

Quantifying the effects of ultraviolet radiation on phytoplankton: Comparisons between Chesapeake Bay and Antarctica (Southern Ocean)

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Introduction and methods

Large-scale assessments of the impact of UV on marine primary production at regional to global scales can be accomplished by coupled models of incident UV spectral irradiance, UV transmittance in the aquatic environment and biological responses to UV. The latter is the focus of this paper, complementing the parallel efforts on optical modeling of the other components that are discussed in other contributions in this volume and elsewhere [Vasilkov *et al.*, 2001].

Quantifying and predicting the response of phytoplankton primary production to UV requires definition of the spectral response through biological weighting functions (BWFs) and temporal response through the kinetics of damage and recovery [Neale, 2000]. These characteristics have been studied in natural phytoplankton assemblages in various Antarctic marine environments (Southern Ocean) and in a sub-estuary (The Rhode River) of the Chesapeake Bay located on the mid-Atlantic coast of the US. The Rhode River was sampled on a monthly basis over a two-year study period [Banaszak and Neale, 2001].

The Antarctic assemblages were sampled during the austral spring period of ozone depletion in the Weddell-Scotia confluence (1993, 1998), Palmer Station (1997, 1999) and McMurdo (1991) [Neale *et al.*, 1998a; Neale *et al.*, 2001; Neale *et al.*, 1994]. BWFs for all these samples were estimated using a custom spectral incubator (photoinhibitor) which exposes phytoplankton to polychromatic illumination from a xenon arc lamp filtered through eight different long-pass filters with nominal cutoffs (50% transmittance) of 280, 295, 305, 320, 335, 350, 370 and 395 nm [Cullen *et al.*, 1992; Neale and Fritz, 2001; Neale *et al.*, 1994]. Neutral density screens are used to vary the intensity within each spectral regime so as to obtain up to 80 different treatments which can be used for simultaneous determination of photosynthetic rates (incorporation of $H^{14}CO_3^-$ into acid-stable organics) in 1-6 ml sample aliquots over a typical 1 h exposure duration.

Measured rates are fitted to either an irradiance (E) or cumulative exposure (H) model depending on the kinetics of damage and recovery [Neale, 2000]. The E model is appropriate for the Rhode River and coastal Antarctic assemblages which attained a steady state rate of photosynthesis during exposure consistent with a significant potential for counteracting UV damage ("repair") [Banaszak and Neale, 2001; Neale *et al.*, 2001]. The H model was applied to assemblages in the Weddell-Scotia confluence where repair was too weak to reach a

steady-state during the exposure period [Neale *et al.*, 1998a].

Results and Discussion

The BWFs of assemblages in both the Rhode River and Antarctica, like most other BWFs for inhibition of photosynthesis by UV, show sensitivity of photosynthesis to inhibition by both UV-B and UV-A [Neale, 2000; Neale and Kieber, 2000]. However, the BWFs vary in both the overall level of sensitivity to UV as well as the relative sensitivity to UV-B vs. UV-A.

The average sensitivity over the entire data set for either the Rhode River or Antarctica is similar, but variation of weighting coefficients around this average spans about an order-of-magnitude [Banaszak and Neale, 2001; Neale and Kieber, 2000]. To address the implications of this variability, as well as variation in other factors, for the overall effect of UV on water-column areal production, calculations were performed of productivity in the presence and absence of UV for various combinations of conditions.

For the Antarctic, the analysis was conducted for conditions in the Weddell-Scotia confluence (WSC), for six different BWFs, and a range of ozone (350-150 DU), cloudiness (50% - clear sky), and vertical mixing (static to 100 m mixing depth). For the Rhode River, the analysis considered June-July conditions, with 8 BWFs, measured variation in spectral irradiance, and measured variation in spectral attenuation by the estuarine waters. Incident, solar UV had a strong effect on the calculated productivity of the WSC, with the daily carbon fixation per unit area typically being about 70-80% of the hypothetical productivity in the absence of UV (i.e. 20-30% inhibition) but with effects varying widely depending on conditions [Neale *et al.*, 1998b].

The strongest modulators of the overall effect of UV on WSC productivity were depth of vertical mixing and BWF. Under some conditions, productivity varied by as much as $\pm 46\%$ depending on the BWF of the assemblage (more typically around $\pm 25\%$). Ozone depletion (150 vs. 350 DU) lead to small, but significant further decreases, with the greatest effect (8% lower) under conditions of shallow mixing (ca. 25 meter mixed layer depth). Despite the generally turbid conditions of the Rhode River, calculated effects during the summer solstice period were still significant, with an average 18% lowering of calculated midday production due to UV [Neale, 2001]. Variation in conditions had a smaller effect than in the WSC, but BWF variability still had the greatest effect on calculated inhibition ($\pm 8\%$), with variations in transparency being

about as important ($\pm 7.5\%$). These results are motivating systematic studies into the causes of variability in phytoplankton response to UV.

Nitrogen availability is a key control on sensitivity, by affecting algal ability to accumulate sunscreens (mycosporine amino acids) and synthesize enzymes involved in defense [Litchman *et al.*, 2002]. As variation in BWFs is better understood, more accurate estimates of the effect of UV on global productivity can be made.

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