Life on the edge: corals in mangroves and climate change

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Abstract. A high abundance and diversity of scleractinian corals have been observed on and near the prop roots of red mangrove (*Rhizophora mangle*) trees in Hurricane Hole, within Virgin Islands Coral Reef National Monument, a marine protected area off St. John, US Virgin Islands. Some of these corals are major reef-building species that suffered high mortality (loss of 60% live cover) on the island's fringing reefs from a disease outbreak following a mass bleaching event in 2005. Some corals are over 1 meter across and clearly survived the 2005/2006 bleaching and disease outbreak. High temperatures (maximum = 31.7°C) led to moderate coral bleaching in the late summer/fall (August-October) of 2010. Two of the most abundant reef-building corals showed different responses, with *Colpophyllia natans* exhibiting minimal bleaching and very low mortality and *Diploria labyrinthiformis* major bleaching with higher mortality. No disease outbreak occurred, and no new bleaching episode occurred in 2011 when temperatures were generally lower. Microhabitat differences in environmental factors (including shading from mangrove trees) could contribute to varying susceptibility to bleaching, and even corals of the same species growing adjacent to each other had different responses. The coral communities in the mangroves (where water temperatures exceed those on the deeper reefs) may be more resistant to thermal stress and could possibly contribute larvae to replenish degraded reefs.

Key words: bleaching, disease, climate change

Introduction

Within the last few years, a high abundance and diversity of scleractinian corals have been observed on and near the prop roots of red mangrove (*Rhizophora mangle*) trees in Hurricane Hole, within Virgin Islands Coral Reef National Monument, a marine protected area off St. John, US Virgin Islands (Rogers 2009). To date, no published papers have been found that indicate such a high number of coral species in any other Caribbean mangrove ecosystems. Hurricane Hole consists of four bays with mangrove-fringed shorelines and no major sources of freshwater. It is not clear why the coral communities in these bays are so diverse or why the individual bays differ so much from each other with respect to coral abundance and diversity. Borck Creek has few corals except at the mouth of the bay, Princess Bay has an intermediate abundance and diversity, and Otter Creek and Water Creek have the highest number of species and individuals. Differences in water circulation and/or seawater chemistry may be driving variations in coral abundance and diversity, with Otter and Water having greater water exchange creating physical and chemical conditions more similar to those on a coral reef than in a mangrove environment.

Some of the corals in the mangroves are major reef-building species that suffered high mortality on the island's fringing reefs from a disease outbreak following mass bleaching in 2005. The living coral cover on reefs around St. John declined by 60% within two years of the bleaching episode (Miller et al. 2009). Although no baseline data on the corals in Hurricane Hole (including species lists, abundance, or bleaching) exist, some coral colonies growing among the mangrove prop roots are over 1 meter across and clearly survived the 2005/2006 bleaching and disease outbreak. Many of these colonies are intact, unlike numerous colonies on the reefs with partial mortality from disease. The objectives of this study were to document coral diversity in Hurricane Hole; to examine bleaching, recovery and mortality of two major reef-building coral species during bleaching in 2010; and to determine what insights these coral communities might provide into resistance and resilience of reefs in the face of global climate change, particularly bleaching.

Material and Methods

An inventory of the coral species was prepared based on surveys done while snorkeling around the perimeter of each bay. A complete census of two of the most abundant, primary reef-building corals, *Colpophyllia natans* and *Diploria labyrinthiformis*, in Otter and Water Creeks was conducted. Subsets of the colonies were examined and photographed to document bleaching and recovery or mortality from November 2010 to May 2011 in Otter, and from November 2010-January 2011 until June/July 2011 in

Water. Bleaching was recorded if any living portion of a coral was pale or white. Recovery was defined as regaining of normal pigmentation. Although it would have been ideal to record the condition (degree of bleaching) of each species in each bay simultaneously, it was not feasible because of the large number of corals. Hobo temperature loggers were deployed at 10 locations in Otter and 8 locations in Water to record temperature every 2 hours. All were attached to prop roots or boulders in water less than 1 m deep.

Results

Coral Species

At least 33 species of scleractinian corals (plus the hydrozoan *Millepora*) are found in Hurricane Hole. The exact number is not known because of the difficulty of differentiating among some of the coral species in the field and taxonomic uncertainties. Some colonies grow close to or directly on the prop roots of red mangrove trees (*Rhizophora mangle*), and others on rocks or hard substrate near shore and down to a depth of about 6 m (Fig. 1).

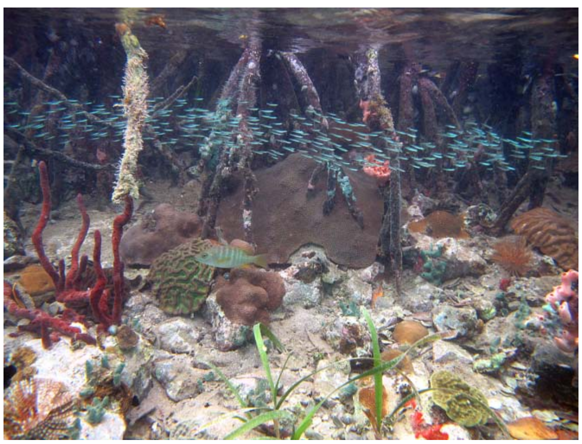

Figure 1. Several coral species in the mangroves.

Otter Creek (n=30 species) and Water Creek (n=28) have a higher abundance and diversity of corals than Princess Bay (n=19) and Borck Creek (n=3). The species with the largest colonies are: *C. natans*, *Montastraea faveolata*, *M. annularis* and *Siderastrea siderea*. The most abundant species are *Agaricia* spp., *Porites* spp., *D. labyrinthiformis* and *C. natans*. Some corals that are quite rare or relatively less abundant on St. John's reefs were found: *Scolymia cubensis*, *S. lacera*; *Mycetophyllia aliciae*, *Eusmilia fastigiata*, and *Dichocoenia stokesi*.

Census of C. natans and D. labyrinthiformis

A total of 151 and 230 colonies of *C. natans* were counted in Otter Creek and Water Creek, respectively. In Water Creek, 626 colonies of *D. labyrinthiformis* were found, and 351 colonies of this species were observed in Otter Creek. These totals include all colonies that were initially observed and those that were found later in the study.

Comparison of Bleaching of C. natans and D. labyrinthiformis

Bleaching was first evident in Princess Bay in June 2010, affecting *Agaricia* spp. and some *Porites.* Moderate to severe bleaching was observed in Otter and Water in August and September 2010, affecting several species including *Agaricia, Porites, D. labyrinthiformis, D. strigosa, S. siderea, Stephanocoenia intersepta, , E. fastigiata, Manicina areolata*, *Montastraea* spp., and *Millepora.* No bleached *C. natans* were seen at this time.

Initially, in November 2010, 111 *C. natans* were found in Otter and 230 in Water. In November 2010, 305 colonies of *D. labyrinthiformis* were examined and photographed in Otter. In Water, 426 colonies of *D. labyrinthiformis* were examined and photographed from November 2010 through January 2011. No completely white colonies of either species were seen, and bleaching (pale and partially bleached or white) was generally more severe in *D. labyrinthiformis* (Table 1). Only five (4.5%) of the *C. natans* colonies in Otter were bleached whereas 179 (58.9%) of the *D. labyrinthiformis* were bleached. Similarly, only four (1.7%) of the *C. natans* in Water bleached whereas 74 (17.4%) of the *D. labyrinthiformis* were bleached **(**Fig. 2).

Figure 2. A bleached *D. labyrinthiformis* colony next to a *C. natans* colony with normal pigmentation.

The peak of bleaching occurred from late September through early November 2010. Signs of recovery were evident on some colonies in both bays beginning in November 2010, following a decline in water temperatures. New bleaching was not observed after the initial surveys in each bay, and colonies that recovered their normal pigmentation had all done so by May/June 2011.

Species	Otter	% Bleached	Water	% Bleached
C. natans	111	4.5	230	1.7
D. labyrinthiformis	305	58.9	426	17.4

Table 1. Percent of colonies of *C. natans* and *D. labyrinthiformis* that were bleached at first observation.

Even corals of the same species growing adjacent to each other had different responses. For example, the sequence of bleaching recovery of two adjacent *D. labyrinthiformis* colonies in Otter Creek (Fig. 3) is representative of other colonies of this species in exposed locations. Both colonies regained their normal color but one had partial mortality.

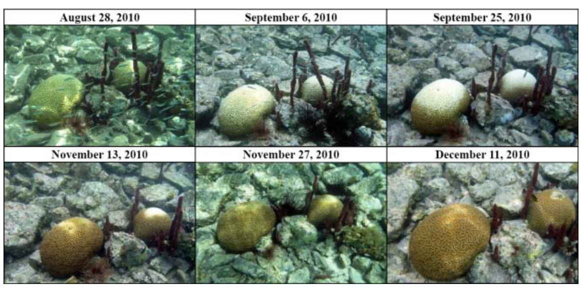

Figure 3. Recovery of two bleached *D. labyrinthiformis* colonies. The colony on the left recovered completely. The upper portion of the colony on the right died.

For both bays, *C. natans* colonies had much lower mortality than *D. labyrinthiformis* colonies (Table 2).

Species	Condition	Otter	% Died Partially	% Died Totally
D. labyrinthiformis	Initially Bleached	115	13.9	4.3
	Normal Pigmentation	72	8.3	2.8
C. natans	Initially Bleached	2	50.0	0
	Normal Pigmentation	67	0	0
Species	**Condition**	**Water**	**% Died Partially**	**% Died Totally**
D. labyrinthiformis	Initially Bleached	25	8.0	4.0
	Normal Pigmentation	271	4.8	3.3
C. natans	Initially Bleached	4	0	0
	Normal Pigmentation	113	0	0

Table 2. Fate of resurveyed colonies of *C. natans* and *D. labyrinthiformis* that were bleached or had normal pigmentation when first observed.

Most colonies of both species recovered with no mortality. Of 179 *D. labyrinthiformis* colonies in Otter that were pale or partially bleached in November 2010, 115 colonies were relocated. From that subset of bleached colonies, five (4.3%) died entirely and 16 (13.9%) died partially by May 2011. One of the 115 colonies was initially bleached and had partial recent mortality. Of the 126 *D. labyrinthiformis* colonies that had normal pigmentation, 72 were resurveyed. Of those, two (2.8%) experienced total mortality and 6 (8.3%) partial mortality. Of 106 *C. natans* colonies that were initially observed with normal pigmentation, 67 were relocated, with none showing any signs of mortality. Two *C. natans* colonies that were initially bleached were relocated, with one showing partial mortality and one showing no mortality.

In Water Creek, of the 74 *D. labyrinthiformis* colonies that were initially bleached, 25 colonies were able to be relocated, and two (8.0%) experienced partial mortality and one (4.0%) experienced total mortality. Of the 552 *D. labyrinthiformis* colonies that initially had no signs of bleaching, 271 were relocated. Of these, thirteen (4.8%) experienced partial mortality, including nine (3.3%) that were partly dead when first observed. One colony that initially had normal pigmentation and no dead portions had died completely by July 2011.

Of the 153 colonies of *C. natans* that initially had normal color, 113 were able to be re-examined. Of the four *C. natans* colonies that were initially bleached, two were relocated with no signs of bleaching by July 2011. None of the *C. natans* colonies had any recent mortality during the study period.

Seawater temperatures and bleaching

Average daily temperatures ranged from 25.9°C to 31.7°C (average 28.8°C) in 2010 and from 25.4°C to 31.2°C (average 28.3°C) in 2011. There was a sharp increase in temperature in August 2010 coincident with a noticeable increase in coral bleaching.

Water temperatures in 2011 were generally lower than in 2010 from January until October, with the exception of the unusually low temperatures in October 2010 associated with Tropical Storm Otto (Fig. 4). In 2010, there were more days with temperatures exceeding 30°C (Fig. 5). Moderate to severe bleaching occurred in the summer/fall of 2010 but not in 2011.

Discussion

To our knowledge, no other Caribbean mangrove ecosystems have as many coral species as those in Hurricane Hole. Some major review papers on prop root communities in Caribbean mangroves do not even mention corals (e.g., Kathiresan and Bingham

2001, Nagelkerken et al. 2008). Many of these colonies are intact, unlike numerous colonies on the reefs with partial mortality from disease. Two major

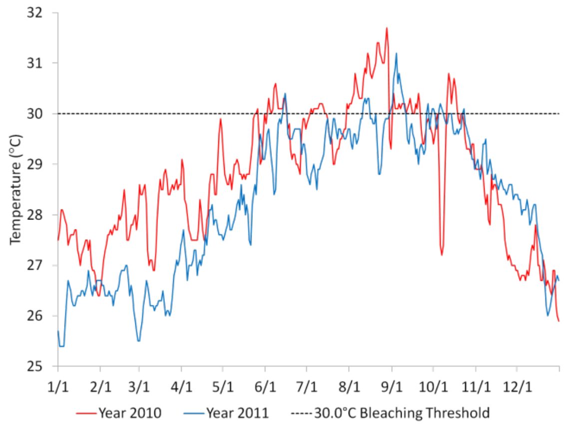

Figure 4. Average daily seawater temperatures in Otter and Water Creeks in 2010 and 2011.

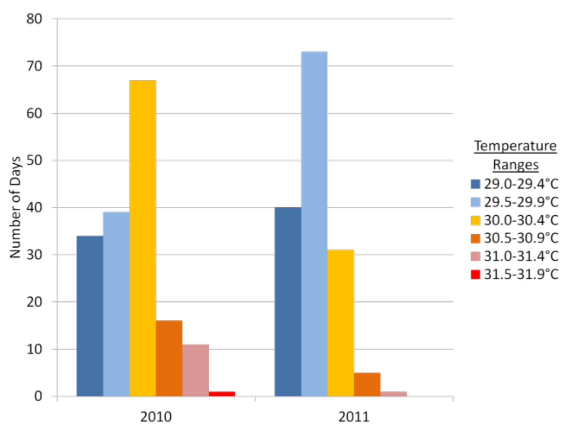

Figure 5. Temperature ranges in Otter and Water Creeks in 2010 and 2011.

reef-building corals had very different responses to high seawater temperatures, with *D. labyrinthiformis* bleaching moderately to severely and *C. natans* exhibiting very little bleaching. Variation in environmental factors over short distances results in microhabitats leading to some variation in responses. Even adjacent corals of the same or of different species exposed to the same environment exhibited different responses.

Many of the coral species in Hurricane Hole bleached in 2010, and bleaching of many species was also seen on the deeper reefs around St. John (NPS, unpublished data). No bleaching episode was observed in 2011 on the reefs or within Hurricane Hole. The water temperatures in Hurricane Hole in 2010 were consistently higher than those on the reefs in 2005 up until September/October (Miller et al. 2009). In 2011, temperatures in Hurricane Hole were higher than in 2005 in winter and fall but not for other time periods. There was no disease outbreak in 2010 in Hurricane Hole or on the coral reefs similar to the one in 2006 following the Caribbean bleaching event in 2005 (Miller et al. 2009). Severe bleaching and some mortality of *C. natans* from disease were noted in 2006 on a St. John reef, although this species is not abundant on the island's reefs (Whelan et al. 2007).

No information on bleaching of Hurricane Hole corals is available for 2005. However, the large size of some of the *C. natans*, *D. labyrinthiformis*, *Siderastrea* and *Montastraea* colonies growing among the mangrove prop roots (up to 1 meter across) make it clear that they did not succumb to bleaching or disease at this time, perhaps because shading by the mangrove trees reduced the photic and thermal stresses to the corals and/or because they have become acclimatized to these stresses. High temperatures and irradiance levels combine to cause bleaching (e.g., Lesser 2011).

Chemical and physical parameters likely play a role in the distribution of corals and their response to bleaching in the fringing mangrove habitats of Hurricane Hole. Although further research is needed, many corals shaded by mangroves did not bleach. Scientists with whom we are collaborating made diurnal measurements of Photosynthetically Available Radiation (PAR) and carbonate system parameters (including pH) at selected sites of similar water depth in Princess, Otter and Water 1) where corals are growing on mangrove prop roots, 2) near mangroves without associated corals, and 3) at sites where corals are growing on rocky outcrops with no shading from mangroves. A preliminary analysis of the data indicates that PAR is considerably lower at mangrove coral sites than at rocky outcrop sites where corals are not shaded; and pH is consistently lower at mangrove sites with no corals than at mangrove and rocky outcrops sites where corals are growing (K. Yates, USGS, unpublished data).

We need to know more about the links among different stressors, for example among high seawater temperatures, bleaching and coral disease (Selig et al. 2006, Bruno et al. 2007, Brandt and McManus 2009, Rogers et al. 2009, Oliver and Palumbi 2011). Further research on how different reef species will respond to global stressors (combined with local ones) is of the highest priority. Little is known of how different species are reacting to the various stressors and how they will react to the increasing effects of climate change (Kleypas 2007, Brown and Cossins 2011). As shown in the present study, coral species vary in their susceptibility to bleaching (see also Marshall and Baird 2000, McClanahan et al. 2009). We need to have a better understanding of the molecular and physiological mechanisms that determine the tolerance of coral hosts and zooxanthellae to different stressors (Coles and Brown 2003, van Oppen and Gates 2006). Corals and other reef species vary in their responses to high seawater temperatures and acidification (Pandolfi et al. 2011).

Corals may be able to acclimatize or eventually adapt to warmer temperatures because of the diversity of their symbiotic dinoflagellates (zooxanthellae) and a variety of physiological mechanisms (e.g., Brown and Cossins 2011). In addition, some studies have shown that corals exposed to high light or high temperatures may later show reduced susceptibility to bleaching (Brown et al. 2002). The high biodiversity of coral reefs means that a high diversity of responses to local and global stressors (including increasing temperatures) is anticipated. Coral species and other reef organisms will differ in their ability to deal with local stresses and the different aspects of climate change (e.g., Loya et al. 2001).

Virgin Islands Coral Reef National Monument was created in 2001 partly to protect the narrow fringe of red mangroves in Hurricane Hole and the shallow nursery areas that provide fish and invertebrate larvae for deeper areas in nearby Virgin Islands National Park. Further research on coral genotypes and on water circulation is needed to determine how the Hurricane Hole mangrove areas are linked or connected to the coral reefs within and outside the national monument and park and whether they are functioning as a source or a sink (or both) with regard to coral larvae. It is possible that the Hurricane Hole coral communities have the potential to provide larvae of some of the coral species, including major reef-building species, to reefs which have declined dramatically since 2005.

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