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

<table>
<thead>
<tr>
<th>Species</th>
<th><em>C. polykrikoides</em></th>
<th><em>C. catenatum</em></th>
<th><em>C. sp.</em></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Size</strong></td>
<td>30-40μm</td>
<td></td>
<td>45-50μm</td>
</tr>
<tr>
<td><strong>Shape</strong></td>
<td>Epicone is conical, hypocone is subspherical.</td>
<td>Cell is subspherical.</td>
<td>Cell is roundly and ellipsoidal shape.</td>
</tr>
</tbody>
</table>
| **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 Chesapeake 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: initiation 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           160 points
Present Korean HABs Monitoring System
- Focused on *Cochlodinium* blooms

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

- **Regular Monitoring (Subsequent development)**: over 300 cells/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

<table>
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<tr>
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</thead>
<tbody>
<tr>
<td>Spatial distribution</td>
<td>Partial area Jinhae Bay</td>
<td>South Sea to Kijang in East Sea</td>
<td>Widespread overall coast</td>
</tr>
<tr>
<td>Highest density (cell/ml)</td>
<td>Less than 8,700</td>
<td>Less than 25,000</td>
<td>Up to 48,000</td>
</tr>
<tr>
<td>Persistency</td>
<td>10 days</td>
<td>20 days</td>
<td>Up to 62 days</td>
</tr>
</tbody>
</table>

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

Environmental Features
- mean SST in Aug.: 24 - 25 °C,
- eastern boundary of tidal mixing area
- coastal front between coastal waters and warm current
- plentiful nutrients input
- tidal curr.: flood(northwestward) ebb(southeastward)
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-eastry wind in late Aug.
- South-western wind in June and July
- 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?**

<table>
<thead>
<tr>
<th>Initiation day (Lunar)</th>
<th>Tide</th>
<th>Julian day</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995. 8.29 (8.22)</td>
<td>Neap tide</td>
<td>241-294</td>
</tr>
<tr>
<td>1996. 9. 4 (7.22)</td>
<td>Neap tide</td>
<td>248-276</td>
</tr>
<tr>
<td>1997. 8.25 (7.22)</td>
<td>Neap tide</td>
<td>237-265</td>
</tr>
<tr>
<td>1999. 8.10 (6.29)</td>
<td>Neap tide</td>
<td>221-275</td>
</tr>
<tr>
<td>2000. 8.22 (6.29)</td>
<td>Neap tide</td>
<td>235-264</td>
</tr>
</tbody>
</table>
Seed population

Thermocline is extinct due to the intrusion of Kuroshiwo

Benthic cyst

Eutrophic coastal water
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

Bloom development

Slightly eutrophic warm water
COD: 1~2mg/L, W.T: 24~26℃, Sal: 32~33

Initiation Bloom

Mixing heterogenous water

Landward (wind SE/flood current)

Dispersion/movement

Seaward (windNW/neap current)

Swimming cell ⇒ Seed population ← Benthic cyst

Bloom development

Bloom development
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

Cochlodinium patches
- peak stage
Initiation of HAB - Known(□) and unknown (□)

- **Known and knownable**
  - Key driving force
    - Coastal eutrophication : N. P.
    - Physical oceanographic properties
      - 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.
Drifting Buoys’ Movement

Fig. Drifting buoy trajectories in Korean Waters.
Fig. Residual currents in the model area.
KOREA

5 cells every 3 minutes
To experiment particle’s movement

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.

Similar with the situation in 1995 when the easterly wind was rare.
Similar with the situation in 1998 when the easterly wind was persisted.

Fig. Computed area of *C. polikrikoides* after 5 days with southeasterly wind.
### Where are HABs go?

<table>
<thead>
<tr>
<th>Driving forces</th>
<th>Direction</th>
<th>Magnitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tidal current</td>
<td>Come &amp; back</td>
<td>Flood-NE, Ebb-SE</td>
</tr>
<tr>
<td>Winds</td>
<td>Surface</td>
<td>SE-to west, landward, NE-seaward</td>
</tr>
<tr>
<td>Migration</td>
<td>Vertical</td>
<td>Day-surface, Night-deep</td>
</tr>
</tbody>
</table>
## What is the velocity?

<table>
<thead>
<tr>
<th>Driving forces</th>
<th>Speed/hour</th>
<th>Travel in 4hrs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tidal current</td>
<td>50cm(1kt)-100cm(2kt)</td>
<td>7-14km</td>
</tr>
<tr>
<td>Tsushima current</td>
<td>3-20kt/d</td>
<td>10-15 days to cross south Sea</td>
</tr>
<tr>
<td>Winds</td>
<td>SE-NE</td>
<td>Variable</td>
</tr>
<tr>
<td>Migration depth</td>
<td>Surface to 20 m</td>
<td>Light dependent</td>
</tr>
</tbody>
</table>
Movement of HAB - Known(□) and unknown (□)

- **Known and knowable**
  - 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
An example of the same season and locality of recurrent HABs
From offshore waters, where?

*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

*C. polykrikoides* can be transported by the Kuroshiwo?
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 collected from Jinhae Bay

Okaichi Eutrophic index = (COD (mg/l) x DIN (mg-at/l) x PO4-P (mg-at/l)) / 3.43

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

Yearly distribution of the number of Red tides since 1981

What is the initiative nutrients? Is it nitrogen or phosphate? Inorganic and organic?
Fig. Annual fluctuation of sea surface temperature in the Korean coastal waters for 32 years

- **East Sea**
  
  \( y = 0.0226x + 16.11 \)

- **South Sea**
  
  \( y = 0.0267x + 18.026 \)

- **West Sea**
  
  \( y = 0.0232x + 14.246 \)

- **Increase of temperature (1°C/36yrs)**
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?
Fig. Species succession in HABs in Yeosu Bay since 1980
□ Masan Bay (highly-eutrophic, COD c.a., 3ppm)

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

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

Noctiluca → Skeletonema → Heterosigma → Heterosigma → Ceratium → Ceratium → Cochlodinium → Cochlodinium

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

Noctiluca → Skeletonema → Chaetocerosa → Heterosigma → Heterosigma → Ceratium → Ceratium → Cochlodinium → 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 in 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
Thank you for your attention.

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