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Short Term Variability of the Phytoplankton Populations in Masan Bay: I. Dynamics

SE JIN PAE* AND SIN JAE YOO
Korea Ocean Research and Development Institute, Ansan P.O. Box 29, Seoul 425-600 Korea

마산만 식물플랑크톤의 단기적 변화양상 : 1. 동태

배세진 · 유신재
한국해양연구소

Masan Bay is infamous for its severe eutrophication, exemplified by frequent red tide incidences and anoxic conditions. We carried out daily observations for 16 days at one site immediately after the summer rainy season in 1988 on the basis that shorter observation intervals be necessary to observe a process with high turnover rate.

In spite of the relatively short survey period, we could observe dramatic changes in abundance and composition of the phytoplankton populations. Cell densities and chlorophyll concentrations changed in the magnitude of 70 and 10 times, respectively. *Skeletonema costatum*, a diatom species, dominated the first peak of phytoplankton biomass and was followed by *Prorocentrum minimum*, a dinoflagellate species, which occurred dominantly in the second peak after about a week. Form the viewpoint of time scale, we suggest that at least a weekly sampling might be appropriate in complex coastal environments as Masan Bay.

While stratification enabled high production in the surface layer, it hindered the transport of silicate from bottom to the surface, which in turn limited the prolonged growth of diatoms. Ensued second peaks of silicate and diatom abundance in the surface layer suggest periodic flux of silicate from bottom across the discontinuity driven by tidal currents.

마산만은 부영양화의 영향으로 적조와 무산소층이 빈발하는 해역으로 알려져 있다. 이 해역의 빠른 turnover rate를 고려할 때 보다 짧은 관측 간격을 필요로 하므로, 1988년 여름 장마 직후 16일간 일일관측을 실시하였다.

비교적 짧은 조사기간에도 불구하고 식물플랑크톤의 양 및 조성에 큰 변화가 있었다. 세포수와 클로로필 농도는 각각 70, 10배의 변화폭을 보였다. 식물플랑크톤 현존량의 첫번째 최고점에서는 규조류인 *Skeletonema costatum*이 압도적 우점종으로 나타났고, 이는 약 1주일 후의 두번째 최고점에서 ***Prorocentrum minimum***으로 우점종의 천이가 일어났다. 이러한 변화의 시간 규모로 볼 때 마산만과 같은 복잡한 연안환경에서는 적어도 1주 간격의 조사가 고려되어야 할 것이다.

성층은 표층에서 높은 성장을 가능하게 했던 반면, 저층에서 표층으로의 규산염 공급을 방해하여 규조류의 지속적인 성장을 제한한 것으로 보인다. 표층에서 잇따라 일어났던 규산염 및 규조류 양의 두번째 최고점은 조류(tidal current)에 의한 저층으로부터 불연속면을 거쳐 일어나는 규산염의 주기적 flux를 시사한다.

INTRODUCTION

Recent emergence of so-called "dynamic biological oceanography" (Legendre and Demers, 1984) emphasizes the role of hydrodynamics as the driving forces of aquatic ecosystems. In estuaries, for example, vertical processes are responsible for changes in taxonomic structure of phytoplankton populations, photosynthetic capability, chlorophyll concentration, and so on, depending on the time scale. Neap-spring tidal cycle, by controlling the strength of the stratification, could produce significant changes in phytoplankton dynamics in a short time period. The changes in the dynamics of phytoplankton populations are expected to be very rapid in eutrophic environments due to high turnover rate of phytoplankton populations.

Located near a metropolitan area and industrial plants, Masan Bay undergoes severe eutrophication, exemplified by frequent red tide incidences and anoxic conditions in the past decades. Although extensive studies have been made in this area (e.g. Park, 1975a, 1975b; Yoo and Lee, 1976; Park, 1979; Yoo and Lee, 1980; Yang and Hong, 1982; Kim *et al.*, 1986), most of them were done with observation interval of more than a couple of weeks. This seems inadequate since the turnover rate of the phytoplankton populations in this area is likely to be less than a day during the summer. Time scale of observations should be determined by the nature of process which is to be resolved (Harris, 1980).

In this study, observations have been conducted on a daily basis immediately after the summer rainy season. This time of the year in Korea represents a very special environments in terms of phytoplankton ecology. A month-long rainy season is usually followed by weeks of fine hot summer weather. In Masan Bay, this means the onset of stratification, ample amount of light, and high temperature after a huge nutrient input. Here, we focus on the role of stratification and silicate in the eutrophication process of the area.

MATERIALS AND METHODS

The site of this study was a station near Cho Do in Masan Bay (Fig. 1), and a daily observation was carried out for 16 days immediately after the summer rainy season in 1988. The measured oceanographic parameters were temperature, salinity and dissolved oxygen, and water samples of phytoplankton and nutrients were collected. Temperature and salinity were measured using a T-S Bridge (Type M.D. 5, National Institute of Oceanography) and dissolved oxygen was measured using a Yellow Springs dissolved oxygen meter (YSI Model 58) at an interval of 0.5-5 m depending on the gradients with depth. Water samples were taken with van Dorn samplers of 5 *l* capacity. For phytoplankton, samples of surface water were collected into a pair of 500 m*l* polyethylene bottles. One was fixed with acid Lugol's solution and used for cell counts and identification. The other was filtered with GF/F filter paper and the filtered paper was frozen with dry ice, and then the chlorophyll concentration was measured in the laboratory by fluorometric method (Yentsch and Menzel, 1963). For nutrients analysis, the sea water which was filtered with membrane filters (pore size = 0.45 μm) was transferred to 20 m*l* polyethylene bottles and was frozen with dry ice. Later in the laboratory dissolved inorganic nitrate, nitrite, phosphate, and silicate were measured with auto-analyzer (Technicon AA II) following the method of Strickland and Parsons (1972).

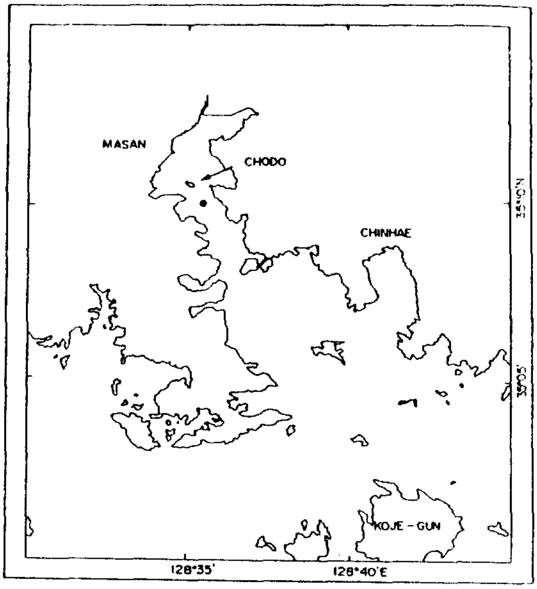

Fig. 1. Location of sampling station.

RESULTS

Hydrography

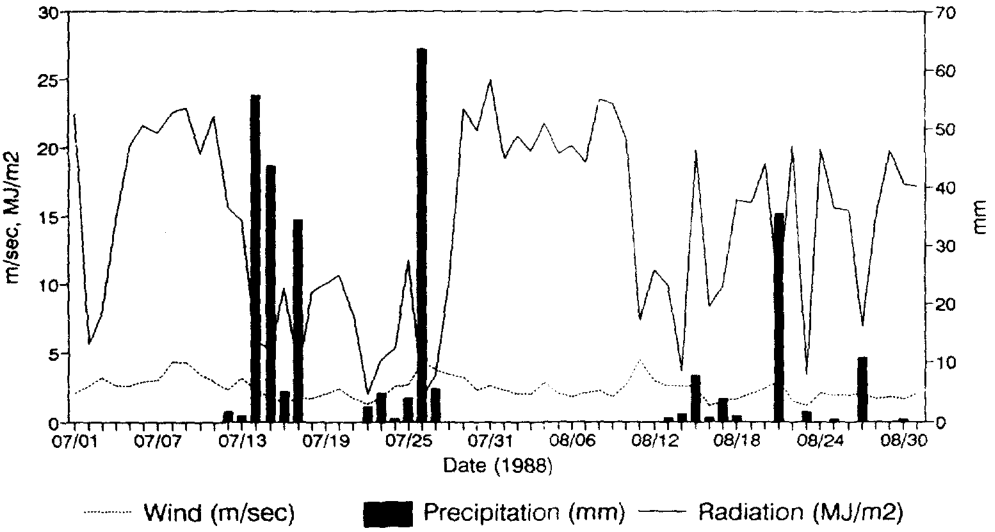

Fig. 2. Weather condition of July and August 1988.

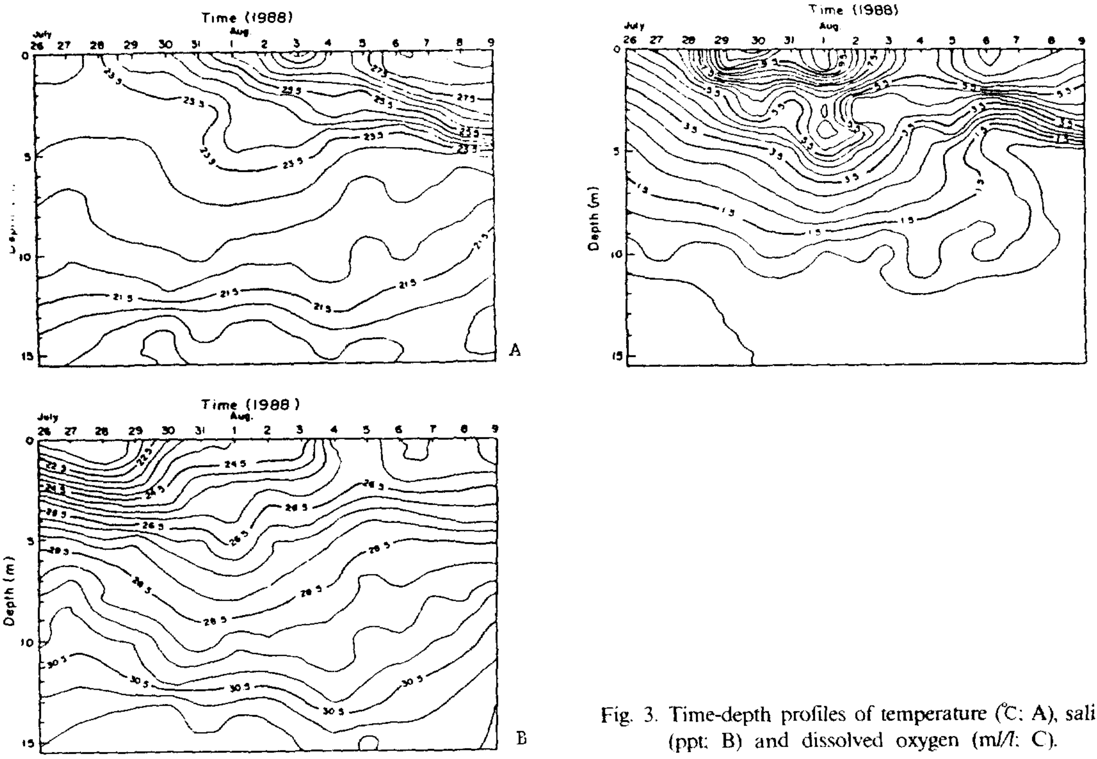

Fig. 3. Time-depth profiles of temperature (℃: A), salinity (ppt: B) and dissolved oxygen (ml/*l*: C).

The weather condition had been very clear and there had been no strong winds until the end of the field work (Fig. 2). The time-depth profiles of temperature, salinity, and dissolved oxygen during the survey period were shown in Fig. 3. The surface temperature at the beginning of the observation ranged about 23 to 24℃ and increased gradually to reach over 28℃ at the end. From the

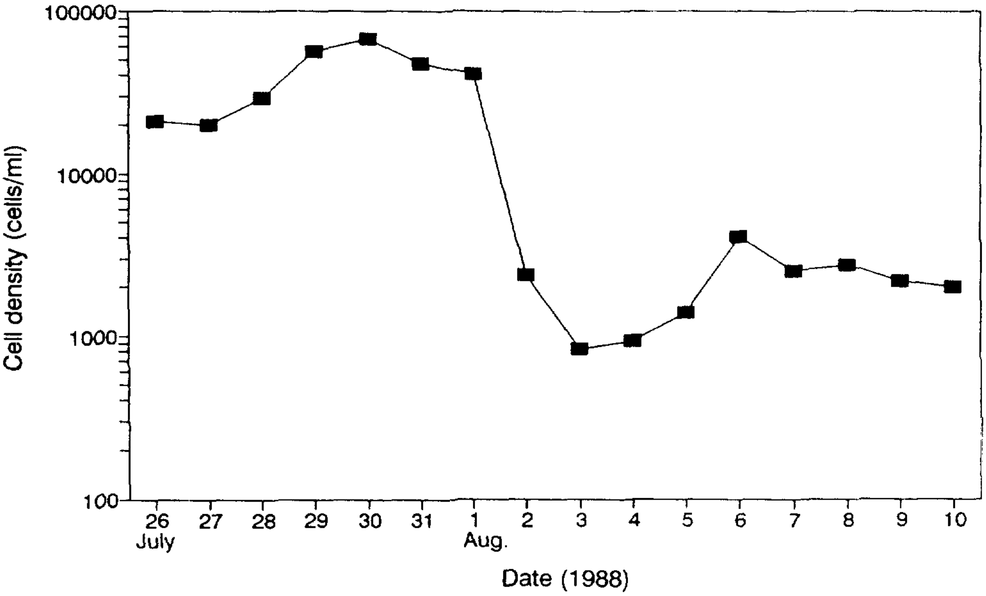

Fig. 4. Time series of phytoplankton abundance in the surface water.

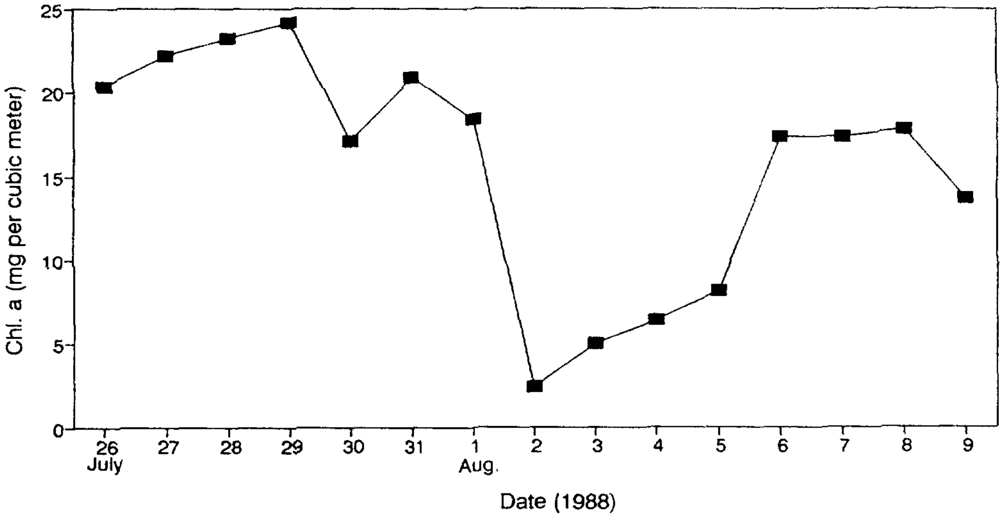

Fig. 5. Time series of chlorophyll *a* in the surface water.

figure the process of a thermocline formation is evident. A strong thermocline was formed at 2 to 5 m depth and relatively moderate gradient was shown below it. In the case of surface salinity, the relatively low values, about less than 22 ppt were observed at the beginning of the survey. This is probably the result of freshwater runoff. This values increased gradually towards the end. Relatively high values of salinity over 30 ppt were present only in the bottom water. Dissolved oxygen in the surface water increased from the beginning and reached maximum values, more than 10 m*l*/*l*, at about July 29 to August 1, and then decreased gradually. At the bottom, on the other hand, an oxygen deficient layer, less than 1 m*l*/*l*, was rising up to 5 m depth towards the end. Dissolved oxy-

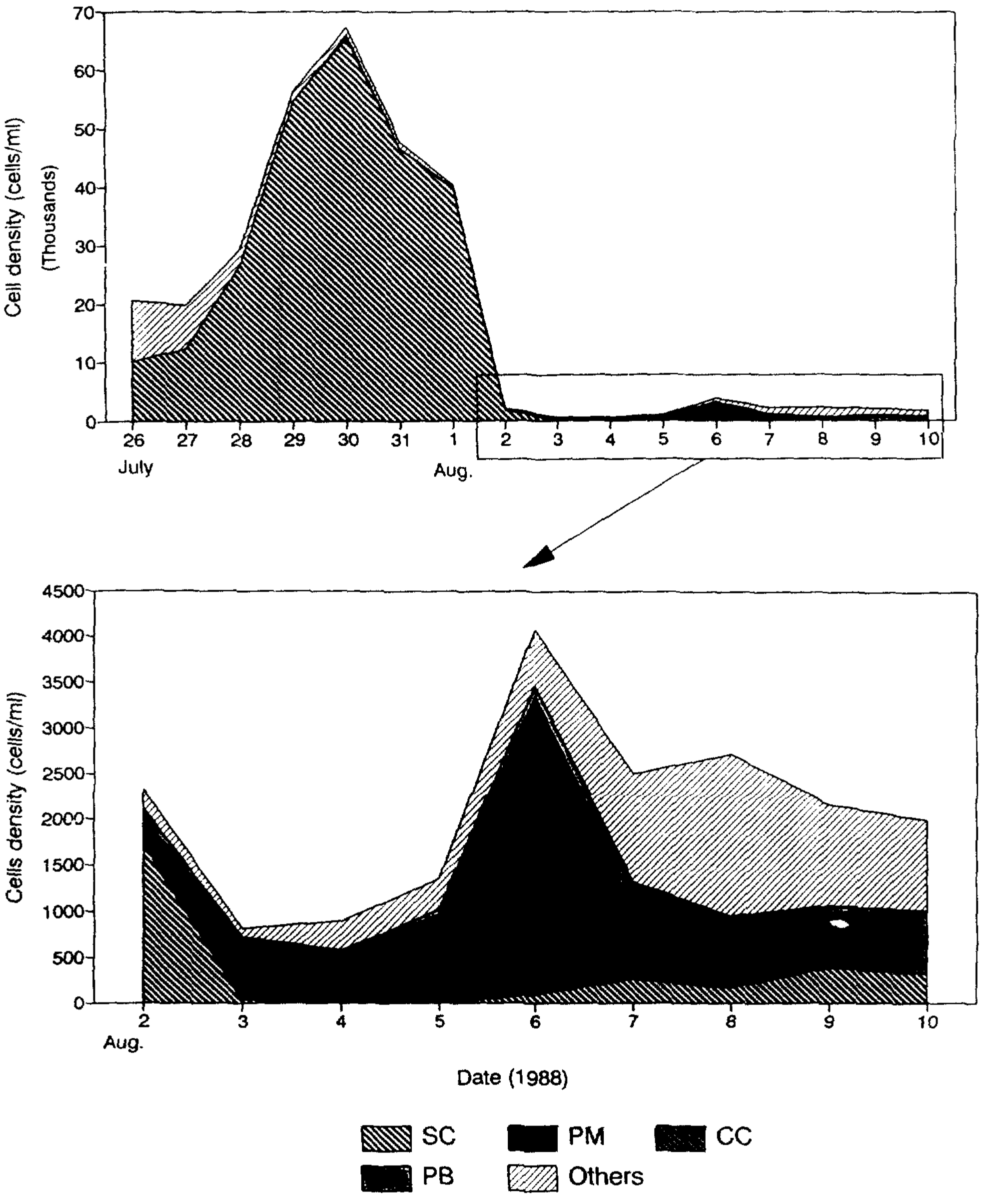

Fig. 6. Changes in phytoplankton species composition (SC: *Skeletonema costatum*, PM: *Prorocentrum minimum*, CC: *Chaetoceros compressus*, PB: *Peridinium bipes*) in the surface water.

gen discontinuity layer appeared to coincide with the thermocline.

Phytoplankton abundance and composition

On the whole, in spite of the relatively short survey period of about two weeks, abundance and composition of the phytoplakton populations changed dramatically. During the survery there were two major peaks of cell densities and chlorophyll concentrations, and the magnitudes of thechanges were 70 and 10 times, respectively. *Skeletonema costatum* dominated the first peak of phytoplankton abundance and was succeeded by *Prorocentrum minimum* which occurred dominantly after about

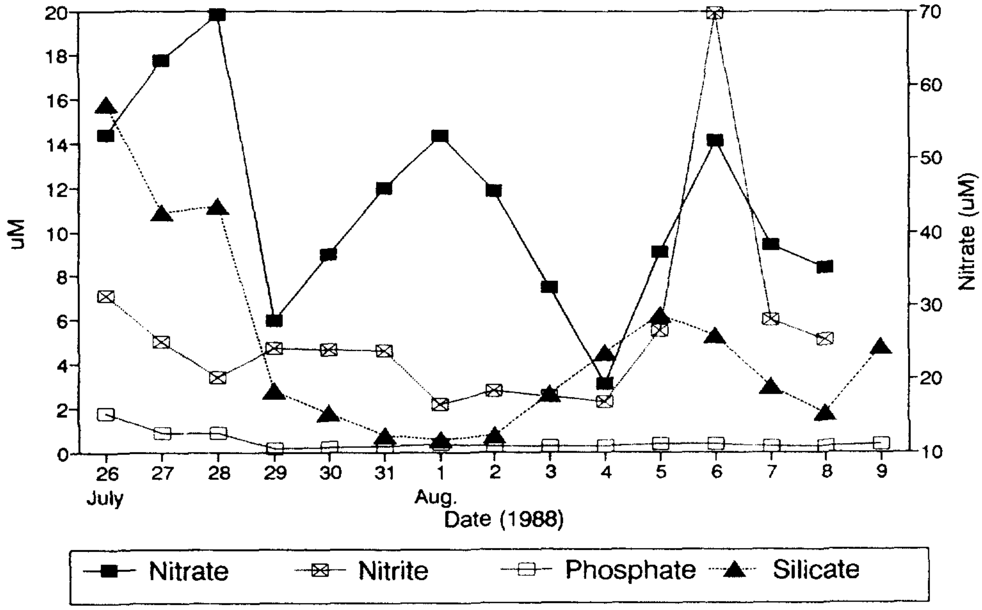

Fig. 7. Time series of nitrate, nitrite, phosphate and silicate in the surface water.

a week.

Most of the phytoplankton cell densities during the survey were relatively high, more than 10^6 cells/*l*. Especially, they showed very high values over 10^7 cells/*l* at the beginning of the survey and the first peak occurred on July 30. After that time, cell density decreased more or less, but on August 2 it decreased abruptly and attained its minimum value of 0.8×10^6 cells/*l* on August 3. Cell density, thereafter, increased again to attain its second peak although it showed lower value compared with the first one, and then decreased to the end of the survey (Fig. 4). The variation of chlorophyll a concentration during the survey was shown in Fig. 5. By and large the pattern of chlorophyll changes agreed well with that of cell density changes. Mostly, the chlorophyll concentration of the beginning of the survey showed relatively high values of over 20 mg/m^3 with its first peak on July 29, and it decreased abruptly to reach its minimum value of 2.4 mg/m^3 on August 2. Subsequently, it increased gradually and formed another peak value of about 17 mg/m^3, except a slight decrease on the last day of the survey. However, the difference of the two chlorophyll peaks was relatively small as compared with that of the two cell density peaks. It might be mainly due to the differences of species composition of those peaks. The first peak was dominated by small-sized *Skeletonema costatum* and the second was by *Prorocentrum minimum* which has large size relative to the former (refer to next paragraph). Thus, the interspecific variation of cellular chlorophyll content could appear to result in such a difference.

Species composition of phytoplankton during the survey was shown in Fig. 6. First peak was dominated by a diatom species, *Skeletonema costatum*, comprising most of the total phytoplankton cells. This *Skeletonema costatum* disappeared on August 3 and was succeeded by *Prorocentrum minimum*, a dinoflagellate species, which occurred abundantly in the subsequent survey period. It occurred more than 3×10^6 cells/*l* on August 6 in the second peak of cell density. Thereafter, *Skeletonema costatum* reappeared, *Prorocentrum minimum* decreased, and other species such as *Chaetoceros compressus* and *Peridinium bipes* occurred considerably. However, there were no distinct dominant species and several species showed relatively diverse occurrence patterns.

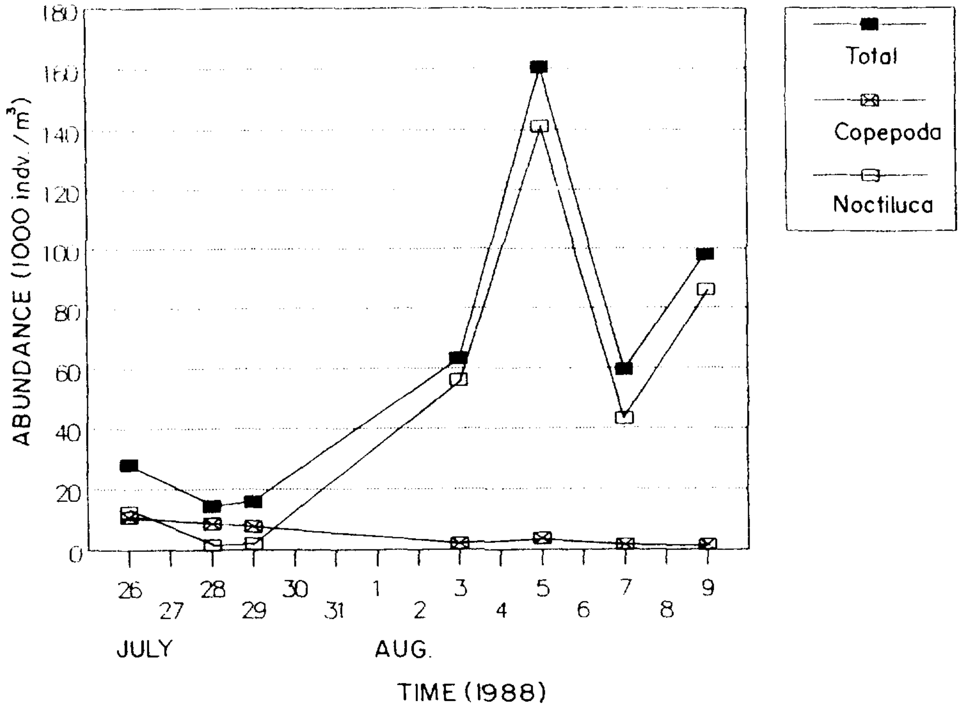

Fig. 8. Time series of zooplankton abundance.

Nutrients

Daily variation of nutrients in the surface water during the survey was shown in Fig. 7. Except the beginning of the survey, phosphate was generally in low concentrations below 1 μM, without showing any distinct pattern. However, nitrogen sources including nitrate and nitrite presented very high concentrations throughout the whole survey. Concentrations of nitrate ranged 20 to 70 μM, and those of nitrite, 2 to 8 μM except the erratic maximum value of 20 μM on August 6. On the whole, the levels of nitrogen sources (NO_3+NO_2) were very high. On the contrary, silicate concentrations showed a salient pattern. They showed maximum value of 15.8 μM at the beginning of the survey, and decreased gradually to quite low values below 1 μM at the period of July 30 to August 2. Thereafter, silicate concentrations started to increase towards August 5.

DISCUSSION

Among the potential factors controlling the abundance of phytoplankton during the survey, none other than silicate seemed to have any relation to the phytoplankton. Phosphate concentrations were generally low without any distinct pattern. Nitrate concentrations were always over 20 μM, and considering the half-saturation constants for nitrate (0.1-10.3 μM; Eppley *et al.*, 1969) it may not have been a limiting nutrient for phytoplankton growth. Zooplankton abundance was out of phase with the phytoplankton (Fig. 8), therefore it could be safely argued that grazing has little effects on the sudden decline of the diatoms.

On the contrary, it appears that the diatoms may have been responding to the availability of silicate with a phase lag of about 3-4 days. The dynamics of silicate with relation to the phytoplankton abundance and composition is shown in Fig. 9. In the figure, a strong inverse cross correlation between silicate and diatom could be recognized. The increase of this diatom species continued until the silicate concentration decreased below 1 μM, and then the silicate depletion was followed by an abrupt decrease of the diatom and a species

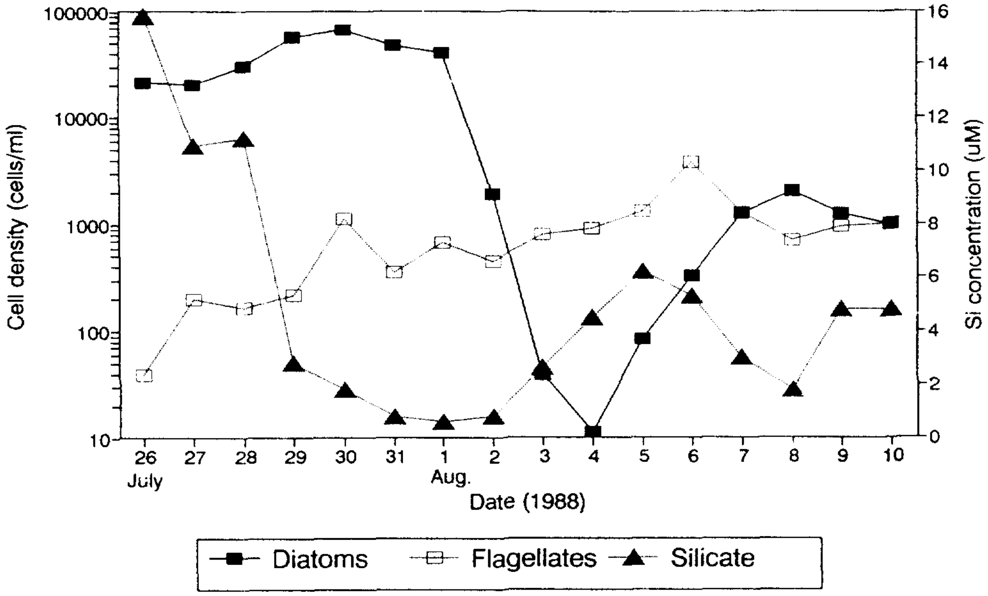

Fig. 9. Changes in the cell number of diatoms and flagellates, and in silicate concentrations in the surface water.

shift to a flagellate group. This pattern was consistent with other studies, e.g. large controlled ecosystem enclosure (CEE) experiment (Parsons *et al.*, 1978). The availability of silicon is often known to affect the productivity and abundance in phytoplankton assemblages. It has been proposed that in fresh waters anthropogenic nutrient inputs typically high in phosphorus and nitrogen, and low in silicon select against diatoms, in favor of non-siliceous taxa (Kilham, 1971; Schelske and Stoermer, 1971, 1972). Officer and Ryther (1980) postulated that coastal waters undergoing anthropogenic nutrient enrichment might be similarly affected and that species shifts from diatoms to other taxa might lead to alteration in trophic pathways.

A prominent feature of the observations is that there were two consecutive peaks of both diatom abundance and silicate within less than two weeks' period. This means that observation interval of longer than a week may not be adequate to study the dynamics of phytoplankton populations in the region. It also raises a question on the source of the second peak of silicate in the surface layer after the silicate was depleted. One possible source is the river runoff, but the amount of freshwater inputs into Masan Bay is very small compared to the volume of upper layer of the study area (C.S. Kim, KORDI, personal communication), and there was no rainfall during the survey. Thus river runoff can be ruled out.

Another possible source is recycling processes. The organic nitrogen and phosphorus components of the diatoms will be recycled rapidly back to an inorganic form mostly through zooplankton grazing and/or bacterial decomposition. On the other hand, the silicon is largely confined to the tests, skeletal material, of the diatoms. The animals which feed on the diatoms do not digest silicon and the tests are excreted. The tests dissolve and recycle silicon at a much slower rate than the organic nitrogen and phosphorus components. The time constants for silicon recycling through dissolution of diatom tests are more than 45 days (Jorgensen, 1955; Lewin, 1961). Therefore, recycling of silicon within the water column can not account for the second peak of silicon which followed after a week.

The last possible source that can be counted is the supply of silicate from bottom water through turbulent diffusion by vertical mixing across the strong density stratification. This could be supported by the fact that the concentration of bottom

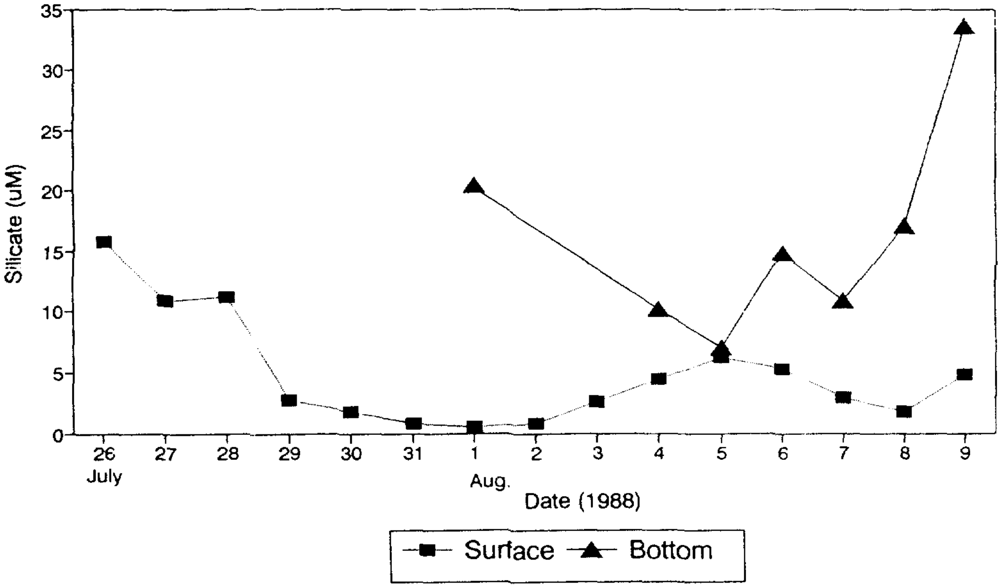

Fig. 10. Time series of silicate in the surface and bottom water.

water silicate started to decrease as that of surface silicate increased (Fig. 10). Vertical mixing in the water column in estuaries and other coastal environments requires an input of mechanical energy that is mainly provided by the tides, the wind stress on the surface and the fresh water runoff. Since it had been very clear without strong winds during the observation period (Fig. 2), the tidal mixing could be elicited as a proximal agency for the silicate supply.

Mixing and stabilization determine the availability of nutrients and light energy necessary for phytoplankton growth (Pingree, 1978). The depth of the layer for optimal phytoplankton growth is determined by the interrelationship between the downward light gradient and the upward nutrient gradient (Demers *et al.*, 1986). According to Legendre (1981), a phytoplankton burst occurs upon stabilization of previously destabilized (and thus nutrient replenished) waters, the transition between the two states being either spatial (e.g. tidal front) or temporal (e.g. spring bloom). Since neither stabilization (which may lead to nutrient limitation) nor destablilization (which may cause light limitation) favors phytoplankton production, the phytoplankton burst on the stable side of front is short, with the result that the phytoplankton production potential, when considering the nutrients, depends mainly on the frequency of stabilization-destabilization of the water column.

In the study area, like many other coastal and estuarine environments (Demers *et al.*, 1986), neap-spring tidal changes might drive the stabilization-destabilization cycle in the water column. In the second paper of this series (Yoo and Pae, in preparation), we extend the analysis using a numerical model, and examine the conditions of tidal mixing and pulsing of silicate into the surface layer.

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