UV transparency in NZ lakes and the impact of UV on freshwater zooplankton and benthic plants

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Abstract. This paper summarises recent research on the transparency of New Zealand lakes to UV radiation, and the sensitivity of key groups of organisms to direct, deleterious impacts. The research has focused on the oligotrophic lakes of the South Island. These lakes show a wide range of UV transparencies, with much of the variation resulting from differences in concentrations of dissolved organic material (DOM). A strong and intuitively correct correlation between area of forest in the catchment and DOM concentration suggests that this is a major determinant of UV transparency. The clearest lake (Lake Coleridge) permits 1% of UVB to penetrate to a depth of 7 m. Dose-response relationships between UVB and mortality in freshwater zooplankton show considerable inter-specific variability. Some zooplankters show no mortality effect at a cumulative dose of 50 KJ m^{-2}. Comparisons of doses required for 1`% mortality in the most sensitive species with the UV climate in lakes suggest that no direct impact of current is likely. Similarly, the plants that grow in the zones of lakes likely to experience measurable UVR are able to tolerate daily exposures considerably greater than they currently experience with no lasting adverse effect. Overall, the combination of tolerance of UVR by organisms and rapid attenuation with depth means that direct impacts of UVR, at current or elevated levels, seems unlikely to pose a threat to lake ecosystems.

Introduction.

Research evaluating the biological effects of ultraviolet radiation (UVR) on aquatic environments, from molecular to ecosystem levels, has been extensive over the past 15 years (see reviews by Häder et al., 1995; Vincent and Neale, 2000). As a result, our understanding of some of the actions and consequences of UVR have increased considerably since stratospheric ozone thinning and associated higher levels of UVB to Earth were first reported.

A significant finding of many of these studies has been that current levels of UVR are sufficiently high to cause short or long term damage to organisms. It has also been found that different species have different physiological or behavioural responses to similar exposures to UVR. Together, these types of observation have given rise to what role current or elevated UVR may play in structure aquatic communities.

In this paper we draw together information obtained on the optics of UV in New Zealand lakes, and the sensitivity of selected organisms to UVR. Many important areas are not touched on, such as phytoplankton responses and the significant of UVR as an oxidiser of dissolved organic material, simply because we do not have any information on these processes.

Methods

The penetration of UVR into lakes was measured using a Biospherical Instruments PUV500. In addition to photosynthetically active radiation (PAR), this instrument measures irradiance in four UV bands, centred on 305, 320, 340 and 380 nm, with 8-10 nm half maximum bandwidth, and depth. Measurements were made as the instrument was lowered through the water at approximately 10 cm intervals. Waveband specific attenuation coefficients ($K_d(\lambda)$) were calculated by log-linear regression of irradiance against depth. To supplement irradiance data, dissolved organic carbon (DOC) was determined using a Dohrman DC180 Low Level Total Organic Carbon Analyser.

UVB impacts on zooplankton wre investigated in a series of laboratory experiemtns. Five common New Zealnad taxa were investigated, three cladocera (*Daphnia carinata, Ceriodaphnia dubia, Bosmina meridionalis*) and two copepods (*Boeckella delicata, Boeckella triarticulata*). The animlas were exposed to a near-natural spectrum of light produced in a sunshine simulator (Figure 1).

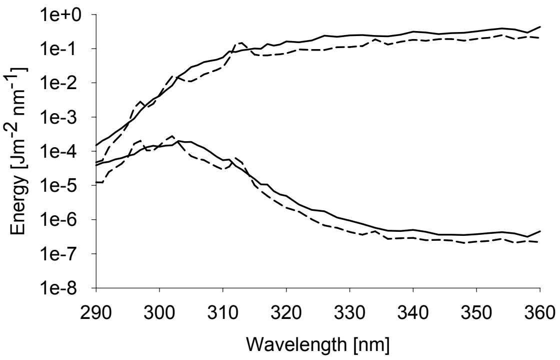

Fig. 1: Spectral composition of the sunshine-simulator (SONSI) in the UV waveband (sun: solid lines; SONSI: dotted lines); upper lines show spectral irradiance; lower lines show weighted spectra using DNA-weighted values.

In all experiments, 2-3 replicates of 20 –30 animals were placed in 5-ml beakers filled with lake water. They were irradiated for 0-8 h with UVB intensities of 0.8-2.0 W m^{-2}, giving cumulative doses of 0-58kJ m^{-2}. Controls were incubated under the same regime, but with UV-opaque filters over the beakers. After exposure, animals were kept for 3 days low light, and the proportion of animals surviving after this time determined. Mortality response curves were fitted to the data as

$$\text{Mortality} = 1/(1+e^{(\alpha-\beta.\log(\text{Dose}))})$$

Where α, β are fitted constants for each species.

To determine the spectral sensitivity of *C. dubia*, 30 animals were exposed to a cumulative dose of 2.4 kJ m^{-2} in 10 nm bands from 280 to 320 nm. An LTI Metrospec monochromator was used to provide the radiation.

Field and laboratory experiments were conducted to investigate the effect of UVR on common submerged aquatic plants. In all cases Pulkse Amplitude Modulated fluorometery (PAM) . PAM allows the status of photosystem II to be assessed, and is particularly useful in determining the extent to which photosynthesis in inhibited with respect to its potential activity. Inhibition can be a result of short term, rapidly reversible down regulation of photosynthesis in response to high light, or more slowly reversible physiologiucal changes induced by prolonged exposure to excess light, or due to weakly reversible photodamage in response to prolonged exposure.

Field experiments involved assessing the degree of slowly reversible inhibition in plants collected from shallow depths of Lake Wanaka and incubated over the course of a day in a lake-side aquarium. These plants were subject to four treatments produced by a series of optical filters. These were; full sunlight, sunlight from which UVB had been filtered using a low pass filter, sunlight minus UVA and UVB, and a high pass filter that allows UVA and UVB but no visible light. At intervals through the day, replicate plants were removed from the aquaria and their maximum fluorescent yields (F_v/F_m) determined after a short period of dark acclimation (Schreiber *et al.*, 1986). F_v/F_m in temporarily dark-adapted plants is a measure of photoinhibition (cf. Krause and Weis, 1991). A Walz PAM2000 was used throughout. Laboratory experiments complemented the field observation. In these, the SONSI was used to expose plants to elevated UVR treatments, and the degree of inhibition determined again using PAM fluorometry.

Results and Discussion.

The series of nine South Island lakes had a wide range of transparencies to UV wavebands. $K_d(320)$ varied from 0.36 m^{-1} in Lake Coleridge, to 60 m^{-1} in Lake Hochstetter. As has been found in previous studies (e.g. Morris et al., 1995) we found that the biggest factor affecting the penetration of UV was DOC concentration (Figure 2).

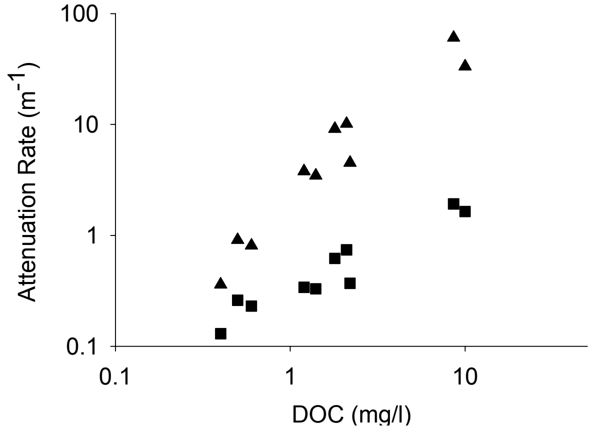

Fig. 2. Relationships between attenuation of PAR (squares) and 320 nm waveband (triangles) and dissolved organic carbon.

We also found that the amount of forest (mostly native beech forest) in a lake's catchment in turn was closely correlated to the DOC concentration. Regression analysis of % forest vs log DOC concentration had an r^2 of 0.89 ($p<0.001$). This raises the interesting issue that changes in catchment land use may be more significant in determining the UVR within a lake than changes in the incident UV. Such changes will affect both UVA and UVB, whereas ozone depletion will only affect UVB. For many photosynthetic organisms, current levels of UVA are considerably more harmful than UVB.

Of the five species of zooplankton tested, two were not responsive to UVB doses of up to 50 kJ m^{-2}. Of those that were sensitive, LD_{10} (dose for 10% mortality) varied between 7 and 25 kJ m^{-2} (Table 1, Figure 3).

The minimum UVB LD_{10} of 7 kJ m^{-2} would be attained at various depths in different lakes. In Lake Manapouri, a moderately attenuating lake, this would be attained at 30 cm depth, whereas in ultra-clear Lake Coleridge, this would be at 3 m. Given that zooplankton

Table 1. LD_{10} and LD_{50} (dose for 10 and 50% mortality) values for five species of zooplankton. All values are in kJ m^{-2}. ND is not detectable.

Species	LD_{10}	LD_{50}
Daphnia carinata	18	35
Ceriodaphnia dubia	25	37
Boeckella delicata	7	32
Boeckella triarticulata	ND	ND
Bosmina meridionalis	ND	ND

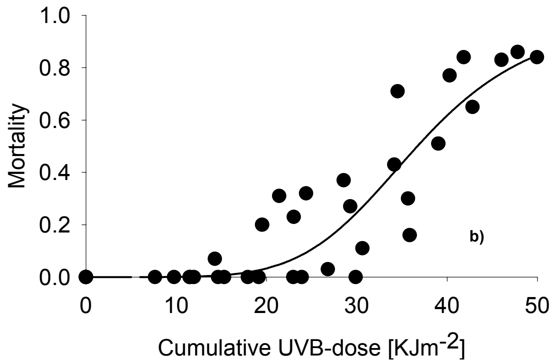

Fig. 3. Dose-response curve for *Ceriodaphnia dubia* to UVB exposure.

exist in a vertically mixed environment, the probability of UVB-induced mortality is low, unless the animals become trapped in shallow water.

Wavelength sensitivity showed that most of the response was in the UVB region, though within that waveband there was little variation in responsiveness (Figure 4).

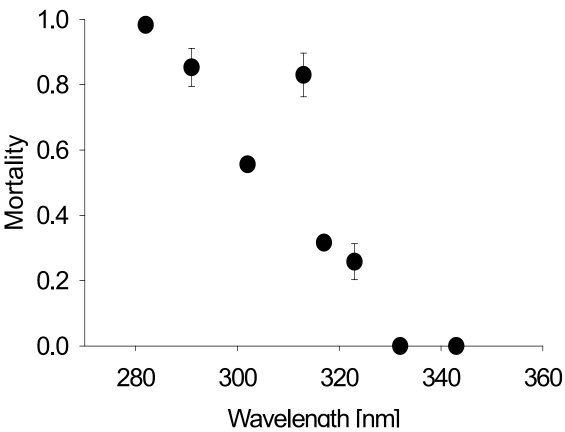

Fig. 4. Wavelength-specific response of *Ceriodaphnia dubia* to 2.76 kJ m^{-2} of radiation.

Unlike zooplankton, benthic plants are trapped in an environment where measurable UVA and UVB exists. However, even when exposed to elevated UVR values, we found little effect on their photosynthetic performance. UVR-induced inhibition of photosynthesis was seen in some species, though this inhibition was mostly related to UVA exposure (Figure 4).

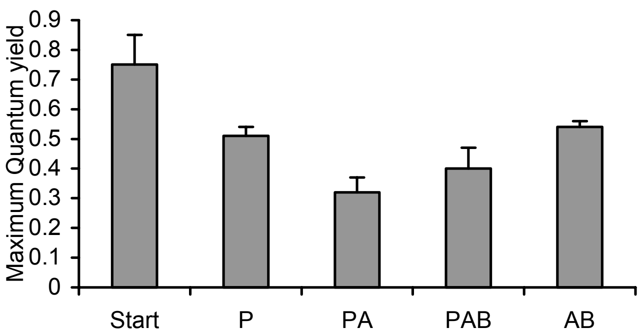

Fig. 5. Effect of exposure to surface irradiance (2 x increase in visible light, 20 x increase in UVR) on the inhibitipon of photosynthesis in *Potamogeton cheesemanii.* P – 400-700 nm, PA 320-700nm, PAB 280-700 nm, AB 280-400 nm.

In Fig 5, under ambient sunlight but no UVR, inhibition of photosynthesis was evident, and this was increased when ambient surface UVA was also applied. UVB (20 x what would normally be experienced by the plant) had no additional effect. In all treatments in Figure 5 full recovery occurred overnight.

Conclusions

Attenuation of UVR within New Zealand freshwaters is rapid, particularly in those lakes in heavily forested catchments yielding highly stained water. Both plants and animals in these lakes show some response to high doses of UVR (relative to ambient), but direct impacts of UVR in natural conditions seems to be unlikely.

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