Original papers

UV-B dose/dose-rate responses of seasonally abundant copepods of Puget Sound*

Douglas B. Dey¹, David M. Damkaer¹,², and Gayle A. Heron²

¹ Coastal Zone and Estuarine Studies Division, Northwest and Alaska Fisheries Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, 2725 Montlake Boulevard East, Seattle, WA 98112, USA
² School of Oceanography, University of Washington WB-10, Seattle, WA 98195, USA

Summary. Refinements in modeling stratospheric processes and recent observational data have generated estimates of moderate future reductions in total global ozone. Nevertheless, considerable uncertainty and concern remain about whether or not the resulting increases in incident solar UV-B could increase the risk of harmful biological effects. The UV-B dose/dose-rate thresholds for five species of copepods collected at the surface in Puget Sound were determined and compared to previously studied zooplankton groups. Generally, species appearing later in the spring and summer were less UV-B sensitive. The UV-B daily-dose and dose-rate thresholds for the five species of copepods, while apparently less than present median incident levels, range from above to below estimated present and future subsurface (1 m) UV-B levels. A separate experiment with a relatively large copepod, Calanus pacificus, in which above and below threshold UV-B dose-rates were administered with various levels of photoreactivating light (UV-A and visible light), indicated the presence of photorepair and its full activation at relatively low intensity. To improve estimates of the extent to which present and predicted UV-B levels affect local populations of copepods and zooplankton, it is essential to more fully understand the natural conditions or processes which influence the composition and intensity of the UV irradiation these animals receive.

Key words: Copepod responses to UV-B

The focus of this report concerns the UV-B dose/dose-rate responses of important, seasonally abundant marine copepods of the Puget Sound region: Acartia sp., an identified but as yet unnamed species closely related to A. clausii Giesbrecht (Bradford 1976); Pseudocalanus spp., species of unresolved taxonomic status; Corycaeus anglicus Lubbock; Epilabidocera longipedata Sato; and Calanus pacificus Brodsky. The ecological importance of these animals, which are found at times in high concentrations in the near-surface layer, is evidenced by their key position in the marine food web and by their active participation in the downward transport of organic matter from the upper layers.

In addition to UV-B dose/dose-rate responses, the question of photoreactivation potentials in copepods is considered. As with earlier studies using shrimp and euphausiids (Damkaer and Dey 1983) and due to the limitations of available light sources, the artificial light regimes used here were unnaturally low in UV-A (316–390 nm) and visible photoreactivating light (391–500 nm). The lack in intensity at these wavelengths, which stimulate the enzymatic photorepair mechanism for UV-B damaged DNA, could influence UV-B tolerance. By varying the level of photoreactivating light administered with a given level of UV-B, this influence can be observed and evaluated.

Very little is known regarding the effects of UV-B on marine copepods. Karanas et al. (1979) reported the survival of developmental stages of the estuarine copepod Acartia clausii exposed to daily UV-B doses approaching natural (Oregon coast) daily doses. Karanas et al. (1981) reported a possible mechanism through which enhanced solar UV could have a great impact on copepod populations without direct killing.

Evidence has also been reported concerning the lack of a behavioral response of the adult copepod Epilabidocera longipedata to enhanced UV-B radiation (Damkaer and Dey 1982). These experiments suggested an inability of the copepod to detect and avoid even lethal levels of UV, since there was no apparent difference in behavior between the UV-irradiated and the non-UV-irradiated copepods.

It is known that many organisms are protected to some degree from UV irradiation by their own pigmentation and this suggests that organisms may have evolved pigmentation as a consequence of the damaging effects of solar light. Damkaer (1982) reviewed several possibilities for this in regard to zooplankton. Hairston (1980) drew attention to the relationship between vertical distribution and pigmentation in some freshwater copepods. Typically, the most-pig-

* Contribution No. 1760 from the School of Oceanography, University of Washington, Seattle, WA 98195, USA

Offprint requests to: D.B. Dey
mented forms are closest to the surface. Because the pressure of predation should be against the conspicuously pigmented forms, Hairston concluded that "photodamage may be a more important selective force than previously supposed." Finally, in a study of the UV-B tolerance of a red-pigmented and a translucent variety of the same copepod species from separate, though nearby, lakes in France, Ringelberg et al. (1984) found that the red copepod tolerated higher artificial UV-B doses.

In recent work with other groups of zooplankton, there have been indications that taxonomically similar forms and life stages possess a similar sensitivity to UV-B (Damkaer et al. 1980). Nevertheless, in Crustacea, while the same basic tissues would likely be involved, and therefore the response would be qualitatively similar, substantial differences in UV-B sensitivity among important copepod species might be expected when one considers the different times and conditions throughout the year during which they are present at the surface. In addition, recent evidence strongly suggests that when evaluating UV-B sensitivity one must consider, together, both the total dose and the dose-rate. It appears that for each of these factors there are levels below which no harmful effects are observed in terms of development, activity, or survival (Damkaer et al. 1981). In view of these considerations, this study was undertaken with the following objectives: 1) to determine UV-B dose/dose-rate tolerance limits for a variety of important copepod species by using realistic combinations of UV-B daily-doses and dose-rates and taking into consideration the influence of photoreactivation potentials on these limits, 2) to evaluate the range of UV-B sensitivity among various species of copepods with respect to their different seasons or periods of surface occurrence and their different geographical distributions, and 3) to evaluate the likelihood that tolerance limits for specific copepods will be exceeded by predicted increases in UV-B irradiation.

Methods and materials

Specimens of the copepod species considered in this report were collected from the upper 0.5 m of Clam Bay (west-central Puget Sound), near midday and under generally sunny conditions. *Acartia sp.*, *Pseudocalanus* spp., and *Corycaeus anglicus* were captured using a 30-cm ring net towed at the surface, at a low speed, and parallel to shore at or just prior to high tide. Specimens of *Epilabidocera longipedata* and *Calanus pacificus* were dipped by hand-net from surface swarms. In all cases, the species selected for experimentation appeared to be the numerically dominant copepod within 0.5 m of the surface at the time of collection.

Test specimens were transferred with a wide-bore pipette to 1000-ml glass beakers (10/beaker) filled with 800 ml of filtered (by sand- followed by glass-fiber-filters, Gelman 1 type E) and partially sterilized (germicidal UV) seawater. Beakers were placed in a flow-through seawater table which maintained water temperatures within the beakers at near ambient levels. Water depth in the beakers was approximately 9 cm. Every other day 400 ml of water in each beaker was replaced with fresh, filtered seawater, and the copepods were fed. *Acartia sp.*, *Pseudocalanus* spp., and *Calanus pacificus* were fed a mixture of phytoplankton, about 2 x 10^5 cells ml^-1 of *Isochrysis* aff. *galbana* ("Tahiti") and *Isochrysis*, *Pseudoisochrysis paradoxa*, and an unidentified flagellate (source: School of Fisheries, University of Washington, Seattle). The small size of these cells, while appropriate for the smaller copepods, raised some concern regarding possible effects on the feeding efficiency of *Calanus pacificus* (Frost 1977). However, survival in the "controls" of virtually 100% after 3 weeks (in two separate experiments), the timely maturation of all copepodid Stage V (CV) to adults, and the considerable quantity of fecal pellets produced daily attested to the sustaining sufficiency of this diet. *Corycaeus anglicus* and *Epilabidocera longipedata* were fed freshly-hatched brine-shrimp nauplii and, in addition, the same concentration of phytoplankton cells was maintained within their beakers to avoid possible shading differences.

In the dose/dose-rate response experiments, the copepods were divided into five treatment groups (each with 4 replicates of 10 animals each), and the artificial light sources and filters were placed over the beakers which had been placed in the water table. Irradiance for each treatment was provided by a double-lamp fixture holding one Westinghouse FS40 "sunlamp" and one "cool white" (CW) fluorescent lamp. UV and visible irradiance levels were regulated by Mylar and cellulose triacetate (CTA) filters which effectively eliminate wavelengths shorter than 315 nm and 290 nm, respectively.

Using the UV-B dose-rate threshold determined in this study for CV and adult *C. pacificus*, photorepair in this organism was evaluated by establishing, in addition to the controls receiving no UV-B, three treatments each below and above the threshold level of each of the three treatments each receiving the same below-threshold level UV-B irradiation, one received 20% of the routine (but unnaturally low) experimental intensity of photoreactivating light, the second treatment 100%, and the third over 150%. The three treatments receiving the same above-threshold UV-B irradiation received 100, 160, and 240% of the routine photoreactivating light. None of the treatments receiving above-threshold UV-B irradiation were administered less than routine photoreactivating light; it was assumed that such low photoreactivating light levels could not be helpful. Different intensities of UV-B and photoreactivating light were provided by different combinations and numbers of FS40 and CW lamps with Mylar or CTA filters. The duration of exposures in all experiments reported here was 3 h each day, centered around solar noon. Light measurement techniques, equipment, and calculations for spectral and biologically-effective UV-B (based on the DNA action spectrum) as well as further details concerning the experimental set-up are described by Damkaer et al. (1980, 1981).

Experiments were conducted during spring and summer 1982–1984 at the National Marine Fisheries Service's Marine Experimental Station on Puget Sound at Clam Bay, Manchester, Washington. Due to the lack of an instrument capable of making reliable subsurface UV-B measurements at Manchester, the penetration of UV-B has been estimated using the attenuation coefficients of Smith and Baker (1979) for moderately productive waters with a high concentration of dissolved organic matter.

Results

In early March 1982, it became apparent through routine morning and midday sampling of the upper meter of Clam