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# The Role of Heterotrophic Protists in the Planktonic Community of Kyeonggi Bay, Korea

WON JE LEE[1] AND JOONG KI CHOI*
*Department of Oceanography, Inha University, Inchon 402-751, Korea*

In order to understand the role of heterotrophic protists in the coastal waters off Inchon, abiotic and biotic factors were measured from January 1992 to February 1993. Microbial carbon biomass (mean 212.9±119.1 μgC/l) was composed of 4.2% bacteria, 0.3% cyanobacteria, 12.1% autotrophic nanoflagellates, 6.6% heterotrophic nanoflagellates, 5.8 heterotrophic ciliates and 71.0% diatom and Mesodinium spp. The carbon biomass of heterotrophic protists (heterotrophic nanoflagellates and ciliates) was highest in October 1992 (mean 37.8±22.5 μgC/l), and was low in August 1992 (mean 21.2±10.8 μgC/l) and in February 1993 (mean 19.5±6.4 μgC/l). However, the contribution of heterotrophic protists to total microbial carbon biomass was higher in January 1992 and February 1993 (about 21%) when the phytoplankton was dominated by nanoplankton than in August and October (about 9%) when large diatoms occurred in large numbers. This study suggests that in Kyeonggi Bay heterotrophic protists might play a more important role as prey for zooplankton and as consumers of bacteria & small phytoplankton in less productive seasons (especially winter) than in productive seasons (autumn), and that the classic trophic pathway from diatoms through copepods to fish might be dominant nearly every season.

## INTRODUCTION

In marine pelagic ecosystems, an initial hypothesis of the marine food web was that most of the primary production was consumed by metazoa. However, it is now recognised that much of the dissolved organic matter fixed by primary producers, and released and excreted by plankton, is utilized by microheterotrophs in the microbial loop (Pomeroy, 1974; Azam *et al.*, 1983; Porter *et al.*, 1985). Much of the organic carbon which is produced by autotrophs is released as dissolved matter and is utilized by heterotrophic bacteria. In turn heterotrophic bacteria are consumed by microzooplankton such as heterotrophic flagellates and small heterotrophic ciliates (Porter *et al.*, 1985). This trophic pathway is called microbial loop. At this time, the microzooplankton appears to be a trophic link between metazoa and this microbial loop (Azam *et al.*, 1983; Sherr and Sherr, 1988; Rublee and Partusch-Talley, 1995; Hwang and Heath, 1997; Hadas and Berman, 1998).

Most of the microzooplankton are heterotrophic protists. They are consumers of bacteria and small phytoplankton, are prey for mesozooplankton (Sherr and Sherr, 1984; Sherr and Sherr, 1988; Pace and Vaqué, 1994), and facilitate remineralization and recycling of elements essencial for phytoplankton and microbial growth (Sherr and Sherr, 1984; Sherr and Sherr, 1988; Jürgens and Güde, 1990; Caron, 1994; Kirchman, 1994) in a wide variety of aquatic ecosystems. For that reason, heterotrophic protists are recognised as an important component functioning as an energy transporter in microbial food webs.

The aim of this study is to understand the role of heterotrophic protists in the planktonic community of Kyeonggi Bay, Yellow Sea by measuring and analysing the seasonal variations of abiotic and biotic factors.

## METHODS

### *Study area and sampling period*

Kyeonggi Bay is a shallow coastal plain estuary about 10—40 m in depth and located in the mid-eastern part of the Yellow Sea (Fig. 1). The estuary and adjacent coastal areas are characterized by a large tidal range up to about 9—10 m (Fig. 2). Strong tidal

*Corresponding author: jkchoi@dragon.inha.ac.kr, phone 032-860-7704
[1]Present address: School of Biological Sciences A08, University of Sydney, NSW 2006, Australia

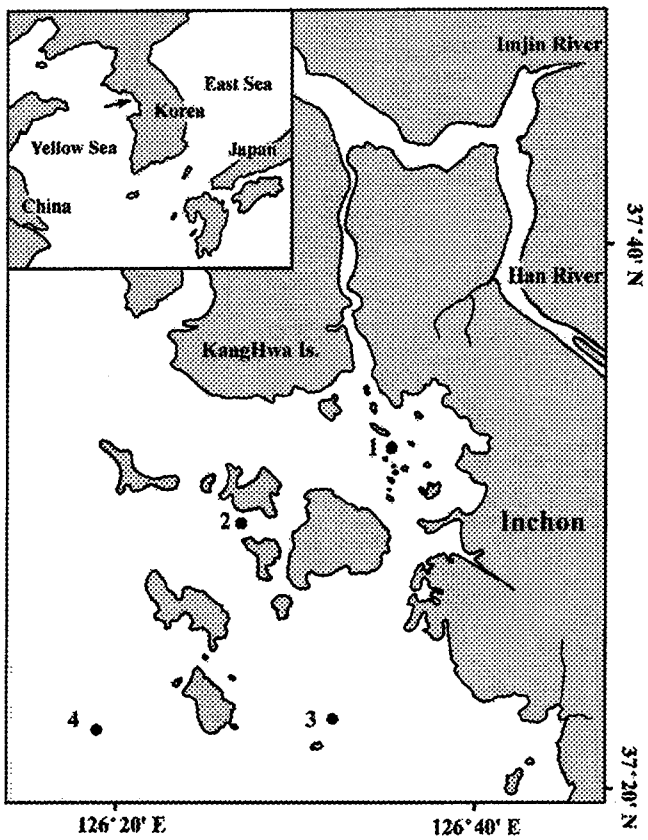


**Fig. 1.** Map showing this study area.

currents resuspend sediment particles and construct variable sedimentary structures on the tidal flats. The resuspension of sediment particles transports various littoral microspecies into the water column and inhibits primary production (Choi, 1985). Tremendous amounts of freshwater, which flow from the Han River and the Imjin River, cause dramatic fluctuation of salinity in the northern part of this bay. Due to inputs of nutrients from the Han River and Inchon city, this study area is extremely eutrophic (Jeon *et al.*, 1994). This study area was once a good nursery ground for many fish and crustaceans, but now has been changed by the stress of environmental pollution.

This study was conducted seasonally at 4 stations [thereafter St(s)], which reflect the characteristics of Inchon coastal area from January 1992 to February 1993. Samples were taken from the surface including the surface microlayer by bucket. The data for primary production, diatoms and zooplankton were taken from Choi (1994).

### *Background measurement*

Temperature and salinity were measured *in situ* using a T-S Bridge (KENT). Inorganic nutrients were analysed with duplicate samples using a UV/VIS Recording Spectrophotometer (Shimadzu double beam, M/D; UV-260) according to Solozano (1969) and Parsons *et al.* (1984). Secchi depth (m) was measured *in situ* with a white disk (diameter, 30 cm). Chlorophyll-*a* concentrations were measured *in situ* with a Turner Design III Field Fluoremeter (Turner Designs Inc.) and also in the laboratory by the Acetone extraction method of Parsons *et al.* (1984). Chlorophyll-*a* concentrations measured using the Field Fluoremeter were calibrated by the values obtained by the extraction method. Primary production was measured using $^{14}C$ method and a Liquid scintillation counter (Packard Tricarb-C). After incubating for 2 –3 hours samples were filtered on Whatman GF/C filters. To estimate contribution of nanophytoplankton to total phytoplankton, water samples for chlorophyll-*a* analysis and primary production were also filtered on 20 μm mesh.

Bacterial production was determined by the $^{3}H$-thymidine method and samples were incubated *in situ* for 3 hours (Fuhrman and Azam, 1982). A factor ($1.7\times10^{18}$ cells per 1M thymidine) was used to convert the produced bacteria to cell number (Fuhrman and Azam, 1982). A conversion factor of $0.17\times10^{-13}$ gC/cell was used to measure bacterial carbon biomass (Lee and Fuhrman, 1987).

### *Microorganisms*

Bacteria, cyanobacteria and flagellates were preserved in a final concentration of 1% formalin and were quantified by epifluorescence microscopy (Nikon type 104) with an UV excitation filter (DM400) within 3 days after sampling.

Bacteria and cyanobacteria were concentrated on 0.22 μm pore-sized Nuclepore polycarbonate black filters and at the same time were stained with DAPI (Porter and Feig, 1980). Flagellates were concentrated on 0.45 μm pore-sized Nuclepore polycarbonate black filters and simultaneously stained with DAPI. We used a higher concentration of DAPI (0.5 – 1 μg/ml) than Porter and Feig (0.01 μg/ml) because a low DAPI concentration did not adequately stain microorganisms. For that reason it was difficult to count microorganisms (especially bacteria) and also because of the masking of stained bacteria by lots of suspended substances. Zweifel and Hagström (1995) demonstrated that a major problem with DAPI staining of marine bacteria is that DAPI does not bind to

DNA well at high salinity (above 12‰). We note that in planktonic ecosystems with lots of suspended substances and high salinity, the DAPI concentration should be increased.

Water samples for counting diatoms and ciliates were preserved with 1% Lugols iodine solution (final concentration). After concentrating water samples to 100 −200 ml by settling, diatoms and heterotrophic ciliates were counted under a light microscope (Nikon type 104) using a Sedgwick-Rafter Chamber (McAlice, 1971).

### *Carbon biomass estimation*

Factors used to convert cell volume to carbon biomass were 19.8 fgC/cell for bacteria (Lee and Fuhrman, 1987), 294 fgC/$\mu m^3$ for cyanobacteria (Cuhel and Waterbury, 1984) and 220 fgC/$\mu m^3$ for flagellates (Børsheim and Bratbak, 1987). For diatoms, after measuring the cell surface area and volume according to Edlers (1979) equation and after measuring plasma volume according to Smaydas (1965) equation, carbon biomass was calculated using Strathmans (1967) equation. The cell volume of heterotrophic ciliates was calculated according to Edlers equation and the conversion factor used was 0.19 pgC/$\mu m^3$ for samples fixed with Lugols iodine solution (Putt and Stoecker, 1989).

### *Data analysis*

We present mean and standard deviation (i.e., mean ±s.d.). Correlations between the abundances of microorganisms and other variables were determined by Minitab (release 12).

## RESULTS

### *Environmental condition*

Water temperature showed a typical seasonal variation from 2.7 to 25.6°C (Fig. 2). The spatial variation of temperature was not great because of vertical and horizontal mixing of water generated by strong tidal actions. Salinity was in the range of 22.9–32.5 ‰ (Fig. 2) and the variation was most marked in the northern part of the bay (Sts 1 and 2), but less so in the central part of the bay (Sts 3 and 4). Inorganic nutrient concentrations were relatively higher in the northern part of the bay than in the central part. Total nitrogen and phosphate concentrations varied from 7.24 to 41.07 μM/l (mean 20.21±8.54 μM/l) and from 0.21 to 2.30 μM/l (mean 0.86±0.46 μM/l), respectively (Fig. 2). Silicate concentration was in the range of 0.19–43.75 μM/l (mean 23.04±15.40 μM/l) and was lowest in October with a mean of 1.22±1.28 μM/l (Fig. 2). It was significantly correlated with the abundance of phytoplankton ($r=-0.789$, $P < 0.001$). Secchi depth was low with a range of 0.2–2.4 m during the sampling period and had a positive correlation with the abundance of phytoplankton ($r=0.519$, $P < 0.05$).

### *Chlorophyll-a, Primary productivity and bacterial productivity*

Chlorophyll-*a* concentration (mean 4.0±3.9 μg/l) was highest in October (mean 10.2±4.3 μg/l) and lowest in January (mean 1.4±0.4 μg/l). It was mean 2.8±0.7 μg/l in April and 3.4±1.0 μg/l in August (Fig. 3). The contribution of phytoplankton less than 20 μm to chlorophyll-*a* concentrations was highest in January (73%), but decreased towards October (28%) when the contribution of net phytoplankton increased. Primary productivity had a mean of 976±1383 mgC/$m^2$/day and showed trends similar to chlorophyll-*a* concentrations ($r=0.922$, $P < 0.001$). The averaged primary productivities were found to be 45±18 mgC/$m^2$/day in January, 309±157 mgC/$m^2$/day in April, 626±390 mgC/$m^2$/day in August and 2523±1859 mgC/$m^2$/day in October (Fig. 3). Bacterial productivity had a mean of 53.7±63.4 mgC/$m^2$/day and was highest in August (mean 134.5±47.0 mgC/$m^2$/day), low in January (mean 10.8±18.0 mgC/$m^2$/day) and April (mean 1.3±1.0 mgC/$m^2$/day) (Fig. 3). It was significantly correlated with temperature ($r=0.810$, $P < 0.001$).

### *Abundances and carbon biomass of microorganisms*

Abundances of most organisms were higher in October than in other months with the exceptions of bacteria and zooplankton.

Bacterial abundance (mean 4.52±1.99×$10^5$ cells/ml) was highest in August (mean 6.22±1.92×$10^5$ cells/ml) and lowest in January (mean 2.61±0.15×$10^5$ cells/ml) (Fig. 4). It was positively correlated with water temperature ($r=0.628$, $P < 0.01$). The mean cyanobacterial abundance of 0.79±0.76×$10^3$ cells/ml was relatively low. It was highest in October (mean 2.08± 0.42×$10^5$ cells/ml) (Fig. 4) and was high in the central part of the bay (Sts 3 and 4). The mean abundances of autotrophic and heterotrophic nanoflagellates were 2.81±1.29×$10^3$ cells/ml and 4.18±4.16×$10^3$ cells/ml,

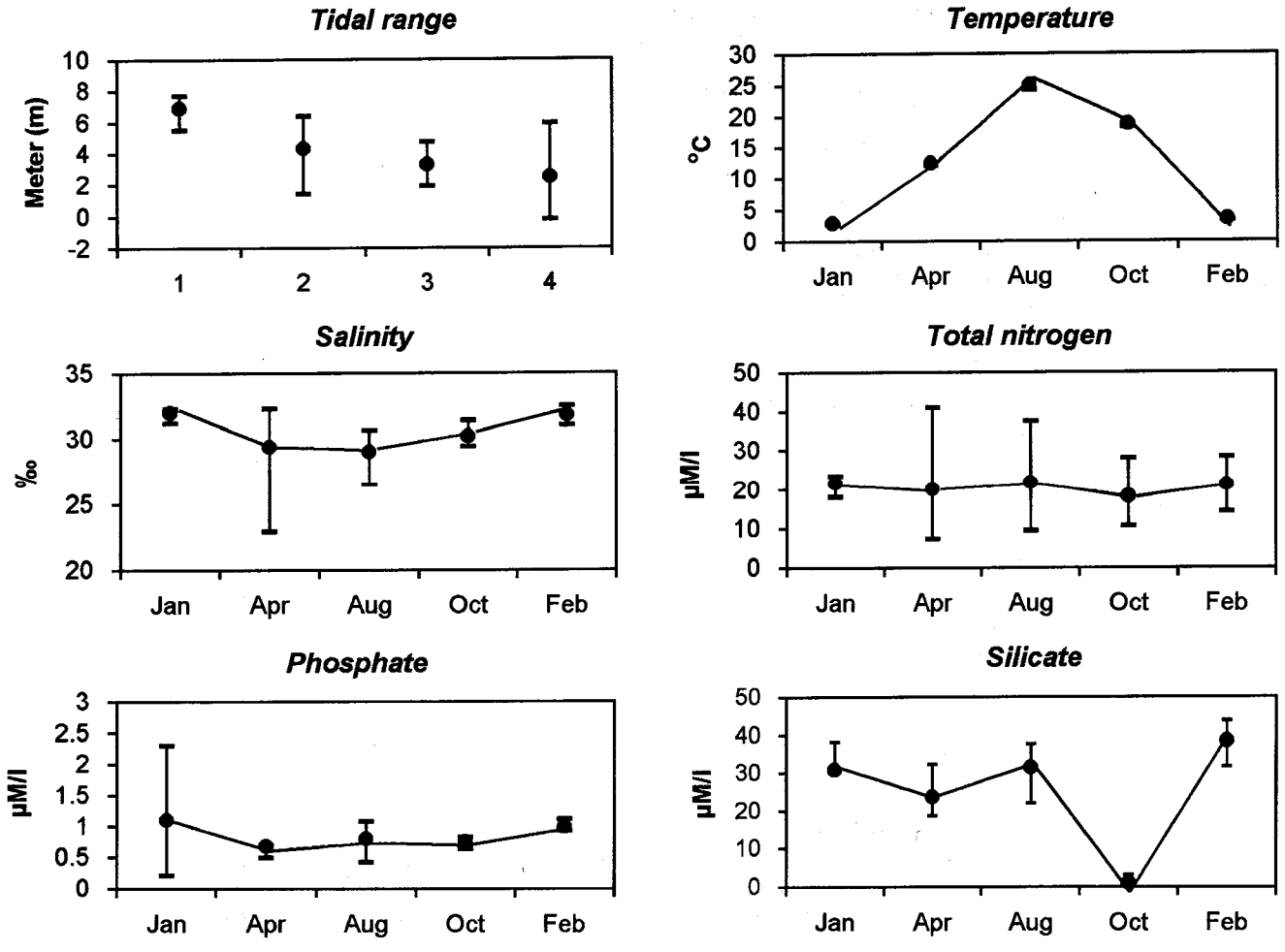


**Fig. 2.** Maximum and minimum values of tidal range at each station, and seasonal variations of temperature, salinity and inorganic nutrients (total nitrogen, phosphate, silicate) (η = mean value)

respectively (Fig. 4). Both were dominated by flagellates less than 5 μm. The abundance of autotrophic nanoflagellates was relatively high in October (mean 4.59±1.54×$10^3$ cells/ml) and low in February (mean 1.88±0.74×$10^3$ cells/ml), and of heterotrophic nanoflagellates was highest in October (mean 11.12±4.93 ×$10^3$ cells/ml) (Fig. 4). The ciliate assemblage had a mean abundance of 5.18±2.98×$10^3$ cell/l and was dominated by small oligotrichs less than 30 μm and tintinnids (mainly the genera *Leprotintinnus* spp., *Tintinnopsis* spp. and *Codonellopsis* spp.) (Fig. 4). The abundance of heterotrophic ciliates was highest in February (mean 8.32±4.29×$10^3$ cell/l) and lowest in August (mean 3.23±1.84×$10^3$ cell/l). The mean abundance of phytoplankton (diatoms & *Mesodinium rubrum*) was 4.37±2.97×$10^5$ cells/l. The abundance was low in January (mean 2.44±0.59×$10^5$ cells/l) when the phytoplankton was dominated by small diatoms such as *Skeletonema costatum* and *Paralia sulcata* (Fig. 4). It was high in October (mean 8.67±3.48×$10^5$ cells/l) when the phytoplankton was dominated by large diatoms such as *Chaetoceros debilis*, *Eucampia zoodiacus* and *Asterionella japonica* (Fig. 4). The abundance of the autotrophic ciliate *Mesodinium rubrum* (mean 2.62±4.02×$10^3$ cells/l) was relatively low in all seasons, and was highest in October (mean 7.64± 7.14×$10^3$ cell/l) and lowest in January (mean 0.38±0.22 ×$10^3$ cells/l). Zooplankton was dominated by mesozooplankton (especially copepods) such as *Acartia* spp., *Paracalanus crassirostris* and *P. parvus*, and had a mean abundance of 5.38±7.92×$10^3$ inds./$m^3$. They were most abundant in August (mean 19.07±6.52×$10^3$ inds./$m^3$) and numbers were low in January (mean 0.19±0.05×$10^3$ inds./$m^3$) and in February (mean 0.55 ±0.16×$10^3$ inds./$m^3$). The mean abundances of zooplankton in April and October were 1.88±1.62×$10^3$ inds./$m^3$ and 5.19±4.37×$10^3$ inds./$m^3$, respectively.

The mean bacterial carbon biomass was 9.0±4.1

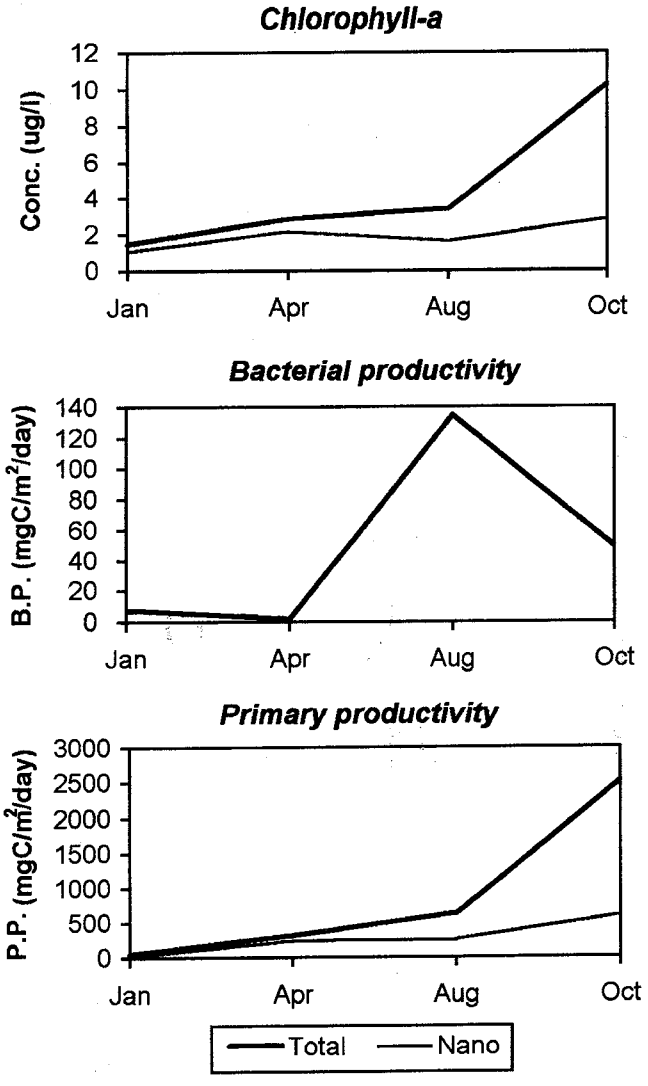


**Fig. 3.** Seasonal variations of chlorophyll-*a* concentration, primary productivity and bacterial productivity.

μgC/l and that of cyanobacteria was 0.6±0.5 μgC/l (Fig. 4). Bacterial carbon biomass was relatively low, but was highest in summer (August). The mean carbon biomasses of autotrophic nanoflagellates, heterotrophic nanoflagellates and heterotrophic ciliates were 25.8±9.9 μgC/l, 14.1±6.1 μgC/l, and 12.4±11.6 μgC/l, respectively (Fig. 4). The carbon biomass of diatoms & *Mesodinum* spp. (mean 151.2±120.2 μgC/l) was highest in October (mean 316.4±143.8 μgC/l) when large diatoms occurred in large numbers, and was low in January (mean 67.0±18.2 μgC/l) and in February (mean 49.4±5.6 μgC/l) (Fig. 4). The monthly averaged carbon biomass of planktonic heterotrophic protists was 28.3±4.5 μgC/l in January, 25.4±8.2 μgC/l in April, 21.2±10.8 μgC/l in August, 37.8±22.5 μgC/l in October and 19.5±6.4 μgC/l in February, while the contribution to total microbial carbon biomass was 21.9% in January, 13.9% in April, 7.9% in August, 9.7% in October and 20.6% in February. Microbial carbon biomass (mean 212.9±119.1 μgC/l) was composed of 4.2% bacteria, 0.3% cyanobacteria, 12.1% autotrophic nanoflagellates, 6.6% heterotrophic nanoflagellates, 5.8% heterotrophic ciliates and 71.0% diatoms & *Mesodinium* spp.

## DISCUSSION

### *Environmental condition*

Kyeonggi Bay is eutrophic and extremely unstable under the influence of the inputs of freshwater and strong tidal actions (Choi and Shim, 1988). Abiotic factors such as temperature, salinity and inorganic nutrients were varied by the influence of freshwater and tidal actions, and biotic factors also may be influenced. In estuarine ecosystems, the abundance and composition of plankton are influenced by tidal levels over a given area (Park and Choi, 1997). Primary production may be influenced by the concentrations of suspended substances due to tidal action (Kang *et al.*, 1992; Kwon and Choi, 1994). In the present study, the abundance of phytoplankton was positively correlated with secchi depth (transparency of water). This evidence suggests that high concentrations of suspended substances might inhibit photosynthesis in phytoplankton.

### *Phytoplankton*

Phytoplankton smaller than 20 μm contributed more than 50% to both chlorophyll-*a* concentration and primary productivity with the exception of October when chlorophyll-*a* concentration and primary productivity were relatively high due to the autumn bloom of large diatoms (*Asterionella japonica*, *Chatoceros deblis*, *Eucampia zoodiacus*). We conclude that phytoplankton less than 20 μm might play an important role as primary producers and prey for grazers in the phytoplankton community in this bay. We also conclude that this study area might be characterized by two different periods: the first period is October when primary production was dominated by large diatoms and the other period is other months when primary production was maintained by phytoplankton less than 20 μm.

### *Heterotrophic bacteria*

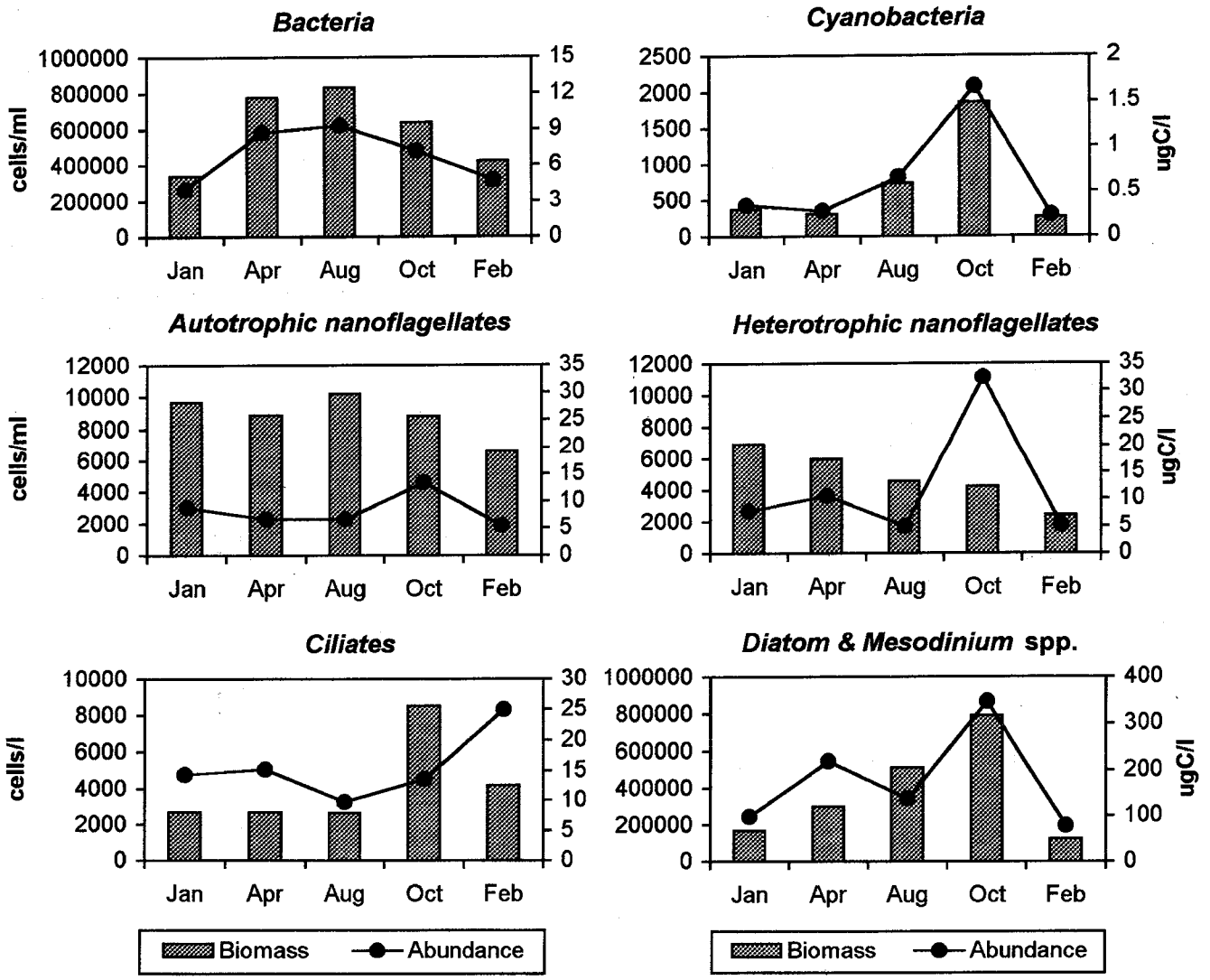


**Fig. 4.** Seasonal variations in the abundances and biomass of heterotrophic bacteria, cyanobacteria, autotrophic nanoflagellates, heterotrophic nanoflagellates, heterotrophic ciliates and diatoms & *Mesodinium* spp.

Heterotrophic bacteria are known to be an important component of pelagic ecosystems (Simon *et al.*, 1992). These bacteria take up much of dissolved organic carbon produced by primary producers as a food source and then are consumed by microzooplankton (Porter *et al.*, 1985; Sherr and Sherr, 1988; Caron, 1994). In many marine ecosystems, bacterial productivity accounts for equivalent to 10–30% of primary productivity (Hagström *et al.*, 1979; Fuhrman and Azam, 1982; Cole *et al.*, 1988). In this present study it showed the general trend with about 17% of primary productivity. About $10^6$ bacteria cells/ml bacteria might support the growth of heterotrophic flagellates (Andersen and Fenchel, 1985), but in Kyeonggi Bay bacterial abundance might be too low to support the growth and maintanance of heterotrophic flagellate population. The increased bacterial abundance in August might be caused not only by the increased metabolism due to an increase in water temperature, but also by a decrease of their major consumers (heterotrophic nanoflagellates). In October we expected bacteria to increase due to exudates of dissolved organic matter (DOM) from diatoms, but bacterial abundance decreased. This might be caused by an increase in heterotrophic nanoflagellate and small aloricate ciliate abundances in this period, and by viral lysis (Suttle, 1994; Fuhrman and Noble, 1995).

### *Heterotrophic flagellates*

Heterotrophic nanoflagellates have been reported to be major consumers of bacteria (Rassoulzadegan and

Sheldon, 1986; McManus and Fuhrman, 1988; Sanders *et al.*, 1989; Wikner *et al.*, 1990; Berninger *et al.*, 1991). Most heterotrophic flagellates, which account for 20–80% of the nanoplankton, are in the size range of 2–5 μm (Geider, 1988) and the flagellates less than 5 μm in size are thought to graze on cells < 1 μm in length (Sherr and Sherr, 1991b). However, even though flagellates 5–15 μm in size are a small component numerically, it is likely that their biomass is equivalent to that of the smaller flagellates (Sherr and Sherr, 1991a). The 5–15 μm size class of heterotrophic flagellates is likely to be important as consumers of pico- to nano-sized cells (Sherr and Sherr, 1992; Sherr *et al.*, 1991). Heterotrophic nanoflagellates may filter 10–100% per day of the water column for bacteria (Fenchel, 1982; Sherr *et al.*, 1986a; McManus and Fuhrman, 1988; Kuuppo-Leinikki, 1990; Choi *et al.*, 1995) and the clearance rate (100%) in winter is higher than that (23%) in summer (McManus and Fuhrman, 1988). It suggests that in winter heterotrophic nanoflagellates may play a significant role as consumers of bacterioplankton. In Kyeonggi Bay, heterotrophic nanoflagellates were dominated by flagellates less than 5 μm. They might depend on picophytoplankton abundance, DOM (Sherr, 1988; Tranvik *et al.*, 1993) and POM (particulate organic matter) as food sources because bacterial abundance was relatively low. The decrease in the abundance of heterotrophic nanoflagellates in August appears to be closely related with the increase in the abundance of zooplankton. The increase in the abundance of heterotrophic nanoflagellates in October might be caused by the decrease of zooplankton abundance. We believe that the decrease of bacterial abundance may be caused by the feeding of heterotrophic nanoflagellates less than 5 μm and by viral lysis. Their grazing pressure on bacteria and picoplankton may be considerable. The grazing rates of heterotrophic nanoflagellates on bacteria in this area are 6–52 Bac HFL $h^{-1}$ (Choi *et al.*, 1995).

### *Heterotrophic ciliates*

Heterotrophic ciliates accounted for 5.8% of the total microbial carbon biomass and were mostly composed of < 30 μm aloricate ciliates and tintinnids. The abundance of heterotrophic ciliates had a positive correlation with those of autotrophic nanoflagellates ($r=0.633$, $P < 0.001$) and heterotrophic nanoflagellates ($r=0.604$, $P < 0.001$). This evidence suggests that high numbers of nanoflagellates may have supported ciliate growth. It is known that heterotrophic ciliates may consume prey in a variety of size ranges (Smetacek, 1981; Jonsson, 1986; Capriulo, 1990). They are thought to be important in the size category of 20–200 μm microzooplankton which consume nano-sized organisms (Sorokin, 1981; Beers *et al.*, 1980, 1982; Gast, 1985). Although most heterotrophic ciliates feed on bacteria less efficiently than flagellates (Sherr *et al.*, 1986b; Sherr and Sherr, 1987), < 20 μm aloricate heterotrophic ciliates are potential consumers of picoplankton (Sherr *et al.*, 1986b). Also, Rassoulzadegan *et al.* (1988) reported that the food of small (< 30 μm) heterotrophic ciliates was 72% picoplankton and 28% nanoplankton. Thus, when small heterotrophic ciliates dominated they may have an important role as consumers of pico- and nanoplankton. Judging from the biomass of flagellates and cyanobacteria in this study area, heterotrophic ciliates could exert a significant influence on the distribution of small diatoms. Although heterotrophic ciliates exercise weak grazing pressure on bacteria, we believe that ciliates may play an important role in the microbial food web because they graze on bacterivorous, heterotrophic flagellates. According to Choi *et al.* (1995), planktonic ciliates took up 17–20% of nanoflagellate production in this area.

### *Heterotrophic dinoflagellates*

Heterotrophic dinoflagellates are significant consumers of small microorganisms in planktonic ecosystems (Lessard and Swift, 1985; Lessard, 1991; Sherr and Sherr, 1994). The abundance and biomass of heterotrophic dinoflagellates less than 100 μm in size are often equivalent to or surpass those of ciliates (Smetacek, 1981; Hansen, 1991; Lessard, 1991; Burkill *et al.*, 1993). Non-armoured dinoflagellates less than 20 μm (e.g., *Gymnodinium* spp. and *Katodinium* spp.) are abundant in most marine environments and are important consumers of nanoplanktonic sized cells (Sherr and Sherr, 1994). We did not measure the abundance of heterotrophic dinoflagellates in the present study, but some of the heterotrophic nanoflagellates enumerated here may have been herbivorous dinoflagellates. In Kyeonggi Bay, Park (1995) reported that the carbon biomass of heterotrophic dinoflagellates made up about 18% of heterotrophic protists and only 1% of the total microbial carbon biomass during the summer season (June–August) when dinoflagellates are more abundant than in other

**Table 1.** Estimates of the ratio of heterotrophic protist biomass to total phytoplankton biomass

| Environment | Ratio | Adopted from |
|---|---|---|
| Temperate esturay | ~20% | Berk *et al.* (1977) |
| Bellinghausen Sea and South George, Antarctica | ~16% | Bröckel (1981) |
| Weddell Sea, Antarctica | 10–25% | Bouddunggen *et al.* (1988) |
| Weddell Sea, Antarctica | | Garrison and Buck (1989) |
| Spring, 1983 | 7–12% | |
| Autumn, 1986 | | |
| Ice-covered station | 15–23% | |
| open water station | 9–14% | |
| Coastal water | 0.4–2.9% | Tiselius (1989) |
| Korean Coastal water | | Park (1995) |
| Summer, 1994 | | |
| red tide periods | 0.7–2.1% | |
| non-red tide periods | 4.9–136% | |
| Kyeonggi Bay | 9.1–29.7% | present study |

seasons in Kyeonggi Bay (Choi, unpublished observation). It suggests that heterotrophic dinoflagellates might not be abundant and might not play a significant role in the planktonic community of Kyeonggi Bay.

### *Zooplankton*

Copepods feed more often on dinoflagellates and ciliates than diatoms (Stoecker and Capuzzo, 1990; Kleppel *et al.*, 1991). In experiments in which the copepods are simultaneously exposed to both heterotrophic ciliates and algae, the clearance rate on heterotrophic ciliates is 2–10 times higher than that on algae (Turner and Anderson, 1983; Stoecker and Sanders, 1985; Stoecker and Egloff, 1987; Wiadnyana and Rassoulzadegan, 1989). In Kyeonggi Bay where large diatoms (*Chaetoceros debilis*, *Eucampia zoodiacus*, *Asterionella japonica*) and small aloricate heterotrophic ciliates were abundant especially in October, heterotrophic ciliates may have difficulty in engulfing diatoms. Thus, diatoms might be mainly consumed by mesozooplankton (*Acartia* spp., *Paracalanus* spp., *Corycaeus affinis*) which may be consumed by carnivorous zooplankton (*Sagitta* spp., fish larvae). This suggests that in seasons when diatoms occupy a large portion of the total microbial biomass, the classic trophic pathway from diatom through copepod to fish may be dominant.

## *Carbon biomass of heterotrophic protists*

Planktonic heterotrophic protists and phytoplankton (include autotrophic flagellates) accounted for 12.4% and 83.1% of the total microbial carbon biomass, respectively. In previous studies the carbon biomass of heterotrophic protists was compared with phytoplankton biomass. In various marine ecosystems it occupied often a large portion of phytoplankton biomass (Table 1). In the present study, the ratio of heterotrophic protist biomass to total phytoplankton biomass (mean 14.9%) was similar to those in other area (Table 1). It was high in January and Feburary (about 29%) and low in April and in October (about 10%). This suggests that in this area heterotrophic protists might play a role as much as those in other areas. The carbon biomass of heterotrophic protists, which mainly consist of small aloricate ciliates and heterotrophic nanoflagellates less than 5 μm, was highest in October and lowest in February. Otherwise the ratio of heterotrophic protists to total microbial carbon biomass was higher in January (21.9%) and February (20.6%) when the phytoplankton was dominated by nanoplankton than in August (7.9%) and October (9.7%) when large diatoms occurred in large numbers. Judging from the ratios of heterotrophic protist biomass to total microbial carbon biomass and to total phytoplankton biomass, in the present study heterotrophic protists might play a more important role as consumers of bacteria & small phytoplankton and as prey for zooplankton less in productive season (winter) than in productive season (autumn).

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