A Short Report on the Changing Ecology of the Pinnacle Reefs of Discovery Bay, Jamaica; 1970s to 2018

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Abstract

When first studied in the 1960s-70s, the ~25-55 m deep pinnacles off Discovery Bay, Jamaica, were well-developed, with high coral cover and a rich associated benthic biota. Biological and geological studies initiated under the leadership of Thomas F. Goreau demonstrated that pinnacle reefs are constructed by expanding frameworks of corals in which sediments are trapped and become lithified *in-situ*. Thus, at least some deep, modern reefs are naturally accreting, high-relief structures, rather than "thin skins" of living corals, overlying the presumed Pleistocene bedrock.

The 50th anniversary of the Discovery Bay Marine Laboratory in 2018 provided an opportunity for us to revisit early research sites on the pinnacles. Combined with observations from field sessions on Dancing Lady Reef in 2013-15, our work has revealed that deep reef communities exposed to multiple stressors are engaged in ecological freefall. Live coral cover and abundance have declined precipitously and most coral skeletons are covered with algae. The present condition of the deeper reefs below 55 m remains unknown.

Keywords: *Agaricia*, Caribbean, coral cover, coral reef degradation, coral reef health, deep fore-reef, Discovery Bay, fore-reef slope, Jamaica, *Montastrea annularis*, *Orbicella*

Introduction

Deep reefs on the narrow shelf off the north Jamaican coast are readily accessible to SCUBA divers. In 1965, Thomas F. (Tom) Goreau established the Discovery Bay Marine Laboratory (DBML), where huge pinnacles with well-developed and diverse benthic communities occurred from ~25-55 m on the fore-reef slope (FRS). Below the FRS, a spectacular, near-vertical to overhanging, deep fore-reef (DFR) cliff descended to the top of the island slope in ~122 m. Goreau and colleagues found corals and calcareous green algae *(Halimeda)* thriving to depths of ~70 m on the DFR and coralline sponges even deeper (Goreau and Graham, 1967; Goreau and Wells, 1967; Hartman and Goreau, 1970). Calcareous reef sediments were either trapped by corals and lithified into reef rock or drained into deeper water (Land and Goreau, 1970; Goreau and Land, 1974). Low-light flattening of corals, a morphological adaptation to decreasing calcification rates at depth (Dustan, 1975), facilitated sediment shedding while helping to stabilize dislodged colonies (Goreau and Hartman, 1963). By the time Goreau died unexpectedly in 1970, DBML had been established as an international center for innovative coral research.

Stressors affecting Jamaican reefs escalated during the 1980s and have continued to the present. As emerging ecological problems on the shallow reefs and newer diving safety rules at DBML reduced routine SCUBA diving below 25 m during the 1980s, its deep reefs faded from the forefront of research interest. In 2012, at an IUCN Global Coral Reef Monitoring Network meeting to discuss Caribbean coral reef change, Peter Gayle, DBML Science Officer, initiated a request to one of us (P. Dustan) to revisit Discovery Bay (DB) to evaluate the condition of the Dancing Lady Reef (DLR) where he had previously carried out *in situ* experiments along a depth cline between the surface and 50 m. Gayle reminded him of the historic value of his photographs and started us thinking of how they could be used to further current conservation efforts. Thus began a series of excursions to DBML to document and better understand the current ecology of the FRS.

Study Site and Methods

The island of Jamaica is situated south of Cuba and southwest of Hispaniola in the West Indies. DB, a bauxite port near the central north coast, is a near-circular bay formed by outflow from an ancient, now extinct river. Although the river is gone, freshwater enters as rainfall, and groundwater flows continuously into the bay via submarine springs, fissures, and seepage. Offshore, an extensive fore-reef terrace and escarpment with large-scale spur and groove morphology (Figures 1, 2) had a high cover of corals and associated benthos before the 1980s. The deeper FRS was a sloping mud/sandy carbonate plain where pinnacles and smaller reef structures protruded through the sediment like the tops of mountains surrounded by flowing sand glaciers (Goreau and Goreau, 1973; Goreau and Land, 1984). The "drop-off" at the base of the FRS in ~55 m, marked the transition to the DFR.
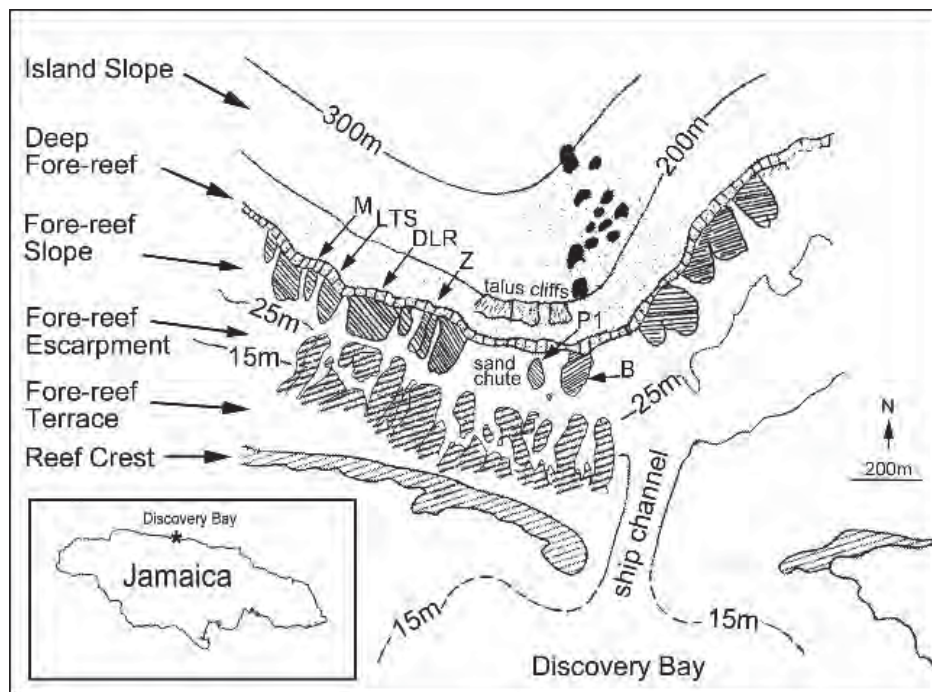

Figure 1. DB fore-reef bathymetry (based on Moore et al., 1976; Dustan and Lang, in press). Hatched areas depict reef features between sand plains or channels.
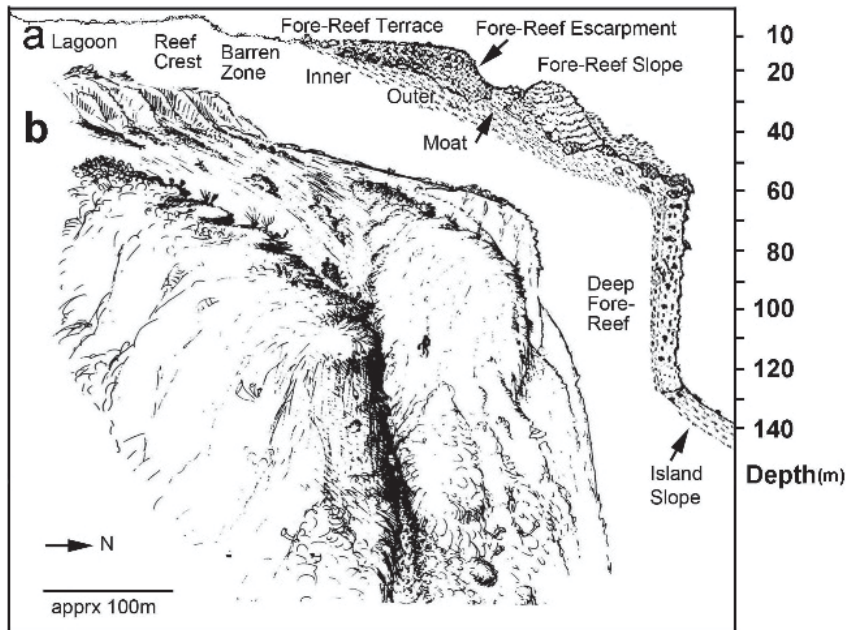
Figure 2. (a) Profile of DB reef tract, FRS pinnacles and the drop-off at ~55 m (based on Lang et al, 1975; Dustan and Lang, in press). (b) DB reef sketch by T.F. Goreau.

Two stony coral species groups comprised a majority of the deep, framework-building corals, each forming nearly monotypic stands on the FRS at DB. A massive species formerly called *Montastrea annularis* (Dustan, 1975) has since been split into a species complex and assigned to an earlier genus, *Orbicella* (Budd et al., 2012). Below ~20 m, *Orbicella faveolata* and *O. franksi* (hereafter called *Orbicella* spp.) are predominantly flat, with near-horizontal living surfaces. Large, framework-building colonies that resembled gigantic bracket fungi or enormous roofing shingles, dominated the upper pinnacles in ~25-45 m (Figure 3). Several species of foliaceous agariciids that were prominent on the lower FRS also flattened with depth, but grew into shapes more reminiscent of the petals of large flowers, often assuming a whorled morphology with their living surfaces inclined so as to easily shed sediments (Figure 4).

Figure 3. Live *Orbicella*-dominated FRS on DLR, 27m, 1971. Photo by P. Dustan.

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Figure 4. Live *Agaricia*-dominated FRS off the eastern side of DB at Pinnacle III, 40 m, 1972.
Photo by P. Dustan.

Early efforts to quantify FRS coral cover at DB were focused on the West Fore Reef, with studies at DLR (Dustan, 1975 for *Orbicella* spp.*)*, Monitor Reef (Porter et al., 1981), Zingorro (Liddell and Ohlhorst, 1981) and Pinnacle 1 (Hughes and Jackson, 1985). Because these data were collected at different times and depths, and with different techniques, we have chosen to focus on the percent cover of *Orbicella* spp. at 30 m (in the area of its highest original cover at DLR). Projected intercept length was measured to the nearest centimeter along a line transect that was placed horizontally ~45 m across DLR in approximately the same position in 1972, 2013, and 2018. Cover of *Orbicella* spp. and of coral and non-crustose algae (cyanobacterial-turf algal mats and macroalgae) was estimated using line-point transects at 30m on Zingorro Reef in 1977 and 1982, and on the Long Term Survey (LTS) portion of the West Fore Reef in 1992 (Liddell and Ohlhorst, 1981, pers. comm.; Liddell et al., 1984; Andres and Witman, 1995). Comparable estimates on Zingorro in 1989 were provided by photo-transects (Liddell and Ohlhorst, 1992). HOBO temperature loggers were placed at 3 m and 30 m on DLR in 2013-2018 for long-term comparison between shallow and deep reef temperatures.

Results and Discussion

In recent decades, the deep reefs off DB have experienced greatly reduced herbivory, repeated coral bleaching-mortality events, coral diseases, degraded water quality, increased sedimentation, and destructive hurricane waves. *Orbicella* spp. at 30 m on the West Fore Reef had averaged ~50% (ranging from ~46-54%) in the 1970s, but their collective cover already had fallen to ~15% on LTS in 1992 and was ~8% at DLR in 2013, when some of the survivors showed signs of disease. As these and other coral species declined, non-crustose algae colonized the newly exposed skeletons, trapping sediment, expanding over live corals, and increasing their cover from ~8% on Zingorro in 1979 to ~55% on LTS in 1992 (Figure 5). By 2013, most of the agariciid colonies deeper on the FRS at DLR

had died and the fragile skeletons of many had vanished. In the fall of 2017, surface seawater temperatures were elevated across the western and southern Caribbean and Jamaica (NOAA, 2018). Recorded temperatures on DLR in September 2017 were over 30°C, with less than 0.25^{o}C difference between 3 and 30 m. Reefs along the north coast of Jamaica, including the FRS at Monitor, were severely affected by bleaching (B. Charpentier, in prep.).

Despite our familiarity with the degraded FRS communities at several sites on the West Fore Reef, we remained uncertain as to how representative they are of other deep reefs along the Jamaican north coast (Dustan and Lang, in press). Thus, our exploratory dives in late April-early May 2018 to FRS depths at six sites along ~3 km of the DB coastline that two of us (P. Dustan and J. Lang) had known well decades before were profoundly sobering. Even on initial descents, it was apparent that coral cover everywhere had dropped precipitously during the last 40-50 years, that the living remnants of many colonies were still pale or bleached (either partially or wholly), and that some were also diseased. Although mostly dead, the robust skeletons of *Orbicella* spp. were still in their original growth positions (Figure 6), and their cover at the 30 m transect on DLR was ~6%. Deep-water agariciids were rare everywhere. In particular, the huge "super colony" of *Agaricia undata* at West Bull (Figure 7) was gone; in its former place were a few small benthic invertebrates and a profusion of macroalgae (Figure 8). Non-crustose algae covered virtually every surface not occupied by living corals, sponges, or alcyonaceans at all sites.
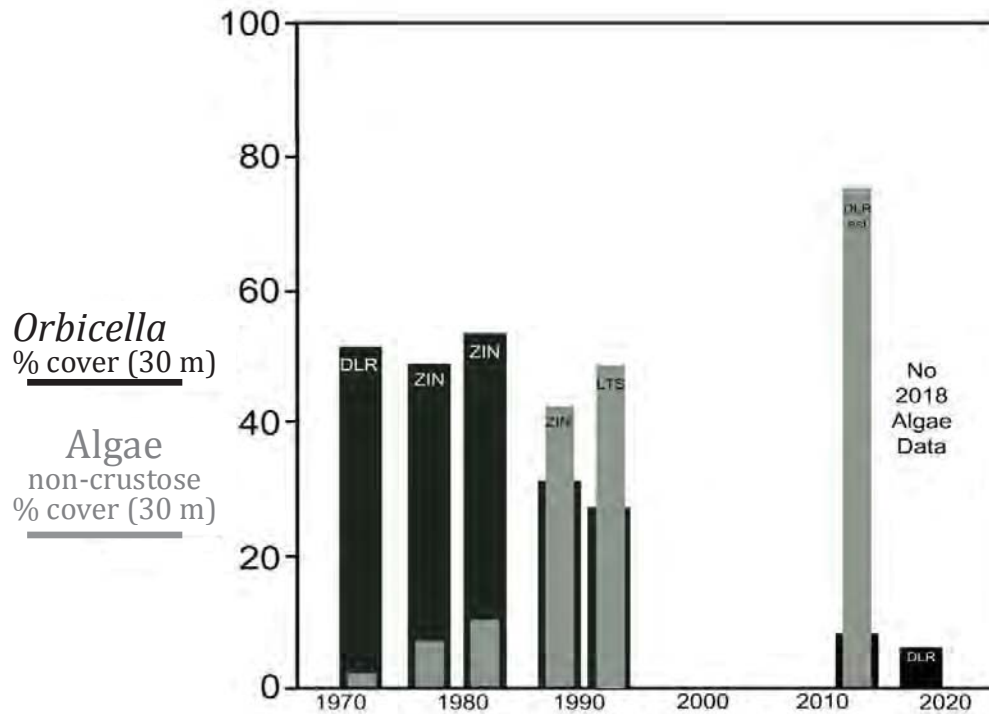

Figure 5. Percent cover of *Orbicella* spp. and non-crustose algae on DB FRS at 30 m. Cover estimates for DLR are from Dustan (1975) and Dustan and Lang (in press); for ZIN (Zingoroo) from Liddell and Ohlhorst (1981, 1992, pers. comm.) and Liddell et al. (1984), and for LTS from Andres and Witman (1995). Algae cover in 2013 was estimated from photographs.
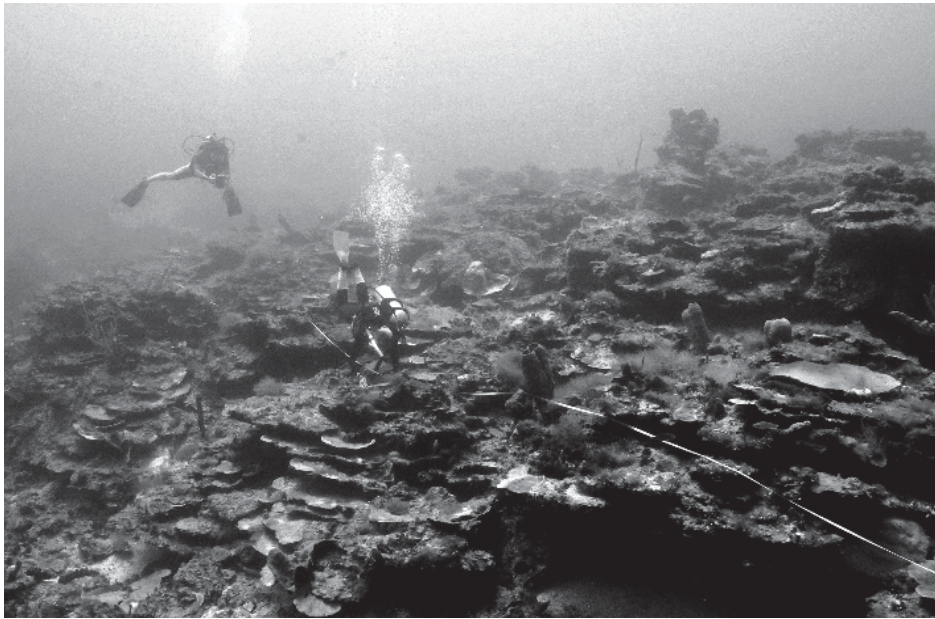
Figure 6. Divers at 30 m along FRS transect on DLR, May 2018. Most of the *Orbicella* "shingles" have died and are now covered with non-crustose algae. Photo by P. Dustan.
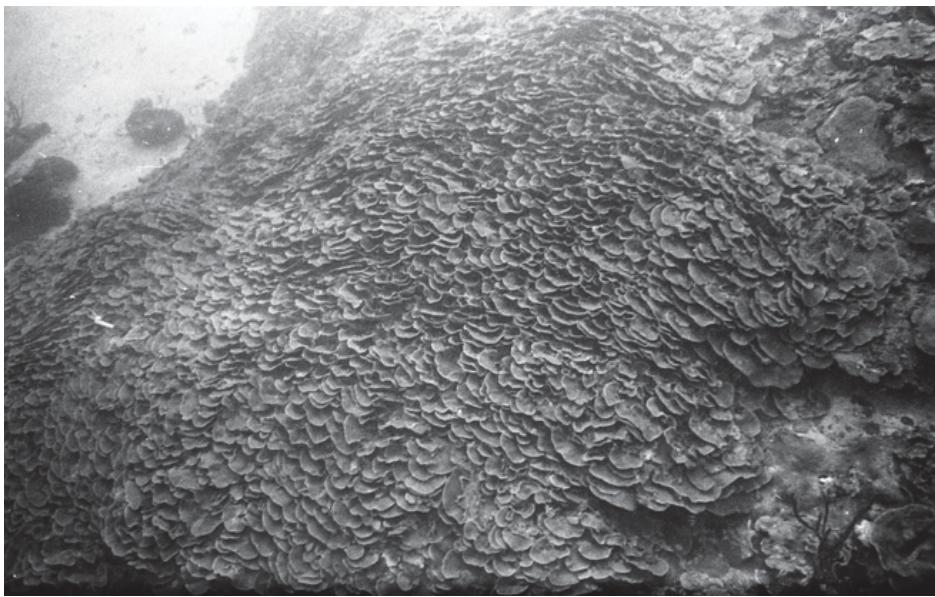

Figure 7. *Agaricia undata* "super colony" at ~40 m, West Bull, 1967. Photo by E. Graham.

Figure 8. Macroalgae dominate the slope formerly occupied by *Agaricia undata* at ~40 m, West Bull,
April 2018. Photo by J. Lang.

In the early 1970s, flattened *Orbicella* spp. on the FRS at DLR extended laterally at rates overlapping the upward growth of round *O. annularis* at 10 m, but had slower upward growth rates (Dustan, 1975). In 1972, *Orbicella* spp. cover at 30 m on the FRS was about twice that of the corresponding transect with its highest abundance at 7 m on the fore-reef terrace (~53% vs. ~25%). By 2013, their respective losses were ~85% at 30 m and 77% at 7 m (where *O. annularis* had also been reduced to ~6% cover). In terms of absolute cover, the loss of *Orbicella* spp. at the 30 m FRS transect was nearly 2.5 times greater than that of *O. annularis* at 7 m. (47% vs. ~19%).

Goreau's (1959) research in Jamaica provided early experimental evidence that the calcification of corals with *Symbiodinium* photosymbionts is enhanced by light – a concept now perhaps better understood as "driven by photosynthesis" (Colombo-Pallotta et al., 2010). Light levels decrease exponentially with depth at DLR (Dustan, 1982); hence, FRS corals have fewer resources derived from photosynthesis than their shallower-water counterparts with which to combat diseases and for growth, repair, reproduction, or other vital necessities. Given our experiences on the FRS off DB, we concur with Rocha et al. (2018) that, especially in areas with anthropogenic disturbances, mesophotic reefs (i.e., reefs at depths of 30-150 m) are "distinct, impacted, and in as much need of protection as shallow coral reefs."

Acknowledgments

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