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Kieler Meeresforsch., Sonderh. 5, 390 – 395. Kiel 1981

Nutrient regeneration in maritime Antarctic sediments

A.C. Tanner[1] and R.A. Herbert[2]

[1] British Antarctic Survey, Cambridge, U.K.
[2] Department of Biological Sciences, The University, Dundee, U.K.

Abstract

Primary productivity in Antarctic inshore coastal waters at Signy Island is high (2 g $C \cdot m^{-2} \cdot day^{-1}$) compared with oceanic production (0.5 g $C \cdot m^{-2} \cdot day^{-1}$). Seasonal changes in phytoplankton, inorganic nutrients, total viable bacterial populations, proteolytic bacteria, denitrifying bacteria and heterotrophic nitrogen fixing bacteria have been followed at 14 day intervals from January 1976 – March 1978. Phytoplankton productivity reached a maximum in early January and this corresponds with a marked decline in NO_3-N (32 μg at $N \cdot l^{-1}$ to $< 5\mu$g at $N \cdot l^{-1}$) and $PO_4^{3-} \cdot l^{-1}$ (2 μg at $PO_4^{3-} \cdot l^{-1}$ to 0.65 μg at $PO_4^{3-} \cdot l^{-1}$). After the collapse of the bloom, NH_4^+ levels reached a maximum and correlated with high populations (1.4×10^5 bacteria/g dry wt) of proteolytic bacteria in the sediment. A large proportion of the heterotrophs (67 %) posses functional phosphatases which may play a significant role in phosphorus regeneration.

Introduction

The Weddell Sea, like other polar seas, is characterised by low temperatures, continual daylight during the summer and almost total darkness in the winter. Despite these environmental constraints, primary production rates in coastal waters surrounding Signy Island (60° 42.2'S,45° 35.7'W) are high, 80–290 g C fixed $\cdot m^{-2} \cdot y^{-1}$ (WHITAKER 1977). These production rates are similar to those reported for Frobisher Bay, Canada (63° 40'N,68° 27'W) by GRAINGER (1979). This study was undertaken in order to determine whether inorganic nutrients limited primary production and how rapidly the nutrient balance of the water column was restored following the collapse of the phytoplankton bloom. No detailed investigations have been previously made of nutrient regeneration in Antarctic coastal waters. Indeed, there are few data even on the occurrence of heterotrophic bacteria in Antarctic waters (PFISTER and BURKHOLDER 1965; MORITA et al. 1971; HERBERT and BELL 1974). MORITA et al. (1971) have demonstrated, using ^{14}C-labelled amino acids, significant heterotrophic bacterial activity at the Antarctic convergence. WALLS (1967) collected sediment and water samples from various locations along the Antarctic convergence and concluded that the bacteria from the Antarctic marine sediments were similar to those found in other oceans.

In this paper data is presented on seasonal changes in phytoplankton populations, inorganic nutrient levels, total aerobic heterotrophic bacteria, denitrifying bacteria, proteolytic bacteria and sulphate reducing bacteria together with rates of denitrification and heterotrophic nitrogen fixation.

Material and methods

The study area

The work was carried out in Borge Bay, an inshore coastal area on the west coast of Signy Island, which is a member of the South Orkney Islands. These islands are located to the west of the Antarctic peninsula. Water and sediment samples were taken from 5 sites in Borge Bay by Scuba diver at 14 day intervals from March 1976 to July 1977.

Chemical and physical analyses

Salinity was determined according to the method of HARVEY (1960). Light penetration was measured as detailed by HERBERT and TANNER (1977). Temperature was measured as the mean of 3 reversing thermometer readings after 20 min equilibration. Nitrate was determined according to the method of BENDSCHNEIDER and ROBINSON (1952), NO_2-N by the method of WOOD et al., (1967), NH_4-N by the method of LIDDICOAT et al. (1975), and PO_4-P using the method of MURPHY and RILEY (1962). Chlorophyll a was estimated according to the method of CREITZ and RICHARDS (1955).

Acetylene reduction technique

Nitrogen fixation rates of the sediments were measured by the acetylene reduction method according to the method of STEWART et al. (1967).

Table 1

Mean rates of anaerobic nitrogen fixation in sediment samples from Borge Bay measured by the acetylene reduction method.

Sampling Site	Mean rate of N_2-fixation (ng N_2 fixed h^{-1} g^{-1} dry wt. sediment)
1	0.56
2	0.40
3	0.65
4	0.47
5	0.39

Determination of denitrification rates

Sediment samples (2 g) were transferred to sterile bijou bottles and amended with 1 ml of a 0.05 % w/v solution ^{15}N-labelled KNO_3 (96.5 % enrichment). The samples were gassed with argon for 30 minutes and then incubated at 2 °C for time periods upto 96 hours. After the required incubation period the reaction was stopped by adding 0.5 ml 25 % w/v trichloroacetic acid. The quantity of $^{15}N_2$ or $^{15}N_2O$ produced was determined by injecting 0.1 ml volumes into a V.G. Micromass model MM2 601 mass spectrometer.

Enumeration of bacterial populations

Total viable counts of heterotrophic bacteria were determined on marine agar (Difco 2216). Proteolytic bacteria were estimated using casein agar supplemented with 25 g $NaCl \cdot l^{-1}$ (COWAN and STEEL 1974). Denitrifying bacteria were determined by the M.P.N. techniques using Giltay's medium supplemented with either glucose or citrate as carbon sources (BOLLAG et al. 1970).

Table 2

Mean rates of denitrification in sediment samples from Borge Bay measured by the production of $^{15}N_2$ and $^{15}N_2O$ from K $^{15}NO_3$.

Sampling Site	Mean rate of denitrification (ng N · l^{-1} · g^{-1} dry wt. sediment
1	4.0
2	3.6
3	2.5
4	2.2
5	2.7

Results and discussion

In contrast to the surrounding land areas water temperatures in the maritime Antarctic exhibit a remarkable constancy ranging from –1.8 °C in mid-winter to a summer maximum of +1 °C with a mean value of –1 °C. The low temperature of the Antarctic marine environment exerts a considerable selective pressure and data obtained in this study show that more than 50 % of the bacteria isolated were psychrophiles. The salinity of Signy Island coastal waters was similarily relatively constant at 34‰ ± 1‰ even though there was a large fresh-water input during the spring snow melt.

Data in Fig. 1 show that the coastal waters surrounding Signy Island are characterised by appreciable transparency and have optical properties similar to type 3 of the coastal water index described by JERLOV (1968). Light penetration through the water column decreases sharply during December and January concurrent with the development of the annual phytoplankton bloom but increases again when the bloom has collapsed until sea-ice forms once more. The annual phytoplankton bloom (Fig. 1) develops rapidly in late November, reaches a maximum in mid-December and collapses equally rapidly in late January. Analysis of inorganic nutrient concentrations

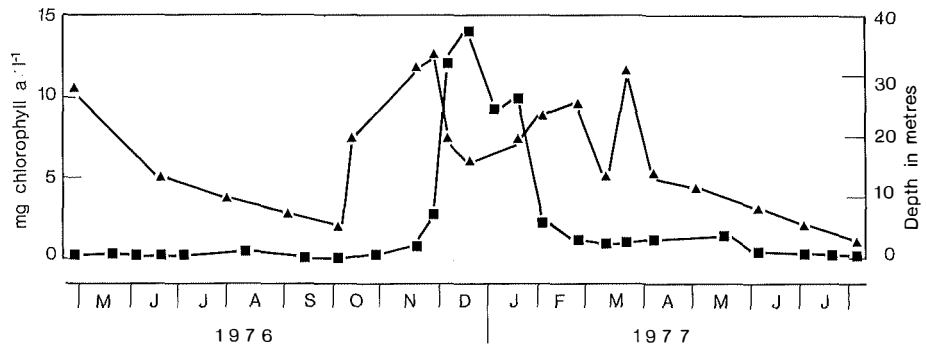

Figure 1

Interrelationship between phytoplankton production and light penetration in Signy Island coastal waters: ▲—▲ 1 % incidient light level, ■—■ chlorophyll a content of the water column.

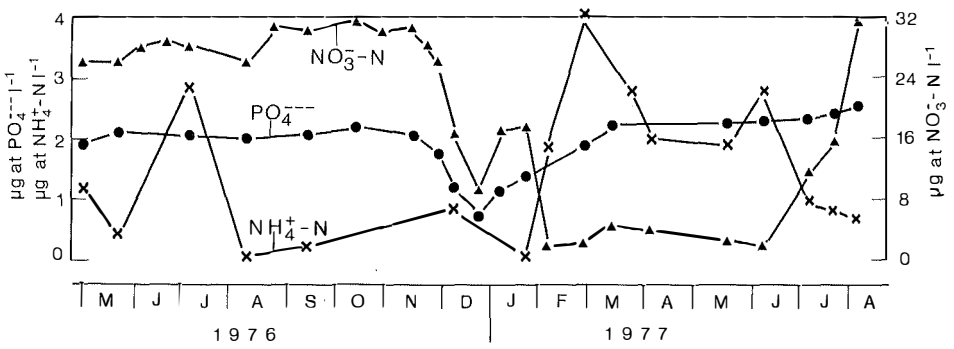

Figure 2

Seasonal changes in inorganic nutrients in the water column at Signy Island: •—• PO_4^{3-} x – x NH_4^+-N and ▲ — ▲ NO_3^--N.

in the water column show marked seasonal changes. Data (Fig. 2) show that inorganic phosphate remains constant throughout the winter and early spring but falls rapidly with the onset of the phytoplankton bloom although it never becomes limiting. Immediately following the bloom inorganic phosphate is rapidly regenerated and although we do not have quantitative data there is a marked increase in the evidence of heterotrophic bacteria producing extracellular phosphatases. From a sample of 144 heterotrophs isolated during this period 67 % produced active phosphatases whilst at other times of the year a significantly lower incidence of phosphatase producers were observed. Ammonia levels in the water column show more erratic seasonal changes but the most noticeable feature is the marked increase of NH_4^+-N in the water column following the collapse of the algal bloom. Data in Fig. 2 show that NH_4^+-N production is correlated with increased populations of proteolytic bacteria in the surface sediments which are degrading the moribund phytoplankton. Nitrate levels (Fig. 2) also show a seasonal periodicity with concentrations decreasing rapidly with the onset of the phytoplankton bloom. Subsequent nitrate regeneration is, however, slow it is not until mid-winter that significant increases occur; the mechanisms of regeneration are not clearly understood. All attempts to isolate marine nitrifying bacteria have so far proved negative. Whilst nitrifying bacteria are known to occur in marine environments (Watson 1963) their numbers are usually low ($<$ 100 viable cells $\cdot$ l^{-1}) and data from BUSWELL et al. (1950) have indicated that at temperatures $<$ 5 °C nitrifying bacteria are metabolically inactive. It is possible that the nitrate is regenerated by the inflow of a nitrate-rich water mass from other regions of the Weddell Sea. Whilst this hypothesis cannot be discounted, it should be noted that the sea is frozen during this period and water circulation is therefore restricted. Nitrite levels are low in the water column (circa 0.45 µ at NO_2-N $\cdot$ l^{-1}) and follow a similar seasonal periodicity to that observed for NO_3-N.

Total viable counts of heterotrophic bacteria (Fig. 3) in the surface sediments are maximal during the phytoplankton bloom and then with the exception of occasional spurious peaks they decline in late autumn and winter. Maximum population densities of heterotrophs during the bloom reflect the increased organic input into the surface sediments which are usually carbon-limited. Populations of proteolytic bacteria also show a well-defined maximum during and immediately following the phytoplankton bloom and this is accompanied by the appearance of maximum NH_4^+-N levels in the

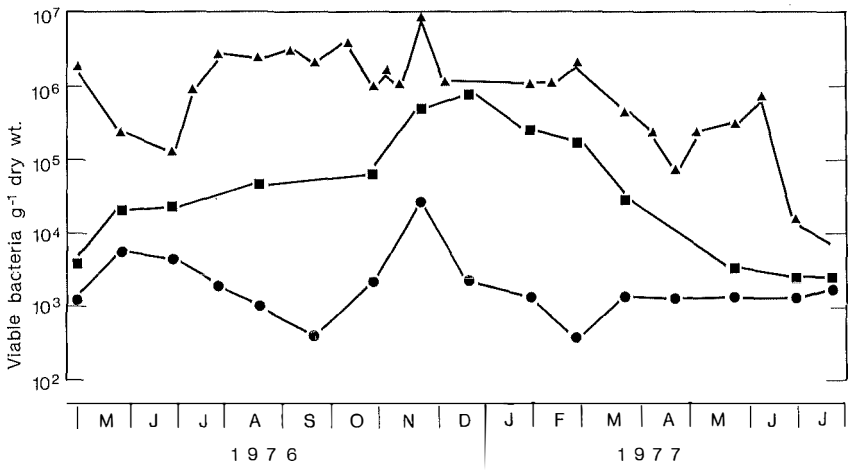

Figure 3

Seasonal changes in bacterial populations in surface sediments in Borge Bay, Signy Island: ▲ – ▲ total heterotrophic bacteria. ■ – ■ proteolytic bacteria. • – • denitrifying bacteria.

water column. Nitrate respiring bacteria (Fig. 3) also show maximal population densities during the phytoplankton bloom and this may reflect the development of localised anoxic microenvironments due to increased heterotrophic activity depleting oxygen in the surface sediments.

Total carbon and nitrogen analyses of the sediments show that both are low (total C 0.54 %, total N 0.05 %) of dry sediment sample of 100 g) and undergo very little seasonal variation inferring that there is very little interchange between the water column and the sediment. Since total nitrogen levels were low we tested the sediments for heterotrophic nitrogen fixation. Data in Table 1 show that low but detectable rates of nitrogen fixation under anaerobic conditons occurred at *in situ* temperatures although the recorded rates are significantly less than those reported for more temperate marine environments (BLAKE and LEFTLEY 1977). The process is limited by carbon availability and significantly higher rates could be achieved by added exogenous carbon sources e.g. glucose, mannitol and pyruvate added to the samples. Sulphate-reducing bacteria belonging to the genus *Desulfovibrio* were the only anaerobic heterotrophic nitrogen-fixing bacteria isolated which would fix nitrogen under marine conditons. Whilst nitrogen fixation represents a potential input of new nitrogen into the sediment, denitrification results in the loss of available nitrogen. Data in Table 2 show that there is a considerable potential for denitrificaton in the sediments which exceeds the input of nitrogen fixation by an order of magnitude. However, *in situ* the process is most probably limited by carbon availability.

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