THE VERTICAL DISTRIBUTION OF MICRO-ZOOPLANKTON AND SOME ECOLOGICAL OBSERVATIONS

By

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Major taxonomic groups of the micro-zooplankton populations were identified and their numerical abundance determined in several depth intervals over the upper 100 or 200 m from coastal (Sta. I), continental shelf (Sta. II and III), and oceanic (Sta. IV) sites in the north-eastern Pacific Ocean. Micro-zooplankton is defined as all animal plankters which passed 202 μ mesh filter cloth. The samples were obtained with a submersible pump system and deck-mounted plankton collecting unit which separated the material into three size fractions. In addition to micro-zooplankton abundance, chlorophyll *a*, phaeo-pigments, and seston dry weight levels were determined on each sample.

Total micro-zooplankton numbers averaged 730, 740, 970, and 270 × $10^3/m^3$ over the euphotic zone at Stations I–IV, respectively, and 250, 140, 88, and 140 × $10^3/m^3$ below the compensation depth at the respective sites. Organisms passing through 35 μ mesh cloth (−35 sample) dominated the populations throughout the water column sampled at each site. Averaged from the depth intervals sampled, the numbers of organisms retained by 35 μ cloth were 25, 12, 7, and 8% of the total micro-zooplankton at Stations I–IV, respectively, while at all sites animals retained by 103 μ cloth (+103 sample) were only 1–2%. Protozoans were numerically dominant in the −35 and +35 samples with metazoans relatively most abundant in +103 samples.

A decrease in the average numbers of micro-zooplankton/m^3 in the euphotic zone was observed between neritic and oceanic sites. However, the greatest number of micro-zooplankton per unit chlorophyll *a* was found at the open ocean site and the lowest number at the coastal station. The possible ecological significance of this distribution is discussed.

INTRODUCTION

Size fractionation of marine phytoplankton populations has shown that generally the majority of plant cells are small, not being retained by fine mesh nets (WOOD and DAVIS, 1956; YENTSCH and RYTHER, 1959; and TEIXEIRA, 1963). Many of the phytoplankters may be of marginal size for efficient use by much of the commonly studied zooplankton, *i.e.* that part of the total animal population which is sampled with nets of a mesh size greater than approximately 0·2 mm (see ANRAKU and OMORI, 1963).

Although there has been considerable speculation that micro-zooplankton may play an important role as a trophic level intermediate between the phytoplankton and the larger zooplankton (*e.g.* BANSE, 1962; MARGALEF, 1967), studies of these small animals have been limited, particularly in oceanic areas. This is partly due to difficulties in adequate sampling.

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Recently we have assembled a submersible pump system with a deck-mounted plankton collecting unit (BEERS, STEWART, and STRICKLAND, 1967) designed to provide reliable quantitative samples of the microplankton. Micro-zooplankton populations in the euphotic zone have been examined at several locations across the California Current (BEERS and STEWART, 1967) and, while it is not possible without data on feeding, reproduction rates and other physiological activities to define the importance of the various taxa in food chain dynamics, the numbers and estimated biomass are consistent with the suggestion that they may have a significant role.

In the present study we have examined the vertical distribution of the standing stock of three size classes of micro-zooplankton within depth intervals in and below the euphotic zone at four locations with different hydrographic conditions in the north-eastern Pacific Ocean. Micro-zooplankton in this study is defined as all animal plankters which pass 202 μ mesh filter cloth and are fixed and preserved in a recognizable form under the experimental procedures followed. In addition, the chlorophyll *a*, phaeo-pigments, and total particulate matter (seston) content of the water have been determined in the same strata. The inorganic nutrient and temperature structure through the euphotic zone was measured at the various sites.

MATERIALS AND METHODS

A complete description of the submersible pumping system and deck-mounted plankton collecting unit is in BEERS *et al.* (1967). Sampling locations are listed in Table 1. Station I was in the neritic province while the other sites were oceanic, Stations II and III being on the continental shelf and Station IV in oceanic water deeper than 3500 m. The sampling dates, although in two different years, were all during the same season (Table 1). All pumping was done around mid-day in order to minimize effects of possible vertical migration of the microplankton. Six depth intervals or strata covering the upper 200 m were sampled at Stations II–IV. At Station I samples were obtained from five intervals from the surface to 100 m. Depth intervals ranged from 10–75 m and were shorter in the euphotic zone than below the compensation depth. The pump was moved through each stratum in short steps, 1–1·5 m, at time intervals, generally 1–2 minutes, dependent upon the anticipated amount of particulate material. In each case the rate of vertical movement was calculated so as to obtain as great a volume of seawater filtered as reasonable without clogging the filter cloths. The pump delivered approximately 130 l/min. Although at no time was there any hose angle apparent at the surface a Benthos

TABLE 1. The location of sampling sites and the estimated depth of the euphotic zone

Station	Date	Location		Depth of water (m)	Depth of euphotic zone (3x Secchi disc) (m)
		Longitude W	Latitude N		
I	12. March 1966	117°19·1′	32°59·3′	110	27
II	13. March 1966	117°58·7′	32°59·3′	900	63
III	7. February 1967	117°30′	32°30′	1100	72
IV	9. February 1967	119°00′	28°30′	3700	100

Submersible Depth Recorder, placed below the pump, was used as a check on the depths of sampling at Stations III and IV.

All plankton and other particulate matter which could pass 202 μ mesh filter cloth was sampled. Two size fractions were separated from the pumped seawater and concentrated by filter cloths in the collecting unit. These were the material retained on 103 μ cloth (+103 sample) and that passing the 103 μ cloth and retained on 35 μ cloth (+35 sample). Organisms and detritus passing the 35 μ cloth (−35 sample) were sampled as described by BEERS and STEWART (1967). All samples were fixed and preserved in approximately 5% formalin buffered with sodium borate or hexamethylene-tetramine to approximately pH 8.

Enumeration of the micro-zooplankton was by the inverted microscope method of UTERMÖHL (1931) using magnifications of 200× (−35 sample) and 100× for the +35 and +103 material. Taxonomic separation of organisms was to major group only. The protozoan groups differentiated were Foraminifera, Radiolaria, Tintinnida, and "Ciliata other than Tintinnida", while the metazoan forms distinguished were naupliar Copepoda, post-naupliar Copepoda, and "other Metazoa". With the exception of the deep samples from Stations I and II, a minimum of 100 organisms were counted in the unconcentrated −35 samples. Total settled volumes ranged from 300 ml to 2300 ml. Four to eight sub-samples of the concentrated +35 and +103 samples were counted. These were each of 1–10 ml, removed from the mixed sample with wide-mouth pipettes. Where practical, 100 organisms of each major group in a sample were counted. The enumeration of multiple sub-samples was thought to be desirable in obtaining a truer average figure for the different plankton groups since chi-square values for testing the randomness of each of the various plankton groups in the sub-samples for any given sample showed some variability, particularly in the metazoan groups. Significant deviations (0·05 level) from random distribution were found in from less than 5% of the samples in the case of Foraminifera (+103) to approximately 50% for the post-naupliar copepods (+103), with an overall average of about 25%. Very significant differences (0·01 level) were found in only approximately one out of ten determinations. In a brief comparison of sub-sampling with the wide-mouth pipette and a Stempel pipette, both of 5 ml volume, no marked difference was seen in the degree of variation encountered. Sub-samples of the +35 samples counted were the concentrated material from 1·2 – 398 l and represented 0·1–4·8% of the total sample, while in the +103 samples the sub-samples were 1·9–9·0% of the total material collected and represented approximately 14–1000 l of the pumped seawater.

Confidence limits for the +35 and +103 samples were estimated for the average values obtained from the sub-samples counted as:

$$\bar{X} \pm t_n\left(\frac{S}{\sqrt{N}}\right)$$

where t_n is the value of student's t for n degrees of freedom, *i.e.* $(N - 1)$, S the standard deviation and N the number of sub-samples. While normal distribution is assumed in this method and there was an indication from the chi-square test that distribution may not have been normal in all cases, the deviations from normality would probably not be large and, moreover, recent indications

are that statistics such as these are not particularly sensitive to deviation from normality (SIMPSON, ROE, and LEWONTIN, 1960). For the −35 counts confidence intervals were calculated according to HOLMES and WIDRIG (1956).

Prior to adding fixative to the pumped samples, aliquots were removed for the determinations of chlorophyll *a* and phaeo-pigments by fluorescence (YENTSCH and MENZEL, 1963; HOLM-HANSEN, LORENZEN, HOLMES, and STRICKLAND, 1965) and the dry weight of the total particulate material by a procedure modified from BANSE, FALLS, and HOBSON (1963). The chlorophyll filters were kept frozen until analysed; seston filters (Whatman GF/C) were dehydrated at approximately 60°C for weighing on a Cahn Electrobalance Model G.

At each station Nansen bottle samples were taken at selected depths through the euphotic zone for analyses of nitrate + nitrite-N, phosphate-P, and

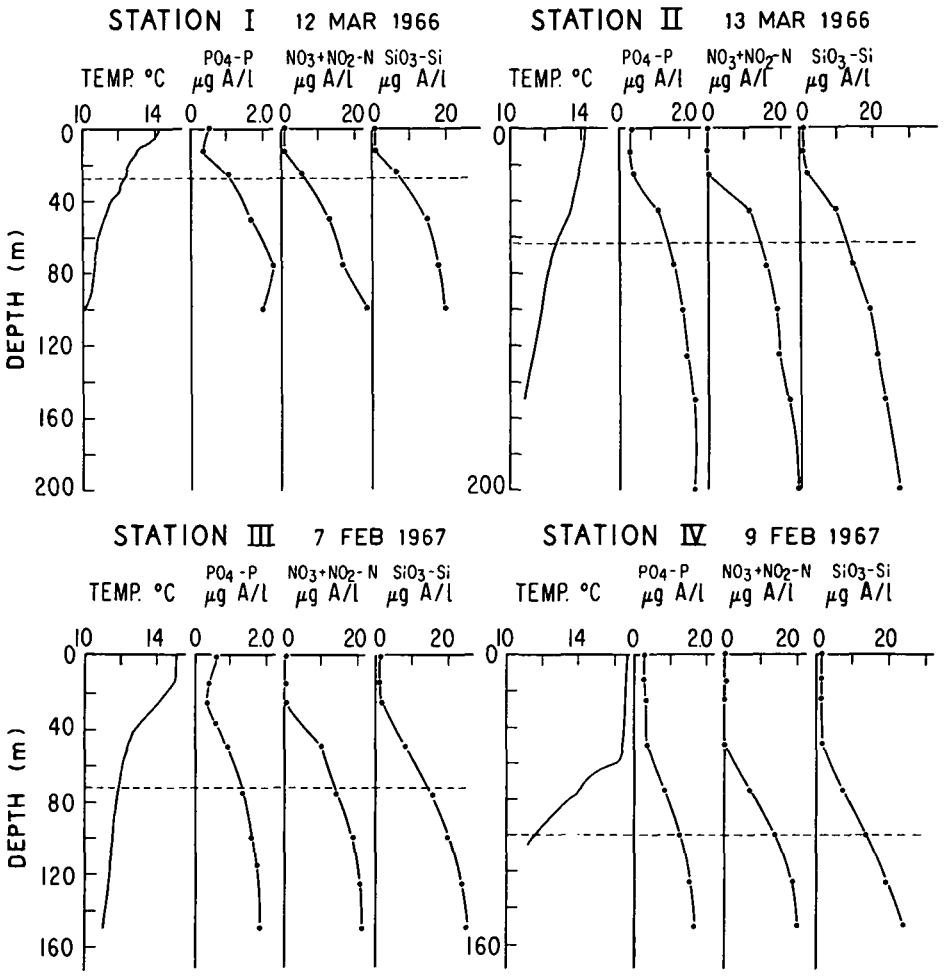

Figure 1. Temperature and inorganic nutrient profiles. Depth of euphotic zone shown by broken line.

silicate-Si by methods included in STRICKLAND and PARSONS (1965). The depth of the euphotic zone was calculated as three times the Secchi Disc depth (Table 1). Temperature profiles were obtained with a bathythermograph.

RESULTS

HYDROGRAPHY

Thermal stratification in the euphotic zone was very weakly developed except at Station IV where a stronger temperature barrier was indicated at approximately 60 m (Fig. 1). Nutrient concentrations over the euphotic depth at the various sites showed general similarities (Fig. 1). In the upper part of the euphotic zone levels were low ($NO_3 + NO_2$–N, <1 µg A/l; PO_4–P, $<0{\cdot}5$ µg A/l) with increasing concentrations ($NO_3 + NO_2$–N $\cong$ 10 µg A/l; PO_4–P $\cong$ 1 µg A/l) measured at mid-depths and deeper within the euphotic. At Stations III and IV this increase can be approximated to start at the base of the isothermal surface layer.

PARTICULATE (PLANKTON + DETRITUS = SESTON) MATTER

Concentrations of particulate matter, measured as dry weight, were highest in the upper depth intervals sampled at all sites (Table 2), while the distribution deeper in and below the euphotic region showed a somewhat variable pattern

TABLE 2. Particulate matter (seston) dry weight, chlorophyll *a*, and phaeo-pigment levels in the various size fractions of the pumped samples

Station	Depth (m)	Particulate matter mg dry weight/m³			Chlorophyll *a* µg/m³			Phaeo-pigments µg/m³		
		−35	+35	+103	−35	+35	+103	−35	+35	+103
I	0–10	710	470	58	4300	1700	76	1400	590	31
	11–19	450	230	29	2800	420	44	1400	140	28
	20–43	630	12	5·5	770	31	1·9	650	13	3·9
	44–64	640	34	2·6	99	18	0·5	300	1·8	1·4
	65–100	540	15	3·1	84	3·5	0·3	300	8·2	0·9
II	0–9	440	18	12	260	7·5	2·5	210	3·3	1·1
	10–24	500	25	18	580	18	3·1	490	13	2·3
	25–49	240	10	13	520	7·8	2·4	580	5·8	2·9
	50–74	130	7·8	5·5	170	5·3	0·8	280	6·3	1·6
	75–124	88	2·8	1·7	41	0·5	0·2	190	2·4	0·9
	125–200	82	1·6	1·5	15	0·2	0·1	110	1·4	0·5
III	0–9	420	250	8·1	320	170	0·5	70	16	0·1
	10–24	410	87	11	480	46	0·7	150	7·0	0·5
	25–49	250	13	7·7	420	6·5	0·9	270	2·6	1·2
	50–74	110	2·7	2·2	75	0·6	0·1	140	1·1	0·2
	75–124	130	1·7	1·2	4·4	0·1	<0·1	33	0·5	0·2
	125–200	250	2·1	1·8	2·0	0·1	<0·1	21	0·4	0·1
IV	0–9	270	3·2	4·0	28	0·2	0·1	18	<0·1	0·1
	10–24	59	3·5	3·8	31	0·2	0·1	13	0·1	<0·1
	25–49	130	2·0	2·1	39	0·3	0·1	28	0·1	0·1
	50–74	98	3·1	2·3	130	0·2	0·3	190	0·3	0·1
	75–124	82	1·2	0·8	20	0·1	<0·1	43	0·4	0·1
	125–200	82	1·5	0·9	1·8	<0·1	<0·1	23	0·3	0·1

at the different locations. Integrated and averaged over the euphotic zone, the amounts of total particulate material, *i.e.* (−35) + (+35) + (+103), at Stations I–IV were 920, 350, 330, and 120 mg dry weight/m^3, respectively, thus showing a seven to eightfold drop from the neritic station to oceanic waters. Total seston through the euphotic depth measured 25, 22, 24, and 12 × 10^3 mg dry weight/m^2 at the respective stations. Below the compensation depth to the bottom (Sta. I) or 200 m (Sta. II–IV) averages of 620, 94, 210, and 85 mg dry weight of particulate matter were found per m^3. The ratio of total particulate matter/m^3 in the euphotic zone to that below the compensation depth was similar (about 1·4–1·5 : 1) at each location except Station II (ratio, 3·7 : 1).

At all stations and depth intervals the greatest amount of material was found in the −35 sample. This varied from approximately 57% (Sta. I, 0–11 m) to 97–98% (Sta. IV, 25–49 m). "Cloth" samples, *i.e.* +35 and +103, contributed an important fraction only in the upper waters at Stations I and III which also had high relative concentrations of chlorophyll *a*. If much of the detritus is fragile as suggested by RILEY (1963) our method of collection may have resulted in the "breakage" of some larger pieces.

CHLOROPHYLL *a*

Vertical distribution of chlorophyll in the strata examined (Table 2) showed that the highest concentration was in the surface at the neritic Station I while on the continental shelf (Sta. II and III) maximum levels were at mid-depths in the euphotic zone. At Station IV a distinct maximum was found correlated with the thermocline depth. Total chlorophyll *a* integrated and averaged over the euphotic zone was 3·6, 0·43, 0·35, and 0·06 mg/m^3 at Stations I–IV, respectively. Summed over the euphotic depth, chlorophyll was 97, 27, 25, and 6 mg/m^2 at these sites. At each station the average chlorophyll level/m^3 in the water sampled below the compensation depth was approximately 10% or less (range, 1·2%, Sta. III – 11%, Sta. I) of that within the euphotic zone.

At all depths the chlorophyll in the −35 samples accounted for the bulk of the total amount. Only in the upper part of the water column at Stations I and III were important levels of "cloth" chlorophyll, *i.e.* + 35 and +103 samples, found. Twenty-eight percent of the total chlorophyll *a* at Sta. I, 0–10 m; 13% at Sta. I, 11–19 m; and 35% at Sta. III, 0–9 m was recovered in the summed +35 and +103 fractions. In all other samples the level of "cloth" chlorophyll was less than 10% of the total. At Station IV this was consistently 1% or less at all depths. Microscope examination showed the +35 and +103 phytoplankton at Station III was dominated by *Gonyaulax polyedra* and other relatively large thecate dinoflagellates. Predominant plant cells in the +35 and +103 samples at Sta. I (0–10 m) were diatoms of which *Nitzschia* cf. *seriata* (about 100 μ long × 7 μ wide) and *Coscinodiscus* sp. were most abundant.

PHAEO-PIGMENTS

Phaeo-pigment concentrations (Table 2) in the upper part of the euphotic zone were significantly less than chlorophyll at each station. However, at the base of the euphotic zone or at the thermocline depth (Sta. IV) and below the compensation depth, phaeo-pigment levels generally exceeded chlorophyll. The ratios of chlorphyll *a* : phaeo-pigments averaged over the entire euphotic

depth varied from 2·5 : 1 to 0·9 : 1 with Stations I and III having about twice the chlorophyll relative to phaeo-pigments whereas at Stations II and IV the ratios were close to or less than unity. Below the euphotic zone to the maximum depth sampled ratios were 0·7 chlorophyll *a* : 1 phaeo-pigments (Sta. I) and 0·2 : 1 at each of the other locations.

TOTAL MICRO-ZOOPLANKTON

The numbers of total micro-zooplankton in the standing stock in each depth interval at the four stations are shown in Figures 2a and 2b for the three size fractions collected and the major groups enumerated, respectively. Greatest abundance of organisms was at depths in the euphotic zone. Integrated and averaged over the euphotic zone the numbers of micro-zooplankton were 730, 740, 970, and 270 $\times$ $10^3/m^3$ at Stations I–IV, respectively. Total micro-zooplankton/m^2 through the euphotic zone at these sites was 200, 470, 700 and 270 $\times$ 10^5. Below the compensation level the average numbers of organisms were 250, 140, 88, and 140 $\times$ $10^3/m^3$ at the respective stations. Protozoa were numerically superior relative to metazoans both within and below the euphotic zone at all stations. Ratios of abundance varied from 7·8 Protozoa : 1 Metazoa (Sta. I, euphotic) to 42·5 : 1 (Sta. IV, below euphotic). More protozoans relative to metazoa were found below the euphotic zone than above the com-

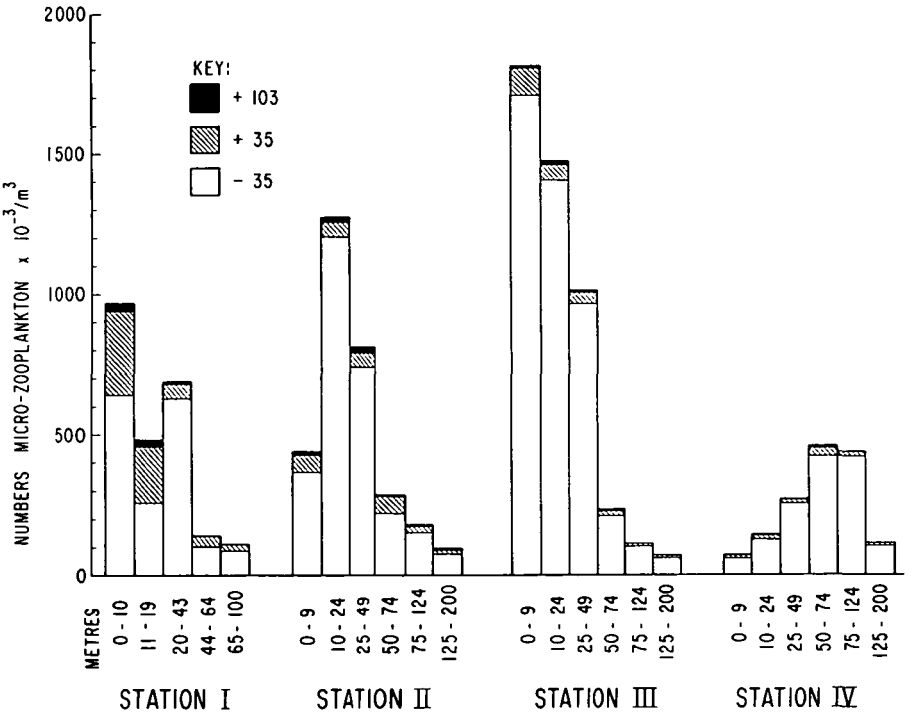

Figure 2a. Total micro-zooplankton in the several depth intervals sampled. Micro-zooplankton in the three size fractions.

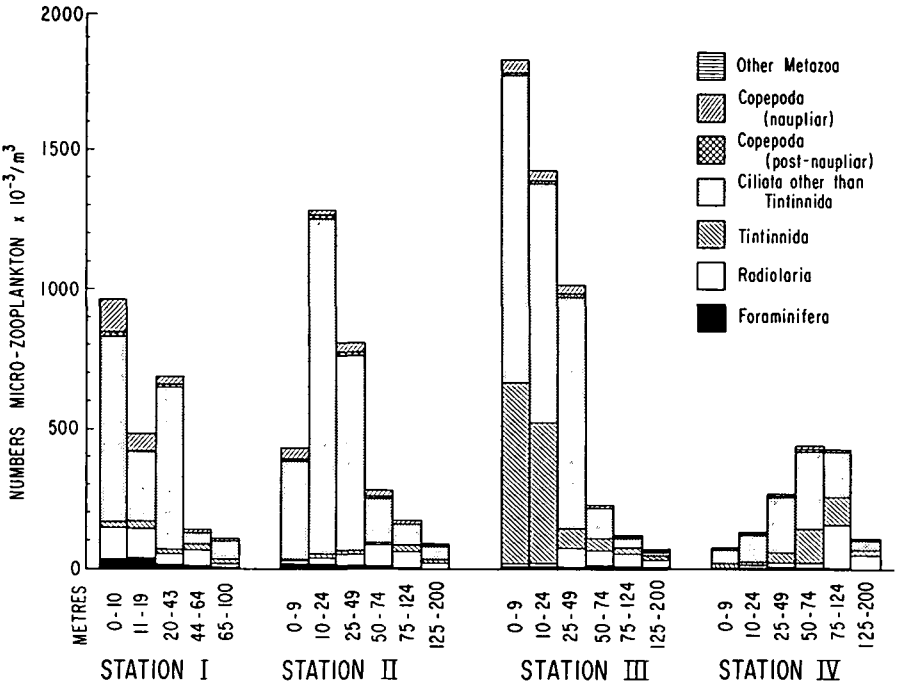

Figure 2b. Total micro-zooplankton in the several depth intervals sampled. Micro-zooplankton in the major taxonomic groups enumerated.

pensation depth at the neritic site and the deep oceanic station whereas the reverse was true at both sites on the continental shelf.

Considering the three size fractions of organisms, the largest numbers of animals were found in the material passing the 35 μ cloth. As a percentage of the total micro-zooplankton populations examined at each depth and station, the numbers of organisms in the −35 fraction ranged from 54% (Sta. I, 11–19 m) to 96% (Sta. IV, 75–124 m). Averaged over all depth intervals, −35 organisms accounted for 73, 86, 92, and 90% of the total numbers at Stations I–IV, respectively. The +35 organisms were an average of 25, 12, 7, and 8% of the total micro-zooplankton numbers at these stations, while only 1–2% were the +103 animals.

−35 Micro-zooplankton

Micro-zooplankton which passed the 35 μ mesh cloth (Fig. 3) were primarily protozoans, comprising an average of 98% of the organisms in this size class. Naupliar copepods, the only metazoans found in this size fraction, although estimated to number up to 18,000/m^3 (Sta. III, 0–9 m), were a small percentage of the total numbers of organisms. Of the protozoan groups, "Ciliata other than Tintinnida" dominated at each of the four sites examined, with species of the oligotrich *Lohmanniella* (LEEGAARD, 1915), found generally in largest numbers. These non-loricate ciliates showed their greatest abundance

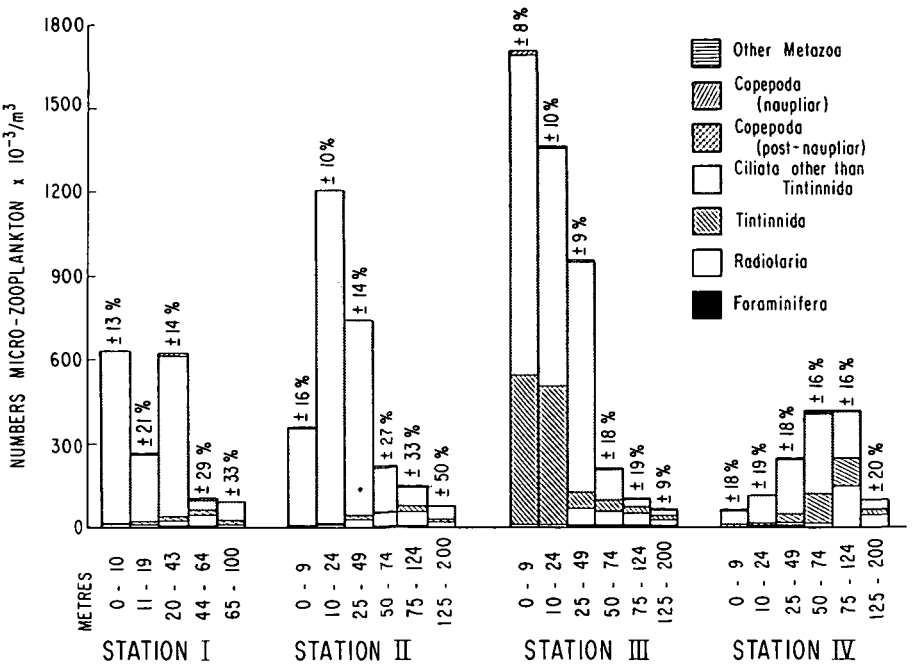

Figure 3. The numerical abundance of micro-zooplankton groups in the −35 size fraction. Limits of confidence for samples shown above each bar as ± percentage of total organisms.

in the euphotic zone, their numbers decreasing markedly below the compensation depth. At Station III large numbers of tintinnid ciliates were also found in the upper two depth intervals sampled. These were principally *Helicostomella* cf. *subulata* whose lorica has an oral diameter of 20 μ and length of approximately 130 μ.

Near the base and just below the euphotic zone increases were recorded in the numbers of protozoan groups other than the non-loricate ciliates, primarily the radiolarians but, to a lesser degree, also the Foraminifera and Tintinnida.

+35 *Micro-zooplankton*

Protozoan groups accounted for 41% (Sta. III, 10–24 m) to 81% (Sta. I, 44–64 m) of the total micro-zooplankton in this size class (Figure 4). Within the euphotic zone the integrated and averaged numbers of protozoans relative to metazoa varied from 1·2 : 1 (Sta. II) to 2·0 : 1 (Sta. I). Below the compensation depth this ratio ranged from 2·0 : 1 (Sta. I and II) to 3·7 : 1 (Sta. IV). Ratios of total abundance of +35 Protozoa in and below the euphotic zone ranged from 1·6 : 1 (Sta. IV) to 6·3 : 1 (Sta. I). In contrast to the −35 samples, the "Ciliata other than Tintinnida" were a generally small segment of the total +35 protozoan population. Only in the upper 20 m at Station I where the holotrich, *Tiarina* sp., was relatively abundant were they numerically important. At Stations I and II, the sarcodinans, *i.e.* radiolarians and Foraminifera,

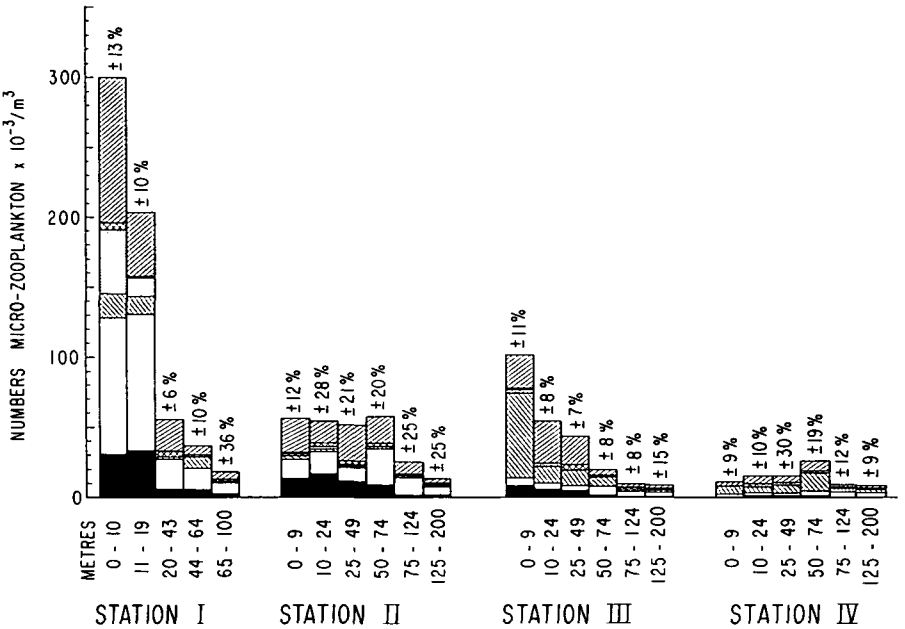

Figure 4. The numerical abundance of micro-zooplankton groups in the +35 size fraction. Key as in Figure 3. Limits of confidence shown above each bar as ± percentage of total organisms.

dominated the protozoan assemblages over all depths. At Stations III and IV tintinnid ciliates were the protozoans in greatest abundance over much of the euphotic zone while radiolarians generally dominated the sub-euphotic protozoan fauna.

In all samples the naupliar copepods were the most abundant metazoans present. Numbers of nauplii were significantly higher in the euphotic zone than below the compensation depth.

Several protozoans which were found infrequently and in small numbers in the +35 samples have not been included in the results. These were the peritrichous ciliate, *Zoothamnium* cf. *pelagicum*, a colonial form, and several flagellates which are attached to diatom frustules. For example, at Station I specimens of the pennate diatom, *Nitzschia seriata*, were found with epizoic cells of *Bicoeca* sp.

+103 Micro-zooplankton

As seen in the smaller size fractions, the greatest concentrations of +103 animals of all the major groups were in samples taken from within the euphotic zone (Fig. 5). However, in contrast to the −35 and +35 samples, metazoa were predominant in this size class at all stations and depth intervals. The metazoan fraction ranged from 52% (Sta. II, 75–124 m) to 88% (Sta. III and IV, 10–24 m) of the totals and averaged 72, 73, 81, and 82% over the entire depth sampled at the four stations, respectively. Ratios of the integrated and averaged

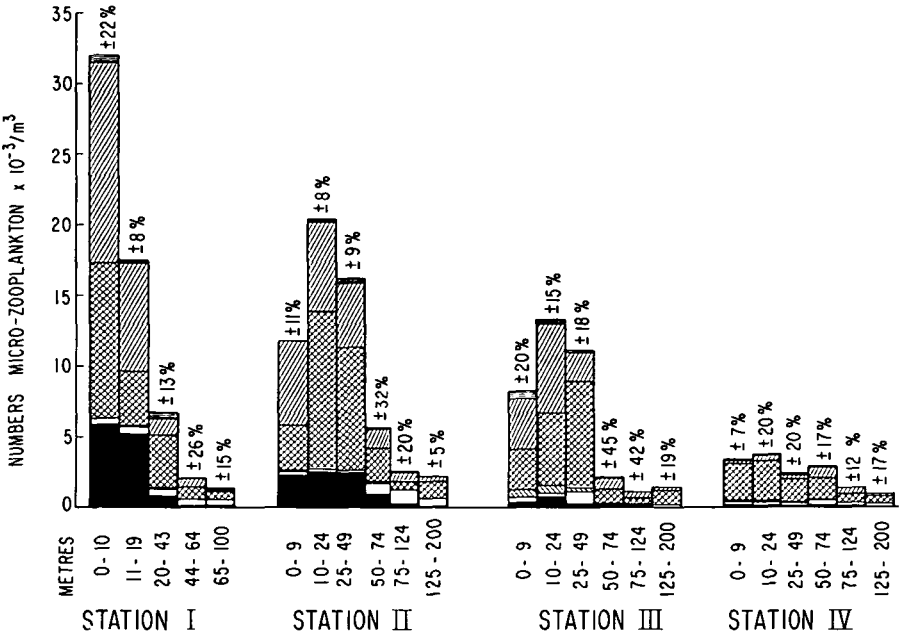

Figure 5. The numerical abundance of micro-zooplankton groups in the +103 size fraction. Key as in Figure 3. Limits of confidence shown above each bar as ± percentage of total organisms.

numbers of protozoans relative to metazoans were 0·2–0·3 : 1 within the euphotic zone at all sites, with similar ratios found below the compensation depth at each station except III (Sta. III +103 Protozoa, 0·6 : +103 Metazoa, 1).

Naupliar and post-naupliar copepods were the principal metazoans. However, small numbers of larval polychaetes, echinoderm and molluscan larvae, cyphonautes, ostracods/cladocerans, heteropods/pteropods and chaetognaths were obtained in this cloth collection and are included in Figure 5 as "other Metazoa".

Foraminifera were the most numerous of the larger protozoans collected. They were generally in greatest abundance within the euphotic zone. The numbers of radiolarians, both absolute and relative to other protozoan groups, increased below the compensation depth. Only small numbers of tintinnids, mainly species of *Eutintinnus*, *Xystonellopsis*, and *Cytarrocylis*, were found.

DISCUSSION

The limited number of observations reported here do not warrant making any but the broadest generalizations regarding the vertical distribution of micro-zooplankton. However, by examining the several parameters measured it is possible to speculate on aspects of the community structure and dynamics at the sites examined and to compare these different marine environments.

The use of numerical abundance has been criticized in considering marine

food chain relationships since it will show a bias favouring the smaller forms (*e.g.* PAASCHE, 1960; SMAYDA, 1965). Application of a biomass or volume term is perhaps more meaningful. Estimates developed for an earlier study (BEERS and STEWART, 1967) indicated that, for example, the volume of the "average" nauplius in the +103 fraction was almost two orders of magnitude higher than that of the −35 nauplius, while a single order of magnitude difference existed between −35 and +103 tintinnid ciliates. In the −35 samples the volume of an "average" naupliar copepod was almost double that of the "average" tintinnid body, approximately five times greater for the +35 organisms and an order of magnitude larger in the +103 samples. However, in terms such as the production of new animal carbon over a given period of time, an important consideration in food chain dynamics, the relationship may be considerably closer between a tintinnid ciliate dividing at frequent intervals and a naupliar copepod developing through several stages than the relative volumes would indicate.

As observed previously (BEERS and STEWART, 1967), the numerical abundance of micro-zooplankton/m^3 averaged over the euphotic zone was significantly smaller at the oceanic station than at the coastal or shelf sites. However, relative to chlorophyll concentration the number of micro-zooplankton was greatest at the oceanic site. Numbers of total micro-zooplankton in the euphotic zone/μg chlorophyll *a* were 200, 1750, 2800, and 4900 at Stations I–IV, respectively, thus showing an approximate order of magnitude difference between the neritic station (Sta. I) and shelf sites (Sta. II and III) with a further doubling at the deep oceanic station (Sta. IV). A three-fold increase between Stations I and IV is found when the numbers of micro-zooplankton per unit seston are considered. Of the seston components, detritus was a much larger fraction at the oceanic station than inshore. This is based on calculations using conversion factors (STRICKLAND, 1960) between chlorophyll and sample dry weight which indicated phytoplankton material accounted for approximately 64% of the total seston at Station I and only 9% at Station IV. The potential value of the detritus as food for the micro-zooplankters is questionable. However, the fact that high standing stocks of detritus relative to chlorophyll are encountered routinely especially in oceanic areas suggests that it may be of limited use to the zooplankton. At Station I where the level of detritus was lower than chlorophyll, its role may be very different from the open ocean.

Of the micro-zooplankton at the neritic site, 73% were in the −35 size class with 25% and 3% in the +35 and +103 fractions respectively, whereas at the deep oceanic site the distribution of organisms in the three size groups was 91%, 7%, and 2%. Likewise, chlorophyll *a* content in the three size classes showed a greater fraction of the total was in the larger sizes at Station I (Sta. I, −35, 83%; +35, 16%; +103, 1%; Sta. IV, −35, 99%; +35, <1%; +103, <1%), although the absolute amount of the bigger material perhaps cannot be considered too significant. Nevertheless, at the inshore station a relatively greater amount of large phytoplankters would be available as a direct food source for larger zooplankton and the relative need for small-sized animals as intermediates in the food chain may be less compared to Station IV. The reverse situation may be true in open ocean communities. In both cases, the relative numbers of micro-zooplankton in the three size fractions studied support this hypothesis.

The relative abundance of protozoans and metazoans can be used as further support for this possible relationship since in terms of mass (volume) the

protozoans in the various size classes are markedly smaller than the metazoan representatives. At Station I ratios of total Protozoa : total Metazoa by numbers were 7·8 : 1 in the euphotic zone and 14·0 : 1 below the compensation depth whereas at Station IV these same ratios were 22·2 : 1 and 42·5 : 1.

The size of food organism which a plankter can utilize is dependent on its feeding apparatus. In the filter-feeding copepods correlations between the size of food taken and distance between setules on the filtering screen have been found (ANRAKU and OMORI, 1963; MARSHALL and ORR, 1966). Even when there may be selection for the larger particles in the size range with which the copepod can manage, the size of food organism is small relative to that of the feeder. Zooplankters such as the sarcodinans (*i.e.* the radiolarians and foraminifera) in our samples might be expected to utilize particles much larger relative to their own size since digestion after engulfing the food through pseudopodial action can be mainly outside the skeletal framework. Station I had considerably higher numbers of sarcodinans in the euphotic zone than the other sites. These were mainly in the +35 size group. However, other groups of protozoans, the ciliates and flagellates, would be expected to take only the small particles relative to their own size since the food is generally taken "inside" the cell for digestion often through a specialized mouth/gullet region. Comparing the total Tintinnida + "Ciliata other than Tintinnida" to the total Radiolaria + Foraminifera at Stations I and IV, ratios of 4·4 : 1 and 12·2 : 1, respectively, were found thus showing markedly greater numbers of ciliates relative to sarcodinans at the open ocean station. If these had been calculated only for the smaller size fractions sampled, then even larger ratios would have been expected.

LORENZEN (1967) has recently studied the vertical distribution of chlorophyll *a* and phaeo-pigments. Our data (Table 2) at the open ocean site (Sta. IV) are similar to his composite picture for such areas derived from a large number of observations. As the result of finding a positive correlation between phaeo-pigment concentration in the euphotic zone and the numbers of copepods in the upper 140 m in addition to no positive evidence for the production of phaeo-pigments through bacterial degradation and/or under conditions of darkness, LORENZEN proposed that the principal source of these chlorophyll degradation products was the result of zooplankton grazing. Furthermore, he suggested, using evidence based on data with copepods captured with a 550 μ mesh net, that the relationship of copepods/total chlorophyll to total phaeo-pigments/total chlorophyll can be used as a measure of grazing pressure. Since it is reasonable to suggest that the micro-zooplankton may be at a lower trophic level in the food chain than the size group he sampled, one would expect this relationship, if valid, to hold when compared with micro-zooplankton populations. Four stations with diverse environments are hardly sufficient to form any conclusions, but in general a similar type relationship was observed when the total micro-zooplankton in the various populations was examined. When considering the depth intervals sampled separately there was a much greater scatter and, to some extent, this may be the result of complications due to diurnal vertical migrations of the micro-zooplankton.

Movements of the various taxonomic groups and/or age groups represented in the micro-zooplankton populations have been little studied. The vertical migration of copepods has been well-documented (CUSHING, 1951). There is then reason to suppose that their developmental stages also show the pheno-

menon to some degree, perhaps in relation to their size compared to that of the adult. Ciliates have well-developed locomotory ability and the vertical movements of tintinnid ciliates have been followed in certain inshore areas. VITIELLO (1964) presented evidence that they concentrate in the surface waters at *night* in the relatively shallow waters of the Bay of Algiers. His data suggest that they may be capable of moving in excess of 50 m in a few hours. GILLBRICHT (1955) reported on the migration of *Tintinnopsis* sp. in response to water stratification. Evidence for foraminiferal vertical movements has been provided by BRADSHAW (1959) and BÉ (1960). Both studies indicated the greatest concentrations in the upper waters during the *day*, the opposite of the tintinnids. BÉ (1960) suggested that the transport of some foraminifera in the upper 100 m during the day may be to below 200 m at night. This direction of movement would be beneficial for the zooxanthellae, autotrophs living symbiotically with various foraminifera. Many radiolarians also harbour zooxanthellae and adjust their vertical position through modification of their calymma contents. In order to minimize differences between stations due to vertical movement of the micro-zooplankton our times of sampling were the same at each site.

SUMMARY

The vertical distribution of micro-zooplankton and their relationship to chlorophyll *a*, phaeo-pigments, and total particulate matter has been examined within and below the euphotic zone at four locations – coastal, continental slope, and deep oceanic waters – in the north–eastern Pacific Ocean.

The abundance of the total micro-zooplankton was greater in the euphotic zone than below it in all environments. Protozoa were numerically superior to Metazoa through the total water column sampled. Of the three size classes of organisms separated largest numbers were found in −35 micron mesh samples with decreasing abundance in +35 and +103 micron size fractions. Protozoa numerically dominated all −35 and +35 samples while Metazoa were in greater abundance in the +103 fraction.

The total numerical abundance of micro-zooplankton averaged over the euphotic zone was greatest at the inshore stations. However, the largest population of micro-zooplankton per unit chlorophyll concentration was found at the deep oceanic site.

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