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Article

Distribution and Abundance of Zooplankton in the Bransfield Strait and the Western Weddell Sea during Austral Summer

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Abstract : Zooplankton community was surveyed during the Seventh Korea Antarctic Research Program, from 28 December 1993 to 11 January 1994. Zooplankton samples were collected at 40 stations from the waters around the South Shetland Islands with a Bongo net and a MOCNESS. A total of 14 taxa of zooplankton were identified. Zooplankton abundances varied at each station as well as with the sampling gears. Zooplankton abundances were higher in the Western Weddell Sea than those in the Bransfield strait. Zooplankton collected with MOCNESS showed a different vertical distribution depending on its depths at selected stations. Copepods were the major components of zooplankton contributing 72.84% (mesh size 333 μm) and 68.36% (mesh size 505 μm) of total zooplankton abundance from the Bongo samples. Salps were the second most abundant group comprising 7.92% (333 μm) and 11.99% (505 μm) of total zooplankton abundance. Euphausiids, chaetognaths, polychaetes, pteropods and ostracods occurred more than 1% of total zooplankton. Copepods were not abundant at stations salps and euphausiids were dominant. *Salpa thompsoni, Euphausia superba, Calanoides acutus, Metridia gerlachei* and *Calanus propinquus* were dominant depending on the stations. The hierarchical UPGMA cluster analysis of dissimilarities between sampling stations is displayed with clusters identified similar habitats. Copepods rarely appeared in the clusters 4 and 5, and they appeared a few in the cluster 3 (or salps were numerous), while copepods were abundant in the clusters 1 and 2. As in the results of cluster analysis, the distributions of dominant taxa have a well identified correspondence to the geological positions included physical factors.

Key words : zooplankton, the Bransfield Straits, the Western Weddell Sea, Austral summer

1. Introduction

The survey of zooplankton community in the Bransfield Strait and the Western Weddell Sea was conducted during the Seventh KARP (Korea Antarctic Research Program). Zooplankton biomass is high in waters adjacent to the Bransfield Strait because of mixing of various neighboring waters during austral summer (Park and Wormuth 1993). The studies of zooplankton in the area have been concentrated to a single species, *Euphausia superba* because of its ecological importance (Brington *et al.* 1987). In this area, other important species and taxa such as *E. crystallorophias* (Everson 1987), copepods (Schnack-Schiel *et al.* 1991; Atkinson 1989; Marin 1988) and salps (Casareto and Nemoto 1986; Nishikawa *et al.* 1995), and seasonal succession, community structures and vertical and horizontal distributions of zooplanktons (Boysen-Ennen and Piatkowski 1988; Park and Wormuth 1993) have been reported. Generally higher primary productivity is found at near the ice edge during austral summer. Therefore, many researchers have interested in the distributions, species compositions and the secondary productivity of the zooplankton which are

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related with the primary productivity (Lancraft *et al.* 1989; Hopkins and Torres 1988; Brinton *et al.* 1987). Information on zooplankton abundances and species compositions near the ice edge, however, is comparatively scarce because of the difficulties with samplings (Delgado *et al.* 1998).

The aims of this study were to clarify distribution, species composition and abundance of the zooplankton community and dominant species near the ice edge in the Western Weddell Sea in comparison with the zooplankton community in the Bransfield Strait. In addition, cluster analysis was conducted to reveal the fragmentation or aggregation patterns of dominant species in the study area.

2. Materials and methods

Zooplankton samples

Zooplankton samples were collected at 40 stations in the Bransfield Strait and the Western Weddell Sea from December 28, 1993 to January 11, 1994 using a 1 m^2 MOCNESS (mesh aperture 505 μm) and Bongo nets (mouth opening 0.28 m^2, mesh aperture 333 and 505 μm). Sampling depth for Bongo nets was limited to 300 m depth. These stations consisted of 35 stations in five transects and additional four stations (show as only one dot in the figure 1) around Deception Island (Fig. 1). The samples were preserved with 5% buffered formalin on board. A total number of 71 samples were collected using the Bongo nets and 56 samples using the MOCNESS. The MOCNESS was towed at stations 2, 31, 49 and D2. It utilized eight nets, each with an effective mouth area of 1m^2 and fitted with 505 μm mesh. Towing speed was approximately 1 $m \cdot sec^{-1}$. The nets were towed in depths of 0-10, 10-20, 20-30, 30-50, 50-75, 75-100, 100-150, and 150-200 m, respectively at stations 2, 31 and 49, and 0-10, 10-20, 20-30, 30-40-40-50-50-75, 75-100 and 100-125 m, respectively at station D2 in Deception Island. At station D2, a total of four MOCNESS towing were attempted at intervals of six hours (22:00, 04:00, 10:00 and 16:00 at local time) to observe the vertical migration of zooplankton. Salps, euphausiids and fish larva were sorted out and counted from whole samples and small metazoan zooplankton such as copepods were counted from aliquots ranging from 1/1 to 1/16 after dividing the samples using a Motoda box. Salps, euphausiids, chaetognaths and copepods were identified to species level under the dissecting microscope. The counted numbers of zooplankton were converted to individuals per 1000 m^3 for a comparison between stations. The filtered volume of seawater was calculated using a flow meter (General oceanic) in the Bongo nets.

CTD castings were completed to obtain the environmental factors, and the values of chlorophyll *a* were estimated during the same periods to use as a comparison with zooplankton abundances.

Data analysis

The cluster analysis (CA) was conducted to present the

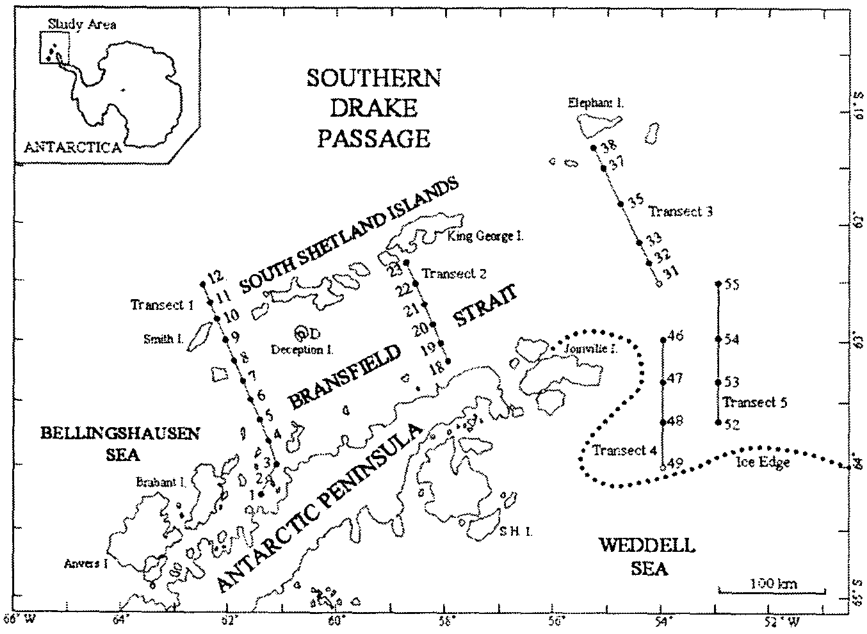

Fig. 1. The 7th KARP biology cruise Track and Stations (1993/94 Austral summer).

associations among variables and sampling sites. Based on the fact that the dominant three taxa occupied over 80% of relative abundance in observed zooplankton, the selected three taxa and the physical environmental factors were provided as input to CA. These selected taxa were salps, euphausiids and copepods. All analyses were carried out by using the MVSP (Multi Variate Statistical Package) software, which was available on the internet at "http://www.kovcomp.com/mvsp/index.html". The process of CA was as follows:

a. calculate a matrix of dissimilarities between all pairs of objects.
b. the first cluster is formed between the two objects with the smallest dissimilarities.
c. the dissimilarities between this cluster and the remaining objects are then recalculated.
d. a second cluster is formed between cluster 1 and the object most similar to cluster 1.
e. the procedure continues until all objects are linked in clusters.

3. Results and discussion

Species composition

Four taxa; salps, euphausiids, copepods and chaetognaths were identified to species level among 14 taxa occurred in the present study. Copepods were the most abundant group and made up 72.84% (mesh size 333 μm) and 68.36% (mesh size 505 μm) of total zooplankton abundance from the Bongo nets. Salps were the next with the proportional

Table 1. Species composition during 7th KARP cruise in Austral summer 93-94.

Salps	*Racovitzanus antarcticus*
Salpa thompsoni	*Rhincalanus gigas*
blastozooid	*Scolecithricella cenotelis*
oozooid	*Scolecithricella minor*
Schiphonophora	*Scutellidium* sp.
Other Medusae	*Temorites* sp.
Pteropoda	*Tisbe racovitzai*
Chaetognatha	Copepoda, nauplius
Sagitta gazellae	Amphipoda
Sagitta marri	Euphausiid
Eukronita hamata	*Euphausia superba*
Copepoda	*Euphausia crystallorophias*
Aetideopsis minor	*Euphausia frigida*
Calanoides acutus	*Thysanoessa macrura*
Calanus propinquus	Calyptosis stage
Calanus simillimus	*Appendicularia*
Candacia maxima	*Ostracoda*
Centrophages sp.	*Isopoda*
Haloptilus oxycephalus	*Unknown Arthropoda*
Harpacticus sp.	*Larvae & Eggs*
Heterohabdus sp.	Polychaeta larva
Latania sp.	Veliger larva
Metridia gerlachei	Bivalve larva
Microcalanus pygmaeus	Mollusca egg
Oithona frigida	Barnacle cyprid
Oithona similis	Crustacean egg
Oncaea antarctica	Fish larva
Paraeuchaeta antarctica	Fish egg

Table 2. Zooplankton abundances and proportions based on the Bongo nets samples during the 7th KARP cruise in Austral summer 93-94.

	333 μm		505 μm	
	Abundance (indiv.1000 m^{-3})	%	Abundance (indiv.1000 m^{-3})	%
Mean Total abundance	5,507	100.00	3,942	100.00
Copepods	4,011	72.84	2,695	68.36
Metridia gerlachei	2,111	38.33	1,929	48.93
Calanoides acutus	653	11.85	469	11.91
Calanus propinquus	302	5.49	109	2.77
Paraeuchaeta antarctica	363	6.58	147	3.73
Microcalanus pygmaeus	84	1.53	-	0.00
Salps	436	7.92	473	11.99
Euphausiids	212	3.86	191	4.83
Euphausia superba	92	1.67	90	2.29
Thysanoessa macrura	53	0.95	61	1.55
Chaetognaths	285	3.37	163	4.14
Ostracods	86	1.57	47	1.18
Polychaets	76	1.40	28	0.70
Pteropods	42	0.75	44	1.12
Eggs & Larvae	239	4.34	98	2.50

compositions of 7.92% (333) and 11.99% (505). Euphausiids and chaetognaths also comprised more than 3% of total zooplankton. Ostracods, polychaets and Pteropods comprised more than 1% of total zooplankton (Tables 1 and 2). Unidentified eggs and larvae made up 4.34% (333) and 2.50% (505). The identified species were one species of salps, four of euphausiids, 23 of copepods and three of chaetognaths, therefore copepods were the most diverse (Table 1).

Salpa thompsoni was only species of salps, consisted of mainly blastozooids, and a few oozooids were found from only few stations. Chaetognaths were dominated by *Sagitta gazellae* and *Eukronita hamata* but *Sagitta marri* rarely occurred.

The dominant species of copepods were large sized ones such as *Calanus propinquus, Calanoides acutus, Metridia gerlachei* and *Euchaeta antarctica. M. gerlachei* was the most dominant zooplankton comprising 38.33% (333) and 48.93% (505) of total zooplankton abundance. These large sized species consisted of higher number of copepodites (CI-CV) rather than adult (CVI). *Microcalanus pygmaeus* and *Scolecithricella minor* were dominant at stations in transect 1 and 2. *M. pygmaeus* was dominant with 1.53% of total zooplankton in Bongo 333 but disappeared in 505 (Table 2). The species non-identified to species level were *Scutellidium* sp. and *Harpacticus* sp. in order Harpacticoida, *Ratania* sp. in order Poecilostomatoida and *Centrophages* sp., *Heterohabdus* sp. and *Temorites* sp. in order Calanoida usually due to the absence of adult in the samples.

Four species of euphausiids occurred: *Euphausia superba, E. crystallorophias, E. frigida* and *Thysanoessa macrura. E. superba* was abundant in the open ocean, while *E. crystallorophias* was dominant in coastal waters. *T. macrura* occurred at nearly all stations. A low number of *E. frigida* occurred only at station 36.

Spatial distribution

The surveyed areas were divided into 5 transects consisted of three in the Bransfield Strait and two in the Western Weddell Sea. Samples obtained with the Bongo nets were used for the analysis of spatial distributions of zooplankton abundances. Total zooplankton abundances ranged from 33 indiv.1000 m^{-3} to 48,546 indiv.1000 m^{-3} (mean: 5,507 indiv.1000 m^{-3}, mesh size 333 μm) and 164 indiv.1000 m^{-3} to 48,288 indiv.1000 m^{-3} (mean: 3,942 indiv.1000 m^{-3}, mesh size 505 μm). There was no significant difference in the distribution pattern of the abundances between each mesh size of Bongo nets, although mean abundance from both mesh sizes showed a gap of 1,565 indiv.1000 m^{-3} (Figs. 2, 3). Copepods were the most abundant taxa in the samples from both mesh sizes. Abundances of copepods ranged from 17 indiv.1000 m^{-3} to 43,790 indiv.1000 m^{-3} (mean: 4,011 indiv.1000 m^{-3}, 333) and from 42 indiv.1000 m^{-3} to 43,589 indiv.1000 m^{-3} (mean: 2,695 indiv.1000 m^{-3}, 505) in the Bongo samples. Salps and euphausiids were also abundant taxa and both were dominant mainly at stations in transects 2 and 3 instead of copepods. Copepod abundances were relatively low where salps and euphausiids were dominant. The difference of mean total abundances between the mesh sized of Bongo nets was depending on the abundances of small sized zooplankton such like

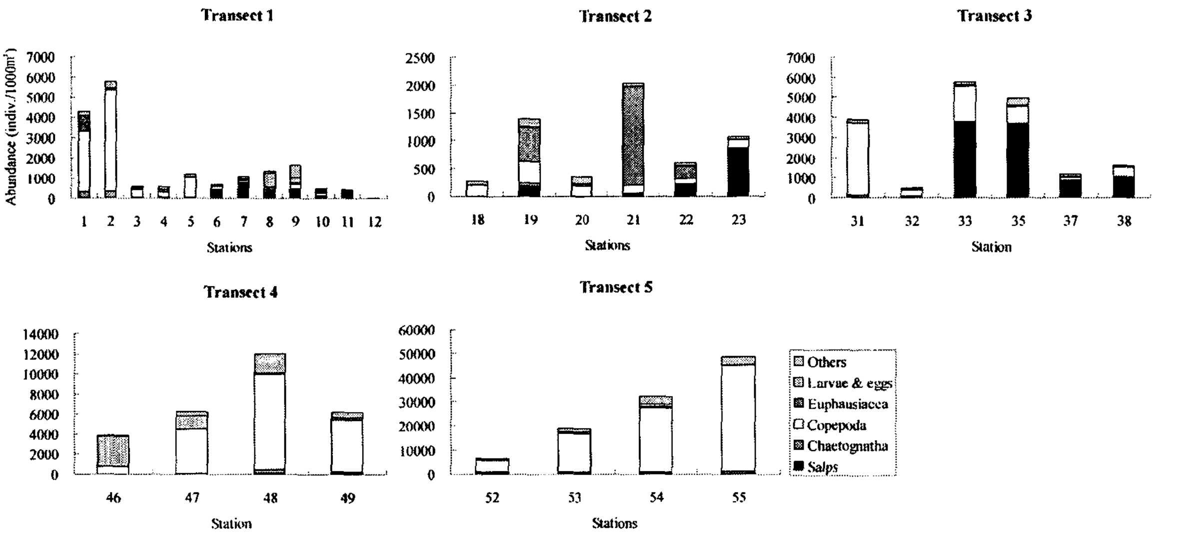

Fig. 2. Numerical abundances of zooplankton according to Bongo sample (mesh size 333).

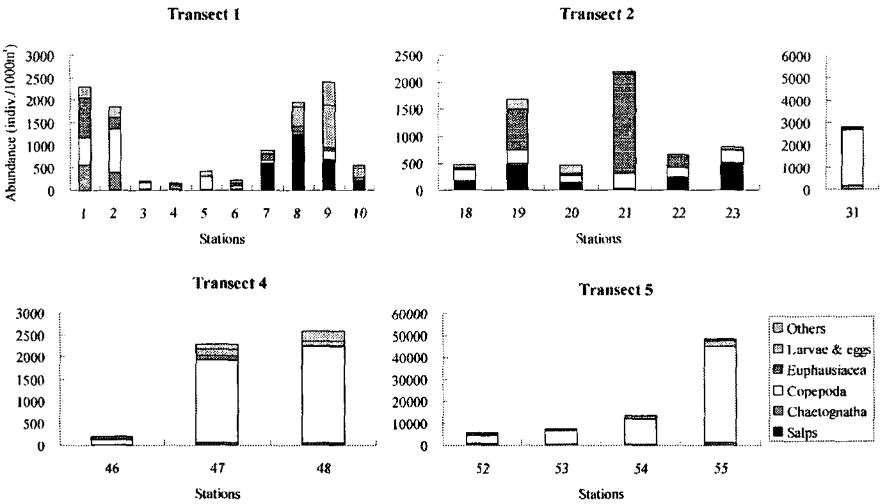

Fig. 3. Numerical abundances of zooplankton according to Bongo sample (mesh size 505).

Microcalanus pygmaeus and *Oithona* spp. Since the small sized copepods could be filtered with a high efficiency in 333 μm mesh rather than in 505 μm mesh, the propositional composition of copepods were 72.84% of total zooplankton abundances in 333 μm but 68.36% in 505 μm (Table 2). The mean zooplankton abundances in present study were similar to the previous report in the region during austral summer (Park and Wormuth 1993).

Zooplankton abundances were higher in transects 4 and 5. Except for station 52, zooplankton abundances were higher than 10,000 indiv.1000 m^{-3} in transect 5. Zooplankton abundances showed some gradient depending on distance from the ice edge. It increased from station 52 located near the ice edge to the northward until station 55. Abundances increased from stations 46 to 48 and decreased again at station 49 in transect 4. Copepods were most abundant in transects 4 and 5 and the most dominant species was *Metridia gerlachei*. Except for stations 1 and 2 in transect 1 zooplankton abundances were lower than 1,000 indiv. 1000 m^{-3}, and the dominant taxon was copepod. Salps and euphausiids were more abundant than copepods in transects 2 and 3, however total zooplankton abundances were lower in these areas compared to the other transects. Although dominant species varied at each station, *Metridia gerlachei* was predominated from nearly all the stations surveyed and affected strongly to total zooplankton abundance with its high abundances in the Western Weddell Sea (for instance, 33,718 indiv.1000 m^{-3} from 505 μm at station 55). As a result, zooplankton abundances were higher in the Western Weddell Sea than in the Bransfield Strait due to the high copepod abundances in the Western Weddell Sea. The dominant taxa were characteristics at each transect, that is copepods and salps in transect 1, euphausiids in transect 2, salps in transect 3 and copepods in transects 4 and 5.

Vertical distribution

MOCNESS was used to observe the vertical distributions of zooplankton at selected four stations, 2, 31 and 49 in the oceanic areas, and D2 in the caldera at Deception Island. At station D2, a total of four MOCNESS tows were attempted at intervals of six hours to observe the vertical migration of zooplankton.

Copepods were the most abundant taxa from Bongo samples at station 2 (Fig. 4a). Most zooplanktons occurred in the deeper layers. Copepods showed high abundance and made up 4,477 indiv.1000 m^{-3} in the depths of 150-200 m. Euphausiids were concentrated to 30-50 m layer and other taxa occurred in the layers deeper than 75 m.

Euphausiid eggs were abundant in the layers of 50-100 m at station 31 (Fig. 4b) and were probably the eggs of *Euphausia superba* since *E. superba* was the only euphausiid found with a significant amount at this station (Fig. 4). Copepods were the most abundant taxon except for the euphausiid eggs. Each zooplankton taxon showed characteristic depth preference. *Calanus propinquus* and *Calanoides acutus* were abundant in the 0-25 m layer, *Microcalanus pygmaeus* in the 75-100 m layer and copepodites stages II and III of *Paraeuchaeta antarctica* in the 150-200 m layer, respectively. Chaetognaths occurred in the layers deeper than 50 m, while pteropods were found from the layers shallower than 50 m.

Copepods were concentrated to the layers deeper than 50 m, while euphausiids occurred in the layers shallower

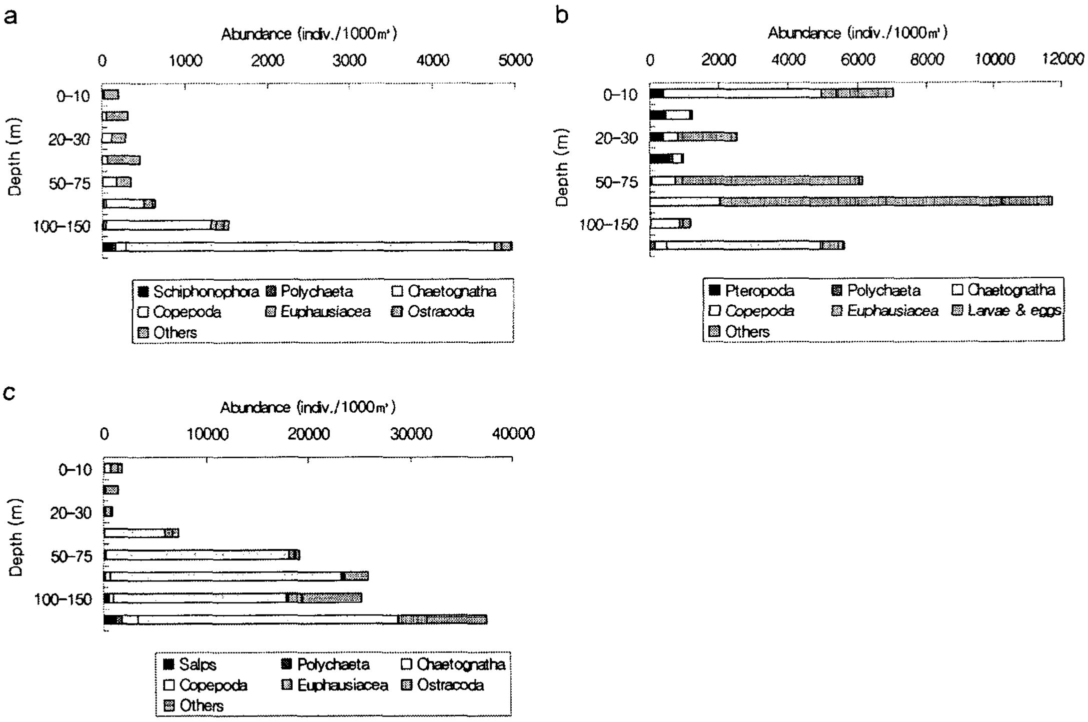

Fig. 4. Vertical distributions of major groups of zooplankton at station 2 (a), 31 (b), 49 (c).

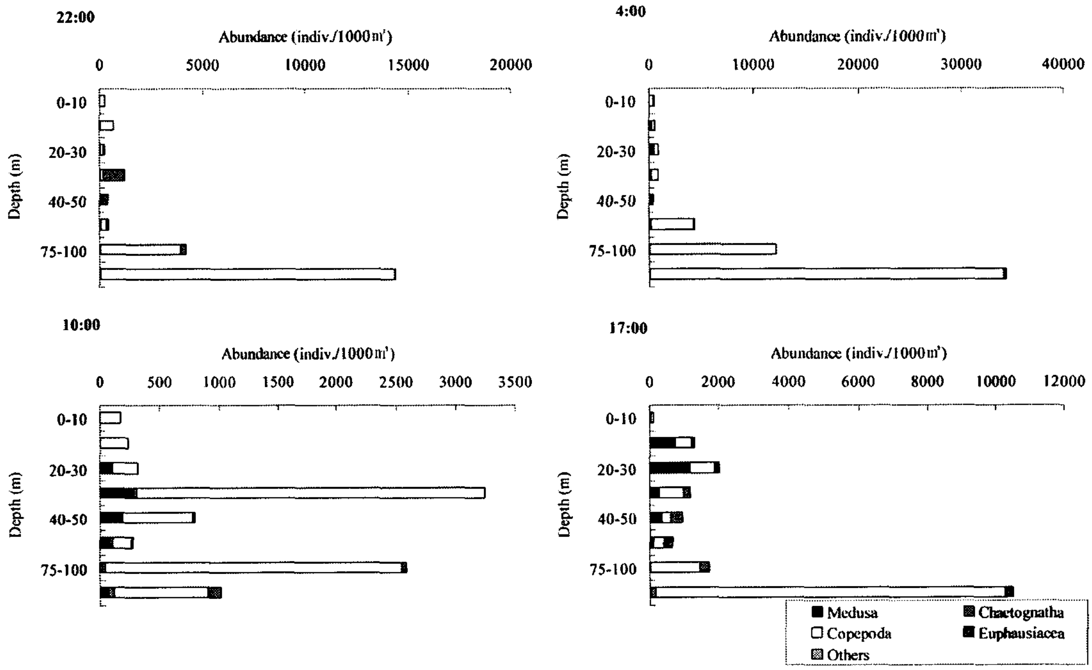

Fig. 5. Vertical distributions of major groups of zooplankton at station D2.

than 50 m at station 49 (Fig. 4c). Ostracods, chaetognaths and polychaets were abundant from the 150-200 m layer but pteropods also occurred in the layers shallower than 50 m as in station 31.

Distribution patterns of zooplankton varied depending on the sampling times at station D2 located in the middle of the caldera at Deception Island (Fig. 5). A dense population of *Euphausia crystallorophias* has been reported in the

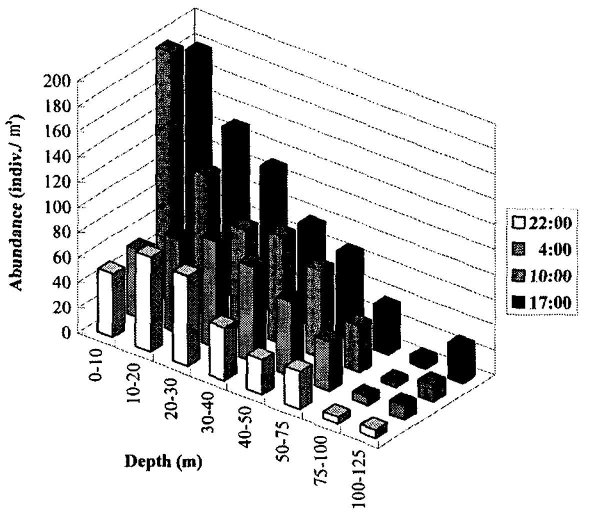

Fig. 6. Abundances of Euphausiid eggs at Deception Island.

caldera at Deception Island (Everson 1987). The eggs and nauplius of *E. crystallorophias* occurred numerously at station D2 (Fig. 6). The abundances of eggs ranged from 5,569 indiv.1000 m^{-3} to 180,705 indiv.1000 m^{-3}. The abundances of naupliius made up to 3,676 indiv.1000 m^{-3}. Eggs mainly occurred in the layers shallower than 75 m at all the sampling times (22:00, 04:00, 10:00 and 16:00 at local time) and their abundances at each layer varied slightly depending on the sampling times.

At near night time (22:00 LT) copepods were the most abundant taxa except for the eggs and naupliius of *Euphausia crystallorophias* at station D2 (Fig. 5a). *Calanoides acutus, Calanus propinquus* and *Microcalanus pygmaeus* were dominant copepods. The dominancy of *M. pygmaeus* was outstanding even among the dominant species. Especially copepods occurred densely in 75-125 m layers due to the high abundance of *M. pygmaeus*. The abundance in the layers of 0-10 m and 10-20 m were due to *Calanoides acutus* and *Calanus propinquus*. Chaetognaths occurred in the layers deeper than 50 m, while hydromedusae occurred in the layers shallower than 75 m.

Microcalanus pygmaeus was also the most dominant species in the second MOCNESS tow at 04:00 LT (Fig. 5b), and copepods abundance was the highest as 34,170 indiv.1000 m^{-3} in 100-125 m layer. Chaetognaths were found in the deeper layers and hydromedusae occurred in 0-75 m layers.

In the third MOCNESS tow at 10:00 LT copepods moved to upper layers depending on the species, and copepod abundance decreased dramatically (Fig. 5c). It was the highest as 3,059 indiv.1000 m^{-3} in 75-100 m layer and was only 787 indiv.1000 m^{-3} in 100-125 m. In contrary *Microcalanus pygmaeus* occurred only in the layers deeper than 100 m. Euphausiids and hydromedusae also moved to the deeper layers than in the previous tows.

In the fourth MOCNESS tow at 16:00 LT copepod abundance increased again up to 10,116 indiv.1000 m^{-3} in 100-125 m layer (Fig. 5d). Euphausiids were abundant in 40-50 m and chaetognaths in 100-125 m. Hydromedusae were abundant in 10-30 m. *Microcalanus pygmaeus* moved to the layers deeper than 125 m.

Calanoides acutus and *Calanus propinquus* showed slightly vertical migration in the present study. They occurred from 0-30 m at 22:00 LT and from 0-40 m at 04:00 LT, respectively. *Calanoides acutus* occurred from 30-40 m with 244 indiv.1000 m^{-3} and *Calanus propinquus* occurred from 40-50 m with 331 indiv.1000 m^{-3} at 10:00 LT. Although both species did not occur at the surface layer (0 -10 m depth) but slightly moved to the upper layers at 16:00 LT. *Calanoides acutus* occurred in 20-30 m and *Calanus propinquus* in 30-40 m at 16:00 LT. Both species

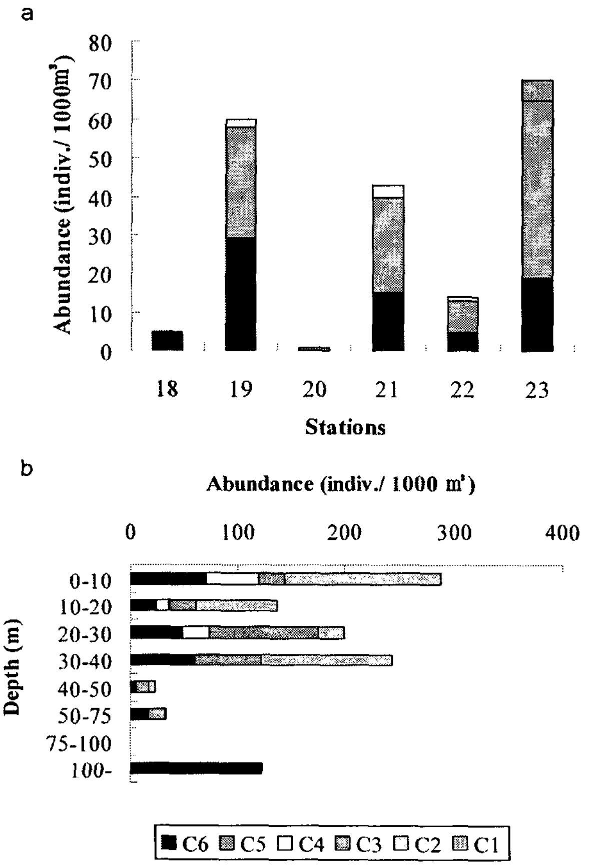

Fig. 7. Abundances of copepod stages of *Calanoides acutus* in transect 2 (a) and *Calanus propinquus* from station D2 at 04:00 (b).

occurred in the near surface waters in all the four MOCNESS tows and the early copepodite stages of both species were dominant in the samples (Figs. 7a, b). These results were well matched with the previous report (Delgado *et al.* 1998; Marin 1988), and supported to the Marin's hypothesis for their life cycle patterns (Marin 1988).

Studies on zooplankton in Antarctic waters have been concentrated on a single important species, *Euphausia superba*. Other major concerns were large sized macrozooplankton (Nishikawa *et al.* 1995; Siegel and Piatkowski 1990). However, small sized copepods (≥1 mm) such as *Oithona* spp., *Ctenocalanus citer, Microcalanus pygmaeus* and *Clausocalanus* spp. occurred abundantly in the coastal waters of the Antarctic Peninsula (Fransz 1988; Foster 1987; Foster 1989; Perissinotto 1989; Hopkins and Torres 1988). These small sized copepods and the copepodites and nauplius of large species are important food items for fish larvae and macrozooplankton (Nishiyama and Hirano 1985; Hoshiai and Tanimura 1981; Takahashi and Nemoto 1984). *Microcalanus pygmaeus* was dominant at station D2 in Deception Island even though a large sized mesh of MOCNESS (505 μm) was used. *M. pygmaeus* and *Euphausia crystallorophias,* important prey items to certain fishes (Takahashi and Nemoto 1984) appeared dominant and were playing an important role in the zooplankton community of Deception Island during the study periods.

Ontogenetic distribution of large sized copepods

The large sized copepods, *Calanoides acutus, Calanus propinquus, Rhincalanus gigas, Metridia gerlachei* and *Paraeucheata antarctica* were common and dominant during the study periods. Generally the copepodites from CI to CV of dominant copepods were much abundant than the adults of those except for *Metridia gerlachei* in the present study.

Calanoides acutus were easily distinguished from other copepods because of its transparent body. Generally the rates of copepodid stages from CIII to CV of *C. acutus* were much higher than those of adult. For instance CV of *C. acutus* was 10,460 indiv.1000 m^{-3} while the adult was only 1,930 indiv.1000 m^{-3} at station 55 in transect 5 in Bongo 333. CI and CII stages of *C. acutus* did not occur during the study period (Fig. 7a). *Calanoides acutus* is ontogenetic seasonal migrators to distribute from depths of 0-250 m in summer and from 500-1000 m in winter (Andrews 1966; Delgado *et al.* 1998; Marin 1988). Usually in January the early copepodid stages of *C. acutus* are more abundant than the adults because they have already completed reproduction in December (Huntley and Escritor 1991).

Calanus propinquus was not so abundant in transect 1 and 2 and consisted of the copepodid stages from CII to the adult (Fig. 7b). The abundances of *Calanus propinquus* increased in transect 3 and all the copepodid stages occurred. Copepodid stages from CI to CV of *C. propinquus* were abundant than the adults at all the stations surveyed. Also copepodid stages from CI to CV were abundant rather than the adults from all the depth layers except for 100-125 m layer in the MOCNESS tows.

Rhincalanus gigas occurred at several stations and the ratio of adults to copepodid stages was higher than those in other large copepods. Since its body size is larger than other species (adult >10 mm), its abundances were higher in the samples from the 505 μm mesh than in the 333 μm mesh of Bongo nets.

Metridia gerlachei was the most dominant species in the present study. *M. gerlachei* occurred only at station 1 and 2, and most of them were copepodites of CIV and CV in transect 1. *M. gerlachei* occurred at few stations in transect 2, in contrary the adults of *M. gerlachei* occurred at nearly all the stations with a higher rate than copepodid stages in transect 3. The adults of *M. gerlachei* were higher than the copepodid stages when their total abundances were higher in transects 4 and 5. It was reported that *M. gerlachei* commonly occurred as a dominant species around Elephant Island during austral summer where its abundances was at its highest with more than six indiv.1000 m^{-3} (Park and Wormuth 1993). The mean abundance of *M. gerlachei* was 2,111 indiv.1000 m^{-3} in the study area (333) and its highest abundance, 33,718 indiv.1000 m^{-3} (505) at station 55 was much higher than in the previous studies (Siegel *et al.* 1992; Hopkins and Torres 1988; Vuorinen and Bonsdorff 1992). The massive abundances of *M. gerlachei* seem due to the high concentrations of chlorophyll a and optimal temperature conditions for the species (Figs. 10a, 11, Park and Wormuth 1993).

Pareuchaeta antarctica is usually the most abundant among the congeners in euphotic zones in austral summer (Ward and Wood 1988). Except for copepodid stages of CI to CV, the adults of *P. antarctica* did not occur in the Bongo 333 samples. The copepodites of CI to CII were dominant, in contrary copepodites from CIV to CV occurred only at the limited stations. The abundances of *P. antarctica* were higher at the stations in transect 1, 4 and 5. CII copepodites were the most dominant with 1,722 indiv. 1000 m^{-3} (333) at station 49 in transect 4. The abundance of CI copepodites was 838 indiv.1000 m^{-3} (333) at the same station. The abundance of CIII copepodites was

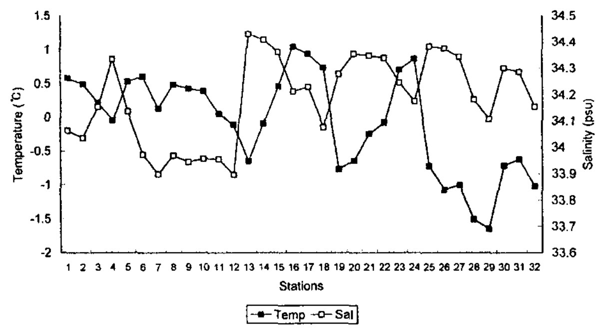

Fig. 8. Variations of temperature and salinity at each station.

1,090 indiv.1000 m^{-3} (333) at station 55 in transect 5. CII of *P. antarctica* was abundant at a depth of 150-200 m with 8,706 indiv.1000 m^{-3} from the MOCNESS tow at station 49.

The adults and juveniles stages of large sized copepods occurred from the different depths. The adults of *Calanoides acutus* were mainly found in the surface layer and usually in the shallower depths than its copepodites. The copepodid stages of *Calanus propinquus* were found mainly in the layers shallower than 75 m and the adults of *C. propinquus* were found from the layers deeper than 100 m at station 2.

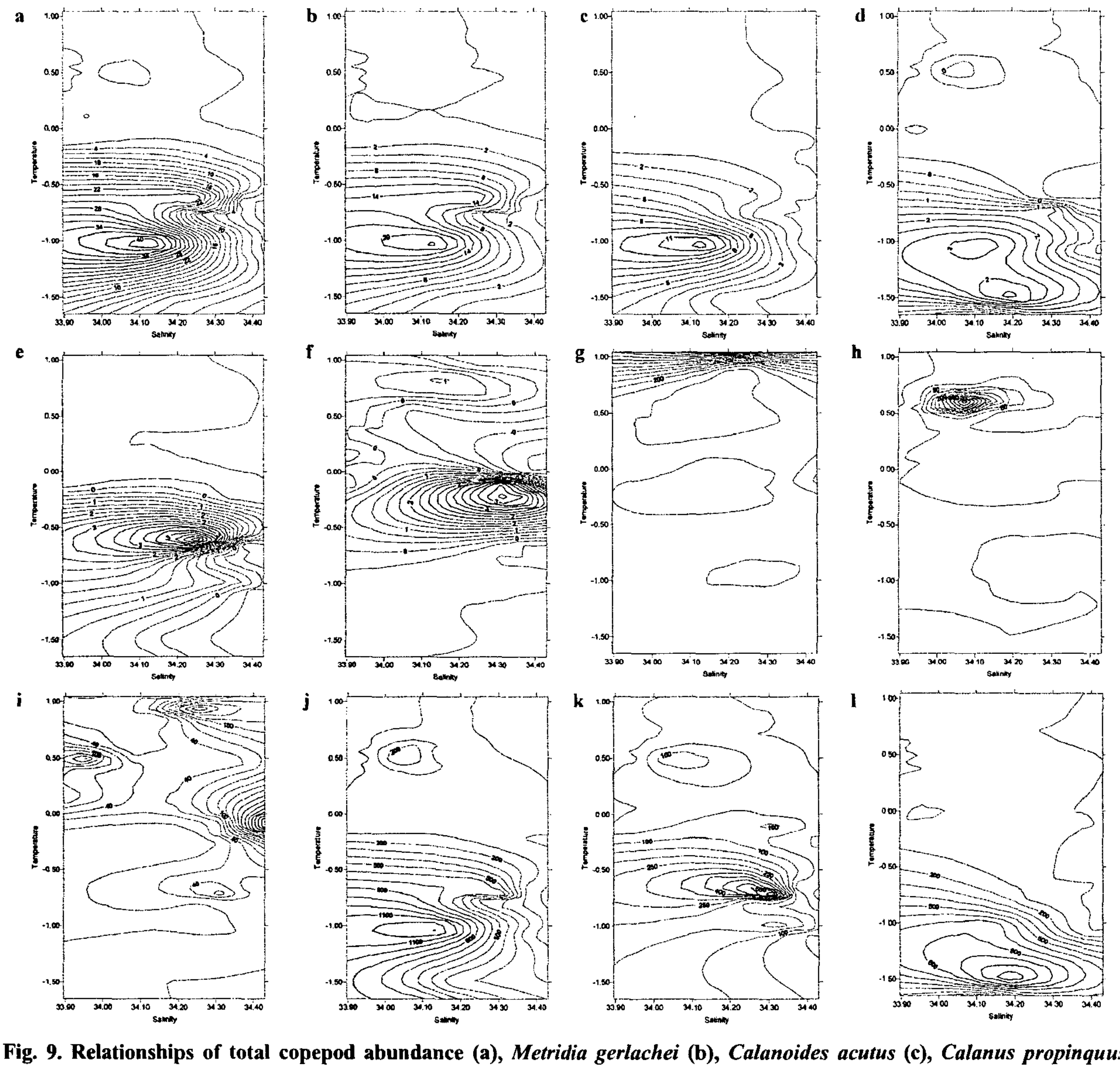

Fig. 9. Relationships of total copepod abundance (a), *Metridia gerlachei* (b), *Calanoides acutus* (c), *Calanus propinquus* (d), *Paraeuchaeta antarctica* (e), *Salpa thompsoni* (f), *Euphausia superba* (g), *Euphusia crystallorophias* (h), *Thysanoessa macrura* (i), *Ekronita hamata* (j), *Microcalanus pygmaeus* (k), *Rhincalanus gigas* (l) with salinity and temperature (Unit: a~f : indiv./m^3, g~l :indiv./1000 m^3).

The adults of *C. propinquus* occurred from all depth layers, however each copepodid stage was distributed separately at different depths, that is, CV from 150-200 m, CIV and CII from 75-100 m, CIII from 30-50 m and CI from 50-100 m, respectively at station 49. The adults of *Metridia gerlachei* were distributed at all depth layers with higher rates than its copepodites except at the deepest depths where the rates of copepodites were higher than its adults at station 49. The adults of *Pareuchaeta antarctica* were mainly distributed at layers deeper than its copepodites.

Relationships between abundance and environmental factors

Temperature ranged from −1.5°C to 1.0°C during the survey periods (Fig. 8). Temperature ranges of transects 4 and 5 in the Western Weddell Sea were lower than 0°C but those of transects 1 to 3 in the Bransfield Strait were higher than 0°C. Also, salinity ranged from 33.9 PSU to 34.4 PSU was a little difference between the two regions, that is, those of the Western Weddell Sea were higher than those of the Bransfield Strait (Fig. 8). The dominant species had optimal ranges of temperature for each species (Fig. 9). The temperature ranges for the dominant species were lower in the present study than in the previous studies (Park and Wormuth 1993). It seems due to the different sampling periods between the studies. Copepod communities showed the highest density at −1°C with more than 40 indiv.m^{-3} where the salinity was 34.1 PSU (Fig. 9a). *Metridia gerlachei* and *Calanoides acutus* showed their highest density at −1.0°C with 20 indiv.m^{-3} and 11 indiv.m^{-3}, respectively (Figs. 9b-c). *Calanus propinquus* showed higher tolerance ranges for temperature and salinity than *M. gerlachei* and *C. acutus* (Fig. 9d), while *Paraeuchaeta antarctica* occurred in temperatures lower than −1.0°C. *Salpa thompsoni* showed the highest abundance at 0°C and 34.3 PSU with three indiv.m^{-3} (Fig. 9f). *Euphausia superba* showed their highest abundance at more than 0.5°C (Fig. 9g). Other species such as *Euphausia crystallorophias, Thysanoessa macrura, Eukronita hamata, Microcalanus pygmaeus* and *Rhincalanus gigas* (Figs. 9h-l) also showed characteristic temperature and salinity values for their optimal distributions. Correlations between total zooplankton abundance and environmental factors were not detected clearly in the study area, however some factors correlated weakly with each zooplankton taxon in certain transect. Salps correlated with salinity in transect 2 ($F=7.811$, $r=0.77$, $0.05<P<0.1$) and copepods with chlorophyll a in transect 5 ($F=5.920$, $r=0.711$, $0.1<P<0.2$).

The values of chlorophyll a were three to seven times higher in the Western Weddell Sea than in the Bransfield Strait and were positively related to the copepod abundance (Fig. 10, $F=3.762$, $r=0.58$, $P<0.001$). Nishikawa *et al.* (1995) reported that the abundances of *Euphausia superba* were higher in the high chlorophyll *a* area. Although Nishikawa *et al.*'s study limited to only salps and euphausiids, their report on the close relationship between zooplankton abundance and chlorophyll a value concurs with the present study.

The hierarchical UPGMA cluster analysis of dissimilarities between sites is displayed with clusters identified some similar habitats (Fig. 11). The cluster was largely affected by the abundances of salps and copepods. Copepods rarely appeared in the cluster 4 and 5, and they appeared a few in the cluster 3 (or salps were numerous), while

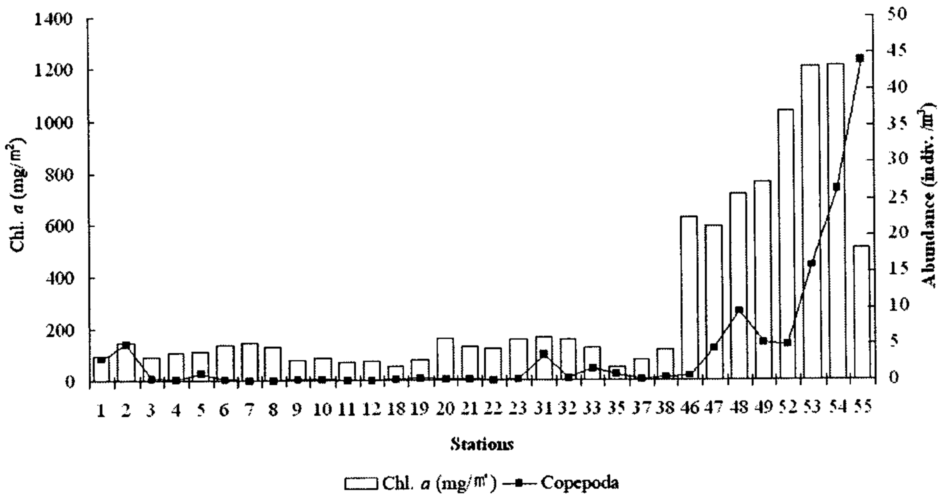

Fig. 10. Comparison between copepod abundances and chlorophyll *a*.

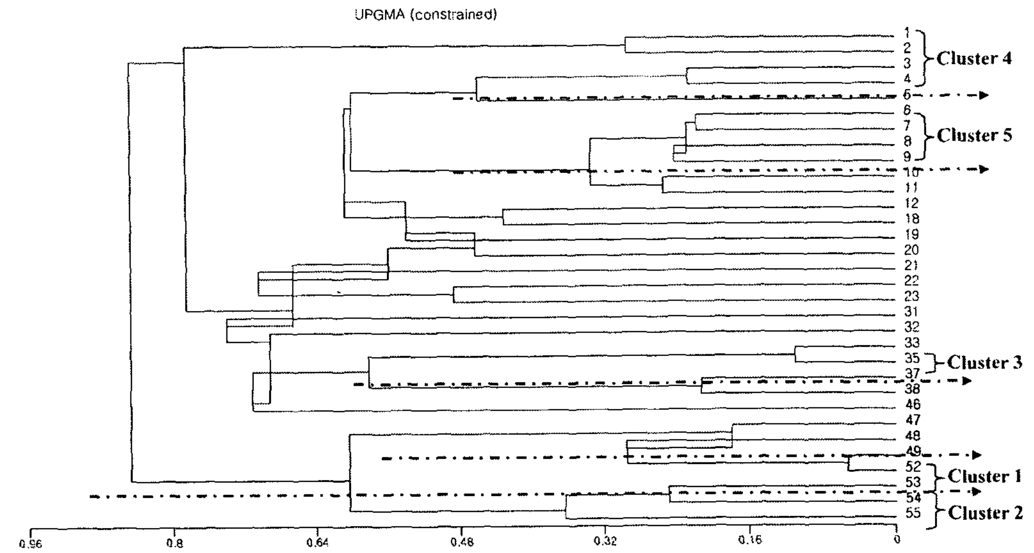

Fig. 11. Dendrogram from hierarchical UPGMA cluster analysis based on a Bray-Curtis matrix of dissimilarities between sites. Five clusters identified most similar conditions were suggested in CA. The other sites showed high dissimilarities did not form clusters.

copepods were abundant in the cluster 1 and 2. Generally the lower dissimilarity showed that copepods were abundant in the cluster 1 and 2. The lowest dissimilarity (0.053) appeared in the cluster 1 consisted of stations 49 and 52 in the transect 4 and 5. Also, low dissimilarity (0.248) appeared in the cluster 2 considered similar habitat condition with the cluster 1, and copepods were the most abundant in the cluster 2 among the comparing clusters. The dissimilarity was low (0.11) in the cluster 3 from transect 3 and salps were the most abundant in the cluster. Copepods and salps appeared rarely in the cluster 4 and 5 from transect 1. As the results of cluster analysis, the distributions of dominant taxa show a well identified correspondence to the geological positions included physical factors.

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