Coastal Algal Blooms Caused by the Cyst-Forming Dinoflagellates

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Eight species, 6 Dinophyceae and 2 Raphidophyceae, caused a bloom in the southeastern coastal waters mainly in Chinhae Bay in Korea from March to September since 1982. *Scrippsiella trochoidea* and *Heterocapsa triquetra* bloomed in March then ensued a vernal species *Heterosigma akashiwo*. And *Cochlodinium* sp. and *Alexandrium affine* were occurred as causative organism in fall next to the estival dinoflagellates *Gyrodinium instriatum* and *Pheopolykrikos hartmannii*. Among them, spatio-temporal similarity of outbreak was significant in *Heterosigma akashiwo* since 1983, and a bit apparent for *Cochlodinium* sp..

The density was in the level from 10^3 to 10^5 *cells/ml* and was dependent on the cell size rather than environmental characteristics.

Introduction

Since the observation on the cyst of extant dinoflagellate by Stein (1983), more than 60 species (Matsuoka et al., 1989) of Dinophyceae are known to produce benthic cyst. Of these dinoflagellates, more than 16 species are known to cause bloom, and 4 are toxic. In Raphidophyceae, 2 species such as *Chattonella* sp.(Imai et al., 1986; Imai and Itoh, 1986; 1988) and *Heterosigma akashiwo*(Honjo and Hanaoka, 1973; Yamochi, 1989) are able to encyst and bloom.

According to the cyst hypothesis (Prakash, 1967; Steidinger, 1975; Wall, 1975; Anderson and Wall, 1978), the bloom caused by dinoflagellates might be initiated by germination of the benthic resting cysts, and thus special attention has been paid on the spatio-temporal distribution of the bloom and biological significance of the benthic cysts. In the Korean waters, these kinds of toxic blooms have frequently occurred especially in Chinhae Bay and its vicinities since 1982 (Park et al., 1988; Kim, 1990).

The present study is aimed to examine a spatio-temporal distribution of the blooms caused by those flagellates and to find out triggering mechanism on the initiation of bloom by benthic cyst population for the purpose of providing biological informations to build dynamic model forecasting the outbreaks of blooms.

Materials and Methods

To investigate the outbreaks of dinoflagellate blooms, phytoplanktons were collected weekly or biweekly at the red tide monitoring stations(Fig. 1) established in the southeastern coastal waters of Korean from February to November since 1982.

Live samples were analyzed qualitatively and quantitatively, or fixed by Lugol or neutralized 2% formalin solution for the next observation and storage. Phytoplankton species was identified under a light microscope and a scanning electron microscope (JEOL 35 CF). For the enumeration of phytoplankton cells, one liter samples from sea water were concentrated into 50 *ml* and then 0.1 to 0.05 *ml* was subsampled on a Sedgwick-Rafter count chamber. Mechanical cell count by Coulter Counter TA-II equipped with 140*μm* orifice was also employed for high density of monospecific bloom.

The bloom is defined when the phytoplankton density exceeds 1,000 *cells/ml* following Murakami (1976) and Park et al.(1988) except *Chattonell* sp. which cause a bloom in the density above 20 *cells /ml*.

Results

Temporal Distribution of Blooms

Eight species of dinoflagellates producing a benthic cyst have caused coastal blooms, of which 6 species were Dinophyceae and 2 were Raphidopyceae (Table 1). This kind of bloom was found in Chinhae Bay for the first time in 1982 and occurred every year since that event for the period from March to September as shown in Fig. 2. Among them, two species of dinoflagellates, *Scrippsiella trochoidea* and *Heterocapsa triquetra* formed a bloom in March, and *Chattonella* sp. in April and then *Heterosigma akashiwo* prevailed and caused dense monospecific bloom over extensive periods mainly from May to July or even in September, and the toxic dinoflagellate *Cochlodinium* sp. appeared as dominant species for three month from August to October just following the sporadic dinoflagellate blooms such as *Gyrodinium instriatum*, and *Pheopolykrikos hartmannii* in mid-August.

Table 1. Eight species of flagellates enable to encyst and to cause a bloom in the southeastern coastal waters of Korea

Dinophyceae
- Gymnodiniales
  - *Cochlodinium* sp.
  - *Gyrodinium instriatum* Freudenthal et Lee
  - *Pheopolykrikos hartmannii* (Zimmermann) Matsuoka et Fukuyo
- Peridiniales
  - *Heterocapsa triquetra* (Ehrenberg) Stein
  - *Alexandrium affine* (Inoue et Fukuyo) Balech
  - *Scrippsiella trochoidea* (Stein) Loeblich, III

Raphidophyceae
- Raphidomonadales
  - *Heterosigma akashiwo* (Hada) Hada, 1977
  - *Chattonella* sp.

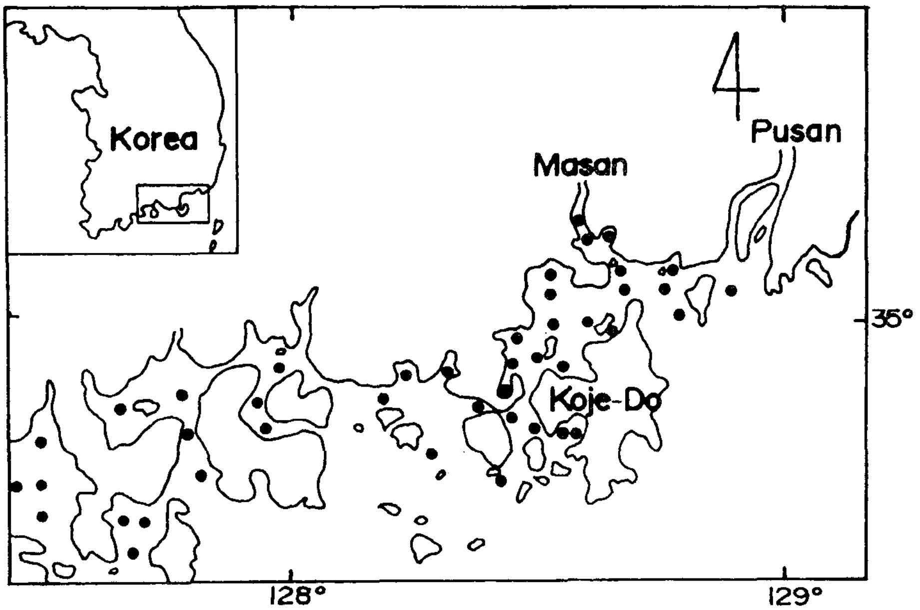

Fig. 1. Location of the sampling stations(●) for red tide monitoring established in the southeastern coastal waters of Korea.

Meanwhile, *Alexandirum affine* bloomed concurrently with *Alexandrium fraterculus* in September 1986 and October 1987 as well.

Spatial Distribution of Blooms

There was once a bloom caused by *S. trochoidea* in Changsaengpo bordering Ulasn Bay in March 1983 and by *Heterocapsa triquetra* in the inner part of Masan Bay in 1989 (Fig. 3). In Chindong Bay, three flagellates, such as *Chattonella* sp., *G. instriatum* and *A. affine* created a bloom in other years. However *Pheopolykrikos hartmannii* gave rise to bloom spreading in wide coastal area from Chindong Bay to the eastern part of Kadok island in 1988. A small flagellate, *H. akashiwo* not only caused a bloom in a wide-spread area such as Masan, Buksin, Chinju and Kamak Bay, but proved to be an endemic species in Masan Bay since 1983.

One of the well-known toxic dinoflagellates, *Cochlodinium* sp., broke out red tide sporadically in southeastern coast of Korea covering Nakdong estuary, Chinhae Bay and off-shore waters around Hak-Lim island, but didn't caused a bloom in the semi-closed Masan Bay where *H. akashiwo* have occurred frequently.

Variation of Bloom Density

Bloom density was generally in the level from 10^3 to 10^5 *cells/ml* as shown in Fig. 2 with the maximum 1.1×10^5 *cells/ml* for minute flagellate, *H. akashiwo,* and 10^4 *cells/ml* for medium sized dinoflagellates such as *S. trochoidea* and *A. affine. Cochlodinium* sp., *G. instriatum* and *Pheopolykrikos hartmannii* formed a bloom in the density fluctuated around 10^3 *cells/ml*. Of these species, *Cochlodinium* sp. showed slightly higher density than the other two species. *Chattonella sp.,* the most biggest cell size, showed the lowest density with the maximum 1,100 *cells/ml.*

In this significant interspecific variation, two evidences are found that cell density is dependent on cell size rather than environmental heterogenity, and bloom density is inversely proportional to cell size, in other words the smaller a cell size, the higher a bloom density.

Discussion

There was a bloom caused by *Scrippsiella trochoidea* in Osaka Bay, Japan (Adachi, 1972) and

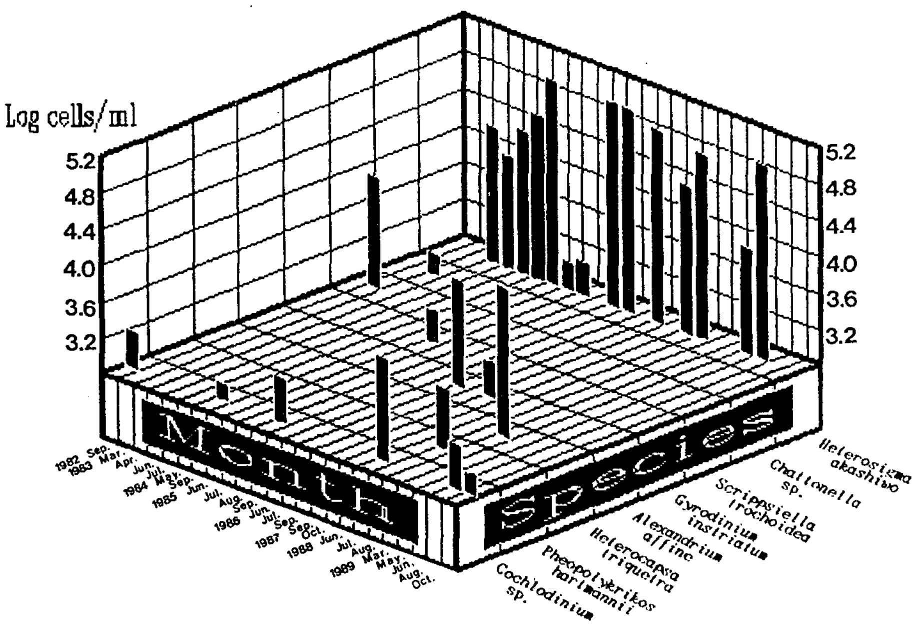

Fig. 2. Temporal distribution of the bloom density plotted against species and year.

Chilean fjords (Clement and Guzman, 1989), and by *Heterocapsa triquetra* in Mikawa (WPTAK, 1979) and Osaka Bay (Yamaji, 1984) in March the same season as in Korea. Endemic species of Masan Bay *Heterosigma akashiwo* caused a persistent bloom in Seto-inland Sea, Japan from spring to fall (Okaichi, 1987). A toxic *Cochlodinium* sp. gave rise to bloom in Harima-nada Seto-inl-nd Sea in August (Yuki and Yoshimatsu, 1989) and *Cochlodinium heterolobatum* had bloomed in north american atlantic coast in mid-summer (Ho and Zubkoff, 1979).

Chattonella sp. bloomed once in Chindong Bay in 1983. This species occurred frequently as causative organism in Harima-nada Seto-inland Sea almost every year (Imai et al., 1986: Shigeru et al., 1989). *Gyrodinium instriatum* and *Pheopolykrikos hartmannii* were also known to form a red tide in Japan (Okaichi, 1987), but no record of occurrence as to *Alexandrium affine* in Japanese coastal waters until now. Therefore, *Alexandrium affine* and *Pheopolykrikos hartmannii* had bloomed only in Korean coastal waters, while *Alexandrium catenella. Polykrikos kofoidi* and *Peridinium conicum* caused a bloom in Japanese coastal waters (Okaichi, 1987).

And another difference is that *Heterosigma akashiwo* showed a conspicuous annual occurrence in Korea, but *Chattonella* sp. was not recorded except 1983.

A ratio of environment volume/cell volume would often be availabe to assess the biomass and carrying capacity of the environment. Iizuka(1980) reported the maximum ratio would be 760 to 830 in phytoplankton community. An estimated ratio in the present study ranged from 4,500 to 50,000. This value is supposed to afford the more space for phytoplankton in a given area. The highest density of *Heterosigma akashiwo, Heterocapsa triquetra* and *Chattonella* sp. was 1.1×10^5, 3.0×10^4 and 1.1×10^3 *cells/ml* respectively. The highest density was much lower than the miximum density surveyed by Iizuka(1985) in Japan.

Therefore, frequent outbreaks of monospecific

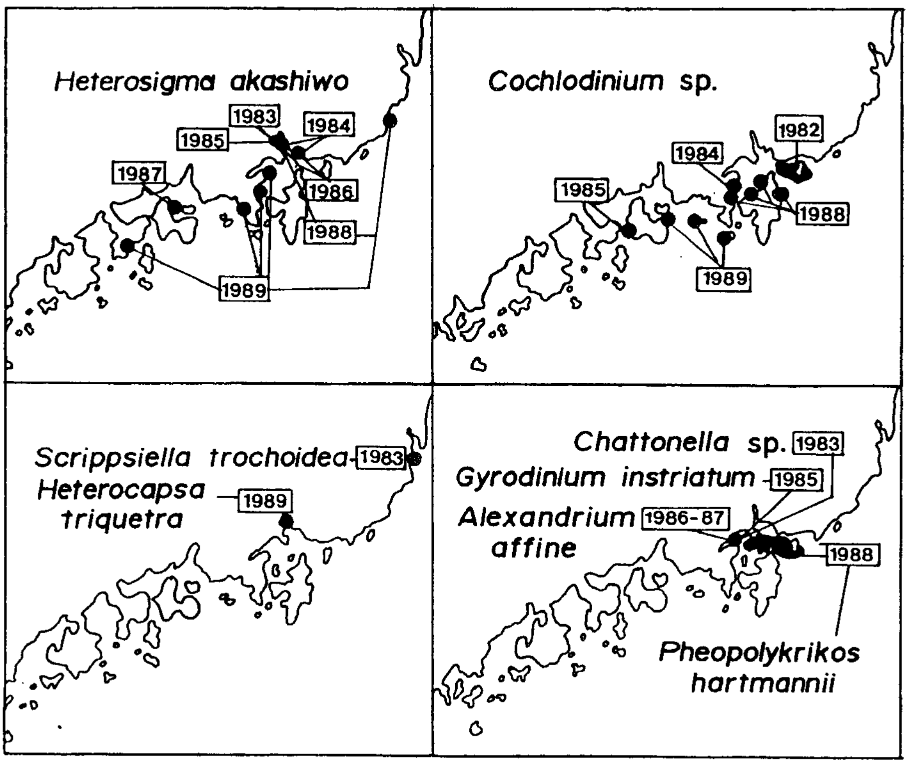

Fig. 3. Spatial distribution of the blooms caused by the cyst-forming flagellates.

dinoflagellate blooms associated with benthic cyst population will be foreseen in Chinhae Bay due to potentialities such as bottom mud deposition in the blooming area (Park et al., 1976; Kim et al., 1987) and ubiquitous distribution by those endemic and year-occurring species of *Heterosigma akashiwo* and *Cochlodinium* sp. might outbreak, if provided with favorable environmental conditions.

Such disadvantageous events can be understand only when cyst distribution and eco-physiological aspects on encystment and excystment are studied in terms of a dynamic model predicting red tide occurrence.

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休眠胞子(Cyst)를 형성하는 渦鞭毛藻類에 의한 赤潮發生

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休眠胞子를 형성하는 渦鞭毛藻類중 우리나라 南海東部와 東海南部의 연안수역 특히 鎭海灣에서 1982년 이래 3월부터 9월에 걸쳐 적조를 일으킨 종은 8종이었으며 이들은 6종의 渦鞭毛藻類와 2종의 綠色鞭毛藻類로 구성되었다.

季節別로는 이른 봄철에 *Scrippsiella trochoidea*와 *Heterocapsa triquetra*종이, 늦봄에 *Heterosigma akashiwo*가 그리고 여름철에는 *Gyrodinium instriatum*과 *Pheopolykrikos hartmannii*가 赤潮를 일으켰다. 한편 *Cochlodinium* sp.와 *Alexandrium affine*는 늦여름부터 가을철에 赤潮를 일으켰다. 이중 *Heterosigma akashiwo*는 매년 같은 곳에서 같은 시기에 발생하는 경향을 뚜렷히 나타냈으며 *Cochlodinium* sp.에서도 이와 같은 특성을 발견할 수 있었다.

한편 적조발생시의 밀도는 10^3~10^5 *cells/ml* 수준이었으며, 밀도변화는 환경특성 보다는 오히려 세포의 크기에 따라 변화하고 있었다.