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Variation of Harmful Algal Blooms in Masan-Chinhae Bay

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ABSTRACT: The temporal variation of algal blooms and species succession were reviewed for Masan-Chinhae Bay since 1981. Thirty-two planktonic species of which 14 species were dinoflagellates and one was a protozoan were identified as the causative organisms responsible for the blooms in Masan-Chinhae Bay. Based on frequency and abundance, more than 90 % of algal blooms occurred from April to September. Spring blooms dominated by either the diatom, *Skeletonema costatum* or the dinoflagellate, *Heterocapsa triquetra*, and *Alexandrium* spp. and the euglenoid, *Eutreptiella gymnastica* were replaced by *Heterosigma akashiwo, Prorocentrum* spp., *Cochlodinium polykrikoides* and *Akashiwo sanguinea*. Following the blooms by these aestival flagellates, diatoms such as *Skeletonema costatum* and *Thalassiosira* spp. became predominant in autumn. Water temperature and salinity played a significant role in the species succession. A continuous supply of organic and inorganic nutrients from the stream waters caused by heavy rainfall gave rise to persistent algal blooms during the summer season.

KEYWORDS: harmful algal blooms, species succession, temporal variation, Masan-Chinhae Bay, Korea.

INTRODUCTION

Since the 1970's, eutrophication has been accelerating in the southern coastal area of Korea due to the continuous supply of nutrients from industrial and domestic waste water discharges. Masan-Chinhae Bay, one of the semi-enclosed bays in the region experiences high level of inorganic and organic nutrients leading to high primary productivity and frequent algal blooms. Thus, Masan-Chinhae Bay is believed to be one of the most heavily polluted areas in Korea.

Since the 1980's, Masan-Chinhae Bay has been extensively studied for variation in water quality and nutrients and species succession and HAB (Harmful Algal Bloom) occurrence[3,5-8,12-16].

It has been reported that Masan-Chinhae Bay shows temporal variation in the hydrographical features: a warm, less saline stratified period, mainly from April to September, and a cold, more saline destratified period showing sufficient mixing from October to March[2,4,11]. In addition, algal blooms by either dinoflagellates or diatoms have occurred frequently, particularly, during high water temperature seasons in Masan-Chinhae Bay. The algal blooms have impacted on the ecological balance of the coastal ecosystem and aquaculture farms nearby.

The objective of this study is to review the temporal variation of algal blooms and species succession including the parameters that might affect to the changes in Masan-Chinhae Bay since 1980's.

MATERIALS AND METHODS

Masan-Chinhae Bay is subdivided into two zones: the less polluted western part of the bay, and the severely polluted inner part of bay comprising Masan Bay and Hangam Bay[4,11]. Monthly field surveys were carried out for 11 stations in Masan-Chinhae Bay from 1996 to 2004 where water samples were collected both for biological analysis, including the species composition of phytoplankton, abundance determination and chlorophyll a analysis, and for nutrient analyses (inorganic nitrogen and phosphorus). Hydrographical data such as water temperature and salinity were measured *in situ* by CTD (Fig. 1).

All the available data such as number of events and spatial distribution of algal blooms were also included in this report irrespective of the locality once it was targeted for Masan, Hangam and Chinhae area.

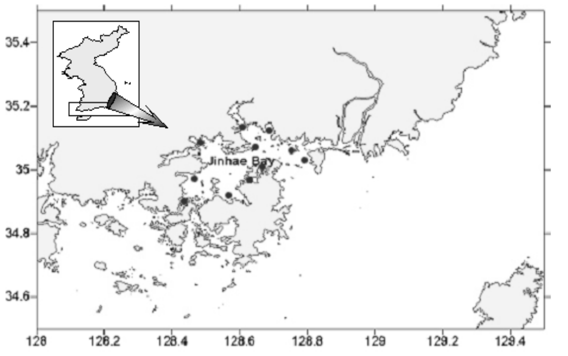

Fig 1. Location of sampling sites in Masan-Chinhae Bay of Korea.

Results and discussion

Since 1981, 7 to 22 algal bloom events has occurred annually in Masan-Chinhae Bay, which accounts for 10 to 25 % of the total algal bloom events that occurred in the same period for all Korean coastal waters (Fig. 2, 3). Based upon frequency and abundance, more than 90 % of monospecific or mixed algal blooms by flagellates or diatoms persistently occurred from April to October in Masan-Chinhae Bay (Fig. 4). Diatoms were key algal species in algal bloom events until mid 1980's, while the number of blooms and occupancy by dinoflagellates outnumbered that of diatoms thereafter.

Strong stratification was found from June to September mainly in the inner part of Masan-Chinhae Bay during which salinity decreased markedly, indicating that the phenomenon was linked to the increase of stream water discharges after heavy rainfall (Fig. 5, 6). There was, also, a close relationship between precipitation and chlorophyll a concentration and/or number of algal bloom events as indicated by the drastic increase of both chlorophyll a concentration and number of algal bloom events with the increase of precipitation (Fig. 7, 8).

Causative organisms responsible for the blooms in Masan-Chinhae Bay were identified as 32 planktonic species of which 14 species were flagellates and one was a protozoan (Table 1). *Prorocentrum* spp. and *Heterosigma akashiwo* have appeared as an aestival endemic species since 1983. Maximal cell density of

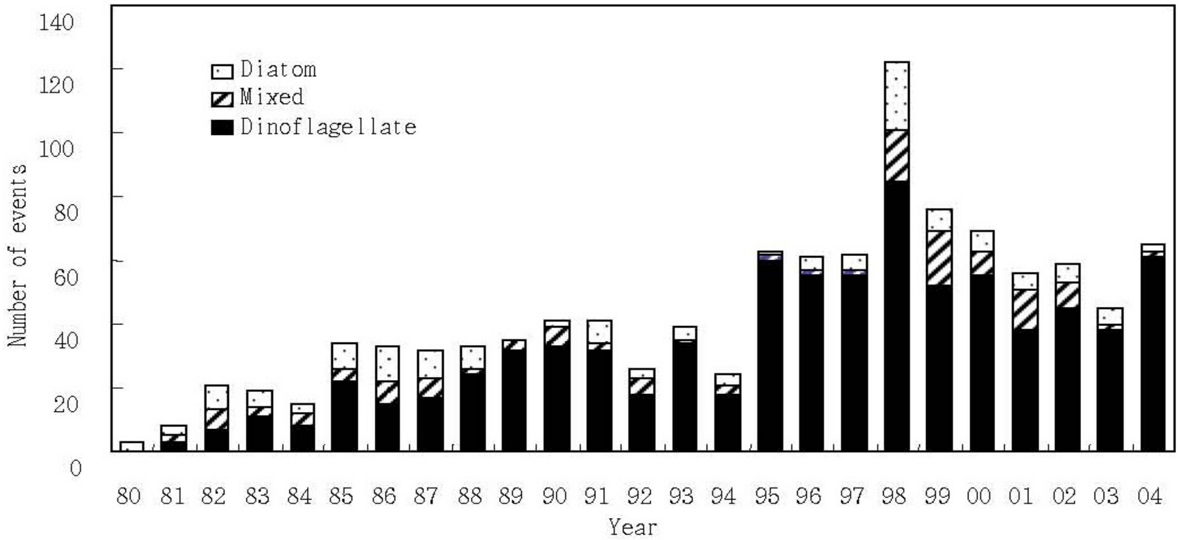

Fig 2. Number of algal bloom events in Korean coastal waters since 1980.

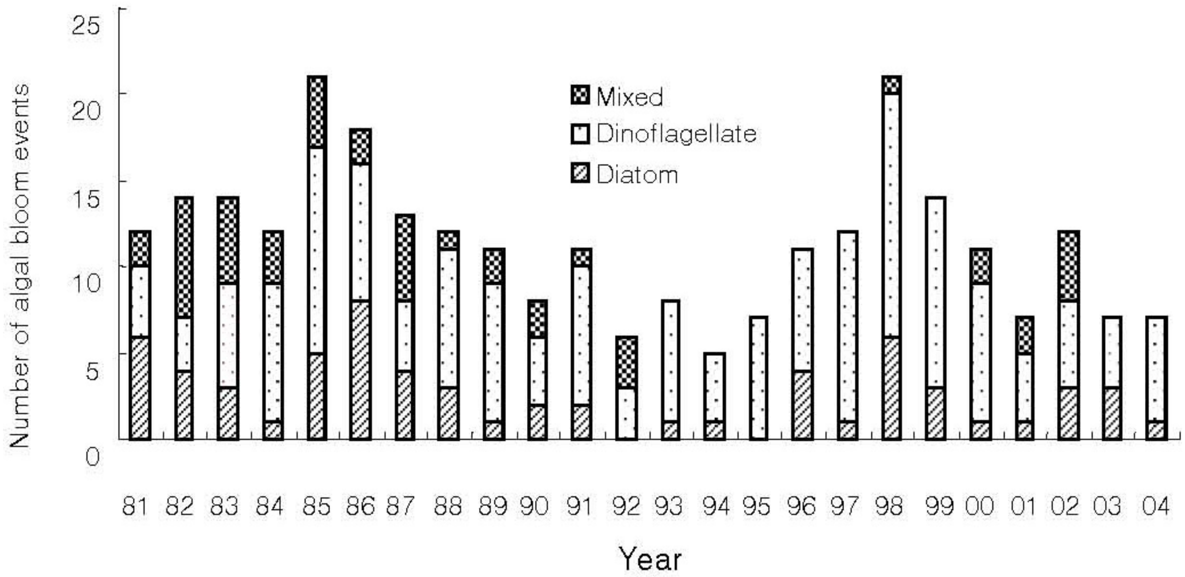

Fig 3. Number of algal bloom events in Masan-chinhae Bay since 1981.

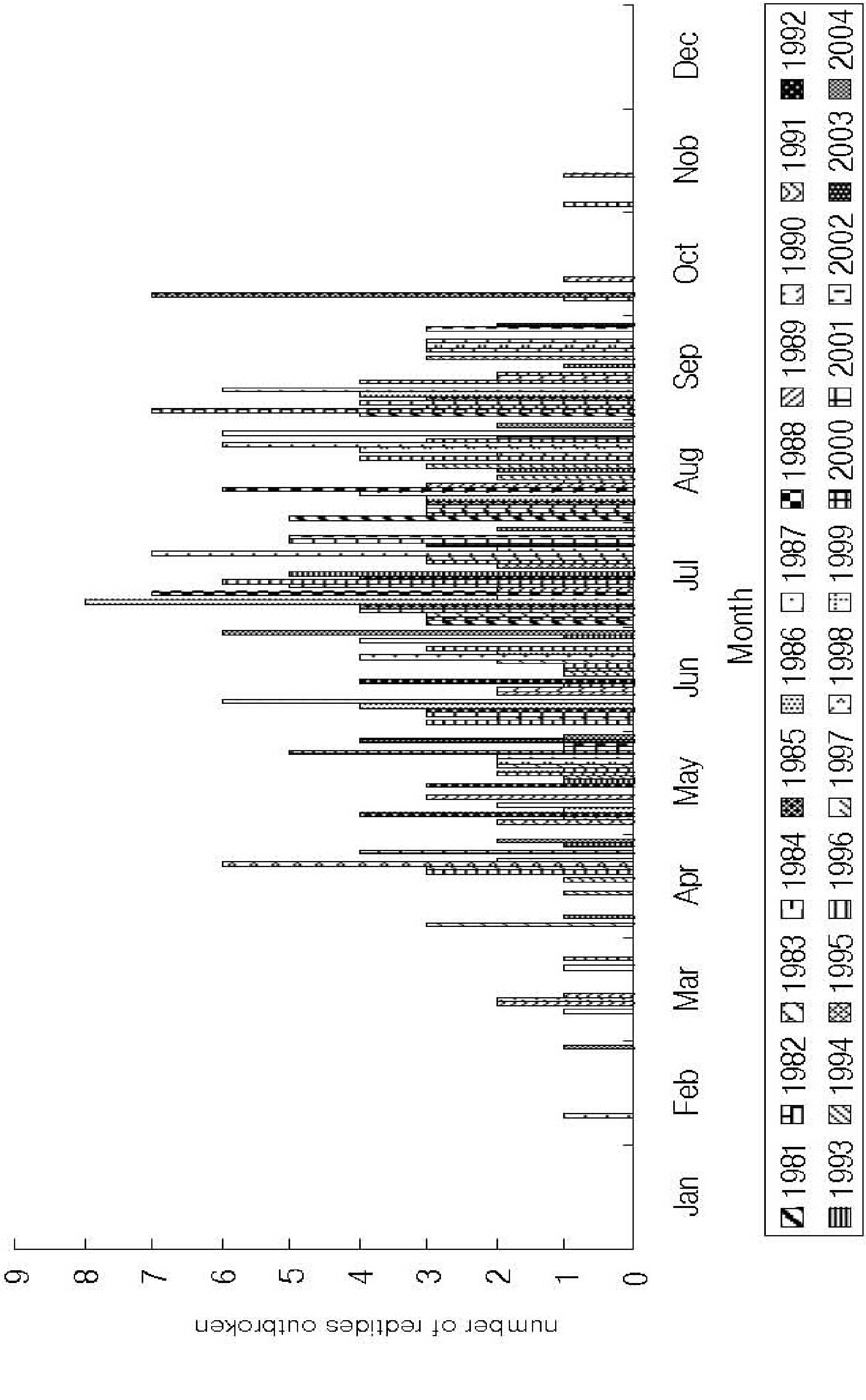

Fig 4. Monthly variation of algal bloom events in Masan-Chinhae Bay since 1981.

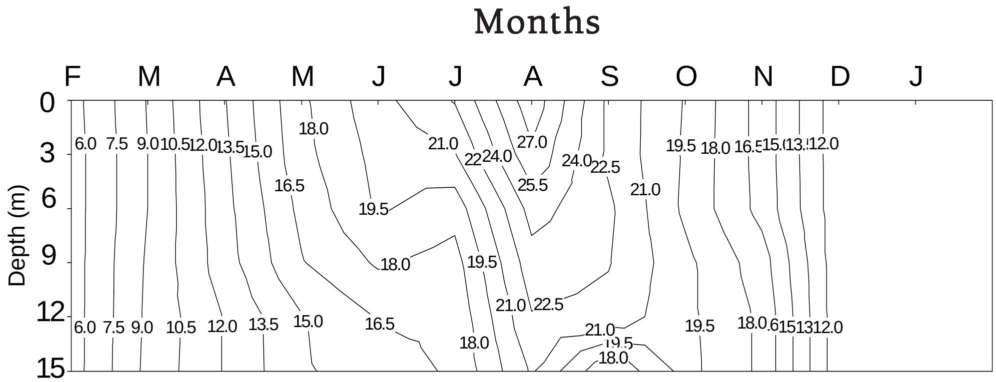

Fig 5. Vertical profile of water temperature in Masan-Chinhae Bay in 2001.

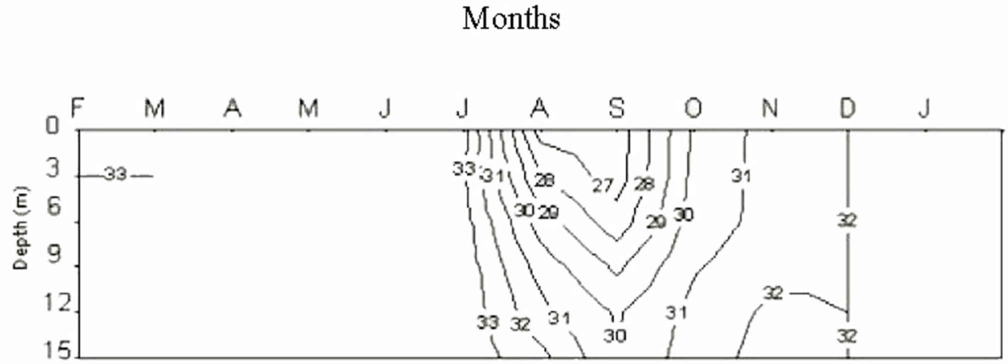

Fig 6. Vertical profile of salinity in Masan-Chinhae Bay in 2001.

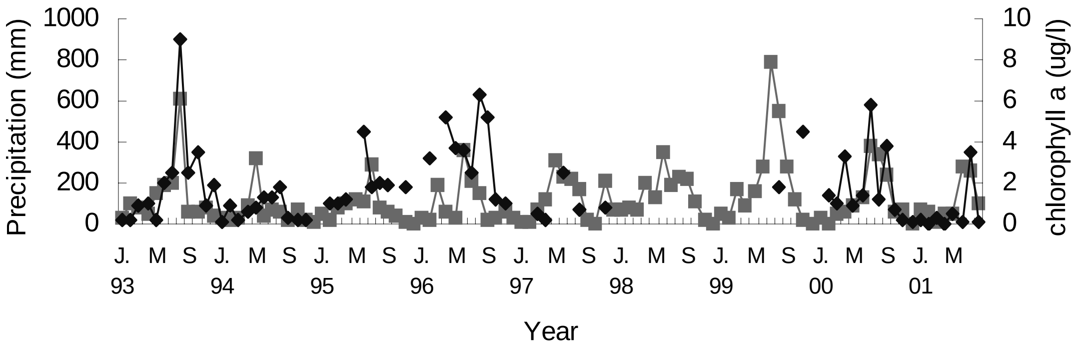

Fig 7. Variation of Chlorophyll a concentration along with precipitation in Masan-Chinhae Bay.

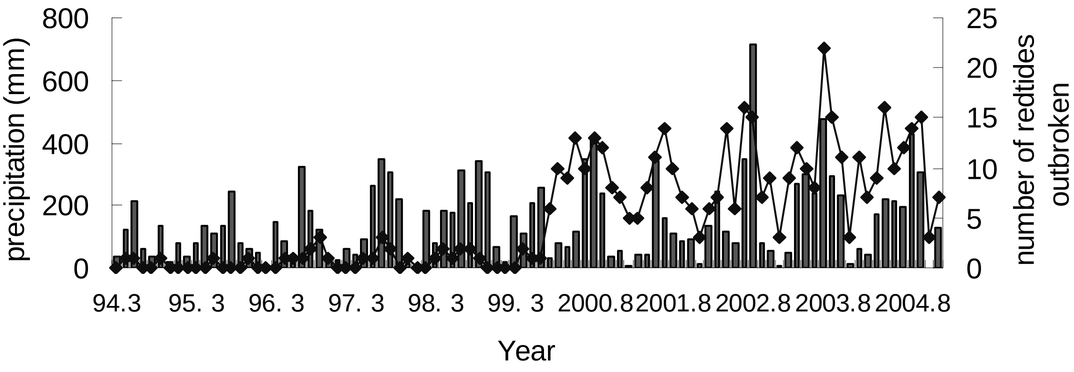

Fig 8. Variation of algal bloom events along with precipitation in Masan-Chinhae Bay.

Table 1. Algal species responsible for algal blooms in Masan-Chinhae Bay since 1972.

Class	Species
Cryptophyceae	*Chroomonas salina*
Dinophyceae	*Akashiwo sanguinea*
	Alexandrium tamarense
	Ceratium furca
	Ceratium fusus
	Cochlodinium polykrikoides
	Gonyaulax polygramma
	Karenia mikimotoi
	Gyrodinium fissum
	Heterocapsa triquetra
	Noctiluca scintillans
	Prorocentrum micans
	Prorocentrum minimum
	Prorocentrum triestinum
	Scrippsiella trochoidea
Raphidophyceae	*Heterosigma akashiwo*
Euglenophyceae	*Eutreptiella gymnastica*
Ciliophora (Protozoa)	*Mesodinium rubrum*
Bacillariophyceae	*Chaetoceros pseudocurvisetus*
	Cylindrotheca closterium
	Eucampia zodiacus
	Leptocylindrus danicus
	Pseudo-nitzschia pungens
	Pseudo-nitzschia seriata
	Pseudo-nitzschia sp.
	Rhizosolenia fragilissima
	Skeletonema costatum
	Stephanopyxis palmeriana
	Thalassionema nitzschioides
	Thalassiosira allenii
	Thalassiosira decipiens
	Thalassiosira rotula

these aestival endemic flagellates increased from 5,000 cells/ml in 1980's to more than 10,000 cells/ml thereafter.

Spring blooms dominated by the diatom, *Skeletonema costatum* and *Chaetoceros* spp. and the dinoflagellates, *Heterocapsa triquetra,* and *Alexandrium* spp., and the euglenoid, *Eutreptiella gymnastica* were replaced by *Heterosigma akashiwo, Prorocentrum* spp., *Cochlodinium polykrikoides* and *Akashiwo sanguinea* (Table 2). Following the blooms of these aestival flagellates, diatoms such as *Skeletonema costatum* and *Thalassiosira* spp. became predominant in autumn, and transition into the winter community was completed.

Water temperature and salinity played a significant role in the species succession. A continuous supply of organic and inorganic nutrients from the stream waters by heavy rainfall gave rise to persistent flagellate blooms during the summer season.

Heterosigma akashiwo, Prorocentrum. minimum, Eutreptiella gymnastica and *Heterocapsa triquetra* showed euryhaline characteristics with remarkable

Table 2. Seasonal species succession of dinoflagllates in Masan-Chinhae Bay

MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV
S. costatum								
H. triquetra								
Eutreptiella gymnastica								
	Alexandrium tamarense							
	Alexandrium catenella							
		Heterosigma akashiwo						
		Karenia mikimotoi						
			Proro. triestinum					
			Proro. dentatum					
			Proro. micans					
			Proro. minimum					
	Akashiwo sanguinea					*Akashiwo sanguinea*		
				Cochiodinium polykrikoides				

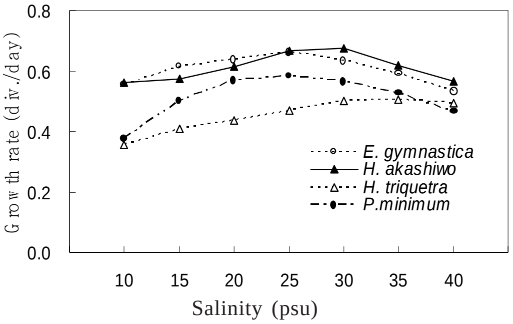

Fig 9. Growth rates of frequent redtide forming dinoflagellates along with salinities.

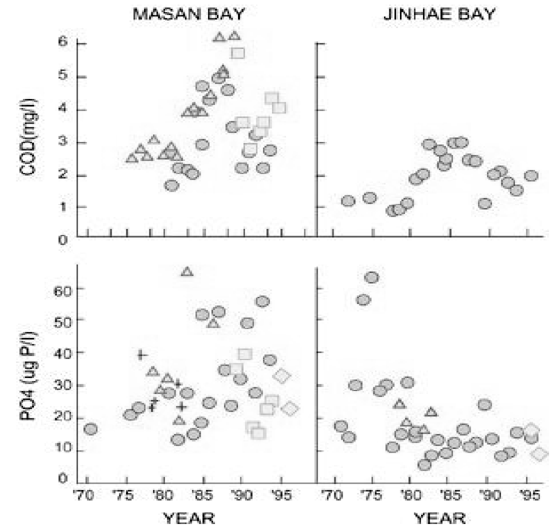

Fig 10. Trends of annual mean values of phosphate and COD concentration in Masan and Chinhae Bay from 1971 to 1996 (Cho et al., 1998).

growth in a broad ranges of salinity, from 15 to 40 psu in culture. Therefore, frequent algal blooms in Masan-Chinhae Bay by those species at extremely low salinities below 25 psu after rainfall were attributed to their euryhaline and slightly halophobic physiological characteristics (Fig. 9).

Annual mean COD and inorganic phosphate concentration in Masan-Chinhae Bay consistently increased from late 1970's to early 1990's and dropped thereafter (Fig. 10). Inorganic nitrogen concentration, also, increased continuously until mid 1980's, peaking in 1985 and then decreasing slightly from late 1980's.

Many dinoflagellates such as *Alexandrium tamarense* and *Gymnodinium catenatum* use both DIP and DOP, although the mechanism and degree of utilization appear to be different for each phosphate compound[1,9,10].

Although a low half-saturation constant is advantageous for nutrient uptake at low nutrient concentrations, it may also decrease the need for DOP utilization. In the rainy season from June to September, nitrogen levels in Masan-Chinhae Bay become surplus via streams[5]. Also, strong stratification during the high water temperature season interrupted the supply of phosphorus from the bottom waters. If it is assumed that phytoplankton absorb nutrients from the surrounding water, DIP will be depleted faster than DIN in the embayment during the high water temperature season when DIP concentration is much lower than the Redfield ratio (N:P=16). A DIP depleted condition would promote the growth of those species that can utilize DOP compounds as a phosphorus source which is known to be essential nutrient for their growth. Dissolved organic phosphorus species in natural seawater are not well characterized yet, and the extent to which *A. tamarense* and *G. catenatum* utilize DOP is also poorly understood. Nevertheless, it can not be excluded that relatively low concentration of dissolved inorganic phosphorus from spring to summer in Masan-Chinhae Bay may enhance the chance for the bloom of harmful/toxic dinoflagellates.

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