Research Letter

Seychelles Lagoon Provides Corals with a Refuge from Bleaching

David Iluz,¹ Razi Vago,² Nanette E. Chadwick,^{1,3,4} Razi Hoffman,¹ and Zvy Dubinsky¹

¹ The Mina and Everard Goodman Faculty of Life Sciences, Bar-Ilan University, Ramat-Gan 52900, Israel

² Department of Biotechnological and Environmental Engineering and Institute for Applied Biosciences, Ben-Gurion University of the Negev, Beer Sheva 84105, Israel

³ Department of Biological Sciences, 101 Rouse Life Sciences Building, Auburn University, Auburn, AL 36849, USA

⁴ Interuniversity Institute for Marine Sciences, P.O. Box 469, Eilat 88103, Israel

Correspondence should be addressed to David Iluz, iluzda@mail.biu.ac.il

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An extensive bleaching event in the summer of the year 1997-1998 affected most reefs along East Africa's shores. In the aftermath of that episode, the reefs of Île Alphonse in the Seychelles were examined and it was found that reefs along the seaward slopes of the island lost >95% of their branching coral colonies, with considerably higher survival of massive species. Île Alphonse features a nearly circular shallow lagoon, with steep seaward slopes. Contrary to our expectations, mortality in the warmer lagoon was far lower than of coral colonies on the surrounding slopes, bathed in deeper and cooler waters. We suggest that corals in the lagoon were protected from UV radiation by leachate stemming from seagrass leaves steeped in the lagoon. Our measurements in the lagoon showed a strong attenuation of ultraviolet radiation, not observed in the waters outside the lagoon, and laboratory examination confirmed that the strong UV absorption of substances leached into seawater from decomposing leaves of the seagrass *Thalassodendron* (= *Cymodocea*) *testudinaceum*. Our findings demonstrate the synergism between elevated seawater temperature and UV radiation in triggering bleaching on shallow reefs.

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Global warming, possibly accompanied by increased UV radiation and oceanic acidification [1], is a likely culprit in the recent worldwide decline of coral reefs. The coral bleaching event of 1997-1998, which spread throughout the Indian Ocean, Southeast Asia, the Caribbean, and parts of the far eastern and western Pacific, is probably the most severe such episode in recorded history [2, 3]. Recent field and laboratory studies have demonstrated that elevated seawater temperatures can indeed induce bleaching in corals [4-7].

While documenting an extensive mortality episode that struck East Africa's coral reefs, we found that, contrary to our expectations, corals on the seaward slopes of a small cay in the Seychelles were the hardest hit, whereas colonies in a warm and turbid lagoon fared much better.

The data for the study were collected in November 1998 during an expedition to Île Alphonse, a coral cay four nautical miles in diameter in the Seychelles archipelago (see Figure 1). Data were collected by SCUBA diving as video

transects, which were subsequently analyzed with image processing software. Analysis of live coral colonies and recently-bleached coral skeletons indicated that, prior to the 1997-1998 bleaching event, the percent cover of live massive stony corals was much higher than that of branching corals inside the lagoon, while the reverse pattern occurred on the outer reef slope (see Figure 2(a)). In contrast, after the bleaching event, most corals of both growth forms survived within the lagoon, while especially the branching corals suffered extensive mortality on the outer reef slope, leading to very low live coral cover (see Figure 2(b)). On the outer reef slope, the mortality of branching colonies reached 100% near the surface, whereas among the massive corals, mortality was about 20% at all depths (see Figure 2(c)). Many of the massive colonies were only partially affected and, in such cases, only their upward-facing portions were bleached. Our observations are in agreement with recent reports that coral colonies in Phuket have been, in many cases, only partially affected [8]. However, there the differences

FIGURE 1: The Île Alphonse lagoon: (a) schematic transects, (b) aerial view.

FIGURE 2: Stony coral percent cover and mortality at Île Alphonse, Seychelles, surrounding the 1997-1998 bleaching episode. Comparison of massive and branching colonies inside the lagoon and on the outer reef slope. (a) Percent cover of live stony corals prior to the bleaching episode, from analysis of live coral colonies and recently-bleached coral skeletons that appeared to have died within the year preceding. (b) Percent cover of live stony corals after the bleaching episode. (c) Mortality rates following the bleaching episode. "Lagoon top" refers to corals on the top of shallow reef patches inside the lagoon, and "lagoon side" refers to corals on the vertical sides of reef patches in the lagoon. Data were collected during November 1998, from 1-m² digitized video quadrates ($N = 12-39$) at each location.

FIGURE 3: The Ile Alphonse lagoon. Leaves of the seagrass *Thalassodendron testudinum* leaching colored substances.

in bleaching resulted from exposure to high light rather than UV radiation, and previous exposure to solar bleaching protected colony faces from subsequent thermal bleaching.

Our attention was drawn to the striking and counter-intuitive differences in coral fate between the turbid and warm (35°C) lagoon and the clearer, cooler (28°C) outer-reef slope. All along the lagoon shore, we noticed a huge accumulation of drying leaves of the seagrass *Thalassodendron* (= *Cymodocea*) *testudinaceum*. Visible amounts of colored substances were being leached into the lagoon water out of this decomposing mass of sea grass (see Figure 3). Underwater light measurements were carried out using a submersion spectroradiometer (Li Cor-1800UW). Measurements were made in the lagoon which had a high content of leaves of the seagrass *Thalassodendron* (= *Cymodocea*) *testudinaceum*, and outside the lagoon there was no effect of these leaves. Upon examination of the spectral distribution of underwater irradiance, we found that the UV/PAR ratio was dramatically reduced in the lagoon (see Figure 4). Indeed, laboratory examination of *Thalassodendron* (= *Cymodocea*) *testudinaceum* leachate revealed a high absorption in UV range. The leaves were left to extract in Red Sea water at 25°C for 24 hours. The extract was scanned on a Varian 340 spectrophotometer in quartz cuvettes, with seawater as the reference (see Figure 5). This result is in agreement with the findings of Stabenau et al. [9] that the seagrass *Thalassia testudinum* releases a UV absorbing substance.

Our findings support previous reports [10] suggesting a synergistic effect of UV and temperature in triggering coral bleaching. Experiments have shown that an increase in UV light causes coral bleaching. UV light experienced by corals can increase in calm waters. The amount of mycosporine-like amino acids in a coral's tissues helps to determine how much UV it can withstand without bleaching [11, 12]. In the case of Ile Alphonse, it is clear that the reduced mortality of corals in the lagoon was not related to reduced temperature or PAR levels but rather to a reduction of UV radiation in lagoonal waters. In general, it seems that in susceptible corals, bleaching may be triggered by synergism between high temperatures and other factors, whether UV, as at Ile

FIGURE 4: Comparison of photosynthetically available radiation, 400–700 nm, (UV/PAR) ratio in the lagoon and on the outer reef slope, as measured with a LiCor-1800UW submersible spectroradiometer.

FIGURE 5: Absorbance spectrum of the leaf extraction of seagrass *Thalassodendron* (= *Cymodocea*) *testudinum*.

Alphonse, or high visible-light insolation. We hypothesize that, although temperatures in the lagoon exceeded those on the outer slope (28°C), seagrass leachate rich in UV-absorbing compounds created an effective UV-blocking filter in lagoonal waters, thereby mitigating bleaching-inducing temperature effects. However, based on our data we cannot exclude the possibility that zooxanthellae clades with higher thermal tolerance may be involved. In such case that would confer additional protection from bleaching on the coral colonies in the lagoon, above that provided by the “UV filter” we report here. It has been suggested that some clades have higher thresholds for bleaching than others [13–15]. We suggest that this UV screening phenomenon, together with long-term adaptive mechanisms developed by lagoonal colonies exposed to higher temperatures, protected this population throughout the 1997–1998 bleaching event. The coral populations that survive in such protected refuges may be a source of propagules for future reef recovery.

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