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DAMAGE DUE TO SOLAR ULTRAVIOLET RADIATION IN THE BRITTLESTAR *OPHIODERMA BREVISPINUM* (ECHINODERMATA: OPHIUROIDEA)

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Many morphological, chemical, and behavioural characteristics of echinoderms have been implicated as defences against ultraviolet light, though no studies have investigated whether adult echinoderms are damaged by this form of radiation. This study tests whether the brittlestar *Ophioderma brevispinum* (Ophiuroidea: Echinodermata) is damaged by solar ultraviolet radiation. Specimens of *O. brevispinum* were exposed to sunlight at a field station on the North Carolina coast. After 4 d of exposure, 12 out of 13 animals were dead and the remaining animal was moderately damaged. The animals in the control treatment, protected by a UV-opaque filter, suffered almost no damage.

Many echinoderms are found in shallow water and many of their physiological and behavioural characteristics have been implicated as protective mechanisms against solar UV radiation. Examples of these include: the covering reaction in the echinoid *Lytechinus variegatus*, visible light-mediated pigment changes in the echinoid *Diadema antillarum*, depth-dependent colour variation in the echinoids *L. variegatus* and *Arbacia lixula*, the perpendicular optical axes of the tests of echinoids found in shallow water, and the presence of UV-absorbing compounds in the tropical holothuroid *Thelenota ananas* and the echinoid *Strongylocentrotus droebachiensis* (Millott, 1955, 1957; Raup, 1960; Fox & Hopkins, 1966; Dunlap et al. 1991; Carroll & Shick, 1996). The implicated functions of the characteristics in each of these studies are based on the presently untested assumption that adult echinoderm tissue is damaged by environmental levels of UV radiation.

In this study, adult specimens of *O. brevispinum* were exposed to solar UV radiation at a field station on the North Carolina coast. *Ophioderma brevispinum* differs from many ophiuroids in that it is active during the day and is often found under only partial cover (Hendler et al., 1995; S.J., unpublished data). It frequently occurs in clear, shallow, tropical waters and therefore risks exposure to high levels of UV light. It is also of particular interest because recent work has suggested that it may use the polarized light regime of shallow water as a warning indicator of dangerous levels of UV light (S.J., unpublished data).

The specimens of *O. brevispinum* used in this study were collected at Old Dan Bank located at 24°50′N 80°50′W, ~2 km north of the Keys Marine Lab, Long Key, Florida, USA. The animals were collected in water 0·2–1·0 m deep and maintained in artificial sea-water (Instant Ocean^{tm}, Aquarium-Systems Mentor, Ohio, USA) at a temperature and salinity approximating that of the collection site (water temperature 30°C, salinity 35 psu).

The animals were tested for sensitivity to UV radiation at the University of North Carolina Institute of Marine Sciences, Morehead City (34°43′N 76°43′W). The animals were put in glass bowls (0·035 m water depth) placed in an outdoor water table equipped with a flow-through sea-water system. The water in the bowls was changed every two hours and its temperature was held constant by the water in the water table. The bowls of 13 animals were covered with sheets of UV-opaque plastic (Polycast^{tm} UF3, Polycast Inc., Stamford, CT, USA). The bowls of 13 more animals were covered with sheets of UV-transparent plastic (Acrylite^{tm} OP4, Cyro Industries, Mount Arlington, New Jersey, USA). The absorption spectra of the two plastics are

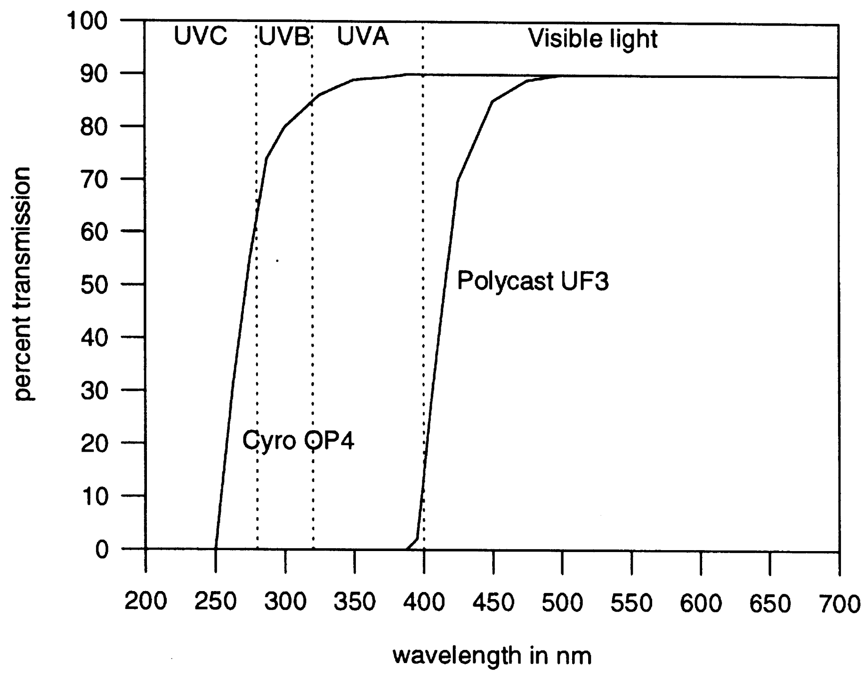

Figure 1. Graph showing the transmission values of 3·2 mm thick sheets of the UF3 (UV-opaque) and OP4 (UV-transparent) plastics from 200 to 700 nm.

shown in Figure 1. The bowls covered with the UF3 plastic were alternated with the bowls covered with the OP4 plastic to eliminate systematic biases in light intensity, water temperature, etc. Autotomized arms and dead animals were removed at regular intervals to prevent fouling of the water. Testing was performed during August, 1996.

The condition of the animals was rated on the following five point scale: 0, no damage; 1, damage to tips of one or more arms; 2, absence of at least half of one arm; 3, absence of at least half of all five arms or perforation of central disk; 4, death. Arm loss was used as an indicator of damage because arm autotomization in ophiuroids and asteroids is correlated with physiological stress (Fell, 1966; Lawrence, 1991). Damage was assessed early in the morning and early in the evening each day.

Surface and underwater measurements of UVB in North Carolina were made using a Spectroline DM-300X spectrophotometer (Spectronics, Westbury, New York, USA). Underwater measurements were made at 0·035 m (the depth of the test animals). The percentage UVB transmission of the OP4 plastic was measured using the same meter. The annual integral of UVB surface irradiance (weighted by the spectral response curve of the DM-300X UVB meter) in the Florida Keys relative to that found in North Carolina was obtained from the Total Ozone Mapping, Aerosol and UVB Monitoring Program (Goddard Space Flight Center, Greenbelt, MD, USA).

The weather during the four days of the animals' exposure was as follows: day 1, partly cloudy; day 2, full sun; day 3, full sun; day 4, full sun until noon followed by heavy overcast. The UVB light levels varied from 0·1W m^{-2} during heavy overcast to 0·5W m^{-2} during early morning and late afternoon full sun to 2·2W m^{-2} during full noon sun. The UVB levels at 0·035 m (the depth of the animals) were 90% of the surface values (excluding the effects of the plastic filters).

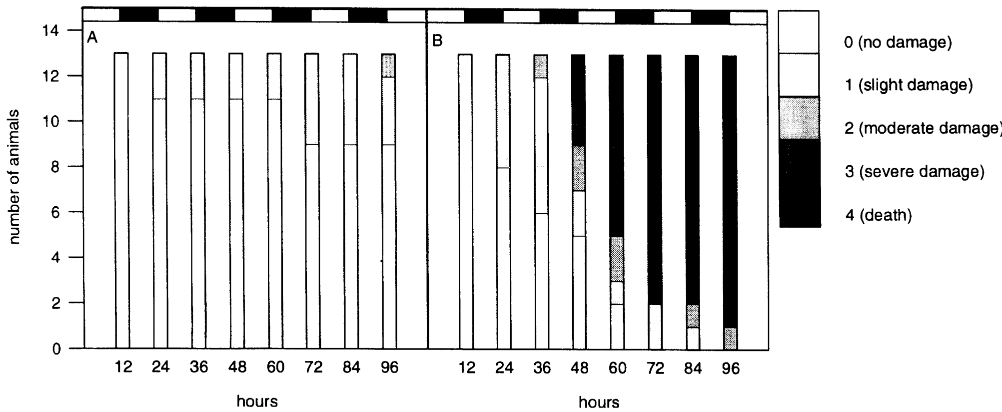

Figure 2. Stacked bar graphs showing the number of animals rated at each damage level versus time of exposure. The white and black rectangles at the top of the graph signify whether corresponding hours occurred during the day or night. (A) Animals placed under UF3 plastic and therefore exposed to negligible amounts of ultraviolet radiation. (B) Animals placed under OP4 plastic and therefore exposed to 72% of the surface irradiance of UVB found on the North Carolina coast in August.

The percentage UVB transmission of the OP4 plastic was 80%. Therefore the animals under the OP4 plastic were exposed to 72% (80×90%) of the surface UVB irradiance. The annual integral of UVB surface irradiance at the North Carolina coast is 70% of that in the Florida Keys.

Figure 2 shows the number of animals rated at each damage level for each evaluation period. The animals kept under the UF3 plastic were almost entirely undamaged with 9 of the 13 animals receiving no damage, three receiving a damage rating of 1, and only one receiving a damage rating of 2 by the end of the test period. The animals kept under the OP4 plastic were heavily damaged with over 90% mortality by the end of the test period. Examination of the individual damage histories of the animals showed that the animals in the OP4 treatment died within 25 $\pm$5 h (mean $\pm$SE) of the time they first showed damage.

Although these animals were tested at a depth of 0·035 m, it is likely that solar UV radiation is dangerous at significantly greater depths in the Florida Keys. Since the UVB exposure in North Carolina is 70% of that in the Florida Keys (see above), the experimental animals received 50% (70×72%) of the surface irradiance of UVB found in the Florida Keys. In Florida Bay water, 50% of the surface irradiance of UVB is found at a minimum depth of 0·6 m (based on summer UVB diffuse attenuation coefficients for Florida coastal water from Smith & Baker (1979)).

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