

Observations of seasonal changes in diatoms at inshore localities near Davis Station, East Antarctica

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Abstract

Seventy-five diatom taxa were identified from net plankton samples collected inshore during winter, spring and summer 1977–8 near Davis Station, East Antarctica. Species richness was found to be higher in winter than in summer; this is the first time this trend has been reported in antarctic coastal regions.

When these taxa were grouped according to the general habitats in which they normally occur, the benthic assemblages dominated the planktonic ones.

Of the plankton, most species were of oceanic origin in winter and late summer and are thought to have been swept inshore by a cyclonic gyre which is known to occur in summer but has not been studied in winter.

Introduction

Broadly speaking the coastline of Antarctica lies between 67°S and 77°S (66°S–70°S on the eastern side and 71°S–77°S on the western side). Over this range of latitude there is no measurable solar radiation for between five and 12 weeks during winter and continuous solar radiation for a similar period during summer. From about 65°S there is continuous sea ice for most of the year amounting to an estimated maximum of 20×10^6 km² in September and a minimum of 4×10^6 km² in March. This compares with the area of the entire antarctic continent of 14×10^6 km².

In the marine environment in this region, nutrients and trace elements are thought to be rarely if ever limiting (Riley & Chester, 1971; Warnke *et al.*, 1973) and low temperatures, although slowing down metabolism (Holm-Hansen *et al.*, 1974), are never inhibiting. The dominant influences on marine algae therefore are probably sea ice and light.

It has often been observed that algae cause discoloration of the undersurfaces of upturned icebergs and sea ice floes, and bands in the lower levels

of sea ice cores. The importance of sea ice as an algal habitat has been confirmed by several studies: of primary production measured by ¹⁴C uptake (Bunt, 1963; McConville & Wetherbee, 1983), biomass as chlorophyll-a determinations (Bunt, 1963; Bunt & Lee, 1970; Burkholder & Mandelli, 1965; Fukuchi & Sasuki, 1981; Meguro, 1962; Perrin *et al.*, in press; Whitaker, 1977), and species composition (Bunt & Wood, 1963; Hoshiai, 1972; Hoshiai & Kato, 1961; Krebs, 1983).

Winter plankton has rarely been looked for (Bunt, 1960; Krebs, 1983; Perrin *et al.*, in press) and only occasionally have diatom populations been reported. In these reports the presence of winter plankton was accounted for in different ways. Bunt (1960) reported planktonic diatoms as virtually absent during winter and suggested that those found under ice in October were carried into the coast from isolated ice-free areas and Krebs (1983) postulated a small resident winter assemblage capable of seeding the water column when conditions became favourable.

This study is of the diatoms found in the water column beneath the ice during winter and spring

1977 and in open water in summer 1977–8, at in-shore localities near Davis Station, East Antarctica (Fig. 1). The more usual habitat of each species observed was assigned to it based upon recent ice, open ocean and epiphyte collections. These habitat groupings were then used to aid in the interpretation of the contribution of each group to the planktonic flora and its seasonal behaviour in this antarctic coastal region.

Study areas

The winter and spring samples (July–November) were collected from a point midway between Plough Island and the Vestfold Hills mainland. The area is sheltered by offshore islands and is enriched by colonies of sea birds on outlying islands and by wallows of southern elephant seals *Mirounga leonina* L. on the mainland during summer (Fig. 1).

The 10 m water column was covered by about 1.8 m of ice until November, and snow cover was minimal, ablation being high. Bottom sediment was silt and mud containing a macroinvertebrate fauna dominated by crustaceans and polychaetes, similar to oxic sediments from nearby areas (Everitt *et al.*, 1980). The water temperature just under the ice, at 5 m and 10 m was -1.8°C throughout this period.

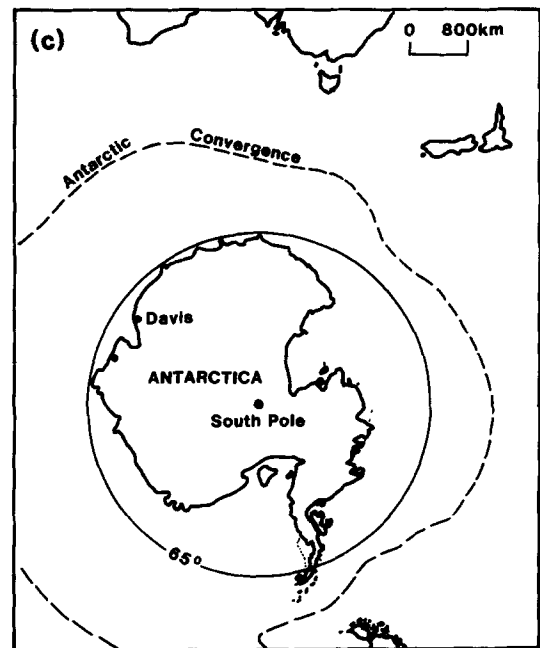
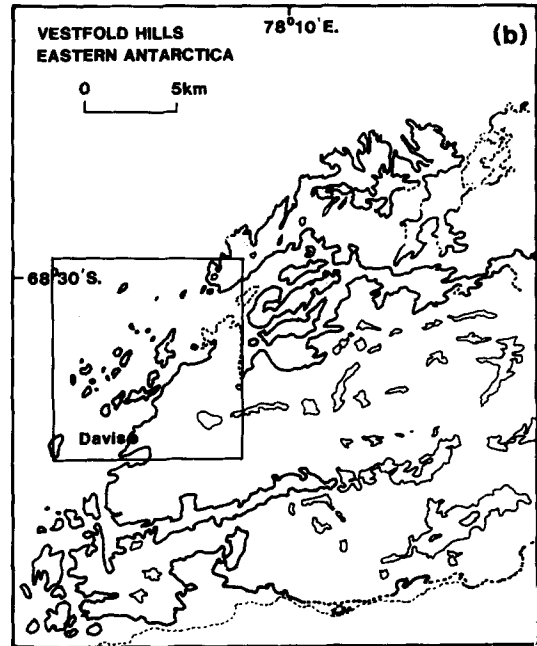
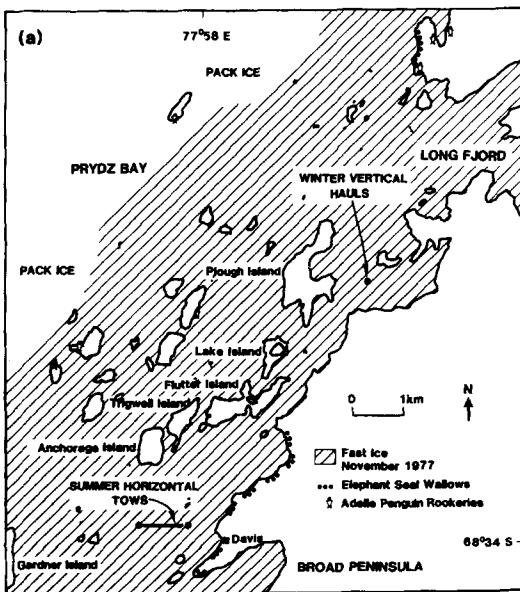


Fig. 1. (a) Study area showing sampling sites, (b) location of the area in the Vestfold Hills and (c) location of the Davis Station in relation to continental Antarctica and 65°S latitude.

December and February collections were taken about 1 km offshore from Davis Station in open water from a boat (Fig. 1). The water depth and bottom sediments were similar to those near Plough Island (Everitt *et al.*, 1980). Unusually high winds were common from November 1977 to February 1978 and were the cause of the earlier than usual ice breakout in late November.

In summer the inshore area is thought to be influenced by a closed cyclonic water circulation emanating from deep water in Prydz Bay and known as the Prydz Bay Gyre (Grigor'yev, 1969; Savatiugin & Komova, 1971; Smith *et al.*, 1984).

Materials and methods

Collection of samples

July, August, September, October and November 1977 samples were collected through a 1 m diameter hole cut through the sea ice by drilling a ring of small holes (11 cm diam.) using a 'sipre' ice auger (Journal of Glaciology 1958) with the aid of a wooden templet. A crowbar with a modified wide, sharp edge was used to cut between these smaller holes releasing the large central core which when removed by rope left a hole with minimal disturbance to the ice-water interface and water column.

The water temperature in winter was measured with a calibrated mercury thermometer from samples collected from three depths using a 8 l Niskin bottle.

Plankton was collected using a size 25 (64 μm pore size) net attached to a 35 cm ring. Five vertical hauls at approximately 1 m s^{-1} were made for each sample. Bottom sediment was obtained using a mechanical suction sampler (King & Everitt, 1980).

December 1977 and February 1978 samples were collected in open water from a boat by horizontally towing the same net through approximately 1 km of water, 1–2 m below the surface, effectively filtering 20 times the volume of water of the winter vertical hauls.

Treatment of samples

The fresh samples were sorted for zooplankton, examined using an inverted light microscope and

fixed in 10% formaldehyde solution for more detailed examination in Australia.

After sedimenting out for several weeks the supernatant was carefully siphoned off. The algal concentrate was then mixed thoroughly and aliquots prepared for scanning electron microscopy using the technique of Marchant & Thomas (1983) before being examined using a JOEL JSM 840 scanning electron microscope. Other aliquots were cleared in 50% nitric acid by the method of Crawford (1971) and strew slides were prepared for light microscopy using Canada balsam as a mountant.

The diatom taxa were placed in groups corresponding to the habitat where they have been most commonly observed (Hart, 1942; Krebs, 1983; Thomas, pers. obs.; Thomas & Jiang, in press). These habitats are: oceanic plankton (OP), from the continental slope and beyond; neritic plankton (NP), from the sublittoral zone and inshore; epiphytic benthos (EB), associated with other microalgae or bottom dwelling macrophytes regardless of habitat; ice benthos (IB), associated with the surface of or contained within the sea ice; and general benthos (B), benthic forms of no particular habitat affinity.

Statistical treatment

Qualitative estimates of abundance of each species were made using the method of Andrews (1972) which ranks each species, by its relative abundance in a light microscope field of view, into four categories ranging from dominant to frequent.

Tests of the null hypothesis of no differences in numbers of species, which gives rise to a chi-square statistic, were applied to the totals of all types, total planktonic, total benthic and oceanic planktonic forms for all sampling occasions.

Results

Seventy-five diatom taxa were identified from the samples. Distinct compositional changes occurred throughout the study period and for each sampling date one or two species appeared to dominate. These were *Rhizosolenia styliformis* var. *longispina* Hustedt (OP) (Fig. 2D) and *Chaetoceros criophilus* Castrane (OP) (Fig. 2A) in July, *Achnanthes vincentii* Manguin (EB) (Fig. 3C, D) in August and

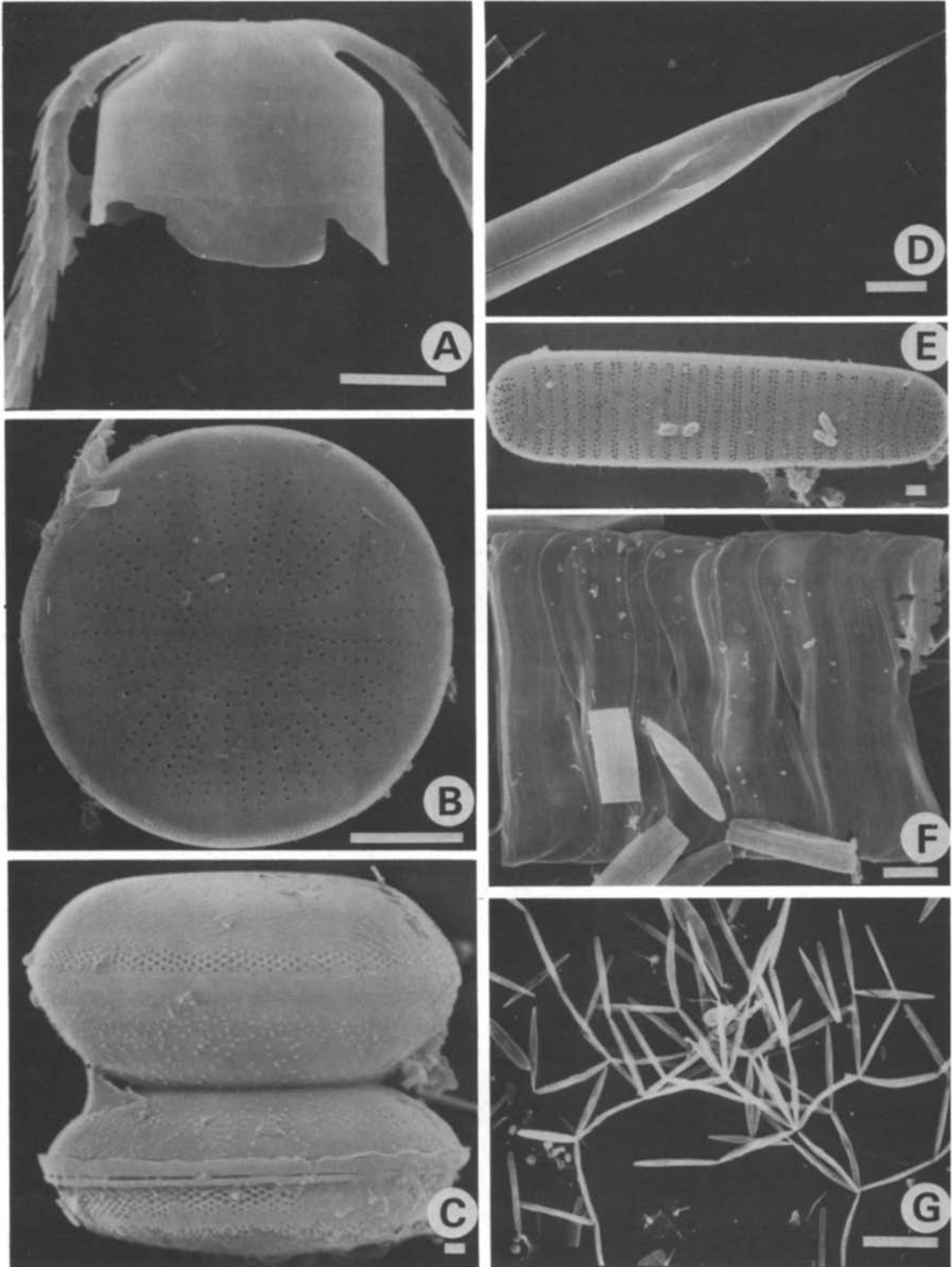


Fig. 2. Representative taxa from oceanic and ice associated forms.

A. *Chaetoceros criophilus*; B. *Actinocyclus actinochilus*; C. *Melosira adeliae*; D. *Rhizosolenia styliformis* var. *longispina*; E. *Nitzschia curta*; F. *Entomoneis kjellmanii*; G. Foliose colony of *Nitzschia frigida*.

Scales: A, B, D, F 10 μm ; C, E 1 μm ; G 100 μm .

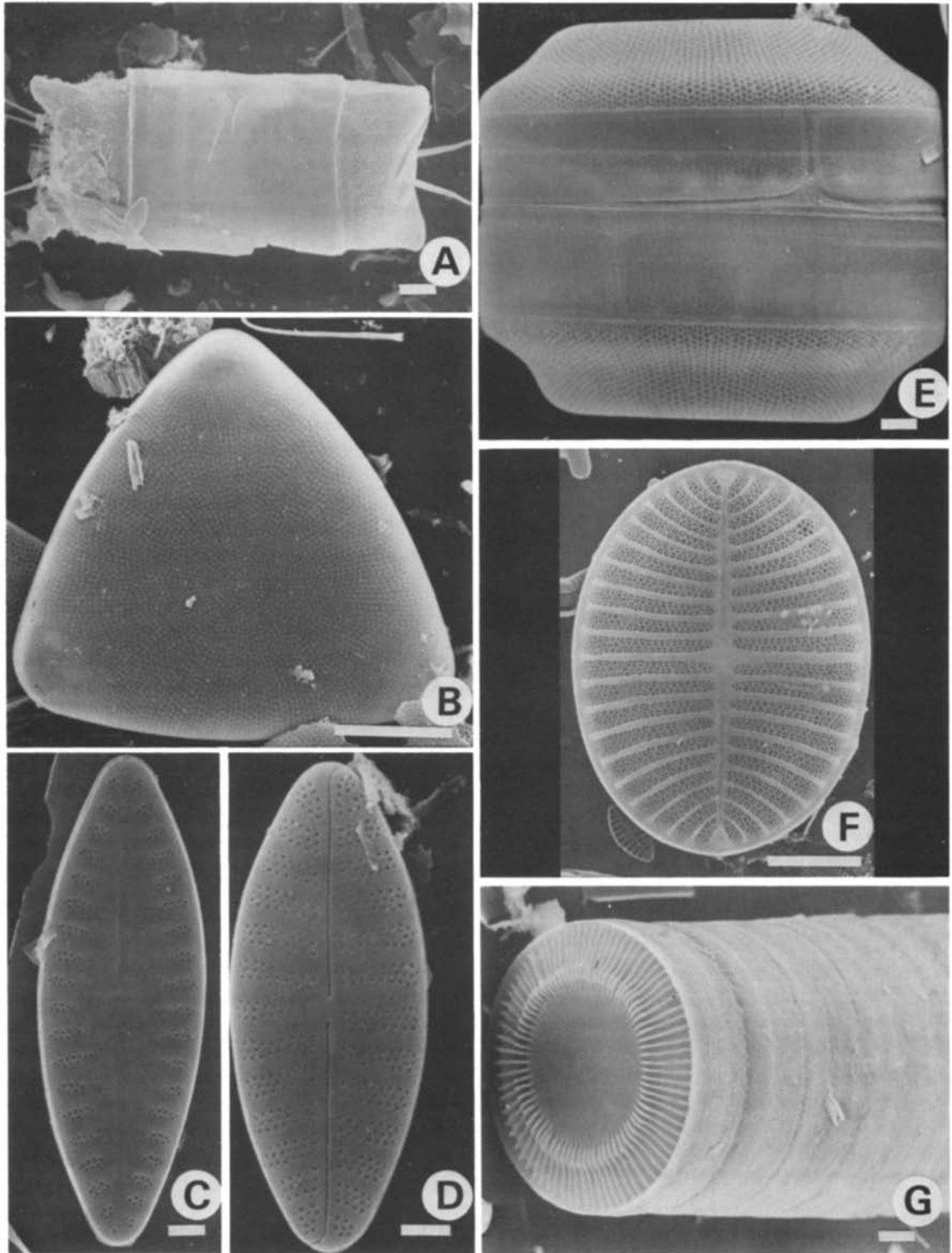


Fig. 3. Representative taxa from neritic and epiphytic forms.

A. *Odontella litigiosa*; B. *Trigonium arcticum*; C. Rapheless valve of *Achnanthes vincentii*; D. Raphe valve of *A. vincentii*; E. *Coscinodiscus bouveti*; F. *Cocconeis fasciolata*; G. *Paralia sol*.

Scales: A, E–G 10 μm ; B 100 μm ; C, D 1 μm .

September, *Melosira adeliae* Manguin (IB) (Fig. 2C) in September, *M. adeliae* and *Paralia sol* (Ehrenberg) Crawford (NP and B) (Fig. 3G) in October, *M. adeliae* in November, *Cocconeis fasciolata* (Ehrenberg) Brown (EB) (Fig. 3F) in December and *Coscinodiscus bouveti* Karsten (NP) (Fig. 3E) in February. Others such as *Odontella litigiosa* (Van Heurck) Hoban (NP) (Fig. 3A) were abundant throughout the whole period. Even though a plankton net with a 64 μm pore size was used, diatoms less than 20 μm (nanoplankton) were common in every sample. This suggests that the net clogged retaining smaller forms, but that they may not have been represented quantitatively. This led to the use of presence/absence rather than a biomass index of the community structure of each sample. If some habitat groups happen to correlate strongly with small diatoms (<64 μm), the results must be viewed bearing in mind this methodological shortcoming. Most cells in each sample were pigmented and assumed to have been alive in the water column at the time of sampling.

A significant decline in total species numbers occurred over the sampling period ($P < 0.02$), but no significance was shown for either total planktonic ($P > 0.05$) or total benthic forms ($P > 0.05$) (Fig. 4). A significant difference however was found for oceanic planktonic forms ($P < 0.01$) (Table 1).

The proportion of total benthic forms to the total number of species was consistently high (Fig. 4): the benthic species represented 59% in July, 74% in August, 86% in September, 78% in October, 84% in November, 83% in December and 61% in February.

Of the benthic groups, the absolute numbers of the epiphytic benthos did not vary much whereas

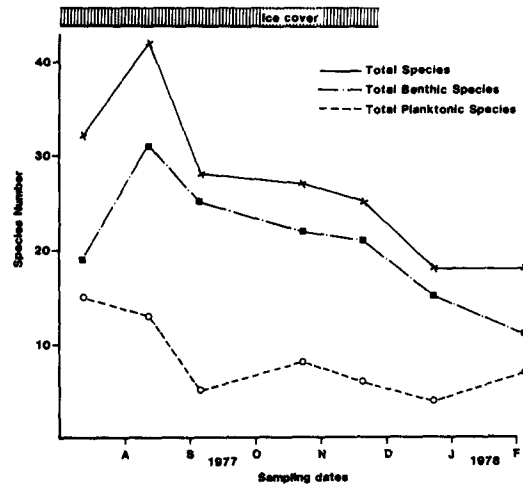


Fig. 4. Changes in species numbers of diatoms found in the water column during winter, spring and summer 1977 and late summer 1978.

the ice benthos and general benthos did, showing consistent, relatively high numbers during the months of ice cover from July to November, and dropping off in December and February when open water prevailed (Table 1).

Discussion

Terms used to describe the habitat preferences of algae, especially in antarctic waters, are quite numerous and sometimes misleading. Hart (1942) described as 'neritic and ice edge forms' some of the algae associated with the pack ice. Bunt (1963) was more specific suggesting 'epontic' for species

Table 1. Number of species belonging to each habitat type for each sampling occasion, July 1977 to February 1978.

| Sampling date | 12.VII.77 | 11.VIII.77 | 4.IX.77 | 21.X.77 | 17.XI.77 | 20.XII.77 | 3.II.78 |
|--------------------|-----------|------------|---------|---------|----------|-----------|---------|
| Oceanic planktonic | 10 | 6 | 0 | 4 | 1 | 1 | 5 |
| Neritic planktonic | 5 | 7 | 5 | 4 | 5 | 3 | 2 |
| Total planktonic | 15 | 13 | 5 | 8 | 6 | 4 | 7 |
| Epiphytic benthic | 7 | 11 | 13 | 8 | 9 | 12 | 5 |
| Ice benthic | 7 | 11 | 8 | 7 | 5 | 1 | 3 |
| General benthic | 5 | 9 | 4 | 7 | 7 | 2 | 3 |
| Total benthic | 19 | 31 | 25 | 22 | 21 | 15 | 11 |
| Total all types | 34 | 44 | 30 | 30 | 27 | 19 | 18 |

adapted to life in the sea ice compared with planktonic for those in the water column. Round (1971) used the term 'cryophilic' to describe diatoms occupying the sea ice while Whitaker (1977) suggested 'sympagic' as a more correctly descriptive term for these forms. Within the ice layer itself even more specific niches have been described (Bunt & Wood, 1963; Meguro, 1962; Whitaker, 1977).

Most of these terms refer to ice associated habitats. Other habitats such as epiphytic benthic and general benthic have been frequently ignored (Thomas & Jiang, in press). In this study diatom taxa were divided into groups that describe the habitat where they have been consistently found, as described above. We assume that these habitats were the most likely sources of seeding cells for those found in the plankton in this study. Since all these groups were found in the inshore plankton some questions arise about their ecological roles.

The benthic diatoms

The combined benthic taxa formed the greater proportion of the total species recorded in the plankton on every sampling occasion (Fig. 4).

The ice flora, which has been described as an 'inverted' benthos by Thomas & Jiang (in press), was an important component of the plankton. Relatively high and consistent numbers of these species occurred from July to November, the months of ice cover, dwindling to only one and three species in December and February respectively (Table 1). One of these, *Melosira adeliae*, dominated the September, October and November plankton samples. Other species commonly found included *Entomoneis kjellmanii* (Cleve) Thomas *sensu* Reimer, *Nitzschia curta* (Van Heurck) Hasle and *N. frigida* Grunow (Fig. 2 E–G).

This seeding of the water column from the ice community may be adventitious. However, circumstantial evidence suggests that at least some taxa use this as a regular mechanism for seeding the water column. Ice associated diatoms have been shown to exhibit higher productivity than planktonic algae and are active earlier in the growing season (Perrin *et al.*, in press). The availability of light, even under a thick ice cover, probably accounts for this, and is substantiated by reports of patchiness of ice algae inversely correlated with snow cover (Bunt & Lee, 1970; Tucker, 1983). This

means that inoculation of actively growing cells into the water column was possible before the true planktonic forms became active. More evidence was given by Hoshiai (1972) of seasonal entrapment of diatoms implying a time lapse release due to gradual melting of the ice.

A further theoretical consideration supporting this ecological role is the Ross Sea ecosystem model of Green (1975) which indicates that the sea ice community probably provides 20% of total annual production in the Antarctic, 60% of which is released from the ice by melting out.

As well as the potential for inoculating the water column with active cells, another role of ice benthos may be in the disintegration of the ice cover itself. Buynitskiy (1968) gave evidence for structural weakening of the ice by algae and Everitt (1980) showed that 'dark bodies' such as algae accelerated melting of ice by absorption of solar radiation.

Water movement caused by currents, tides and possibly the cyclonic gyre would have increased the likelihood of inoculation of benthic diatoms into the water column in this area by flushing them off their 'benthic' surfaces.

Species diversity of epiphytic benthic diatoms was relatively high and consistent throughout the study period although the species composition changed. In winter, suspension of bottom living forms (*Trachyneis aspera* (Ehrenberg) Cleve, *Ampthora bongrainii* M. Peragallo, *Achnanthes brevipes* Agardh, *Cocconeis fasciolata*, *Navicula gelida* var *parvula* Heiden & Kolbe and *Trigonium arcticum* (Brightwell) Cleve (Fig. 4B)) is thought to have arisen from the effects of water movement. However, during this time epiphytes were also found on planktonic algae. *Achnanthes vincentii*, for example, the dominant diatom in the plankton during September and October, was commonly found on some larger diatoms regardless of origin. During summer when the sea ice was absent, wind driven mixing is thought to have been mainly responsible for the presence of normally bottom living epiphytes in the water column. *Cocconeis schuettii* Van Heurck, other *Cocconeis* spp and *Opephora pacifica* (Grunow) Petit appeared and the ubiquitous epiphytic diatom *Cocconeis fasciolata* dominated the December sample.

The planktonic diatoms

True planktonic diatoms were found throughout the study period with no significant change in numbers of species. However, the oceanic component changed dramatically: the greatest number of species occurred in July and declined thereafter, with a small upsurge in February (Table 1). Open ocean forms, such as *Actinocyclus actinochilus* (Ehrenberg) Simonsen, *Chaetoceros criophilus* and *Rhizosolenia styliformis* var. *longispina*, dominated the July sample (Fig. 2A, B & D).

The only way to account for the occurrence of these oceanic taxa inshore is by the intrusion of an oceanic water body. In this area a likely mechanism is the Prydz Bay gyre which has been recorded in summer (Smith *et al.*, 1984) but to date not monitored during winter.

The presence of the oceanic planktonic diatoms *Chaetoceros criophilus*, *Corethron criophilum* Cas-tracane and *Thalassiothrix longissima* var. *antarctica* Cleve & Moller in both winter and summer support this hypothesis. Corroborative evidence is provided by the capture in July and August of adult *Calanoides acutus* Giesbrecht, an oceanic copepod usually found from below 250 m depth only in winter (Hopkins, 1971; Nakemura *et al.*, 1982) and from surface waters only in summer (Mackintosh, 1937). Tucker (1983, in press) also caught immature *C. acutus*, as well as some other oceanic zooplankters, in this region in winter.

Species richness

The number of species changed significantly during the study. Highest numbers occurred in winter with a decline through spring to summer (Fig. 2). This was despite having effectively sampled 20 times more water by horizontal net tow in December and February.

Conversely, chlorophyll-a determinations of the water column in this area ranged from 0.10 mg m⁻³ in September 1982 to 5.89 mg m⁻³ in January 1983 (Marchant *et al.*, in press). Evidence of a mixed water column in summer 1977–8 was given by the presence of sponge spicules in the December sample and moribund *Trigonium arcticum* frustules as well as living bottom-dwelling epiphytic diatoms in both the December and February samples.

Very few interseasonal comparisons of the diatom flora in the water column have been made in antarctic waters and those that have are contradictory. Krebs (1983) found no change in species numbers between winter and summer and Bunt (1960) reported plankton as virtually absent in winter and increasing in diversity through summer, almost the reverse of our observations.

Since information is sparse and somewhat inconsistent it is difficult to account for these trends. However, Krebs (1983) suggested a strategy to explain his observations which could be applied to our findings and which makes sense ecologically for this environment. The strategy requires the existence over winter of a small planktonic assemblage of diatoms capable of seeding the water column when conditions become favourable.

As well, the sea ice is an obvious habitat for those taxa capable of surviving in the osmotically variable brine pockets that form (Horner 1981). Here they can maximise the opportunity for trapping any available light without the problems associated with maintaining their position in the water column. It is to be expected that neritic and particularly benthic forms will be found to dominate the under ice flora, even well out to sea; these taxa have evolved in the nearshore environment, which is normally more variable than that experienced by the oceanic plankton, and may thus be better adapted to survive in the brine channels of the ice. Therefore, unlike the situation reported for the relatively oligotrophic waters of the Arctic by Horner (1981), the relatively nutrient rich neritic waters near Davis Station contain algae drawn from various seeding habitats, both benthic and planktonic, with the colonisers varying as the environment changes throughout the year.

The combination of these overwintering planktonic and benthic adapted diatoms in the sea ice illustrates how diatoms can survive the winter in sufficient concentrations to dominate the water column for most of the ice-free period. Furthermore, in the absence of sea ice flora, the large expanse of the deep ocean would be left almost depauperate of diatoms after the winter until recolonised from the north or from near antarctic stocks. This would substantially reduce the observed productivity of this region.

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