

The Effects of Ultraviolet Radiation (UVB) on Periphyton

BIOS 569 - Practicum in Aquatic Biology

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ABSTRACT

A decline in atmospheric ozone in recent years has led to concern about the effects of ultraviolet radiation on ecosystems throughout the world, including aquatic ecosystems. While water attenuates UVB radiation with depth, the UV rays can still penetrate several meters in clear freshwater lakes. This ability of UV radiation to penetrate beneath the surface of freshwater lakes has led to some concern over the effects of the wavelengths on algae and other aquatic organisms. The purpose of this study is to determine the effects of UVB radiation on periphyton and to collect samples for a study on the effects of UV rays on aquatic invertebrates. This was carried out by floating 32 panels of plexiglass-- sixteen which blocked out UVB wavelengths (UF3) and sixteen of which were transparent to UVB rays (UVT) on the surface of Crampton Lake, Land O'Lakes, WI. Beneath the panels, strips of polyethylene hung as surfaces for colonization by periphyton and grazers. After 3.5 weeks, the polyethylene strips were removed from the water and the algal chlorophyll was analyzed by fluometry. At depths shallower than 0.95 m chlorophyll a levels on the strips which were exposed to ultraviolet rays were significantly lower than on the strips which were not. The UVB effect was attenuated with depth so that greater than 0.95 m depth the effect was completely absent. Phaeophytin: chlorophyll a ratios were not significantly different between the two treatments suggesting that UVB radiation does not breakdown chlorophyll a but instead inhibits its production.

INTRODUCTION

In recent years, the decline in atmospheric ozone has led to concern over the penetration of ultraviolet radiation onto the earth's surface. As ozone is the main filter of UV rays, decreases in atmospheric ozone levels have been correlated to increases in UVB (280 to 300 nm) radiation reaching the surface of the earth. The amount of ultraviolet radiation reaching the earth fluctuates with the latitudinal, seasonal, daily, and yearly changes in atmospheric ozone concentration. Although UVB penetration is primarily determined by atmospheric ozone, other factors, including tropospheric ozone, clouds, aerosol, gases such as nitrogen dioxide and sulfur dioxide, and surface reflections play a role in UVB levels. Nevertheless, there is mounting evidence that UVB radiation levels are increasing (Williamson and Zagarese 1994). Along with this mounting evidence come questions pertaining to the effects of UV radiation on aquatic ecosystems.

Schindler et al (1996) demonstrated that UVB radiation can penetrate depths of several meters in extremely clear freshwater lakes. However, the ability of UV radiation to penetrate far below the surface of freshwater lakes is dependent primarily on the concentration of dissolved organic content (DOC) within the lake. DOC concentrations greater than 4.0 mg/L provide protection from UVB penetration; however, the depth to which UVB rays reach begins to increase exponentially as levels of DOC decrease below about 4.0 mg/L (Schindler et al 1996). In Ontario, decreases in DOC in freshwater lakes are due to climate warming (Schindler et al 1996). Warming and drying have led to a decrease in the DOC transferred to lakes from terrestrial water tables and streams due to the lowering of the water table. Decreases in DOC levels have also been correlated with increasing acidification of many lakes (Schindler et al 1996). If predicted climate warming occurs elsewhere, such interactive effects of DOC, pH, and UVB radiation may increase.

With the penetration of UV radiation into freshwater lakes, it is important to understand the effects of this radiation on aquatic organisms and their ecosystems. Williamson (1995) proposed hypotheses for the effects of UVB wavelengths on aquatic ecosystems, especially in regard to zooplankton. Two of these hypotheses, however, might extend to periphyton. One of these, the solar ambush hypothesis suggests that those aquatic organisms which do not have the ability to defend themselves against UV radiation will be damaged. The solar cascade hypothesis states that UVB radiation will affect organisms primarily by affecting their predators or prey (Williamson 1995). Cabrera and Pizarro's (1994) results from their study on the effects of UVB on phytoplankton support Williamson's solar ambush hypothesis: following days with high UVB radiation, there was a decrease in the chlorophyll a concentration in the top meter of freshwater lakes and on the days with the highest levels of UVB wavelengths there were the largest decreases in chlorophyll a. Bothwell et al's (1994) data, however, supports Williamson's solar cascade hypothesis in that the presence of UVB and UVA radiation leads to decreases in colonization by insect larvae which in turn led to an increase in periphyton growth. These findings suggest that the decrease in insect larvae, which feed on the periphyton, led to an increase in periphyton growth. Evidently, the effects of UVB radiation on one trophic level can lead to a change in the behavior of number of organisms on another trophic level. Williamson's solar cascade hypothesis may be correct.

The purpose of this study was to measure the effects of UVB radiation on periphyton and aquatic invertebrates in order to determine whether Williamson's solar ambush hypothesis or his solar cascade hypothesis holds true for periphyton. Although samples were collected for both invertebrates and algae, only the algal growth were analyzed in the course of this study. This study also sought to determine the relationship between water depth and the effects of UV radiation in a clear freshwater lake with relatively little DOC.

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This study was expected to show that algal growth slows when exposed to UVB radiation as demonstrated by a decrease in chlorophyll a concentration in samples exposed to UVB rays. In relation to depth, there should be a decrease in chlorophyll a concentration along with an increase in depth with lower levels of chlorophyll a for those samples exposed to UVB radiation. Also, the concentration in the samples exposed to UV should converge with the concentration of those not exposed to UV due to the attenuation of the UVB radiation at around 1 m since the average DOC of Crampton Lake is 4.58 mg/L (M. Pace, unpublished data). Although it is expected that algal growth will decline due to exposure to UVB radiation, there is the possibility that there will be an actual increase in periphyton growth. As Bothwell et al (1994) found, periphyton growth could increase due to a decline in aquatic invertebrates which feed on the algae.

MATERIALS AND METHODS

This study was performed on Crampton Lake, Land O'Lakes, WI. Crampton Lake is almost 72 acres in size, and its maximum depth is not known although temperature, oxygen, and light profiles have been performed down to 14.0m (Guide to UNDERC 1992). Crampton Lake has high water clarity which is due to many factors including DOC which is 4.58 mg/L (M. Pace Unpublished data). Crampton's clarity is also due to its alkalinity of 0.09 mg/L and its pH of 6.0 (Guide to UNDERC 1992). These factors contribute to the types of macrophytes which live in Crampton Lake. Crampton is relatively free of large macrophytes and those macrophytes which do grow stay small in size. The north shore of Crampton Lake was chosen as the site for this experiment due to the water clarity which allows UVB rays to penetrate to around 1.0 m below the surface (Schindler et al 1996) (Fig. 1).

A light profile was measured with a Li Cor light meter on Crampton Lake in the sampling area using depths ranging from 0.0 to 4.0 m using 0.5 m increments.

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In order to measure the effects of UVB radiation on algal growth and invertebrate populations, panels of plexiglass, one-half of which were UVB transparent and one-half of which were not, were suspended about one-half inch above the surface of Crampton Lake using a floating PVC frame anchored. The panels were positioned along the north shore of Crampton Lake in pairs, with one UF3 ("-UVB") panel immediately next to one UVT ("ambient UVB") panel in about 2-3 m of water. Attached to this framework were four pieces of clear polyethylene plastic which served as the substrates for the colonization of the periphyton and of the invertebrates. Thirty-two pieces of 0.61m x 0.61m plexiglass were used—sixteen pieces of -UVB plexiglass and sixteen pieces of ambient UVB plexiglass. The plexiglass pieces were supported about 1.27 cm above the water surface by a 1.27 cm PVC frame and brick anchors were positioned in such a way that the long axis of the frame ran east-west ensuring the maximum exposure of the strips, suspended from the north edge, to light possible. Each pair of panels was positioned approximately two meters apart.

The four strips of polyethylene plastic (1.75 m x 0.1 m) which were attached to the north side of the PVC frame served as the substrate for colonization by the periphyton and the invertebrates. Two strips were used to measure algal colonization and the other two were used to measure invertebrate colonization. The strips were attached to the frame with 18 cm between them. Weights attached to the bottom of each strip by duct tape minimized movement of the strips in the water. Before the strips to be processed for algae were attached to the frame, they were divided into 11-2.5 cm segments using a Sharpie marker at depths of 1.5, 4.75, 7.5, 11, 14, 33.5, 47, 67, 95, 126, and 154 cm below the surface of the water. The strips for invertebrates were marked at depths centered on 1.5, 4.0, 6.5, 9.0, 11.5, 32, 48, 61, 88, 110.5, and 143.5 cm below the water's surface. The first six depths for invertebrates had segments which were 2.5 cm in length while the last six depths had segments which were 5.0 cm in length. Since only the south side of the strips would be subject to the plexiglass treatment, the north side of the strips was not sampled.

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The panels were placed in the water on 10-11 June, 1996 and remained in the water through July 5, 1996, when they were sampled. While the panels were in the water, they were checked every two to three days in order to clean off the plexiglass and to ensure that the frames were retaining their proper compass orientation. During the sampling process, the strips were first taken to a boat while snorkeling and then gently lifted into the boat. Once inside the boat, each strip was cut into the eleven smaller strips at the demarcated depths. Both the algae and the invertebrate strips were scraped with a razor blade to remove all of the periphyton or invertebrates, respectfully. The periphyton was scraped into black film canisters and the invertebrates were scraped into whirlpaks with 70% ethanol. These samples were taken back to the lab for analysis.

In the laboratory, the invertebrate samples were set aside to be analyzed later while the algal samples were analyzed for chlorophyll a and phaeophytin using flourometry. Both chlorophyll a and phaeophytin values were obtained using the following equations:

$$\text{Chl a } (\mu\text{g}/\text{cm}^2) = (F_b - F_a) * Q$$

$$\text{Phaeophytin } (\mu\text{g}/\text{cm}^2) = ((R * F_a) - F_b) * Q$$

where $Q = m * (R/(R-1)) * (\text{extraction volume}/\text{surface area})$

$m = \text{scale factor}$

$R = \text{acid ratio} = 9.2$ (average for all gains)

$F_b = \text{fluorescence before acidification}$

$F_a = \text{fluorescence after acidification}$

extraction volume = 0.0262 L

surface area = 0.25 m²

The resulting chlorophyll a and phaeophytin values were then plotted by treatment and depth using Systat.

RESULTS

Light Profile: Light penetration illustrated that Crampton Lake was clear, and might therefore be susceptible to UVB effects (Fig. 3).

Chlorophyll a Measurements for UF3 and UVT Treatments: On -UVB strips, periphyton chlorophyll a levels decreased with an increase in depth (Fig. 2A). However, on the ambient UVB strips, there was no significant decrease in chlorophyll a levels between 0.0m and 1.54 m (Fig. 2A).

Phaeophytin Measurements for UF3 and UVT Treatments: Phaeophytin measurements were taken along with chlorophyll a measurements. For those samples which were -UVB, a general decreasing trend in the amount of phaeophytin was found with an increase in depth to 95.0 cm. After 95.0 cm, however, the phaeophytin levels increased again. No general trend, however, was exhibited by phaeophytin levels for the ambient UVB samples (Fig. 2B).

Comparison of Chlorophyll a and Phaeophytin Measurements Between the UF3 and UVT Treatments: Down through 47.0 cm, the treatment which was exposed to UVB radiation had significantly lower chlorophyll a than the treatment which was UVB blocked. At 67.0 cm, no significant difference existed between the two treatments although the depth profile suggested that chlorophyll a under -UVB was 25% higher than under ambient UVB. At a depth of 95 cm, clearly no difference existed between treatments (Fig. 2A). The patterns for phaeophytin were very similar (Fig. 2B)

DISCUSSION

UVB radiation clearly has a negative impact on algal growth. The -UVB samples had much higher chlorophyll a measurements than the ambient UVB samples in the periphyton samples taken from above 95.0 cm with significant differences existing at 47.0

cm and above. The attenuation of the UVB radiation was probably due to the dissolved organic carbon (DOC) present in Crampton Lake (Schindler et al 1996). While Crampton Lake is a fairly clear oligotrophic lake, it has a DOC content of 4.58 mg/L. This DOC concentration led to the hypothesis that the ultraviolet effect would be observed down to 1.0 m in Crampton Lake (Schindler et al 1996). Although there were no significant differences below 47.0 cm, the UVB effect did extend to 95.0 cm in depth which is consistent with the findings of Schindler et al (1996).

In order to examine whether UVB radiation actually destroyed chlorophyll a within the algal samples or whether it simply led to a decrease in algal growth, phaeophytin: chlorophyll a ratios were calculated from Figure 2. Comparing the -UVB and the ambient UVB treatments, there was no trend with depth for either treatment. Since phaeophytin is a breakdown product of chlorophyll a, it would be expected that if the UVB radiation was destroying the chlorophyll a, the phaeophytin: chlorophyll a ratios for the ambient UVB samples would be significantly larger than those for the -UVB treatment through 95.0 cm where the UV effect ended. However, this was not the case. So, instead of UVB actually breaking down chlorophyll a into phaeophytin, it seems as if UVB actually slows the production of chlorophyll a within the periphyton or inhibits the growth of the algae.

It was expected that in relation to depth, there would be a decrease in chlorophyll a measurements with an increase in depth for both the -UVB and the ambient UVB treatments. While this was observed in the -UVB treatment, it was not seen in the ambient UVB treatment. According to the light profile, even at the deepest sample depth in this study (1.54 cm), there was still about 45% incident light, which is plenty of light for periphyton to grow. For the ambient UVB treatment, the fact that the UV effect was attenuated with depth could explain why the chlorophyll a measurements stay about the same. Although there was more light at the shallower depths, the UVB radiation exposure was more intense. So, even though there was more light, there was not more algae. At the deeper depths, there was less light (although still an adequate amount for periphyton

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growth), but there was a smaller UV effect so periphyton growth is not effected to the same degree. This could result in the lack of a strong trend with depth for the ambient UVB treatment. However, in the -UVB treatment there was indeed a decrease in chlorophyll a measurements with an increase in depth. Since the -UVB treatment was not exposed to UVB radiation, the decrease in light which accompanied the increase in depth did lead to a decrease in chlorophyll a in the periphyton.

Although there was a significant difference between the -UVB and the ambient UVB treatments in the amount of chlorophyll a present in the periphyton through a depth of 47.0 cm, the significance of the difference could have been larger if the ambient UVB and the -UVB panels had been separated from each other rather than in pairs, only inches apart. Also, the UV effect might have extended deeper had the panels been placed in water deeper than 2-3 m. If the panels had been placed in deeper water, disturbance of the bottom, which might have decreased available light to the periphyton, would not have been a factor in the depth to which the UVB effect extended.

Bothwell et al (1994) found an increase in algal growth when exposed to ultraviolet radiation due to a decrease in grazer numbers. Although this study demonstrated a decrease in periphyton growth when samples were exposed to UVB rays, we will not know what role other members of the food web played until the invertebrate samples are processed. The decrease in periphyton might have repercussions down the food web on the grazers which feed on the periphyton and possibly on predators many trophic levels away in the food web. In order to fully understand the effects of UVB radiation on aquatic ecosystems, studies should be initiated which study the effects of ultraviolet wavelengths on all members of the ecosystem.

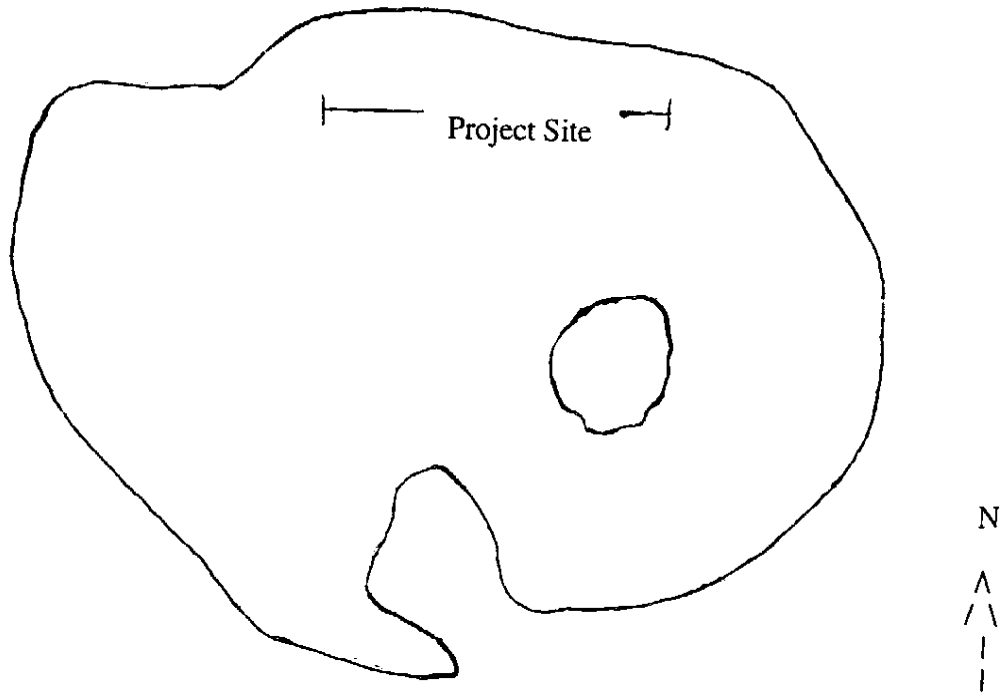


Figure 1. Map of Crampton Lake, Land O'Lakes, WI, with Experimental Site Indicated.

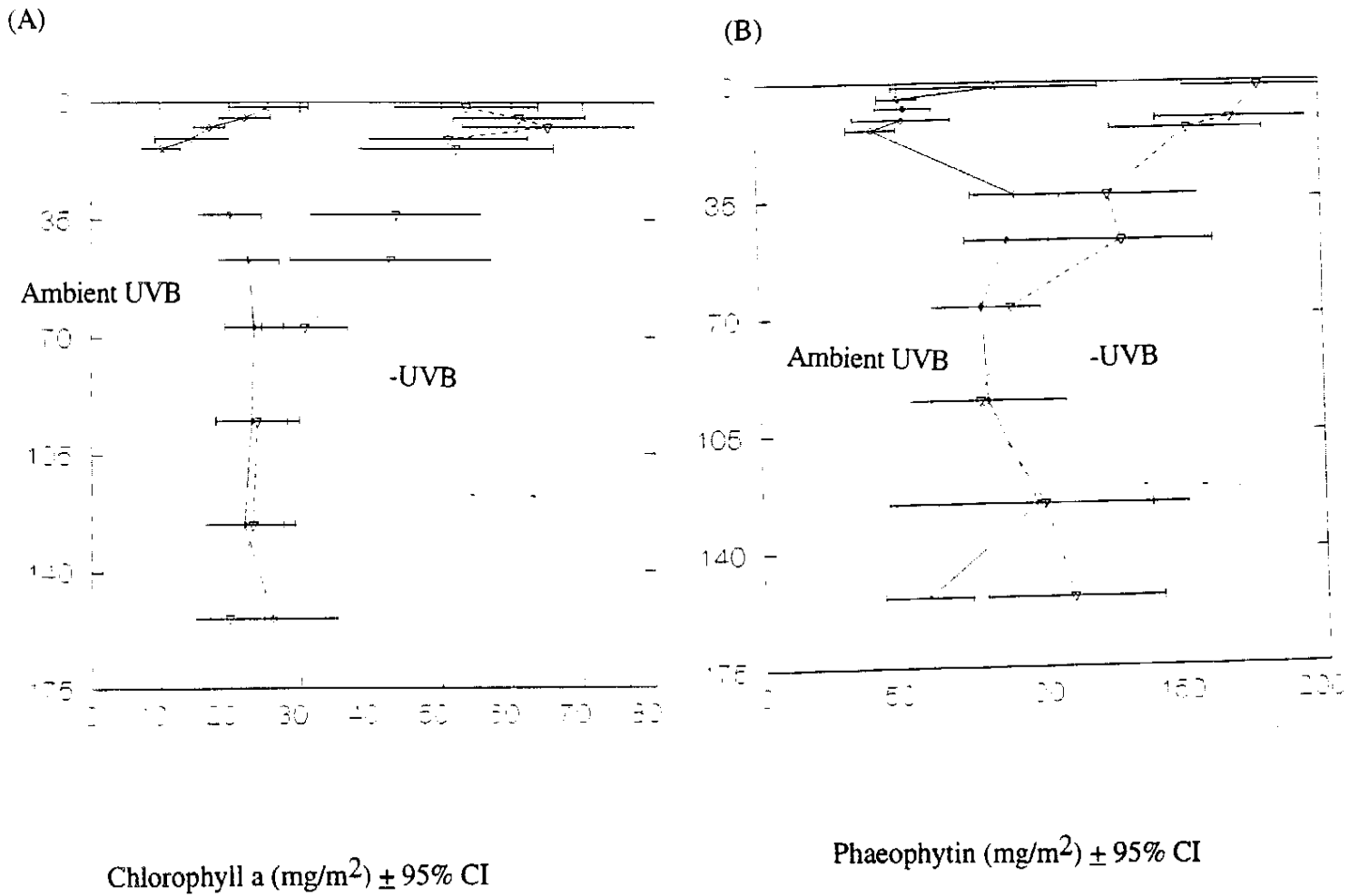


Figure 2. The Relationship Between Depth and (A) Chlorophyll a Content and (B) Phaeophytin Content of Periphyton Samples for -UVB and Ambient UVB Treatments.

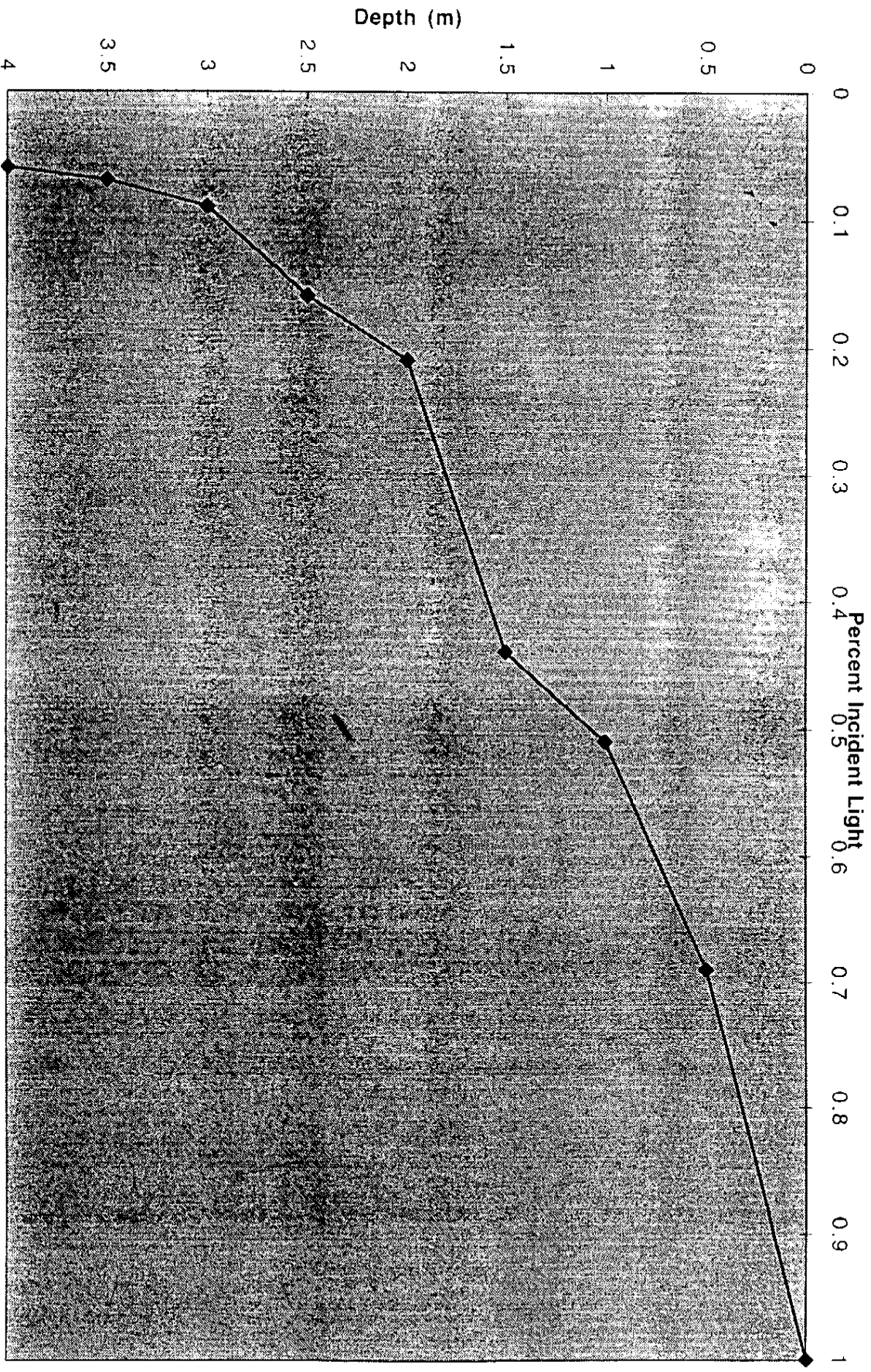


Figure 3. The Relationship Between Depth and Percent Incident Light on Crampton Lake.
Land O'Lakes, WI.

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