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Standing crops of planktonic ciliates and their prey organisms, picoplankton and nanoplankton, around the continental shelf break in the East China Sea

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Abstract : Standing crops of planktonic ciliates, nanoplankton and picoplankton were investigated around the continental shelf break in the East China Sea. They were 1.0×10^{1}–2.08×10^{3}, 2.15×10^{5}–6.45×10^{6} and 6.14×10^{7}–1.01×10^{9} cells/l, respectively. Vertical profile of planktonic ciliates was almost parallel to that of autotrophic nanoplankton. On the other hand, the profiles of heterotrophic nanoplankton and picoplankton, though similar to each other, were different from that of ciliates. These results might indicate that energy and carbon flux flowing into ciliate plankton is mainly from the production of autotrophic nanoplankton in this area. Picoplankton and heterotrophic nanoplankton might be less influential on ciliate production.

Key words : *Planktonic ciliates, Picoplankton, Nanoplankton, East China Sea*

1. Introduction

Planktonic ciliates, nanoplankton and picoplankton are essential components in marine microbial food webs. Ciliates are known to ingest nanoplankton(GIFFORD, 1985; VERITY, 1985) and picoplankton (SHERR and SHERR 1987; BERNARD and RASSOULZADEGAN, 1990). Nanoplankton, especially heterotroph, is also an important predator on picoplankton (TANAKA and TANIGUCHI, 1996; TANAKA *et al.*, 1997). Relationships between the two plankton out of these three have been quantitatively investigated. Picoplankton abundance correlates to heterotrophic nanoplankton abundance (SANDERS *et al.*, 1992), while in some case the relationship is weak though statistically significant (GASOL and VAQUÉ, 1993). Furthermore, standing crops of nanoplankton correlates well to ciliate plankton in the western Pacific Ocean (SUZUKI *et al.*, 1998). LYNN and MONTAGNES (1991) however report that the correlation between picoplankton biomass and planktonic ciliate biomass is poor. An entire figure composed of these three groups is not easily obtained from these relationships because these reports were obtained individually on space and time. A simultaneous investigation on these three plankton groups is indispensable for prevailing their trophic structure.

In this study, standing crops of planktonic ciliates, nanoplankton and picoplankton were simultaneously investigated around the continental shelf break in the East China Sea. There is a boundary between the water of continental shelf and that of the Kuroshio current in this region. The shelf water is rich in nutrients from large river, Changjiang River, and sometimes productive, e. g. 1570 mg C/m^2/d (HAMA, 1995). On the other hand, the Kuroshio water is poor in nutrient and less productive, e. g. 60 mg C/m^2/d (TANIGUCHI, 1972) and 209–290 mg C/m^2/d (HAMA, 1995). Various substances in the shelf water are mixed and conveyed out by the Kuroshio current flowing to north-east along the continental slope. To estimate the transportation of particulate organic carbon and other biogenic substances, the investigation of microbial components as well as organisms in the classical food chain is essential.

2. Method

On May 29, 1996, three stations around the continental shelf break in the East China Sea

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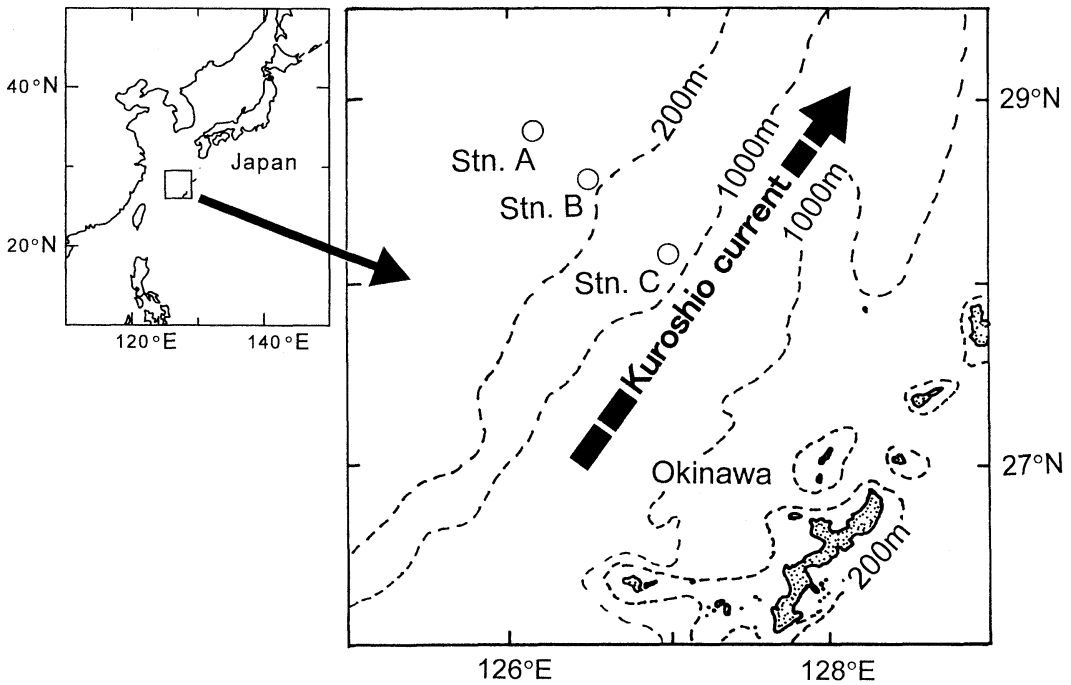

Fig. 1. Location of stations in the East China Sea occupied on the cruise of the T/S Kakuyo Maru in early summer of 1996. Position of the Kuroshio current is cited from the Quick Bulletin of Ocean Condition, No. 11 (1996).

(Fig. 1) were investigated by T/S Kakuyo-Maru, Nagasaki University. Temperature and salinity were measured with a CTD. Thirty three water samples from upper 110 to 400 m were taken with a rosette multisampler equipped with the CTD. Bottom depth at Stns. A, B and C were 113, 134 and 910 m, respectively.

Preparation for picoplankton (0.2 to 2 μm in equivalent spherical diameter) and nanoplankton (2 to 20 μm in ESD) counting was carried out on board immediately after sampling. An aliquot of 40 ml water was fixed with glutaraldehyde at final concentrations of 0.5 %. Ten ml of the fixed sample was stained with DAPI for picoplankton counting and filtered through a 0.2 μm pore size and black pre-stained Nuclepore filter (SHERR *et al.*, 1993). Another 20 ml was stained with proflavin for nanoplankton and filtered through a 0.6 μm pore and black pre-stained Nuclepore filter (SHERR *et al.*, 1993). The prepared filters were stored in a freezer (−20 ℃) until microscopic observation in laboratory.

Within one month after sampling, picoplankton and nanoplankton were observed under an epifluorescence microscope (Nikon BHC) at 1000× magnification using UV and Blue excitation, respectively. Twenty fields for picoplankton equivalent to 1.38×10^{-3} ml and 1690 fields for nanoplankton equivalent to 2.34×10^{-1} ml were examined. Their detection limit were 7.52×10^{5} cells/l and 4270 cells/l, respectively. Although small-sized ciliates, less than 20 μm in ESD, occurred occasionally, such ciliates were not counted in nanoplankton category. Autotrophic nanoplankton were separately counted from heterotrophic one according to the red emission of chlorophyll pigments.

For the examination of planktonic ciliates, 200 ml of water aliquot was fixed on board with Bouin's solution at final concentration of 5 % (JEROME *et al.*, 1993). Fixed water samples were stored in cool and dark place. After returning to laboratory, samples were concentrated with a sedimentation cylinder and observed under biological microscope (Nikon BHC) using a Sedgwick-Rafter slide. Detection limit of

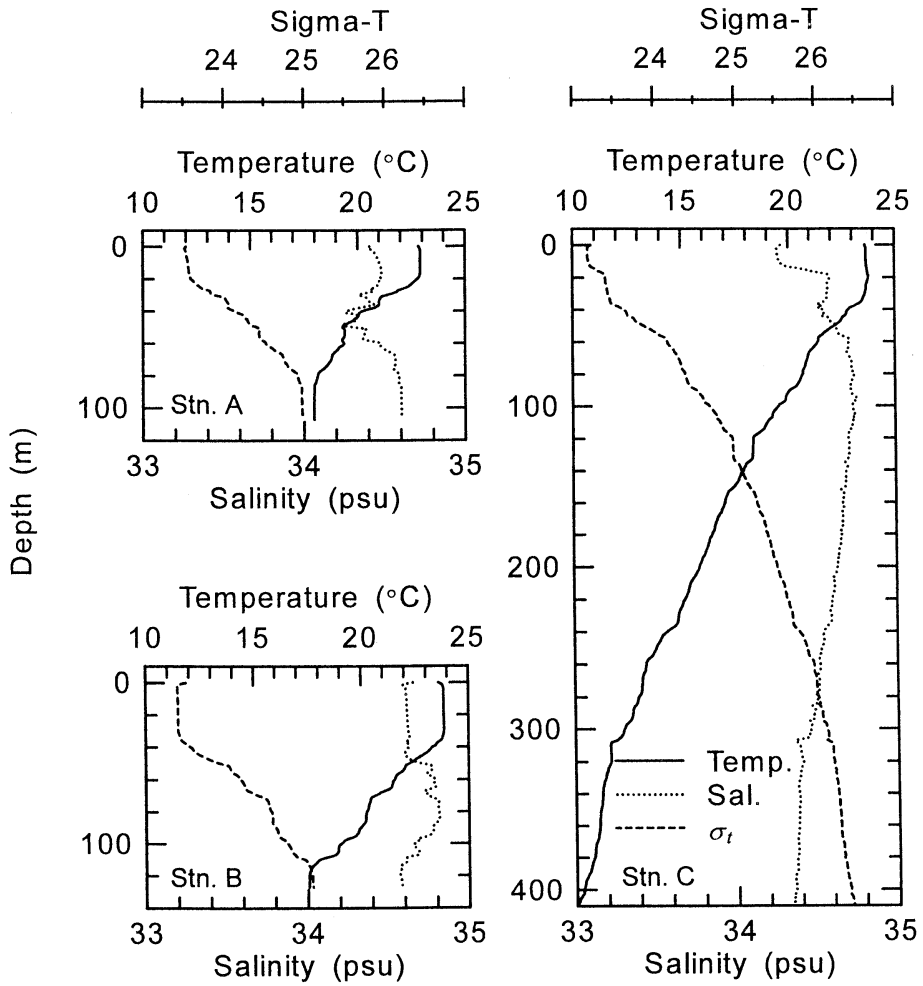

Fig. 2. Vertical profiles of water temperature, salinity and sigma-T.

ciliate counting was 5 cells/l. *Mesodinium* spp., other naked ciliates and loricated ciliates were separately counted by their morphological features.

3. Result and Discussion

Sampling stations were located on the boundary between the shelf water and the Kuroshio water (Fig. 1) according to the report of the Quick Bulletin of Ocean Condition (1996). Stn. A was more influenced by the shelf water and Stn. C was by the Kuroshio water.

Mixing layer was observed in the surface at every station (20–40 m in thickness) (Fig. 2). Water temperature and salinity at 0 m depth was 22.8 – 23.6 ℃ and 34.29 – 34.66 psu, respectively. Below this layer, water temperature decreased with depth, salinity however did not show conspicuous change while it fluctuated in fine scale around 40–100 m depth, and sigma-T resulted in increasing with depth. At Stns. A and B, undeveloped picnocline occurred also near the bottom (10–20 m in thickness).

Picoplankton abundance at Stns. A and B was 4.31×10^{8}–9.93×10^{8} cells/l and did not show noticeable change throughout the water column (Fig. 3). On the other hand, the abundance at Stn. C decreased gradually with depth, especially in the deeper layer, i. e. from 1.01×10^{9} cells/l at 0 m depth to 6.14×10^{7} cells/l at 400 m. These abundances are comparable to those

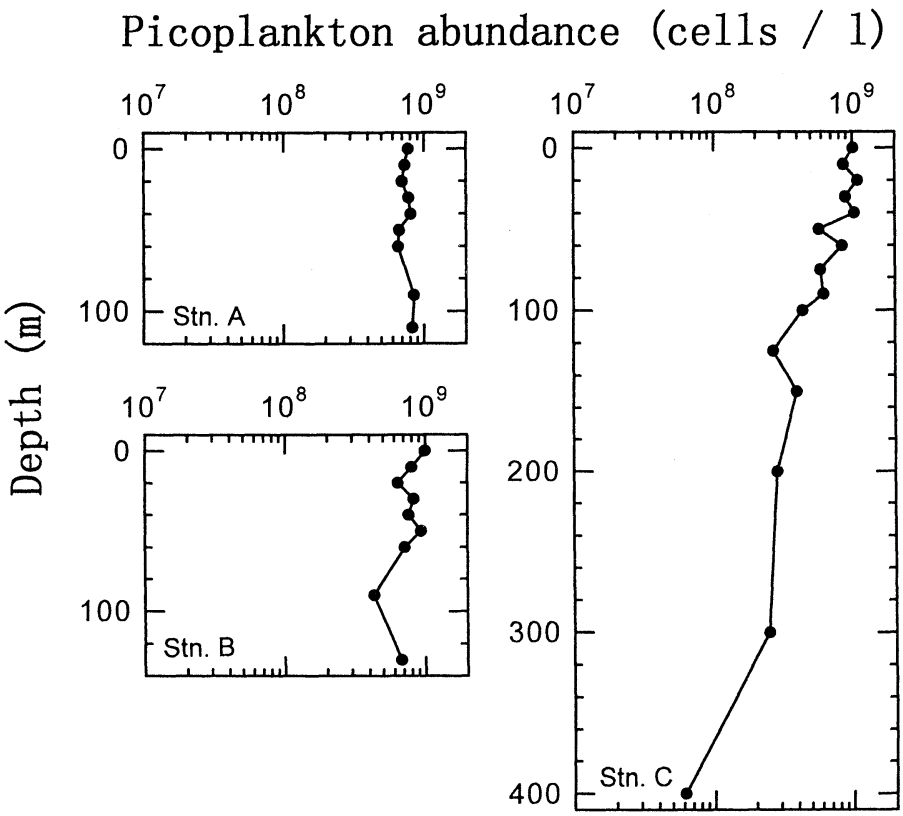

Fig. 3. Vertical profiles of picoplankton abundance.

of coastal and offshore waters, e.g. $0.5-3.0\times10^9$ cells/l in summer of Onagawa Bay, the northeastern Pacific coast of Japan (TANAKA and TANIGUCHI, 1996) and 10^8 cells/l order of magnitude in Kashima-Nada, the lower reach of the Kuroshio current (ISHIGAKI *et al.*, 1997).

Abundances of total nanoplankton, autotrophic nanoplankton and heterotrophic nanoplankton were 2.15×10^5–6.45×10^6, 1.73×10^4–5.65×10^6 and 1.85×10^5–1.69×10^6 cells/l, respectively (Fig. 4). Although autotrophic nanoplankton dominated over heterotrophic one in the surface at every station, it became subordinate below 150 m depth at Stn. C. These standing crops were comparable to those of other oceanic waters, e. g. $6.9\times10^5-1.38\times10^6$ cells/l of total one, $1.44\times10^5-5.25\times10^5$ of autotrophic one and $3.76\times10^5-1.17\times10^6$ of heterotrophic one in Sargasso Sea (CARON, 1983) and 1.45×10^5–3.18×10^6 cells/l of total one in off eastern Australia (SUZUKI *et al.*, 1998). They were however slightly smaller than that of eutrophic coastal sea water, e. g. 1.0×10^6–8.8×10^6 cells/l of heterotrophic one in northern Hiroshima Bay, Seto Inland Sea, Japan (IMAI and YAMAGUCHI, 1996).

Total ciliate abundance was 1.0×10^1–2.08×10^3 cells/l (Fig. 5). It was also comparable to other warm waters around Japan, e. g. 30–3040 cells/l in the East China Sea in August (OTA, 1995), 40–1760 cells/l in Toyama Bay in August (SUZUKI and TANIGUCHI, 1997). The decrease of ciliate abundance with depth was stronger than those of picoplankton and nanoplankton especially at Stn. C.

Among the three ciliate groups, *Mesodinium* spp. were hardly observed. They occurred at only three layers of Stn. A and their abundances were less than 85 cells/l. Even if they were all autotrophic one, i.e. *M. rubrum*, their contribution to primary production might be trivial in the continental shelf edge of the

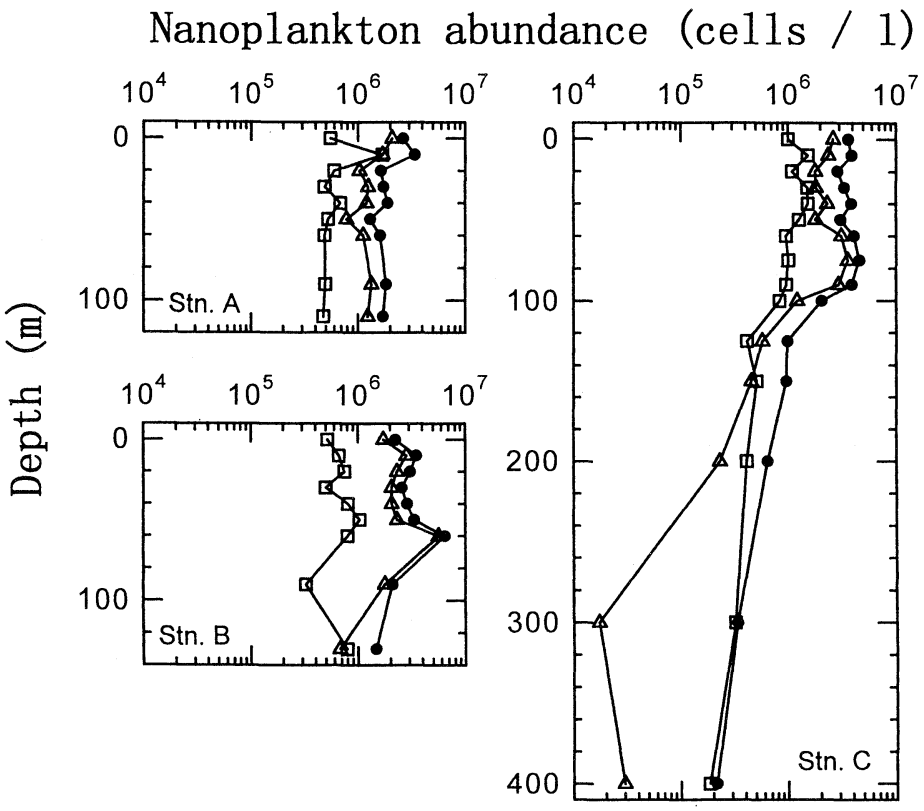

Fig. 4. Vertical profiles of nanoplankton abundance. ●: total nanoplankton, △: autotrophic nanoplankton, □: heterotrophic nanoplankton.

East China Sea.

Loricated ciliates occupied small proportion to total ciliates. Its ratio to total ciliates was less than 0.14. Naked ciliates except *Mesodinium* spp., on the other hand, dominated throughout the water column at every station. Such small proportion of loricated ciliates was also reported in oligotrophic and open sea areas (SUZUKI and TANIGUCHI, 1998).

Abundance ratio of picoplankton to heterotrophic nanoplankton ($3.33 \times 10^2 - 1.91 \times 10^3$) was stable, while it slightly decreased with depth (Fig. 6B). The vertical profile of picoplankton was parallel to that of heterotrophic nanoplankton. Picoplankton might have a close relationship with heterotrophic nanoplankton, as is usually reported in various sea areas (e. g. SANDERS *et al.*, 1992). On the other hand, the ratio to autotrophic nanoplankton (1.27×10^2–1.43×10^4) and that to ciliate plankton (4.13×10^5–7.07×10^6) increased substantially with depth (Figs. 6A and C). The vertical profiles of autotrophic nanoplankton and ciliates showed stronger decrease with depth rather than that of picoplankton. The relationship between picoplankton and autotrophic nanoplankton and that between picoplankton and ciliates might be trivial in this area. The contributions of autotrophic nanoplankton and ciliate plankton toward the microbial food webs were relatively large in the shallow layer and small in the deep layer.

The ratio of autotrophic nanoplankton to ciliates (1.92×10^2–1.90×10^4) did not show a significant change throughout the water column, while it varied widely (Fig. 7A). Autotrophic nanoplankton showed nearly parallel profile to ciliates. It might have a close relationship with ciliates and sustain the standing crop of ciliates. On the other hand, the ratio of heterotrophic nanoplankton to ciliates (2.85×10^2–1.85×10^4) increased with depth (Fig. 7B). Heterot-

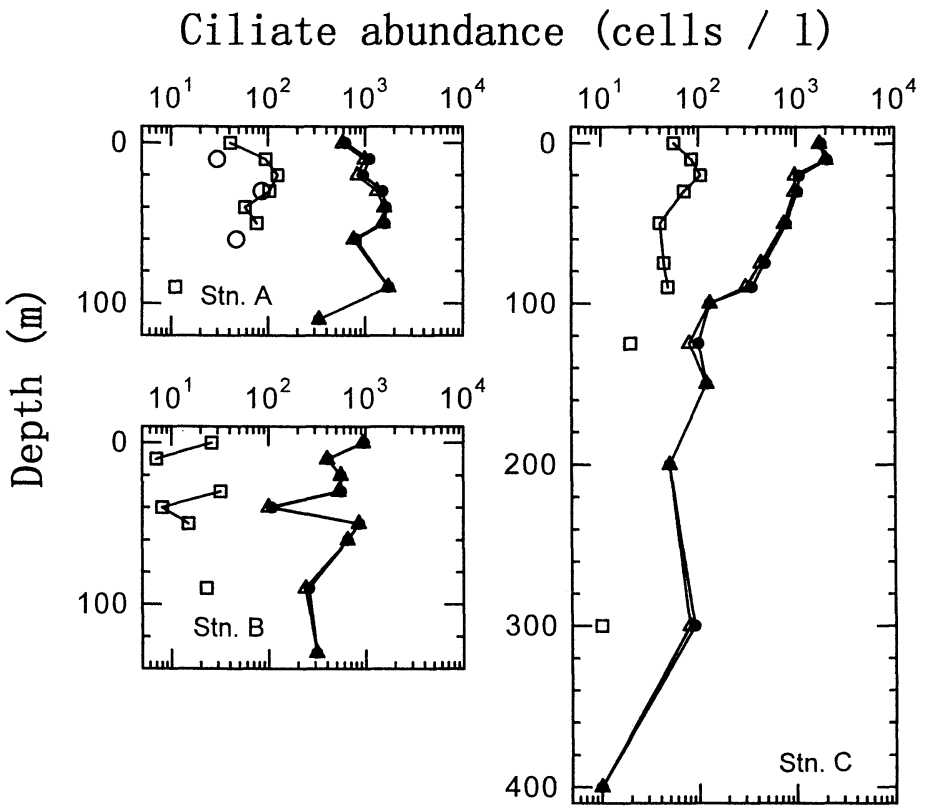

Fig. 5. Vertical profiles of ciliate abundance. ● : total ciliates, △ : naked ciliates except *Mesodinium* spp., □ : loricated ciliates, ○ : *Mesodinium* spp.

rophic nanoplankton showed dissimilar profile to ciliates, i.e. the former decreased more weakly with depth. The relationship between heterotrophic nanoplankton and ciliates might not be so substantial as that between autotrophic nanoplankton and ciliates.

From these abundance ratios, it is considered that there are two independent routes of energy flux in the microbial components; one is from picoplankton to heterotrophic nanoplankton and the other is from autotrophic nanoplankton to ciliate plankton. The former is relatively important in the deep layer and the latter is in the shallow layer. These scheme is different from the original microbial loop that the bacterial production is the primary energy source for ciliate production (AZAM *et al.*, 1983). Considering the microbial processes integrated through an entire water column, the shelf break zone in the East China Sea might be the boundary of microbial energy route, i. e. the link from autotrophic nanoplankton to ciliates is important in the continental shelf area and that from picoplankton to heterotrophic nanoplankton is in the Kuroshio current area.

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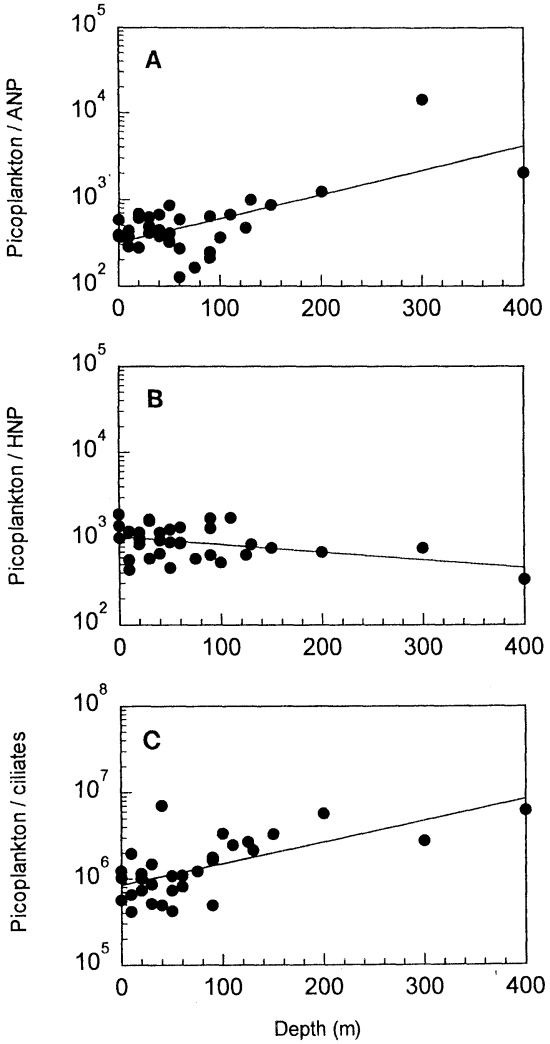

Fig. 6. Relationship between depth and abundance ratio of picoplankton to other plankton groups. Linear lines are drawn by the least square mehod on semilogarithmic scale. A: picoplankton / autotrophic nanoplankton (ANP), B: picoplankton / heterotrophic nanoplankton (HNP), C: picoplankton / ciliate plankton

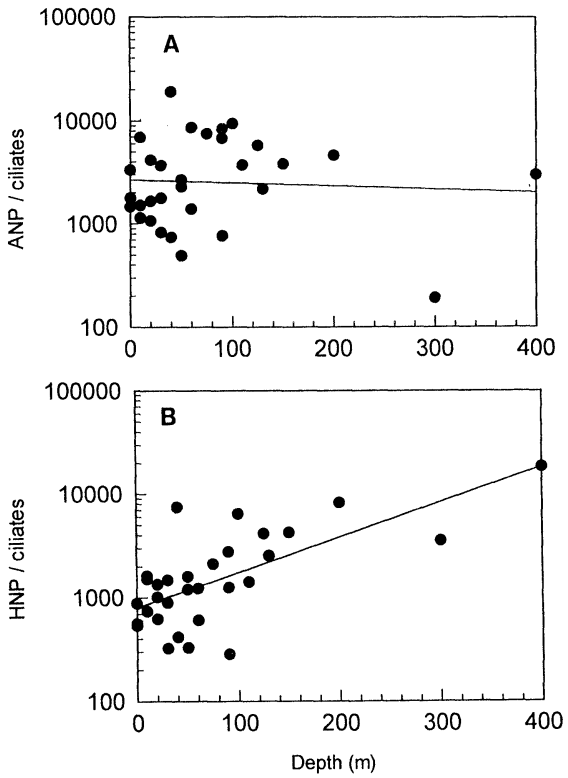

Fig. 7. Relationship between depth and abundance ratio of nanoplankton to ciliate plankton. Linear lines are drawn by the least square method on semilogarithmic scale. A: autotrophic nanoplankton (ANP) / ciliate plankton, B: heterotrophic nanoplankton (HNP)/ciliate plankton

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