Ultraviolet Radiation in Aquatic Ecosystems

BIOS 569 – Practicum in Field Environmental Biology

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Abstract

Ultraviolet radiation (UVR) can harm many types of aquatic organisms, but its penetration into different habitat types (lakes, streams, wetlands, and vernal pools) remains largely unknown. This survey studied the amount of UVR penetrating different aquatic systems that have contrasting vegetative canopy and water chemistry. Water and canopy density was sampled from vernal ponds, streams, wetlands, and lakes on the University of Notre Dame Environmental Research Center. Using data on canopy and UVR absorbance, the amount of UVB penetrating 5 cm was calculated. All habitats were sampled twice: once in early June and once in early July. Lakes had the lowest absorbance of UVR and the highest levels of UVR irradiance at 5 cm. Vernal pools had the greatest canopy density, the greatest UVR absorbance, and consequently, the least UVR irradiance. UVR penetration would be expected to be highest in lakes and streams and lowest in wetlands and vernal ponds. Thus it appears UVR flux into lakes, streams, and wetlands may warrant concern, but UVR is not likely a critical factor affecting organisms in vernal ponds.

Introduction

Ultraviolet radiation (UVR) is a potentially important physical factor in aquatic ecosystems, as it may have a variety of detrimental effects on aquatic organisms (Williamson 1995). Most harmful affects of UVR are largely due to UVB, the highly energized short wavelengths (280-320 nm; Schindler et al. 2001). For example, UVB has been shown to inhibit algal photosynthesis, inhibit phytoplankton and bacterioplankton growth, and contribute to increased amphibian mortality. (Bothwell et al. 1994; Benner et al. 2000; Williamson 1995). Given these effects, increased UVB may lead to decreased biomass productivity, potentially disrupting key food web processes (Hader et al. 1998). As such, there is a need to better understand what controls UVB penetration and flux into aquatic ecosystems.

Two major controls of UVB penetration into freshwaters are dissolved organic material (DOM) and plant canopy. DOM, a heterogeneous composition of plant, microbial, and animal particles that are in various stages of decomposition, is the primary absorber of UVB (Schindler et al. 2001). DOM absorption of UVB can lead to photodegradation (Hader et al. 1998). This could lead to a positive feedback where UVB exposure also leads to more UVB flux and less DOM protection. Plant canopy also influence the amount of ultraviolet radiation by absorbing and reflecting UVB. Plant canopy may remove up to 90% of the incident light (Schlinder et al. 2001).

UVB likely differs across types of aquatic ecosystems that have different amounts of canopy cover and DOM. A recent review found that bogs contain the most DOM, whereas wetlands less and rivers have less (Wetzel 2001). However, this study did not account for canopy and did not specifically consider UVB. Different categories (bogs versus lakes) were also not compared within the same landscape, leading to the potential that landscape characteristics may account for these differences. Many recent studies have assessed how canopy affects UVB. Grant (1991) found that greater than eighty percent of UVB reached the ground floor in a corn field, whereas Yang (1993) found that on average only about twenty-five percent of UVB reached the bottom of a hardwood forest.

UVB flux into lakes can also differ according to season. Seasonal differences in UVB penetration depends on the total flux of UVB and seasonal stratification patterns (Hargreaves 1997). Total solar radiation increases during the spring into summer north of the Equator. For example, the UV intensity at any depth in Discovery Bay (California) was found to be greater in March than in December (Fleischmann 1989). Greater fluxes in UVB also influence the photodegredation of DOM leading to more UVB penetration (Hargreaves 1997). This effect is likely most significant for shallow water and clear lakes.

This survey examined the flux of UVB penetration in different aquatic ecosystems in the same landscape. I surveyed vernal pools, wetlands, streams, and lakes on University of Notre Dame Research Center (UNDERC). The definition of vernal pools used was small pools of water that dry up as the summer progresses. In this study, wetlands refer to marshes and bogs. I predicted that UVB exposure would be greater in lakes than in streams, vernal pools, or wetlands. Streams, wetlands, and vernal pools may have high amounts of DOM and canopy to block UVB (Schindler et al. 2001). Lakes were predicted to have the highest exposure to UVB because of low canopy and low amounts of DOM.

Materials and Methods

Ten vernal pools, ten wetlands, ten streams, and ten lakes were haphazardly chosen on the UNDERC property (Fig. 1; Table 1). Each site was sampled once from May 31 to June 2 and again from July 13 through July 15. From the June sampling period until the July sampling period vernal ponds 3, 11, and 25 had dried up as well as wetlands 3,5, and 6 and stream 9. At each site the conductivity, pH, and temperature were measured using a Quanta (Hydrolab Corporation, Austin, Texas). The canopy density was also determined using a densitometer from the center of the habitat. Due to time constraints, we assumed the canopy of lake centers was zero. Water samples were taken from the top of the water at each habitat using a 100mL plastic bottle. The water was then filtered with a pre-rinsed 0.2 micrometer membrane filter and chilled in amber bottles until analysis. A scanning spectrophotometer (Ocean Optics USB2000, Florida) was used to measure the UVB absorbance. To determine the average

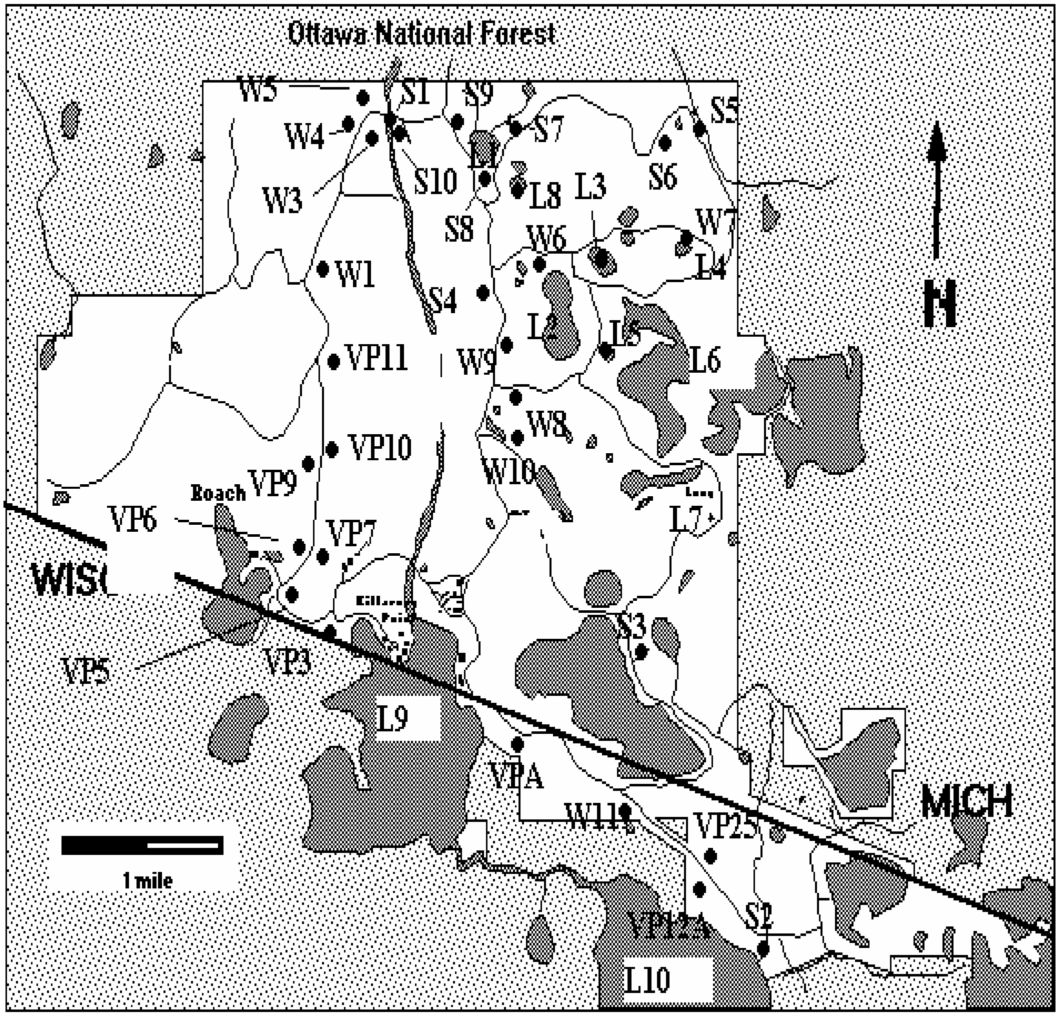

Fig. 1. Map of the Aquatic Sites Sampled. VP = Vernal Pool, W = Wetland, S = Stream, and L = Lake.

Table 1. GPS coordinates of the sites sampled.

Habitat	NUMBER	GPS N	GPS W
Vernal Pool	3	46*13'31.3"	89*32'22.1"
Vernal Pool	5	46*13'41.6"	89*32'36.0"
Vernal Pool	6	46*13'44.3"	89*32'31.4"
Vernal Pool	7	46*13'44.3"	89*32'30.1"
Vernal Pool	9	46*13'53.5"	89*32'22.9"
Vernal Pool	10	46*14'08.2"	89*32'20.6"
Vernal Pool	A	46*13'09.2"	89*30'58.8"
Vernal Pool	11	46*14'31.2"	89*32'26.5"
Vernal Pool	25	46*12'46.1"	89*29'51.7"
Vernal Pool	12A	46*12'46.7"	89*29'52.5"
Wetland	1	46*14'51.4"	89*32'21.2"
Wetland	3	46*15'06.2"	89*32'25.1"
Wetland	4	46*15'11.3"	89*32'20.1"
Wetland	5	46*15'30.9"	89*32'11.1"
Wetland	6	46*15'01.9"	89*30'52.7"
Wetland	7	46*15'06.4"	89*29'46.6"
Wetland	8	46*14'30.3"	89*30'55.6"
Wetland	9	46*14'31.2"	89*31'10.3"
Wetland	10	46*15'15.3"	89*31'07.1"
Wetland	11	46*12'47.7"	89*30'01.4"
Stream	2	46*12'22.1"	89*29'05.7"
Stream	1	46*15’33.1	89*32’02.4”
Stream	3	46*13'22.3"	89*30'05.3"
Stream	4	46*14'52.5"	89*31'10.6"
Stream	5	46*15'11.4"	89*29'27.5"
Stream	6	46*15'27.1"	89*30'12.2"
Stream	7	46*15'33.5"	89*30'56.5"
Stream	8	46*15'15.9"	89*31'10.2"
Stream	9	46*15'31.4"	89*31'51.3"
Stream	10	46*15'32.5"	89*32'01.7"
Lake	1	46*15’23.1”	89*31’20.2”
Lake	2	46*14'53.5"	89*30'39.1"
Lake	3	46*15'04.4"	89*30'29.0"
Lake	4	46*15'06.4"	89*29'46.6"
Lake	5	46*15'07.3"	89*29'45.7"
Lake	6	46*14'50.5"	89*30'16.5"
Lake	7	46*14'09.4"	89*29'58.8"
Lake	8	46*15'16.4"	89*31'06.4"
Lake	9	46*13'25.3"	89*31'21.1"
Lake	10	46*12'13.1"	89*29'04.9"

UVB absorbance on each water sample, wavelengths 280nm through 320nm were averaged. To estimate the flux of UVB penetrating the stream, the Stream-UVB model was employed (Frost, unpublished data). The model, $I_Z = I_O\ (C_r) * \exp^{(-Kd *z)}$, was used to determine the amount of UVB penetrating the aquatic habitat. Z represented the water column depth, which was set to 5 cm, and I_o represented the irradiance above the canopy, which was set to 2220000 W cm^{-2}- an average mid-day value for cloudless days in this region (Frost, P. unpublished data). C_r represented an index of attenuation of UVB by the forest canopy. This was calculated using the equation $C_r = -0.431 + 1.5787 \exp^{(-m)} – 0.0435 \ln(\Theta)$, where m was the proportion of canopy cover and Θ was the solar zenith angle, which was set to 45^o, a normal mid-summer value for this geographic region (Grant et al 1991). If Cr was less than zero, we set its value to zero. K_d represented the attenuation coefficient and was calculated using the equation $K_d = -\ ((\ln 10^{(2-\text{Absorbance})})/0.01)$. Categorical differences were identified by using one-way ANOVA tests in SYSTAT 10. A Tukey’s multiple comparison test was used to ascertain which habitats were different. A nonparametric one-sample KS/Lillifors test was done to make sure that the data was normally distributed. Natural log transformations of UVB reaching 5 cm and absorbance were done to normalize the data distribution.

Results

In June the canopy cover was the greatest over vernal pools and had an average canopy cover of 81.7%. Streams had an average canopy cover of 59.3%, and wetlands had an average of 43.4% (Fig. 2). The difference between the habitat canopy was insignificant (ANOVA p=0.065). In July canopy cover differences were significant between the different aquatic habitats (Fig. 2; ANOVA p=0.024). Canopy cover was greatest over vernal pools with an average of 97.5%. Canopy cover was 57.9% over streams and 46.4% over wetlands. The change in canopy cover from June to July was not significant for any of the habitats.

UVB absorbance for both sampling dates is shown in Figure 3. Differences in absorbance were significant in June (ANOVA p=0.001), with the highest absorbance value of 0.803 cm^{-1} occurring in vernal pools. Wetlands had an average absorbance value of 0.539 cm^{-1}, streams had an average absorbance value of 0.388 cm^{-1}, and lakes had the lowest absorbance rate with a value of 0.195 cm^{-1}. In July the absorbance was significant (ANOVA $p<0.001$) and followed the same pattern. The vernal ponds had an average absorbance value of 1.400 cm^{-1}, wetlands had an average absorbance value of 0.616 cm^{-1}, streams had a value of 0.56 cm^{-1}, and lakes had a value of 0.188 cm^{-1}. An increase from about 0.803 cm^{-1} to 1.400 cm^{-1} in vernal pools was significant (ANOVA p=0.021), but other habitats were unchanged through the summer.

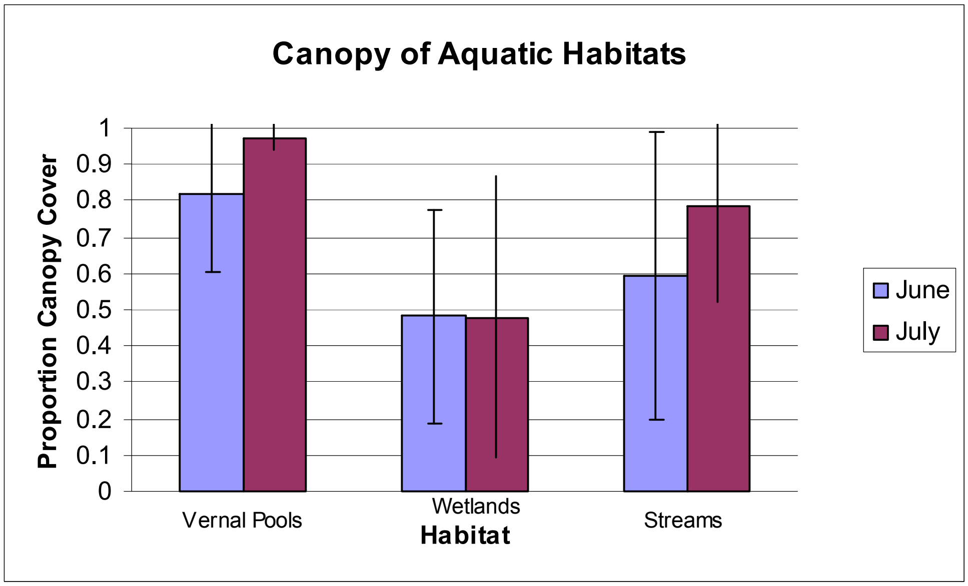

Fig. 2. Canopy cover of UNDERC aquatic habitats. These data were collected using a densitometer at the water's surface in the center of each surveyed habitat. The arrow bars represent standard deviation.

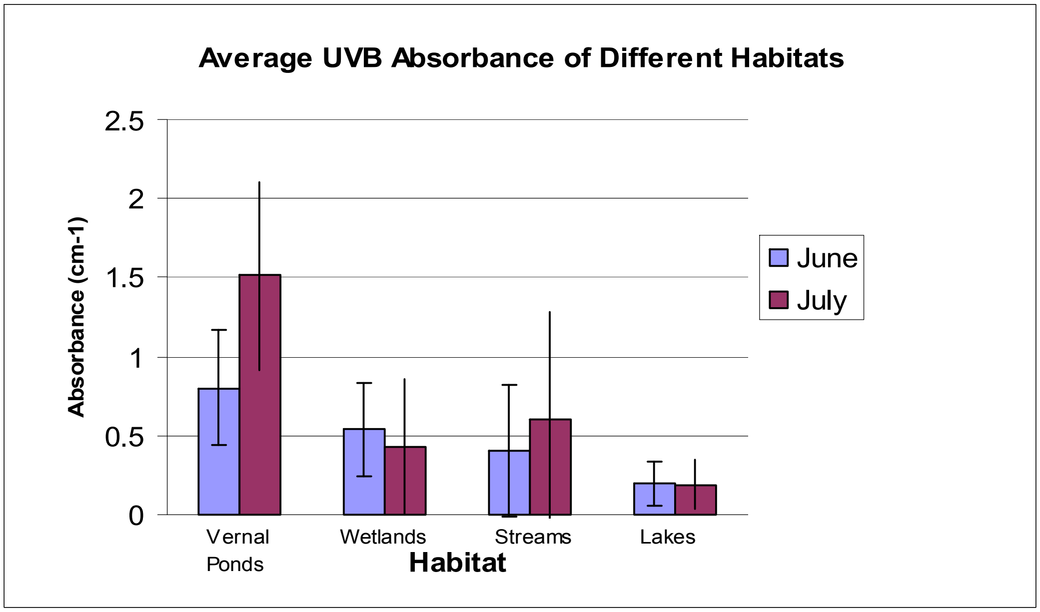

Fig. 3. Average UVB (280-320nm) Absorbance of Aquatic Habitats. The arrow bars represent standard deviation.

Figure 3 shows the amount of UVB reaching a depth of 5 cm in each habitat. In June differences in the amount of light reaching 5 cm below the water surface of the different aquatic habitats was significant (ANOVA p=0.001). 17.5% of atmospheric UVB reached 5 cm in lakes, followed by 6.6% in streams, followed by 3.9% in wetlands, and finally 0.026% of light reached 5 cm in vernal ponds. The same significant trend was followed in July (ANOVA p=0.004). 20.5% of atmospheric UVB reached 5cm in lakes, 13.8% in streams, 5.6% in wetlands, and $8.2*10^{-7}$% in vernal pools. Irradiance at 5 cm increased from June to July in wetlands, lakes, and streams. This increase was significant in lakes (ANOVA p=0.004) and streams (ANOVA p=0.004).

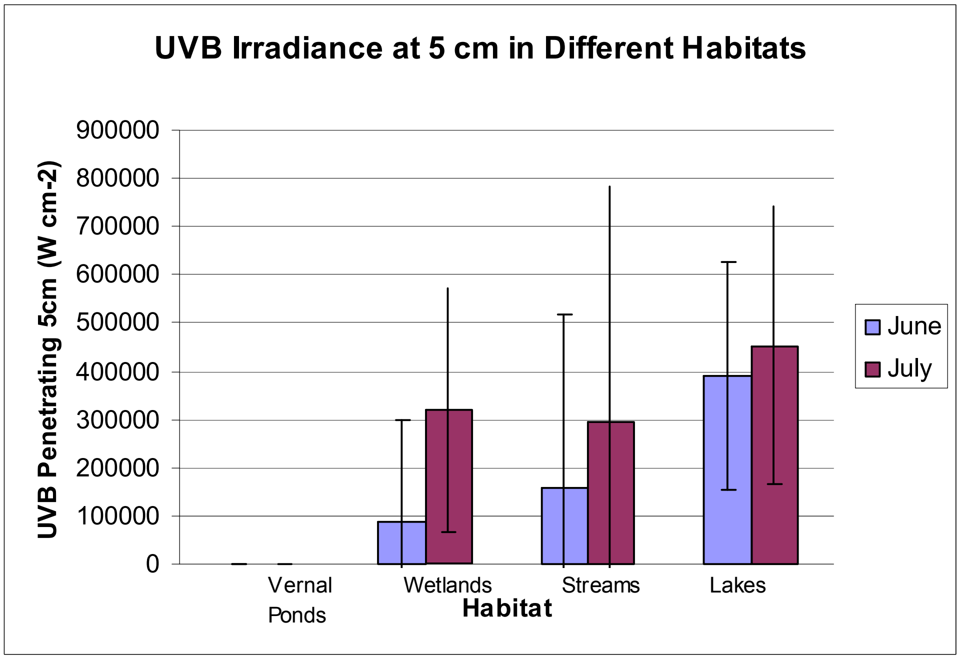

Fig. 3. Amount of UVB Reaching 5cm in Different Aquatic Habitats. The vernal pool values are so small that they do not appear on the graph, but there is a decrease in light irradiance from June to July. These values were calculated using the absorbance and canopy in equation. The arrow bars represent standard deviation.

Discussion

Ultraviolet radiation was greater in lakes than in streams, vernal pools, and wetlands. This is partially because the lakes used in this study had canopy cover only along the shore, leaving most of the lake with little canopy protection. Plant canopies provide protection by absorbing and reflecting UVR (Schindler et al. 2001). Lakes had the lowest UVB absorbance value likely because they contain the least amount of dissolved organic material (J. Larson, personal communication). Since lakes had a low UVB absorbance, more incident light was able to penetrate 5 cm. The combination of low UVB absorbance and no canopy results in the highest UVB irradiance at 5 cm of any surveyed habitat. The amount of irradiance in lakes increased significantly from June to July. This could be due to solar radiation photodegrading and mineralizing DOM, leaving less DOM to attenuate UVB. DOM is responsible for short-wavelength absorption in water, and UVB radiation has been found to break down DOM; decreasing absorbance, mineralizing and increasing its bioavailability (Hader et al. 1998). A second hypothesis for this increase is that there is less surface flow into the lake as the summer goes on, therefore there is less DOM flowing into the lake (cite). The combination of no canopy, low absorbance, and high UVB irradiance means that lakes are subjected to a high amount of atmospheric UVB.

A high amount of UVB likely penetrates streams because they have an intermediary canopy and a moderately low UVB absorbance. Streams appeared to be most variable as some streams had very low canopy density, similar to wetlands, while others were completely covered by canopy, similar to that of vernal pools. Streams had lower absorbance than wetlands and vernal ponds. This could be because this water has less contact with rich soils. Despite having a higher average canopy density, streams were found to have a greater amount of UVB flux reaching 5 cm than wetlands. The change in UVB irradiance from June to July increased significantly. Explanations for the increase in UVB irradiance in lakes may also explain the increase in streams; photo-reactions in the DOM pool and less inputs of organic material.

Lower canopy density and lower UVB absorbance means that more UVB flux penetrates wetlands than vernal pools. In contrast, wetlands are exposed to less UVB than streams and lakes because of their higher UVB absorbance and because of higher canopy density (than lakes). While more shaded, wetlands did not have large trees, but only small trees and grasses for protection. This led to lower canopy densities compared to vernal pools and streams. Wetlands had lower UVB absorbance rate than vernal pools, possibly because they contain less DOM. Organic matter content is significantly higher in wetlands than in streams and lakes, likely explaining the higher UVB absorbances (Chin et al.1998). Another reason that wetlands had higher UVB absorbances than streams is because the water moves only slowly, allowing more DOM to accumulate. Because wetlands had higher UVB absorbance values than streams and higher absorbance and canopy values than lakes, they allowed less UVB to penetrate 5 cm.

These results show that ultraviolet radiation on lakes, streams, and wetlands may be a significant factor affecting communities. A high incidence of atmospheric light is reaching into the water and this potentially has profound effects on the aquatic organisms. UVR is a stress on bacterioplankton, which plays an important role in the carbon cycling in aquatic ecosystems by taking up DOM and remineralizing it (Hader et al. 1998). UVR also inhibits algal photosynthesis, and stresses the fish life in lakes and streams (Bothwell et al. 1994; Williamson 1997). Although many harmful affects of UVR have been identified, more study is needed to determine the implications for entire ecosystems (Williamson 1995).

Vernal pools were most protected from ultraviolet radiation. They had the greatest canopy cover in both June and July. Vernal pools also had the greatest UVB absorbance, likely because of their high content of DOM (J. Larson, personal communication). Because the vernal pools absorbed the most light and had the greatest canopy, they had the least amount of light reaching 5 cm. Although the absorbance rate increased significantly from June to July, the light irradiance decreased slightly but not significantly. This could be because of photo reactions in the DOM pool and because the water had been exposed to light for a longer period in July than in June. Vernal pools were the only habitat in which UVB irradiance decreased, but it was not enough to be biologically significant.

The results on vernal pools indicate that UVB is not likely an important factor affecting vernal pools. As such, the study of UVB effects on organisms that use vernal pools is not as important as the study of life in lakes, streams, and wetlands. For example, many studies on the harmful effects of UVB on amphibians are conducted. Because many amphibians use vernal ponds to live and breed, and virtually no UVB reaches vernal ponds, this indicates that these studies may not be as important as studies in other aquatic habitats. Additional work on the amount of UVB penetrating the vernal pools each year is needed to see if more flux is occurring due to ozone depletion. However such increases are not likely to be large enough compared to increases likely to occur due to the destruction of forest canopy.

In conclusion, lakes had the highest UVB irradiance, vernal pools had the lowest irradiance, wetlands were intermediary, and streams were highly variable. It appears UVB flux into lakes, streams, and wetlands may warrant concern, but UVB is not likely a critical factor affecting organisms in vernal ponds. Additional studies could address how the hydrology of aquatic habitat affects the UVB irradiance, and how the irradiance changes seasonally.

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Works Cited

Benner, R. and S. Ziegler. 2000. Effects of Solar Radiation on Dissolved Organic Matter Cycling in a Subtropical Seagrass Meadow. Limnology and Oceanography 45: 257-266.

Bothwell, M.L., C.M. Pollock, and D.M.J. Sherbot. 1994. Ecosystem Response to Solar Ultraviolet-B Radiation: Influence of Trophic-Level Interactions. Science 265: 97-100.

Brown, M.J., G.G. Parker, and N.E. Posner. 1994. A Survey of Ultraviolet-B Radiation in Forests. The Journal of Ecology 82: 843-854.

Chin, Y.P., S.J. Traina, and C.R. Swank. 1998. Abundance and Properties of Dissolved Organic Matter in Pore Waters of a Freshwater Wetland. Oceanography 43:1282-1296.

Fleischmann, E.M. 1989. The Measurement of Penetration of Ultraviolet Radiation into Tropical Marine Water. Limnology and Oceanography 34: 1623-1629.

Grant, R.H. 1991. Ultraviolet and Photosynthetically Active Bands: Plane Surface Irradiance at Corn Canopy Base. Agronomy Journal 83: 391-396.

Hader, D.P., H.D. Kumar, R.C. Smith, and R.C. Worrest. 1998. Effects on Aquatic Ecosystems. Journal of Photochemistry and Photobiology 46: 53 -68.

Hargreaves, B.R. and D.P. Morris. 1997. The Role of Photochemical Degradation of Dissolved Organic Carbon in Regulating the UV Transparency of Three Lakes on the Pocono Plateau. Limnology and Oceanography 42: 239-249.

Schindler, D.W. and M.A. Xenopoulos. 2001. Physical Factors Determining Ultraviolet Radiation Flux into Ecosystems. Ecosystems, Evolution, and Ultraviolet Radiation eds: 36-62.

Wetzel, R.G. 2001. Limnology: Lake and River Ecosystems 3rd ed. Academic Press, San Diego.

Williamson, C.E. 1995. What Role Does UV-B Radiation Play in Freshwater Ecosystems? Limnology and Oceanography 40: 386-392.

Yang, X., Miller, D.R. and Montgomery, M.E. (1993) Vertical Distributions of Canopy Foliage and Biologically Active Radiation in a Defoliated/Refoliated Hardwood Forest. Agricultural and Forest Meteorology 67: 129-146.