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Macrofaunal shallow benthic communities along a discontinuous annual cycle at Admiralty Bay, King George Island, Antarctica

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Abstract Temporal variations in composition and density of the benthic macrofauna at two stations (12 and 25 m depth) were studied in Admiralty Bay, King George Island, Antarctica. Samples were carried out using an van Veen sampler between March and December 1999 (winter) and December 2000 and March 2001 (summer), comprising a discontinuous annual cycle. Sediment organic matter showed a marked seasonal cycle, with lowest values at middle winter. Communities showed little variations in density and composition. Temporal variations were not detected at 25 m depth. Variations at 12 m were related to one iceberg impact and to wind generated hydrodynamism, as a function of wind direction, intensity and fetch. As winter scarcity of primary production did not seem to affect macrofaunal community densities, nutrient availability for the benthos in winter can be related to the remineralization of sediment organic matter by bacterial activity.

Introduction

Researches on benthic communities in Antarctica were carried out mostly on summer surveys (Platt 1979; Oliver and Slattery 1985; Wägele and Schminke 1986; Wägele and Britto 1990; Arnaud 1985, 1998; Arnaud et al. 1986, 1998; Gambi et al. 1994, 2000). Studies including year-round sampling or winter-summer comparisons are scarce; they report a high standing crop with low temporal variability in community densities and compositions (Lowry 1975; Kauffman 1977; Tucker 1988; Mühlenhardt-Siegel 1989; Battershill 1990).

However, Zhang et al. (1986, p. 141), reported that “population density showed obvious seasonal variations”. The responses of shallow benthic communities to seasonal variations on primary production in Antarctica are still not well established but primary production is known to influence the shallow benthos mainly through winter resource limitations (Grebmeier and Barry 1991; Nedwell et al. 1993, 1995; Arntz et al. 1994; Clarke 1996a, b; Gambi et al. 2000).

Composition of Antarctic fauna is comparatively well known (Retamal et al. 1982; Parulekar et al. 1983; Arnaud et al. 1986). Communities seem to be composed by long-lived individuals (Arntz et al. 1994; Clarke 1996), and hence recovery of benthic communities after impacts can take years (Arntz et al. 1994). On the other hand, Peck et al. (1999) found that after an iceberg impact, species return time, via locomotion from adjacent areas, is about 10 days. Hydrodynamism can be considered a factor contributing to the temporal variability of shallow communities due to substratum instability (Wu et al. 1992a, b). Hence, year-round studies are necessary in order to assess response modes of benthic communities to seasonal variation in Antarctica, mainly in the highly physically impacted shallow environments.

The main goal of this study is to evaluate if density and composition of shallow benthic communities are affected by: (1) winter resource limitations, (2) iceberg impacts, and (3) hydrodynamism generated by storms. For these purposes we studied the temporal variation of the shallow benthic macrofauna at two stations (12 and 25 m) in Admiralty Bay (King George Island, Antarctica) from March to December 1999 (winter) and from December 2000 to March 2001 (summer).

Materials and methods

Abiotic factors

Wind speed, wind direction, air temperature and surface solar radiance were measured continuously using a

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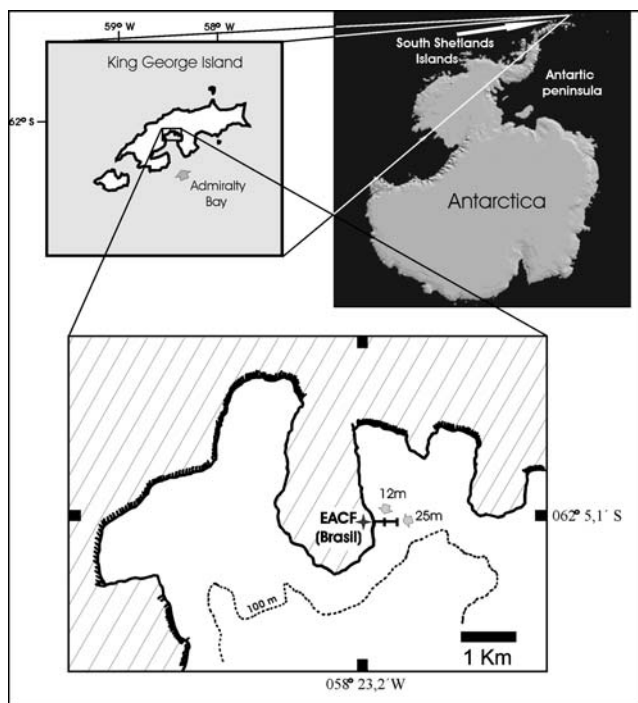


Fig. 1 Study area, adjacent to the Brazilian Antarctic Station “Comandante Ferraz” (EACF). Arrows show 12 and 25 m depth isobaths, over which are located the stations studied

Campbell Scientific 21X datalogger¹ along the study period. Water temperature was measured at 1 m deep using a sampling bottle and digital and mercury thermometers. Light intensity at 25 m depth was measured on 12 occasions along winter, between March and September 1999, using a StowAway Light Intensity Logger. Measurements were obtained after calibrating the logger for 5 min immediately under the surface and then lowering it to a 25-m depth, where readings stabilized for approximately 5 min before recovering. Irradiance at 25 m was transformed to percentage of surface irradiation, to avoid sensor deviations due to sea water low temperatures.

Organic-matter (OM) content of the sediment was determined by ignition (500°C/1 h), with six replicates for each sample, at both depths along the winter. Results were compared using One-Way ANOVA and a Tukey-Kramer Multiple Comparisons Test (Sokal and Rohlf 1995). Owing to its low frequency values, sediment organic matter contents results were previously submitted to an arcsine transformation (Underwood 1997).

Ice impacts

Frequency of ice impacts (icebergs and growlers) was continuously monitored at the study area. Iceberg

positions and size were estimated by triangulation from shore. Only icebergs that remained grounded at the study area for more than 24 h were considered as impacting. This period was considered necessary in order to assure that the iceberg was effectively lying over the bottom in the study area, and consequently causing a mechanical impact on the study benthic community.

Macrofauna

Studied stations were located respectively about 100 and 200 m eastern of the Brazilian Station (EACF) shore (052°23.2'W; 062°5.1'S; Fig. 1), on the 12 and 25 m depth isonimies. Nine surveys were conducted between March and December 1999 (9 months period), comprehending the austral winter, and four between December 2000 and March 2001 (4 months period), comprehending the austral summer, at both depths (Table 1). For each sample, six random replicates were collected. Sampling was carried out manually, using a 0.056 m² van-Veen grab; depth was determined via a weighted rope. Samples were sieved through a 0.5 mm mesh. Specimens were fixed in 4% formaldehyde and preserved in 70% alcohol, and identified to taxonomic groups (Thompson 2003). Resulting densities (ind/0.01 m²) were log-transformed ($\log(x+1)$, Sokal and Rohlf 1995) prior to analysis. A principal component analysis (PCA, Hair et al. 1998) was carried out using the averages of replicates of each sample. Temporal variation for each taxonomic group was tested using an One-way Analysis of Variance (ANOVA, Underwood 1997; Hair et al. 1998) and a Tukey-Kramer Multiple Comparisons Test (Sokal and Rohlf 1995).

Results

Meteorology

Winter Between March and December 1999 wind speed average was 22.9 km h⁻¹; the maximum was 159.44 km h⁻¹ (September 15, 1999). No preferential wind direction was found. Average wind speed was over 18.5 km h⁻¹ on 52.11% of the entire period, and average speeds over 100 km h⁻¹ occurred approximately each 20 days along the entire winter (Table 1). Minimum air temperature during the study varied between -0.30°C (March 11, 1999) and -16.32°C (August 26, 1999). Water temperature below surface (at 1-m depth) varied, on the studied area, from 2°C (March 18, 1999) to -2.5°C (August 22).

Maximum daily surface solar irradiance varied from 5.96 W m⁻² (June 21, 1999) to 916 W m⁻² (November 6, 1999) with a daily maximum average of 198.32 W m⁻². Total winter average was 58.09 W m⁻². Near the bottom, at the 25 m depth station, light incidence varied from 149 W m⁻² (March 16, 1999) to 0 W m⁻² (May 10, 1999—Fig. 2).

¹Data provided by Dr. Alberto Setzer, INPE, Brazil

Summer Eastern winds prevailed on 31% of the time followed by Northwestern (21% of the time). Average wind speed was 14.6 km h^{-1} . Even though wind speeds over 100 km h^{-1} were usual during summer, maximum speeds were lower when compared to the winter period. Maximum surface irradiance on summer varied between $1,006.0 \text{ W m}^{-2}$ (December 22, 2000) and 88.4 W m^{-2} (February 13, 2001), with an average of 155.2 W m^{-2} . Average daily maximum irradiance was 534.22 W m^{-2} , more than a twofold increase over the winter average (198.32 W m^{-2}).

Organic matter

Organic matter (OM) content of the sediment at 25 m depth varied significantly during winter ($P < 0.05$), starting from 5.55% (April, 22), reaching its lowest value (3.83% in May, 31 and increasing again to 5.52% in August, 25. At 12 m depth, OM varied from 4.83% in April, 2–3.10% in May, 31, and climbing again to 5.09% in August, 25 (Fig. 3). Sediment organic matter content was significantly different between both depths along the entire winter.

Ice impacts

During the study only two icebergs impacted the area. One grounded in winter at the 12 m station and remained for 12 days (16–27 of July). The other one grounded at summer at the 25 m station and remained for over 20 days (February, 20 to end of March). Sea surface froze for 17 days during winter, between August 30 and September 15 of 1999, being broken by the strongest winds of the entire studied period (Table 1). Formation of anchor ice was not observed during the study.

Macrofauna

A total of 58,768 specimens from 13 taxa were sampled, splitted in 44,758 at 12 m and 14,010 at 25 m. Bivalvia, Polychaeta and Oligochaeta were the dominant groups. Bivalvia dominated in 9 out of 14 samples, Polychaeta in three out of 14 samples and Oligochaeta in only one out of 14 samples.

Bathymetric differentiation of community was evident in the PCA (Fig. 4) results, with the first axis (63.85% of total variance) clearly differentiating stations according to depth. The second axis showed only a very slight differentiation between summer and winter stations (12.7% of total variance). ANOVA results for each taxonomic group separately (one-way) confirmed such pattern, with total density at 12 m depth being significantly ($P < 0.05$) higher than that observed at 25 m depth along the entire study period.

The shallower station (12 m) presented significant temporal variations for some particular taxonomic groups, but not for total community density ($P > 0.05$), suggesting that abiotic factors (icebergs, hidrodinamism) affected different taxonomic groups in different ways (Fig. 5). Community composition at this depth varied significantly in samples 7 (August 4, 1999) and 9 (September 20, 1999). At sample 7, the highest density of Oligochaeta (average: $358 \text{ ind./0.056 m}^2$; $n=6$) of the whole study was recorded, associated to the lowest values for the remaining taxa (average: $211 \text{ ind./0.056 m}^2$; $n=6$), being this reduction highly significant ($P < 0.01$) for Ostracoda and Priapulida (Fig. 5). In survey 9 (September 20, 1999) the lowest diversity of the entire study ($H' = 1.31$) was recorded, caused mainly by the low densities of Oligochaeta, Ostracoda, Cumacea, Gammaridea and Polychaeta, and the high values of Gastropoda and Bivalvia (Fig. 5). This pattern of variation corresponded, respectively, to an iceberg grounded at the studied area at 12 m between July 16 and July 27, 1999, 8 days before sample 7 (August 4, 1999); and to a 9-h-long storm (September 15, 1999) with strong southern winds (average speed = 86 km h^{-1} ; maximum speed = 159 km h^{-1}).

On the other hand, the deeper station (25 m) did not vary temporally as regards both taxonomic groups densities and community composition (Fig. 6). Nevertheless, a recurrent pattern of lower densities on winter (April 15–August 6) could be observed for Bivalvia, Gastropoda, Oligochaeta and Polychaeta (Fig. 6).

Discussion

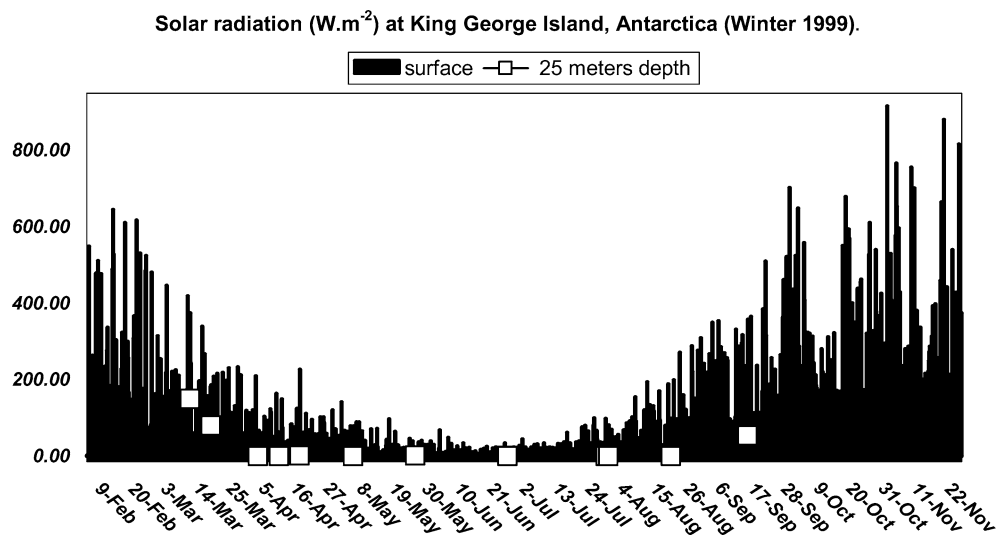
Antarctic benthic communities seem to be characterized by several wide-distributed species in a wide depth range, despite a shelf-slope gradient in relative composition (Piepenburg et al. 2002). Temporal shifts

Table 1 Climatic conditions between samples along winter (1999): minimum air temperature, maximum wind speed and direction (km h^{-1})

Winter 1999	March 1–16	March 17–April 2	April 3–22	April 23–May 10	May 11–31	June 1–July 1	July 2–August 4	August 5–25	August 26–September 20
Maximum wind speed (km h^{-1})	132.6	123.1	129.4	96.6	124.5	124.5	147.4	141.4	159.4
Direction of maximum wind	NE	NE	W	N	NW	E	S	E	S
$T^{\circ}\text{C}$ minimum	−0.30	−1.12	−1.19	−3.99	−5.78	−14.26	−15.49	−16.32	−15.85

Sampling dates are underlined

Fig. 2 Solar radiation at the surface and at 25 m depth in the study area along the austral winter (February–November 1999)



in abundance and composition are likely to be stronger in the near-shore benthos, driven by ice and wave induced impacts (Peck et al. 1999), which produce vertical gradients of disturbance (Gutt et al. 1996).

In shallower depths (12 m), shifts in macrofaunal communities were related mainly to ice impacts and hydrodynamism induced by storms. Both factors are frequent throughout the entire year, and are related to the sheltering level of the area under study, i.e., its relative location in regard to icebergs paths or storm waves. These factors are function of fetch size and depth of the surrounding areas, associated to the prevailing strong winds along the Antarctic coasts.

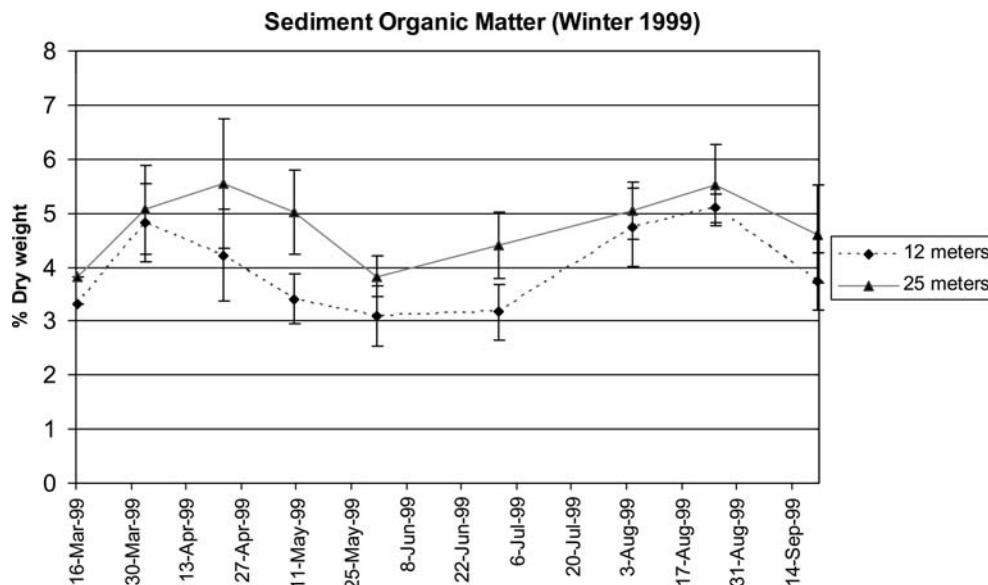
The grounding of an iceberg at the 12 m station caused a strong decrease in benthic group densities on the sampling after impact (sample 7). As this sample was carried out nine days after the iceberg grounding, it

seems that macrofaunal community had not yet fully recovered from the impact, a pattern different from those observed for meiofaunal communities of similar depths (Peck et al. 1999). The striking massive densities of oligochaetes in this sample would suggest an opportunistic behaviour of this taxon, a pattern also observed in other physically disturbed benthic communities (Engel and Kvitek 1998).

On the next sample (August 28, 1999), 21 days after sample 7, communities appeared to be fully recovered, because they did not show significant differences when compared with previous or later samples (except for samples 7 and 9). This suggests that communities are able to recover from non-extensive ice impacts, in a relatively fast way, by re-invasion or recolonization from nearby areas.

The role of hydrodynamic forces on structuring antarctic shallow benthic communities was noticeable in the

Fig. 3 Sediment organic matter content (dry weight) at 12 and 25 m depth along the austral winter (March 16–September 20, 1999)



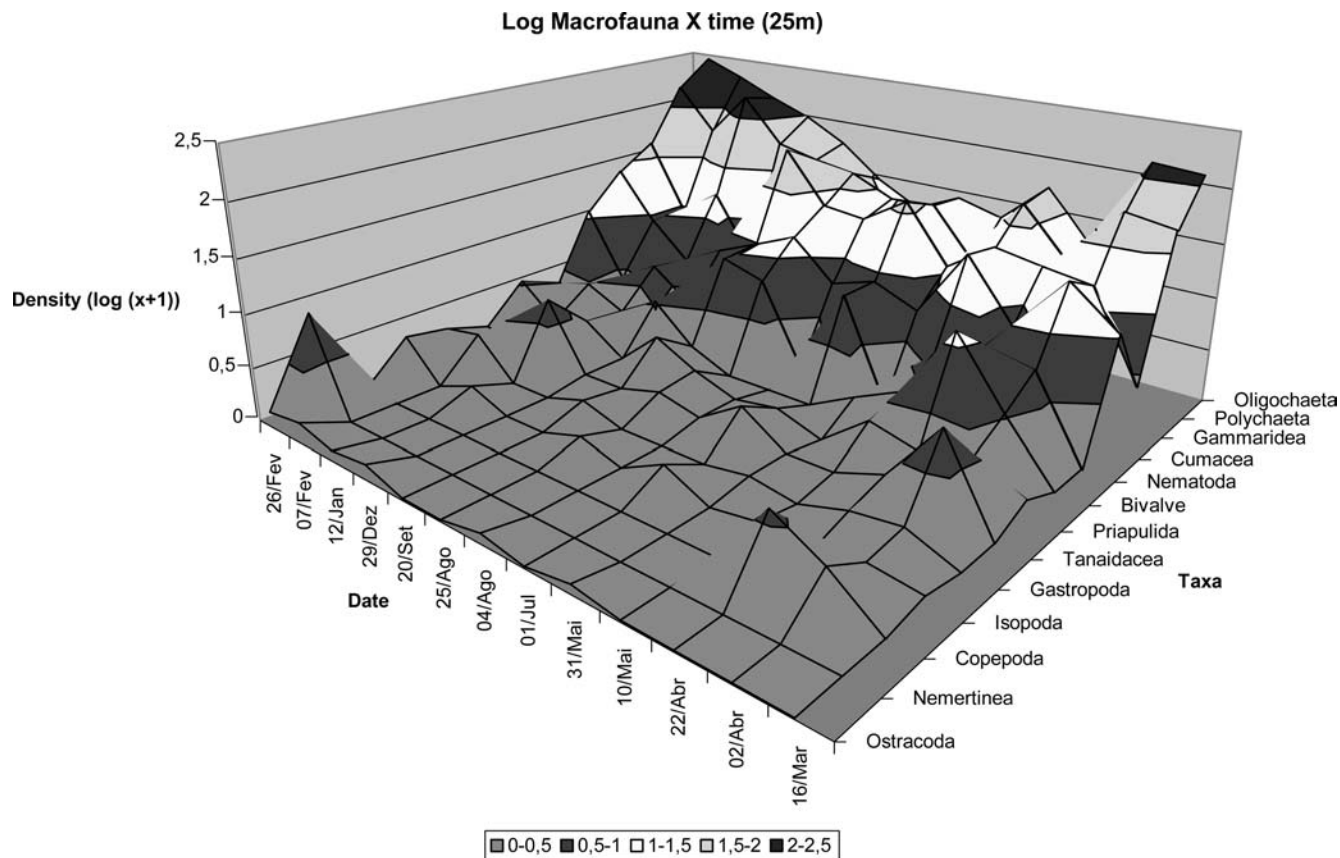


Fig. 6 Macrofaunal groups transformed densities ($\text{Log}(x+1)$) at 25 m depth along an annual cycle. Falling densities coincide with the period of light absence at this depth (approximately April 8–August 9, 1999)

dinamism causes a decrease on densities of most groups, except those bearing heavy body structures (molluscs, for example); and oil contamination affects communities

at the species-level regarding specific physiological constraints (Stark et al. 2003). Hence, recognition of specific patterns of shift in benthic community structure is helpful for impact assessment in Antarctica, in order to avoid future misinterpretations when environmental monitoring is required.

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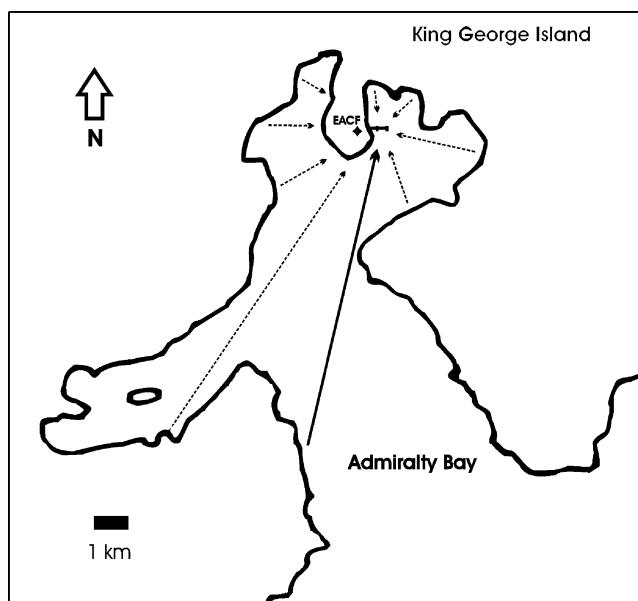


Fig. 7 Admiralty Bay, showing the available wave fetches as a function of wind direction and station locations. Longer fetches are those from the south quadrant (*bold arrow*)

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