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Journal of Marine Systems 17 (1998) 289–303

JOURNAL OF MARINE SYSTEMS

Microzooplankton biomass distribution in Terra Nova Bay, Ross Sea (Antarctica)

S. Fonda Umani [a,*], M. Monti [a], C. Nuccio [b]

[a] *Laboratory of Marine Biology, Via Piccard 54, 34010 Trieste, Italy*
[b] *Department of Plant Biology, Via Micheli 1, 50121 Firenze, Italy*

Received 15 October 1995; accepted 15 August 1997

Abstract

This work describes the spatial and vertical distribution of microzooplankton (20–200 μm) abundance and biomass of the upper layers (0–100 m), collected during the first oceanographic Italian expedition in Antarctica (1987/1988) in Terra Nova Bay (Ross Sea). Biomass was estimated by using biovolume calculations and literature conversion factors. Sampling was carried out at three depths, surface, 50 and 100 m. The dominant taxa were made up of tintinnid ciliates, ciliates other than tintinnids, larvae of micrometazoa and heterotrophic dinoflagellates. The abundance of the total microplankton fraction had its absolute maximum in the center of Terra Nova Bay at the surface with 31 042 ind. dm^{-3}. The areal and vertical distribution of heterotrophic microplankton biomass differs from that of abundance. On the basis of hydrological conditions, phytoplankton composition and biomass and microzooplankton biomass and structure it is possible to identify three groups of stations: 1—northern coastal stations (intermediate chlorophyll maxima, microphytoplankton prevalence, low microzooplankton biomass); 2—central stations (high surface chlorophyll, nanoplankton prevalence, high abundance of microzooplankton); 3—northern stations (deeper pycnocline, nanoplankton prevalence, high microzooplankton biomass at intermediate depths).

Résumé

L'objet de cette étude a étail la distribution spatiale et verticale de l'abondance et de la biomasse du microzooplancton échantillonné pendant la première expédition antarctique italienne (1987/1988) a Terra Nova Bay (Ross Sea). Les échantillons ont été prélevés à trois différentes profondeurs: surface, 50 et 100 m. Les taxa dominantes ont été les tintinnides ciliés, les ciliés autre que les tintinnides, les larves de micrometazoaire et les dinoflagelles hétérotrophes. La valeur maximale (31 042 ind. dm^{-3}) d'abondance du microzooplancton total a été mesurée dans le niveau de surface de la zone centrale. La distribution spatiale et verticale de la biomasse du microzooplancton hétérotrophe est différente de celle de l'abondance. Trois groupes de stations ont été mis en évidence sur la base des conditions hydrologiques, de la composition et la biomasse du phytoplancton et la structure et la biomasse du microzooplancton: 1—stations côtières du nord (valeur maximal de chlorophylle dans les niveau intermédiaires, majorité de microphytolancton et faible biomasse du microzoo-

* Corresponding author. Tel.: +39-40-224400; Fax: +39-40-224437; E-mail: labbioma@univ.trieste.it

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PII: S0924-7963(98)00044-X

plancton); 2—stations centrales (haute valeur de chlorophylle de surface, majorité de nanoplancton et forte abondance de microzooplancton); 3—stations du nord (pycnocline plus profonde, majorité de nanoplancton, hautes valeurs de biomasse du microzooplancton dans les niveau intermédiaires). © 1998 Elsevier Science B.V. All rights reserved.

Keywords: microzooplankton; Terra Nova Bay; tintinnid ciliates

1. Introduction

The role of heterotrophic microzooplankton in the interpretation of the biological processes occurring in the Southern Ocean increased in the last decade due to the discovery of its importance as a key link in the transfer of newly formed organic matter by nano and picoplankton to mesozooplankton (Gifford, 1988; Alder and Boltovskoy, 1991; Burkill et al., 1993, 1995).

Pico- and nanoplanktonic producers often dominate the post-bloom successional stages of Antarctic phytoplankton accounting for up to 80–90% of total autotrophic production (Alder and Boltovskoy, 1993; Garrison et al., 1993). Microplanktonic heterotrophs, which almost alone are able to feed on nanoplankton and repackage the organic material into a size suitable for consumption at higher levels of the food web, can sustain in large part the high standing stock of Antarctic crustaceans. Among the heterotrophic microplankters, ciliates (including tintinnids), microcrustacea and various invertebrate larvae are all relevant in terms of biomass. Heterotrophic dinoflagellates also contribute significantly to the microheterotrophic biomass (Dodge and Priddle, 1987; Bjørnsen and Kuparinen, 1991; Elbrächter and Zölfel, 1993) sometimes accounting for more than 50% of the total heterotrophic biomass (Alder and Boltovskoy, 1993), and more than 60% in the 0–150 m depth range (Boltovskoy and Alder, 1992). Their distribution is affected by high heterogeneity, with patches of relatively high abundance related to some particular current pattern (Dodge and Priddle, 1987). The purpose of this work is to present the areal and vertical distributions (in the upper 100 m) of heterotrophic biomass in Terra Nova Bay (Ross Sea) during an austral summer (1987/1988) and their relationship with the water column structure and chlorophyll *a* distribution.

2. Materials and methods

During the 1987/1988 cruise hydrological profiles were performed at each station by means of a Meerestechnik Mod. KMS multiparametric (CTD) probe with a frequency of 8 readings/s (Boldrin and Stocchino, 1990).

Downwelling PAR irradiance and downwelling, upwelling and scalar underwater irradiance were

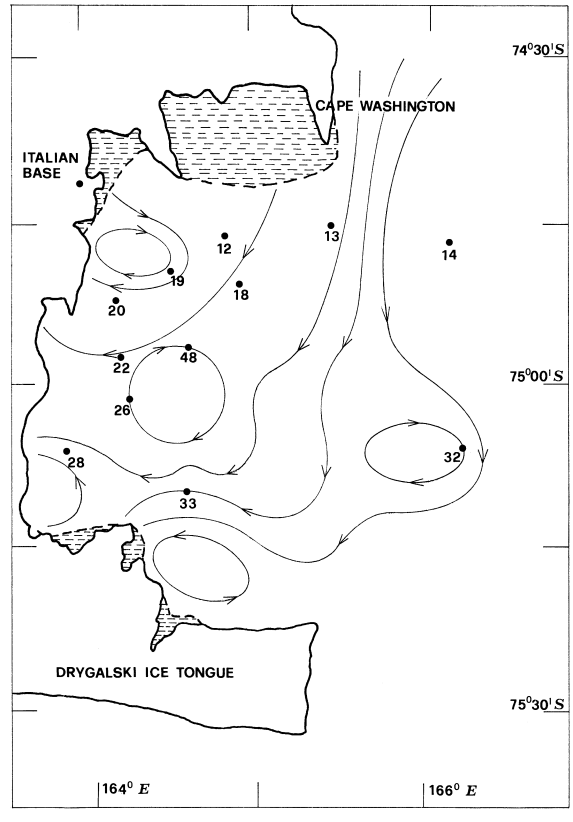


Fig. 1. Study area and sampling stations with the most important currents (redrawn from Stocchino and Manzella, 1991).

measured by means of LI-COR quantum sensor (Innamorati et al., 1990). Chlorophyll *a* concentrations were determined spectrophotometrically or fluorometrically, after extraction in 90% acetone (Innamorati et al., 1990).

From 9 January 1988 to 2 February 1988 water samples for microzooplankton analyses were obtained with sampling bottles at 3 depths (surface, 50 m, and 100 m) at 12 stations in Terra Nova Bay (Fig. 1). At each station water samples were simultaneously collected at the same depths for chlorophyll *a* concentration and nano—and micro—phytoplankton analyses. Sampling times varied between 10 AM and 8 PM. Each station was occupied once; stations 20, 19, 22, 26, 28 and 33 were sampled between 9 and 15 January; stations 12, 13, 14, 18, 48 and 32 between 24 January and 2 February. The farthest stations from the coast were stations 32 (42 miles) and 14 (33 miles); all other stations were within 15 miles from the coast.

For each sample, 2 l of water were collected, concentrated on 20 μm mesh, and reduced to 250 cc. For dinoflagellate counting, unfiltered water was used. Samples were preserved with 4% formaldehyde solution buffered with sodium tetraborate. Subsamples (50–100 ml) were then examined in a settling chamber using an inverted microscope (magnitude $\times 200$ and $\times 320$), according to the method of Utermöhl (1958).

The biomass of microzooplankton organisms was estimated by measuring the linear dimension and equating shapes to standard geometric figures or combinations of them. Measurements were taken for each species (or groups of eggs, larvae, etc.) on more than 100 individuals (max. 394 for *Cymatocylis drygalskii*) for the abundant taxa and on the few present individuals for rare taxa. Conversion factors used to transform these volumes into organic carbon values were, dinoflagellates: pg $C = \mu m^3 \times 0.13$ (Edler, 1979); tintinnids: pg $C = \mu m^3 \times 0.053 + 444.5$ (Verity and Langdon, 1984); ciliates other than tintinnids: pg $C = \mu m^3 \times 0.14$ (Putt and Stoecker, 1989); all other groups: pg $C = \mu m^3 \times 0.08$ (Beers and Stewart, 1970).

The dinoflagellates included in our computation were all species belonging to the *Protoperidinium* genus (Dodge and Priddle, 1987; Elbrächter and Zölfel, 1993) or *Gyrodinium lachryma* (Lessard and Swift, 1986) and *Gymnodinium* sp. (Bjørnsen and Kuparinen, 1991).

The microzooplankton composition at each station and at the three depths was organized in a matrix of 34 rows (taxa) and 36 columns (stations depths).

Cluster analysis, based on the complete linkage method, was computed by MATEDIT (Burba et al., 1992) on the matrix after calculating the correlation coefficient on species and the similarity ratio on stations' depths.

3. Results

3.1. Hydrology

The study area in Terra Nova Bay extended approximately between 74°30′ and 75°30′S and 164°00′ and 166°00′E (Fig. 1). The maximum depth (> 1100 m) is in the central part of the Bay bordered by a high and rocky coast and characterized by an extremely steeply sloping sea-floor (Brambati et al., 1989). The hydrology of the study area, during the summer period is characterized by the presence of a stable pycnocline and high temperature and salinity gradients. The thick surface layer of Antarctic Surface Water (AASW) has temperatures exceeding 0°C. In the coastal areas the surface layer is characterized by a salinity of > 34.7 psu and temperatures between 1.9°C to 2.1°C. This area is affected by prevailing surface thermal processes due to both atmospheric and orographic phenomena which can maintain the polynya over winter. Eastward, the offshore surface water is affected by dilution processes due to meteoric ice melting. Consequently, the salinity is < 34.6 psu. Below the AASW a homogeneous water body of Ross Sea Shelf Water (RSSW) is present. Here the salinity increases slightly towards the bottom with an average temperature of -1.9°C and salinity of 34.9 psu (Boldrin and Stocchino, 1990).

During the 1987/1988 cruise pycnocline deepened from 50–75 m depth of the first sampled coastal stations (19, 20, 22, 26, 28 and 33) to 100 m depth of the last northern stations (12, 13, 14 and 18); the easternmost station 32 and central station 48, sampled during the second period, still showed pycnocline at 50–75 m depth (Fig. 2); the latter was

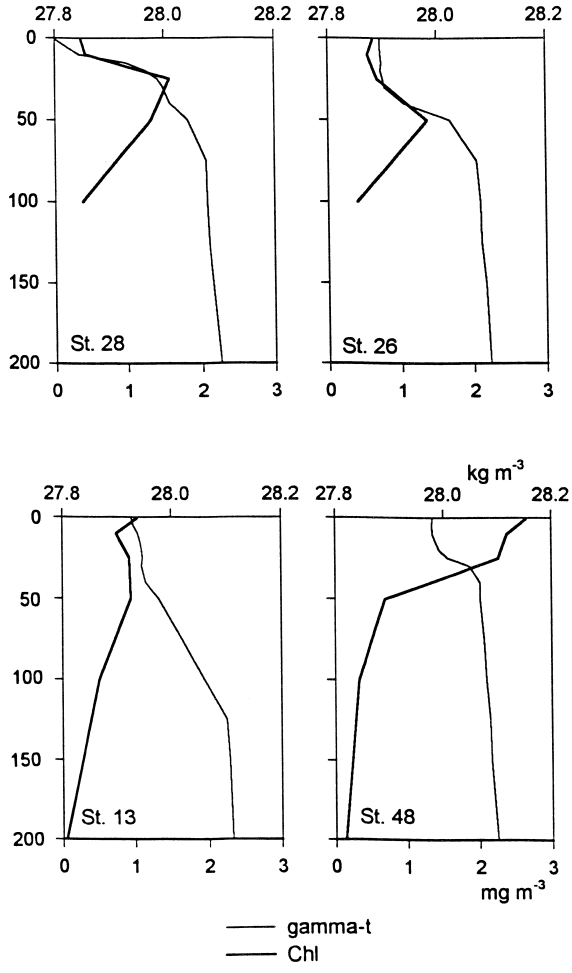


Fig. 2. Density and chlorophyll *a* typical profiles of the three main group of stations: stations 28 and 26 show profiles of coastal stations (19, 20, 22, 26, 28 and 33); station 13 shows profile of northern stations (12, 13, 14 and 18); station 48 shows profile of central stations 48 and 32.

characterized by the lowest temperatures (from -0.6°C at surface to -2.0°C at 300 m depth). At all other stations surface temperature was > 0.6°C, with maxima at the most southern stations 28 and 33 (> 1.6°C). Only at station 20 surface temperature was < 0°C. At the surface the lowest salinity was found at the easternmost stations 14 and 32 (< 34.6 psu); while at all other stations it was > 34.75 (Boldrin and Stocchino, 1990).

The surface currents are constituted by two branches (Fig. 1): the first originates from the NE in the northernmost part of the Bay and the second from the E in the southernmost region south of 75°S. The NE current invades the central area and then turns N to become the coastal current. The second one, from the E, after reaching the Drygalski Ice Tongue, turns N to join the coastal current. Generally the surface circulation is characterized by a stable cyclonic gyre (Stocchino and Manzella, 1991).

3.2. Chlorophyll a and phytoplankton distribution

Absolute surface chlorophyll maxima (> 2.3 mg m^{-3}) were recorded at stations 32 and 48; at stations 12, 13, 14 and 18 less intense (< 1.3 mg m^{-3}) surface or subsurface maxima were registered (Fig. 3). At all other stations, the chlorophyll maximum occurred at depths ranging from 25 to 50 m, corresponding to the different water mass structures (Fig. 2). At stations 32 and 48 the euphotic layer depth (Z_{eu}) was particularly thin; where 1% of surface PAR recorded at 21 and 22 m depths, respectively. Z_{eu} was maximum at station 14 (43 m). Integrated over 100 m depth chlorophyll (Fig. 4) was higher in the coastal northern area, followed by the central part of the grid.

Phytoplankton abundance (Fig. 5) was maximum at station 48 (25 m depth), reaching 963×10^3 cell l^{-1}; at this depth 90.77% of total phytoplankton was constituted by nanoplankton. This station was the richest also at surface and 10 m depth, and still nanoplankton was the dominant fraction, as well as at stations 14, 18, 20, 32 and in the upper layers of 12 and 13. Microphytoplankton prevailed at stations 19, 22, 26, 28 and 33; nanoplankton generally increased below 50 m depth. Total phytoplankton abundance at these stations ranged between 2×10^3 and 166×10^3 cell l^{-1}. Generally, the highest total abundances of phytoplankton corresponded to the highest percentages of nanoplankton.

3.3. Microzooplankton abundance and biomass

Abundance of the total microplankton fraction (including dinoflagellates, tintinnids, aloricate ciliates, larvae and eggs of invertebrates) is maximum (Fig. 6) at station 48 at the surface (31 042 ind. dm^{-3}), due to the conspicuous contribution of *Pro-*

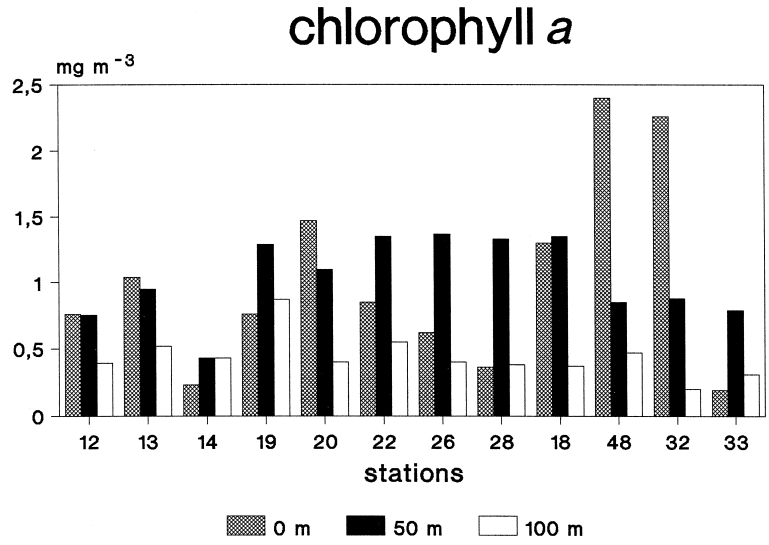


Fig. 3. Chlorophyll *a* values (mg m^{-3}) at surface, 50 and 100 m.

toperidinium defectum, *P. mediocre* and *Gymnodinium* sp. At the surface at all other stations, values are lower and variable. The contribution by dinoflagellates is considerable everywhere. At intermediate depths numbers were more uniform than in surface waters and dinoflagellate contribution to the total abundance was of the same order as at the surface (Fig. 7a and b). At 100 m, the maximum, although less than 20 000 ind. dm^{-3}, appears at station 13; at all other stations values are low, particularly when dinoflagellates are absent (Fig. 7c).

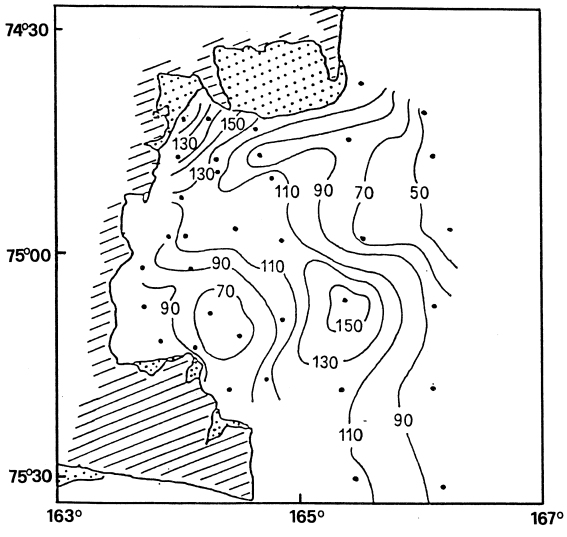
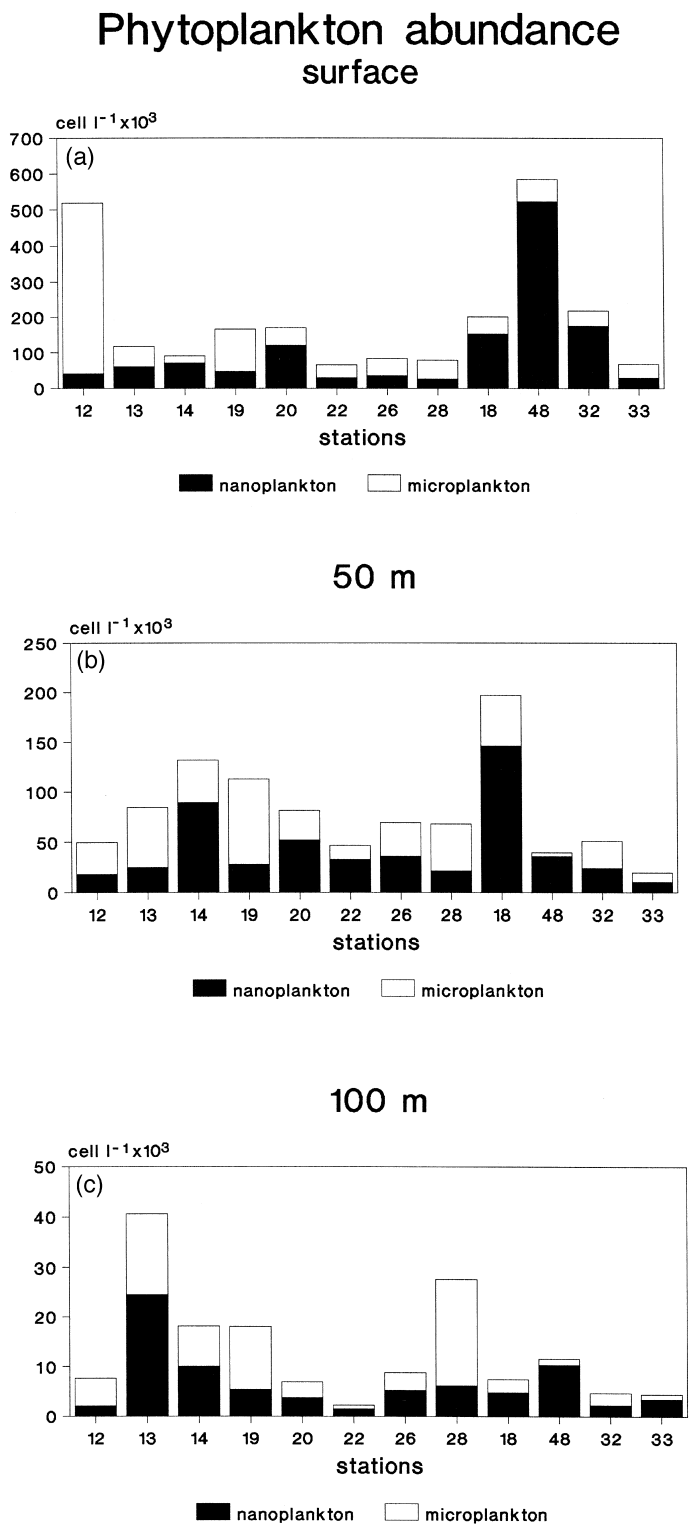


Fig. 4. Contour map of integrated over 100 m depth chlorophyll *a* (from Innamorati et al., 1992).

In Table 1, where individual biovolume and carbon content calculated for each organism is reported, it is noticeable that the biomass values of some dinoflagellates, in particular *Protoperidinium antarcticum* and *P. pseudoantarcticum*, are in the same range as tintinnid carbon values. The other dinoflagellates are 10–20 times less abundant in terms of carbon biomass.

The spatial and vertical distribution of heterotrophic microplankton biomass shows a quite different pattern from that of abundance (Fig. 8). At the surface, the richest station was 13, while at station 48, biomass is relatively high but of the same order of magnitude as at all other stations. At intermediate depths, stations 13 and 14 exhibited biomass maxima more than 4 times higher than at all other stations. Only at 100 m depth at stations 14 and 13 was there a good correspondence between abundance and biomass distribution.

The high values at stations 13 and 14 are due to the conspicuous presence of dinoflagellates (Fig. 9), which account for more than 97% of the total (station 14; 100 m). At these stations, a bloom of the very large *P. antarcticum*, whose carbon content is


Phytoplankton abundance
surface
cell l⁻¹x10³
(a)
700
600
500
400
300
200
100
0
12 13 14 19 20 22 26 28 18 48 32 33
stations
nanoplankton
microplankton
50 m
cell l⁻¹x10³
(b)
250
200
150
100
50
0
12 13 14 19 20 22 26 28 18 48 32 33
stations
nanoplankton
microplankton
100 m
cell l⁻¹x10³
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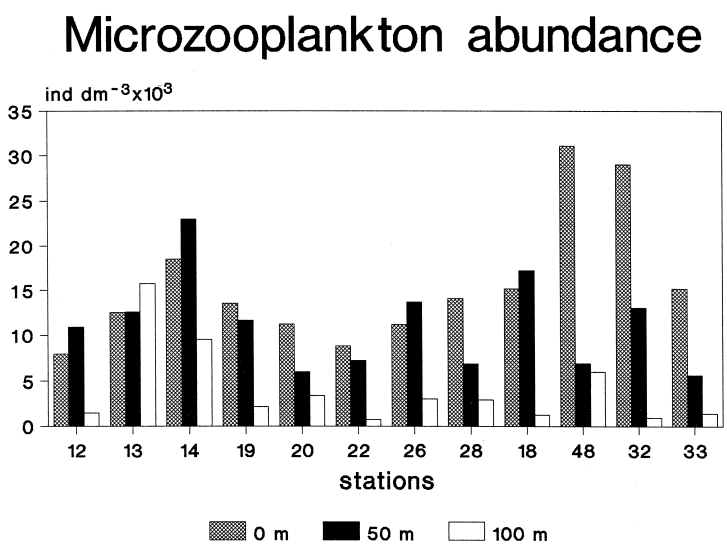

Fig. 6. Total microzooplankton abundance (ind. dm^{-3}) at surface, 50 and 100 m depth.

60 930 pg C (Table 1), was particularly developed at 50 m depth.

At all other stations the contribution of dinoflagellates to the total biomass is generally higher at the surface. The differences observed between abundance and biomass distribution are mainly due to the different composition of the heterotrophic dinoflagellate community at the various stations: e.g., at station 48 (surface) *P. defectum* and *P. mediocre* dominated, characterized by a small biovolume and consequently low carbon content (Table 1).

The contribution to the total biomass of ciliates other than tintinnids is again more important at the surface with a maximum of 26% at station 22 and generally it is more than 10%.

Tintinnids show generally the highest percentage at intermediate and bottom layers with a maximum of 82% at station 22 at 100 m.

The biomass of eggs and larval forms of invertebrates, among which the contribution of copepod nauplii is not very significant, was more abundant in the northern coastal stations (12, 18, 19 and 20), reaching a maximum of 31% of the total biomass at stations 19 at 50 and 100 m.

3.4. Community structure

Cluster analysis defined 2 main stations' depth groups: 1 and 2 (Fig. 10); group 2 is comprised by 100 m samples of stations 19, 20, 22, 12, 33 and 26.

Group 1 can be divided into six subgroups: 1.1 and 1.2 identified surface samples of stations 13, 22, 12, 33, 14, 19, 28 and 50 m samples of station 19. Group 1.3 included surface samples of stations 18, 26 and 32 and 100 m samples of stations 28 and 32. Group 1.4 comprehended 50 m samples of stations 18, 28, 26, 32, 22, 33 and 12; group 1.5 samples at 50 and 100 m depths of stations 13 and 14. In group 1.6 are included all the depths of station 48, surface and 50 m of station 20 and the 100 m sample of station 18.

Cluster analysis applied on species identified six groups of species (Fig. 11): only group C is more or less homogeneously distributed in all the stations' depth groups (Table 2), being constituted primarily

Fig. 5. Phytoplankton abundance at surface (a), 50 m (b) and 100 m depth (c). Bars division show nanoplankton and microphytoplankton relative contribution to the total abundance.

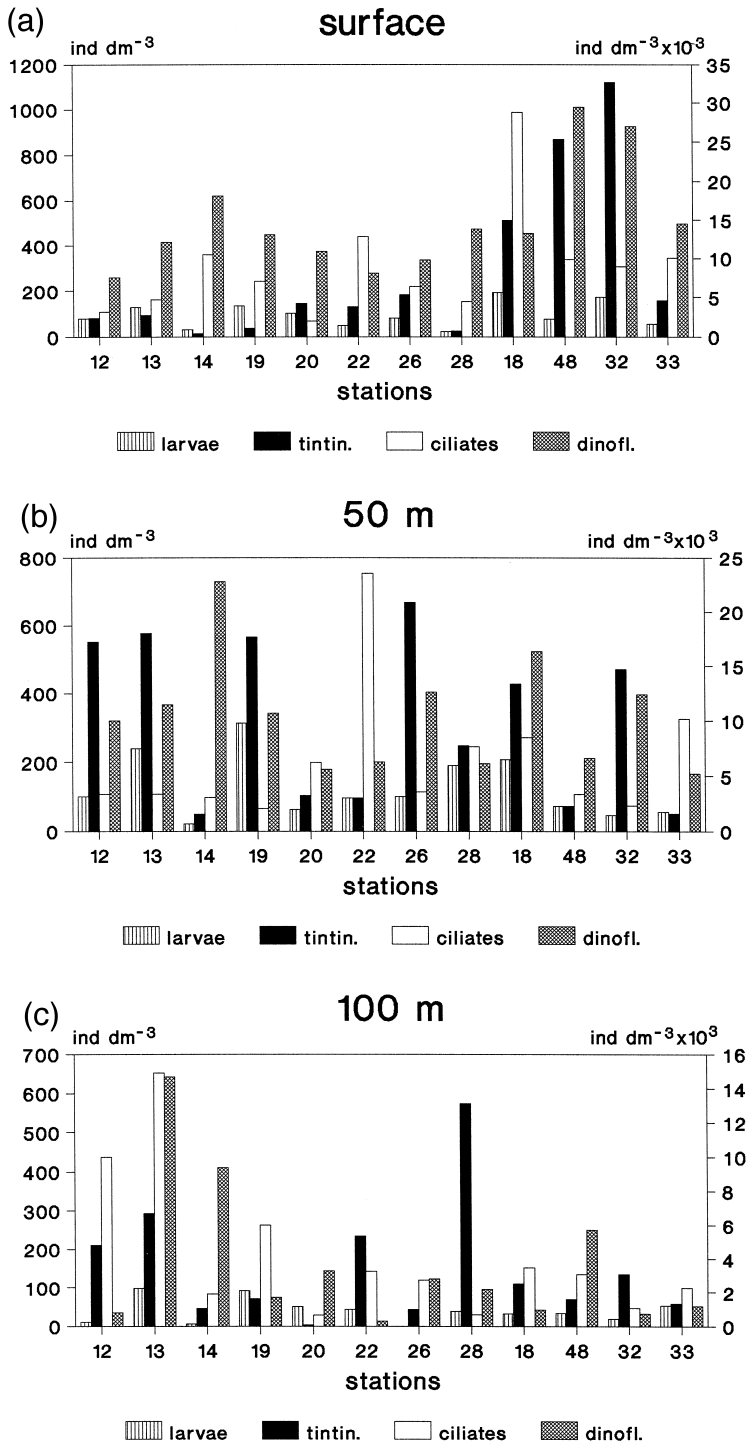

Fig. 7. Microzooplankton abundance (ind. dm^{-3}) of dinoflagellates, tintinnids, ciliates and larvae and eggs, at surface (a), 50 m (b) and 100 m (c). Second scale is used to show dinoflagellate abundances.

Table 1
Individual biovolume and carbon content

	μm^3	pg C
Dinoflagellates		
Gymnodinium sp.	4320	561
Gyrodinium lachryma	3470	4520
Protoperidinium adeliense	7600	990
P. antarcticum	468700	60930
P. applanatum	11970	1560
P. defectum	6790	880
P. pseudoantarcticum	278220	36170
P. mediocre	14930	1940
P. unipes	24870	3230
Tintinnids		
Cymatocylis drygalskii	467440	25220
C. flava	800220	42860
Cymatocylis sp.	513980	27680
Laackmanniella naviculaefera	384200	20810
L. prolongata	312870	17030
Laackmanniella sp.	247100	13540
Codonellopsis gaussi	98770	5680
C. glacialis	57270	3480
Codonellopsis sp.	116000	6590
Salpingella sp.	251200	13760
Coxliella frigida	72350	4280
Ptychocylis sp.	108090	57730
Ciliates		
Ciliates A	36250	5070
Enchelys sp.	61790	8650
Prorodon sp.	101900	14260
Lacrymaria sp.	9650	1350
Halteria sp.	127510	17850
Strombidium sp.	21040	2940
Patronella sp.	100970	14140
Leegardiella sp.	27450	3840
Lohmaniella sp.	25960	3630
Oligotricha sp.	84780	11870
Larvae and eggs		
Nauplii	367500	29400
Limacina veliger	569890	45590
Larvae unid.	145680	11650
Eggs unid.	112530	9000

by *Cymatocylis* sp. and rare species such as *Sticholonche zanclea* and *Laackmaniella naviculifaera*.

Group A was constituted by heterotrophic dinoflagellates, is typical of 50 and 100 m depths of northern offshore stations (13 and 14).

Groups B and D species characterized the intermediate depths of group 1.4 (above). In group B, *P. defectum* and *Laackmaniella prolongata* prevailed, in group D, *Lohmaniella* sp., *Leegardiella* sp. and unidenfied ciliates as well as *Cymatocylis flava* prevailed.

Group E species in which *Cymatocylis drigalskii* prevailed, characterized the upper layer of the coastal stations (group 1.1).

Group F species of which the most abundant is *Codonellopsis gaussi* characterized the upper layers at stations 18, 26 and 28 and the 100 m depth of stations 28 and 32.

Samples from coastal stations at 100 m depth of (group 1.6) were characterized by the absence or scarcity of all groups of species.

4. Discussion and conclusion

On the basis of the water column structure it is possible to identify 3 main groups of stations: Group 1: coastal stations 19, 20, 22, 26, 28 and 33, sampled at the end of microphytoplankton bloom, with a pycnocline located between 50 and 75 m depths, maxima of chlorophyll located just above the pycnocline and intermediate values of Z_{eu}; Group 2: stations 32 and 48, sampled during the second part of the cruise, with a pycnocline still between 50 and 75 m depths, high chlorophyll maximum at surface and the shallowest euphotic layer; Group 3: northern stations 12, 13, 14 and 18, sampled during the second part of the cruise at the beginning of nanoplankton bloom, with a deeper pycnocline at, about 100 m depth, less intense surface maxima of chlorophyll and deeper Z_{eu}.

In group 1 total phytoplankton abundance was lower with a higher percentage of the microphytoplankton fraction in the upper layer and an increase of the nanoplankton fraction in the deeper layers, with the sole exception of station 20 which exhibited features similar to group 3 (see below).

In group 2, phytoplankton abundance was the highest with maxima in the upper layers constituted almost exclusively by nanoplankton.

In group 3, phytoplankton abundance was still high, characterized by high percentages of nanoplankton and maxima at 25–50 m depths.

Group 1 was characterized by low microzooplanktonic biomass, which was slightly higher at interme-

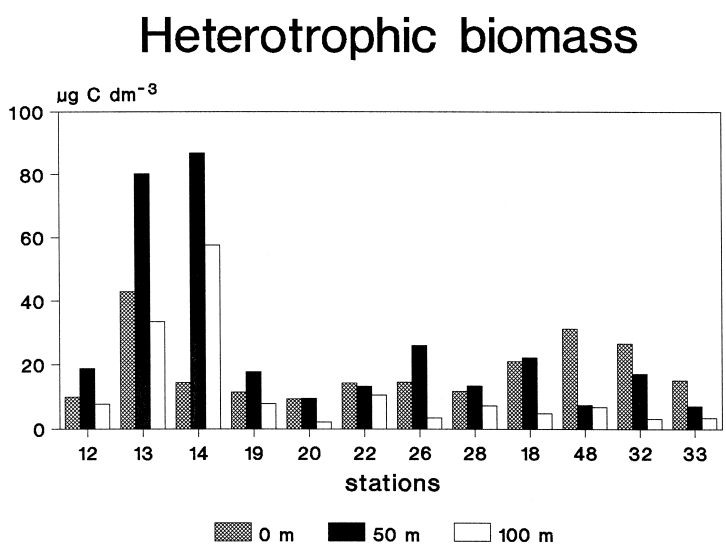

Fig. 8. Total heterotrophic biomass (µg C dm^{-3}) at surface, 50 and 100 m.

diate depths. Microzooplankton abundance showed the same pattern.

Group 2 was characterized by intermediate values of heterotrophic biomass with surface maxima, mostly due to tintinnids. Here too microzooplankton abundance was the highest with surface maxima.

In group 3, two stations (13 and 14) showed a particularly high microzooplankton biomass at 50 and 100 m depths while all other stations belonging to this group showed high abundances at intermediate depths.

Cluster analysis clearly separated stations 13 and 14 at 50 and 100 m depths from the others, due to the high percentage of some species of heterotrophic dinoflagellates such as *Protoperidinium antarcticum* and *P. mediocre*. These stations are the most northern and offshore and they were sampled at the end of the cruise.

Stations 48 and 20 at all the depths were also separate from the others due to the prevalence of *P. defectum* at surface and to the presence of *Laackmaniella* spp., Pteropoda larvae and the richness of unidentified ciliates at all depths.

Surface samples of stations 18, 26 and 32 were grouped together with 100 m samples of stations 32 and 28 due to the dominance of *Codonellospis gaussi*.

For all other stations, cluster analysis generally separated the water column into three discrete layers (surface, intermediate and bottom), indicating that depth impose structure on microzooplankton communities more than other variables. This is true also for phytoplankton communities (Nuccio et al., 1992) which showed well defined structures at each layers, particularly at 50 m depth where a *Phaeocystis* bloom was recorded at all the stations of the grid.

Water mass structure changed during the cruise which covered firstly coastal stations and later offshore stations: the pycnocline deepened from the former to the latter, reaching 100 m depths. Chlorophyll distribution changed from maxima at intermediate depths (25–50 m) to surface maxima and phytoplankton composition shifted from microplankton to nanoplankton dominance. In summary, it would appear that the first leg of the cruise encountered the end of the initial phytoplankton bloom (Innamorati et al., 1992; Nuccio et al., 1992), characterized by high percentages of microplankton while the second leg encountered the onset of a secondary bloom, mostly due to nanoplankton.

The contribution of heterotrophic biomass (10–200 µm) appears more significant in the lower layers and in particular at 50 m depth, which corresponds to the pycnocline and to the base of the photic zone during the first cruise leg. This particular vertical distribution might be explained by the predator/prey relationships characteristic for microplankton con-

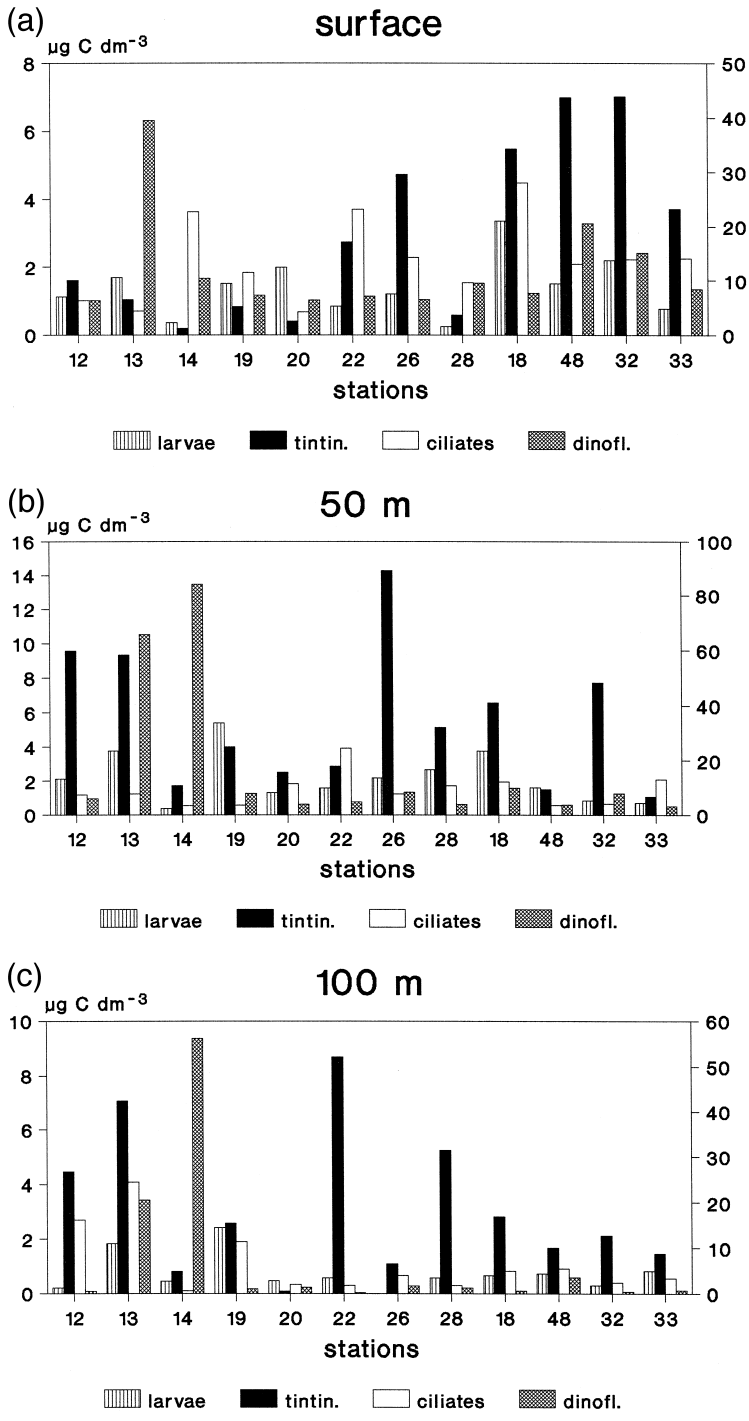

Fig. 9. Heterotrophic biomass (µg C dm^{-3}) of dinoflagellates, tintinnids, ciliates, larvae and eggs, at surface (a), 50 m (b) and 100 m (c). A second scale is used to show dinoflagellate biomass.

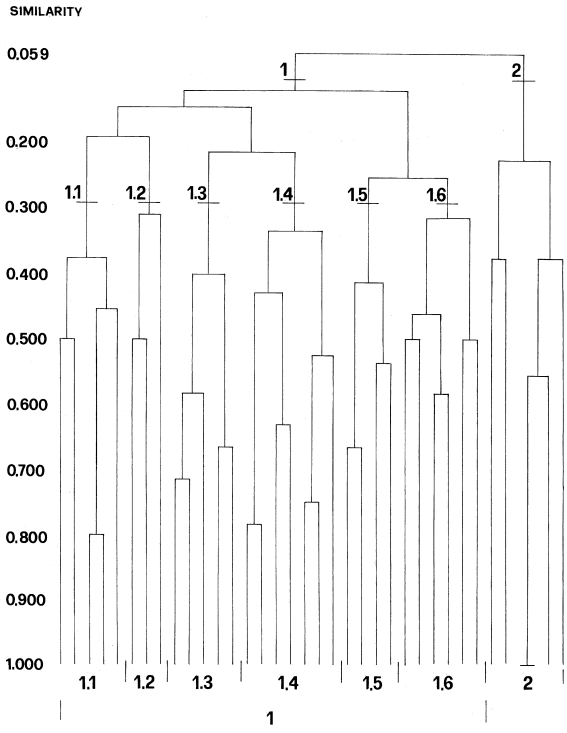

Fig. 10. Grouping of stations using the dendrogram classification obtained by processing the species/samples matrix with the similarity ratio and complete linkage method.

sumers which generally feed on particles < 20 μm (Rassoulzadegan et al., 1988; Pierce and Turner, 1992). Below the 25% of irradiance depth (4.5–11 m) there was an increase in the picoplankton contribution to total primary production (Magazzù and Decembrini, 1992). The relative abundance of this fraction as well as that of nanoplankton at the base of the photic zone could be considered the most important factor influencing the vertical distribution of heterotrophic microplankter biomass even if other factors (i.e., vertical stability of the water column, lower inter specific competition, etc.) could have contributed to determining this distribution pattern.

The role of microzooplankton consumers in the Southern Ocean carbon appears less important at the surface than in aphotic layers where they utilize primarily pico- and nanoplankton producers and slow down the sinking of organic material through the production of small faecal pellets with lower settlement rates than large pellets produced by macrograzers (Longhurst, 1991).

Our values of total heterotrophic biomass appear consistently higher than those found in the Weddell-Scotia Confluence Area in 1988/1989 where maximum average values were less than 4 μg C dm^{-3} at 20 m depth (Alder and Boltovskoy, 1993) or less than 8 μg C dm^{-3} in the Weddell Sea in 1989 (Boltovskoy and Alder, 1992). This is probably due to the great contribution of heterotrophic dinoflagellates which were present in our samples, averaging 12.23 ± 19.1 μg C dm^{-3}. Dinoflagellates generally show lower values: e.g., from 0.35 to 1.95 μg C dm^{-3} in the Weddell Sea in 1987 (Boltovskoy et al., 1989) and from 0.02 to 13.2 μg C dm^{-3} in the Confluence Area (Alder and Boltovskoy, 1993). Their values of tintinnid carbon ranged respectively from 1.64 to 9.05 μg C dm^{-3} and from 0.02 to 9.28 μg C dm^{-3}. Again in the Weddel Sea, Buck et al. (1992) found tintinnid carbon ranging from 0.02 to 1.3 μg C dm^{-3}. Our mean value of 3.88 ± 9.3 μg C dm^{-3} fits well in the range found in the previous cruises.

As regards areal distribution, dinoflagellates strongly influence the general pattern which exhibits

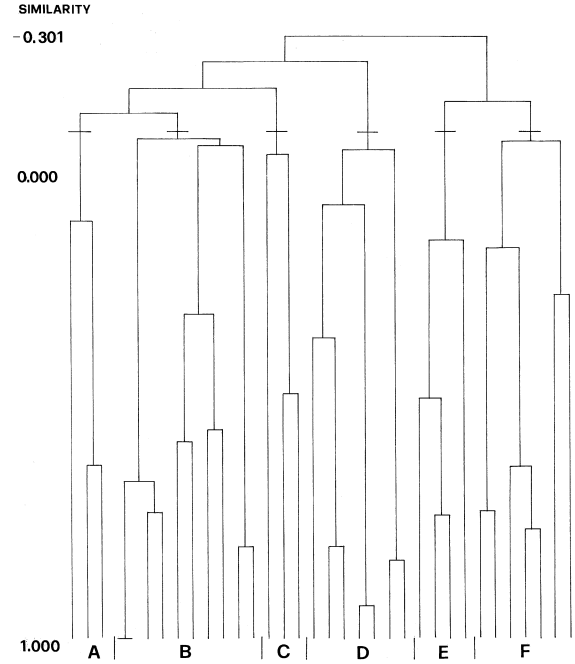

Fig. 11. Grouping of species using the dendrogram obtained by processing the species/samples matrix with the coefficient correlation and complete linkage method.

extreme patchiness. This behaviour is often reported for heterotrophic dinoflagellates in the Southern Ocean (Dodge and Priddle, 1987; Elbrächter and Zölfel, 1993; Alder and Boltovskoy, 1993) and was thought to be associated with the flow of some particular current (Dodge and Priddle, 1987). The maximum of abundance observed at station 48 corresponds to the centre of the cyclonic gyre which establishes itself in the centre of Terra Nova Bay (Stocchino and Manzella, 1991). Another maximum is recorded at station 32 which corresponds to another gyre. At stations 48 and 32, the water mass structure is apparently similar to those of the coastal area, sampled during the first part of the cruise, but the phytoplankton community is mostly constituted of nanoplankton. Here we found the highest values of chlorophyll, of total microzooplankton abundance and of tintinnid biomass.

On the other hand the two richest stations in terms of biomass (stations 13 and 14) are the most influenced by the incoming current from the north-eastern offshore area which is evidently characterized by very large size dinoflagellate communities (namely, *P. antarcticum* and *P. pseudoantarcticum*).

The contribution of dinoflagellates to the total heterotrophic biomass is more important in the upper layers as is often observed (Boltovskoy and Alder, 1992; Alder and Boltovskoy, 1993). In our case,

Table 2
Reconstructed matrix following cluster analysis results

		1.1					1.2			1.3				
		13 0	19 50	22 0	12 0	33 0	14 0	19 0	28 0	18 0	26 0	32 0	28 100	32 100
A	Gyrodinium lachryma	173							338					
	Protoperidinium antarcticum	519												
	Protoperidinium mediocre	173	324						676		676			
B	Protoperidinium cfr. adeliens													
	Cymatocylis conica													
	Leackmanniella prolongata	2	313	5				6		91	9		72	56
	Coxiella frigida		3											
	Protoperidinium defectum		1620			1014	477	928	2366	780				
	Cytharoides sp.													
	Leackmanniella sp.	2	66		5	2				18	9			
	Pteropoda larvae	2	16							14				
	Protoperidinium cfr. pseudoant.													
	Codonellopsis sp.	65	16	27	27	14	8		3					
C	Sticholonche zanclea						2							
	Leackmanniella naviculaefera													
	Cymatocylis sp.	2	13	5	5	19		6		10	9	10	17	6
D	Strombidium sp.						10	14			54			
	Lohmaniella sp.													
	Leegardiella sp.		5											
	Laboea sp.													
	Ciliates A		19				2	3	3				3	19
	Cymatocylis flava													
	Cymatocylis vanhoffeni							6						
E	Protoperidinium applanatum			676	676			818						
	Protoperidinium unipes	173	324	676	676									
	Patronella sp.			116	116					3	47		3	
	Cymatocylis drygalskii	22	156	92	92	122	6	19	23	65	159	29	41	19
F	Enchelys sp.	15		32	32	40	236	19	80	60	24	73	17	15
	Prorodon sp.		3	70	70	56	101	3		57	52	54		4
	Lacrymaria sp.									29	6	39		
	Codonellopsis gaussi									309	65	1003	446	28
	Codonellopsis glacialis									18	4	73		
	Ptychocylis sp.													
	Salpingella sp.													26

Table 2 (continued)

1.4							1.5				1.6						2					
18 50	28 50	26 50	32 50	22 50	33 50	12 50	13 50	13 100	14 50	14 100	18 100	48 0	48 50	48 100	20 0	20 50	19 100	20 100	22 100	12 100	33 100	26 100
								204	1134	816												
									2079	1020		2068		288								
		324																				
		2																				
154	156	535	266	10	20		304	178		36		83	28	16	30	8	3					
		2																				
2337	1296	1620	2096	474	894	474	996		189	816		3619			779	1056						
												6										
						10	62	43	4	4	33	50	5									
		12	3				2	5			5	17	14	5	4	8						
							1660															
							106	18														
										4			2	16							2	
																16						
		5		8		8	28	3	4	2	5		9	23	19	29		3	5	5		2
				8	40	8					2			3		5	17	8	3	3	2	
3		14	3	18	29	18	2	3	4										5	5	7	5
9	3	7	2	8	20	8	2										6	5				
				3		3																
	168	7	10	699	148	699	14	13	86	80	141	182	104	101	22	66	171	24	127	127	81	108
6	15	17		34	3	34	2	20	28		31	6			24		31		154	154		
				3	3	3			2					8					16	16	7	
		648	262															156				
				237		237										352						
14		53		5	31	5																
91	64	82	46	36	20	36	71	33	12	4	24	28	28	21	67	48	37		59	59	51	39
34	8	17	35	3	3	3	32	15		2	2	6		5					3	3		
43	8	7	8				2															
29	10				6																	
145	8	22	127	3	6						5	704	5	3								
		2	12			3																
3	3														4							
29	3		20			3					14					3						2

their contribution both in terms of abundance and biomass is still high also at 50 m depth. Again this might be explained by a higher availability of appropriate food items at this depth.

On the basis of cluster analysis, each layer was separated from the others, indicating depth to be the most influential parameter in structuring community composition.

Stations 20 and 48 appeared different from all the others, as well as stations 13 and 14 at lower depths, due to the peculiarity of their populations.

Summing up, it appears that water mass characteristics and structures, as well as timing of sampling, strongly influenced the distribution of phytoplankton biomass and composition which mostly influence the distribution of microzooplankton biomass. The microzooplankton community composition appears more related to patchiness of dominant species, which changed over the sampling time.

Acknowledgements

This work was supported by the Italian National Antarctic Research Program. Thanks are due to crew members of R/V *Polar Stern* and especially to Prof. Letterio Guglielmo who collected the samples during the cruise. The authors wish to thank Dr. Mike Lucas for reviewing the manuscript and for his constructive comments, and the three anonymous reviwers for suggestions and critical remarks on the manuscript.

References

Alder, V.A., Boltovskoy, D., 1991. Microplanktonic distributional patterns west of Antarctic Peninsula, with special emphasis on the tintinnids. Polar Biol. 11, 103–112.

Alder, V.A., Boltovskoy, D., 1993. The ecology of larger microzooplankton in the Weddel-Scotia Confluence Area: horizontal and vertical distribution patterns. J. Mar. Res. 51, 323–344.

Beers, J.R., Stewart, G.L., 1970. Numerical abundance and estimated biomass of microzooplankton. In: Strickland, J. (Ed.), The Ecology of the Plankton off La Jolla, California, in the Period April through September 1967. Bull. Scripps Inst. Oceanogr. 17, 67–87.

Bjørnsen, P., Kuparinen, J., 1991. Growth and herbivory by heterotrophic dinoflagellates in the Southern Ocean, studied by microcosm experiments. Mar. Biol. 106, 1–9.

Boldrin, A., Stocchino, C., 1990. On the Hydrological characteristics of Terra Nova Bay. Nat. Sci. Com. Ant. Ocean. Camp. 1987–1988, Data Rep. 1, 11–57.

Boltovskoy, D., Alder, V.A., 1992. Microzooplankton and tintinnid species-specific assemblage structures: patterns of distribution and year-to-year variations in the Weddel Sea (Antarctica). J. Plankton Res. 14, 1405–1423.

Boltovskoy, D., Alder, V.A., Spinelli, F., 1989. Summer Weddell Sea microplankton: assemblage structure, distribution and abundance, with special emphasis on the Tintinnina. Polar Biol. 9, 447–456.

Brambati, A., Fanzutti, G.P., Finocchiaro, F., Simeoni, U., 1989. Sediments and sedimentological processes in the Ross Sea continental shelf (Antarctica): results and preliminary conclusions. Boll. Ocean. Teor. Appl. 7, 159–188.

Buck, K.R., Garrison, D.L., Hopkins, T.L., 1992. Abundance and distribution of tintinnid ciliates in an ice edge zone during the austral summer. Antarct. Sci. 4 (1), 3–8.

Burba, N., Feoli, E., Malaroda, M., Zuccarello, V., 1992. Un Sistema informativo per la Vegetazione. Sotware per l'archiviazione della vegetazione italiana e per l'elaborazione di tabelle: Manuale di utilizzo dei programmi. Quaderni CETA 2, 1–78.

Burkill, P.H., Edwards, E.S., John, A.W.G., Sleigh, M.A., 1993. Microzooplankton and their herbivorous activity in the northeastern Atlantic Ocean. Deep Sea Res. 40, 479–494.

Burkill, P.H., Edwards, E.S., Sleigh, M.A., 1995. Microzooplankton and their role in controlling phytoplankton growth in the marginal ice zone of the Bellinghausen Sera. Deep Sea Res. 42, 1277–1290.

Dodge, J.D., Priddle, J., 1987. Species composition and ecology of dinoflagellates from the Southern Ocean near South Georgia. J. Plankton Res. 9 (4), 685–697.

Edler, L., 1979. Recommendations on methods for marine biological studies in the Baltic Sea. Phytoplankton and chlorophyll. Baltic Marine Biol. 5, 1–38.

Elbrächter, M., Zölfel, M., 1993. Taxonomy and ecology of heterotrophic ice-flagellates. In: Spindler, M., Dieckmann, G., Thomas, D. (Eds.), The Expedition ANTARKTIS X/3 of RV Polastern in 1992. Ber. Polarforsch. 121, 26–29.

Garrison, D. L, Buck, K.R., Gowing, M.M., 1993. Winter plankton assemblage in the ice edge zone of the Weddel and Scotia Seas: composition, biomass and spatial distribution. Deep Sea Res. 40 (2), 311–338.

Gifford, D.J., 1988. Impact of grazing by microzooplankton in the Northwest Arm of Halifax Harbour, Nova Scotia. Mar. Ecol. Prog. Ser. 47, 249–258.

Innamorati, M., Mori, M., Lazzara, L., Nuccio, C., Lici, M., Vanucci, S., 1990. Ecology of phytoplankton. In: Nat. Sci. Com. Ant. Ocean. Camp. 1987–88, Data Rep. I, Genova, 161–238.

Innamorati, M., Lazzara, L., Massi, M., Mori, G., Nuccio, C., Saggiomo, E.V., 1992. Indagine sulla biomassa fitoplanctonica nel Mare di Ross in relazione ai fattori ambientali. In: Gallardo, V.A., Ferretti, O., Moyano, H.I. (Eds.), Atti Seminario Internazionale Oceanografia in Antartide. ENEA—Progetto Antartide-Italia, 235–252.

Lessard, E.J., Swift, E., 1986. Dinoflagellates from the North Atlantic classified as phototrophic or heterotrophic by epifluorescence microscopy. J. Plankton Res. 8, 1209–1215.

Longhurst, A.R., 1991. Role of the marine biosphere in the global carbon cycle. Limnol. Oceanogr. 36 (8), 1057–1526.

Magazzù, G., Decembrini, F., 1992. I risultati di produzione primaria delle crociere oceanografiche 1987–1988 e 1989–1990 del Programma Nazionale di Ricerche in Antartide. In: Gallardo, V.A., Ferretti, O., Moyano, H.I. (Eds.), Atti Seminario Internazionale Oceanografia in Antartide. ENEA—Progetto Antartide-Italia, 273–284.

Nuccio, C., Innamorati, M., Lazzara, L. and Mori, G., 1992. Popolamenti fitoplanctonici nella Baia di Terranova, Mare di Ross. In: Gallardo, V.A., Ferretti, O., Moyano, H.I. (Eds.), Atti Seminario Internazionale Oceanografia in Antartide. ENEA—Progetto Antartide-Italia, 253–262.

Pierce, R.W., Turner, J.T., 1992. Ecology of planktonic ciliates in marine food webs. Rev. Aquat. Sci. 6 (2), 139–181.

Putt, M., Stoecker, D.K., 1989. An experimentally determined carbon: volume ratio for marine oligotrichous ciliates from estuarine and coastal waters. Limnol. Oceanogr. 34, 1097–1103.

Rassoulzadegan, F., Laval-Peuto, M., Sheldon, R.W., 1988. Partitioning of the food ration of marine ciliates between pico- and nanoplankton. Hydrobiology 159, 75–88.

Stocchino, C., Manzella, G.M.R., 1991. Analisi delle correnti marine di Baia Terra Nova (Mare di Ross-Antartide). C.N.R. Area di ricerca di Genova, 1–55.

Utermöhl, H., 1958. Zur Vervollkommung der quantitativen Phytoplankton-Methodik. Mitt. Int. Ver. Theor. Angew. Limn. 9, 38.

Verity, P.G., Langdon, C., 1984. Relationships between lorica volume, carbon, nitrogen, and ATP contents of tintinnids in Narragansett Bay. J. Plankton Res. 6, 859–868.