Effects of ultraviolet radiation on macroinvertebrates and algal biomass in stream and lake environments

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Abstract

There is serious environmental concern today about the depletion of the earth's ozone layer. Ozone protects the biota of the earth's surface from the harmful effects of solar ultraviolet (UV) light. The objectives of this study were to determine the effects of UV radiation on the colonization and growth of algae and macroinvertebrates in two different habitats, a lake and a stream. My hypothesis was that UV radiation would have an adverse effect on the colonization and growth of algae and macroinvertebrates in both habitats. A field experiment suggested that UV radiation had an adverse effect on the algal biomass in the lake but not in the stream: UV-shielded substrates in the lake had more biomass at the end of the 40 day sampling period than UV-unshielded substrates. I did not detect an effect of UV radiation on the growth and colonization of macroinvertebrates in either environment.

Introduction

One of today's most serious environmental concerns is the depletion of the earth's ozone layer. Although the processes leading to ozone reduction involve decades, leading some to believe that ozone depletion is a problem of the future (Worrest and Caldwell, 1986), even if corrective action is taken today, these processes will take many years to reverse. Therefore, there is widespread concern about the possible harmful effects of ozone reduction.

These concerns have foundation. Although ozone constitutes a very small proportion of the stratosphere, it plays a major role in life on this planet. One of these roles is protection: ozone is a strong absorber of ultraviolet radiation. It protects the earth's surface from a series of potentially harmful biological effects of solar ultraviolet light, commonly designated as UV-A and UV-B light. The integrity of the ozone layer has been a subject of great concern because destruction of this protective layer increases the penetration of ultraviolet radiation.

The effects of UV light can be seen in humans, animals, and plants. Most of the known biological effects are harmful. UV-B radiation can alter DNA activity in organisms, inducing inheritable genetic damage in cells with both lethal and mutagenic effects. It can transform eukaryotic cells to an altered state that can lead to certain types of cancer in the whole organism (Tyrrell, 1986). UV-B can also disrupt cellular DNA in bacteria and halt DNA and RNA synthesis in slime molds (Hader, 1986). By altering DNA activity, it can interfere with cell growth and division, as well as other vital cellular activities. Not only does UV first cause primary (DNA) damage, but it can also influence the organism's way of handling that damage (Rupert, 1986). Fortunately, there are various types of DNA alterations that act to repair some of this damage in both prokaryotic and eukaryotic cells (Rupert, 1986), although irreversible damage can be inflicted.

UV radiation also affects higher levels of biological systems. UV-B radiation has been shown to decrease photosynthetic activity (Bothwell et al., 1994). Even slightly increased levels of exposure to UV-B light can affect the development, motility, and photoorientation of microorganisms (Hader,1986). Although these levels of exposure did not immediately kill the cells, they had a catastrophic effect on the survival of the organisms.

Over 100 plant species have been screened for sensitivity to UV radiation and have displayed a wide range of responses (Teramura, 1986). Yet despite this large amount of information, it is not clear whether UV radiation, as a result of ozone depletion, is the sole factor involved in this damage. One possible reason for this is that nearly all information on the biological effects of UV comes from experiments under controlled conditions that are rarely found in nature. Under actual field conditions where multiple environmental factors operate, organisms would commonly experience multiple stressors simultaneously.

The possibility of increased exposure to UV radiation has caused great concern about the stability of the ozone layer. The destruction of ozone molecules has increased in the past few decades due to human activity: the NO_2 from fertilizers used in the agricultural industry, the NO from aircraft emissions, and the halogenated compounds from the man-made cholorofluorocarbons have all been implicated in destroying ozone. The quantification, however, of the possible ozone depletion and related increases in UV penetration due to these agricultural and domestic activities has usually been based on theoretical models (Brasseur and Rudder, 1986).

The objectives of this study were to determine the effects of UV radiation on benthic macroinvertebrates and algae in two different aquatic habitats. A stream and a lake habitat were used to study the community structure and density of macroinvertebrates with and without exposure to UV radiation, as well as the accumulation of algal biomass with and without exposure to UV radiation. My hypothesis was that UV radiation would have an adverse effect on the colonization and growth of algae and macroinvertebrates in both habitats.

Methods

Study Site

I conducted my field experiments in conjunction with Ms. Sarah Sawicki, who also used the same equipment and locations. The stream study area was a riffle in Tenderfoot Creek (Gogebic Co., Michigan) (Fig. 1). The stream experiment was conducted in an easily accessible, shallow area. The depth of the water at the site varied from 0.4 meters at its deepest at the beginning of the summer 1995, to about 0.25 meters deep at its shallowest during the middle of the summer 1995. The depth of the water was more often closer to the shallower depth for most of the summer. The average velocity of the stream water for the 6 week sampling period was 0.44 m/s. Trees and other vegetation did not shade the study site.

The lake experiment was conducted in Crampton Lake (Vilas Co., Wisconsin). The experiment was conducted about 10 meters from the dock in the northwest corner of the lake. The depth of the water at that site was approximately 2 meters. Trees and other vegetation did not shade the study site.

Experimental Design

Algae and macroinvertebrates with and without exposure to UV radiation were collected from styrofoam wedged in plastic baskets in each habitat. Baskets were situated in pairs (blocks for statistical analysis), one open to all solar radiation, designated (+)UV, and one shielded from UV radiation, designated (-)UV. The (-)UV basket had a sheet of UV-absorbing plexiglass covering the entire top opening of the basket, and secured to the basket with a single large rubber band. The plexiglass shielded the algae and macroinvertebrates on the styrofoam from exposure to ambient UV radiation, and therefore served as the UV-reduced treatment. The (+)UV basket did not have this UV-absorbing plexiglass and thus the algae and macroinvertebrates were exposed to UV. The baskets themselves had many openings on all four sides, so as to allow water flow, or any other moving material or organisms, through the baskets. Eight pairs of (-)UV and (+)UV baskets were placed in each of the two aquatic habitats.

A. 

B. 

Fig. 1. The study sites where I conducted the field experiments: A. the stream environment, B. the lake environment.

For each habitat, the eight pairs of baskets (16 total) were attached to a floating wooden apparatus to keep the baskets together and accessible. The wooden frame, 1.27 m X 1.09 m, had a stabilizing crossbar with five plastic rods U-bolted at the ends and at the crossbar. Long pieces of styrofoam were glued and tied to the outside edge of the frame to keep the entire sampler afloat. The plastic rods, being bolted underneath the rack, also ensured floatation. Each basket was tied in several places to the plastic rods with microfilament to secure them to the wooden rack. Since the upper lips of the baskets were attached to the plastic rods which sat on top of the water, the styrofoam pieces, being at the bottom of the 3.8 cm deep baskets, were therefore completely submerged. To further secure the wedged styrofoam pieces to the baskets and also to keep them submerged, a single piece of twine was used to secure the styrofoam wedges to the bottom of the basket. (The twine gave little or no obstruction to algal or macroinvertebrate growth.) The racks themselves were anchored down with cement blocks, with four blocks attached at the corners for the stream apparatus, and one block attached at one corner for the lake apparatus.

Experimental units were sampled on days 10, 17, 27, 33, and 41 for the stream and days 10, 16, 26, 32, and 40 for the lake. Sampling was done in conjunction with Ms. Sawicki. Two styrofoam cores were taken from the (+)UV basket and two from the (-)UV basket, totaling 32 cores from each habitat and 64 cores total per sampling period. Light readings were taken periodically with a meter, and current velocity was also measured during each sampling period. In general, the lake units were cored and processed in the morning, the stream units were cored and processed in the afternoon, and biomass was measured the following day. (Although it appears that we sampled the two habitats on different days, we set up the lake experiment one day earlier than the stream experiment; thus, different sampling day numbers.) The stream baskets required daily cleaning of accumulated debris that impeded current flow and light penetration.

Sampling Design

The same procedures were used for processing the cores from each habitat. From each habitat, we randomly collected two styrofoam cores exposed to UV radiation (ambient treatment) and two styrofoam cores without exposure to UV (UV-reduced treatment) from each of the eight designated pairs for each sampling period. The same size plastic coring device (7.5 cm^2) was used at each habitat and sampling period. The cores were placed algae-side up in small, labeled tupperware containers, with each pair and treatment having its own container (32 containers for each habitat). A small amount of stream/lake water was also placed in the containers to keep the cores moist. Once the 64 styrofoam cores were taken, they were carefully transported back to the laboratory in a cooler with ice to keep them cool and dark before processing . Water and weather conditions were also noted during each sampling period.

In the laboratory, I collected all macroinvertebrates from the styrofoam cores and the collected water by using forceps to manually remove the invertebrates. Each sample was preserved in a separate, previously labeled vial with 70% ethanol. I then counted, sorted, and identified each invertebrate to order, and in most cases, to family under a dissecting microscope. Once the macroinvertebrates were removed, one core from each habitat was then used to determine algal biomass. (The other styrofoam core was used in Ms. Sawicki's part of the experiment to analyze chlorophyll A and phaeophytin.) Using the dull side of an x-acto knife, the upper side of each core was carefully scraped of its biomass from upper side of the core. The scraped mass was placed onto a previously weighed and labeled aluminum pan. The pan was then allowed to dry overnight in a preheated drying oven set at 51°C. After approximately 24 hours, the aluminum pan with dried biomass was weighed. The biomass for that particular core could be calculated by subtracting the weight of the pan alone from the weight of the pan plus biomass. Data were analyzed for the final sampling date only, using randomized blocks ANOVA. Blocks were basket pairs and the treatments were (+)UV and (-)UV. Data from the different habitats (lake or stream) were analyzed separately.

Results

Response in algal biomass

In Tenderfoot Creek, Algal biomass under (-)UV and (+)UV treatments accumulated at about the same rate until day 17, with little growth under either condition, but increased sharply from 17-40 days in both treatments (Fig. 2). The (-)UV biomass accumulated at its greatest rate between day 17 and day 27, where its growth was 0.0848 mg/cm^2 per day; the slowest rate between days 27 and 33 at -0.0004 mg/cm^2 per day. The (+)UV biomass accumulated at its greatest rate between days 33 and 41 at 0.0702 mg/cm^2 per day; its slowest rate was between days 10 and 17 at 0.00246 mg/cm^2 per day. The greatest difference in biomass was at day 27: 0.92611 ± 0.17 mg/cm^2 ($x \pm SE$) for (-)UV compared to 0.61078 ± 0.1 mg/cm^2 for (+)UV; a difference of 0.31533 mg/cm^2 (Fig. 2). Due to the high variation, there was no significant effect of UV radiation on final algal biomass in the stream ($F_{1,11} = 0.222$, $p = 0.647$) (Fig. 4).

In Crampton Lake, there similarly was little accumulation of algae during the first 16 days in either (+)UV and (-)UV treatments. Biomass increased substantially from days 26 to 40. The largest increase for (-)UV biomass was between days 16 and 26 at 0.0031 mg/cm^2 per day, and the smallest increase between days 0 and 10 at 0.0017 mg/cm^2 per day. For (+)UV biomass, the largest increase also was between days 16 and 26 at 0.0225 mg/cm^2 per day, and the smallest rate was between days 32 and 40 at -0.0133 mg/cm^2 per day. The greatest difference in lake biomass was at day 40: 0.5286 ± 0.14 mg/cm^2 for (-)UV compared to 0.2345 ± 0.04 mg/cm^2 for (+)UV; a difference of 0.29413 mg/cm^2 (Fig. 3). There was a two-fold difference in the final means for the UV treatments in the lake, but due to high variation, this difference was only marginally significant ($F_{1,11} = 4.137$, $p = 0.067$).

The final stream biomass was higher than the final lake biomass, with a difference of 1.03 mg/cm^2 for (-)UV biomass and 1.1 mg/cm^2 for (+)UV biomass between the two habitats (Fig. 4). The stream substrates were noticeably more brown than the lake substrates. The standard errors are generally less for the lake means than for the stream means; and with the exceptions of day 41 in the stream and day 16 in the lake, the standard errors are less in the (-)UV treatment than in the (+)UV treatment in both habitats.

Response of Macroinvertebrates

The numbers of macroinvertebrates in the stream showed no apparent relationship to the treatments. The (+)UV substrates on day 17 had a very large number of invertebrates as compared to substrates other days. The invertebrate numbers on days 27, 33, and 41 were lower and relatively constant (Fig. 5). No macroinvertebrates were found on the lake substrates.

Four different orders of invertebrates colonized the stream substrates: Diptera, Ephemeroptera, Plecoptera, and Trichoptera (Table 1). On days 10 and 17, most of the invertebrates were chironomid midges (Diptera). Days 27, 33, and 41 showed relatively low numbers of Diptera, and a greater number of Ephemeroptera. Plecoptera were found only on day 17, and Trichoptera (Hydropsychidae) only near the end of the experiment.

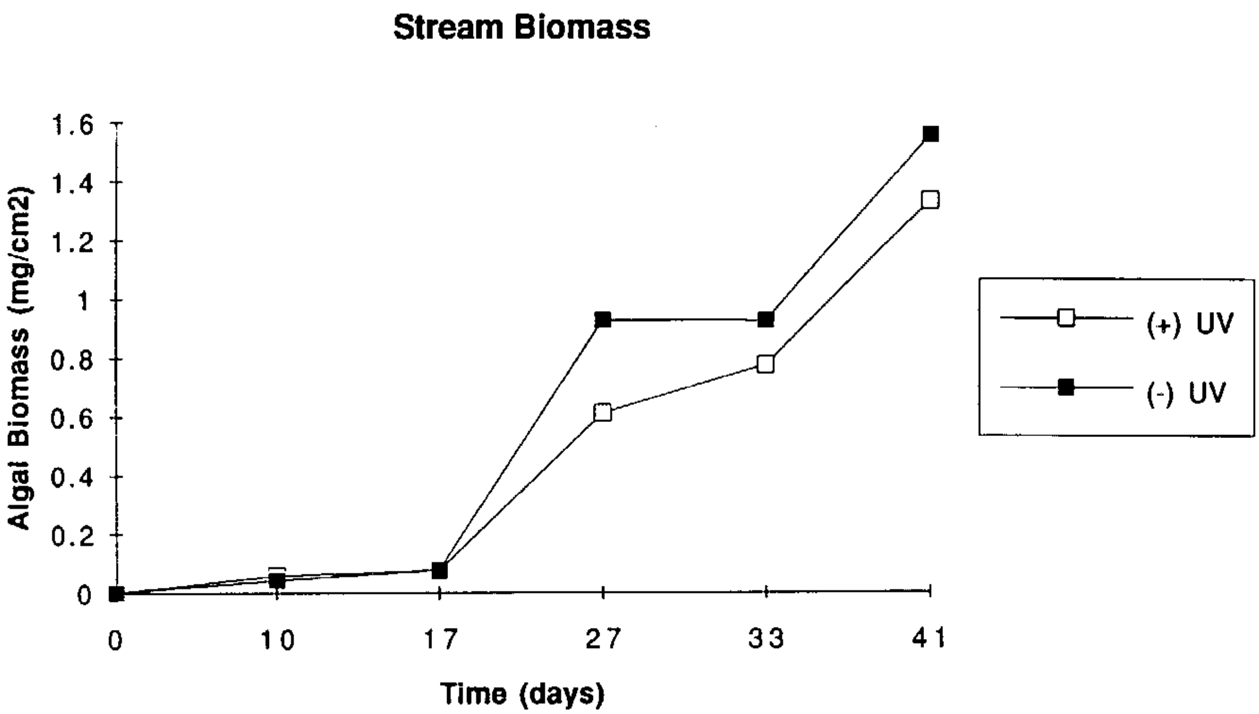

Fig.2. Accumulation of algal biomass for (-)UV and (+)UV treatments in the stream over the 41-day experiment.

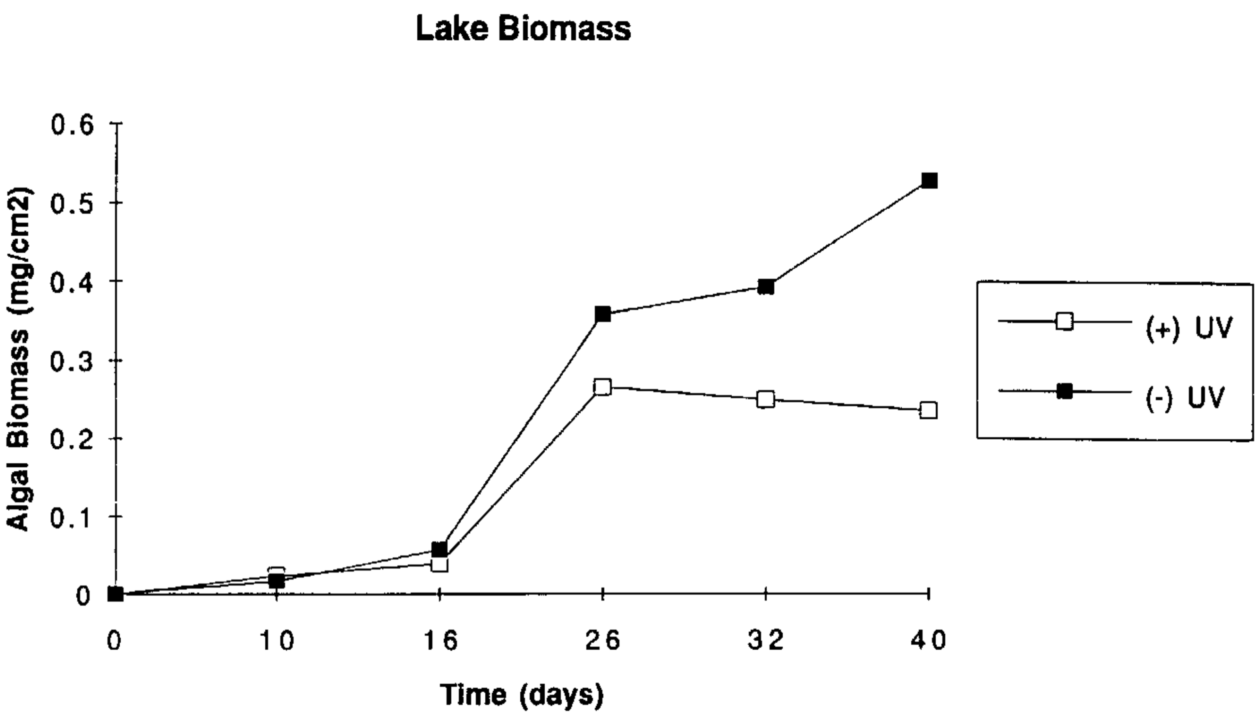

Fig.3. Accumulation of algal biomass for (-)UV and (+)UV treatments in the lake over the 40-day experiment.

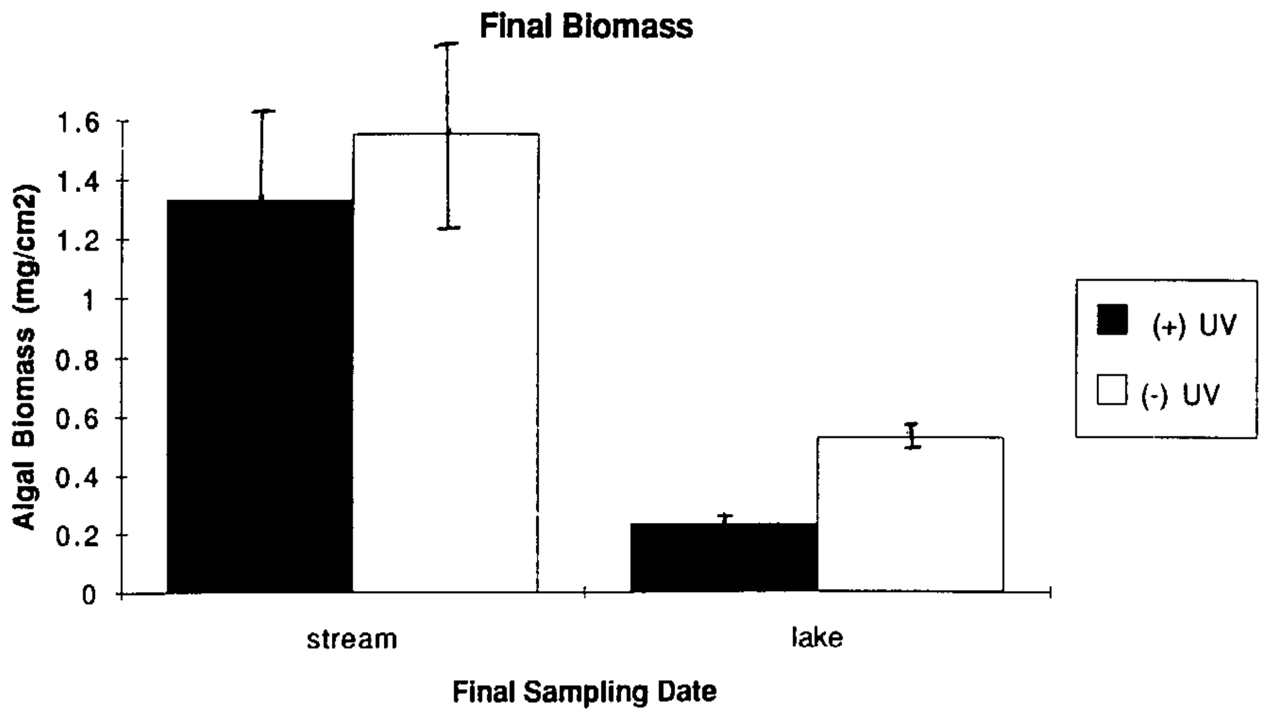

Fig.4. A comparison of the final algal biomass between (-)UV and (+)UV treatments in the stream and in the lake. The final stream biomasses are approximately 10 times greater than biomasses in the lake.

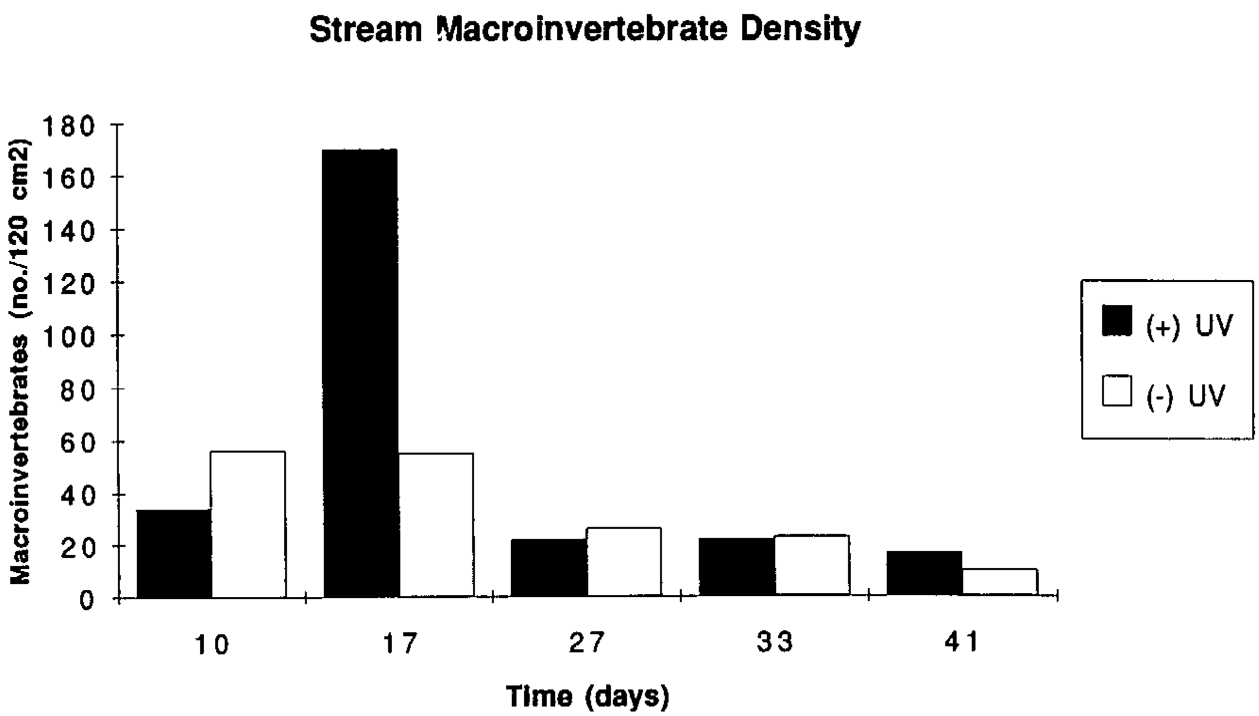

Fig.5. Numbers of macroinvertebrates collected from experimental substrates in the stream over the 41-day experiment.

STREAM MACROINVERTEBRATE NUMBERS

Day	10	17	27	33	41
Diptera					
Chironomidae	90	111	6	1	1
Simulidae	0	96	0	0	0
Ephemeroptera	0	16	39	36	23
Plecoptera	0	2	0	0	0
Trichoptera					
Hydropsychidae	0	0	2	3	3
Total	90	225	47	40	27

Table 1. Numbers of macroinvertebrates collected for (-)UV and (+)UV treatments in the stream over the 41-day experiment.

Discussion

The results of my study suggested that UV radiation had a negative effect on the accumulation of algal biomass in the lake, but not in the stream environment. Although only marginally significant, the (-)UV treatment in the lake had more biomass at the end of the 40-day experiment than the (+)UV experiment. It appears that many more factors, other than just UV radiation, played a role in modifying the accumulation of algae. There were, however, several limitations to this study that may explain the lack of response to UV radiation in the stream as compared to the marginal response in the lake. In the stream, the plexiglass over the (-)UV treatment was designed to shield only the UV radiation and allow light penetration, but at times the plexiglass blocked other the light as well. Leaves and other debris fell on top of the glass, partially or even completely blocking the light from reaching the substrate underneath. There was also foam accumulation on some of the units, both (-)UV and (+)UV, which also impeded light and shaded the substrate. In both the lake and the stream, the plexiglass itself had a thin film, perhaps microbial, growing mainly on the underside of the glass, which was cleaned frequently. This film not only may have impeded the light, but may have altered the accumulation of algae or macroinvertebrates. Heavy rains and storms broke the rubber bands securing the plexiglass to the baskets, sometimes temporarily displacing the plexiglass on the (-)UV treatment. During these times, both the (-)UV and (+)UV treatments were subject to UV penetration.

Overall, the results showed that the final stream algal biomass was much greater than the final lake biomass. It appears that the proximity of surrounding vegetation and debris accumulation have roles in biomass growth. Since the stream had moving water, more debris was caught on the sides of the baskets, as well as on the rack itself. Some of this debris may have lodged in the styrofoam and collected as biomass. The debris may also have served to shade the algae and macroinvertebrates. Its presence may have prevented algae and invertebrates from being carried away by flow. The lake experiment was in still water and had much less debris caught in and around the baskets, and on the rack itself. Any algae accumulating on these units may have been easily dislodged. The stream apparatus was also more exposed to allochthonous material. The lake apparatus was placed quite far from surrounding vegetation and was not as susceptible to falling leaves and other allochthonous material. The lake experiment was also more exposed to the wind and rain which may have reduced algal and macroinvertebrate accumulation. Other factors, such as nutrient concentrations, also may have contributed to the difference.

The results of this experiment suggested that there was no significant effect of UV radiation on macroinvertebrates in either habitat. There was high variation in the numbers of macroinvertebrates collected from the stream. The variation may have been related to other factors, such as the time of the year or breeding season of the individual species. For example, on day 17, the stream (+)UV treatment had a very large number of blackflies (Simulidae), probably because it was the black fly hatching season. Bothwell's conclusion that macroinvertebrates are sensitive to UV radiation (Bothwell, et al. 1994) was not apparent in my experiment.

No macroinvertebrates were found on the lake substrates. This could be due to high exposure to wind and rain, thereby preventing invertebrates from being able to colonize. Also, since there was little growth of algaė in the lake (Sawicki 1995), food may have been lacking.

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