Palmer LTER: Photoadaptation in a coastal phytoplankton bloom and impact on the radiation utilization efficiency for carbon fixation

OSCAR SCHOFIELD[*], BARBARA PRÉZELIN, *and* MARK A. MOLINE, *Department of Biology and Marine Science Institute, University of California, Santa Barbara, California 93106*

[*]Present address: *Southern Regional Research Center, New Orleans Louisiana 70179*

The occurrence and demise of most phytoplankton blooms show a strong coherence with sea-water density fields; increasing biomass concentrations are associated with shallow mixing depths. This relationship supports the view that phytoplankton require a stable light environment, which allows the phytoplankton sufficient time to photoacclimate and overcome light-limitation of growth (Mitchell et al. 1991). Characterizing photoacclimation within a planktonic population over time has been difficult to document, however. As part of the Long-Term Ecological Research (LTER) program, the temporal dynamics of a phytoplankton bloom were documented near Palmer Station (64°40'S 64°03'W) during the austral summer months of 1991–1992. The ability to follow the formation of this bloom over time can provide insight into the photoadaptational capabilities of the phytoplankton and the corresponding impact on water column optical properties.

Water samples were collected from station B within the nearshore sampling grid of the LTER (Prézelin et al. 1992). Significant symbols are listed in the table. *In situ* light levels (Q_{par}) were measured (Biospherical QL-100 scalar irradiance meter), and discrete water samples were transported back to Palmer Station in blackened carboys. Attenuation coefficients [K, per meter (m^{-1})] were calculated from *in situ* Q_{par}. Phytoplankton pigmentation was determined by high-performance liquid chromatography following the protocols described in Prézelin et al. (1992). Photosynthesis-irradiance (P-I) curves were determined using described procedures (Prézelin et al. 1992). *In situ* photosynthetic rates were calculated from the maximum photosynthetic rate [P_{max}, milligrams of carbon per cubic meter per hour (mg C m^{-3} h^{-1})], light-limited slope of the P-I curve (α, mg C m^{-3} h^{-1} per micromole photons per square meter per second)—[α, mg C m^{-3} h^{-1} (μmol photons

$m^{-2}\ s^{-1})^{-1}$—and Q_{par}. The radiation utilization efficiency (ε) was calculated, as

$$\varepsilon = \frac{163.8 \cdot P_{max} \cdot \tanh\left(\dfrac{Q_{par}}{P_{max}/\alpha}\right)}{K \cdot Q_{par}} \qquad (1)$$

where the constant of 163.8 converts 1 mg of carbohydrate to its energy equivalent in μmol photons (Kirk 1994, pp. 290–303).

During the last 2 weeks of December 1991, a phytoplankton bloom occurred at station B (figure 1). The concentration of chlorophyll-a (chl-a) increased by several orders of magnitude (from <0.1 mg m^{-3} to >10 mg m^{-3}). Temperature-salinity profiles during the formation of the bloom suggested the same water mass remained in Arthur Harbor (Smith personal communication). Mixed-layer depth grew shallow during the

blooms, confining algal populations to the upper 20 m of the water column. Dissipation of the bloom during the second week of January 1992 coincided with storm activity, and low biomass water was advected into the area of station B (Moline, Prézelin, and Schofield 1994).

Temporal variation in ε at station B is presented in figure 2. Values of ε showed large fluctuations over the season, with values ranging from <1 to 22 percent (±4.4 percent). Highest values of ε were observed during the bloom (ε and chl-a positively correlated, R^2=0.43, $p<0.05$). The theoretical maximum value of ε is 25 percent (Kirk 1994, pp. 290–303). This maximum is determined by assuming light is attenuated only by phytoplankton and, thus, in reality ε must be lower than 25 percent. Our highest values approached the theoretical maximum and, to our knowledge, are the highest ε values ever recorded. The highest values are evidence that an antarctic phytoplankton bloom can operate at maximal efficiencies. Since ε combines the optical properties of the water column, algal biomass, and photosynthetic activity, it therefore is not a direct index for photoadaptive status. Values of ε, however, can be used to estimate the product of the spectrally weighted absorption coefficient ($\bar{a}_{ph}$) and the operational quantum yield (ϕ) (product of $\bar{a}_{ph}$ and ϕ shall be referred as ε_c, Smith et al. 1987), parameters which describe the photoadaptive state of any plant. Because $\bar{a}_{ph}$ reflects in situ biomass, ε_c is divided by chl-a.

$$\frac{\varepsilon_c}{chl\text{-}a} = \frac{\bar{a}_{ph}\cdot\phi}{chl\text{-}a} = \frac{K\cdot\varepsilon}{[chl\text{-}a]\cdot 1.197} \qquad (2)$$

Values of ε_c per chl-a describe the degree to which the phytoplankton are able to harvest and use in situ Q_{par}. The prebloom phytoplankton had the highest values of ε_c (figure
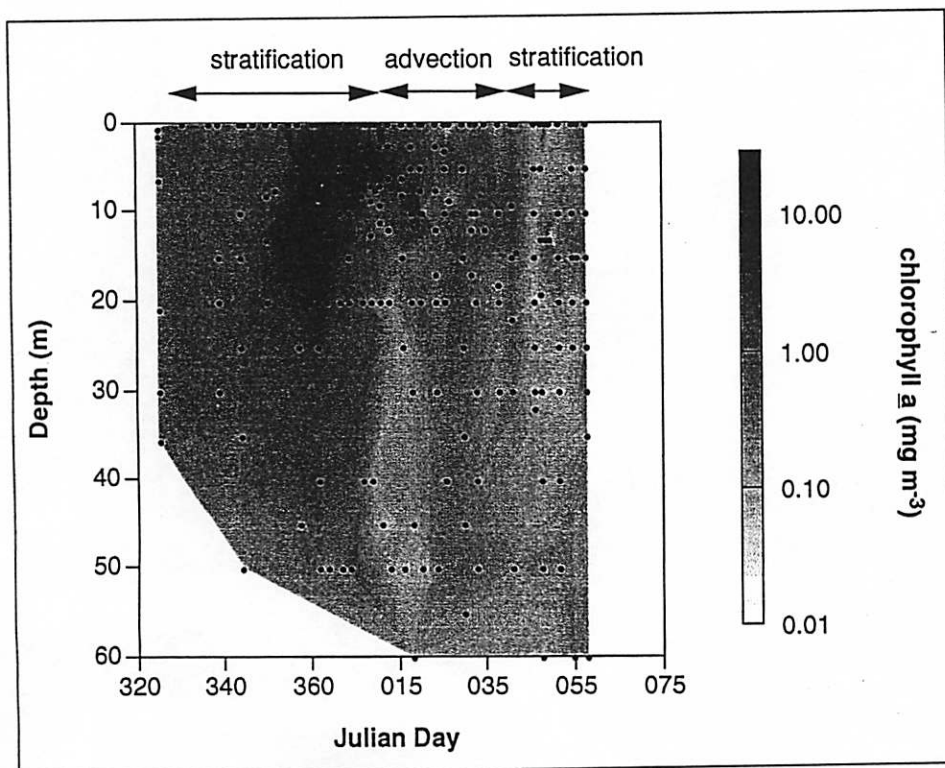

Figure 1. Contour of chlorophyll-a concentration (mg m^{-3}) at LTER station B from December 1991 through February 1992. Station B is located near Palmer Station (exact location described in Prézelin et al. 1992). Black circles indicate discrete samples. Periods of stratification and advection are denoted by arrows.
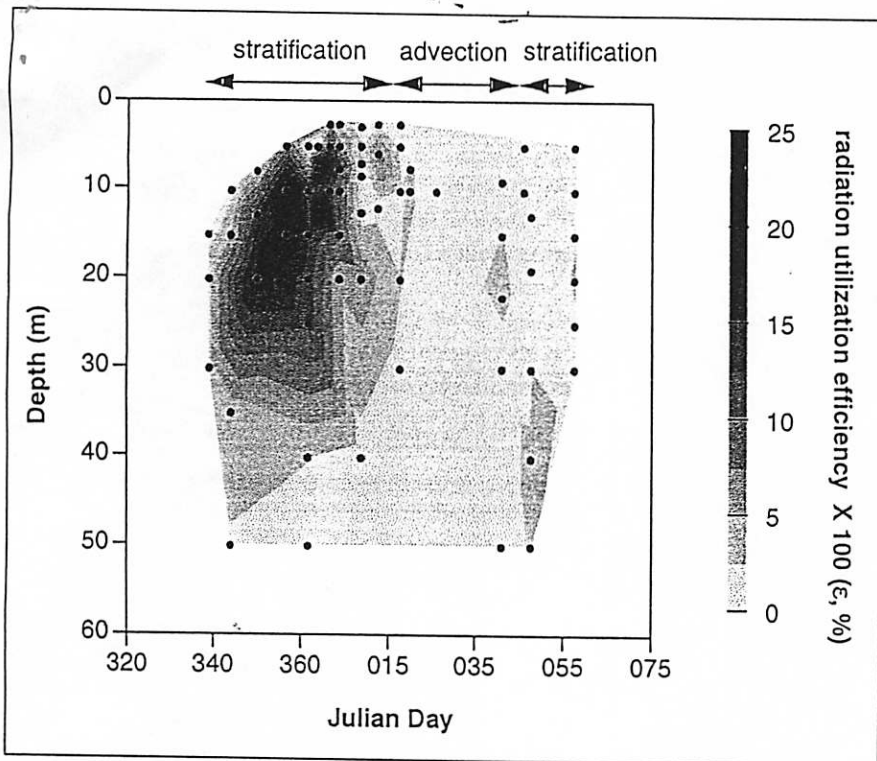
Figure 2. Contour of the photosynthetic radiation utilization efficiency (ε, %) at LTER station B during December 1991 through February 1992. Black circles indicate discrete samples. Periods of stratification and advection are denoted by arrows.
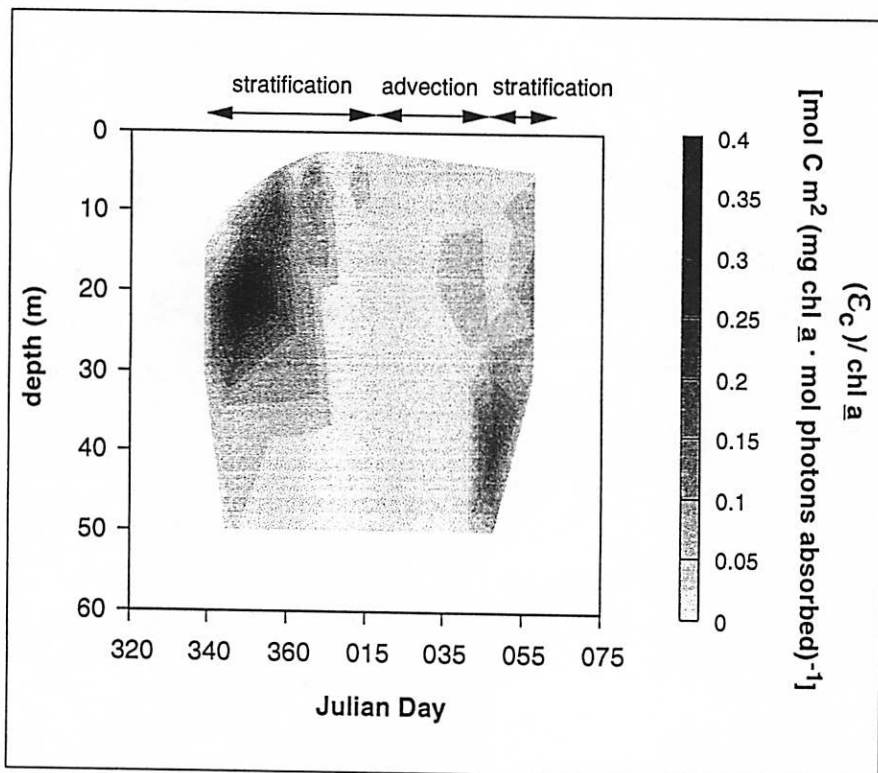

Figure 3. Contour of the chlorophyll-a-specific product of the spectrally weighted absorption coefficient ($\bar{a}_{ph}$, m^{-1}) and the operational quantum yield for carbon fixation (φ, mol C fixed mol^{-1} photons absorbed) at LTER station B. The sampling grid is identical to that in figure 2. Periods of stratification and advection are denoted by arrows.

3), a finding that reflected photoacclimation by the algae. The large increases in biomass (figure 3) appeared to lag just after ε$_c$ values had increased, and that lag suggested that the photophysiology was optimized before the phytoplankton bloomed. The degree to which the optimization was due to $\bar{a}_{ph}$ and/or φ is being assessed. Regardless of the specific mechanism, this preliminary analysis provides strong evidence that once phytoplankton were given a stable light environment, algae quickly photoacclimated on the timescale of a few days.

References

Kirk, J.T.O. 1994. *Light and photosynthesis in aquatic ecosystems* (2nd ed.). Cambridge University Press. Cambridge.

Mitchell, B.G., E.A. Brody, O. Holm-Hansen, C. McClain, and J. Bishop. 1991. Light-limitation of phytoplankton biomass and macronutrient utilization in the southern ocean. *Limnology and Oceanography*, 36(8), 1662–1677.

Moline, M., B.B. Prézelin, and O. Schofield. 1994. Palmer LTER 1991: Temporal variability in physical, chemical, and optical parameters: Effects on phytoplankton bloom dynamics. *Earth Observing System*, 75(3), 217.

Prézelin, B.B., M. Moline, K. Sydell, 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.

Smith, R.C. 1994. Personal communication.

Smith, R.C., R.R. Bidigare, B.B. Prézelin, K.S. Baker, and J.M. Brooks. 1987. Optical characterization of primary productivity across a coastal front. *Marine Biology*, 96(3), 575–591.