Statistical analyses of environmental predictors for phytoplankton photosynthetic parameters and productivity in an antarctic time series database

MARK A. MOLINE and BARBARA B. PRÉZELIN, Department of Biological Sciences, University of California, Santa Barbara. Santa Barbara, California 93106

OSCAR SCHOFIELD, Institute of Marine and Coastal Studies, Rutgers University, New Brunswick, New Jersey 08903-0231

From 3 December 1991 to 27 February 1992, 249 discrete water samples were collected at the Palmer Long-Term Ecological Research (LTER) program's station B (Waters and Smith 1992). For each discrete sample, physical, biological, and chemical measurements were made including incident irradiance, in situ irradiance, temperature, density, and nitrate, phosphate, silicate, particulate organic carbon, and particulate organic nitrogen levels. In addition, 15 distinct algal pigments were determined by high-performance liquid chromatography (HPLC), and the algal pigments were classified into groups based on their functionality (i.e., photoprotective carotenoids and photosynthetic carotenoids). In addition,
photosynthesis-irradiance (P-I) relationships were determined for each sample from which the photosynthetic parameters $P_{\text{max}}$ (photosynthetic capacity) and alpha (the light-limited photosynthetic efficiency) were derived. Further details of sample collection and analyses are described elsewhere (Prezelin et al. 1992; Moline et al. in press).

The dynamics of the physical, chemical, and biological components of the system were highly coupled at station B over the 1991–1992 season (Moline et al. in press). In early December 1991, freshwater input from melting fast ice and nearby coastal glaciers and low wind speeds permitted the water column to stratify. This enhanced stability allowed a large bloom (approximately 30 milligrams of chlorophyll-a per cubic meter) to develop, a size that depleted macronutrients to detection levels (Moline and Prezelin 1994). This bloom accounted for 75 percent of the integrated productivity over the season (Moline and Prezelin in preparation). A period of high wind advected the water mass out of the area, and for the following 2 months, the water column was well mixed. The phytoplankton community varied over the season with diatoms, chrysophytes, cryptophytes, or prymnesiophytes dominating at any given time. This study examines the temporal variability in the P-I parameters.

Stepwise forward and backward multiple linear regression analyses were used with the above variables to generate algorithms to predict the P-I parameters. The statistical (enter/remove) constraint for the analyses was $p<0.015$. This approach was similar to that used by Schofield et al. (1993) within the Southern California Bight. Once significant variables and their coefficients were determined, the algorithms were verified using nonparametric randomization regression techniques. Results of these analyses are presented in the table. A majority of the variance in both alpha and $P_{\text{max}}$ were explained by density and the concentration phosphate and nitrate, respectively. The relationship improved with the addition of the biomass indicator, chlorophyll-a. Full pigmentation information provided only a slightly stronger relationship, suggesting that over the season, despite large variations in nutrient concentration, water column stability, and community composition, the capacity of light harvesting by phytoplankton changed little. The $P_{\text{max}}$ and alpha values predicted from these regressions were then used to estimate the in situ productivity ($P_s$) using the following relationship (Platt and Gallegos 1980),

$$P(z, t) = P_{\text{max}}(\frac{Q_z(z, t)}{I_z(z, t)})$$

where $I_z$ is equal to $P_{\text{max}}$/alpha and $Q_z$ is the in situ light field [400–700 nanometers (nm)]. Once the in situ productivity based on the predicted $P_{\text{max}}$ and alpha variables had been estimated, the productivity estimated from the measured P-I parameters was determined using the same approach. The predicted productivity and measured productivity from station B were then compared (figure 1). Sixty-five percent of the variance in productivity could be explained by the P-I parameters predicted from density and the nutrient concentrations (figure 1A). The relationship, however, was biased toward the higher

![Figure 1](image)

**Figure 1.** Comparison of in situ primary productivity calculated from predicted $P_{\text{max}}$ and alpha and measured $P_{\text{max}}$ and alpha. Variables used to predict $P_{\text{max}}$ and alpha are included in the figure. $R^2$ values are indicators of how well the predictor variables were for $P_{\text{max}}$ and alpha. The closeness of the regression line (solid) to the 1:1 line (dashed) indicates how well the regression calculated the variable coefficients. (mg C m$^{-3}$ h$^{-1}$ denotes milligrams of carbon per cubic meter per hour.)

### Results of multiple linear regression analyses from Palmer LTER station B (p-value for regression is <0.00001 in all cases)

<table>
<thead>
<tr>
<th>Category of variables</th>
<th>Photosynthetic parameter variables</th>
<th>Significant independent</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical + nutrient</td>
<td>$P_{\text{max}}$ Alpha</td>
<td>$\sigma$, $\text{NO}_3$</td>
<td>0.65</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\sigma$, $\text{NO}_4$</td>
<td>0.59</td>
</tr>
<tr>
<td>Physical + nutrient +</td>
<td>$P_{\text{max}}$ Alpha</td>
<td>$\sigma$, $\text{NO}_3$, $\text{Chl-a}$</td>
<td>0.84</td>
</tr>
<tr>
<td>chi-a</td>
<td></td>
<td>$\sigma$, $\text{PO}_4$, $\text{Chl-a}$</td>
<td>0.83</td>
</tr>
<tr>
<td>Physical + nutrient +</td>
<td>$P_{\text{max}}$ Alpha</td>
<td>$\sigma$, $\text{NO}_3$, $\text{PPC}$</td>
<td>0.86</td>
</tr>
<tr>
<td>HPLC</td>
<td></td>
<td>$\sigma$, $\text{PO}_4$, $\text{PSC}$</td>
<td>0.85</td>
</tr>
</tbody>
</table>

* Photoprotective carotenoids
* Photosynthetic carotenoids

Antarctic Journal — Review 1995
productivity values; it predicted the bloom accurately (75 percent of the seasonal productivity) but performed poorly when predicting the periods of low productivity. As before, when chlorophyll-α was added as a predictor variable for $P_{\text{max}}$ and alpha, the relationship greatly improved (figure 1B). The addition of algal pigmentation in the regressions shifted the relationship to nearly 1:1 and was a better predictor than chlorophyll-α for the periods of low productivity (figure 1C).

The regressions used in figure 1C, derived from station B, were then used to predict in situ productivity at station E, 3 kilometers from station B within the same LTER nearshore grid (Waters and Smith 1992). The measured production is shown with depth over the 3-month sampling period in figure 2A. The calculated production, based on the regressions from station B, is shown in figure 2B. Even though the regressions overestimated productivity by approximately 10 percent over the season, the main features of production could be detected and the relationship was significant.

Results from this study show that for 1991–1992, the physical- and nutrient-based regression model described the majority of the spring/summer variation in productivity; however, the predictive linkages were strongly dependent on the occurrence of a bloom in stratified, nutrient-depleted waters. For periods of water column instability, the physical- and nutrient-based regression model was not adequate to predict variability in primary productivity, unless knowledge of phytoplankton pigmentation was incorporated into the regression. Lastly, primary productivity at station E could be significantly predicted using the outcome of the regression analyses from station B. This suggests the dynamics of these antarctic coastal stations are closely coupled and exhibit similar processes controlling primary production.

Special thanks go to K. Seydell, K. Scheppe, P. Handley, T. Newberger, and B. Frank for assistance in the field. This work was supported by National Science Foundation grant OPP 90-11927 awarded to B.B. Prézelin. This is Palmer LTER contribution 90.

References


