

MICROZOOPLANKTON BIOMASS IN THE ARCTIC AND SUBARCTIC PACIFIC OCEAN IN SUMMER

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Abstract: Microzooplankton biomass and its relative abundance to net-zooplankton biomass were estimated in the Chukchi and Bering Seas and the northern North Pacific Ocean in summer. The dominant taxa were ciliates other than tintinnids, tintinnid ciliates and copepod nauplii. While the dominancy in individual number was high in the order described, nauplii were the most important in weight. Regional distribution of ciliates other than tintinnids coincided with that of chlorophyll stocks, being small in oceanic waters in the south, large in shelf waters in the north and largest at the shelf break in the center of the investigation areas. While the same positive relationship to chlorophyll was also observed roughly in tintinnids, it was not always substantial in copepod nauplii. Foraminifera, radiolarians, rotifers, and larvae of pteropods and bivalves formed minor constituents of the microzooplankton assembly.

Microzooplankton biomass estimated in this investigation (1.57–26.75 g wet weight/m²) was larger than the previously reported values from various arctic and subarctic seas. Its relative abundance to net-zooplankton (4.4–36.5%) was, though at the same level in other boreal seas, lower than those in the tropical and subtropical seas. This indicates that, in turn, contribution of nanoplankton to total phytoplankton is smaller in the boreal seas but larger in the tropics.

1. Introduction

The standing crops of total phytoplankton in summer are large in the boreal sea area where extensive winter mixing replenishes the euphotic layer with rich nutrients, and small in the tropical and subtropical sea areas where nutrients in the euphotic layer have been depleted under permanent stable conditions. On the other hand, the relative abundance of nanoplankton to total phytoplankton can be supposed to be large in the tropical seas but small in the boreal seas (*cf.* MALONE, 1980). The latter is recently proved (FURUYA and MARUMO, 1983).

Since the food relationship of most microzooplankters is probably established with nanoplankton rather than with total phytoplankton (*cf.* SPITTLER, 1973; TANIGUCHI, 1977), it is most likely that a relative importance of the microzooplankton to net-zooplankton is also large in the tropics but small in the high latitudes. However, only a few works from this point of view have been done in the high latitudes (LEBRASSEUR and KENNEDY, 1972; TAGUCHI, 1976; DOHI, 1982).

In this paper, quantitative data on microzooplankton biomass in the subarctic Pacific Ocean, the Bering and Chukchi Seas in summer are reported. Based on these

data, the relative abundance and the regional distribution of the microzooplankton are determined and compared with those reported from the tropical and subtropical seas.

2. Methods and Materials

One-liter water samples were collected with Niskin bottles from several layers in the upper water column at 15 stations, which had been selected along a north-south section from the Chukchi Sea to the northern North Pacific through the Bering Sea (Fig. 1). The samples were preserved by adding 10 ml of borax neutralized formalin. After standing, plankton were concentrated about 100 fold by gently withdrawing the supernatant with a siphon and then examined under an inverted microscope. Individual number and body size of the microzooplankters were taken.

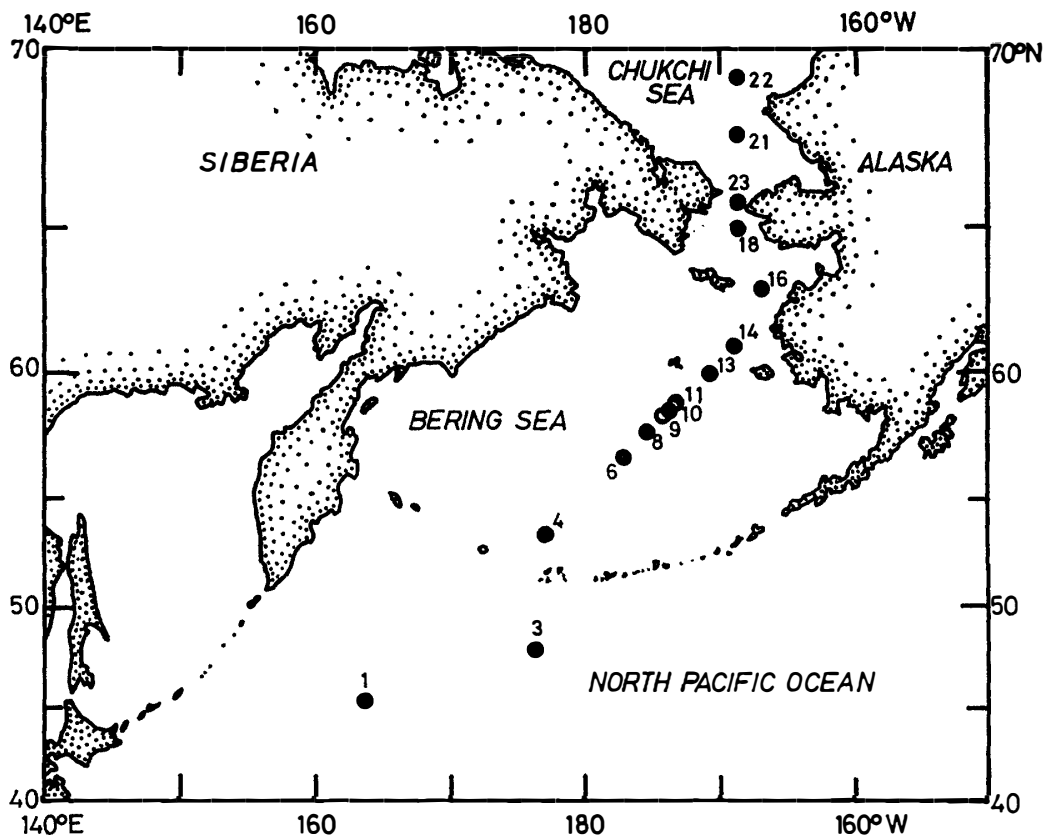


Fig. 1. Microzooplankton sampling stations which were occupied on the Cruise KH-78-3 of R. V. HAKUHO MARU in July 1978.

Volume of individual microzooplankters could be calculated by assigning proper geometric shapes to the organisms (see Appendix). Integrated biomass through the water column at each station was then calculated and compared with the net-zooplankton biomass which was estimated by the standard vertical hauls (150–0 m) with a Norpac net made of 350 μm netting in oceanic waters or in shelf waters from the near-bottom layer to the surface. The number of chambers of foraminiferal shells was

also counted but the result will be published elsewhere (TANIGUCHI and BÉ, unpublished).

Data on temperature, salinity and phytoplankton chlorophyll measured on other aliquots of the same water samples are cited from HATTORI (1979).

3. Results

3.1. Environmental background

In oceanic deep sea areas such as the North Pacific (Stns. 1 and 3) and Bering basin waters (Stns. 4 and 6), the water is stratified weakly, except at Stn. 6 where a thermocline occurs at a shallow depth between 30 and 50 m. In shelf waters of the Bering (Stns. 13, 14, 16 and 18) and Chukchi Seas (Stns. 21–23), thermal stratification of water, though weak at just north of the Bering Strait, was well defined. A halocline is not developed in the seas, except at Stns. 16 and 22 where the water of salinity less than 30‰ covered the surface and its temperature exceeded 10°C, the highest record in this investigation. The surface temperature in general was then high in the shelf waters in the north and low in the oceanic waters in the south. Cold bottom water with temperature below 0° or 2°C is one of the characteristic features of the hydrography in the shelf waters (Fig. 2a).

At the shelf break between the oceanic and shelf waters (Stns. 8–11), upwelling of the deep basin water, though not extensive, was indicated by a slight dome of contours of salinity (Fig. 2a) and of various nutrients (*cf.* HATTORI, 1979).

Only chlorophyll stocks of total phytoplankton were measured without sieving phytoplankton by size. Levels of the stocks were low in the oceanic waters and mid-shelf waters, and at the northernmost station (Fig. 2b). Hydrographic conditions of these three areas were characterized by a less intense thermocline (oceanic water), the extremely cold bottom water (mid-shelf) and the completely heated surface water (mid-shelf and northernmost stations). On the other hand, the levels of chlorophyll concentration were high in the northern basin, at the shelf break and in the southern Chukchi Sea. These are the areas where a marked thermocline is developed at a shallow depth, a slight upwelling occurs, and the surface heating does not advance or the surface is still covered with "new water". A large but patchy stock in the bottom layer observed at Stn. 21 might be derived from the newly melt ice. The same phenomena were already found and described by TANIGUCHI (1969), TANIGUCHI *et al.* (1976) and SAITO and TANIGUCHI (1978).

3.2. Distribution and abundance of microzooplankton taxa

The most dominant microzooplankters were non-loricate ciliates other than tintinnids or so-called naked ciliates such as the genera *Cyclotrichium*, *Laboea* (Plate A-1, Figs. 1–2), *Lohmanniella*, *Strobilidium* (Plate A-1, Figs. 3–4), *Strombidium* (Plate A-1, Figs. 5–7) and *Tontonia* (Plate A-1, Figs. 8–9). Tintinnid ciliates such as species of the genera *Acanthostomella*, *Codonellopsis*, *Parafavella*, *Ptychocylis*, *Stenosemella* and *Tintinnopsis*, and copepod nauplii followed naked ciliates. In addition to these, foraminifera and radiolarians (Protozoa, Sarcodina), *Noctiluca* (Protozoa, Dinoflagellata), medusae (Cnidaria), *Synchaeta* (Rotatoria) (Plate A-2, Fig. 8), *Sagitta* (Chaetognatha), *Limacina* (Mollusca, Pteropoda), *Fritillaria* and *Oikopleura*

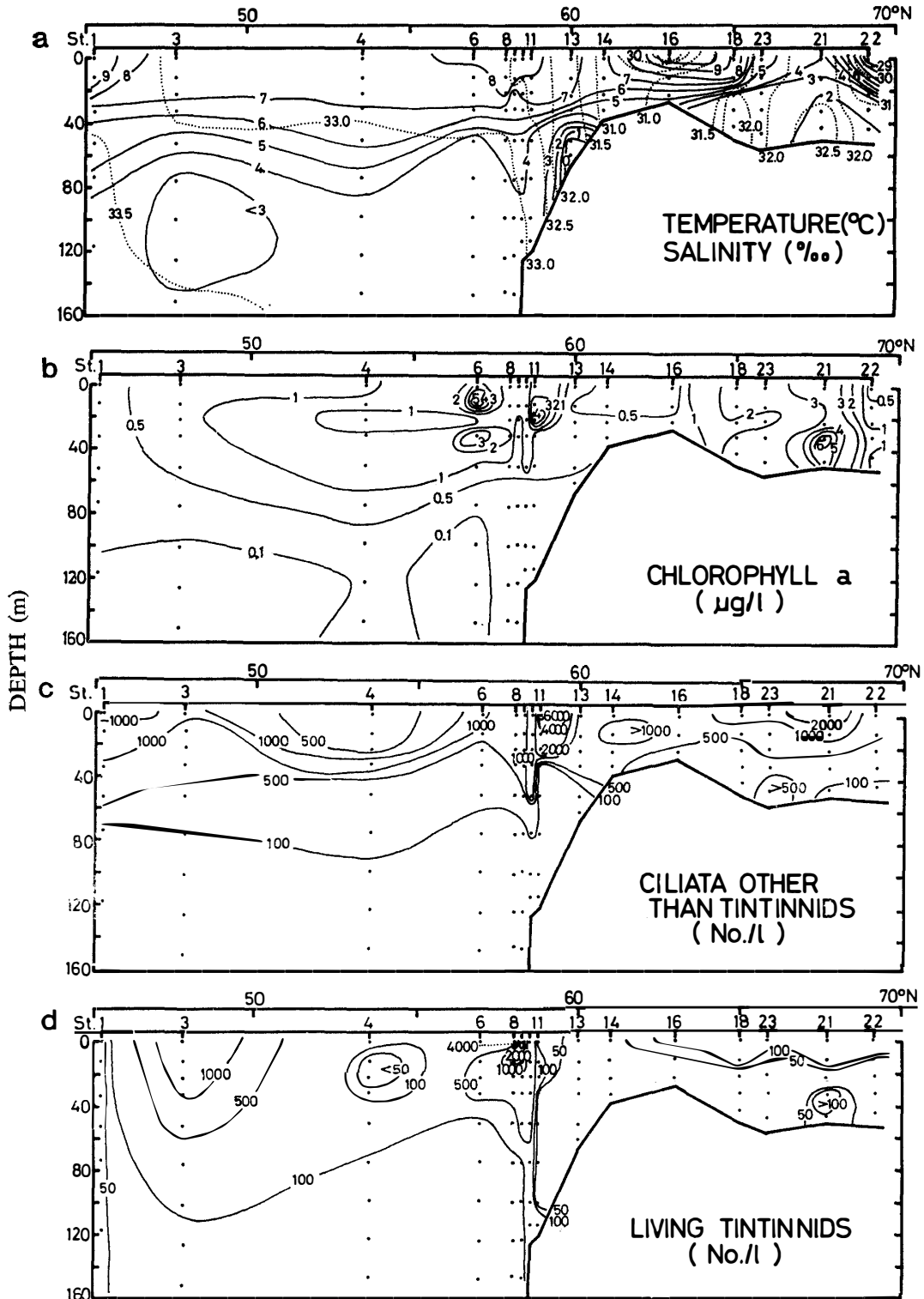


Fig. 2. Vertical profiles of environmental parameters and population densities and biomasses of various microzooplankton in the area of investigation. (a) temperature (solid line) and salinity (dotted line), (b) chlorophyll a concentration, (c) ciliates other than tintinnids, (d) tintinnids having intact lorica which were probably alive at the sampling time.

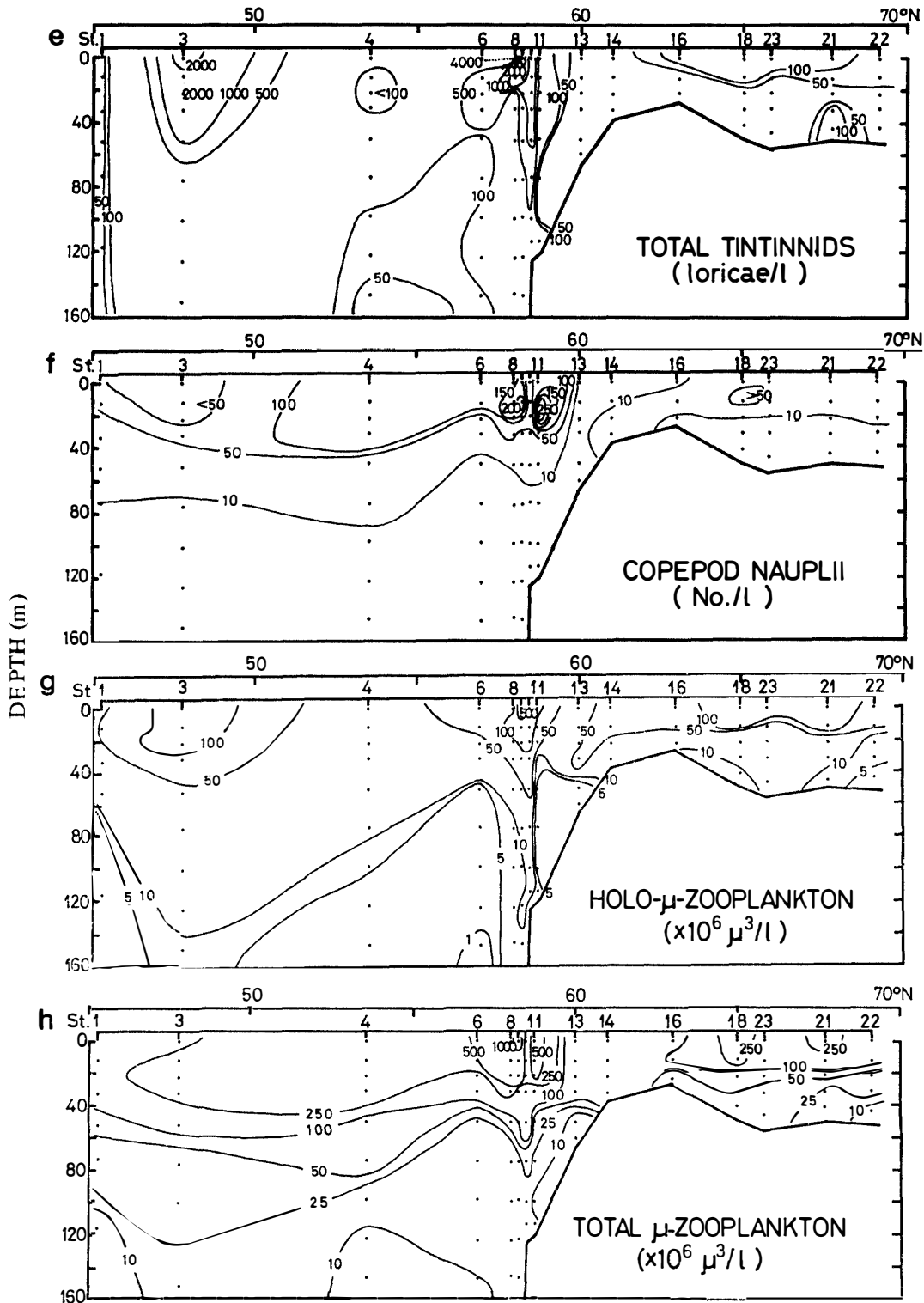


Fig. 2. (Continued) (e) total tintinnids including broken loricae which might have been attacked by larger zooplankton, (f) copepod nauplii, (g) biomass in volume of holomicrozooplankton which is composed of naked and tintinnid ciliates, foraminifera, radiolarians and rotifers, (h) biomass in volume of total microzooplankton including holomicrozooplankton and larvae of copepods, pteropods and bivalves.

(Prochordata, Appendiculata), copepod copepodites, and benthos larvae were also found in small numbers. Among them, however, organisms larger than 200 μm in maximum dimension were excluded from further analyses. Dominancy of naked ciliates and tintinnids was high in number, and nauplii were the most dominant component of the biomass. The rest constituted a minor part of the microzooplankton assembly in both number and biomass.

The contour of density of naked ciliates generally coincided with that of chlorophyll. Among commonly observed values of 500–1000 individ./l in the upper 50 m, the highest density (6644 individ./l) occurred at the surface at Stn. 11, which is located at the shelf break. The surface population at Stn. 21 in the Chukchi Sea was also large, viz. 2888 individ./l (Fig. 2c).

Intact loricae and broken loricae were separately counted to indicate living and dead numbers of tintinnids. The distribution of living tintinnids and the sum of living and dead tintinnids are illustrated in Figs. 2d and 2e. Living tintinnids were abundantly distributed in the surface layer at the shelf break. The maximum density of 4173 individ./l was recorded there. The density was also high in the surface layer of the oceanic waters, especially at Stn. 3, while it was low in the shelf waters. The total number of loricae was double the living number in the oceanic waters, but at the shelf break and in the north broken loricae formed a negligible part of the total number.

Acanthostomella norvegica (Plate A-3, Figs. 1–2), *Codonellopsis frigida* (Plate A-3, Figs. 3–4), *C. contracta* (Plate A-3, Fig. 5), *Parafavella denticulata* (Plate A-3, Figs. 8–10), *P. jorgenseni* (Plate A-3, Figs. 11–13), *P. subrotundata* (Plate A-4, Figs. 1–3), *P. ventricosa* (Plate A-4, Figs. 4–5) and *Ptychocylis obtusa* (Plate A-4, Figs. 6–9) were important components of the tintinnid populations in the oceanic waters, and *Ptychocylis* spp., *Tintinnopsis lohmanni* (Plate A-2, Fig. 6) and other *Tintinnopsis* spp. were important in the shelf waters. Although their density decreased with depth, *Stenosemella nivalis* (Plate A-2, Fig. 4) was predominant in the bottom layer at the shelf break and at Stn. 21 in the shelf waters. Species of *Stenosemella* are known to inhabit bottom layers of the shallow seas (CHESTER, 1978a; DOHI, 1982).

As a whole, the contour of density of tintinnid populations was somewhat different from that of chlorophyll distribution, being small in the shelf waters, whereas chlorophyll was rich there. At the shelf break and in the oceanic waters, however, the density was high as seen in the chlorophyll concentration.

Density of copepod nauplii exceeded 100 individ./l in the surface layer of the Bering basin waters and the shelf break. The highest density reached 260 individ./l at 10 m at Stn. 11. In the shelf waters of the Bering and Chukchi Seas, the nauplius population was small (Fig. 2f). Although these distributional modes coincided partly with the chlorophyll distribution, a positive relationship between the two may not be always substantial. The contour of the nauplius distribution coincided with that of chlorophyll in the oceanic waters and at the shelf break. However, the nauplius biomass was small in the chlorophyll-rich shelf waters.

In the vertical distribution of the three taxa just mentioned, the following features were commonly observed; decrease of density with depth was very rapid in the shelf waters and beneath 20–30 m their density was negligibly low excepting the bottom population of *Stenosemella* at Stn. 21. This phenomenon was probably caused

by a sharp vertical gradient of temperature and salinity which separated earlier the bottom system from the surface system. On the other hand, the distribution of the comparable surface microzooplankton populations extended down to the depth of 80–100 m in the oceanic waters. These indicate that the vertical extension of the epipelagic habitat was deep in the oceanic waters but shallow in the shelf waters in the boreal sea areas. Therefore, the biomass per unit volume of water averaged over the upper 100 m in the oceanic waters was higher than that over the entire water column in shallow shelf waters (30–50 m), and this trend was particularly pronounced in tintinnid and nauplius distribution (Figs. 2e and 2f).

Most individuals of foraminifera, radiolarians, rotifers and larvae of pteropods and bivalves were in the microzooplanktonic size. Foraminifera were distributed commonly throughout the water column in the oceanic waters, where the maximum density was 28 individ./l (75 m at Stn. 3). The density tended to decrease towards north and finally disappeared for the northern part of the shelf waters. Radiolarians occurred sporadically in the oceanic waters and were rarely found in the shelf waters. The maximum density was 3 individ./l (150 m at Stn. 3 and 125 m at Stn. 8).

The distribution of rotifers and bivalve larvae, in contrast with foraminifera and radiolarians, was confined to the shelf waters. Their maximum density was recorded at the surface at Stn. 23 to be 49 and 27 individ./l, respectively. Pteropods (juvenile *Limacina*) were distributed over the entire areas. Their density was high in the oceanic waters attaining the maximum of 29 individ./l at 30 m at Stn. 10 and low in the shelf waters. There could not be found a positive correlation between the last-mentioned five taxa and chlorophyll.

3.3. *Holo- and meromicrozooplankton*

Among microzooplankters identified here, naked and tintinnid ciliates, foraminifera, radiolarians and rotifers can be considered to be holomicrozooplankton but copepod nauplii and larvae of pteropods and bivalves were meromicrozooplankton (*cf.* TANIGUCHI, 1977). Figures 2g and 2h show the holomicrozooplankton biomass in volume excluding broken loricae of tintinnids, and the total microzooplankton biomass including meromicrozooplankton. Because the average size of tintinnids was larger than that of naked ciliates, the distributional pattern of biomass of holomicrozooplankton was essentially the same as that of tintinnids (Fig. 2g). Biomass of the total microzooplankton was about two times larger than the holomicrozooplankton biomass in the shelf waters where pteropod and bivalve larvae were abundant. On the other hand, the total biomass attained to 2–10 times of holomicrozooplankton in the oceanic waters (Fig. 2h). Decrease of biomass with depth was again sharp in the shelf waters and averaged values over water columns were large in the oceanic waters but small in the shelf waters, as seen in the population densities. This trend was more pronounced in the total biomass than in holomicrozooplankton.

3.4. *Relative abundance of microzooplankton to net-zooplankton*

Integrated biomass of microzooplankton through water column could be calculated by assuming their specific weight is unity, and then their relative abundance to net-zooplankton biomass can be determined. The integration was made through the

Table 1. Biomasses of total and holomicrozooplankton and net-zooplankton in the northern North Pacific, Bering Sea and Chukchi Sea in summer.

Station number	Total microzooplankton (g wet wt/m ²) (A)	Holomicrozooplankton (g wet wt/m ²) (B)	Net-zooplankton (g dry wt/m ²) (C)	Ratio (%)	
				A/C	B/C
Northern North Pacific					
1	9.94	2.15	4.35	22.9	5.0
3	14.82	6.19	1.95*	—	—
Mean	12.38	4.17			
Bering Basin waters					
4	22.09	1.94	14.25	15.5	1.4
6	11.54	2.11	6.90	16.7	3.1
8	21.02	5.52	21.15	9.9	2.6
9	26.75	9.59	17.55	15.2	5.5
10	18.05	7.71	11.44	15.8	6.7
11	24.10	2.15	35.64	6.8	0.6
Mean	20.59	4.84	17.82	13.3	3.3
Bering shelf waters					
13	2.49	1.72	3.35	7.4	5.1
14	2.64	1.72	No data	—	—
16	1.57	0.88	0.78	20.0	11.2
18	5.26	2.08	1.44	36.5	14.5
Mean	2.99	1.60	1.86	21.3	10.3
Chukchi Sea					
21	4.18	2.75	3.62	11.6	7.6
22	2.63	1.03	5.93	4.4	1.7
23	4.01	1.81	3.83	10.5	4.7
Mean	3.61	1.86	4.46	8.8	4.7

* This value was excluded from further calculations (see text).

upper 100 m column where most microzooplankton inhabited the oceanic waters or from the surface down to near bottom in the shallow shelf waters (Table 1). Of the data on net-zooplankton biomass, the lower value at Stn. 3 is likely to have resulted from some sampling errors, because relevant parameters such as nutrients, chlorophyll, primary productivity, suspended solid *etc.* indicate that the biological productivities at this station might exceed that at Stn. 1 (*cf.* HATTORI, 1979). Therefore, this datum is not adopted in further discussion.

Integrated biomass, especially of total community, was clearly large in the oceanic waters. This arose from the facts that thickness of water column and average biomass in it were both greater in those waters. Mean biomasses of total microzooplankton in the deep oceanic waters and in the shallow shelf waters were 12.38–20.59 and 2.99–3.61 g wet wt/m², respectively. Those of holomicrozooplankton were 4.17–4.84 and 1.60–1.86 g wet wt/m², or they accounted for 24–34% and 52–54% of the total biomass in the respective areas. The rest were mainly occupied by copepod nauplii, the regional distribution of which is given in Fig. 2f. Their relative abundance to net-zooplankton, although the degree of discordance among the oceanic and shelf waters was consequently different for total and holomicrozooplankton, was 4.4–36.5%

for the total community and 0.6–14.5% for holomicrozooplankton (Table 1).

4. Discussion

Table 2 gives the reported values, mostly the maximum values, of the density of representative microzooplankton populations in the boreal sea areas by previous workers.

Density of naked ciliates in coastal waters is very high. In some cases it is noted that a large part of the naked ciliate populations was occupied by *Mesodinium* sp. as-

Table 2. Population density of naked ciliates, tintinnid ciliates and copepod nauplii previously recorded from the arctic and subarctic sea areas. The density is given in individual number per liter.

Sea area	Naked ciliates	Tintinnid ciliates	Copepod nauplii	Sampling season	Sampling gear and depth (m)	Reference
Kara Sea		1.4		September	Net (# 73), 0–25	BURKOVSKY, 1976a
White Sea		43		July	Net (# 77), 0–25	BURKOVSKY, 1976b
Oslofjord, Norway	1500–10500	0.01–0.1 320–4220	100–1280	Winter June–September	Bottle, 0–2	PAASCHE and KRISTIANSEN, 1982
Gullmar Fjord, Sweden		379		July	Net (30 μ m), 1	HEDIN, 1975
Bedford Basin, Canada		100–100000*		Summer	Bottle, 0–15	PARANJAPE, 1980
Strait of Juan de Fuca, Canada-USA	Ca. 3000–12000	–2010	–160	June	Bottle, 0	CHESTER, 1978b
Saanich Inlet, Canada	1700–11880**		2–22	Winter–Spring	Pump, 0–5 & 0–15	TAKAHASHI and HOSKINS, 1978
Off Washington, USA coastal water	2700–27000	360–2000	20–160	October	Bottle, 3	LANDRY and HASSETT, 1982
oceanic water	Ca. 1500–2800	–100	–63	July	Bottle, subsurf. chl. max.	CHESTER, 1978a
Pacific Subarctic Current		–60	–200	Summer	Bucket, 0	OHWADA and ASAOKA, 1963
Off Sanriku, Japan oceanic water	813–4782	–220 –700	–30 –21	Winter Spring	Bottle, 0–500 Bucket, 0	SANO, 1966 TANIGUCHI, 1983
		–320	–340	Summer	Bottle, 0–500	SANO, 1966

* Single population of *Helicostomella subulata*.

** Total ciliate populations probably including tintinnids.

sociated with a symbiotic alga (*e.g.*, CHESTER, 1978b; TAKAHASHI and HOSKINS, 1978). In the oceanic areas naked ciliates are likely to occur on the level of several thousand individuals per liter in warm seasons, and the density counted in the Bering and Chukchi Seas was on this level (Fig. 2c).

Tintinnids are also productive in the coastal waters, where population density of 1000–5000 individ./l is usually found. The density of the oceanic populations is about one order of magnitude lower than this. Crawling Bedford Basin with a *Helicostomella* population (100000 individ./l) reported by PARANJAPÉ (1980) might be an unusual case; such a dense population has not been observed in other coastal areas of the world oceans. Even in eutrophic and productive estuaries and embayments such as River Tamar estuary, England (DALE and BURKILL, 1982), Bay of Algeria (VITIELLO, 1964), Vellar estuary, India (KRISHNAMURTHY and NAIDU, 1977), Tokyo Bay, Japan (MARUMO *et al.*, 1974), the density of total populations seldom exceeds 35000 individ./l.

In the Kara and White Seas, though their latitudinal positions are almost the same as the Bering and Chukchi Seas, tintinnid populations are quite smaller than in the latter seas. Tintinnid biomass might be also small in the high Arctic Ocean (*cf.* TIBBS, 1967). These suggest that tintinnids cannot inhabit persistently high arctic nor low arctic sea areas under negligible influence of currents from the south, *e.g.*, Gulf Stream and Pacific Subarctic Current. No indigenous tintinnid species to the Arctic Ocean have been known.

Copepod nauplii are probably not always abundant in coastal waters compared with oceanic waters. In the boreal seas, spawning season of most copepods is limited to spring-summer and then the density of nauplius populations in this season might be undifferent with localities. In other words, a temporal difference within the same locality may sometime be greater than a regional difference. A range from a few tens up to 400 individ./l seems to indicate an average variability of their density (Table 2 and Fig. 2).

Population densities of these three dominant components in the present study areas are generally comparable with or larger than other oceanic areas but smaller than coastal areas of the boreal seas in summer.

Apart from major components, only a few previous data are available for minor microzooplankters. Referring to them it can be indicated that, although radiolarians sometimes occur nearly 50 individ./l (CHESTER, 1978b), foraminifera usually occur less than 5 individ./l (CHESTER, 1978b; TANIGUCHI, 1983) in the boreal seas. The present study areas, therefore, are rich in foraminifera but poor in radiolarians. However, as mentioned previously, foraminifera were totally absent in the shallow shelf waters of the Bering and Chukchi Seas. They can be found again in the deep waters further north (TIBBS, 1967; BÉ and TOLDERLUND, 1971).

The results on biomass of microzooplankton and its relative abundance to net-zooplankton estimated in this study can be compared with the previously reported values from subarctic and north temperate sea areas, though the values had been reported in very diverse dimensions (Table 3). As a whole, microzooplankton abundance in the northern North Pacific and Bering basin waters is larger than in other oceanic sea areas such as the Gulf of Alaska and the Sanriku waters. The abundance in the shelf waters of the Bering and Chukchi Seas is also larger than in other shallow sea

Table 3. Biomasses of microzooplankton and net-zooplankton in the arctic and subarctic sea areas.

Sea area	Microzooplankton (A)	Net-zooplankton (B)	Ratio (%) (A/B)	Reference
Chukchi Sea	3.61 g wet wt/m ² (0-50 m)	4.46 g dry wt/m ² (0-50 m)	8.8	This study
Bering Sea				
shelf waters	2.99 g wet wt/m ² (0-50 m)	1.86 g dry wt/m ² (0-50 m)	21.3	This study
basin waters	20.59 g wet wt/m ² (0-100 m)	17.82 g dry wt/m ² (0-150 m)	13.3	This study
Gulf of Alaska	15 mg wet wt/m ³ (0-100 m)	115 mg wet wt/m ³ (0-150 m)	13.0	LEBRASSEUR and KENNEDY, 1972
Northern North Pacific	12.38 g wet wt/m ² (0-100 m)	4.35 g dry wt/m ² (0-150 m)	22.9	This study
Strait of Georgia, Canada	14 mg wet wt/m ³ (0-100 m)	300 mg wet wt/m ³ (0-150 m)	4.8	LEBRASSEUR and KENNEDY, 1972
Saanich Inlet, Canada*	16.8 mg C/m ² (0-25 m)	No data	—	TAKAHASHI and HOSKINS, 1978
Akkeshi Bay, Japan	0.37-6.4 mm ³ /m ³ (0-20 m)	—	0.02-0.9	TAGUCHI, 1976
Funka Bay, Japan**	21.47 mm ³ /m ³ (0-80 m)	159.63 mm ³ /m ² (0-80 m)	15.9	DOHI, 1982
Off Sanriku, Japan				
oceanic cold water	4.80 g wet wt/m ² (0-100 m)	42.27 g wet wt/m ² (0-150 m)	11.3	TANIGUCHI (unpublished)
oceanic warm water***	1.73 g wet wt/m ² (0-100 m)	7.32 g wet wt/m ² (0-150 m)	23.7	TANIGUCHI (unpublished)

* Sum of ciliate biomass in 0-5 m and nauplius biomass in 0-25 m.

** Only tintinnid biomass was included.

*** The water mass was derived from the subtropical Kuroshio Current.

areas except Funka Bay, Japan. If copepod nauplii are taken into account, the microzooplankton biomass in Funka Bay might exceed the present values in the shelf waters.

The relative abundance of microzooplankton to net-zooplankton in the boreal seas ranges from 4.8 to 22.9%, excepting uncommonly low values in Akkeshi Bay (Table 3). Although the range is not narrow, the values are lower than those in tropical, subtropical and southern temperate seas (*cf.* ENDO *et al.*, 1983) as well as in the warm water mass off Sanriku, Japan (Table 3). These facts indicate that the relative abundance of microzooplankton is small in the boreal seas, which in turn suggests that contribution of nanoplankton to total phytoplankton is smaller in the boreal seas than in the tropics (FURUYA and MARUMO, 1983). However, this does not necessarily follow that the microzooplankton is not important in the boreal seas. As mentioned previously, their absolute biomass in the boreal seas is comparable to or sometimes exceedingly larger than those in the tropical and subtropical seas. Consequently, the fundamental importance of the microzooplankton, especially of the holomicrozooplankton, as an energy transferrer which is interlinking nanoplankton and bacteria to net-zooplankton must be emphasized in the boreal seas.

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Appendix

Table A-1. Assigned geometric shape, measured body size and calculated body volume of representative microzooplankters in the Arctic and Subarctic Pacific Ocean. D =diameter, L =length and L/D =length/diameter ratio of the plankters, and r =radius of the assigned shapes.

Microzooplankter	Shape	Size (μm)	Volume ($\times 10^3 \mu\text{m}^3$)
Ciliates other than tintinnids ¹⁾			
<i>Cyclotrichium</i>	Sphere (I)	$D=27.5 \pm 6.8$ ($n=70$)	10.9
<i>Lacrymaria</i>	Sphere (II)	$D=46.0 \pm 3.7$ ($n=674$)	51.0
<i>Laboea</i>	Sphere (III)	$D=56.0 \pm 4.2$ ($n=321$)	91.8
<i>Lohmanniella</i>	Cone (I)	$D=16.6 \pm 0.5$, $L/D=1.3 \pm 0.2$ ($n=50$)	1.6
<i>Strobilidium</i>	Cone (II)	$D=27.9 \pm 6.3$, $L/D=1.4 \pm 0.2$ ($n=83$)	8.0
<i>Strombidinopsis</i>	Cone (III)	$D=51.4 \pm 7.3$, $L/D=1.6 \pm 0.2$ ($n=350$)	57.3
<i>Strombidium</i>	Cylinder	$D=46.6 \pm 10.4$, $L/D=1.1 \pm 0.1$ ($n=104$)	88.2
<i>Tontonia</i>			
<i>Trimyema</i>			
Others			
Tintinnid ciliates			
<i>Acanthostomella norvegica</i>	Cylinder (2/3L) + cone (1/3L)	$D=23.8 \pm 0.8$, $L=38.4 \pm 2.6$ ($n=163$)	13.3
<i>Codonellopsis frigida</i>	Cylinder (1/2L) + sphere (1/2L)	$D=23.5 \pm 0.6$, $L=71.7 \pm 1.4$ ($n=85$)	35.5
<i>C. contracta</i>	Cylinder (1/3L) + sphere (2/3L)	$D=25.0 \pm 1.9$, $L=72.5 \pm 2.8$ ($n=20$)	39.8
<i>Leprotintinnus pellucidus</i>	Cylinder	$D=38.8 \pm 1.6$, $L=159.7 \pm 19.1$ ($n=20$)	188.7
<i>Parafavella denticulata</i> ²⁾	Cylinder (1/2L) + cone (1/2L)	$D=51.4 \pm 2.6$, $L=181.5 \pm 59.7$ ($n=25$)	250.8
<i>P. jorgenseni</i>	Cylinder (2/3L) + cone (1/3L)	$D=43.7 \pm 1.5$, $L=97.0 \pm 6.1$ ($n=43$)	113.2
<i>P. subrotundata</i> ³⁾	Cylinder	$D=56.8 \pm 2.1$, $L=152.2 \pm 19.9$ ($n=63$)	385.7
<i>P. ventricosa</i>	Cylinder	$D=60.9 \pm 3.1$, $L=279.5 \pm 45.7$ ($n=61$)	814.2
<i>Ptychocylis obtusa</i> (Stns. 1-11) ⁴⁾	Cylinder (2/3L) + cone (1/3L)	$D=54.4 \pm 1.2$, $L=87.6 \pm 5.4$ ($n=63$)	158.4
<i>P. obtusa</i> (Stns. 13-23) ⁴⁾	Cylinder (2/3L) + cone (1/3L)	$D=66.7 \pm 0.4$, $L=121.4 \pm 6.0$ ($n=113$)	330.0
<i>Salpingacantha ampla</i>	Cylinder ($r=0.2D$)	$D=40.0 \pm 1.4$, $L=227.4 \pm 11.0$ ($n=9$)	45.7
<i>Salpingella acuminata</i>	Cylinder ($r=0.2D$)	$D=43.0 \pm 2.3$, $L=243.3 \pm 15.7$ ($n=7$)	56.5
<i>Stenosemella nivalis</i>	Sphere ($r=D$)	$D=17.6 \pm 1.0$, $L=45.4 \pm 1.2$ ($n=16$)	22.8
<i>Tintinnopsis lohmanni</i>	Cylinder (1/2L) + cone (1/2L)	$D=45.9 \pm 2.1$, $L=67.5 \pm 5.0$ ($n=66$)	74.4
Other <i>Tintinnopsis</i>	Cylinder (1/2L) + cone (1/2L)	$D=35.7 \pm 9.9$, $L=66.3 \pm 13.0$ ($n=305$)	44.2
Rotatoria			
<i>Synchaeta</i> sp.	Cone	$D=81.6 \pm 2.4$, $L=130.0 \pm 10.8$ ($n=10$)	226.6
Copepoda			
Nauplius larvae	Ellipsoid	$D=70.8 \pm 16.9$, $L/D=1.98 \pm 0.11$ ($n=637$)	367.5

¹⁾ Identification of species and genera of ciliates other than tintinnids during routine cell countings was sometimes very difficult. Therefore, only their shape and size were determined and then their wide range of body size was divided into three size classes.

²⁾ Also including a few number of *P. dilatata*, *P. gigantea*, *P. hadai* and *P. hemifusus*.

³⁾ Also including a few number of *P. cylindrica* and *P. rotundata*.

⁴⁾ Also including a number of *P. arctica*, *P. cylindrica* and *P. drygalskii*. Because body size of *Ptychocylis* was clearly smaller at the southern stations (Stns. 1-11) comparing with that at the northern stations (Stns. 13-23), the two geographical groups were separately dealt.

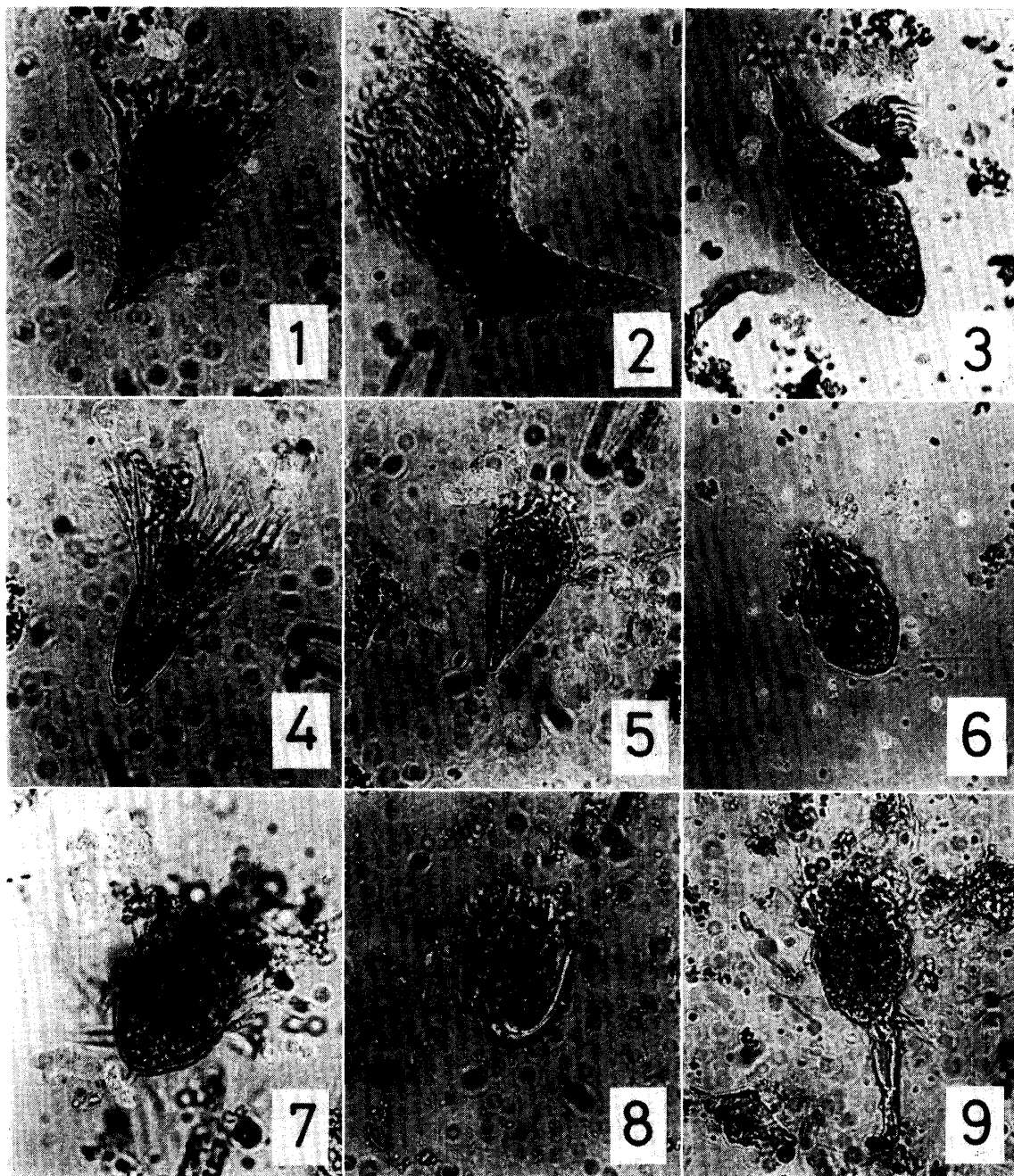


Plate A-1. Ciliata other than tintinnids ($\times 224$). Since these microphotographs were taken during routine cell countings, other detrital particles also came out.

- Fig. 1. *Laboea strobila* LOHMANN.
- Fig. 2. *Laboea strobila* LOHMANN, "monster form?"
- Fig. 3. ?*Lacrymaria* sp. (large specimen) and *Strobilidium* sp. (small specimen).
- Fig. 4. *Strobilidium acuminatum* (FAURÉ-FREMIET).
- Fig. 5. *Strombidium conicum* (LOHMANN).
- Fig. 6. *Strombidium lagenula* FAURÉ-FREMIET.
- Fig. 7. *Strombidium* sp. cf. *stylifer* LEVANDER.
- Fig. 8. *Tontonia* sp. cf. *gracillima* FAURÉ-FREMIET.
- Fig. 9. ?*Tontonia gracillima* FAURÉ-FREMIET.

Plate A-2

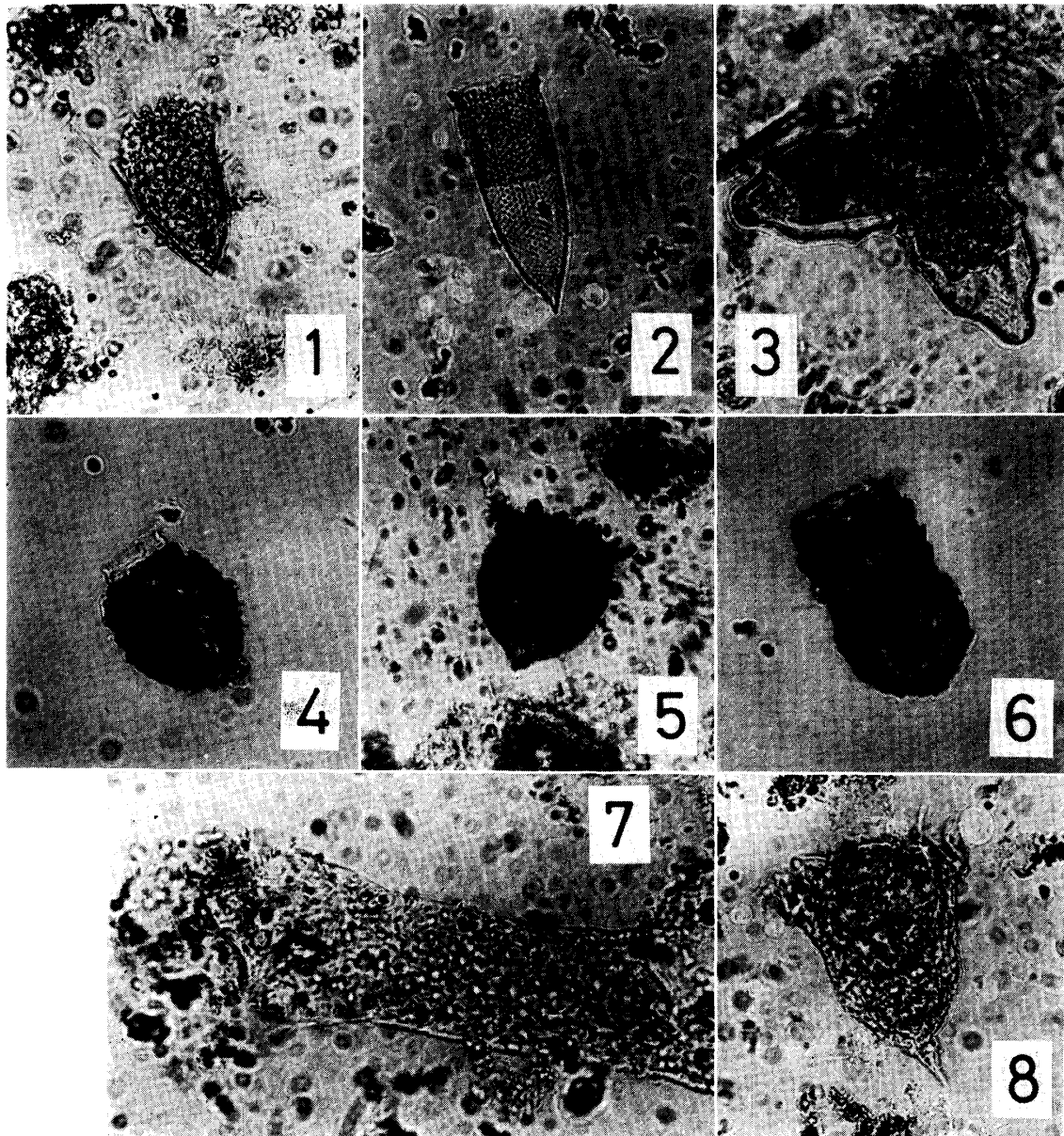


Plate A-2. Tintinnid Ciliata and Rotatoria ($\times 448$ for Figs. 4 and 6; $\times 224$ for the rest).

- Fig. 1. Unknown tintinnid having a hyaline conical lorica.
- Fig. 2. Abnormal lorica of *Parafavella jorgensei* HADA of which suboral part is constructed in duplicate.
- Fig. 3. Unusual conjugation of *Ptychocylis obtusa* BRANDT. Left individual seems to be conjugating to the other two individuals, while no conjugation occurs between the latter. Top individual has an abnormal lorica of which aboral end is incomplete.
- Fig. 4. *Stenosemella nivalis* (MEUNIER).
- Fig. 5. *Tintinnopsis fimbriata* MEUNIER.
- Fig. 6. *Tintinnopsis lohmanni* LAACKMANN.
- Fig. 7. Copepod fecal pellet containing an *Acanthostomella* lorica (right side) and a few crunched *Parafavella* loricae at the left end.
- Fig. 8. *Synchaeta* sp. (Rotatoria).

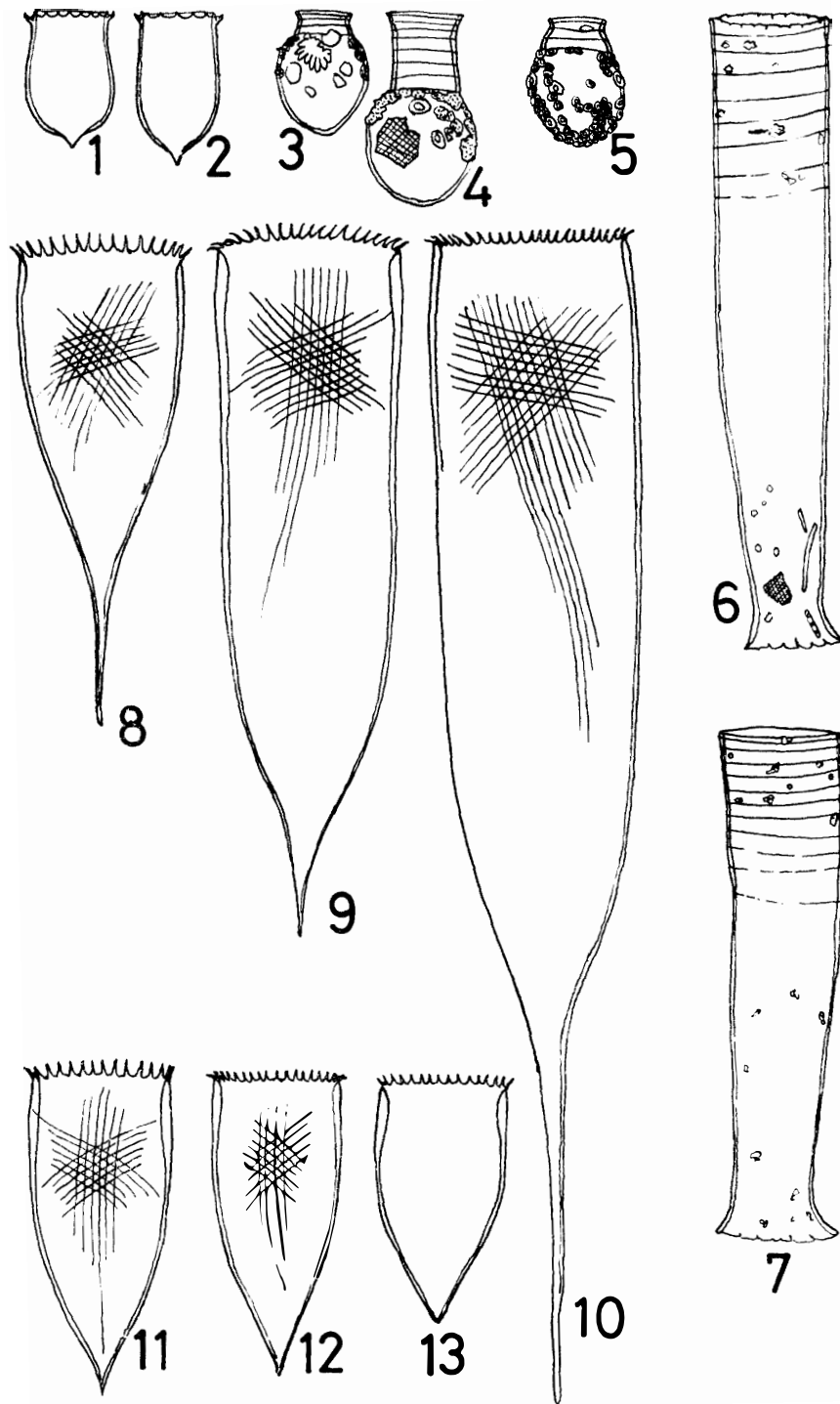


Plate A-3. Dominant tintinnid Ciliata-I ($\times 362$).

- Figs. 1-2. *Acanthostomella norvegica* (DADAY).
- Figs. 3-4. *Codonellopsis frigida* HADA.
- Fig. 5. *Codonellopsis contracta* KOFOID and CAMPBELL.
- Figs. 6-7. *Leprotintinnus pellucidus* (CLEVE).
- Figs. 8-10. *Parafavella denticulata* (EHRENBERG).
- Figs. 11-13. *Parafavella jorgenseni* HADA.

Plate A-4

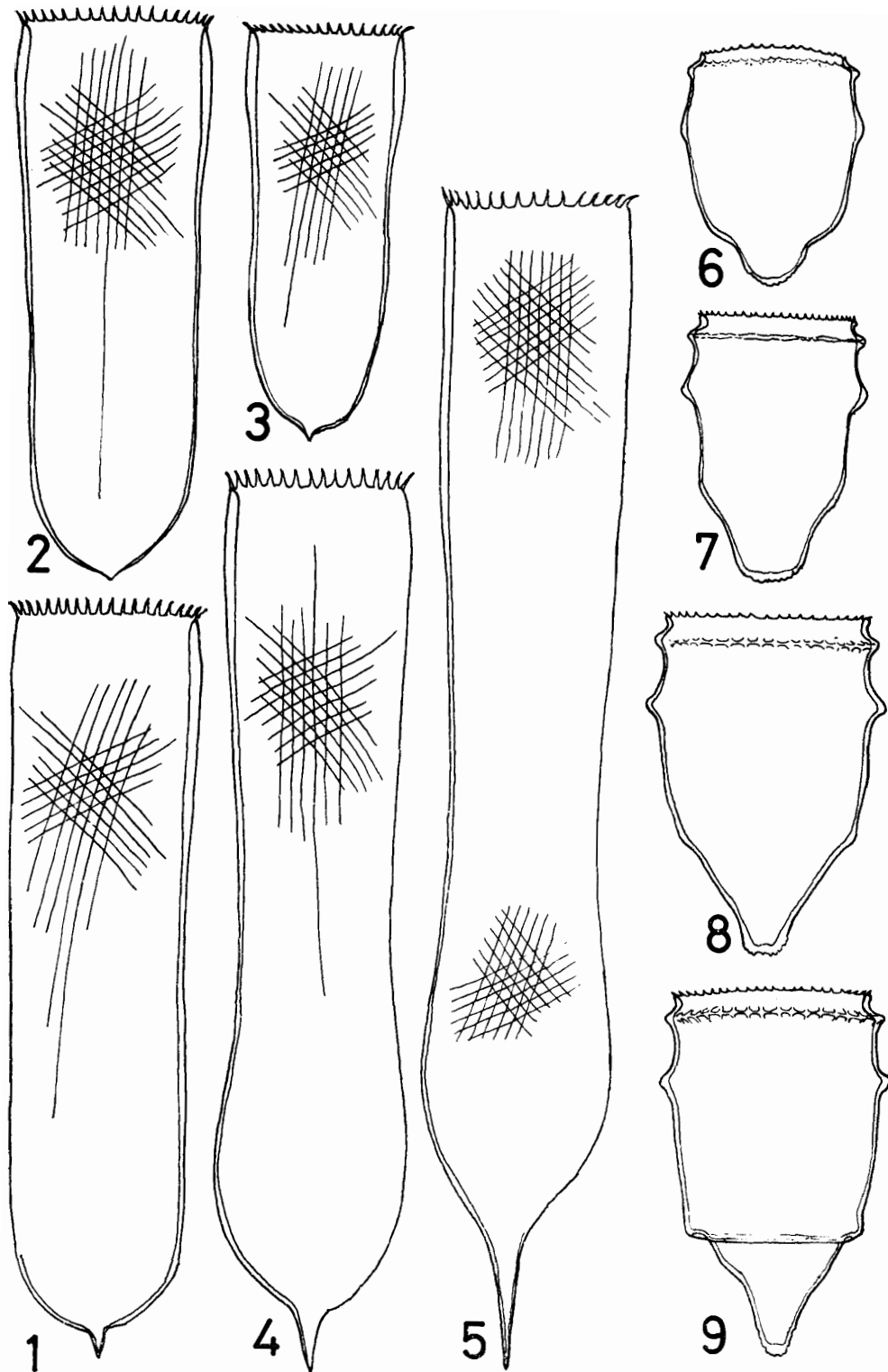


Plate A-4. Dominant tintinnid Ciliata-II ($\times 362$).

Figs. 1-3. *Parafavella subrotundata* (JÖRGENSEN).

Figs. 4-5. *Parafavella ventricosa* (JÖRGENSEN).

Figs. 6-7. Small-sized *Ptychocylis obtusa* BRANDT occurred at Stns. 1-11.

Figs. 8-9. Large-sized *Ptychocylis obtusa* BRANDT occurred at Stns. 13-23.