Icecolors '93: Biological weighting function for the ultraviolet inhibition of carbon fixation in a natural antarctic phytoplankton community

NICOLAS BOUCHER, BARBARA B. PRÉZELIN, T. EVENS, R. JOVINE, B. KROON, M.A. MOLINE, and O. SCHOFIELD, Marine Primary Productivity Group, Department of Biological Sciences, University of California, Santa Barbara, California 93106

The goals of the Icecolors '93 expedition were

- to develop a space/time climatology of incident and penetrating spectral irradiance for the southern oceans,
- to quantify the ultraviolet (UV) dependency of primary production for pelagic (Prézelin, Boucher, and Matlick in press) and substrate-associated (see Evens et al., Antarctic Journal, in this issue; Schofield, Kroon, and Prézelin in press) antarctic phytoplankton communities, and
- to determine the UV inhibition effects on key target sites. (See Jovine and Prézelin, Antarctic Journal, in this issue; Kroon, Schofield, and Prézelin in press.)

The study was conducted at Palmer Station, Antarctica, prior to the opening of the ozone "hole" and during the onset of depletion (August and September 1993) and onboard the R/V Polar Duke along the Antarctic Peninsula for the remainder of the austral spring. In 1993, the ozone hole developed in early August and did not close before late December (figure 1). It was the most severe depletion ever recorded over the Antarctic Peninsula, and its occurrence reinforced the need for a better understanding of the effect of UV radiation on the antarctic ecosystem.

The impact of UV radiation on primary producers is a concern because the timing of the ozone diminution over the southern oceans and concomitant increases in UV-B radiation coincide with the beginning of the phytoplankton growing season (Smith et al. 1992, pp. 509-537). An important step to improve predictive models of phytoplankton productivity in enhanced-UV environments is to determine the spectral dependency of the sensitivity of natural communities to ambient UV radiation. With the knowledge of such a biological weighting function, one can link any change in UV radiation—dependent upon season, time of the day, cloud and ice cover, stratospheric ozone concentration, and position in the

Figure 1. Stratospheric ozone column concentration (DU) above Palmer Station, Antarctica (Meteor 3 TOMS data), and midday (1200 Greenwich mean time) UV-B (280-320 nm) irradiance [in microwatts per square centimeter (µW cm⁻²)] at the Palmer Station National Science Foundation/Office of Polar Programs UV-monitoring station (Booth et al. 1994) during the Icecolors '93 expedition.
water column—to the inhibition of carbon uptake in antarctic phytoplankton and quantify the increment of biologically damaging radiation associated with a diminution in ozone concentration (radiation amplification factor). Here, we introduce the results from an experiment designed to estimate a biological weighting function for primary production inhibition in antarctic phytoplankton under natural irradiance. We present the newly derived function and show that the sensitivity of in situ antarctic phytoplankton to ambient UV-B (280–320 nanometers (nm)) at the end of the winter was greater than that measured under artificial light conditions for temperate marine phytoplankton and terrestrial plants.

At the time of our measurement (16 September, Julian day 259), the ozone column concentration ranged from 230 to 260 Dobson units (DU) and was in the middle of a 3-day transition from 175 to 350 DU (figure 1). The amount of UV-B radiation reaching the Earth’s surface was, therefore, slightly enhanced due to the ozone diminution, but the total daily irradiance was still relatively low because of the large solar zenith angle. A surface-water sample was collected at 0800 hours at Long-Term Ecological Research (LTER) station B near Palmer Station, Antarctica (Waters and Smith 1992). Aliquots were quickly dispensed in polyethylene bags (Prézelin, Boucher, and Smith 1994, pp. 159–186), placed flat in outdoor temperature-controlled incubators, and covered with long-pass filters designed to remove increasingly broader wavelength in the UV region while leaving the longer wavelength for the most part unchanged. The 50-percent transmittance cut-offs of the filters combined with the bags were 299, 314, 324, 328, 383, and 402 nm. The average transmittance of the filters in the photosynthetically available radiation (PAR, 400–700 nm) region ranged from 81.4 to 86.8 percent. Duplicate samples were removed from each incubator every hour from 0935 to 1800 hours local time to determine the time course of carbon uptake for each treatment.

In all six treatments, the cumulative volumetric production (in milligrams of carbon per cubic meter (mg C m$^{-3}$)) increased over the course of the day, and the rate of increase was greatest at midday when PAR was highest. Carbon uptake was highest in the Q$_{PAR}$ only treatment (UF4, 402 nm cut-off) or Q$_{PAR}$ with the addition of the longest wavelengths of UV-A radiation (MC, 383 nm cut-off). The samples exposed to unfiltered radiation (UVT, 299 nm cut-off) showed the lowest uptake rates. After 1200 hours, primary production was significantly different in the six incubators, and the inhibition of carbon uptake was related to the amount of UV radiation transmitted through the filters (figure 2).

To get a daily average inhibition for each treatment, we regressed the carbon fixation rates measured hourly in each treatment with the rates measured under PAR only. The extent of a downward deviation from a slope of unity is, therefore, a measure of the fractional inhibition of primary production. Primary-production measurements under all UV treatments were well correlated to the primary-production measurements under PAR only (average $r^2$=0.97±0.01). The average daily inhibition by UV radiation was 34.3±0.01 percent. The inhibition due to the radiation removed by the pyrex 2 filter—

the radiation removed, in the first approximation, can be considered UV-B radiation—was 14.6 percent or 43 percent of the total inhibition. UV-A radiation was, thus, responsible for a 19.7 percent inhibition though the longer wavelengths of UVA slightly enhanced primary production (0.5-percent enhancement under the MC filter) suggesting that these wavelengths had photosynthetic functions.

Over any incubation interval, the total inhibition of carbon fixation rates by UV radiation in each incubator ($I_U$) is a function of the dose impinging the organism [$Q(\lambda)$] and the average sensitivity of the organism to the radiation or biological weighting function ($\varepsilon(\lambda)$):

$$I_U = \int_{\lambda_U}^{\lambda_P} Q(\lambda) \varepsilon(\lambda) d\lambda$$

To deconvolute the biological weighting function (figure 3A), we followed the iterative nonlinear fitting method outlined by Rundel (1983), using the spectral irradiance obtained from the onsite National Science Foundation UV-monitoring station (Booth et al. 1994, pp. 17–37). At the end of the austral winter, the phytoplankton sensitivity to UV radiation decreased exponentially with wavelength, and the longest wavelengths ($\lambda$>368±12.8 nm) enhanced primary production. Antarctic phytoplankton appeared more sensitive to an increase in the UV-B to UV-A balance than did temperate marine phytoplankton (Cullen, Neale, and Lesser 1992) and terrestrial plants (Jones and Kok 1966; Caldwell 1971) (figure 3B). The radiation amplification factor for the function as measured using the power rule (Madronich 1993, pp. 17–69; Booth and Madronich 1994, pp. 39–42) was in the upper region of the radiation amplification factor range for plant damages as tabulated by Madronich (1993). The use of any DNA-action spectra (Setlow 1974; Hunter, Taylor, and Moser 1979) as a biological weighting function would, however, overestimate the predicted effects of the ozone depletion on primary production.

![Figure 2 Time course of cumulative primary production under the six different UV treatments](image)
We thank S. Madronich and R.C. Smith for helpful discussions. This research was supported by National Science Foundation grant OPP 92-20962. (This is an Icecolors ’93 contribution.)

References


