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NOMOGRAMS FOR BIOLOGICALLY EFFECTIVE UV

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ABSTRACT

Regressions were determined establishing relationships between absolute UV-B irradiance (285-315 nm) and commonly used weighting functions for biological effectiveness. Nomograms were prepared from these regressions for both artificial and solar UV-B irradiance. Under well-defined conditions the nomograms may be used to rapidly compare data-sets which are derived from different weighting functions.

INTRODUCTION

Inadequate knowledge of proper weighting functions for evaluating the relative biological effectiveness of different UV-B wavelengths remains a major obstacle in understanding the effects of incident solar ultraviolet irradiation. All quantitative discussions and predictions regarding ambient or enhanced levels of UV-B irradiation are greatly affected by the choice of a weighting function (National Academy of Sciences, 1979) Different investigators have employed different weighting functions for calculating effective doses of UV-B. Sometimes different normalization wavelengths, the wavelength where biological effectiveness is 100%, have been used for the same action spectrum. While each weighting function, based on an observed action spectrum, might be justified under particular conditions, the most appropriate weighting function for most groups of

aquatic organisms has not been determined.

Because of the variety of action spectra for biological effectiveness, and the frequent need to compare different authors' data-sets, we found it useful to establish a practical relationship between absolute UV-B irradiance (285-315 nm) and some common weighting functions.

METHODS

Absolute UV-B irradiance measurements were made with an Optronic Laboratories® Model 741 spectroradiometer coupled with a HP® 9815A computer. The spectroradiometer was periodically recalibrated using a National Bureau of Standards lamp of standard spectral irradiance. Measurements were also made using the Robertson-Berger (R-B) Sunburn Ultraviolet Meter (Berger et al., 1975; Billen and Green, 1975). Ambient and enhanced solar irradiance at 285-315 nm was simulated with double-lamp fixtures, each holding one Westinghouse® FS-40 fluorescent "sunlamp" and one "cool white" (CW) fluorescent lamp, transmitting through cellulose triacetate plastic sheets (CTA). UV-B intensity was adjusted by varying the CTA thickness (combinations of 5-, 10-, and 20-mil sheets) and the distance between the UV-B source and the spectroradiometric sensor. Other general techniques for the measurement of artificial and solar UV-B were as described by Damkaer et al. (1980).

The analytical representations of Green and Miller (1975) were used in calculations with two of the biological weighting functions: (1) the DNA action spectrum (Setlow, 1974),

$$\epsilon_{DNA}(\lambda) = \exp\left\{ k \left[\frac{1}{1 + \exp\left[(\lambda-\lambda_o)/\lambda_f\right]} - 1 \right] \right\} \quad (1)$$

where $k = 13.82$, $\lambda_o = 310$, and $\lambda_f = 9$,

and (2) the generalized action spectrum for plants (Caldwell, 1968),

$$\epsilon_{PLANT}(\lambda) = A\left[1-(\lambda/\lambda_c)^n\right] \exp - \left[(\lambda-\lambda_o)/\lambda_f\right] \quad (2)$$

where A = 2.618, n = 2, λ_c = 313.3, λ_o = 300, and λ_f = 31.08.

The analytical representation of Green et al. (1974) was used for the erythema (sunburning) action spectrum,

$$\epsilon_{ERYTHEMA}(\lambda) = \frac{\alpha}{1 + \exp[(\lambda-\lambda_o/\Delta)]} + \frac{4\alpha' \exp[(\lambda-\lambda_o') / \Delta']}{(1+ \exp[(\lambda-\lambda_o') / \Delta'])^2} \quad (3)$$

where α = 0.04485, Δ = 3.130, λ_o = 311.4, α' = 0.9949, Δ' = 2.692, and λ_o' = 296.5.

The R-B meter Sunburn Units (SU) were read directly from the instrument. The spectral response of this meter is shown with several other commonly used action spectra in NAS (1979).

Polynomial regressions were derived using the HP computer with standard statistical software for regression analysis. The range of absolute UV-B irradiance (285-315 nm) values in the nomograms includes normal laboratory levels as well as ambient levels measured over four years at our experimental site at Manchester, Washington. Absolute irradiance was limited to wavelengths no longer than 315 nm since all of the weighting functions sharply decline above this point. However, absolute irradiance between 285-320 nm may be estimated by adding 40% and 100%, respectively, to values reported here for the lamps and the sun.

RESULTS

Because of the spectral differences in UV-B irradiance between the lamps and the sun (Damkaer et al., 1981), a separate set of regressions is required for each. Given B, the absolute irradiance (285-315 nm) in Wm^{-2} from one FS-40 lamp combined with one cool-white lamp and both transmitting through CTA, the respective weighted irradiance (285-315 nm) using each of the functions can be estimated:

$$\text{DNA(Setlow)} = (1.4\times10^{-2})B^2 - (1\times10^{-2})B + (4\times10^{-3})$$

$$\text{Plant(Caldwell)} = (3.1\times10^{-2})B^2 + (2.7\times10^{-2})B + (9\times10^{-3})$$

$$\text{Erythema} = (-3.3\times10^{-3})B^2 + (1.2\times10^{-1})B + (4\times10^{-3})$$

$$\text{R-B Meter(SU)} = (1.2)B^2 + (5.3\times10^{-1})B + (3.9\times10^{-1})$$

Given S, the absolute incident solar irradiance (285-315 nm) in Wm^{-2}, the weighted solar UV-B irradiance can be estimated:

$$\text{DNA(Setlow)} = (-2\times10^{-3})S^2 + (9\times10^{-3})S - (1\times10^{-3})$$

$$\text{Plant(Caldwell)} = (-7.9\times10^{-3})S^2 + (6\times10^{-2})S - (6.2\times10^{-3})$$

$$\text{Erythema} = (2\times10^{-4})S^2 + (6.4\times10^{-2})S - (1\times10^{-2})$$

$$\text{R-B Meter(SU)} = (1.8\times10^{-2})S^2 + (2.8)S - (2.8\times10^{-1})$$

Using the relationships established by these regressions, nomograms were constructed which provide rapid conversions among weighting functions most commonly applied to biological effectiveness of UV-B in aquatic ecosystems (Figs. 1 and 2).

DISCUSSION

It must be emphasized that nomograms can provide only an estimate of equivalent irradiance values among the weighting functions. The applicability of nomograms is limited by difficulties in exactly duplicating experimental conditions and techniques. Among the factors to consider when using the nomograms are number, type, and age of artificial light sources, type, thickness, and condition of light-filters, and wavelength band. Nevertheless, the nomograms are useful not only in comparing the levels of UV-B irradiance used by other investigators but, by using the two nomograms together, one can also compare artificial laboratory levels of irradiance with natural levels.

While the FS-40 lamps with CTA filters provide a reasonable simulation of solar UV-B irradiance, there are well-documented differences in spectral irradiance between this artificial source and the sun. These spectral differences account, in general, for the differences in scale between the two nomograms. They also account, in part, for the differences in shape of

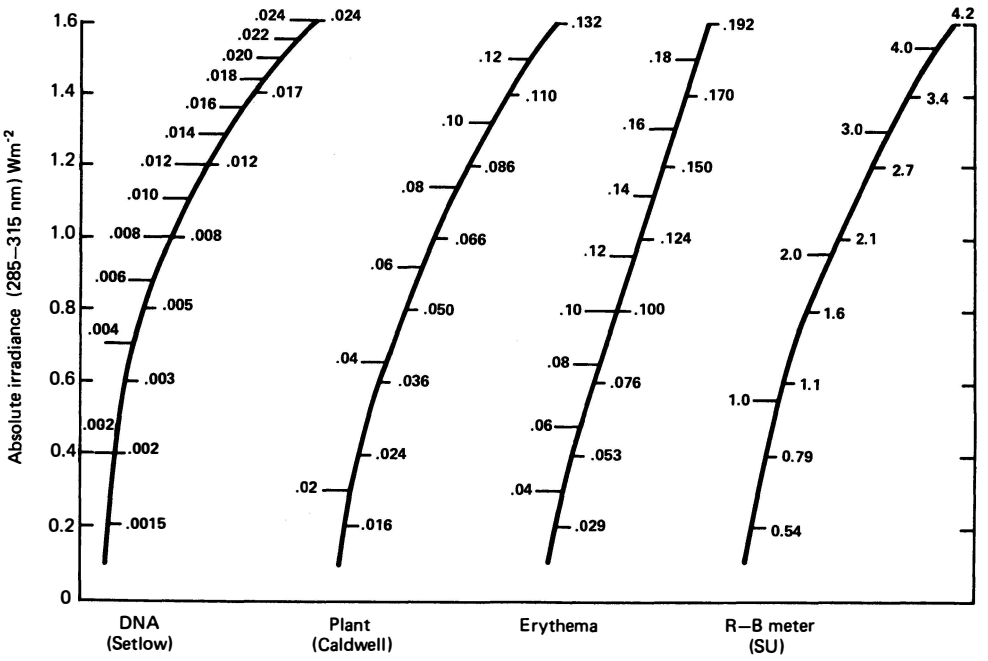

Figure 1. Nomogram for artificial (FS-40 + CW + CTA) absolute irradiance (285-315 nm), to estimate biologically effective UV-B irradiance from four weighting functions. A horizontal line connecting the left and right scale of absolute irradiance will intersect the other scales at the estimated equivalent values.

the two DNA curves and the two Plant curves (Figs. 1 and 2). With the lamps, absolute irradiance is primarily regulated by the thickness of CTA filters. High absolute irradiance values are achieved with a very thin filter which also allows more of the shorter UV-B wavelengths to penetrate. Because the DNA and Plant weighting functions increase sharply at the lower end of the UV-B range (NAS, 1979), high levels of absolute irradiance from the lamps lead to accelerated increases in DNA-weighted irradiance and, to a lesser extent, in Plant-weighted irradiance (Fig. 1). On the other hand, with increases in total solar absolute irradiance the intensity of shorter wavelength UV-B does not increase in the same proportion as with the lamps. At the same time the large increases in longer wavelength solar UV-B are given extremely low weightings in the DNA and Plant action spectra (NAS, 1979). Therefore, with increases

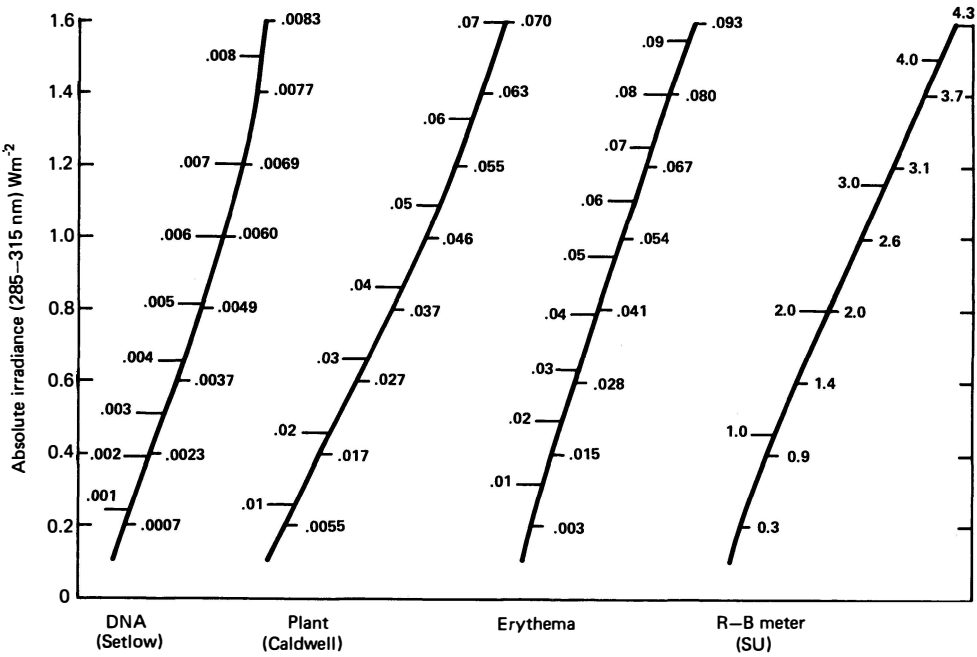

Figure 2. Nomogram for solar (Sun + Sky) absolute irradiance (285-315 nm), to estimate biologically effective UV-B irradiance from four weighting functions. A horizontal line connecting the left and right scale of absolute irradiance will intersect the other scales at the estimated equivalent values.

at high levels of absolute irradiance in nature, DNA- and Plant-weighted irradiances increase at a much lower rate than with the artificial sources of UV-B (Fig. 2).

The determination of appropriate UV-B weighting functions of biological effectiveness for a variety of aquatic organisms must be one of the priorities of future investigations. Without this work there will be difficulties in relating and comparing data and conclusions.

REFERENCES

Berger, D., D. F. Robertson, and R. E. Davies. 1975. Field measurements of biologically effective UV radiation. Impacts of Climatic Change on the Biosphere, CIAP Monogr. 5, 1(2): 235-264.

Billen, D., and A. Green. 1975. Comparison of germicidal activity of sunlight with the response of a sunburning meter. Photochem. Photobiol. 21: 449-451.

Caldwell, M. M. 1968. Solar UV radiation as an ecological factor for alpine plants. Ecol. Monogr. 38: 243-268.

Damkaer, D. M., D. B. Dey, and G. A. Heron. 1981. Dose/dose-rate responses of shrimp larvae to UV-B radiation. Oecologia (Berl.) 48: 178-182.

Damkaer, D. M., D. B. Dey, G. A. Heron, and E. F. Prentice. 1980. Effects of UV-B radiation on near-surface zooplankton of Puget Sound. Oecologia (Berl.) 44: 149-158.

Green, A., and J. H. Miller. 1975. Measures of biologically effective radiation in the 280-340 nm region. Impacts of Climatic Change on the Biosphere, CIAP Monogr. 5 1(2): 60-70.

Green, A., T. Sawada, and E. Shettle. 1974. The middle ultraviolet reaching the ground. Photochem. Photobiol. 19: 251-259.

National Academy of Sciences. 1979. Protection against depletion of stratospheric ozone by chlorofluorocarbons. Washington, D. C.

Setlow, R. B. 1974. The wavelengths in sunlight effective in producing skin cancer: a theoretical analysis. Proc. Nat. Acad. Sci. 71: 3363-3366.