Light-saturated primary production in Antarctic coastal waters

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During the austral spring and summer seasons from 1991 to 1994, 756 discrete water samples were collected at the Palmer Long-Term Ecological Research (LTER) program stations B and E (Moline and Prézelin 1997a). For each discrete sample, photosynthesis-irradiance (P-I) relationships (n=25) were determined. Photosynthetic parameters $P_{\text{max}}$ (the light saturated photosynthetic potential), $\alpha$ (the light-limited photosynthetic efficiency), $I_k = P_{\text{max}}/\alpha$; an estimate of the minimum irradiance required for the onset of light-saturated photosynthesis), $\beta$ (the efficiency of photoinhibition), and $I_t$ (the irradiance threshold for the onset of photoinhibition) were derived from the P-I relationships and then used to calculate primary production for each discrete sample. The diel patterns of each parameter were also measured weekly and incorporated into the production calculations to produce daily rates of primary production throughout the water column over the 3-year sampling period. $Q_{\text{par}}$ (400–700 nanometers (nm)) irradiance values for the productivity calculations were obtained by integrating surface/in-water irradiance measurements taken while sampling and incident irradiance recorded continuously every 5 minutes at Palmer Station over the three sampling seasons. Primary production estimates were also calculated using theoretical clear-sky $Q_{\text{par}}$ irradiance, calculated from Morel (1991) and Antoine (personal communication) using an atmospheric correction (350 Dobson units for ozone content and 2 centimeters precipitable water content). Light-saturated primary production was quantified as the fraction of production operating at $P_{\text{max}}$ at an irradiance greater than the measured value of $I_k$. Further details of sample collection and analyses are described elsewhere (Claustre, Moline, and Prézelin in press; Moline and Prézelin 1997a,b).

Primary production for the nearshore LTER stations showed significant variability with each season and between years (figure 1A). Much of the seasonal variability was the result of fluctuations in biomass as a result of advective processes and vertical mixing within the water column (Moline and Prézelin 1997b). The temporal changes in the taxonomic structure of the water column also significantly affected the measured rates of carbon uptake (Claustre et al. in press). High interannual variability resulted from differences in the stability and durations of low wind speeds between years. Significantly higher production was measured during a large diatom bloom in December 1991 (figure 1A). The percentage of primary production that was light-saturated over the three spring and summer periods averaged 47±17 (figure 1B). A seasonal trend was evident; peak saturation occurred during the peak solar irradiance and a generally lower percentage of saturation occurred earlier and later in the year. During the 1991–1992 bloom, light-saturated production was lower and may have been a result of light limitation by self-shading (Moline et al. 1997, pp. 67–72; Moline and Prézelin 1997a).

Cloud cover significantly decreased the incident surface irradiance by an average of 37±24 percent from clear sky conditions and was consistent between years (figure 2A). On occasions, measured irradiance was higher than modeled clear-sky irradiance, probably resulting from light reflectance off surrounding snow cover and glaciers in this coastal envi-

Figure 1. (A) Average daily depth-integrated primary production measured at stations B and E and (B) the percent of light-saturated primary production for three austral springs and summers between 1991 and 1994. Hatched bars indicate the presence of sea ice during the 1993–1994 season. (gC m$^{-2}$ d$^{-1}$ denotes grams of carbon per square meter per day.)
The decrease in surface irradiance from cloud cover was estimated to decrease water column primary production by as much as 73 percent (November 1994) with an average of 20±17 percent for all three seasons (figure 2A).

Light-saturated primary production was also calculated using modeled clear-sky irradiance. When the effect of cloud cover was removed, the percent light saturation increased by 8.4±9.8 percent (figure 2C). No seasonal trends were evident, however, the percentage of change in the light-saturated primary production during the 1991–1992 season was not as great as the following two seasons. This smaller change may have been a result of the high in situ light attenuation due to high biomass during the bloom (December 1991 to January 1992) and toward the end of the sampling season in February 1992 (figure 2A).

The relatively small increase in the light-saturated production compared to the increase in irradiance when cloud cover was removed shows that the majority of production in these coastal waters was light-saturated over the season and also that light saturation was at a maximum. This finding is further illustrated by comparing the percentage of light saturation (calculated using the measured irradiance values) to the measured daily irradiance for all sampling days over the 3-year period (figure 3). For samples collected in open water, the maximum percentage of light-saturated production increased with increasing light. The percent saturation itself, however, saturated (at approximately 70–75 percent) at irradiiances greater than 20–25 einstein per square meter per second (E m⁻² s⁻¹). These irradiance levels indicate that these phytoplankton have the potential of being light-saturated from the end of September to the middle of March, nearly the full growing season in these polar waters. This long growing season may result from both the value of $I_k$ (and depth within the water column where the irradiance is equal to $I_k$) and the fact that for a portion of the day, light is not saturating. Therefore, approximately 25–30 percent of water column primary production occurs below the depth where $I_k=Q_{par}$ and/or in the early and late hours of the daily solar cycle. Samples taken when the region was ice covered did not begin to show light saturation until daily irradiance values were above approximately 50 E m⁻² s⁻¹.

Results from this highly resolved temporal study quantify light-saturated primary production in this coastal region and show that these phytoplankton are generally light-saturated during most of the growing season from September to March. These results also argue against light-limitation being a major factor limiting primary production in the southern oceans.

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References