Radiation and coral bleaching

SIR — Gleason and Wellington[1] ignore any effect that irradiance in the waveband 400–700 nm (photosynthetically active radiation, PAR) might have had on the bleaching they observed in coral colonies transplanted from 24 to 12 m depth. Under their experimental regime (use of cut-off filter), they subjected corals at each depth to two different irradiance profiles. The first, their 'UV present' specimens, received 100% ultraviolet radiation and 100% PAR for that depth; the second, 'UV absent' specimens, received 0% ultraviolet radiation and 92% PAR. At 12 m depth the transplanted corals subjected to the former profile bleached whereas ulceras those subject to the latter did not. Gleason and Wellington unequivocally conclude that the bleaching response was a product of increased ultraviolet rather than enhanced PAR. They do not consider that the bleaching could also have been due to the 8% difference in PAR levels, or to a synergistic effect between the two types of radiation.

Undoubtedly the conclusion which they reached is the most appealing in the context of their paper, and may well be persuasive in logical terms. Scientifically, however, there are alternatives. Gleason and Wellington could have avoided the problem, which has been mentioned in earlier studies[2,3], by introducing a third treatment whereby transplanted colonies were placed under neutral density filters reducing the irradiance across the whole waveband (280–700 nm) by 8%. (Stainless steel wire mesh is a suitable material with a uniform attenuation at all ultraviolet and PAR wavelengths which can be tailored to provide appropriate attenuation). If thereby the ultraviolet irradiance had been reduced below any damage threshold at 12 m they could simply have incorporated an additional, shallower transplant depth.

Solar radiation is increasingly being recognized as a factor involved in bleaching of corals and other organisms that share a zooxanthellae symbiosis. Studies involving field manipulations[4] and laboratory experiments[5] at environmentally realistic irradiances have identifield an involvement of solar ultraviolet, but to a subtle degree rather than visible bleaching. The assignment of roles to specific radiation wavelengths is complex because of changes in spectral quality and quantity under varying atmospheric conditions, and is further complicated by the underwater physical environment. Additional biological factors such as symbiotic interactions between the zooxanthellae and their animal hosts, and the need to consider the biological effectiveness (action spectra) of different wavelengths (a consideration which Gleason and Wellington ignore in their dismissal of the waveband 280–300 nm), yet further add to the experimenter's burden. Although Gleason and Wellington have helpfully added to the general evidence implicating solar radiation in coral bleaching, they are not yet in the position to attribute it solely to ultraviolet radiation.

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GLEASON AND WELLINGTON REPLY — Dunne suggests that we were premature in attributing the coral bleaching we observed in our experiments[1] to ultraviolet radiation because we did not take into account an 8% difference in PAR between treatments with and without ultraviolet; and because we did not consider potential synergistic effects of the two types of radiation. Although we admit that Dunne's first criticism identifies an imperfection in the experimental design, we believe it is highly improbable that this small difference between treatments caused the bleaching.

Coral colonies placed in 'UV present' and 'UV absent' treatments at 12 m depth were exposed to mean intensities of 106.07 W m^{-2} (s.e. = 6.65, n= 17 days, where daily values represent averages of scans obtained hourly between 1,000 and 1,300 h with a Li-Cor LI1800 spectroradiometer) and 97.58 W m^{-2} (8% reduction), respectively. Arguing that a difference of 8.49 W m^{-2} induced the bleaching in 'UV present' treatments assumes that *Montastrea annularis* colonies transplanted from 24 to 12 m depth were exposed to PAR intensities that were right at the boundary of their visible light tolerance. Our new (unpublished) data indicate this is probably not the case. Colonies of *M. annularis* moved from 24 m to less than 0.25 m depth, and when shielded from ultraviolet radiation showed no photoinhibition of photosynthesis following repeated exposure to PAR over a 12 h period. These results indicate that *M. annularis* can tolerate changes in PAR that are much more extreme than were introduced by our experimental manipulations.

Dunne's second criticism, that the bleaching may be the result of a synergistic effect between photosynthetically active and ultraviolet radiation while possible, also appears unlikely. In our experiment, coral colonies in 'UV present' treatments at 24 and 12 m depth were subjected to mean PAR intensities of 61.75 W m^{-2} (s.e., 5.15; range, 29.28–95.67 W m^{-2}; n=18 days) and 106.07 W m^{-2} (s.e., 6.65; range, 41.07–147.52 W m^{-2}; n=17 days), respectively. Because of the overcast sky conditions and below-average water column clarity that prevailed during our field study in September–October 1991, PAR intensities experienced by colonies transplanted to 12 m depth were close to those observed at 24 m depth July 1991 (PAR mean = 85.21 W m^{-2}, s.e. = 7.26, range = 38,54–109,50 W m^{-2}; n = 11 days). Thus, *M. annularis* colonies transplanted from 24 to 12 m depth were not exposed to radical increases in PAR. Further, the 24.5% enhancement in daily mean PAR intensities observed between 24 m depth in July 1991 and 12 m depth in September–October 1991 compares to increases of 37.2% for ultraviolet–A (320–400 nm), 220.0% for ultraviolet–B (300–320 nm) for the same depths and time periods. The biological action spectra for both DNA[6] and plant responses[7] is greatest, by several orders of magnitude, at wavelengths below 330 nm, making ultraviolet a more likely cause of the coral bleaching.

In summary, while we agree that Dunne has revealed a potential problem in the experimental design, the available evidence provides strong support for our conclusion that increases in ultraviolet radiation that result from rapid changes in water column conditions may be an important parameter contributing to coral bleaching events. We stand by that conclusion.

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Longest read?

SIR — If the statistical methods of Gott (*Nature* **363**, 315–319; 1993) for predicting future longevity on the basis of past longevity are applicable to all events, does this mean that there is a 95% probability we will be reading correspondence relating to the original article for the next 30.6 years?

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