Effects of solar UV radiation on shallow stream invertebrates

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Abstract

Here we summarize results from several experiments examining the efects of UV on invertebrate colonization and behaviour. During in-stream colonization experiments, total invertebrate biomass was highly inhibited by UV radiation, particularly the UVA (320 - 400 nm) portion of the spectrum. This response was largely due to the response by the dominant grazer in this system, *Dicosmoecus* sp., which increased by more than 20-fold under UVA+UVB shielded treatments compared with those exposed to full spectrum sunlight. UV also influenced trophic interactions, resulting in significantly greater algal acrrual under UV-exposed treatments due to the supression of invertebrate grazers. Further behavioural experiments on *Dicosmoecus* suggest this species most likely visually detects UVA, and may utilize levels of UVA as a visual cue to avoid UVB damage. Our results suggest that UV, particularly UVA, is a significant factor controlling colonization and potentially for stimulating drift in stream insects. Although UVA is not affected by ozone depletion, other environmental issues such as climate change, land-use, and acid deposition can affect both UVA and UVB eposure to aquatic systems through their effects on DOC concentration, and may be of even greater importance for mediating the effects of UV on aquatic ecosystems.

Introduction

There has been increasing concern and examination of the potential deleterious impacts of ultraviolet radiation (UV) on aquatic environments because of global ozone depletion. These effects can be complex, not only having direct effects on biota (Bothwell *et al.* 1993), but on trophic interactions (Bothwell *et al.* 1994, Kelly et al. 2001) and behaviour (Kelly and Bothwell 2002). The sensitivity of organisms to UV can vary considerably, presumably due to differences in pigmentation, photo-repair capacity, or other physiological differences. Stream invertebrates which utilise the exposed surfaces of river substrata may be particularly vulnerable to UV exposure because biologically significant doses of UV-B radiation can easily penetrate to these shallow depths.

Behavioural adaptations have been shown to be important for avoiding high UV (Kelly and Bothwell 2002). Stream invertebrates have long been observed to behaviourally avoid both physical and biological stresses by drifting. Alternatively, invertebrates may occupy habitats protected from high solar irradiance during peak sunlight hours such as the undersides of rocks or the shaded margins of streams. We examined the effects of solar UV radiation on benthic stream invertebrates in a series of in-stream colonization and behavioural experiments in the Little Qualicum River, British Columbia, Canada.

Methods

Colonization Experiment: A 91-day (May 19 - August 19, 1996) colonization experiment was conducted in the Little Qualicum River under varying UV exposure. Solar exposure to the streambed was manipulated by using three types of large-area (2 m^2) long-pass filters (PAR+UVA+UVB [OP4 acrylic], PAR+UVA[Mylar-d], and PAR [UF4 Plexiglas]) suspended over non-shaded portions of the river. Invertebrate community and algal biomass were measured in gravel filled colonization trays removed from underneath the filters at three-week intervals (Days 28, 49, 70, and 91) over the experiment.

Behavioural Experiments: Experiments were conducted in the following spring (May 16-20, 1997) to examine behavioural responses to solar exposure of a select number of invertebrate taxa that were found to be sensitive to UV during the 1996 colonization experiment. Behavioral responses to UV were assessed using in-stream enclosures (60 cm wide x 30 cm long x 6 cm deep). Photopreference was determined by allowing insects to chose between two different sunlight filtering treatments covering each half of the enclosure. The solar exclusion filters used were the same as those used in the long-term colonization experiment, plus an additional treatment of a neutral density screen to reduce sunlight intensity by half in combination with OP-4 acrylic, for 50% (PAR+UVA+UVB). Photopreference was determined hourly over daylight periods by counting the number of insects (50 total) in each half of the enclosure.

Light: Measurements of PAR, UVA and UVB during the two experiments were made with an Optronics OL-752 spectroradiometer equipped with a 5" submersible integrating sphere.

Results and Discussion

Figure 1 summarizes benthic community results from the 91-d colonization experiment in the Little Qualicum River under varying UV exposure. We observed a large increase (mean 20-fold) in the mean total invertebrate biomass when UVA+UVB (i.e., PAR) was screened compared with those exposed to full spectrum sunlight (PAR+UVA+UVB)(Fig 1a). The majority of this measured response was due to a single taxon, *Dicosmoecus* sp., which comprised >90% of the total invertebrate biomass under the PAR treatment by the end of the experiment (Fig 1b). The effects of the UV exclusions also tended to increase over time in comparison to full spectrum sunlight treatments, possibly due to the large increases in streambed UV-exposure which occurred over our experiment caused by seasonal declines in both river level (mean depth decreased from 42 to 24 cm) and dissolved organic carbon (DOC decreased from 1.9 to 0.9 mg/L). As a result, mean total daily UVA exposure to the streambed under the full spectrum treatments increased 3.4-fold (284 to 970 mmoles m^{-2} d^{-1}) and UVB increased 11.5-fold (2 to 23 mmoles m^{-2} d^{-1}) between the first and final week of the experiment. Screening of only UVB (i.e., PAR+UVA) had no significant effect on total invertebrate or *Dicosmoecus* biomass (Fisher LSD test, $P > 0.05$). This finding is in contrast to those of previous investigations which have observed UVB wavelengths to predominantly inhibit invertebrates. Results from this experiment suggest that UVA radiation may also affect colonization by invertebrates in shallow streams.

Inhibitory effects of UV on benthic invertebrates were also reflected in the accrual of algal biomass, as previously found by Bothwell et al. (1994). By the end of the experiment chl. *a* and epilithic C biomass were more than 50% lower under PAR treatments than under either PAR+UVA and PAR+UVA+UVB treatments (Fisher LSD test, $P < 0.05$) (Fig 1c & d). UV can reduce algal accrual directly by inhibiting photosythesis and algal growth rates (Bothwell et al. 1993), or can indirectly promote accrual by suppressing grazers (Bothwell et al. 1994) in a so-called "solar cascade". Results from our experiment suggest that indirect effects of UV on higher trophic levels appears to be the dominant factor controlling algal accrual in this system.

Figures 2 and 3 summarize data from behavioural experiments conducted on *Dicosmoecus* using in-stream enclosures. As found in the 1996 colonization experiment, *Dicosmoecus* showed a strong photo-preference for environments shielded from UVA+UVB (Fig 2b). This response was consistent over most of the day (i.e., 09:00 - 18:00) and was not influenced by solar intensity (Fig 2a). *Dicosmoecus* showed a smaller photo-preference for the exclusion of either UVB only, or 50% of all irradiance (using neutral density screening), although these were not significantly different from full spectrum sunlight treatments (Fig 2c & d). In experiments where the filters covering each half of the enclosure were switched at mid-day (Fig 3), there was a rapid response by *Dicosmoecus* to migrate back to the UVA shielded side of the enclosure (Fig 3a &

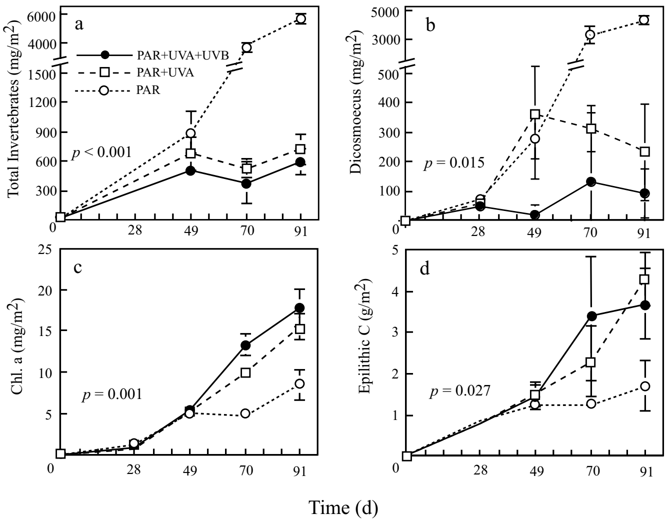

Figure 1. Summary of the results (means ± SD, n=3) for benthic invrtebrates (a. total invertebrtaes, and b. *Dicosmoecus* sp) and algal biomass (c. chlorophyll a, and d. eplilithic carbon) during the 91-d colonization experiment in the Little Qualicum River under variable UV exposure. P-values on each panel are the results of a repeated measures ANOVA comparing the three treatments.

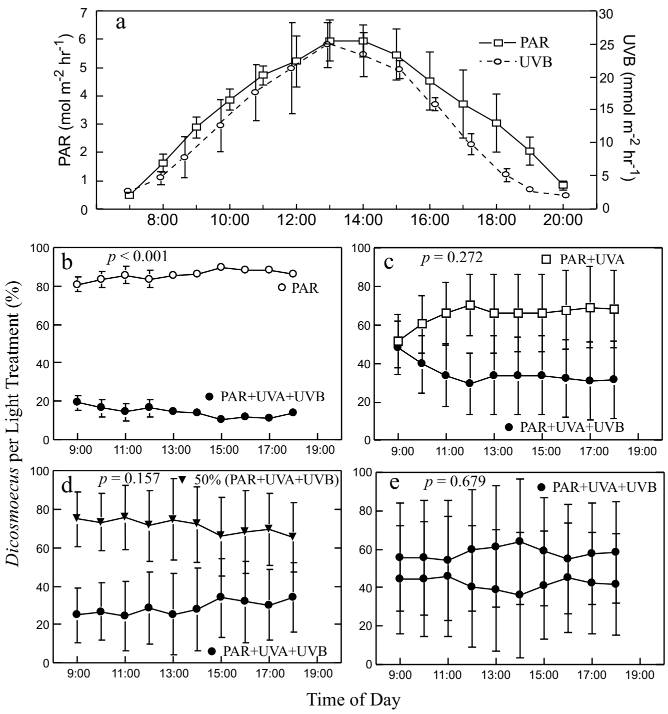

Figure 2. Results of behavioural experiments conducted on *Dicosmoecus* sp. using in-stream enclosures with paired radiation treatments covering each half of the enclosure. Values represent the proportion of *Dicosmoecus* in each half of the enclosure (mean ± SD, n=4) over daylight hours. Hourly PAR and UVB flux (mean + SD, n=4) during the experiment is shown on panel a. P-values represent the results from chi-square tests.

b). Such an immediate response to changes in the impinging radiation may indicate that this species can visually detect UVA wavelengths. Several species of dipterans, including blackflies, *Chaoborus* sp. and chironomid larvae have also been shown to detect, and behaviorally avoid exposure to UVA radiation. While near ultraviolet radiation is not known to cause substantial physiological damage to insects, these organisms may utilize levels of UVA as a visual cue to avoid UVB damage.

Our results suggest that UV is a significant factor controlling colonization and potentially for stimulating drift in stream insects. However, it is also apparent that UVA could be equally, if not more important than UVB in its effects on stream invertebrates. Although UVA is not affected by ozone depletion, other environmental issues such as climate change, land-use (e.g., deforestation), and acid deposition can affect both UVA and UVB penetration into aquatic systems through their effects on DOC concentration (Schindler et al. 1996). As such these issues may be of even more importance for mediating the UV-effects on aquatic ecosystems.

If UV flux continues to increase in stream systems, invertebrates may be faced with competing constraints on their behaviour. If individuals do not risk being predated upon by drifting from high UV environemts, they may suffer damaging effects of UV exposure. This alteration of invertebrate behaviour has the potential to also affect other trophic levels, as avoidance of UV could lead to increased availability of prey for fishes and decreased densities of grazers on plants. Already evidence of complex trophic interactions created by UV exposure has been documented (Bothwell et al. 1994, Kelly et al. 2001). These results indicate that UV effects are not always simply direct cause and effect, but as complex as the systems in which they occur.

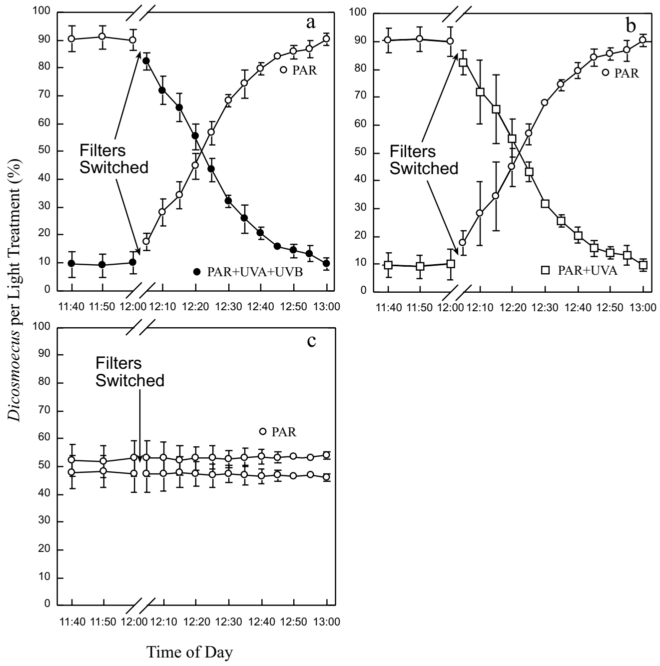

Figure 3. Behavioural experiment results for *Dicosmoecus* sp. photo-preference under paired radiation treatments. Filters covering each half of the enclosure were switched at 12:00. Values represent the proportion of *Dicosmoecus* under each half of the enclosure (mean $\pm$ SD, n=3) over time.

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