Oceanographic studies of epipelagic ammonium dynamics in Scotia Sea

D. C. Biggs and R. R. Bidigare

Department of Oceanography
Texas A&M University
College Station, Texas 77843

R. Wilsterman and J. J. McCarthy

Department of Biology
Harvard University
Cambridge, Massachusetts 02138

Biogenic regeneration of ammonium by zooplankton excretion and its uptake as a preferred nutrient by marine phytoplankton is thought to play an important role in structuring marine food webs (Walsh and Dugdale, 1971; Eppley, Venrick, and Mullen, 1973; McCarthy, Taylor, and Taft, 1977; Eppley et al., 1979). To investigate the turnover rate of NH_4^+ in surface waters of the Southern Ocean and its role in promoting the very high biological productivity evident there, we surveyed the regional distribution of NH_4^+ while aboard ARA *Islas Orcadas* on two biological oceanographic cruises to the Scotia Sea. Austral late winter/early spring cruise 17 (2 September through 14 October 1978) and austral summer cruise 19 (22 February through 9 April 1979) followed cruise tracks with similar station coverage (figure 1 in El-Sayed et al., 1979). Profiling efforts were coordinated with shipboard experiments to measure planktonic uptake and excretion of NH_4^+.

We constructed vertical profiles of NH_4^+ from Niskin casts from the surface to 400 meters in depth at 13 stations on cruise 17 and at 27 stations on cruise 19. To provide vertical detail in near-surface waters, bottles were tripped at depths corresponding to 100, 50, 25, 12, 6, 1, 0.1, and 0.01 percent of surface irradiance. At four stations on cruise 19, where hydrocasts were run every 4 to 6 hours, we found that measurable diel reductions in NH_4^+ concentration occurred within the photic zone during daylight hours.

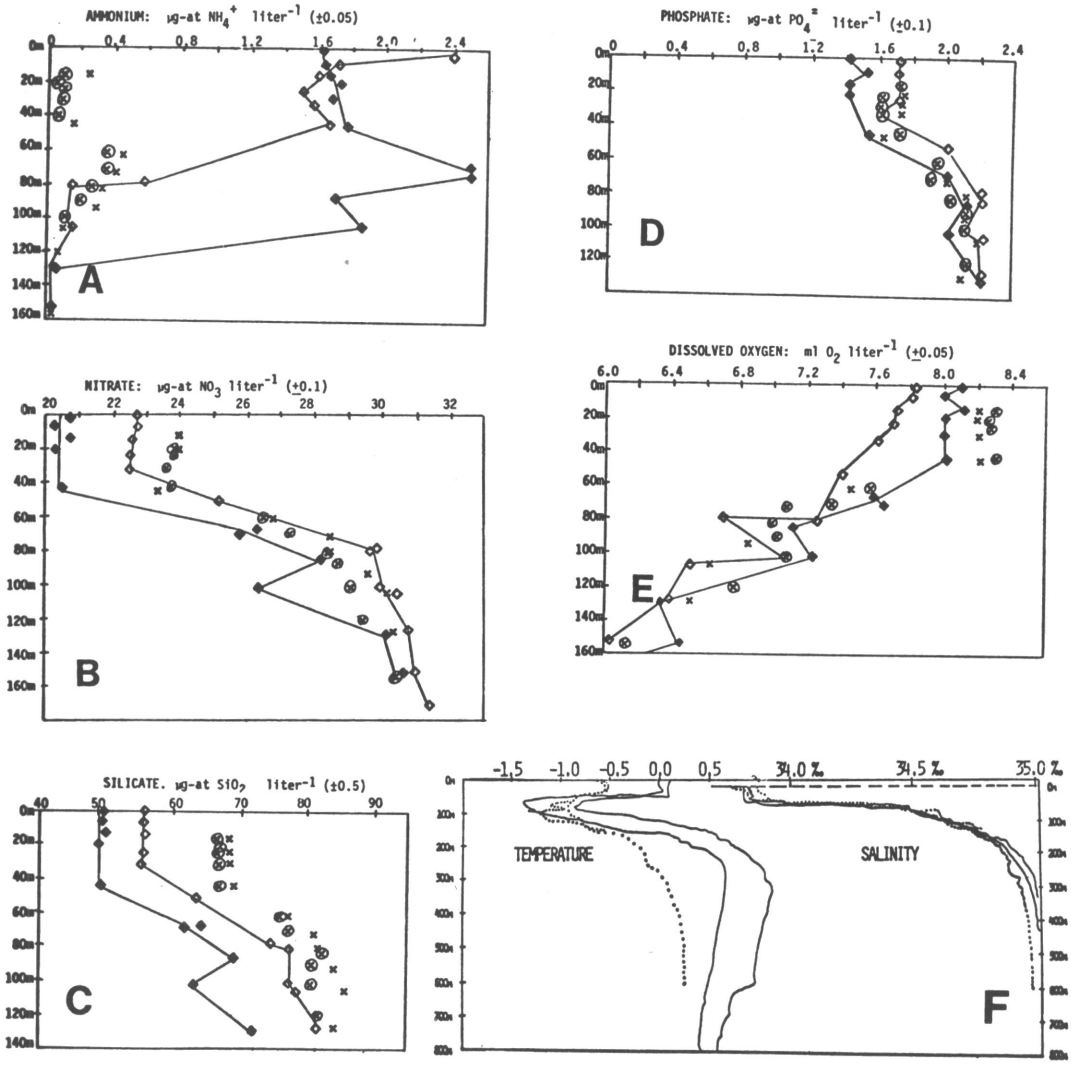
The highest NH_4^+ concentrations were consistently encountered at depths of less than 150 meters. In austral spring, oceanic surface waters south of the polar front ranged in concentration from about 0.1 to 0.6 microgram-atom of NH_4^+ per liter. Ammonium concentrations were uniformly higher at stations sampled five months later. In fact, NH_4^+ values in excess of 1.4 microgram-atoms per liter and as high as 2.4 microgram-atoms per liter were measured in the surface outflow from the Weddell Sea (stations 17 to 20) in austral summer.

The Scotia Sea NH_4^+ profiles contrast rather sharply with those measured during summer 1977–78 in the Ross Sea. In the Ross Sea, NH_4^+ concentrations in the upper 100 meters were rarely greater than 0.2 microgram-atoms per liter, although concentrations reached 0.8–1 microgram-atom per liter at depths between 100 and 300 meters (El-Sayed et al., 1978).

While ammonium profiles in regions of the Scotia Sea overlain by drifting pack ice were not greatly different from those in open water, atypical NH_4^+ profiles were recorded in the vicinity of a 20-square-kilometer tabular iceberg encountered at 59°35′S/28°10′W during cruise 19. Rather than being enriched in the vicinity of the iceberg, however, as may have been predicted from studies of Parker et al. (1978) or Jacobs, Gordon, and Amos (1979), ammonium was markedly depleted from surface waters. Concentrations were reduced sixfold to tenfold in the upper 80 meters in hydrocasts taken 0.5 kilometer and 10 kilometers from the iceberg, relative to concentrations measured at stations about 50 kilometers on either side of the iceberg (figure A). By comparison, vertical profiles of nitrate, silicate, phosphate, dissolved oxygen, and salinity differed by less than 10 percent from the respective distributions at one or both of the adjacent stations (figures B through F).

The lack of a low-salinity surface zone, combined with the cold surface temperature near the iceberg, suggests that in situ melting was minimal at this location. Biological activity (enhanced NH_4^+ uptake or reduced NH_4^+ excretion) may have created the unusually low surface ammonium concentrations in the vicinity of the iceberg. Alternatively, wind-induced upwelling generated by the berg itself (see Buckley et al., 1979) may have occurred, which would effectively dilute the surface water with deep water poor in NH_4^+. Some upwelling of deep water is supported by the silicate data; silicate showed a greater increase between surface and deep water than did salinity or the other measured nutrients, and silicate concentrations were measurably and consistently higher at all depths between the surface and 150 meters near the iceberg than at adjacent stations (figure C).

To estimate the nitrogenous needs of the phytoplankton and to investigate whether biogenic NH_4^+ uptake may cause the diel reductions in NH_4^+ concentrations observed within the euphotic zone or the marked depletion in NH_4^+ in the vicinity of the iceberg, comparative measurements of $^{15}NH_4^+$ and $^{15}NO_3^-$ uptake were made at most of the biological stations occupied on cruise 19. Four-liter water samples taken from Niskin casts to depths of 100, 50, 6, and 0.1 percent of surface irradiance were spiked with ^{15}N and incubated for 4 hours



Distribution of (A) ammonium, (B) nitrate, (C) silicate, (D) phosphate, (E) dissolved oxygen, and (F) temperature-salinity in Scotia Sea surface waters in vicinity of a 20 square kilometer tabular iceberg. Key: X points=water samples from STD cast taken 0.5 kilometers from iceberg; O points=samples from cast taken 10 kilometers away; solid lines=similar casts made at adjacent stations 50 kilometers on either side of iceberg.

and 24 hours in a waterbath on deck. Ambient light levels were simulated by neutral density screening. Details of a similar ^{15}N incubation procedure and analysis have been given in McCarthy, Taylor, and Taft (1977).

Experiments to characterize the uptake kinetics of NH_4^+ also were performed. At five stations, samples incubated at surface light intensity were enriched with a series of four greater-than-ambient concentrations of ammonium to study the relationship between NH_4^+ uptake and concentration. In two other experiments, the time course of $^{15}NH_4^+$ uptake over a 24-hour period was investigated by terminating experiments after 4, 8, 12, and 24 hours.

Measurements of NH_4^+ excretion by zooplankton, begun in 1977–78 in the Ross Sea, were continued for comparison in the Scotia Sea. As was the case in the Ross Sea, weight-specific excretion rates were uniformly higher at stations north of the polar front than at stations south of this marked gradient in surface temperature, both for unsorted zooplankton and for specific groups of animals. The polar front represents a discontinuity of 6 to 11° C in surface temperature in the Scotia Sea, and Q_{10} values (2.6 ± 0.7) calculated for each of the major taxonomic groups of zooplankton reflected this.

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Chemical and microbial characterization of particulate organic matter in Scotia Sea and northern Weddell Sea

M. C. Kennicutt II, R. A. Warner, and S. Z. El-Sayed

Department of Oceanography
Texas A&M University
College Station, Texas 77843

In a joint cooperative program between U.S. and Argentine scientists and with support from the Argentine Navy, Texas A&M personnel participated in both the austral late winter/early spring cruise 17 and the austral summer cruise 19 of the ARA *Islas Orcadas* to the Scotia Sea and the northern Weddell Sea. Presented here are the preliminary findings on surface lipids, heterotrophic ^{14}C uptake, and chemical fractionation of autotrophic ^{14}C uptake taken from the two multidisciplinary cruises.

The chloroform-extractable lipid fraction of near-surface particulate matter in the Scotia Sea was studied with large volume samples (70–90 liters) collected at stations 3, 5, 6, 18, 24, 28, and 30 (El-Sayed et al., 1979). Gravimetric analysis of lipids (Jeffrey, 1979) showed that lipid material ranged from 10 to 35 percent of the particulate organic carbon. Lipid concentrations varied from 3.5 to 30.9 micrograms per liter and are comparatively lower than previous reports of particulate lipids of 90 to 200 micrograms per liter in the Scotia Sea (Jeffrey and Bottino, 1966; Jeffrey and Bottino, 1967). This discrepancy may be related to differences in the time of year and the sample sites. The concentration of lipids collected in the ice pack appeared to be lower than the concentration in open water. Lipid content did not correlate with the content of ATP, total organic carbon, chlorophyll, or nutrients, but correlation was demonstrated between particulate organic carbon concentration and lipid concentration (correlation coefficient = 0.7).

The lipid samples were further characterized by gas chromatography and gas chromatography/mass spectrometry, and a series of n-alkanes from C_{16} to C_{32} were detected. Total alkane concentration varied from 18 to 79 nanograms per liter (ng/l). Alkane concentration in surface particulates of the Gulf of Mexico, reported by Jeffrey in 1979 (20 to 90 ng/l in fall; 90 to 250 ng/l in winter) and by Calder in 1976 (55 ng/l in fall; 49 ng/l in winter) are very similar to those for the Scotia Sea. A series of olefins and the branched chained hydrocarbons (pristane and phytane) were observed in the lipid samples, along with free fatty acids and fatty acid esters. Numerous unidentifiable peaks were present in the chromatograms of the lipid samples. Further studies are in process to identify more compounds in the lipid samples, to define seasonal variations, and to determine any differences between lipids in temperate climates and those in polar climates.

On ARA *Islas Orcadas* cruise 19, six stations were occupied in which triplicate four-liter surface samples were inoculated with 200 μCi of $NaH^{14}CO_3$; after 12 hours of incubation, these were fractionated into proteins, polysaccharides, and lipids (Bligh and Dyer, 1959; Morris Glover, and Yentsch, 1974). Samples laced with $HgCl_2$ were used as controls. From each sample, primary productivity and chlorophyll measurements were made. Incorporation predominately occurred in the protein fractions—in polysaccharides from 10 to 30 percent and in lipids less than 1 percent. All these fractions, as well as primary productivity, were highest off of Zavadoski Island (station 21) and lowest at the polar front (station 32).

Glucose and glycolic acid labeled with ^{14}C were inoculated into triplicate 250-milliliter subsamples while duplicate subsamples laced with $HgCl_2$ were run as controls (Smith, 1967, modified). Sterile butterfly Niskin bags were used to sample from 5 meters and all materials were autoclaved and prechilled. During cruise 17, the glycolic acid was preferred over the glucose by an order of magnitude; the reverse occurred, but to a lesser degree, during cruise 19. Overall uptake values for cruise 17 were lower than for cruise 19 (figures 1 and 2) and these values will be compared to microbial biomass to determine if population changes account for the differences in uptake. Direct microbial counts using scanning