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Symposium-in-Print: UV Effects on Aquatic and Coastal Ecosystems

Introduction: Enhanced UV-B Radiation in Natural Ecosystems as an Added Perturbation Due to Ozone Depletion

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INTRODUCTION

This issue of the journal contains 16 articles in a symposium-in-print about the effects of UV radiation (UVR) on natural ecosystems. These articles result from a 5 year multidisciplinary project on UVR and UV effects on natural systems carried out by a network of 17 principal investigators from 13 institutions in 5 countries. The research project's aim was to test the effect of UVR on natural systems, including marine, freshwater and coastal environments, on a continental scale in the Americas. The symposium-in-print presents results of field sampling and field and laboratory experiments to document UVR effects in natural gradients, both latitudinal and altitudinal, and test hypotheses on what controls UVR exposure and UVR effects, such as dissolved organic carbon loading in lakes and the evolution of trophic dynamics in marine systems. The symposium-in-print is a unique contribution because of its multidisciplinary scope, the geographical scale of the experiments and the diversity of systems studied.

The discovery of the Antarctic ozone hole in 1986 brought the public's attention to the degradation of the ozone layer by anthropogenic contamination of the stratosphere (1). In one of the most successful stories of environmental international policy, the Montreal Protocol was implemented in 1990 to control emissions of chlorofluorocarbons and other gases creating chlorine and bromine derivatives that interact with ozone to produce two molecules of oxygen (2). Ozone absorbs radiation strongly in the UV and the presence of ozone and oxygen in the atmosphere results in the absorption of nearly all solar radiation with a wavelength of <290 nm. As a result, virtually no UV-C radiation (200–280 nm) reaches the Earth's surface, UV-B radiation (280–320 nm) is significantly absorbed (mostly by ozone) and only a small fraction (<3%) of UV-A radiation (320–390 nm) is absorbed by ozone.

The effect of UVR on natural ecosystems is function of several biotic and abiotic factors that interact directly with the ecosystem components and alter the relationship among those components (3). Additionally, the system provides feedback mechanisms that either increase or decrease the direct effect of UVR. The articles in the symposium-in-print are based on the premise that natural ecosystems have dealt with UVR as a natural stress factor since the beginning of life on Earth (4) and the present increase in UVR due to stratospheric ozone decrease is an added perturbation to the system.

Incident UVR depends on geometric factors such as Sun-Earth distance and solar zenith angle; UVR can be modified in the atmosphere by gases, aerosols and clouds and is further a function of altitude and surface albedo (5). In the water, UVR is strongly affected by dissolved organic matter that alters its transmission to depth because of absorption and scattering. Net damage by UVR is a balance between damage and repair (6). Damage is dependent on radiation exposure or amount of UVR absorbed by the organism or system. At the organism level the damage can be avoided, screened or repaired (7). At the system level deleterious effects at the population level can be ameliorated by differential damage to a predator thus decreasing predation pressure (8). In addition community composition can be altered because of differential damage to certain components. For example, damage to large cells in planktonic communities favors a microbial loop and small cells rather than net plankton and larger grazers. The research presented in the symposium-in-print focuses on the main pathways of net UVR damage on diverse natural ecosystems, emphasizing common processes along environmental gradients.

CONTRIBUTIONS TO THE SYMPOSIUM-IN-PRINT

The studies in the symposium-in-print examined the responses of ecosystems at various localities to realistic future levels of UV radiation. Key questions addressed were as follows. How will systems at different latitudes react to increased UV-B on a short-term and long-term basis? Do higher latitude systems have a higher capacity of recovery (resilience) than lower latitude systems because of their adaptation to extreme environmental stress? Each environment has specific questions, such as the role of *Salicornia* sp. in salt marshes and the effect of dissolved organic matter in lakes. With four research lines, one modeling effort and studies on the socioeconomic impact of UVR on human populations, these projects assessed UVR effects on a regional scale, from Canada to Antarctica.

Our main scientific objective was to evaluate the similarities and differences of the effect of UVB on natural marine, freshwater and marsh ecosystems. Diaz *et al.* (9) showed that conditions of low

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ozone and increased UVB (measured as radiation at 305 nm) are present everywhere from subtropical to Antarctic ecosystems in the southern hemisphere. In tropical areas increased UVR due to low ozone can happen at any time of the year. In sub-Antarctic areas low ozone and high UVB levels are predictably present in the austral spring during the time of influence of the Antarctic ozone hole. A decreasing relationship between 305 and 340 nm UVR and an increasing relationship between 305 nm UVR and ozone level was observed in higher latitudes, indicating that factors such as cloud cover tend to dominate in northern sites and that ozone levels dominate in southern sites. Rosales *et al.* (10) estimated that data provided from the National Atmospheric and Space Administration Total Ozone Mapping Spectrometer on the Earth Probe satellite are similar to radiometric data from the region within an error of 4%.

The balance between UVB to UVA is critical to the ability of biological systems to experience net damage to UVB exposure. It was predicted that areas of high UVB and clear skies, such as those found in tropical latitudes, would provide a high ratio of UVB to UVA, resulting in higher net damage by allowing for minimum repair and acclimation. At the community level the responses of the effect of UVB were experimentally assessed in large-volume enclosures filled with water with natural communities. Belzile *et al.* (11) present evidence from previous research that experiments involving mesocosms (enclosures of *ca* 2000 L) are appropriate for the determination of UVR effects on ecosystem structure (*e.g.* species composition and trophic relationships) and function (*e.g.* production and carbon cycling) in large-scale experimental units. Diaz *et al.* (12) presents an in-depth analysis of how to best mimic enhanced UVB irradiance under 30% and 60% ozone depletion, similar to low ozone and ozone-hole conditions.

The results indicate important differences in the responses of ecosystems to UVR as an added stressor. Van den Belt *et al.* (13) argued that, on a global scale, although UVR-induced changes in the marine systems may *affect* climate change, marshes are expected to be primarily *affected by* climate change. Costa *et al.* (14) showed that marshes are primarily affected by sea level change and are sensitive to climate events, such as El Niño 1997, and thus, that the impact of UVB becomes apparent when these other environmental factors relax. In marine systems UV-B enhances microbial dynamics, changing the balance between autotrophic to heterotrophic systems (15). Ferreyra *et al.* (16) suggested that such a change will impact the oceanic carbon cycle in coastal regions where half of the oceanic primary productivity occurs in <25% of the world ocean area and where most of the world fisheries are concentrated. Ferrero *et al.* (17) reproduced these results in a model showing that the shift to heterotrophy is caused by changes in predator-prey interactions between microzooplanktonic ciliates whose extreme sensitivity to UVB relaxes the grazing pressure on bacteria and suspended carbon and increases the concentration of dissolved organic matter providing excess substrate for bacteria. Furthermore, Momo *et al.* (18) model apparent competition between bacteria and small phytoplankton cells caused by decreased grazing due to UVR damage on a common predator, the ciliates. Higher heterotrophy decreases the role of the ocean as a sink for atmospheric CO_2 as more CO_2 is produced through respiration. In this way, UVB damage in marine systems increases CO_2 in the atmosphere and exacerbates climate change.

Roy *et al.* (19) showed how the shift in the balance between heterotrophy and autotrophy in marine systems exposed to UVR is achieved despite the ability of phytoplankton to counteract UVB damage and thus maintain high levels of photosynthetic activity that fuels autotrophic production. Hernando *et al.* (20) demonstrated that the effect of UVB on marine phytoplankton production is highest in areas of high stratification with high exposure. Bouchard *et al.* (21) further documented that water column mixing, representative of natural surface oceanic environments where wind introduces shear, provides an environment in which average exposure to UVB does not produce noticeable net damage to the photosynthetic apparatus of phytoplankton, as measured by Photosystem II D-1 protein. Mohovic *et al.* (22) observed how physiological adaptation can partly account for this acclimation. Phytoplankton concentrates UV-absorbing compounds (*i.e.* mycosporine-like amino acids) and photoprotective pigments (*i.e.* ββ-carotene) in cells stressed by UVB. Furthermore, Roy *et al.* (19) and Hernando *et al.* (20) showed how changes in community structure allow for replacement from sensitive to more-resistant species, characterized by high concentration of UV-absorbing compounds. Thus, mixing alleviates the effect of UVB damage to phytoplankton by facilitating cellular repair and community acclimation. These results further suggest that UVB affects ecosystem properties in marine systems, such as diversity and species richness.

Marinone *et al.* (23) measured zooplankton species richness and specific diversity in South American temperate lakes and showed that decreased community structure can be found in water bodies with high potential for UVR exposure. A threshold value of mean water column irradiance of approximately 10% of incident radiation seems to limit both species richness and diversity to minimum values. Light transmission and optical properties, and thus mean UVB exposure, are mainly controlled by content of dissolved organic matter. Because lake transparency is affected by inputs of allochthonous organic matter from surrounding basins, the authors suggested that changes in lake optical characteristics (*i.e.* changes in atmospheric conditions, changes in precipitation patterns and vertical displacement of the tree line) may result in sudden shifts in UVR distribution in the water column and thus zooplankton community structure of ''optically thin'' lakes. Libkind *et al.* (24) present a convincing argument that Patagonian freshwater yeasts display an apparent relationship between their ability to produce photoprotective compounds, their tolerance to UVR exposure and their ability to colonizing habitats highly exposed to UVR. Similarly, zooplankton community structure in oligotrophic Chilean lakes depend primarily on water transparency, with copepods dominating over daphnid cladocerans in lakes of high transparency and low levels of dissolved organic matter (25). Thus, the overall effect of UVR on freshwater systems is sensitivity to environmental change brought about by global change factors, similar to those in marsh systems.

The presence of certain pollutants, such as oil products from ships, potentates the effect of UVR on communities, enhancing heterotrophic carbon cycle in marine coastal systems (26). Similarly, in the presence of nutrient stress phytoplankton becomes highly sensitive to UVR (27). Multiple stressors, such as UVB in the presence of pollutants, or lack of nutrients have an added effect on community damage.

In summary, the publications in this symposium-in-print present new results on how UVB affects biodiversity by promoting species that are UVB resistant. This affect is common in marine and freshwater systems and occurs at all trophic levels studied to-date (phytoplankton, microzooplankton and zooplankton). Furthermore, it is clear that in the presence of multiple stressors, such as UVB radiation and nutrient deficiency or pollutants, there is an additive or multiplicative effect. Conversely, other environmental processes, such as water column mixing, have an ameliorating effect, shifting the balance from damage to repair. Ecosystems either contribute to climate change under UVB stress, as in marine coastal systems, or their sensitivity to UVB is mostly affected by climate change, as in lakes or in salt marshes.

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