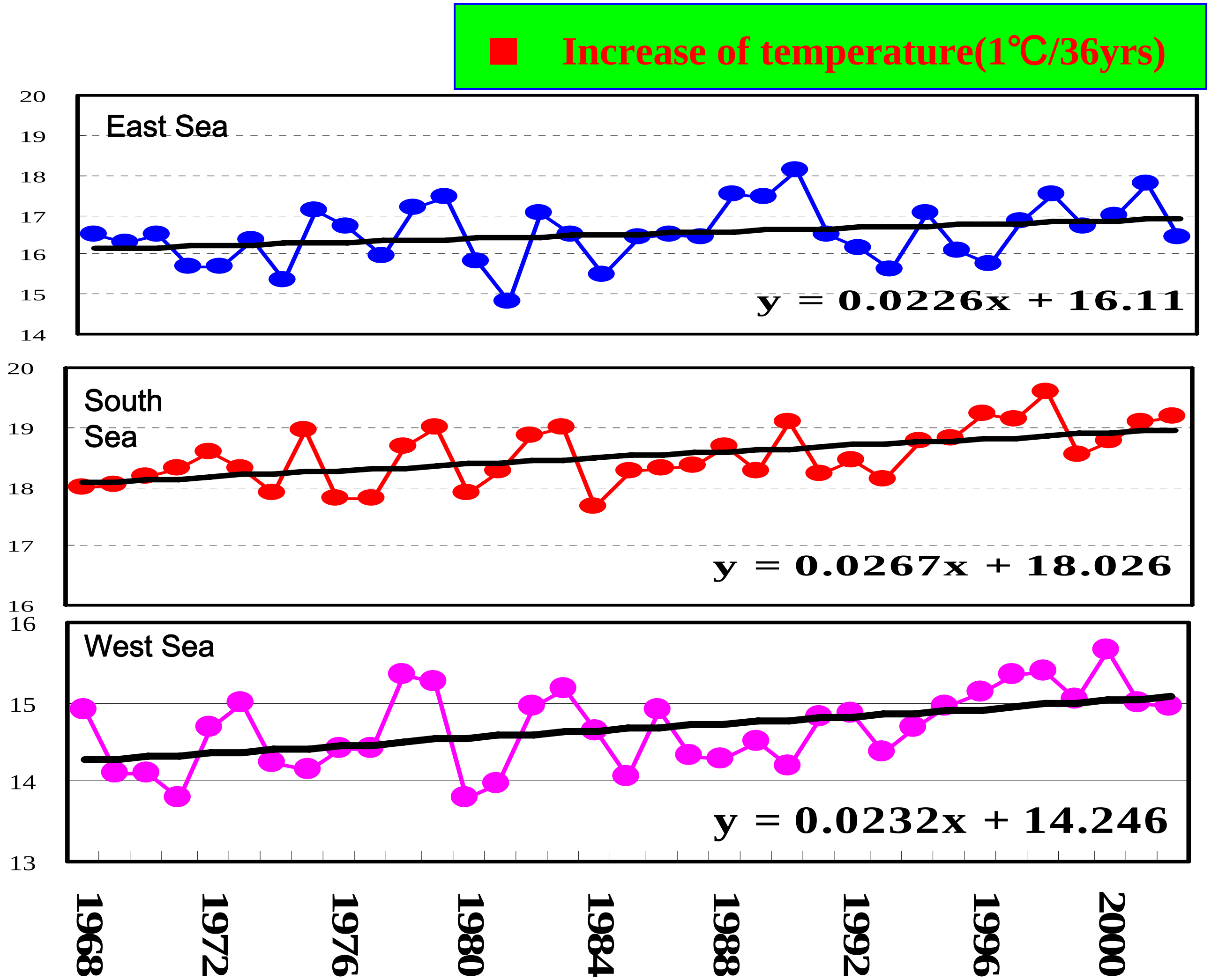
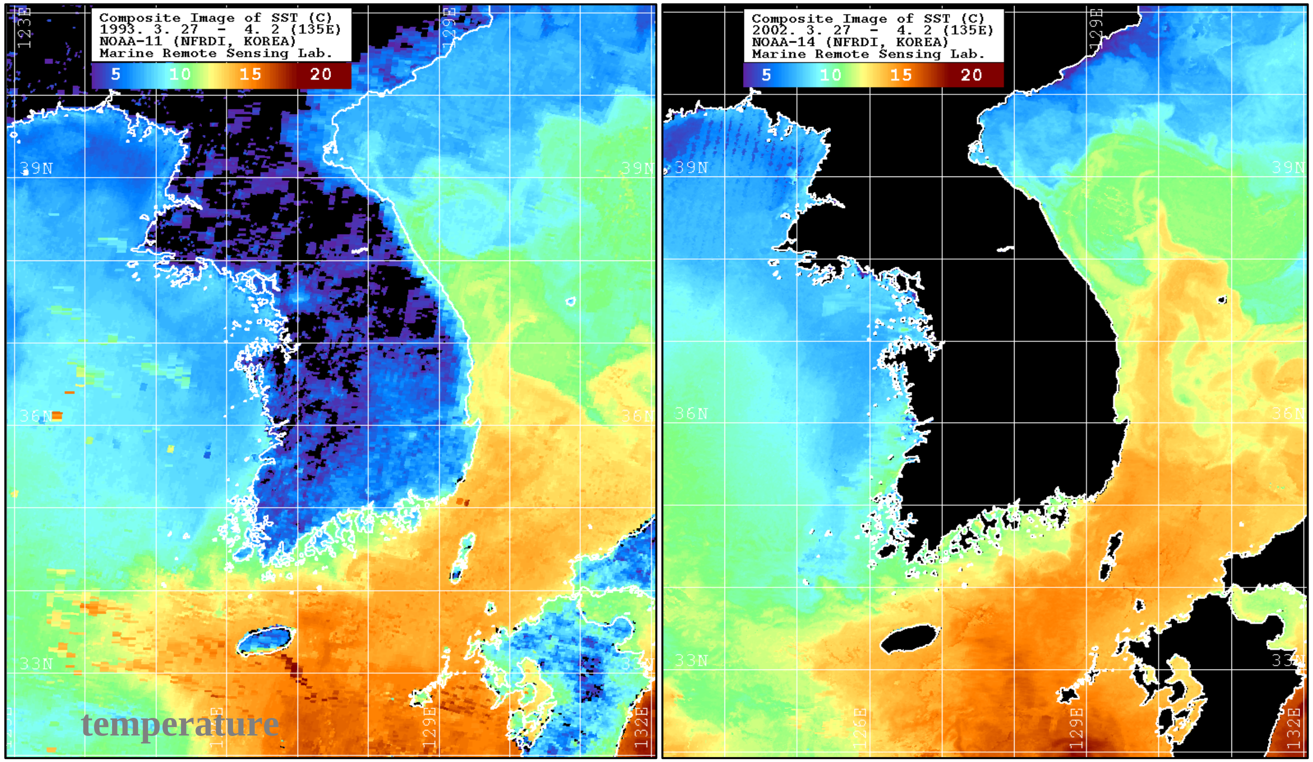


Fig. Annual fluctuation of sea surface temperature in the Korean coastal waters for 32 years

■ Kuroshiwo extend more to the north as the years go



What makes such increase of high density ?
Is it nutrient or coastal warming ?

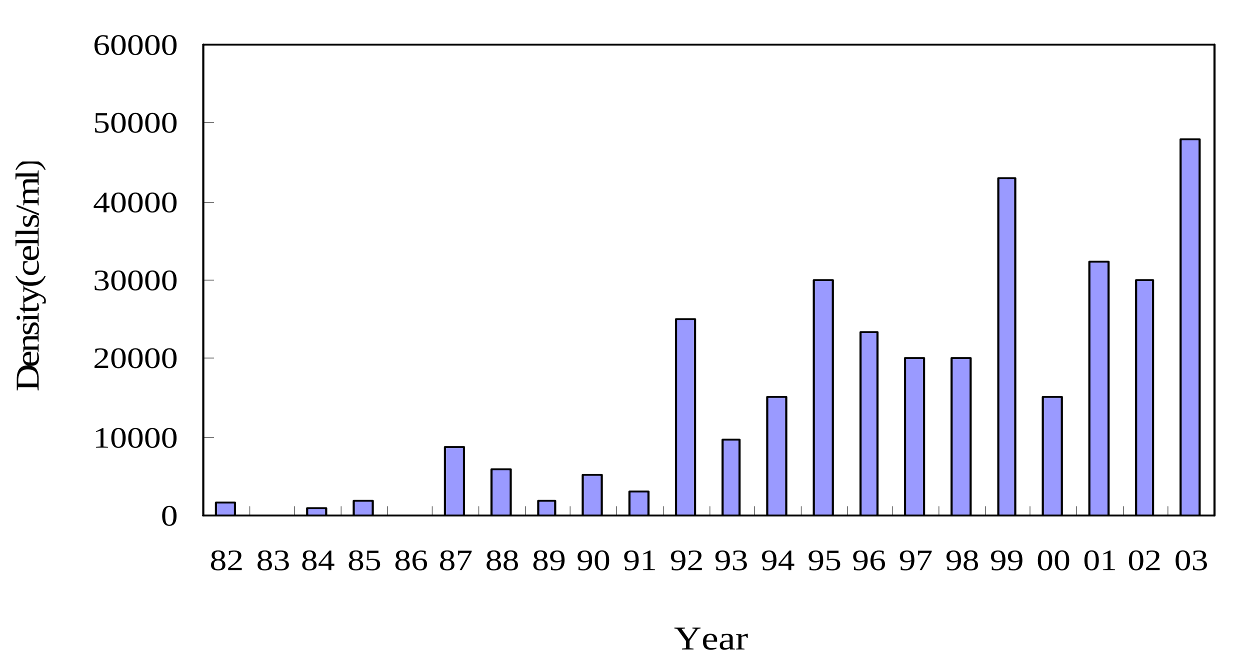


Fig. Annual fluctuation of the highest density of *C. polykrikoides* blooms in Korean waters since 1982.

3. Are they on the climax of the species succession ?

Species succession

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.	

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

Fig. Species succession in HABs in Yeosu Bay since 1980

□ 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.

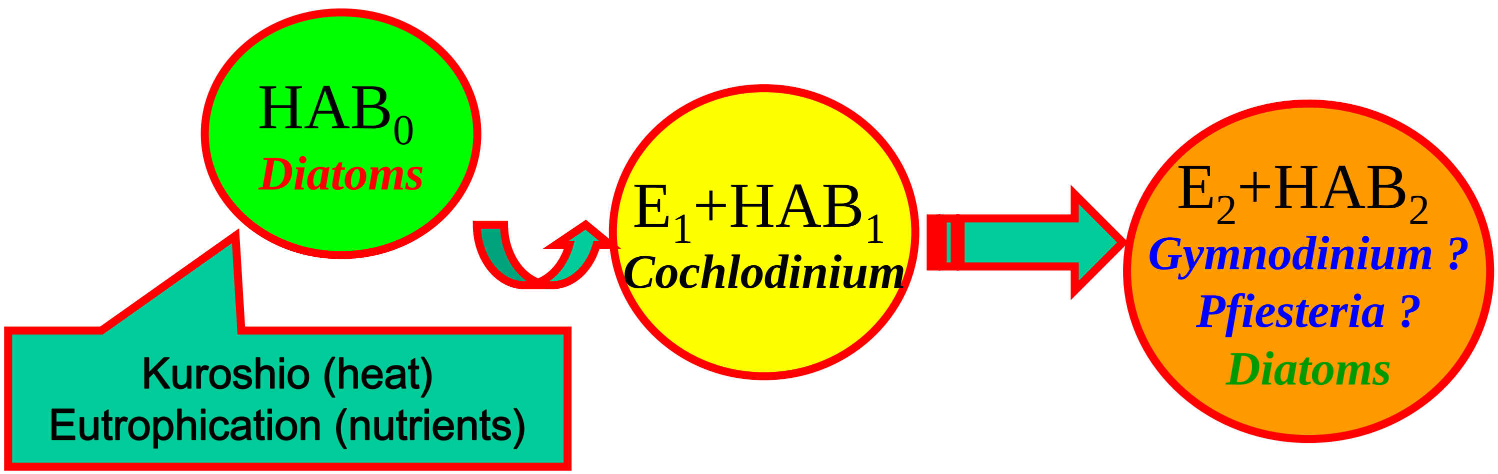
Noctiluca → SkeletonemaH / eterosigma / Prorocentrum → Skeletonema / Heterosigma / Ceratium / **Cochlodinium** → **Cochlodinium**

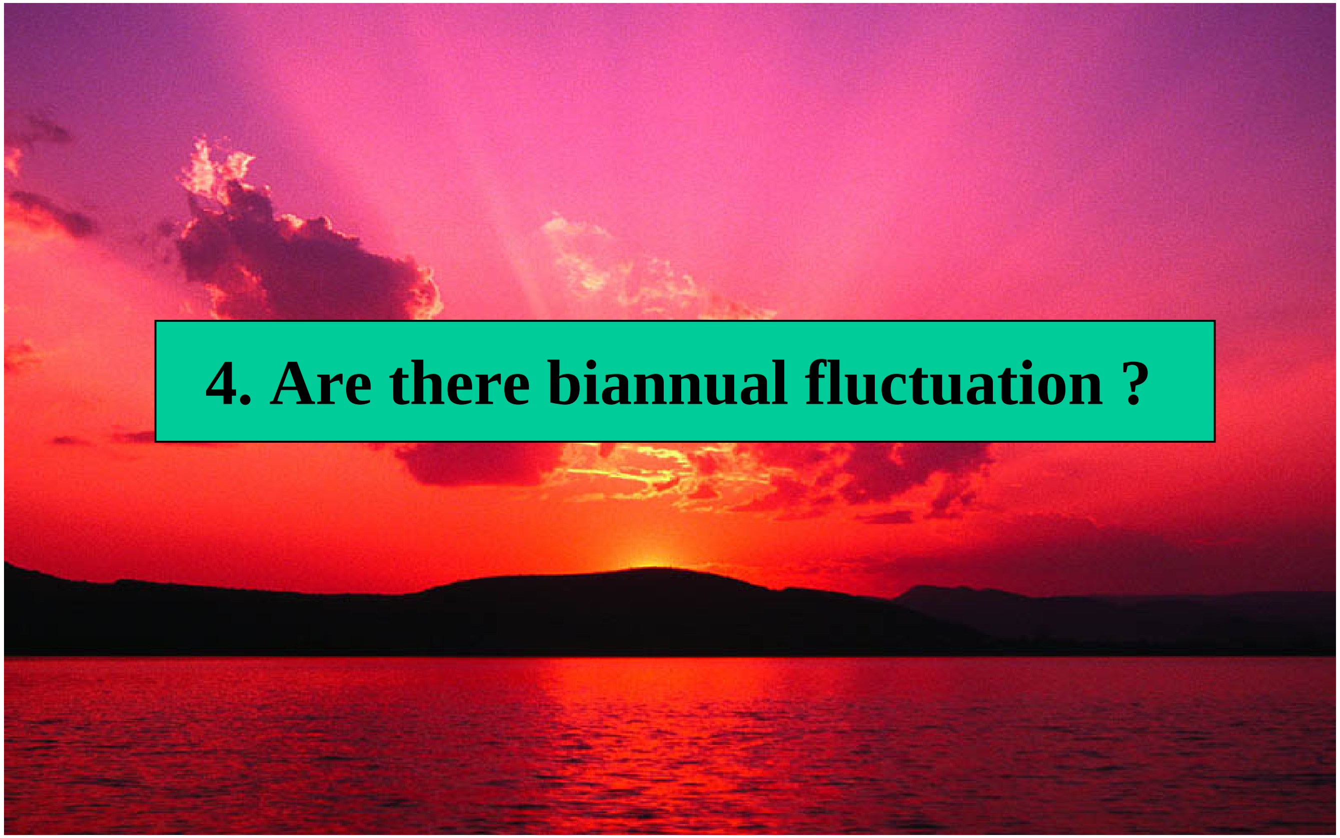
□ Tongyoung Coast (eutrophic, COD *c.a.*, 1ppm)

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

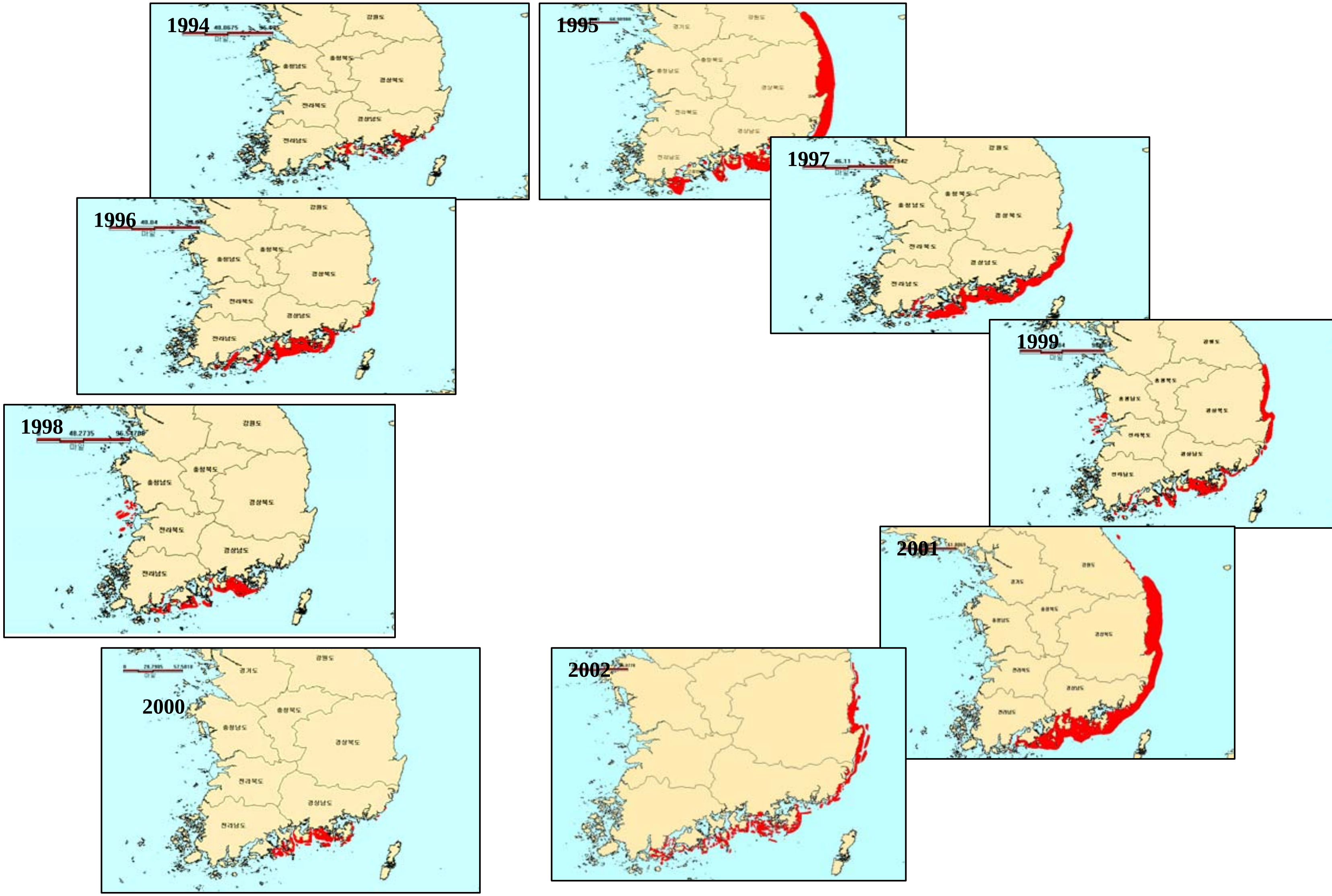
Noctiluca / Heterosigma / Gymnodinium → Skeletonema / Chaetocerosa / Heterosigma / Ceratium / **Cochlodinium** → Gymnodinium / **Cochlodinium**

What dinoflagellate will replace *Cochlodinium* ?




4. Are there biannual fluctuation ?

Annual variation of the area affected by *C. polykrikoides* bloom in Korean Waters.



What makes such kind of biannual fluctuation ?

- The suspected cause of annual fluctuation of HABs
  - Upwelling in the southeastern coastal area
  - Coldwater mass in the southwestern coastal area
  - Quasi-biennial oscillation also occurred in the oceanographic variations of SST and salinity in the Northern part of the East China Sea in periods 1995-2001

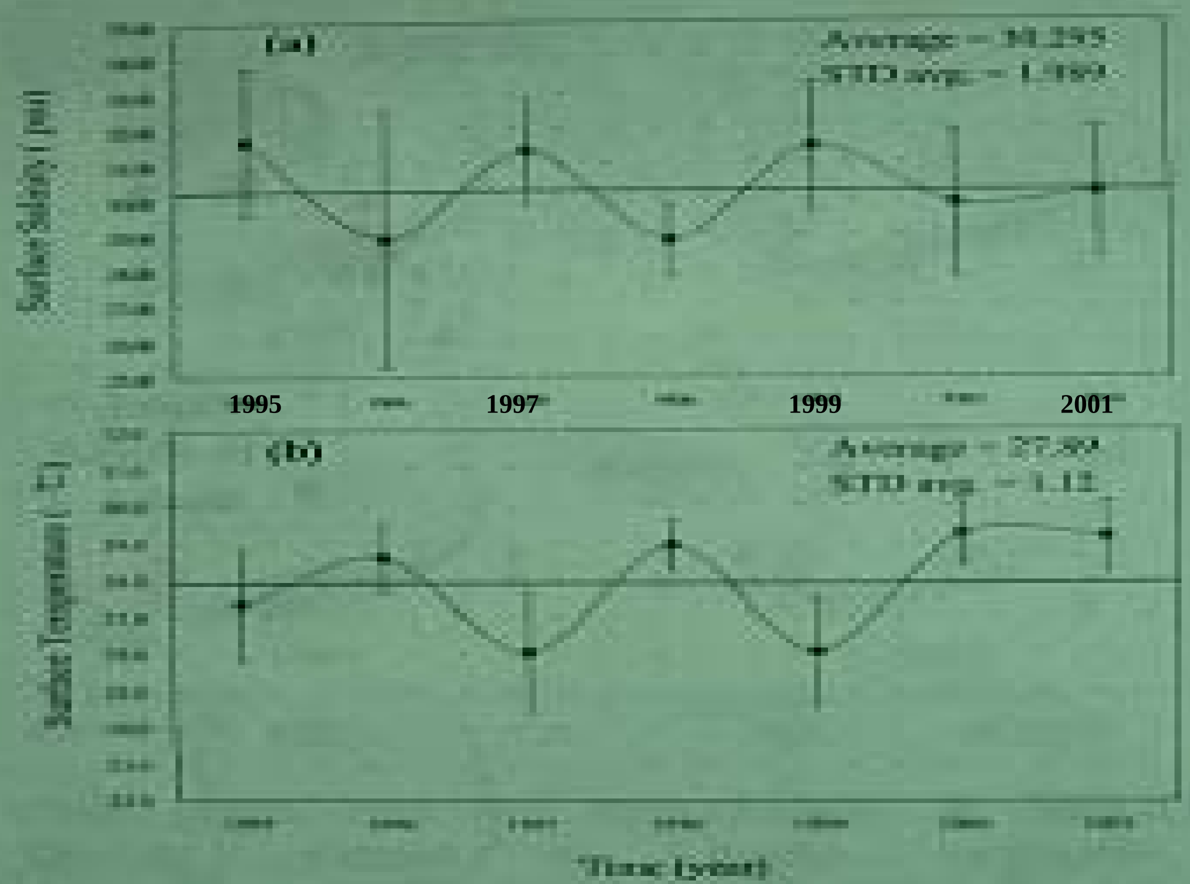


FIGURE 9. Year to year fluctuations of the surface salinity(a) and surface temperature(b) in the northern part of the East China Sea(314-317 observing lines) during 1995-2001

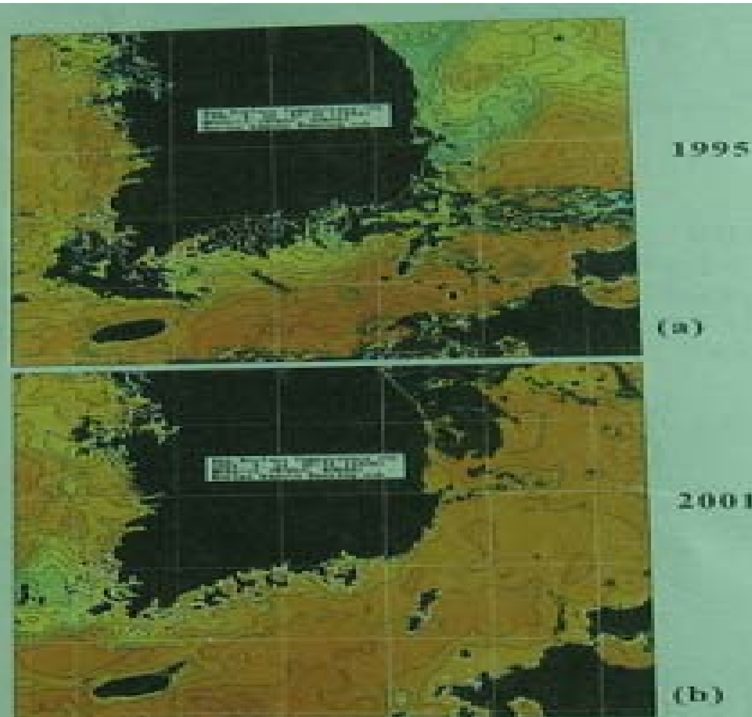


FIGURE 11. SST imageries derived from NOAA satellite when huge red tide occurred in August, 1995 and 2001(These SST charts show the variation of upwelling cold water related to the distribution of red tide in the eastern coastal areas of the Korean peninsula)

(a) The upwelling cold water occurred in August, 1995

(b) However, the cold water did not occur August, 2001

Conclusions

■ The known

- Initiation : eutrophication, Kuroshio
- Movement : tidal currents, winds

■ The unknown

- Life cycle and encystment
- Key nutrient species on the population dynamics
- Species succession and annual fluctuation

APEC. Firework display “ Let's go together”, Busan, Nov.16, 2005