

# Palmer LTER: Impact of a large diatom bloom on macronutrient distribution in Arthur Harbor during austral summer 1991–1992

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A set of stations, within 3.2 kilometers of Palmer Station, was established as part of the Palmer Long-Term Ecological Research (LTER) program to discern patterns and time/space scales of trophic variability within the foraging range of the local bird populations (Waters and Smith 1992). Here, we present observations from station B ( $z=70$  meters), located off Bonaparte Point within Arthur Harbor, which was intensely sampled from 21 November 1991 to 27 February 1992. The subset of Palmer 1991–1992 data from station B illustrates the timing and magnitude of formation and dissipation of a large summer diatom bloom and the significant impact that bloom had on inorganic nutrient availability within the water column.

Employing a Zodiac Mark V sampling platform, we collected 257 whole-water samples from discrete depths with a 5-liter (L) GoFlo bottle, transferred the samples to darkened carboys, and took them to the laboratory at Palmer Station for analyses within 1 hour of collection. One-liter samples were filtered on a 0.45-micrometer ( $\mu\text{m}$ ) nylon filter for high-performance liquid chromatography (HPLC) determination of chlorophyll-*a* (chl-*a*) and other algal pigments using procedures described in Prézelin et al. (1992). Additional replicate samples (300 milliliters) were also filtered through a 0.4- $\mu\text{m}$

polycarbonate nuclepore filter, and the filtrate was collected and frozen at  $-40^{\circ}\text{C}$  for later nutrient analysis. Inorganic phosphate ( $\text{PO}_4^{3-}$ ), nitrate ( $\text{NO}_3^-$ ), and silicate [ $\text{Si}(\text{OH})_4$ ] concentrations were determined at the University of California at Santa Barbara Marine Science Analytical Laboratories following methods described in Johnson, Petty, and Thomsen (1985, pp. 7–30).

The development of a large bloom occurred during the second week of December 1991 and was coincident with the break up and melting of the pack ice. The taxonomic identification of whole-water samples confirmed the dominance of centric diatoms (*Coscinodiscus* spp.) (D. Karentz personal communication). Figure 1 illustrates the large temporal variation in chl-*a* abundance during the 3-month sampling period. Over the duration of the bloom, chl-*a* concentrations changed by three orders of magnitude [0.3–30 milligrams of chl-*a* per cubic meter ( $\text{mg chl-}a \text{ m}^{-3}$ )]. The highest concentrations occurred between 0 and 10 meters (peak chl-*a* concentration was  $29.5 \text{ mg chl-}a \text{ m}^{-3}$ ) where the water column tended to be highly stratified and light saturated for photosynthesis (Moline et al. in press). Biomass then slowly declined during the first 2 weeks of January 1992. Temperature and salinity data (not shown) suggest a well-mixed, low-chl-*a* biomass

water mass advected into the area during the second week of January 1992, apparently replacing the biomass-rich stratified water mass (Moline et al. in press).

Figure 2 shows the temporal changes in vertical distributions of  $\text{NO}_3^-$ ,  $\text{PO}_4^{3-}$ , and  $\text{Si}(\text{OH})_4$  over the 3-month sampling period. Most striking was the reduction of  $\text{NO}_3^-$  and  $\text{PO}_4^{3-}$  to levels below detection [ $\text{PO}_4^{3-} < 0.1 \text{ micromolar } (\mu\text{M})$ ,  $\text{NO}_3^- < 0.5 \mu\text{M}$ ] during the bloom and prior to its advection out of the region. As might be expected, the  $\text{Si}(\text{OH})_4$  concentration was also significantly reduced ( $>40 \mu\text{M}$  to  $<25 \mu\text{M}$ ), but not depleted, during the diatom bloom. The simplest explanation was that an essential nutrient, other than  $\text{Si}(\text{OH})_4$ , was limiting cell

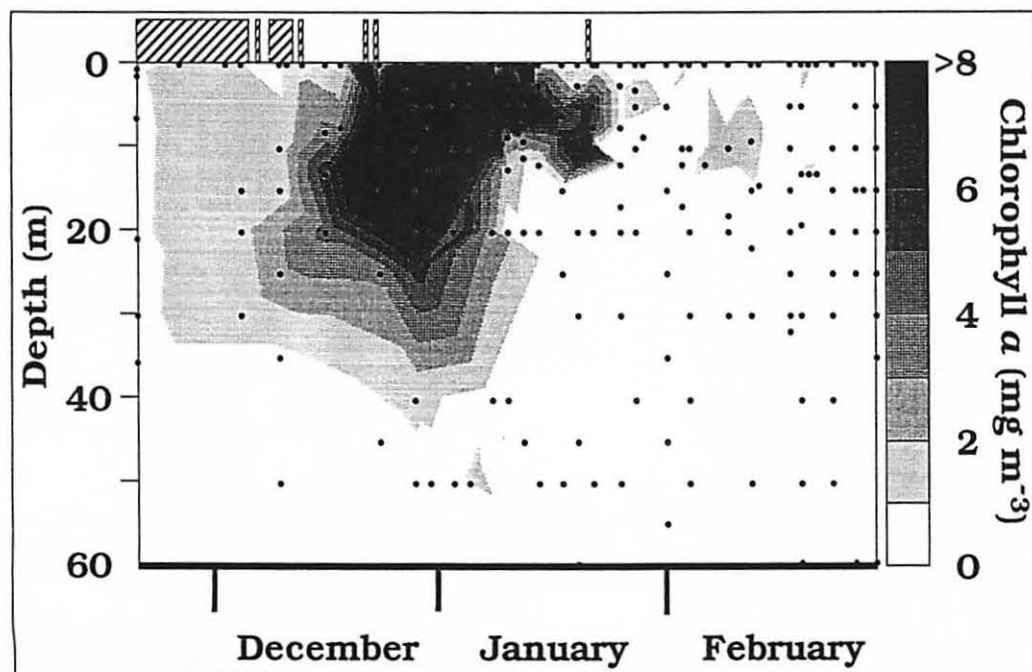


Figure 1. Vertical distribution of chlorophyll-*a* at station B from 21 November 1991 to 27 February 1992. Sampling times and depths are indicated by closed circles. Concentrations are given in milligrams per cubic meter ( $\text{mg m}^{-3}$ ). Daily presence or absence of pack ice is also shown by hatch bars.

growth rates. An alternate possibility is the half-saturation constant ( $K_s$ ) value for  $\text{Si(OH)}_4$  uptake was exceptionally high for this *Coscinodiscus* diatom. Previous studies have found  $K_s$  values for  $\text{Si(OH)}_4$  as high as  $89.4 \mu\text{M}$  for antarctic diatoms (Sommer and Stabel 1986).

We believe that, if the diatom bloom was not  $\text{Si(OH)}_4$ -limited, it was likely  $\text{PO}_4^{3-}$ -limited. The  $\text{NO}_3^-:\text{PO}_4^{3-}$  ratio increased during December, and the difference between the nonbloom and bloom conditions was significant ( $14.14 \mu\text{M} \pm 2.99$  vs.  $48.65 \mu\text{M} \pm 28.66$  respectively,  $p < 0.01$ ). Figure 3 illustrates that the increased  $\text{NO}_3^-:\text{PO}_4^{3-}$  ratio was due to the disproportionate depletion of  $\text{PO}_4^{3-}$  over  $\text{NO}_3^-$ . The linear regression for the combined pre- and postbloom  $\text{NO}_3^-:\text{PO}_4^{3-}$  data gives values (station B 91-92:  $\text{PO}_4^{3-} = 0.055 \text{NO}_3^- + 0.362$ ,  $n = 166$ ,  $r^2 = 0.79$ ) nearly identical to those reported by Kamykowski and Zentara (1989) for the southern oceans using the NODC (National Oceanographic Data Center) dataset [NODC:  $\text{PO}_4^{3-} = 0.059 \text{NO}_3^- + 0.312$ ,  $n = 38,282$ ,  $r^2 = 0.73$ ]. During the bloom, the significant deviation from this line suggested that  $\text{PO}_4^{3-}$  became limiting and resulted in the biomass decrease documented in early January 1992, prior to the advection event (figure 1). A study of a summer diatom (*Rhizosolenia* spp.) bloom in 1985 near Palmer Station (Holm-Hansen et al. 1989) provides supporting evidence that  $\text{PO}_4^{3-}$  limitation may be an episodic event that limits plant growth along the Palmer Peninsula. Holm-Hansen and his colleagues reported high particulate organic carbon (POC)/ATP (average=665) and chl-*a*/ATP (average=7.6) ratios in the presence of undetectable  $\text{PO}_4^{3-}$  concentrations ( $< 0.1 \mu\text{M}$ ), suggesting that this combination of observations may have been the result of the onset of  $\text{PO}_4^{3-}$  limitation inducing high cellular levels of both POC and chl-*a* and relatively low cellular ATP concentrations.

After the 1991-1992 bloom, we detected an increase in  $\text{PO}_4^{3-}$  and  $\text{NO}_3^-$  concentrations to prebloom levels, while at the same time we were measuring an abrupt decrease in the  $\text{Si(OH)}_4$  concentration through-

out the water column from  $30 \mu\text{M}$  to  $20 \mu\text{M}$  (figure 2). The dramatic macronutrient shifts in the water column during this period were due to the advection of a different water mass into the region. The  $\text{PO}_4^{3-}$ -rich,  $\text{NO}_3^-$ -rich, and  $\text{Si(OH)}_4$ -poor water mass observed the latter half of this study could have been a result of offshore surface water (usually high  $\text{PO}_4^{3-}$ ,  $\text{NO}_3^-$ , and  $\text{Si(OH)}_4$  concentrations) mixing with coastal glacial meltwater (high  $\text{PO}_4^{3-}$  and  $\text{NO}_3^-$  concentrations and no  $\text{Si(OH)}_4$ ). Such common mixing processes would have had a diluting effect with  $\text{Si(OH)}_4$  while not affecting the  $\text{PO}_4^{3-}$  and  $\text{NO}_3^-$  concentrations.

This study confirms previous findings that inorganic nutrients are significantly depleted during large episodic blooms in areas of the southern oceans (Jennings, Gordon,

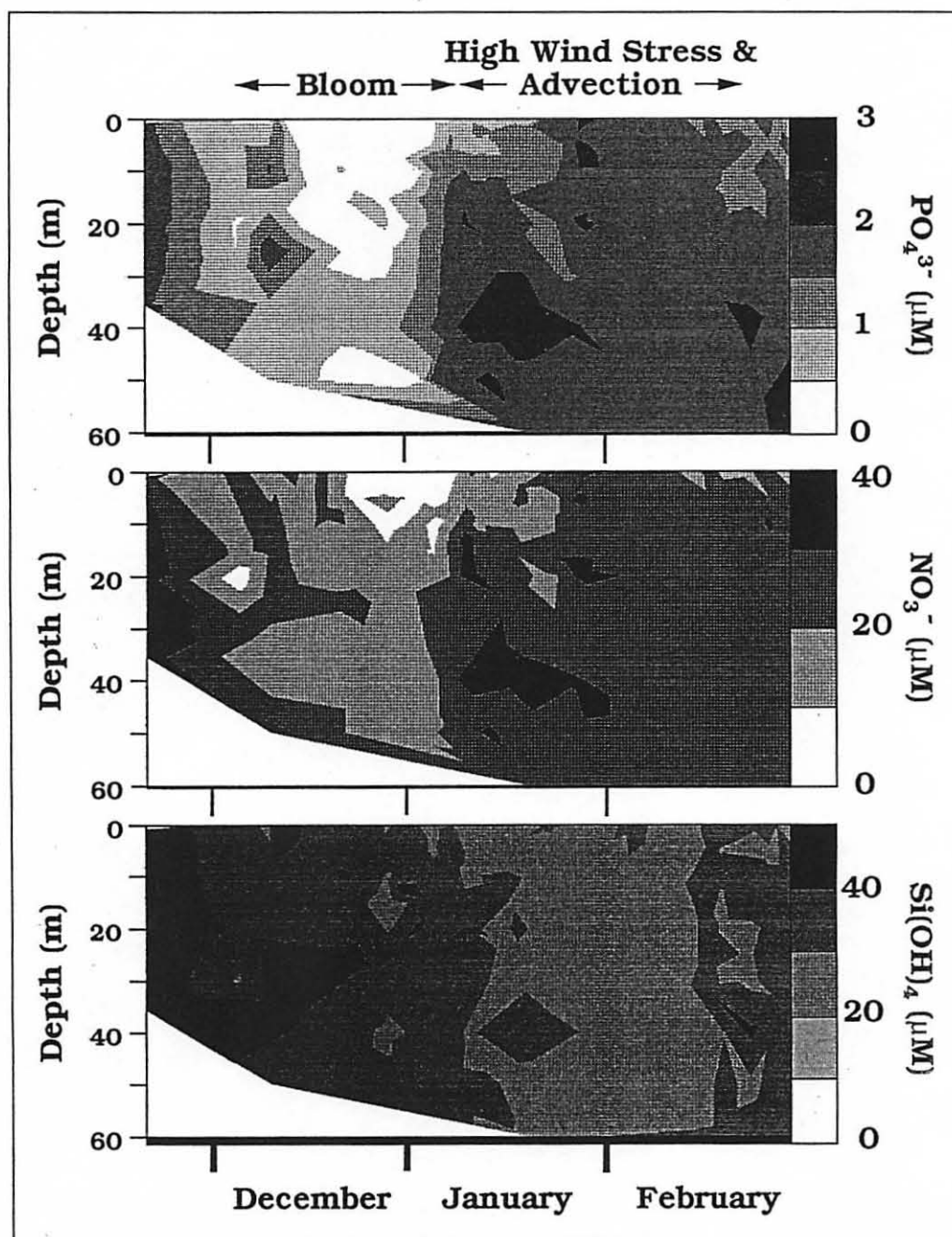


Figure 2. Concentrations of  $\text{PO}_4^{3-}$ ,  $\text{NO}_3^-$ , and  $\text{Si(OH)}_4$  at station B from 21 November 1991 to 27 February 1992. All concentrations are given in  $\mu\text{M}$ . See figure 1 for sampling times and depths.

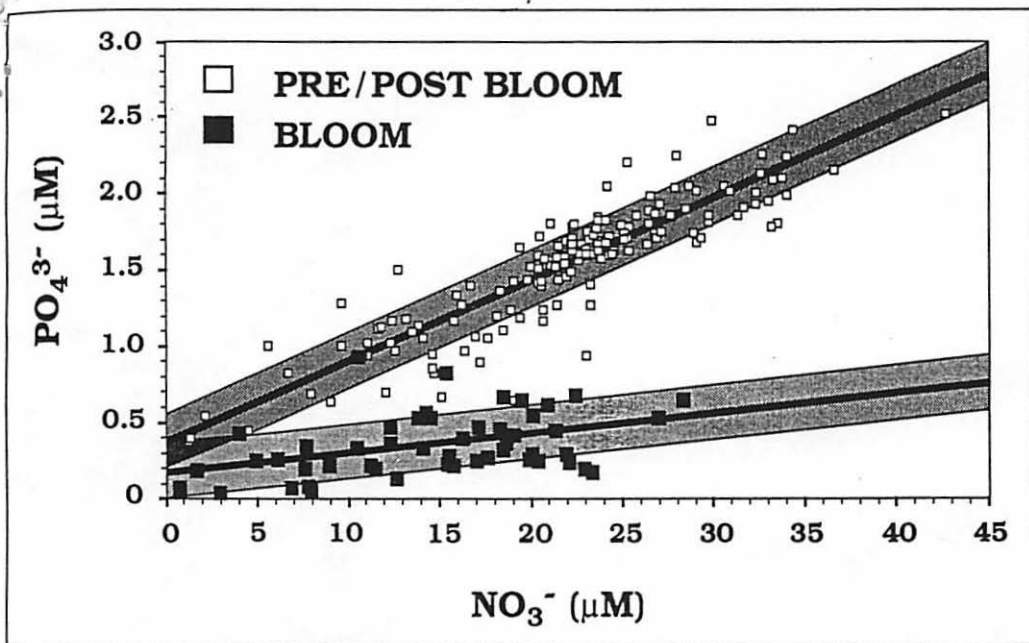


Figure 3. Comparison of inorganic  $\text{NO}_3^-$  and  $\text{PO}_4^{3-}$  for all depths over the 3-month sampling. Regression lines represent the pre- and postbloom (open squares) ( $\text{PO}_4^{3-} = 0.055 \text{NO}_3^- + 0.362$ ,  $n=166$ ,  $r^2=0.79$ ) and bloom conditions (closed circles) ( $\text{PO}_4^{3-} = 0.055 \text{NO}_3^- + 0.362$ ,  $n=49$ ,  $r^2=0.19$ ) from 10 December 1991 to 9 January 1992.

and Nelson 1984; Priddle, Heyward, and Theriot 1986; Holm-Hansen et al. 1989). The timescales for macronutrient depletion appeared to be similar to those of bloom formation (3–5 weeks). The significant temporal shifts in the inorganic nutrient ratios found here indicate nutrient uptake rates are dynamic and respond to changing environmental conditions. Some estimates of phytoplankton processes, which assume fixed nutrient signatures, may, therefore, have limitations in coastal regions and other areas of potentially high biomass (i.e., marginal ice zones).

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