Polar Biol (2006) 29: 263–269
DOI 10.1007/s00300-005-0049-6

ORIGINAL PAPER

C. A. Echeverría · P. C. Paiva

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

Received: 14 July 2004 / Revised: 7 July 2005 / Accepted: 12 July 2005 / Published online: 2 September 2005

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 where 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 hydrodinamism, 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 Antartica, 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) hidrodinamism 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

C. A. Echeverría (✉) · P. C. Paiva
Laboratório de Polychaeta, Depto. de Zoologia,
Universidade Federal do Rio de Janeiro, CCS, bloco A,
sala A0-104, subsolo. Av. Brigadeiro Trompowsky, S/N,
Cidade Universitária, Ilha do Fundão, Rio de Janeiro,
CEP: 21949-900 Brasil
E-mail: caecheve@acd.ufrj.br

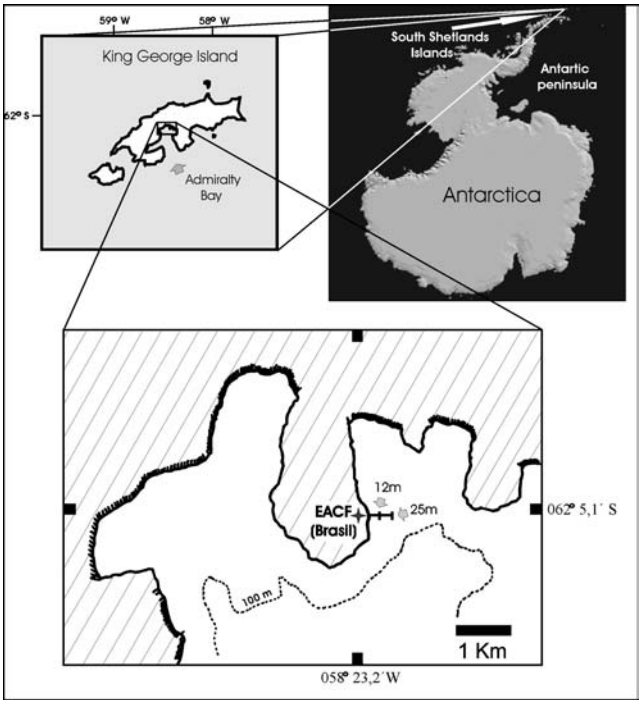

Fig. 1 Study area, adjacent to the Brazilian Antarctic Station "Comandante Ferraz" (EACF). *Arrows* show 12 and 25 m depth isobaths, over which are located the stations studied

Campbell Scientific 21X datalogger[1] 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 m^2 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 m^2) 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).

---

[1] Data 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 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 it 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 where 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.

Bathimetric 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 ind./0.056 m^2; $n = 6$) of the whole study was recorded, associated to the lowest values for the remaining taxa (average: 211 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°C minimum	−0.30	−1.12	−1.19	−3.99	−5.78	−14.26	−15.49	−16.32	−15.85

Sampling dates are underlined

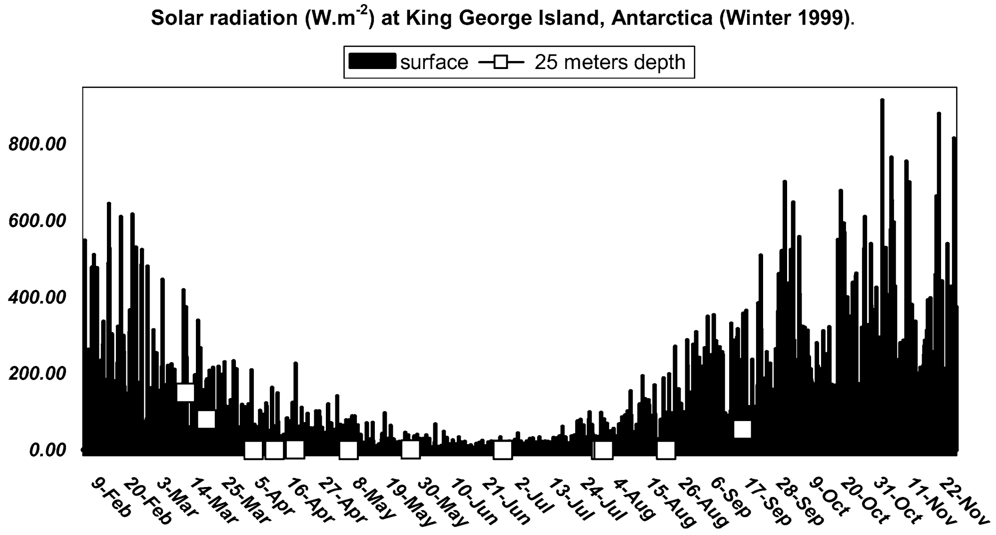

Fig. 2 Solar radiation at the surface and at 25 m depth in the study area along the austral winter (February–November 1999)

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

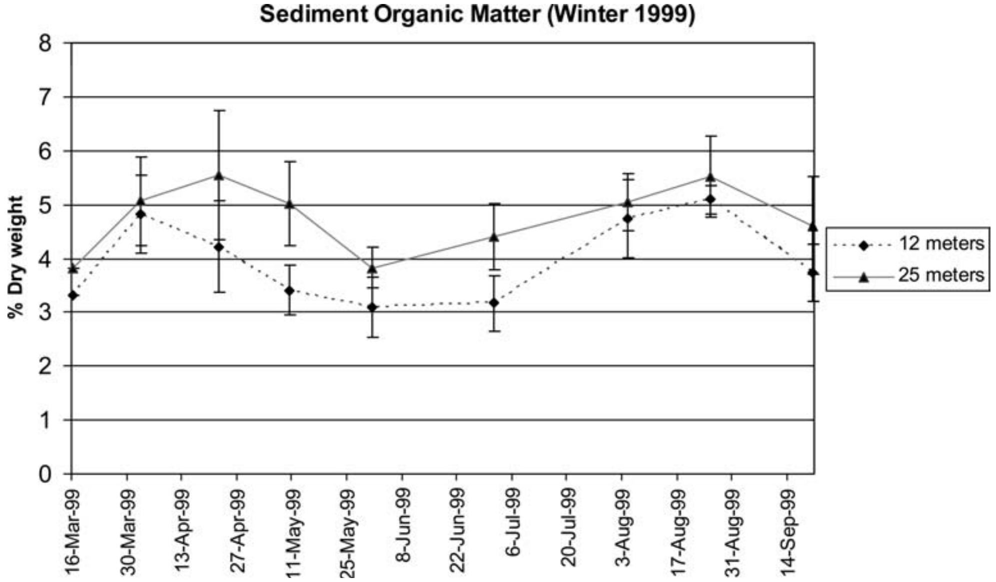

Fig. 3 Sediment organic matter content (dry weight) at 12 and 25 m depth along the austral winter (March 16–September 20, 1999)

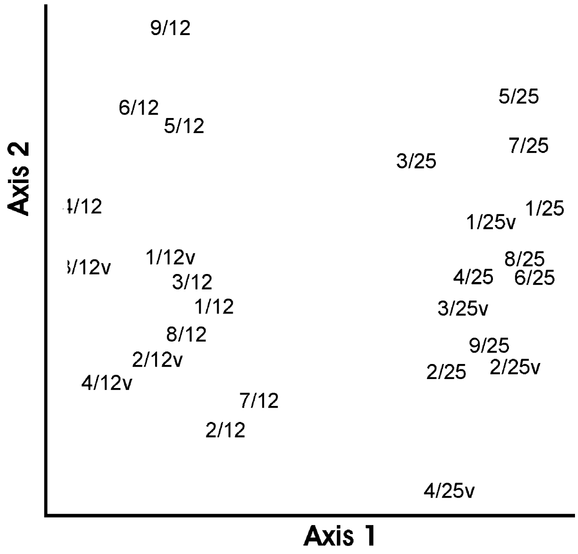

Fig. 4 Principal Component Analysis showing stations and dates (ex: 4/12v: 4th sample, 12 m depth, v: summer). Axis 1 discriminated stations by depth, even those from different years, explaining 63.85% of total variance. Axis 2 explained 12.7% of the remaining variance, slightly discriminating summer from winter stations

after-storm sample 9 (September 20, 1999), expressed by a decrease on the densities of several taxa such as Gammaridea, Cumacea and Polychaeta. This observed pattern differed from the ice-disturbance pattern detected on sample 7 because the former did not affect Gastropoda and Bivalvia densities. Probably, such resistance to wave-induced hydrodynamism is a function of their heavier bodies and physical resistance owing to the presence of calcareous shells. Other recorded storms in the area along the study period did not disturb communities at the same level. This can be attributed to the relation between wind direction and station locations, and consequently to the lack of a fetch length enough to allow a fully developed sea. Strong winds are common in the study area, but a fetch longer than 3 km is only possible for southern winds (Fig. 7), because study stations are sheltered from storm waves from all remaining directions.

The 9-h storm of September 15, 1999, with southern waves, would have a fetch of ca. 10 km long allowing a 2-m high theoretical significant wave in open waters, strong enough to affect depths up to 90 m (Open University 1998). Peck et al. (1999) mentions that 100 km h^{-1} winds could induce water movements intense enough to ressuspend meiofauna at depths up to 9 m.

Differential patterns of shift in shallow benthic community structure in Antarctica allow for the discrimination between natural disturbances (small icebergs, storm generated hidrodinamism) or anthropogenic contamination. For instance, ice impacts cause an overall diminution on all group densities; strong hidro-

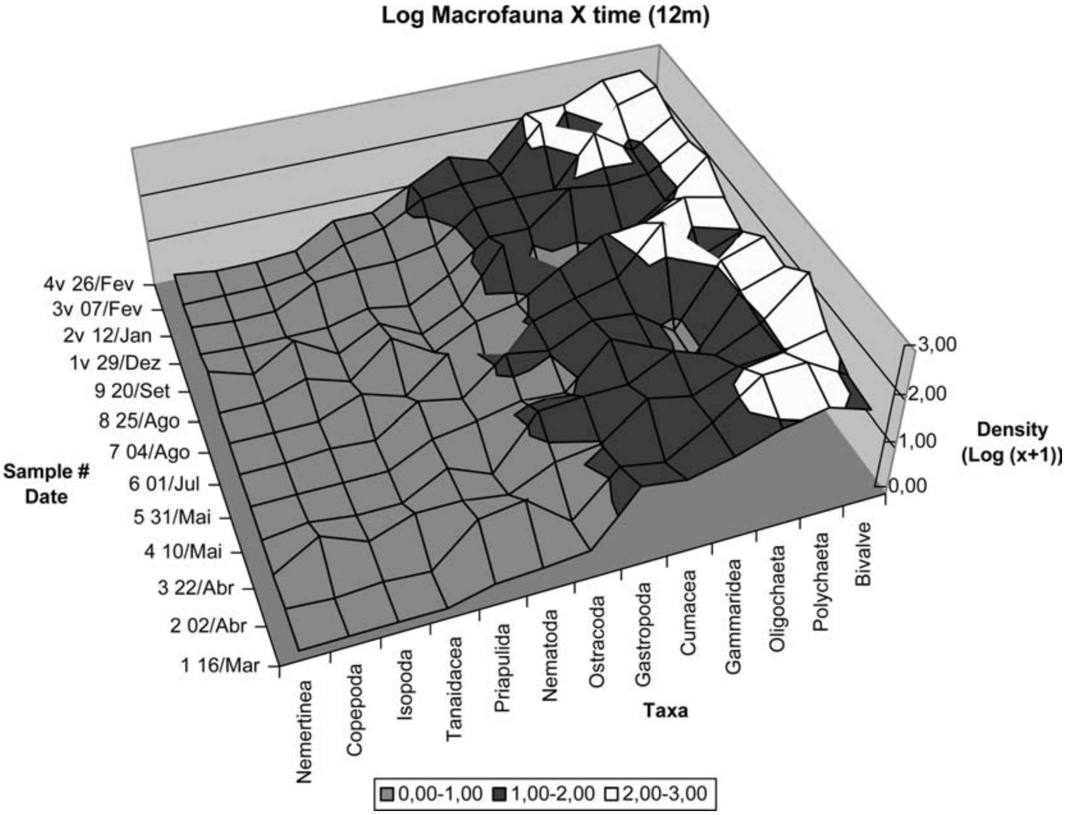

Fig. 5 Macrofaunal groups transformed densities (Log $(x+1)$) at 12 m depth along an annual cycle. Falling densities coincided with an iceberg grounding event (sample 7, August 4, 1999) and a major storm generated hydrodynamism (sample 9, September 20, 1999)

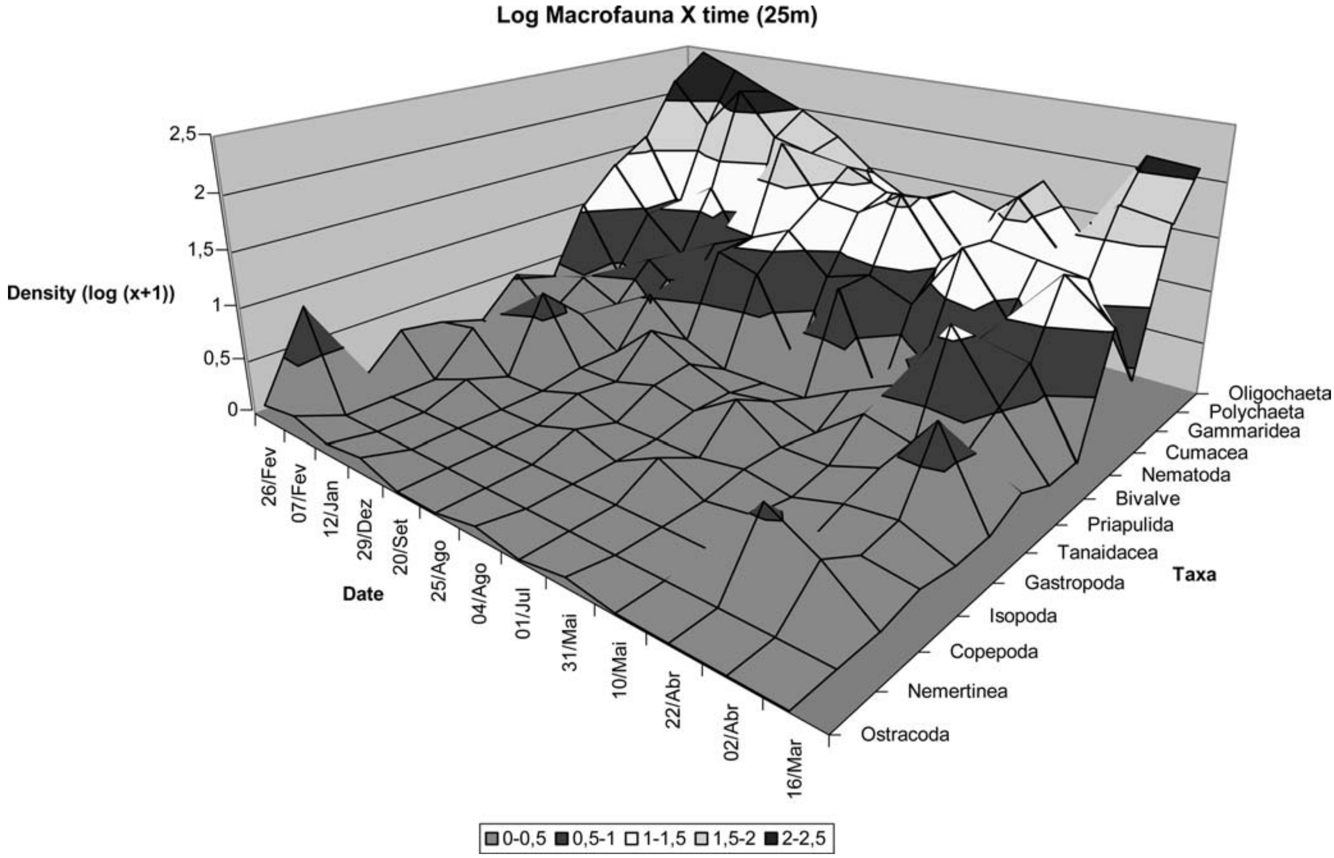

Fig. 6 Macrofaunal groups transformed densities (Log $(x+1)$) at 25 m depth along an annual cycle. Falling densities coincide with the period of light absence at this depth (approximately April 8–August 9, 1999)

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 constrains (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.

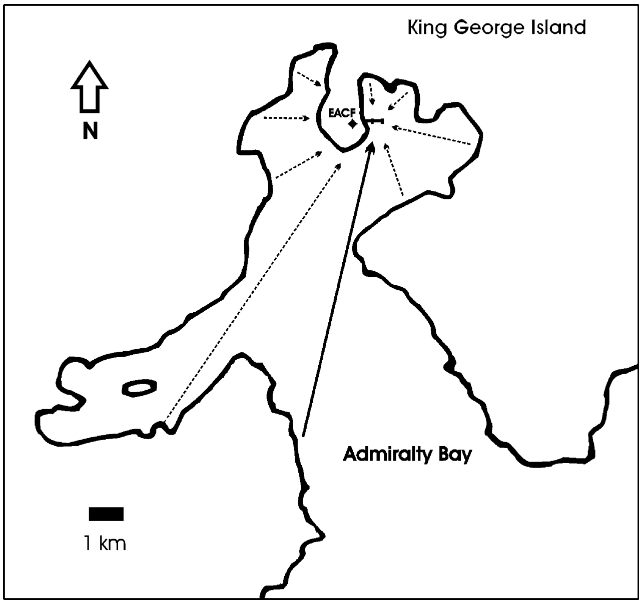

Fig. 7 Admiralty Bay, showing the available wave fetches as a function of wind direction and station locations. Longer fetches are those from the south quadrant (*bold arrow*)

Acknowledgements Authors wish to thank the CNPq-PROANTAR, SECIRM, and specially to the crew of the Brazilian Antarctic Station "Comandante Ferraz" for their crucial help in field work. We also wish to thank three anonymous reviewers for comments and criticism, and to Dr. Fernando Fernandez for reviewing the manuscript and for helpful comments.

References

Arnaud PM (1985) Essai de synthese des particularites eco-biologiques (adaptations) des invertebres benthiques antarctiques. In: Mayzaud P (eds) Adaptations des etres marins aux eaux froides: aspects physiologiques et ecophysiologiques: seminaire anime par p. Mayzaud, Paris, pp 117–124, 6–13 Novembre 1984

Arnaud PM, Jazdzewski K, Presler P, Sicinski J (1986) Preliminary survey of benthic invertebrates collected by Polish Antarctic Expeditions in Admiralty Bay (King George Island, South Shetland Islands, Antarctica). Pol Polar Res 7(1–2):7–24

Arnaud PM, López CM, Olaso I, Ramil F, Ramos-Esplá AA, Ramos A (1998) Semi-quantitative study of macrobenthic fauna in the region of the South Shetland Islands and the Antarctic Peninsula. Polar Biol 19:160–166

Arntz WE, Brey T, Gallardo VA (1994) Antarctic zoobenthos. In: Ansell AD, Gibson RN, Barnes M (eds) Oceanography and marine biology: an annual review. UCL, London, pp 241–304

Battershill CN (1990) Temporal changes in antarctic marine benthic community structure. N Z Antarct Rec 10(1):23–27

Clarke A (1996) Marine benthic populations in Antarctica: patterns and processes. In: Foundations for ecological research West of the Antarctic Peninsula. Antarctic Research Series. American Geophysical Union, pp 373–388

Clarke A (1996b) Benthic marine habitats in Antarctica. In: Ross RM, Hofmann EE, Quetin LB (eds) Foundations for ecological research west of the Antarctic Peninsula. Antarctic research series. American Geophysical Union, pp 123–133

Engel J, Kvitek R (1998) Effects of otter trawling on a benthic community in Monterey Bay National Marine Sanctuary. Conserv Biol 12(6):1204

Gambi MC, Lorenti M, Russo GF, Scipione MB (1994) Benthic associations of the shallow hard bottoms off Terra Nova Bay, Ross Sea: Zonation, biomass and population structure. Antarct Sci 6(4):449–462

Gambi MC, Mazzella M, Lorenti M, Scipione MB (2000) Spatio-temporal variability in the structure of Benthic populations in a physically controlled system off Terra Nova Bay: the shallow hard bottoms. In: Faranda G, Ionora (eds) Ross Sea ecology. Springer, Berlin Heidelberg New York, pp 527–538

Grebmeier J, Barry J (1991) The influence of oceanographic processes on pelagic-benthic coupling in polar regions: a benthic perspective. J Mar Syst 2(3–4):495–518

Gutt J, Starmans A, Dieckmann G (1996) Impact of iceberg scouring on polar benthic habitats. Mar Ecol Prog Ser 137:311–316

Hair JFJ, Anderson RE, Tatham RL, Black WC (1998) Multivariate data analysis. Prentice Hall, Englewood Cliffs p 730

Kauffman TA (1977) Seasonal changes and disturbance in an antarctic benthic mud community. PhD Thesis, University of California

Lowry JK (1975) Soft Bottom Macrobenthic Community of Arthur Harbor, Antarctica. Antarct Res Ser 23(1):1–19

Mühlenhardt-Siegel U (1989) Quantitative investigations of Antarctic zoobenthos communities in winter (May/June) 1986 with special reference to the sediment structure. Arch FischWiss 39:123–141

Nedwell DB, Walker TR (1995) Sediment-water fluxes of nutrientes in an Antarctic coastal environment: Influence of bioturbation. Polar Biol 15(1):57–64

Nedwell D, Walker T, Ellis-Evans J, Clarke A (1993) Measurements of seasonal rates and annual budgets of organic carbon fluxes in an Antarctic coastal environment at Signy Island, South Orkney Islands, suggest a broad balance between production and decomposition. Appl Environ Microbiol 59(12):3989–3995

Oliver JS, Slattery PN (1985) Effects of crustacean predators on species composition and population structure of soft-bodied infauna from McMurdo Sound, Antarctica. Ophelia 24(3):155–175

Open University (1998) The ocean basins: their structure and evolution. Butterworth-Heneman, New York, p 258

Parulekar AH, Ansari ZA, Harkantra SN (1983) Benthic fauna of the Antarctic Ocean—quantitative aspects. Tech Publ Sci Rep FIEA 1:213–218

Peck L, Brockington S, Vanhove S, Beghyn M (1999) Community recovery following catastrophic iceberg impacts in a soft-sediment shallow-water site at Signy Island, Antarctica. Mar Ecol Progr Ser 186:1–8

Platt HM (1979) Ecology of King Edward Cove, South Georgia: macro- benthos and the benthic environment. Br Antarct Surv Bull 49:231–238

Retamal A, Quintana R, Neira F (1982) Analisis cuali y cuantitativo de las comunidades bentonicas en Bahia Foster (Isla Decepcion) (XXXV Expedición Antartica Chilena, enero 1981). INACH Serie Cientifica 29:5–15

Sokal RR, Rohlf FJ (1995) Biometry, The Principles and Practice of Statistics in Biological Research, 3rd edn. W.H. Freeman & Company, San Francisco, p 887

Stark JS, Snape I, Riddle JM (2003) The effects of petroleum hydrocarbon and heavy metal contamination of marine sediments of Antarctic soft-sediment assemblages: a field experimental investigation. J Exp Mar Biol Ecol 28:21–50

Thompson BW, Riddle MJ, Stark JS (2003) Cost-efficient methods for marine pollution monitoring at Casey Station, East Antarctica: the choice of sieve mesh-size and taxonomic resolution. Mar Poll Bull 46:232–243

Tucker M (1988) Temporal distribution and brooding behaviour of selected benthic species from the shallow marine waters off the Vestfold Hills, Antarctica. In: Ferris J, Burton H, Johnstone G, Bayly I (eds) Biology of the Vestfold Hills, Antarctica. Hydrobiologia, pp 151–159

Underwood AJ (1997) Experiments in ecology: their logical design and interpretation using analysis of variance, 1. Cambridge University Press, London, p 504

Wägele JW, Brito TAS (1990) Die sublitorale Fauna der maritimen Antarktis Erste Unterwasserbeobachtungen in der Admiralitaetsbucht. Nat Mus 120(9):269–281

Wägele JW, Schminke HK (1986) Leben in eisigen Tiefen: Benthosforschung in der Antarktis. Nat Mus 116(6):184–193

Wu B, Chen M, Wu Q, Huan F (1992a) A study on the quantity of shallow sea benthos in the Great Wall Bay, Antarctica. Antarct Res Nanji Yanjiu 4(4):55–61

Wu Q, Wu B, Chen M, Huan F (1992b) Community analysis of shallow sea benthos in the Great Wall Bay, Antarctica. Antarct Res Nanji Yanjiu 4(4):62–67

Zhang X, Lu P, Zhang K (1986) Population distribution of benthos and seasonal variation of biomass in the inshore water of Davis, Antarctica. In: Ed PL (eds) A collection of Antarctic Scientific Explorations 3. Chinese National Antarctic Research Expedition, China, pp 141–145