A flagellate- and ciliate-dominated microbial community in the land-fast ice

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In land-fast ice, such as found in McMurdo Sound, the development of diatom-dominated sea-ice microbial communities (SIMCO) in the lower congelation ice and in the underlying platelet ice layer are well-described (Palmisano and Sullivan 1983). High salinities (up to 150‰) in the upper ice brine channels have been hypothesized to limit the distribution of SIMCO to the lower 20–25 centimeters of the approximately 175 centimeters of annual ice in McMurdo Sound (Kottmeier and Sullivan 1988). We report a unique flagellate and ciliate-dominated SIMCO in the brine channels and pockets of the upper congelation ice during the late austral spring and early summer in eastern McMurdo Sound.

We sampled the upper ice at approximately weekly intervals both at the ice edge and at a station off Hut Point between 11 December 1989 and 12 January 1990. Two transects of the sound were also made to examine spatial variability in the ice. Samples were collected by drilling 4-inch diameter holes approximately 50 to 75 centimeters into the annual ice. Loose ice was removed and then the brine was allowed to accumulate in the hole. The accumulated liquid was collected by gently pumping it by hand through a 330-micrometer nitex mesh into a bottle. The mesh excluded pieces of ice and thus minimized changes in salinity due to ice melt in the sample. Samples were analyzed for salinity and for chlorophyll *a*. Microalgae and protozoa in the samples were enumerated and classified as autotrophs or heterotrophs using a combination of transmitted light and epifluorescence microscopy (table). Scanning electron microscopy was used to examine further the dominant members of the assemblage (figure).

We measured salinities above and below that of ambient seawater in the brine (table). Hypersaline conditions were most pronounced early, but as the ice began to melt, salinities below 34‰ were observed. Chlorophyll values decreased in the brine as the ice began to melt and tended to be low in samples collected near the ice edge (table).

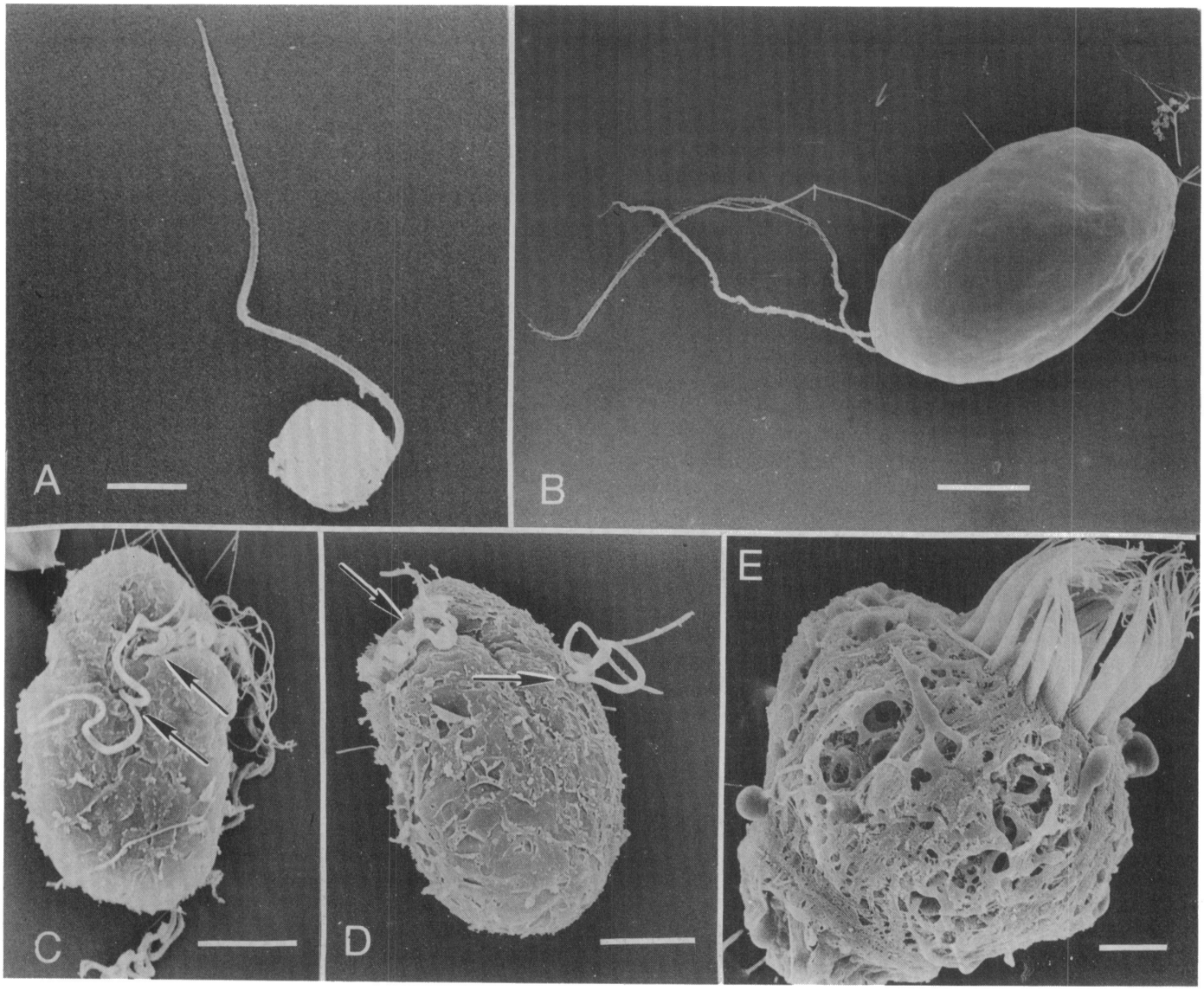
Diatoms were rare (generally less than 2×10^3 per liter) in our samples although these are the dominant forms in lower ice SIMCO (Palmisano and Sullivan 1983). Autotrophic nanoflagellates (figure, block A), autotrophic athecate dinoflagellates (figure, blocks C and D) and ciliates (figure, block E) dominated the upper ice assemblage (table). In mid-December, we observed dinoflagellate densities in the brine of over 10^6 per liter and ciliate densities of over 10^4 per liter. Most of the dinoflagellates were autotrophic and the dominant ciliate (figure, block E) may have been photosynthetic (Stoecker, Michaels, and Davis 1987). In late December, the assemblage changed. Many of the dominant organisms developed sexual stages (such as the planozygotes shown in figure, block C and D) and/or formed cysts. The flora and fauna became more diverse and heterotrophs increased in relative abundance.

Although the microbial assemblages we describe in this article from the brine channels in the upper congelation ice at McMurdo are distinct from the assemblages previously reported from land-fast ice (Garrison, Sullivan, and Ackley 1986), they have features in common with assemblages reported from antarctic pack ice (Garrison and Buck 1989). The community we describe from the upper land-fast ice and the pack ice community are both found near the surface of the ice in brine

Characteristics of brine community in upper 1 meter of congelation ice, McMurdo Sound, late spring 1989–1990

Station	Dates	Sample size (N)	Salinity (‰)	Chlorophyll *a* (in micrograms per liter)	Cells per liter		
					Ciliates	Dinoflagellates	Other (c) Flagellates
Station "H" (approximately 7.4 kilometers west of Hut Point)	11 Dec–1 Jan	6	14–66	1.00–2.91	$<1.0 \times 10^2$ to 1.9×10^4	4.6×10^4 to 3.7×10^6	1.3×10^5 to 4.0×10^6
Station "IE" (ice edge)	12 Dec–12 Jan	5	20–24[a]	0.28–0.60	7.6×10^2 to 1.1×10^{3}[b]	1.3×10^4 to 3.4×10^{5}[b]	1.3×10^6 to 9.5×10^{6}[b]
Transects of southeast	23 Dec	3	32–53	1.64–3.89	2.6×10^2 to 4.4×10^3	1.3×10^6 to 2.4×10^6	4.2×10^6 to 9.5×10^6
McMurdo Sound	9 and 10 Jan	6	19–48	0.23–0.54	+[d]	6.5×10^4 to 1.6×10^6	4.4×10^5 to 2.8×10^6

[a] 27 December and January only.
[b] Quantitative data only available for three samples.
[c] Mostly ≤5-micrometer cells.
[d] + denotes present; no quantitative data available.



Scanning electron micrographs of critically point-dried organisms from the upper sea ice brine. A. Autotrophic flagellate with a single flagellum visible, possibly *Mantoniella* sp. Scale bar = 2 micrometers. B. *Cryothecomonas* sp., a biflagellated, phagotrophic heterotrophic flagellate. Scale bar = 5 micrometers. C. and D. Planozygote of autotrophic athecate dinoflagellate. Arrows denote the two paired flagella characteristic of this stage of the sexual life cycle. Scale bar = 5 micrometers. E. A ciliated protozoan, *Strombidium* sp. which was common in the ice brine. Scale bar = 5 micrometers.

channels and pockets, and both are dominated by flagellates and ciliates. Furthermore, many of the genera and perhaps species that we observed in the upper ice at McMurdo have been reported from the pack ice (Corliss and Synder 1986; Garrison and Buck 1989; Thomsen et al. in preparation). These taxa are thought to be rare in the deeper congelation ice and platelet ice SIMCO (Kottmeier and Sullivan 1988).

We believe that the upper ice brine community in the land-fast ice at McMurdo will be an excellent model system in which to investigate the adaptations of sea-ice microorganisms to transitions between planktonic and ice-bound existence. Microorganisms in the upper ice brine in both pack ice and land-fast ice experience extremes of salinity, temperature, and light. The land-fast upper ice community provides an excellent opportunity to investigate the physiological and life history responses of sea-ice microorganisms to the extreme and rapidly changing environment in which they thrive.

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Seasonal changes in cell size and abundance of bacterioplankton during the *Phaeocystis* sp. bloom in McMurdo Sound

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Cell size must be known to determine the biomass of natural bacterioplankton (Psenner 1990). In addition, cell size contains information about both bacterial growth rates and protozoan grazing pressure (Andersson, Larsson, and Hagstrom 1986). Bacterial cell size and growth rate are positively correlated (Ammerman et al. 1984). The average cell size of natural bacterioplankton, however, is generally smaller than in experimental manipulations where grazing pressure is reduced. A number of protozoans selectively graze large bacteria (Gonzalez, Sherr, and Sherr 1990). Thus, in temperate waters, protozoan grazing apparently maintains even rapidly growing bacterioplankton below their maximum obtainable size (Ammerman et al. 1984). Here, we examine season changes in cell size to obtain qualitative information about how grazing influences the bacterioplankton community in McMurdo Sound.

Seawater samples were collected at six depths between 0 and 100 meters from station IE at the edge of the sea ice of eastern McMurdo Sound or through an established hole in the annual sea-ice at station H about 30–60 kilometers south of station IE. Direct counts of bacterioplankton abundance were made for subsamples filtered directly onto 0.2-micrometer filters (TBAC) and in subsamples passed through a 2-micrometer filter prior to filtration onto the 0.2-micrometer filter (BAC). The difference between TBAC and BAC was used to estimate the number of bacteria in the >2-micrometer fraction (>2BAC). The >2BAC fraction includes the largest free-living bacterioplankton as well as bacteria attached to particles. Bacterioplankton size was estimated from linear dimensions of cells in photomicrographs of TBAC samples pooled from 15 and 50 meters.

Areal concentrations of chlorophyll integrated over the upper 100 meters remained low (<10 milligrams per square meter) until late December when a bloom of large (>200 micrometers) *Phaeocystis* sp. colonies caused a 10–30-fold increase in chlorophyll (figure, block A).

Bacterioplankton abundance and cell volume (determined from photomicrographs) both increased by factors of about 2–3 between late November and late December (figure, blocks B and C). Transmission electron microscopy confirmed the increase in cell volume in bacterioplankton at or above 50 meters at station IE (table 1). The increase in average cell size in late December was due largely to an increase in the number of very large rods and cocci.

Maximum abundance of >2BAC coincided with the onset of the *Phaeocystis* sp. bloom and the period of maximum cell size (figure, block D). In separate experiments in early January, about 33 percent of the bacterioplankton did not pass a 202-micrometer mesh (data not shown). Thus, increased abundance of >2BAC was due, at least in part, to changes in the number of bacteria associated with large particles, probably *Phaeocystis* sp. colonies rather than increased bacterioplankton cell size. Microscopy confirmed that *Phaeocystis* sp. colonies were often colonized by dense accumulations of bacteria.

By mid-January, the *Phaeocystis* sp. bloom was in decline and chlorophyll concentrations had decreased relative to the early January maximum. Bacterioplankton abundance remained constant but cell size decreased to pre-bloom levels at both stations.

Seasonal changes in bacterioplankton size in McMurdo Sound greatly affect the estimation of bacterioplankton standing stock. For example, at the ice edge at 15 and 50 meters, bacterioplankton biovolume (abundance X size), and presumably biomass, increased by a factor of 7 between 27 November and 27 December whereas the change in bacterioplankton abundance alone was only about 2.

During the *Phaeocystis* sp. bloom, bacterioplankton growth rates reportedly increase by over an order of magnitude relative to pre-bloom rates, presumably because of increased substrate availability (Kottmeier et al. 1987; Guillard and Hellebust 1971). Abundances and estimated clearance rates of heterotrophic flagellates, the major grazers of bacterioplankton in temperate