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Vertical organic inputs and bio-availability of carbon in an Antarctic coastal sediment

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Abstract: Measurements were made of organic fluxes at a coastal sediment at Signy Island, South Orkney Islands, Antarctica, between December 1990 and March 1992. The deposition rate of organic matter to the sediment was measured at the same time with a maximum sedimentation rate of 306 mg C m^{-2} d^{-1}. The rates of sedimentary organic input were small during winter ice cover, and the organic content of the sediment declined during this period as available organic matter was depleted. Fresh organic input occurred as soon as the sea-ice melted and ice algal biomass was deposited to the sediment; and was sustained during the spring after ice break-up by continued primary production in the water column. The proportion of available carbon in surface sediments was measured during a seasonal cycle using *Pseudomonas aeruginosa* as an indicator organism over the 0–1 cm depth horizon. Variations in the amount of organic matter deposited to the sediments and the proportion of available carbon were observed during the seasonal cycle. Seasonal variations of benthic activity in this coastal sediment was regulated by the input and availability of organic matter, and not by seasonal water temperature, which was relatively constant between –1.8 and 0.5 C.

Key words: Antarctica, Signy Island, coastal sediments, organic deposition, available carbon, seasonality.

Introduction

Although permanently at low temperature, around 0°C, parts of the Southern Ocean has been considered to be amongst some of the most productive marine regions of the world (El-Sayed 1984; Holm-Hansen 1985; Kottmeier *et al.* 1987). The Antarctic is characterised by seasonal sea-ice growth and retreat, which during the summer releases its contents to the water column (Zwally *et al.* 1983; Clarke 1988). The annual cycle of sea-ice formation and breakout produces a distinct seasonal pattern of phytoplankton productivity (Heywood and Whitaker 1984). In the near-shore marine environment of the Antarctica three sources of microalgal primary production has been identified: phytoplankton, ice-associated microalgae and benthic microalgae (Gilbert 1991a, b). Sea-ice algae have long been recognised as an important source of carbon at high latitudes (Horne *et al*. 1969; Palmisano *et al*. 1988). During the decline of the spring ice bloom, diatoms are removed and they rapidly sink out of the water column (McConville *et al*. 1985). Matsuda *et al.* (1990) found seasonal variations in particulate organic matter under Antarctic fast-ice between 1.6 g C m^{-2} to 9 g C m^{-2}. Sedimentation of this material occurs rapidly to the benthos and plays an important role in carbon fluxes between the ice and the benthos (Kopczyńska 1981; Palmisano and Sullivan 1983; Grossi *et al.* 1987). Phytoplankton primary production is the major carbon source supporting bacterial secondary productivity in the Antarctic (Findlay *et al.* 1992). Primary production at Signy Island has been shown to vary between 86 and 289 g C m^{-2} y^{-1} (Whitaker 1982). The microphytobenthic communities at Signy Island are also important sources of organic material to sediments, with up to 14% of sediment organic content consisting of diatoms (Gilbert 1991a, b).

The bottom sediments in marine ecosystems are important sites of mineralization and nutrient recycling (Nedwell 1989) and in shallow inshore coastal areas as much as 50% of the total net primary production may impact bottom sediments (Jørgensen 1983). This production of organic matter must be balanced by equivalent degradation of organic detritus so that elements contained in the organic matter are recycled to support further production (Nedwell *et al.* 1993). Organic matter consumed by the benthos is associated with a large flux of inorganic nutrients from the sediments to the overlying water at high latitudes (Nedwell and Walker 1995; Rysgaard *et al.* 1996). In aerobic sedimentary communities detritus is degraded and oxidised by a complex community of micro-organisms (Nedwell 1984). Below this layer organic matter is mineralised mainly by anaerobic, sulphate-reducing, denitrifying and methane-producing bacteria (Jørgensen 1982; Purdy *et al.* 2003). Microbial biomass in the Antarctic can be remarkably high (Tanner and Herbert 1982; Palmisano *et al.* 1985) with heterotrophic bacteria relying mainly on primary production for their energy supply (Fiala and Delille 1992). These bacteria contribute significantly to energy transfer in the Antarctic (Delille and Perret 1991; Delille 1992) and show strong seasonal variations in density (Delille and Bouvy 1989). Measurements to examine benthic microbial activity were previously made at Signy Island (Nedwell 1989; Nedwell *et al.* 1993; Nedwell and Walker 1995). The rates of microbial activity in these studies were comparable to rates in some studies in temperate regions at much higher temperatures (Senior *et al*. 1982; Nedwell and Takii 1988). This work was undertaken to examine the fluxes of organic matter to the shallow coastal sediments at Signy Island over a complete annual cycle and to establish the seasonal changes in sediment organic carbon content and whether these changes are reflected in the bio-availability of this organic material.

Materials and methods

The work was carried out at Signy Island (60°42’ S, 45°36’ W) in the South Orkney Islands, between December 1990 and March 1992. The sampling site was located in Factory Cove with a maximum depth of 9 m. The site has been described previously (Nedwell *et al.* 1993; Nedwell and Walker 1995). Factory Cove has fast-ice up to 1 m thick for between 70 and 241 days, and monthly mean seawater temperature low, ranging from –1.8°C to +0.5°C (Bone 1972; Clarke *et al.* 1988). The sediment was blackened below a light brown surface layer approximately 1 cm thick and supported a variety of invertebrates. The physical characteristics of the sediment have been described in detail by Walker (1993). All cores of sediment for analysis were taken by SCUBA divers, and in all cases samples were returned to the laboratory within 10 min.

Nine vertical sediment cores were taken from Factory Cove at approximately monthly intervals (fortnightly during summer algal blooms) using 60 ml hypodermic syringes. Cores were taken over the 0–5 cm depth horizon and were capped using suba-seals. Care was taken to ensure that 2 cm of seawater remained above the sediment to maintain an intact sediment/water interface and were then frozen at –20°C. Frozen sediment was extruded and slices were cut with a fine saw. Slices of sediment were taken every 1 cm over the 1–5 cm horizon, with the surface 0–1 cm divided into 0.5 cm slices. Three cores were used for both AFDW and CHN analysis. Slices of sediment for AFDW analysis were oven dried at 601C for 3 d to constant weight, followed by LOI in a furnace oven at 500°C for 24 h before being reweighed and AFDW determined. CHN analysis was performed in the UK and sediment was stored in plastic vials and kept frozen at –2°C after weighing. As a precaution to remove any inorganic carbon before analysis the sediment was treated with dilute hydrochloric acid (6M). Once carbonates had been removed the sediment was oven dried to constant weight as before and carbon and nitrogen was measured in a CHN analyser (Perkin-Elmer model 2400).

The British Antarctic Survey had an array of sediment traps in inner Borge Bay, just outside Factory Cove. Each sediment trap array consists of 4 individual polypropylene pipes (27 cm length, internal diameter 9 cm) held vertically in a moored dura-pipe collar suspended in the 20 m deep water column at a depth of 10 m. A similar duplicate sediment trap was deployed for 4 months at the Factory Cove site, consisting of four sediment traps of 12 cm length (internal diameter 5.5 cm) were suspended 2 m off the sediment bottom in 9 m of water column. The measurements of settlement rates with these duplicate traps proved to be statistically indistinguishable from those of the traps just outside Factory Cove. The measurements within the Cove were therefore discontinued, and the data from Borge Bay were used. SCUBA divers recovered the traps at approximately monthly intervals, but at fortnightly intervals during the phytoplankton bloom. The material in the trap was not preserved in any way, and the flux estimate is probably an underestimate. Recovered trap contents were filtered through glass fibre (GF/C) filters and dried to constant weight at 60°C. Sub-samples of the dried material were frozen for subsequent analysis of organic carbon and nitrogen with a CHN analyser (Perkin-Elmer model 2400). The remaining material was combusted at 500°C for 12 h and the organic content (AFDW) was then measured. Data from this array of sediment traps should be treated with caution and as they were below the 5:1 aspect ratio suggested by Bloesch (1988, 1994),which is the critical limit to avoid sediment resuspension. As no sediment preservation technique was used, the monthly sediment flux is likely to be an underestimate due to losses from microbial degradation.

At the same time as collections for AFDW and CHN analysis were done, sediment was sub-sampled in slices as described for organic content and frozen at –20°C for assays of available organic carbon. On return to the UK assays were carried out to determine the amount of available organic carbon present in the sediment. Sediment extracts were performed using a modification of the method used by Nedwell (1987) to extract available carbon from the samples. The top 1 cm depth slice from a sample was thawed and extruded into a centrifuge tube and an equal volume of boiling distilled, deionised water was added. It was resuspended by agitation then allowed to cool before being centrifuged at 6000 × g for 20 min. The resultant clear supernatant was a combination of sediment pore water and hot water extract which was frozen until required. A modification of the method used by Seki *et al.* (1968) was used to measure the amount of microbiologically available organic carbon in the sediment extracts. A simple mineral salts medium supported the growth of *Pseudomonas aeruginosa* when an available carbon source was added. The medium contained: 2.6 g l^{-1} K_2HPO_4; 1.0 g l^{-1} $(NH_4)_2SO_4$; 2 ml 10% w/v $MgSO_4 \cdot 7H_2O$; 5.0 g l^{-1} NaCl and 1 l of distilled water. The pH was adjusted to 7.2 by the addition of K_2HPO_4 solution before sterilisation in an autoclave for 15 min at 15 psi. Magnesium sulphate solution was added aseptically after sterilisation separately to avoid precipitation. An 18 h slope culture of *Pseudomonas aeruginosa* was grown up in a 30°C incubator on nutrient agar. Loopfuls of this culture were streaked out on 6 agar plates to check for purity. The inoculum for the assay was obtained by centrifuging down (10000 rpm for 10 min) a 10 ml sample of a 24 h culture of *P. aeruginosa* in mineral salts medium with 0.05 g glucose added. The pellet was washed aseptically once in sterile mineral salts medium without glucose, centrifuged and the supernatant was discarded. The pellet was again resuspended in a further 10 ml of sterile mineral salts medium without glucose. This procedure allowed growing cells to be inoculated into the test media without adding available carbon to the assay medium. To each assay flask was added aseptically 45 ml of minimal medium, 5 ml of sediment extract solution or standard, and each flask was inoculated with 0.35 ml of inoculum suspension. The flasks were incubated in a water bath at 30°C, shaken at 180 cycles min^{-1} to maintain aeration. The assay flasks were incubated and growth determined by nephelometer until the maximum OD reading was achieved. Assay flasks were all optically standardised each with a long arm which could be placed into a nephelometer to take readings aseptically. The growth of *P. aeruginosa* in response to available carbon was calibrated with media containing known amounts of glucose. The standard glucose solution was filter sterilised by passing through a sterile membrane filter (0.2 µm, Millipore, UK) to prevent caramelization of the glucose. Glucose standards (0.1 g ml^{-1}) were always included in each run to allow for minor fluctuations in assay conditions. Blanks containing no added carbon were also routinely included. Maximum growth occurred in the assays of sediment extracts usually after 3 d, presumably as a result of the slower availability of the organic carbon substrates in the extracts compared to glucose. The available carbon in the sediment extracts was calculated by comparison with the glucose standards, and expressed in terms of mg C ml^{-1} (glucose equivalents). The available carbon was also expressed as a percentage of the total organic carbon measured in the same sediment at the same time of year.

Results

The organic matter content (AFDW) throughout the study period (data from Nedwell *et al.* (1993)) is illustrated in Fig. 1. There was significant seasonal varia-

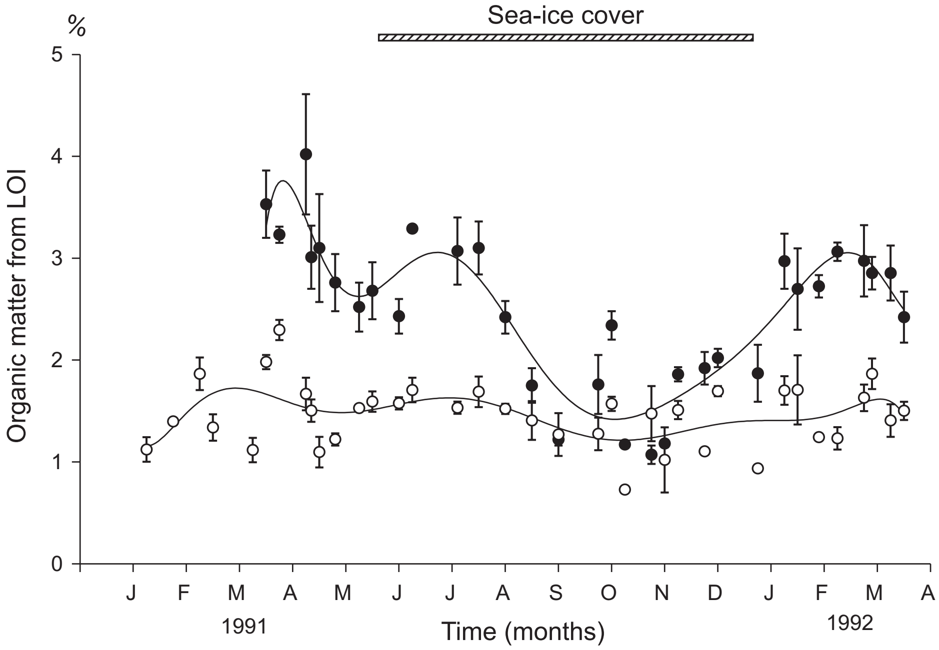

Fig. 1. Variation in sedimentary organic content (AFDW) in the 0–0.5 cm (●) and 1–2 cm (○) depth horizon from Factory Cove. Plotted values are means ± 1 SE (*n* = 3). From Nedwell *et al.* (1993).

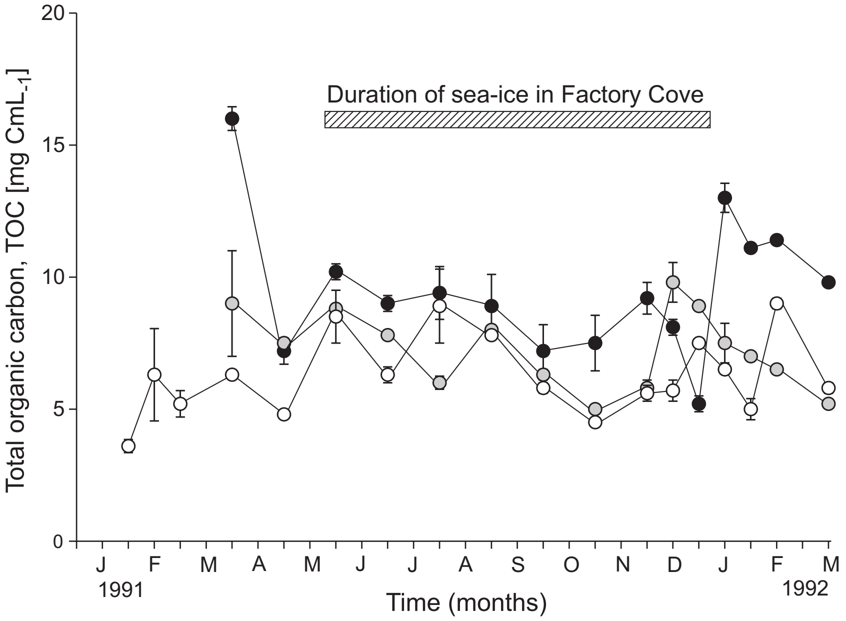

Fig. 2. Variation of total organic carbon, TOC (mg C ml^{-1}) in the surface sediments of Factory Cove in the 0–0.5 cm (filled circles), 0.5–1 cm (grey circles) and 1–2 cm (open circles) depth horizons. Plotted values are means ± 1 SE ($n = 3$).

tion in organic matter in the top 0–0.5 cm slice, consistent with seasonal changes in the input of organic matter to the bottom sediment. This seasonal variation was damped in the 0.5–1 cm layer (data not shown), and was virtually undetectable in the 1–2 cm layer where the organic matter content was essentially constant throughout the year. The total annual variation in organic carbon in the sediment was determined by converting the organic content (AFDW) to equivalent organic carbon content using the carbon values measured with the CHN analyser. Thus, based on this seasonal variation in the sediment organic carbon content, Nedwell *et al.* (1993) derived a minimum estimate of organic matter input and degradation over the top 0–1 cm horizon of 10.6 moles C m^{-2} y^{-1}. Total organic carbon (TOC) is shown in Fig. 2, down to 2 cm over the 0–0.5, 0.5–1 and 1–2 cm depth horizons. As with the AFDW, significant seasonal variation in organic matter is illustrated over the top 0–0.5 cm slice, again consistent with seasonal changes in the input of organic matter. It is difficult to see any seasonal trends in the 0.5–1 and 1–2 cm depth horizons, although the TOC content is consistently lower in the deeper 1–2 cm layer. The TOC gives actual carbon instead of AFDW which is assumed to be 50% of the organic content. Fig. 3, illustrates variation in C:N ratios with respect to depth. There was no significant difference between the 0–0.5 cm depth horizon when compared to both the 0.5–1 cm and 1–2 cm depth horizons (one-way ANOVA, followed by t-test; $P < 0.05$, $n = 54$). The molar C:N ratios of organic matter in the surface 0–1 cm layer of sediment averaged 13.5 (SD = 3.8, $n = 54$).

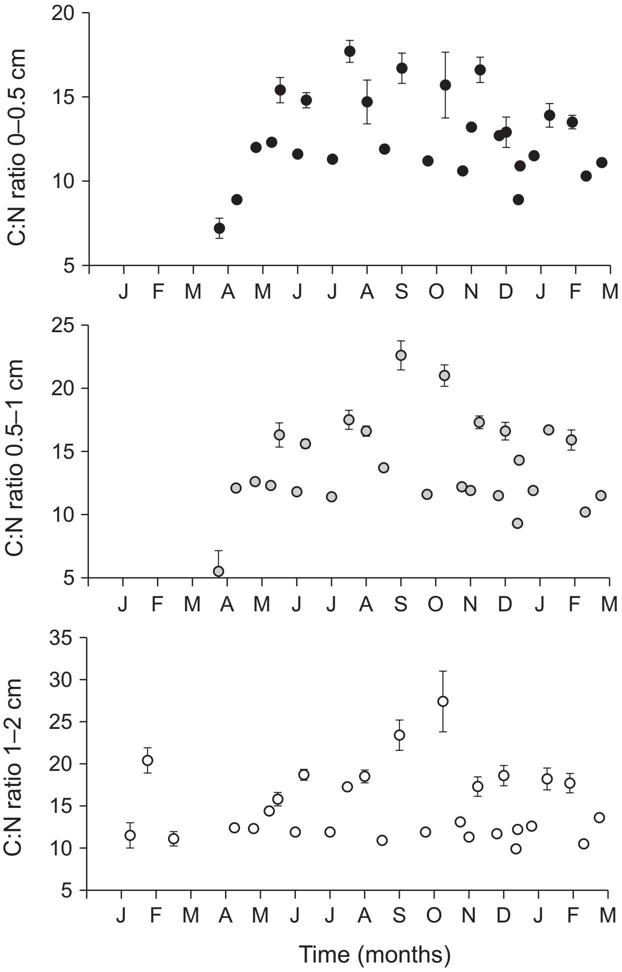

Fig. 3. The ratio of C:N (moles ml^{-1}) with respect to depth. Plotted values are means ± 1 SE ($n = 3$).

Fig. 4 shows the downward fluxes of organic carbon (expressed as log mg organic matter (AFDW)) measured in the sediment traps during the period from April 1989 to February 1992 (data collected by BAS and adapted from Nedwell *et al.* (1993)). Minimum fluxes were detected during September, coinciding with the end of the ice cover. Downward fluxes of organic matter increased during the latter part of winter (before ice break up in the spring), when ice-algae were deposited into the water column. The 1991 winter was unique, in that the ice melted *in situ* giving rise to a pulse of organic matter to the sediment. Normally, in other years the ice is blown out or is broken up by storms before the melt leads to significant deposition of material. The organic deposition rate continued to increase at the start of the phytoplankton bloom, and reached a peak in late summer. When the downward flux of material was integrated with respect to time, annual organic car-

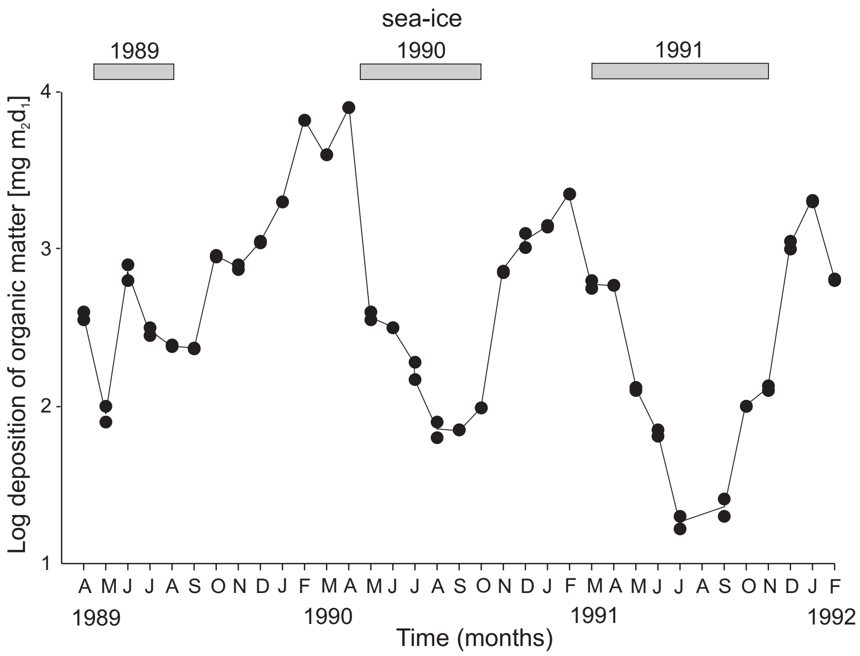

Fig. 4. Log of deposition rates of organic matter in duplicate sediment traps deployed in the water column at Small Rock. Data collected by BAS and adapted from Nedwell *et al.* (1993).

bon inputs of 32.9 moles C m^{-2} y^{-1} for September 1989 to August 1990; and 16.5 moles C m^{-2} y^{-1} for September, 1990 to August, 1991 were obtained. Data for sediment traps from Factory Cove are presented in Table 1.

Table 1

Mean monthly deposition rate in sediment traps at Factory Cove ($n = 4$).

Date	Deposition rate (mg C m^{-2} d^{-1})
17/09/91-15/10/91	102.1
16/10/91-15/11/91	200.4
16/11/91-06/12/91	305.6
07/12/91-03/01/92	306.8

Glucose standards were linear over the range 0–200 mg C l^{-1} and are shown in the calibration curve in Fig. 5. The peak concentrations of available carbon can be observed in Fig. 6, during April 1991 and again during December 1991. These events occurred at roughly the same time as detrital deposition of primary production to the sediment surface. The concentrations of available carbon were stable during the winter and remained unchanged from June to November 1991. The lowest concentrations of available carbon occurred during January 1991 and December demonstrates the decrease in available carbon with increased depth of sediment. Organic matter from primary production impacts the sediment surface and it is here that the highest concentrations of available carbon are found. The avail-

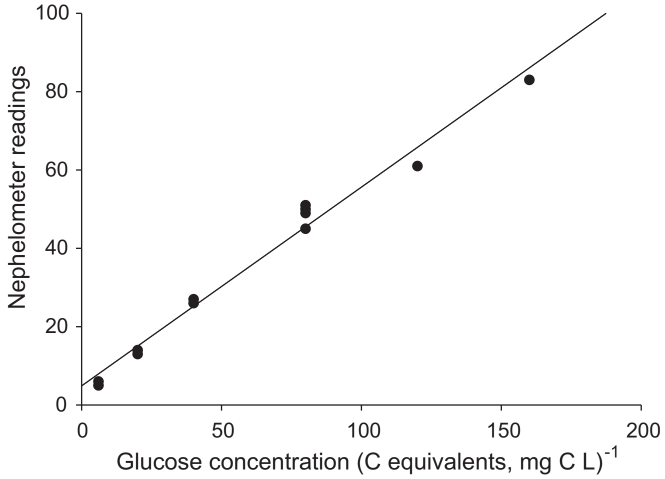

Fig. 5. Calibration of *Pseudomonas aeruginosa* grown in minimal media against a range of glucose concentrations (C equivalents, mg C l^{-1}). ($R^2 = 0.98$).

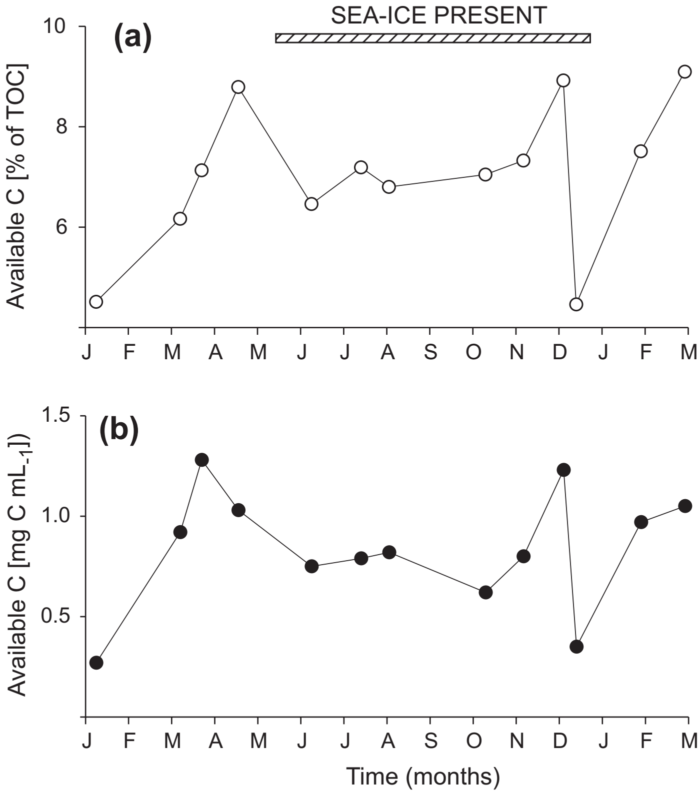

Fig. 6. The proportion of available carbon (a) (expressed as a % of total organic carbon) and available carbon (b) (mg C ml^{-1}), using *Pseudomonas aeruginosa* as an indicator organism over the 0–1 cm depth horizon from Outer Mooring sediments. Single data points are given.

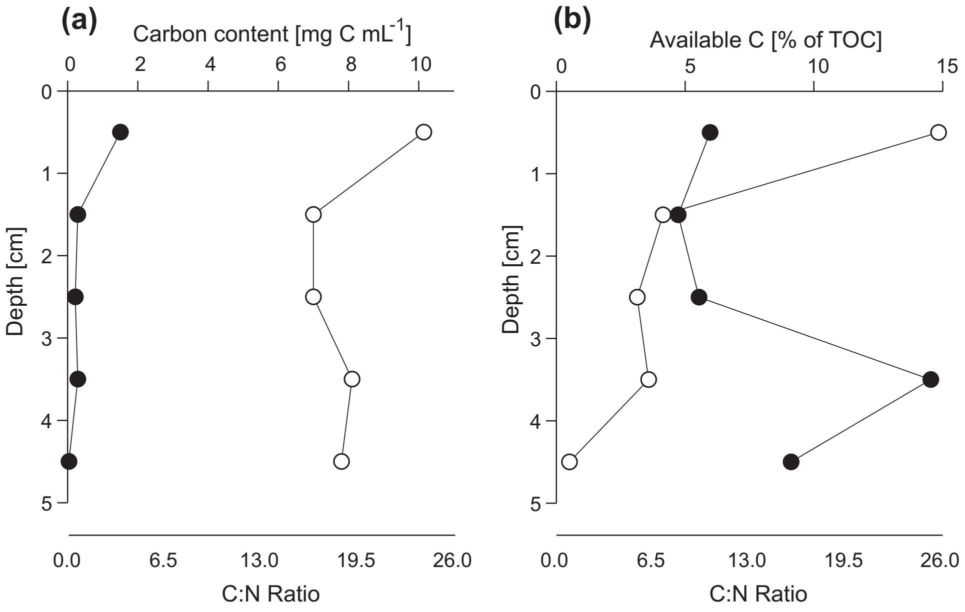

Fig. 7. Profile of a sediment core taken from Factory Cove, during peak of the summer phytoplankton bloom. (a): ● – available carbon; ○ – total organic carbon, and (b): ● – C:N ratios; ○ – available carbon (% of TOC). Single data points are given.

able carbon, TOC (both expressed as mg C ml^{-1}) and available carbon as a percentage of the TOC decrease with increased sediment depth. The C:N ratios for this core do not show any trends with increase in depth.

Discussion

The results show a strong seasonal pattern of settlement of organic detritus and organic matter accumulation in the surface layers of sediment, falling sharply with depth. Platt (1979) found up to 35 mg g^{-1} of organic carbon in surface layers of sediment in King Edward Cove, South Georgia and showed significant reductions of organic carbon with sediment depth. The input of organic matter to the sediments at Signy Island occurred through settlement of organic detritus through the water column (Gilbert 1991a, b).

There were marked seasonal changes in the organic content of the 0–0.5 cm layer of sediment, although the seasonal variation was damped with increased depth. Surface organic carbon appeared to be high during the summer after deposition of organic detritus (Nedwell *et al.* 1993; Nedwell and Walker 1995). However, in the winter there was negligible settlement of organic matter due to limitation of primary production, therefore surface sediment organic matter was rapidly depleted by microbial degradation and feeding of the benthic zoobenthos. Several authors have examined benthic zoobenthos in Factory Cove and amphipods were the most abundant bioturbators (Bone 1972; White and Robins 1972; White 1984). The second most abundant bioturbator present was *Mysella charcoti* (S. Hain, personal communication). Infauna was restricted to the surface 1 cm of sediment and bioturbation effects were mainly in this horizon. Bouvy and Soyer (1989) found high densities of meiofauna in the surface layers of a Kerguelen mud flat, but these were much lower densities than were found in the surface layers of Factory Cove sediments (own unpublished data). The seasonal trend of sediment organic content was virtually indistinguishable over the 1–2 cm depth horizon. Newell *et al.* (1993) found that surface organic carbon depletion coincided with decreasing rates of organic mineralization. During the winter it was found that organic mineralization was mainly driven by sulphate reduction in contrast to the summer months which was dominated by aerobic respiration within surface sediments. This probably reflected the progressive burial of available organic matter by bioturbation which was rapidly mixed into the top 1 cm by a dense amphipod community (Nedwell and Walker 1995). Below this depth the seasonal response was damped. Maximum sedimentary organic content was detected during late summer, coincident with maximum organic matter settlement rates, and then declined during autumn when settlement rates decreased. The organic content of the surface sediment continued to decline during winter, as it was presumably mineralised by the benthic biota, and increased again during the following spring in November 1991, when a fresh supply of organic matter settled from the ice algae. Lack of further organic input during the winter depleted the amount of available organic carbon in the surface sediment and therefore diminished the relative importance of aerobic respiration during that period. Berkman *et al.* (1986), similarly, found decreasing concentrations of surface organic matter during the winter at McMurdo Sound and seasonal organic carbon in surface sediments in a Greenland fjord was also noted by Rysgaard *et al.* (1996).

There also appears to be a pronounced seasonal trend in total organic carbon (TOC) in surface sediments in Factory Cove, with this trend diminishing over deeper horizons. Higher concentrations of TOC at the sediment surface, were probably due to the rapid input of organic matter, and the subsequent decrease of TOC during winter could be attributed to the mineralization of this labile material. This access of fresh organic matter in the bottom sediment stimulated the benthic respiration rates and emphasised the importance of organic carbon supply to the control of benthic microbial activity (Nedwell *et al.* 1993). The average measured C:N ratio in surface sediments was 13.5:1. Nedwell and Walker (1995) calculated an estimated C:N ratio of 103:1 derived from measurements of the organic matter oxidisation and NH_4^+ efflux from the sediment during the same season. This discrepancy between measured and estimated C:N ratios suggests there may be other major unmeasured fluxes of nitrogen from these sediments.

This study shows the extreme seasonality of organic carbon availability in the Antarctic coastal environment and its inter-annual variation. Organic deposition rates decreased during the winter as primary production becomes light limited after the formation of sea-ice (Gilbert 1991a). An initial increase of organic matter settlement was observed during May to June 1991 immediately after ice formation, which was permitted by the reduced turbulence of the water column. Primary productivity was negligible during the winter and was demonstrated by deposition rates shown in Fig. 4. Seasonality of input was detected with sediment traps in Frobisher Bay, Arctic Canada (Atkinson and Wacasey 1987; Hsiao 1987). During spring, the development of an under ice community (Horner and Schrader 1982; Palmisano and Sullivan 1983; Palmisano *et al.* 1988) constitutes some of the first primary production of the year, along with pelagic picoplanktonic production. Melting of the sea-ice, with the deposition of ice algae biomass into the water column, contributes the first input of new organic carbon into the coastal sediments towards the end of winter and may also seed the water column with algae (Horner 1982). This is illustrated by the increased settlement rates of organic matter and the increased organic content of the surface layer of sediment during November and December 1991, before the ice cover disappeared. After the breakup of winter ice, the spring algal bloom then further increased the deposition rate of organic matter through the water column to its peak in late summer. Organic carbon within the surface layers of sediment continued to increase after the peak of the algal bloom which generally occurs during late December and January (Whitaker 1982). Platt (1979) found that the highest sediment accumulation rates in King Edward Cove, South Georgia were between December and January. Therefore, this organic matter supply controls sedimentary activity rather than the constantly low temperatures (Nedwell *et al.* 1993; Rysgaard *et al.* 1996; Knoblauch *et al.* 1999).

Sediment fluxes in this study are likely to under-estimates due to losses from microbial degradation as no preservation material was used and the aspect ratios could have allowed losses of material due to resuspension (Bloesch 1988, 1994). However, this shallow coastal site was ice-covered for 8 months during the 1991 winter, which would have reduced wave energy and near bottom resuspension from wind driven currents, probably allowing most of the organic material to be retained by the traps. The strong relationship in Fig. 5 demonstrates the importance of using *P. aeruginosa* as a sensitive indicator organism for measuring the bioavailability of organic carbon in these Antarctic coastal sediments which are strongly influenced by seasonal input of organic matter. The strong seasonality in the amount and proportion of available carbon mirrors the inputs of deposition and surface organic contents of these sediments. Bio-available carbon content of the sediment decreases with increasing depth which is reflected in the organic carbon content and TOC of sediments in Factory Cove. C:N ratios in the surface layers of Factory Cove demonstrated strong seasonal cycles. Delille and Bouvy (1989) also found seasonal trends in C:N ratios in Antarctic sediments. The changes in available carbon and C:N ratios with depth are probably influenced by the switch from aerobic respiration to anaerobic sulphate reduction and nitrogen metabolism. Periods of high organic enrichment coincide with increases in C:N ratios (Jones 1976; Matsuda *et al.* 1986). Organic matter at surface of sediments has C:N ratios similar to that of living plankton, whereas organic matter decomposing at depth in sediments appears to be relatively depleted in nitrogen (Martens and Jannasch 1983). The amount of fresh organic matter available to deeper sediments is much less than that available to the top 0–0.5 cm layer, as less bioturbation occurs there. Without a supply of fresh material the C:N ratios at the 1–2 cm horizon showed very little seasonality. Bouvy and Soyer (1989) measured seasonal C:N ratios in the top 1 cm oxidised layer of a mud flat at Kerguelen Islands. They found lower values in autumn and winter. Below the oxidised layer there was no distinct seasonality, but the organic carbon and nitrogen was lower than in the surface layers. In the early stages of detrital decomposition, organic nitrogen is mineralised more rapidly than organic carbon, resulting in an initial increase of the C:N ratio (Seki *et al.* 1968). Mean C:N ratios of 6.1 were found in Admiralty Bay, King George Island (Dawson *et al.* 1985), which were comparable with the present data.

Labile organic carbon, easily available for microbial utilisation, is confined to surface layers (Balba and Nedwell 1982; Nedwell 1987). This was demonstrated in the core taken on 3/1/92, as available carbon decreased rapidly with depth. Nedwell (1987) found that growth of *P. aeruginosa* was proportional to the amount of available carbon in the pore water. The amount of soluble, microbiologically labile organic material present in the surface layer of coastal marine sediments may vary seasonally (Seki *et al*. 1968). This is partly true for the seasonal study of available carbon on Signy Island sediments. The peaks of available carbon occurred shortly after most organic matter had been deposited to the sediment surface. During winter, when there was little or no sedimentation of organic matter, the amount of available carbon remained unchanged. However, low levels of available carbon were detected during summer of both years when higher levels would have been expected. This may have been due to the rapid mineralization of available organic matter during the early part of the algal bloom when much of the material had yet to be deposited. The data show that the proportion of the total organic carbon in the sediment which is present in the pools of labile organic carbon available for microbial metabolism is small. The pool size of available carbon decreases rapidly away from the site of input of organic matter down the sediment profile. This study shows that the intense short input of organic matter ensures a strong seasonal pattern in sediment organic carbon content and also a seasonal trend in the amounts of bio-available carbon within.

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