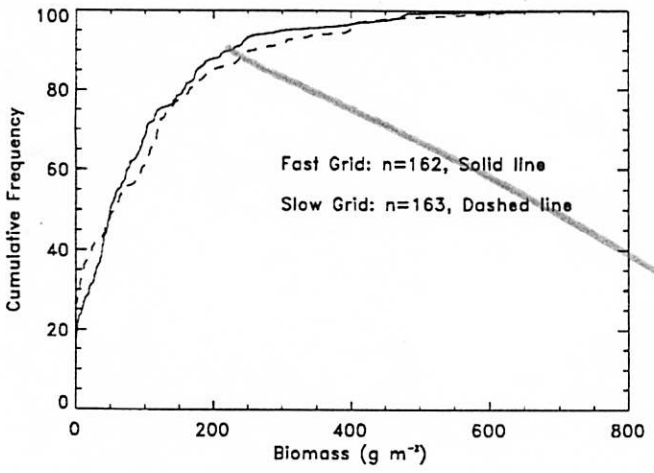

Figure 3. Cumulative frequency distribution of the mean krill biomass (g m^{-2}) of 1-km subsamples for the fast (solid line) and slow (dashed line) surveys.

References

Cram, D.L., J.J. Agenbag, I. Hampton, and A.A. Robertson. 1979. SAS *Protea* Cruise, 1978: The general results of the acoustics and remote sensing study, with recommendations for estimating the abundance of krill (*Euphausia superba* Dana). *South African Journal of Antarctic Research*, 9(1), 3–14.

Kalinowski, J., and Z. Witek. 1985. Scheme for classifying aggregations of antarctic krill (*BIOMASS Handbook* No. 27). Scientific Committee on Antarctic Research/Scientific Committee on Oceanic Research.

Lascara, C.M., E.E. Hofmann, L.B. Quetin, and R.M. Ross. 1993. Palmer LTER: Overview of krill acoustic studies and results from the Antarctic Peninsula grid. *Antarctic Journal of the U.S.*, 28(5).

Quetin, L.B., R.M. Ross, and K. Baker. 1993. PALMER long-term ecological research (LTER): An overview of the 1992–1993 season. *Antarctic Journal of the U.S.*, 28(5).

Ross, R.M., and L.B. Quetin. 1992. PALMER long-term ecological research (LTER): An overview of the 1991–1992 season. *Antarctic Journal of the U.S.*, 27(5), 235–236.

Waters, K.J., and R.C. Smith. 1992. Palmer LTER: A sampling grid for the Palmer LTER program. *Antarctic Journal of the U.S.*, 27(5), 236–239.

Palmer LTER: Grazing by the antarctic krill *Euphausia superba* on *Nitschia* sp. and *Phaeocystis* sp. monocultures

KAREN L. HABERMAN, ROBIN M. ROSS, *and* LANGDON B. QUETIN, *Marine Science Institute, University of California, Santa Barbara, California 93106*

Previous studies suggest that growth and reproduction of antarctic krill are generally food limited in the southern oceans (Ross and Quetin 1986). Although antarctic krill are primarily herbivores, it is not known whether they ingest and assimilate different types of phytoplankton with similar rates and efficiencies. Such knowledge is important if we want to understand how the patterns of phytoplankton abundance and species composition affect the krill's food availability. In particular, can food availability be accurately determined from measurements of total chlorophyll, or do we need to use more detailed measurements of species composition? The prymnesiophyte *Phaeocystis* spp. is a relevant example. Although it periodically occurs in thick blooms and can dominate the southern oceans phytoplankton assemblage at certain places and times (Prézelin et al. 1992), the question of its edibility and nutritional value for various grazers has been the subject of several investigations (Verity and Smayda 1989; Estep et al. 1990; Hansen, Tande, and Berggreen 1990; many others). Results vary widely between these studies, and none has been published on euphausiids. Here we report the results of preliminary experiments comparing the ingestion rates of krill on diatoms to those on *Phaeocystis* sp. in laboratory feeding experiments.

Between January and March 1993, ingestion rates on *Nitschia* sp. and *Phaeocystis* sp. by subadult and immature krill between 25 and 35 millimeters (mm) total length were quantified in the laboratory. Krill were collected in the Palmer nearshore area using a 500-micrometer (μm) mesh ring net deployed from a Zodiac. Experiments were conducted in large tubs containing 50 liters of a mixture of unialgal phytoplankton culture and filtered sea water. Phytoplankton were kept suspended with a plunger-type stirrer (Frost 1972). They were also mixed by hand prior to taking water samples for phytoplankton growth rates. Controls were monitored prior to a 6-hour (h) experimental period during which krill fed. Immediately prior to the experimental feeding period, krill were acclimated to the experimental food type and level by feeding for 6 h in experimental size tubs. Five 100-milliliter (mL) water samples were collected during each sampling period. Sampling intervals varied between experiments (see figures). Samples were filtered onto GF/C filters, the contents extracted in 90 percent acetone and measured on a Turner Design Model 10-005 fluorometer (Smith, Baker, and Dunstan 1981).

Experiments were conducted in parallel on *Phaeocystis* sp. and *Nitschia* sp. Initial chlorophyll-*a* concentrations were approximately equal, and krill were from the same net tow and holding aquarium. This approach allowed direct comparisons to be made between ingestion rates on different phytoplankton types while controlling for variability in experimental conditions and krill nutritional history.

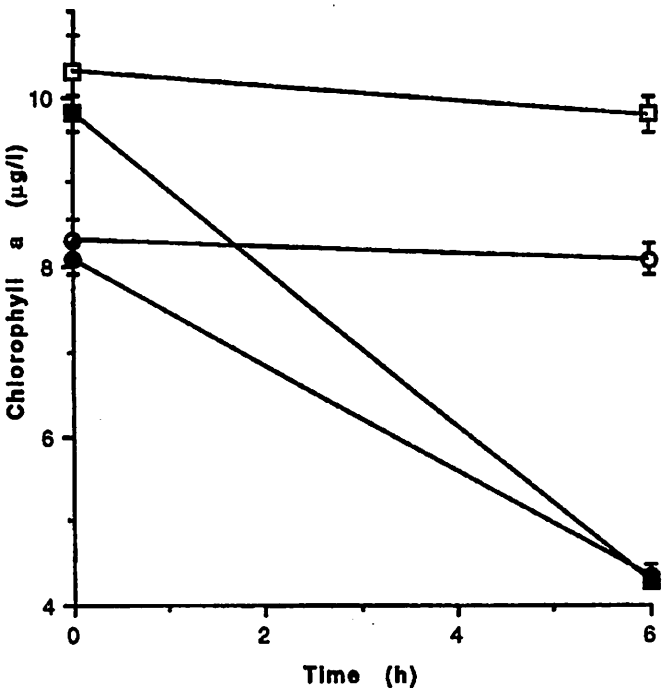

Figure 1. Grazing by krill on *Nitschia* sp. and *Phaeocystis* sp., 5 January 1993 experiment. Graph depicts the change in chlorophyll-*a* concentration through time in each of the control tubs (*Nitschia*: open squares; *Phaeocystis*: open circles) and experimental tubs with n=35 krill (*Nitschia*: filled squares; *Phaeocystis*: filled circles).

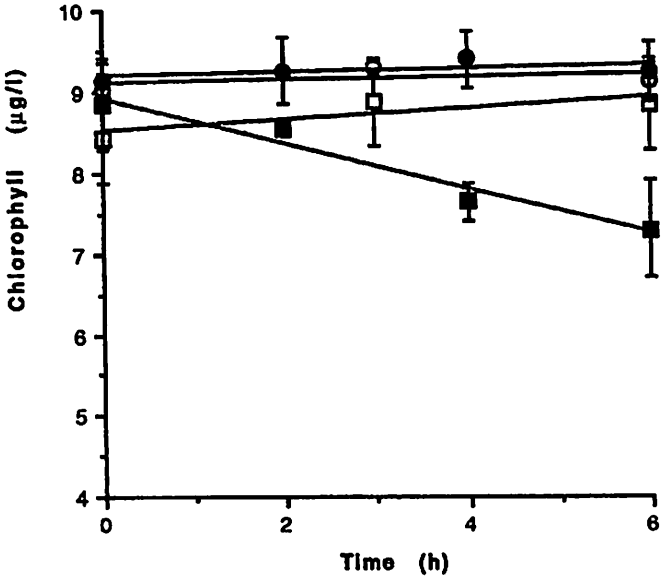

Figure 2. Grazing by krill on *Nitschia* sp. and *Phaeocystis* sp., 1 March 1993 experiment. Graph depicts the change in chlorophyll-a concentration through time in each of the control tubs and experimental tubs (see figure 1 caption for symbol description).

In the first of the three paired experiments (5 January), grazing rates were similar for both *Nitschia* sp. and *Phaeocystis* sp.: 1.20 and 0.84 micrograms (µg) of chlorophyll-*a*/krill-h, respectively (figure 1, calculations modified from Marin, Huntley, and Frost 1986). In contrast, during the second and third paired experiments (22 February and 1 March), there were significant differences between the grazing rates on *Nitschia* sp. and *Phaeocystis* sp. The diatom, *Nitschia* sp., was ingested during the two experiments at the rates of 0.88 and 0.49 µg chlorophyll-*a*/krill-h, respectively, but ingestion rate on *Phaeocystis* sp. was not detectable during either experiment (see figure 2 for 1 March data). One major difference among the experiments was the form of *Phaeocystis* sp. Although *Phaeocystis* sp. from the same monoculture was used in all experiments, during the 5 January experiment, *Phaeocystis* sp. appeared almost exclusively in its flagellated, single-celled form. The cells were actively moving, and there was only an occasional colony. In contrast, during the 22 February and 1 March experiments, there were many fewer single cells, no motility was noted, and most of the *Phaeocystis* sp. occurred in its colonial form, with most colonies 100–200 µm in diameter. The cultures were also more "mucousy" in appearance. Their brownish-green gut coloration indicated to researchers that krill in the *Phaeocystis* sp. treatments for 22 February and 1 March were ingesting some phytoplankton. Many of these krill had boluses of food in their feeding baskets, and similar boluses were seen in the water, perhaps indicative of active rejection of *Phaeocystis* sp. colonies. The fact that *Nitschia* sp. was eaten in all cases during these paired experiments rules out the possibility that the krill simply were not feeding.

The experiments described here are preliminary in nature, but they suggest that the physiological state of *Phaeocystis* sp. affects its usefulness to antarctic krill. The importance of *Phaeocystis* sp. in the antarctic phytoplankton community, shown by other Palmer LTER researchers (Prézelin et al. 1992) emphasizes the need for further investigations on *Phaeocystis* sp. as a possible food source for antarctic krill.

This work was supported by National Science Foundation grant OPP 90-11927. We wish to acknowledge the help of those who built and manned the Zodiac trawling rig: Tim Newberger, Dave Vella, Mark Talkovic, Robert Duran, Vance Vredenberg, Sharon Stammerjohn, and Mike Hearne. (This is Palmer LTER publication number 18.)

References

Estep, K.W., J.C. Nejstgaard, H.R. Skjoldal, and F. Rey. 1990. Predation by copepods upon natural populations of *Phaeocystis pouchetii* as a function of the physiological state of the prey. *Marine Ecology Progress Series*, 67, 235–249.

Frost, B.W. 1972. Effects of size and concentrations of food particles on the feeding behavior of the marine planktonic copepod *Calanus pacificus*. *Limnology and Oceanography*, 17, 805–815.

Hansen, B., K.S. Tande, and U.C. Berggreen. 1990. On the trophic fate of *Phaeocystis pouchetii* (Hariot). III. Functional responses in grazing demonstrated on juvenile stages of *Calanus finmarchicus* (Copepoda) fed diatoms and *Phaeocystis*. *Journal of Plankton Research*, 12(6), 1173–1187.

Marin, V., M.E. Huntley, and B. Frost. 1986. Measuring feeding rates of pelagic herbivores: Analysis of experimental design and methods. *Marine Biology*, 93, 49–58.

Prézelin, B.B., M. Moline, K. Seydel, and K. Scheppe. 1992. Palmer LTER: Temporal variability in HPLC pigmentation and inorganic nutrient distribution in surface waters adjacent to Palmer Station, December 1991–February 1992. *Antarctic Journal of the U.S.*, 27(5), 245–248.

Ross, R.M., and L.B. Quetin. 1986. How productive are antarctic krill? *Bioscience*. 36, 264–269.

Smith, R.C., K.F. Baker, and P. Dustan. 1981. *Fluorometer techniques for measurement of oceanic chlorophyll in the support of remote sensing* (SIO Ref. 81-17). La Jolla, California: Scripps Institute of Oceanography, University of California at San Diego.

Verity, P.G., and T.J. Smayda. 1989. Nutritional value of *Phaeocystis pouchetii* (Prymnesiophyceae) and other phytoplankton for *Acartia* spp. (Copepoda): Ingestion, egg production, and growth of nauplii. *Marine Biology*, 100, 161–171.

Palmer LTER: Dissolved silicic acid–nitrate relationships during austral autumn 1993

TERRENCE HOULIHAN *and* DAVID M. KARL, *School of Ocean and Earth Science and Technology, University of Hawaii, Honolulu, Hawaii 96822*

The study of biogeochemical processes in representative antarctic marine ecosystems is a high-priority scientific objective of the U.S. Joint Global Ocean Flux Study (JGOFS) program (Anderson 1993). Carbon and bioelement (especially silica) fluxes in the southern oceans are significant on global scales but are, at present, poorly constrained due to undersampling. Consequently, we are unable to construct accurate coupled physical-biogeochemical models or to predict the response of the southern oceans to global environmental change.

The southern oceans ecosystem has traditionally been viewed as a macronutrient-saturated (that is, nitrate-, phosphate-, and silicic-acid–saturated) habitat (Holm-Hansen et al. 1977; Nelson and Treguer 1992). Substantial depletions in mixed-layer nutrients have been reported, however, in selected coastal and ice-edge ecosystems (Holm-Hansen et al. 1989; Karl, Tilbrook, and Tien 1991; Karl et al. 1992). Furthermore, the downward flux of biogenic particulate matter measured for selected habitats appears to be among the highest reported for any marine ecosystem (Honjo 1990; Karl et al. 1991), yet the export of particulate silica appears to be uniquely decoupled from the export of particulate carbon in the southern ocean (Anderson 1993). As one component of the austral autumn Palmer long-term ecological research (LTER) cruise aboard the R/V *Nathaniel B. Palmer*, we measured nutrient concentrations throughout the 1.8×10^5 square kilometer (km^2) LTER study area to help define the regional variability in water-mass distributions (Hofmann et al., *Antarctic Journal*, in this issue) and to map the patterns and magnitudes of the regional upper-ocean nutrient depletions resulting from biological activity. We focus here on the dissolved silicic acid–nitrate relationships which have been the subject of considerable discussion in recent years (Zentara and Kamykowski 1981; Le Jehan and Treguer 1983; Kamykowski and Zentara 1985; Nelson and Treguer 1992).

Vertical profiles of silicic acid concentrations along the 10 across-shelf LTER station transects (Waters and Smith 1992), exemplified by selected data for LTER line 800 (figure 1), displayed systematic patterns of nutrient depletion with increasing distance from shore (also see figure 2). Nitrate concentrations also revealed surface-water depletions but did not display the strong spatial coherence (figure 3) observed for silicic acid. Based on a model 2 linear regression analysis of water samples collected at all stations and water depths [that is, nitrate (in micromoles per liter)=17.61+0.161× silicic acid (in micromoles per liter); n=1,088], we conclude that the LTER study region exhibits a potential for "excess" nitrate at total silicic acid depletion. This contrasts sharply with data collected from the Ross Sea, data that exhibit a silicic acid excess (Kamykowski and Zentara 1985).

These regional distribution patterns were contrary to our expectations for at least two additional reasons. First, we had not expected to see significant upper water-column silicic acid or nitrate depletions—especially the large silicic acid depletions at selected offshore stations—in these waters in late austral autumn. Second, we did not anticipate the large implied silicon-to-nitrogen (Si:N) export ratio (6.2 by moles) for these waters.

We hypothesize that these two characteristic features could be the result of a late season production of diatom spores, which are characteristically more silicified than vegetative cells (French and Hargraves 1980). This could explain the high Si:N "uptake" ratios which we deduce from these data. The onshore-to-offshore gradient in surface-water silicic acid concentrations may be a direct result of deeper mixing offshore and corresponding effects on photosynthetically available radiation. Physiological processes, including light limitation, are known to induce spore formation in diatoms. Due to their increased sinking rates (Smayda and Boleyn 1966; Davis, Hollibaugh, and Seibert 1980) and high Si:N contents, the export of diatom spores from the euphotic zone could explain the distributional patterns observed during the austral autumn LTER cruise. One prediction of this hypothesis is a high Si:N ratio in particulate matter collected by sediment