DISTRIBUTION PATTERNS OF CHAETOGNATA, POLYCHAETA, PTEROPODA AND SALPIDAE OFF SOUTH GEORGIA AND SOUTH ORKNEY ISLANDS

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ABSTRACT

The distribution pattern, frequency and density (ind./1000 m) of different mesozooplankton species from the South Georgia Islands, South Orkney Islands and the Weddell-Scotia Confluence were analyzed using data obtained in 1994. The maximum densities of the species found were: Eukrohnia hamata (5330), Sagitta gazellae (1052), Clione limacina antarctica (450), Spongiobranchaea australis (375), Clio sulcata (100), Limacina helicina (4076 x 10³), Limacina retroversa (71 x 10⁴), Pelagobia longicirrata (29170), Rhynchonereella bongraini (117), Tomopteris carpenterii (26), Tomopteris planktonis (498), Tomopteris septentrionales (498) and Salpa thompsoni (189). Species density and frequency decreased from South Georgia to the South Orkney Islands, recording intermediate values at the Weddell-Scotia Confluence. Species density in the South Orkney area seemed to be limited by variations in temperature and salinity. The southern area around South Georgia showed the highest density of species, probably due to the influence of the Southern Front of the Antarctic Circumpolar Current. The presence of species characteristic of sub-Antarctic waters such as L. retroversa in the Confluence area could be related to the southward movements of eddies that originate in the Polar Front.

RESUMO

Foram analisados os padrões de distribuição, frequência e densidade (ind. 1000 m) de diferentes espécies de mesozooplâncton encontradas em torno das ilhas Georgias e Orcadas do Sul no verão de 1994. As densidades máximas apresentadas pelas espécies principais foram: Eukrohnia hamata (5330), Sagitta gazellae (1052), Clione limacina antarctica (450), Spongiobranchaea australis (375), Clio sulcata (100), Limacina helicina (4076 x 10³), Limacina retroversa (71 x 10⁴), Pelagobia longicirrata (29170), Rhynchonereella bongraini (117), Tomopteris carpenterii (26), Tomopteris planktonis (498), Tomopteris septentrionales (498) e Salpa thompsoni (189). A densidade e frequência das espécies diminuíram das ilhas Georgias em direção às Orcadas, registrando-se valores médios na confluência Weddell-Scotia. A densidade de espécies nas Orcadas parece estar limitada pelas variações na temperatura e salinidade. Nas Georgias, a área sul mostrou a maior densidade de espécies, e isto poderia ser devido à influência da Frente sul da Corrente Circumpolar Antártica. A presença de espécies características de águas sub-antárticas (Ex. L. helicina) na confluência Weddell-Scotia poderia estar relacionada com o movimento dos vórtices da Frente Polar em direção Sul.


INTRODUCTION

Many studies have highlighted the high biological productivity around the South Georgia Islands (WARD et al., 2002, 2003; GILPIN et al., 2002; ATKINSON et al., 2001; WHITEHOUSE et al., 1996; ATKINSON; PECK, 1988) and, to a lesser extent, the South Orkney Islands (SIGLEO et al., 2000). Research has been focused mainly on euphausiids (particularly Euphausia superba) and copepods, (e.g. ATKINSON, 1998; VORONINA, 1998; FRANSZ; GONZALEZ, 1997), while other components of the mesozooplankton have scarcely been investigated. However, they may play a major role in our understanding of the productivity of the Southern Ocean.
Pteropods (thecosomes and gymnosomes) are ubiquitous components of zooplankton communities, with some species being extremely abundant in different areas. The genus Limacina is often reported as one of the components of mesozooplankton in sub-Antarctic and Antarctic waters, and may represent an important food source for whales and large fish (VAN DER SPOEL; DADON, 1999). The gymnosomes are also frequent but usually in low abundances, showing a very patchy distribution since most species are specialized predators (LALLI; GILMER, 1989). The presence and density of thecosomes and gymnosomes are affected by ecosystem changes (HUNT et al., 2008). Salps can be important during spring and summer through the formation of blooms, when they can be significant grazers of primary production. They consume a wide range of food particles with 100% efficiency (FORTIER et al., 1994; MADIN; CETTA, 1994) competing effectively with other primary consumers. Chaetognaths are active predators and constitute a link in the transfer of energy from copepods (their primary prey) to higher trophic levels (TERAZAKI, 1998). Planktonic polychaetes include both grazers and voracious predators (PETTIBONE, 1963), but are less abundant than chaetognaths. Some species may, at times, be the dominant forms in the plankton community and can be of considerable importance as food for fishes (PETTIBONE, 1963). Available data indicate that pteropods, polychaetes, salps and chaetognaths are regionally significant components of the Southern Ocean pelagic ecosystem. It was on this basis that the present work studied the frequency and density of species, their relationship with some environmental variables, and the horizontal and vertical distribution patterns of these mesozooplankton groups around the islands of South Georgia and South Orkney and the Weddell Scotia Confluence to expand the information available on their ecological aspects.

**Material and Methods**

The South Georgia Island (SG, 53°10’-55°48’S and 34°4’-39°8’W) and the South Orkney Islands (SO, 57°37’-61°1’S and 45°14’-50°31’W) are located in the Atlantic sector of the Southern Ocean (Fig. 1). The Antarctic Circumpolar Current (ACC) flows eastward around the Antarctic continent as a series of parallel strips delimited by fronts, including the Polar Front (PF) to the north, the Southern Front of the Antarctic Circumpolar Current (SACC, SACCF and SBACC) to the south (ORSI et al., 1995). SG and SO are located to the north of SO (DEACON, 1982; PATTERSON; SIEVERS, 1980) and to the south of the SBACC.

A total of 383 samples were collected in 1995 from 104 oceanographic stations located around SO (March 11-23) and SG (February 10-24 and March 25-April 2). Sampling was carried out on board the R.V. Dr. Eduardo L. Holmberg. Figure 1 shows the study area, the locations of the oceanographic stations sampled and the mean position of the PF, SACCF and SBACC, according to Orsi et al. (1995). Oceanographic data were obtained at each sampling station with a Neil Brown Instrument Systems (NBIS) MKIII CTD profiler (data in TOSONOTTO, 2000).

Zooplankton samples were taken in oblique tows using a Nansen net (0.70 m mouth opening, 200µm mesh size) equipped with a flowmeter, at four depth strata (0-25, 25-50, 50-100, and 100-200 m). The samples were preserved in 5% buffered formaldehyde. All the polychaetes, chaetognaths and salps were sorted out, stained with methylene blue, identified under a dissecting microscope and counted. Aliquots containing at least 100 individuals of thecosomata were obtained with a Russell subsampler (due to the large number of organisms in this group), identified and counted.

To analyze the vertical distribution pattern of the most frequent species, the density (log x+1), where x=ind/1000 m, was compared as between day and night for each stratum using analysis of variance (ANOVA) with two fixed factors: stratum (levels: 0-25, 25-50, 50-100, and 100-200 m) and time of the day (levels day and night). When appropriate, post-hoc comparisons were made with the Tukey test. Assumptions of normality and homoscedasticity were previously tested with Kolmogorov–Smirnov and Bartlett’s tests, respectively (SOKAL; ROHlf, 1997). Differences were considered statistically significant at p<0.05.
The relationships between the density (ind./1000 m) of each species and the following environmental and spatial-temporal variables: temperature, salinity, mean depth, distance to the bottom, day length and time of the day, were analyzed with the canonical correspondence analysis method (CCA, TER BRAAK, 1987, 1990) using the CANOCO program. Latitude and longitude were used as co-variables.

**RESULTS**

The variations in salinity and temperature found at SG, SO and the WSC are shown in Figures 2 (a, b). Around SG, salinity varied between 33 and 34.3 and temperature between 5.4 and 3.0 °C. Around San Pedro Island (the main SG island), a temperature drop from 3.0°C to 1.5°C, and an increase in salinity from 33.7 to 34.3, can be observed when transposing the SACCF (Figs 2 a, b). Around SO the ASW presented salinities between 34.3 and 33.7 and temperatures between 1.5°C and 0.8°C.

Although the PF was undetected during the sampling, it is known to occur in the vicinity of SG (GORDON, 1971; ORSI et al., 1995) and its average location is shown in Figure 1. The greatest variations in temperature and salinity were observed at the WSC.

The species found in the present study included the chaetognaths: *Eukrohnia hamata* (Möbius), 1875, *Sagitta gazellae* Ritter-Zahony, 1909; the pteropods *Clione limacina antarctica*, (Smith, 1836), *Clio sulcata* (Pfeffer, 1879), *Limacina helicina* (Phipps, 1774), *Limacina retroversa* (Fleming, 1823); the polychaetes, *Pelagobia longicirrata* Greeff, 1879, *Rynchonereilla bongraini* (Gravier, 1911), *Tomopteris carpenterii* Quatrefages 1866, *Tomopteris planktonis* Apstein, 1900, *Tomopteris septentrionalis* Quatrefages, 1866 (Polychaeta), and the salp *Salpa thompsoni* (Salpidae) Foxton, 1961.
The species frequency of occurrence differed between oceanic areas. Around the SG, *L. retroversa* appeared in 76% of the samples, *P. longicirrata* in 44%, *E. hamata* in 34%, and *S. gazellae* in 16%. In the Weddell-Scotia Confluence, the most frequent species were *P. longicirrata* and *S. thompsoni* (55% of the samples) followed by *L. retroversa* (29%) and *E. hamata* (22%). The frequency of *L. helicina* was similar in both areas (74-76%) and only juveniles of *E. hamata* and *S. gazellae* were found. The remaining species showed a frequency lower than 16%. Around SO the highest frequency was that of *L. helicina* (75%), followed by *P. longicirrata* (12.5%), the only two species found.

Fig. 2. Horizontal distribution of Temperature (°C) and Salinity at South Georgias Islands (SG), South Orkney Islands (SO) and Weddell-Scotia Confluence (WSC). White dots: Sampled stations, PF: Polar Front, SACCF: South Antarctic Circumpolar Current Front, SBACC: Southern Boundary of the Antarctic Circumpolar Current. 316: northernmost station of the Weddell-Scotia Confluence.
Horizontally and Vertically Distributed Species

Thecosomata

Limacina helicina was found at most stations. Its density varied between 25 and 4076 x 10^3 ind./1000 m, being highest to the south and east of SG, intermediate in the WSC and lowest around the SO (Figs 3 a, b). It was found in all the strata studied (Figs 4 a, b), its density being significantly higher at nighttime (Table 1).

Limacina retroversa had a similar distribution to that of L. helicina but occurred at higher densities (19 and 71 x 10^3 ind./1000 m). Its abundance was higher at SG, decreased in the WSC and only a few individuals were found at SO (Figs 3 c, d). Around SG, densities increased significantly at night, with maximum values for the uppermost stratum (Table 1). In the WSC, it was found exclusively at night, with a higher density at between 50-100 m depth (Figs 4 c, d).

Fig. 3. Density (individuals per 1000 m) and horizontal distribution of the species recorded around South Georgia Islands (SG), South Orkney Islands (SO) and at the Weddell Scotia Confluence (striped area). Limacina helicina (a, b), Limacina retroversa (c, d), Clio sulcata (c, d), Spongiobranchea australis (e, f), Clione limacina antarctica (e, f), Eukrohia hamata (g, h), Sagitta gazellae (i, j), Pelagobia longicirrata (k, l), Rhynchoherella bongraini (m, n), Tomopteris planktonis (m, n), Tomopteris septentrionalis (m, n), Tomopteris carpenterii (m, n), Salpa thompsoni (o).
Fig. 4. Density (individuals per 1000 m) and vertical distribution of the species recorded around the South Georgia Islands (SG), South Orkney Islands (SO), the Weddell-Scotia Confluence (WSC). **Limacina helicina** (a, b), **Limacina retroversa** (c, d), **Clio Sulcata** (e, f), **Clio limacina antarctica** (g, h), **Spongiobranchea australis** (i, j), **Eukrohia hamata** (k, l), **Sagitta gazellae** (m, n), **Pelagobia longicirrata** (o, p), **Rhynchoherella bongraini** (r, s), **Tomopteris planktonis** (t, u), **Tomopteris septentrionalis** (v, w), **Tomopteris carpenterii** (x), **Salpa thompsoni** (y).
Table 1. Results of the analyses of variance (ANOVA) of two fixed factors: stratum (four levels: 1=0-25, 2=25-50, 3=50-100, 4=100-200 m) and time of the day (day/night); and Tukey’s “a posteriori” comparisons. In bold: P<0.05.

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Clio sulcata was a rare species with a patchy distribution, showing the lowest density around SG (ca. 28 ind./1000 m) and the highest density in the WSC (100 ind./1000 m). It was not found around SO (Figs 3 c, d) and was almost completely absent during the day and, although abundant at night, it did not migrate into the 0-25 m layer (Figs 4 e, f).

Clione limacina antarctica was recorded at a few stations located to the south and east of SG and in the WSC, while it was absent around SO (Figs 3 e, f). The highest abundance (450 ind./1000 m) was observed at the northernmost station of the WSC, densities tending to increase at night and below 25 m depth (Figs 4 g, h). Spongiobranchaea australis was more frequent around SG, less frequent in the WSC and absent at SO. Density ranged between 13 ind./1000 m around SG to 375 ind./1000 m at the northernmost station of the WSC (Fig 3 e, f). Densities tended to increase at night and between 50-100 m depth (Figs 4 i, j).

Chaetognatha

Eukrohnia hamata was the most frequent and abundant chaetognath species. It was more frequent around SG, decreased in the WSC and was absent around SO (Figs 3 g, h). Density ranged between 15 and 5330 ind./1000 m, higher values being found north of 59°40’. It was present at all depths (Fig. 4 k, l) and no significant differences were found among strata (Table 1). Abundance tended to increase at night around SO. Most of the individuals found between 0-200 m depth were at stage I (ovaries as small round bodies, testes as thin tubes) and theremainder, which were at stage II (ovaries and testes undergoing development, seminal vesicles absent), were found below 150 m depth.

Sagitta gazellae was only found around SG and in the WSC. It was more frequent to the south of SG and density was higher at offshore stations (1052 ind./1000 m), with values decreasing southward (Fig. 3 i, j). There were significant differences in density among strata (Table 1). Density was higher between 100-200 m depth at SG and 50-100 m at WSC (Figs 4 m, n). All individuals were at stage I.

Polychaeta

Pelagobia longicirrata was the most frequent and abundant polychaete species. Its density ranged between 11 and 10810 ind./1000 m around SG, was higher (29170 ind./ 1000 m) at stations north of the WSC and decreased toward SO, where it was only found at one station (Fig. 3 k, l). In general, density was higher to the south and east of SG (off the shelf) and at night. This latter fact was evidenced by large nighttime densities in the 25-50 and 0-25 strata (Figs 4 o, p). Although there were no significant differences among strata (Table 1), this species was more abundant between 50-0 m depth.

Rhynchonereella bongraini was a rare species with a patchy distribution, occurring at a few stations around SG. The highest density (117 ind./1000 m) was reached in the south of the WSC but the species was absent at SO (Figs 3 m, n). It was found in all strata of the WSC, but only between 100200 m at SG; its density tended to increase at night (Figs 4 r, s).

Tomopteris planktonis was found scattered throughout the study area, with densities between 9 and 498 ind./1000 m. The higher densities were recorded offshore, to the southeast of SG and the lowest to the north of SO (Figs 3 m, n). Density varied...
significantly between strata (Table 1), with higher values between 100 and 200 m depth (Figs 4 t, u). At SG a distinct diel migration was evident.

*Tomopteris septentrionalis* was found at a few stations around SG, mainly to the southeast of the islands, and was absent at latitudes below 59°40’S. Density ranged between 13 and 498 ind./1000 m (Figs 3 m, n), and was higher at night (Figs 4 v, w).

*Tomopteris carpenterii* was only found at a few stations to the south of SG, from 0 to 200m, with densities between 11 and 26 ind./1000 m (Figs 3 m, n), and exclusively at night (Fig. 4 x).

Salpidae

*Salpa thompsoni* was found between 57 and 59°S and was absent around SG. The oozooid/blastozooid ratio was 1:36. Density ranged between 19 and 189 ind./1000 m³ (Fig. 3o) with higher values at night (Fig. 4 y).

Statistical Analysis

The following variables were significant in the CCA: mean depth (p= 0.001), distance to the bottom (p= 0.001), day length (p= 0.001), and mean temperature (p= 0.013). Figure 5 shows the resulting ordination diagram. The results did not show separate groups of species clearly, they seemed rather to be arranged along the mean depth and temperature axes. *Limacina helicina*, *L. retroversa* and *Pelagobia longicirrata* are more likely to be related to lower mean depths and higher temperatures, whereas *R. bongraini*, *T. septentrionalis* and *C. limacina antarctica* showed the opposite pattern. In the area around SO, the species were not clustered according to the environmental or spatial variables considered (p>0.05).

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Gallotti and Marschoff (2004) showed, *Euphausia* number, with higher values than those found for the dominant species, with much higher densities of juveniles of both species in deeper layers of the Weddell Sea (1000-500 m) during late austral spring, suggesting that this result was related to an adaptation of the life cycle of these species to the hard seasonal conditions of the Antarctic. Although *Salpa thompsoni* is the most abundant and common salp species in the Southern Ocean, it was not found off SG or SO in this study. Its absence around SG may be related to elevated chlorophyll-a concentrations usually present in the area (GILPIN et al., 2002; ATKINSON et al., 2001).

High phytoplankton concentrations can cause the clogging of the salps' filter feeding system (HARBISON; MCALISTER, 1979) which may lead to the inability to feed. Perissinotto and Pakhomov (1998) found that *S. thompsoni* virtually disappeared when chlorophyll-a concentrations reached levels between 1.5 and 3 mg./m, suggesting that this species prefers waters with intermediate values of phytoplankton. Deibel (1985) found that at high food concentration, the muscular contraction of salps became shallow and irregular, causing a decline of the clearance rate and the clogging of the filtering apparatus. Temperature also affects muscular contraction, and in some species, the temperature decrease produces a slowing or a cessation of muscular contraction, thereby affecting the feeding rate. Further, some observations suggest that the population growth of *Salpa thompsoni* is slower in the ice-edge area (CASARETO; NEMOTO, 1986). The influence of the cold waters from the Weddell Sea is probably the cause of the absence of this species to the south of SO, while the intermediate values of temperature and chlorophyll-a found in the WSC favor the occurrence of *S. thompsoni* in this area. On the other hand, our results indicated that this species reached its highest density in the euphotic zone of the open ocean in both day and nighttime. The 1:36 oozooid: blastozooid ratio found in this study and the presence of young blastozooids suggests that the oozooids were reproducing actively. However, the population did not reach the densities commonly observed in summer (1000 ind./100 m) during blooms as was found by Chiba et al. (1999). Although the most frequent species around SG, *L. helicina*, *L. retroversa* and *P. longicirrata* were found at all the depths studied, they were more abundant between 0 and 100 m depth. The vertical variations in their density may be due to diel migrations and to a lesser extent to net avoidance. Many pteropod species show low densities in shallow waters, when they migrate to deeper strata, and higher densities at night, when they migrate upwards. In addition, Stok-Bowitza (1981) suggested net avoidance for the polychaete *P.*
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