# Salp distribution and size composition in the Atlantic Sector of the Southern Ocean

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#### Abstract

Salp abundance and length frequency was measured from large scale CCAMLR synoptic survey conducted in the Atlantic Sector of the Southern Ocean in 1999/2000 season. Results from regional survey around Elephant Island in 1994/95 and 1996/97 seasons were dealt as well. In the large scale study, the salp abundance was higher in the Antarctic Peninsula and South Sandwich Island areas compared to the central Scotia Sea. The likely reason for this pattern was thought to be negative effect of the above threshold phytoplankton abundance for salp filter feeding performance. Cluster analysis of the salp size compositions resulted in three clusters for each of the survey. Clusters composed of large salps located in warmer waters during the large scale survey, as well as the regional survey in other seasons. Inferring from the size compositions of the salp populations, it was thought that timing of intense budding was earlier in the warmer waters. Possible spatio-temporal pattern of budding events in the Southern Ocean was further discussed.

#### Introduction

The pelagic tunicate *Salpa thompsoni* is often known to exhibit dense swarms in the Antarctic waters (e.g. Nishikawa et al., 1995, Loeb et al., 1997). Although salps are not a major dietary item for Antarctic predators, they play important role in the Antarctic ecosystem. As a herbivorous species, due to their high filtering rate, they are often thought as a serious competitor against other herbivorous plankton species, such as Antarctic krill, in the Antarctic waters (Siegel and Loeb, 1995; Loeb et al., 1997). Also from the geochemical viewpoint, they are thought to work as an important biological pump removing carbon particles from surface waters down to the deeper layers (Persinotto and Pakhomov, 1998). These evidences imply the necessity of knowing the spatio-temporal distribution and abundance, to understand the ecological process in the Southern Ocean. Salps are known to reproduce rapidly when they encounter favorable food conditions (Alldredge and Madin, 1982) and exhibit patchy distributions. Does this mean that the occurrences of salp blooms are random? Or do they have any general trend in time and space? To solve this question, synoptic survey of salp demography concurred with biological and environmental observation was desired.

CCAMLR 2000 synoptic survey (Trathan et al., 2001) provided an excellent opportunity to investigate the above problem. Although the main objective of the synoptic survey was to improve estimates of Bo (pre-exploitation biomass) used in the krill yield model to estimate sustainable yield for Area 48 (CCAMLR, 1998), salp observation was also dealt as one of the key measurement during the survey.

In this paper, by using abundance and size composition of *Salpa thompsoni*, from the synoptic survey, and smaller scale observations around the Elephant Island in other two seasons as well, we aim to discuss any possible spatio-temporal pattern of their bloom occurrence.

# **Material and Methods**

During January-February 2000, four vessels from CCAMLR member nations participated in the synoptic survey in year 2000: Kaiyo Maru (Japan), Atlantida (Russia), James Clark Ross (UK) and Yuzhmorgeologia (USA). Net sampling was performed along the transect lines (Figure 1) by RMT1+8 (Rectangular Midwater Trawl; Baker et al., 1973), the standard gear among the four vessels (Siegel et al., in press).

At each station, a quantitative standard double oblique tow was conducted from the surface down to 200 m (or to within 10 m of the bottom at stations shallower than 200 m). Samples from RMT ranged from a few grams to several kilograms in weight. The total volume of the net catch was measured (total drained sample volume). For catches with a total volume of less than 1 litre all the sample were sorted. The minimum requirement was that all the krill and salp specimens to be counted and measured immediately after the catch. If at all possible then the rest of the zooplankton either should be identified to the species level and counted, or stored in 10% buffered formalin solution for later analyses.

All salps were removed from samples smaller than 1 litre and counted. From larger samples a random subsample of 1 litre were taken. *Salpa thompsoni* and *Ihlea racovitzai* were identified according to Foxton, (1966), and Foxton (1971). The different forms (aggregate/solitary) were identified and measured as well in two of the vessels. In the other two vessels, the two forms were not delineated, or they were deliniated but the length measurements were performed only for aggregate forms (Figure 1). Whenever possible, a minimum of 100 specimens per species were measured. The internal body length (Foxton, 1966) was measured to the mm below with an accuracy of 1 mm size classes.

Surveys in Elephant Island area were undertaken by Polerstern (Germany) in 1994/95 and 1996/97 seasons. The sampling protocols were basically the same as those used during the CCAMLR 2000 Synoptic Survey. In short, double oblique tows using RMT-8 net down to depth of 200m were performed. Both the different forms (aggregate/solitary) were identified, however, the internal body lengths were only measured for the aggregate forms.

The spatial distribution of the salp population was analyzed using a cluster analysis to compare between station similarities in salp size composition. The hierarchical fusion of clusters was preferred using Ward's method to link homogeneous clusters and the eucledean distance coefficient was applied for the diversity analysis. Only stations with minimum of 20measued specimens were applied to cluster analysis.

Each length frequency distributions was weighted by size of the catch and the filtered water volume before data were combined for the composite length frequency distributions.

#### Results

1999/2000 field season (The CCAMLR Synoptic Survey)

Abundance distribution

Two salp species were observed during the January-February survey. Those were *Salpa thompsoni* and *Ihlia racovitza*.

Biomass of *S. thompsoni* (aggregate plus solitaries) is shown in Fig. 2a. Although they distributed throughout the surveyed area, the abundances in the central Scotia Sea were relatively low. Amongst the two different sexual forms (aggregate/solitary), at the stations where the two forms were delineated, aggregates dominated in number (Table 1). The main salp distribution was from the area around the South Shetland Islands throughout the South Orkney Islands, and the area east of South Sandwich Islands. Average biomass through out the survey area was 82.8 ind/1000m<sup>3</sup>. The largest biomass (1806 ind/1000m<sup>3</sup>) was recorded at station JC26(2) (58.5S, 49.1W) (Table 1).

The distribution of the solitary forms is shown in figure 3a. Its abundance distribution showed similar pattern to the total number (Fig. 2a), but the number was lower (3.7 and 0.33 ind/1000m<sup>3</sup> for maximum and mean density in the Scotia Sea area, and 6.0 0.89 ind/1000m<sup>3</sup> for maximum and mean density in the Antarctic Peninsula strata (Table 1).

*I. racovitzai* was recorded only at two stations around South Orkney Islands. The density was low (0.35 and 0.06 ind/1000m3) compared to *S. thompsoni*. Due to their small number we will not deal with this species further, and concentrate the further discussion to *Salpa thompsoni*.

Length frequency distribution

# Aggregate form

Length frequency distributions of the aggregates were applied to cluster analysis. In case of stations where two forms were not delineated, individuals larger than 80mm were removed from the length frequency distributions, since these sizes are obviously be out of size range of aggregate forms (Foxton, 1966). There were still possibilities of solitary forms included in length class smaller than 80mm. However, since the number of the solitary form is generally very low compared to number of the aggregate form (Table 1), we assumed the effect of the contaminations of the solitaries to the length frequency distributions should be negligible. In case, after the completion of the cruise, portions of sub-samples from these stations were examined after the cruise, and were confirmed that solitary forms should be negligible in number.

At a distance level of 0.8, length frequency distributions clustered into three distinct groups of stations (Fig. 4a). Fig. 2b shows the length distribution of each cluster. Cluster 00-A was mainly composed of 14-62mm salps, with modal length of 34mm. Cluster 00-B was mainly composed of 8-44mm salps, with modal length of 26mm. Cluster 00-C was mainly composed by 4-40mm salps, with modal length of 12mm.

Spatial distributions of these clusters are expressed in Figure 2a by using different symbols. Cluster 00-A, the largest size group, mainly distributed along the South Shetland Islands and to the north west of the South Orkney Islands and in the Bransfield Strait. Its distribution was further observed at the northern edge of the surveyed area of the central Scotia Sea, but the density along this area was rather low. Cluster 00-B, the middle size cluster also distributed along north of the South Shetland Islands as well, but towards inshore compared to Cluster 00-A. Cluster 00-B extended to the east beyond the South Orkney Islands. It was also observed to the north of the South Sandwich Islands. Cluster 00-C, the smallest sized cluster mainly distributed to the east of the South Sandwich Islands. It also distributed along the southern edge of the surveyed area in the east half of the Scotia Sea, and some in the center of Scotia Sea but in low numbers. It was also observed at a station to the north of Elephant Island in high number.

# Solitary form

Due to the low number of solitary forms caught, cluster analysis was not performed. Therefore, the length frequency was compiled for the Antarctic Peninsula area, and the Scotia Sea area.

The size composition in the Antarctic Peninsula strata, interestingly showed two distinct size ranges (20-60mm and 80-150mm). The smaller group was mainly composed of animals smaller than 50mm. Those are thought to be still immature and seemed not to be contributing to budding of aggregate forms yet (Foxton, 1966). The larger group with mode at 100-120mm, may have been older stages that have already completed releasing most of their aggregate chains (Foxton, 1966).

On the other hand, the length composition in the Scotia Sea strata showed more or less wider range (0-120mm) with its mode at 20-40mm. This indicates that almost half of the solitaries (0-60mm) are yet to be matured, and the other half (60-100mm) may actively contributing to budding of aggregate chains.

#### S. thompsoni in other field seasons

#### Elephant Island area, Novermber/December, 1994

The highest and the mean abundances were 43 and 5.6 inds/1000m<sup>3</sup> (Table 1). Relatively high abundances were observed in the area north west of the Elephant Island grid (Fig. 5a). Results of the cluster analysis showed three clusters at distance level of 0.78 (Fig. 4b). They were Cluster 94-A, large size group (main size range of 8-26mm with a mode at 20mm); Cluster 94-B, middle size group (main size range of 10-32mm, with main mode at 14mm with small shoulders at 20 and 30mm); Cluster 94-C, small size group (main size range of 6-28mm with a modes at 8 and 12mm, and a small mode at 26mm as well) (Fig. 5b). The area of high abundances were mainly towards the north west of the survey grids, where most of the stations belonged to Cluster 94-A. Cluster 94-B and 94-C were in smaller number, and distributed towards south east of Cluster A. Densities in the south east half of the grid was extremely low.

Elephant Island area, December, 1996

During this survey, S. thompsoni distributed widely throughout the Elephant

Island grid in high abundance with exception of south and north west of Elephant Island where salp density was low (Fig. 6a). The highest and the mean abundances were 1041 and 114.4 inds/1000m<sup>3</sup> (Table 1). The length frequency distribution was clustered into three groups at distance level of 0.8 (Fig.4c). They were Cluster 96-A, large size group (main size range of 12-50mm with multiple modes between 24-44mm); Cluster 96-B, middle size group (main size range of 6-36mm, with main broad peak with mode at 20mm); Cluster 96-C, small size group (main size range of 6-34mm with a mode at 12mm) (Fig. 6b). Cluster 96-A was mainly observed to the north of Cluster 96-B. Cluster 96-C was mainly observed at the southern edge of Cluster B. Salp densities in the area to the north west and south of the Elephant Island seemed to be relatively lower than the rest of the stations.

# Estimation of daily carbon demand

Carbon abundance was calculated from the length frequency distribution and abundance data (individuals/m<sup>3</sup>) using carbon-length relationship (Huntley et al., 1989). Daily carbon demand per m<sup>2</sup> per day was calculated by assuming their daily carbon demand as 25% of their body carbon (Huntley et al., 1989) (Figure 7). In every case, the mode was observed in the lowest increment, 0-5mgC/m<sup>2</sup>/day. Among 1996/97 and 1994/95 seasons in the Elephant Island area, the frequency distribution showed higher carbon demand in the 1996/97 season. This could be explained by the effect of higher salp abundance plus larger individual size.

## **Discussion and conclusions**

## Abundance and distribution

The large scale water mass analysis during the CCAMLR 20000 Synoptic Survey (Brandon et al., in press) showed influence of the Weddell Sea water at the stations located in the south of the Scotia Sea. Krill distribution observed in the same survey showed outflow from the Weddell Sea krill population into the Scotia Sea, which implies the stronger influence of Weddell Sea water this season (Siegel et al., in press). Generally, according to Foxton (1966), *S. thompsoni* is an animal of the middle

Southern Ocean latitudes (45-55°S) being more or less absent from the water of the Weddell drift and in higher latitudes from the region of the East Wind drift. Salp abundance in our survey generally followed this pattern, however, the abundance in the central part of the Scotia Sea was also low (Fig. 4a).

Salps are filter feeders which collect food particles using mucous nets (Alldredge and Madin, 1982). Because of this unique feeding mechanism, it is known that their feeding nets can become clogged when they encounter very high concentrations of particles (Harbison and Gilmer, 1976), and this may exclude them from areas of unusually high particle concentrations (Harbison et al., 1986). The overview from the satellite image (Holm-Hansen et al., in press) showed high Chl-a concentration in the central part of Scotia Sea where the salp densities were low. On the other hand, where chl-a concentrations were low, such as the Antarcttic Peninsula area and in South Sandwich Island area, salp abundances were high.

Persinotto and Pakhomov (1998) found drastic reduction of salp feeding rate when Chl-a level exceeded threshold level of 1 to 1.5 ug Chl-a/L, and lead to the collapse of the salp population. This agrees with our result which generally showed constant low salp abundance when the Chl-a concentration was higher than 1mg/m<sup>3</sup> (Fig. 8).

Family Salpidae are known to repeat alternations of generations between an asexually reproducing generation and a sexually reproducing generation (Nishikawa et al., 1995). Burst of the salp population is caused by the asexual reproduction (budding). Daponte et al. (2001) demonstrated that the formation of swarms is directly dependent on the number of buds per block of each solitary specimen. These studies imply that optimal food condition with high abundance of seed population (solitaries) may lead to higher number of buds, and eventually lead to formation of intensive bloom. In our study, the density of solitaries in Scotia Sea was lower than those in the Antarctic Peninsula Area (Table 1). Moreover, Chl-a concentration in the central Scotia Sea was above threshold for salps' capability. These factors may have had co-effect to retain the salp abundance at low level in this area.

There are other possible explanations for this kind of miss match distributions between salp and Chl-a abundances. The first possible reason is salps grazing down phytoplankton community (Loeb et al., 1997). In our study, in the year 2000 survey, the daily carbon demand by salps was less than 10mgC/m<sup>2</sup>/day at 57% of the observed stations, and less than  $20 \text{mgC/m}^2/\text{day}$  at 80% of the observed stations (Fig. 7). Comparing this value to the known primary productivity throughout the Scotia Sea (100 to 1,400mgC/m<sup>2</sup>/day, El-Saved and Weber, 1982), it was far below those values. Therefore, grazing pressure by salps may have not be high enough to control the Chl-a concentration and distribution in year 2000. Again, in Elephant Island area, carbon demand of all stations in 1994/95 season was less than 5mgC/m<sup>2</sup>/day. In case of 1996/97 season, carbon demand at 74% of the was less than  $30 \text{mg/m}^2/\text{day}$ . This value is also less than 10% of the mean productivity of 374 mgC/m<sup>2</sup>/day (Helbling, et al., 1995). The second possible reason for the salp-Chl-a miss match is the biological segregation between salps and krill, forcing salps to distribute in area of relatively lower phytoplankton density (Nishikawa et al., 1995). However, during the synoptic survey, the krill distribution pattern (Siegel et al., in press) did not necessarily show mismatch pattern against salp distribution. Overall evidence suggest that the salp abundance and distribution pattern observed in our study are likely to be governed by Chl-a concentration. High chl-a concentration area seemed unfavorable for salps.

# Size composition and their distribution

Throughout our cluster analysis, we generally observed clusters with larger salps (Cluster-00A) distributing to the north and smaller (Clusters-00B and C) to the south of the Scotia Sea and South Sandwich Island area. In the Antarctic Peninsula area, Cluster-00A distributed off shore of the South Shetland Islands and in the Bransfield Strait. Cluster 00B distributed as a narrow band along the shelf edge north of the South Shetland Islands (Fig. 2a). What are the possible causes of this distribution pattern?

According to the spatial distribution of clusters north of the Antarctic Peninsula area, slightly smaller size group (Cluster –00B) distributed as a narrow band along the area close to South Shetland Islands. Larger size group (Cluster-00A) distributed in the oceanic region and in the Bransfield Strait. In the area north of South

Shetland Islands, a shear current is formed within the frontal zone and a sluggish current towards the inshore (Ichii et al. 1998). This current pattern may retain the substances passively advected. High abundance with similar size composition implies the idea that the passive drifters such as salps are mechanically retained in the area north of the South Shetland Islands. This may be one of the reason why uniform cluster (Cluster-00B) distributed parallel to the north of the South Shetland Islands.

When cluster distribution was compared with the temperature distribution during the survey (Brandon, in press), it showed a general trend that stations with salps of larger size distribute where temperature was relatively high, and vise versa, especially in the Scotia Sea strata (Cluster-00A tended to distribute along the northern area where the temperature was relatively high). The size distribution of Cluster-00A, which lack smaller sizes may indicate lack of recent intensive budding. On the other hand, Cluster-00C have mode at 10mm, which indicate recent intensive budding (Foxton, 1966). Given the distribution pattern of these clusters (Fig. 2b), earlier budding may have taken place in area along the Antarctic Peninsula and north edge of Scotia Sea, where temperature was relatively high.

It is known that growth rates of tunicates are temperature dependent when other factors are held constant (Paffenhofer, 1976, King, 1982). Therefore, the animals living in warmer waters may grow faster than the salps distributing in lower temperature conditions. Also, timing of the intensive budding should be earlier, which give them bigger chance of growing larger. Increased salp by-catch in krill fisheries at higher temperature conditions (Kawaguchi et al., 1998) also supports the idea that salps favor warmer waters.

Cluster analysis of salp size distribution for 1994/95 and 1996/97 field season in Elephant Island area both resulted in three groups. Although the mean salp densities are substantially different in these two field seasons, we could see consistency in spatial distributions of size clusters, which showed larger clusters distributing towards the north west of the survey grid, on the other hand, smaller sized clusters distributed towards the south east of the survey grid. Huntley et al. (1989) has indicated spatial separation of size groups, and concluded that the larger size groups were advected from up stream areas along the Antarctic Peninsula area where smaller salp were found. According to Siegel and Harm (1997), in the southern Bellingshausen Sea, regional differences were not only observed for salp abundances, but also for the spatial distribution of salp size groups. A more northern group consisted of larger salps which were found under the influence of West Wind Drift waters in high abundance, while distinctly smaller salps in low numbers occurred in southern waters of the East Wind Drift. The authors concluded that salps on the southern shelf were advected from the oceanic region and trapped under unfavorable conditions such as long dense ice cover and low phytoplankton inhibiting salp growth and recruitment, showing extremely low abundance and smaller size.

In the Elephant Island area grid, figures in Amos (2001) indicated that the surface water has a general temperature gradient of decreasing trend from northwest towards the southeast, and the boundaries of the five water zones run southwest-northeast direction across the survey grid (Helbling et al., 1995). In our results, the different size groups did not seem to distribute in upstream downstream relationship as mentioned in Huntley et al. (1989), but more likely to be related to the water mass (Figs. 5 & 6). The larger clusters seemed to be confined to Zone I and II waters, which has influence of warm west wind drift. As mentioned earlier, the growth rate and timings of budding should be heavily dependent on environmental factors such as temperature and food concentration. Although the reason for the spatial distribution in our study cannot be concluded due to lack of detail information, it may be possible to explain that water mass which has higher temperature environment may have contributed for rapid growth and solitaries resulting as earlier budding and larger size composition compared to salp groups distributing in lower temperature water masses.

# Implication to the spatio-temporal pattern of salp budding (asexual reproduction)

Given the ability of salps to reproduce rapidly when they encounter favorable conditions, and their characteristics to exhibit opportunistic patchy distributions (Alldredge and Madin, 1982), we first expected to obtain random distribution of the size groups. Interestingly, however, from the large scale survey, we generally obtained synchronous pattern in size composition parallel to the isotherm lines described in

Brandon et al. (in press). This implies that the intense budding and the growth rate were generally synchronized among the waters with the similar temperatures, and the timing of budding was earlier in the warmer waters. This idea was also supported by the results from the smaller scale surveys (around the Elephant Island area). In these smaller scale surveys, the size compositions were defined by the water masses (Figs. 5 & 6), which also had an indication of earlier budding occurring in the warmer water masses. Above this, 1996/97 season which showed warmer water temperature compared to 1994/95 season (Amos, 2001), showed higher salp abundance and larger size.

Throughout our investigation, there was a clear indication that the factors governing the timing of intense budding was water temperature conditions, but at the same time, it was shown that a certain level of phytoplankton concentrations might have negative effect. Since the water temperature has a gradient from north to south, and the temperature increases as the season progresses from spring to summer, the general spatio-temporal pattern of salp budding event may be conceived to proceed from north to south. It is known that ice edge phytoplankton bloom proceed south as the ice edge retreats (Lancelot, et al., 1993). This is mainly composed by large chain forming diatoms (Scoal et al., 1997), and is effectively grazed down by high grazing pressure of krill swarms passing through the area in summer (Treguer et al., 1992). If we extend our speculation, it could be conceived that area of intensive salp budding may follow after the phytoplankton bloom. But this may happen with a certain delay, possibly by following after area where krill grazed down the dense phytoplankton bloom down to the level which salps can cope with.

In the present study, we only dealt with single surveys for each season, therefore it was impossible to corroborate the spatio-temopral idea proposed above. Since growth and reproduction are rapid in Salpadae, it is impostant to identify the maturity stages as well as length to understand the status of their reproduction and growth. It is therefore desired to perform further biological analysis of the preserved samples from the CCAMLR-2000 synoptic survey in the future for the better understandings of salp ecology.

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Table 1. Numerical biomass (inds/1000m<sup>3)</sup> of Salps during The CCAMLR Symoptic survey in 1999/2000 season, and regional surveys conducted in Elephant Island area in 1994/95 and 1996/97 seasons.

|           | Month   | Area*  | Aggregates |       |    | Solitaries |      |    | Solitary+Aggregates |       |     |
|-----------|---------|--------|------------|-------|----|------------|------|----|---------------------|-------|-----|
| Season    |         |        | max        | mean  | n  | max        | mean | n  | max                 | mean  | n   |
| 1999/2000 | Jan/Feb | Whole  | nd         | nd    | nd | nd         | nd   | nd | 1806                | 82.8  | 113 |
|           | Jan/Feb | Sand   | nd         | nd    | nd | nd         | nd   | nd | 712                 | 79.2  | 29  |
|           | Jan/Feb | Scotia | 1806       | 25.7  | 60 | 3.6        | 0.33 | 38 | nd                  | nd    | nd  |
|           | Jan/Feb | Pen    | 860.4      | 137.8 | 24 | 6.0        | 0.89 | 18 | nd                  | nd    | nd  |
| 1996/97   | Dec     | Eleph  | nd         | nd    | nd | nd         | nd   | nd | 1041                | 110.7 | 92  |
| 1994/95   | Nov/Dec | Eleph  | nd         | nd    | nd | nd         | nd   | nd | 43                  | 4.1   | 77  |

Abbreviations of the Area

Whole: The entire survey area (Total of South Sandwich area, Scotia Sea area, and Antarctic Peninsula area), Sand: South Sandwich Island area, Scotia: Scotia Sea area, Pen: Antarctic Peninsula area.

nd: not determined





Fig. 1. Map of RMT stations covered during the international CCAMLR Synoptic Survey 2000 in January/February 2000.  $\bullet$ : Abundance and length measured deleneated in different forms (aggregate and solitary forms),  $\circ$ : Abundance recorded as total (aggregates plus solitaries). Lengths measurements were done for only aggregates,  $\diamond$ : Abundance and length recorded as totsl (aggregates plus solitaries).



Fig. 2. (a) Distribution of salp numerical density (taotal number).
:Cluster-00A, 

Cluster-00B, 
:Cluster-00C.
:Station where cluster analyses were not performed.
(b) The size distribution of the three size clusters.



Fig. 3. (a) Distribution of solitary form in numerical density. Open circles denote the stations with zero catch. (b) Compiled size distributions in Antarctic Peninsula area and Scotia Sea area.



Fig. 4. Dendrogram resulting from cluster analysis of salp size groups.



Fig. 5. (a) Distribution of salp numerical density (taotal number).
:Cluster-94A, 

Cluster-94B, 
:Cluster-94C.
:Station where cluster analyses were not performed. Source of water mass delineation is based on January survey in the same field season conducted by AMLR Program (AMLR, 1995). (b) The size distribution of the three size clusters.



Fig. 6. (a) Distribution of salp numerical density (taotal number).
:Cluster-96A, 

Cluster-96B, 
:Cluster-96C.
:Station where cluster analyses were not performed. Source of water mass delineation is based on January survey in the same field season conducted by AMLR Program (AMLR, 1997). (b) The size distribution of the three size clusters.



Fig. 7. Frequency distributions of daily carbon demand (mgC/m<sup>2</sup>/day). (A) CCAMLR-2000 Synoptic Survey, (B) Elephand Island area, Nov/Dec. 1994, (C) Elephand Island area, Dec. 1996.



Fig. 8. Scattered diagram of salp abundance polotted against Chl-a concentration at 10m depth. Hatched area denotes the threshold Chl-a concentration described in Persinotto and Pakhomov (1997).