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A study on the recovery of Tobago's coral reefs following the 2010 mass bleaching event

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ABSTRACT

In 2010, severe coral bleaching was observed across the southeastern Caribbean, including the island of Tobago, where coral reefs are subject to sedimentation and high nutrient levels from terrestrial runoff. Here we examine changes in corals' colony size distributions over time (2010–2013), juvenile abundances and sedimentation rates for sites across Tobago following the 2010 bleaching event. The results indicated that since pre-bleaching coral cover was already low due to local factors and past disturbance, the 2010 event affected only particular susceptible species' population size structure and increased the proportion of small sized colonies. The low density of juveniles (mean of 5.4 ± 6.3 juveniles/m^{-2}) suggests that Tobago's reefs already experienced limited recruitment, especially of large broadcasting species. The juvenile distribution and the response of individual species to the bleaching event support the notion that Caribbean reefs are becoming dominated by weedy non-framework building taxa which are more resilient to disturbances.

1. Introduction

Caribbean coral reefs are among the most heavily impacted marine ecosystems on the planet (Bellwood et al., 2004; Edmunds and Elahi, 2007). Since the 1970s many Caribbean reefs have experienced unprecedented levels of decline in coral cover, from about 50% to 10%, and are transitioning into algal dominated environments (Gardner et al., 2003; Roff et al., 2011; Jackson et al., 2014). This ecological change has been attributed to the reduction of herbivory, due to overfishing and the regional die-off of grazing urchins in the 1980s, increased terrestrial runoff, marine pollution and possibly related disease outbreaks (Hughes, 1994; Jackson et al., 2014). Furthermore, ocean warming has led to episodes of mass coral bleaching and related coral mortality, which have contributed to the overall decline in coral cover (Eakin et al., 2010). Considering that the frequency and intensity of thermal stress is projected to increase in the near future in the Caribbean (Donner et al., 2007), the future of Caribbean coral reefs depends in part on their resistance and resilience to bleaching.

Bleaching, the paling of corals due to the loss of the symbiotic microalgae *Symbiodinium*, makes coral colonies vulnerable to complete or partial mortality and susceptible to infectious diseases (Ward et al., 2000). Severe mass bleaching events can often lead to a significant decline in coral cover and a change in community composition (Hoegh-Guldberg et al., 2007). Bleaching-induced mortality can alter the abundance and size of colonies within a population (McClanahan et al., 2009), which in turn may affect the reproductive output and by extension the post-beaching recovery of the reef. The recovery of a given population from bleaching depends on the diversity, abundance, size and health of surviving coral colonies, as well as their fecundity, larval settlement success, recruitment success, and the suitability of the environmental conditions (Tamelander, 2002; Baker et al., 2008; Crabbe, 2009). Other environmental disturbances such as terrestrial runoff or fishing pressure may further undermine the recovery process (Burt et al., 2008). To improve our understanding of post-bleaching recovery it is important to assess the impact of bleaching on coral assemblages and the ability of coral taxa to sexually reproduce within their given environment (Birrell et al., 2005; Smith et al., 2005; Irizarry-soto and Weil, 2009).

Coral reefs in Tobago have experienced many of the same stressors as many other Caribbean coral reefs like sedimentation, nutrient runoff, and the thermal stress events of 1998, 2005 and 2010 (Eakin et al., 2010; Lapointe et al., 2010; Mallela et al., 2010). Bleaching was observed in 29–60% of colonies across Tobago in 2010 (Alemu I and Clement, 2014); only 2–8% of bleached corals suffered from mortality but the post-bleaching spread of coral disease likely led to further mortality (Alemu I, 2011). While there have been assessments of benthic cover, recruitment on artificial substrates and some growth modeling in Tobago (Mallela and Crabbe, 2009), little is known about the ability of different coral populations to recover from the bleaching events and whether it is influenced by local problems of terrestrial runoff and sedimentation (Lapointe et al., 2010; Mallela et al., 2010).

In this study, we investigate the recovery of coral communities from the 2010 mass bleaching event across three distinct reef systems exposed to different levels of sedimentation. First, we evaluate the effect of the bleaching event on demographics of the dominant coral species

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by examining the changes in the population size structure from 2010 to 2013. Second, we quantify the juvenile coral community across different reef systems, as juvenile abundance indicates the ability of coral populations to reproduce sexually and recruit (Ritson-williams et al., 2009; Arnold and Steneck, 2011). Third, we assess the rate and composition of sedimentation at each site, as high levels of sedimentation are known to affect the growth stages of coral lifecycle (Wittenberg and Hunte, 1992; Miller et al., 2000; Fabricius, 2005). While there are a few studies of changes in coral population structures following mass bleaching in the region (Manfrino et al., 2013; Crabbe, 2009), this is the first to integrate population size structure, juvenile abundance and sediment data to assess the factors that influence recovery from disturbance. The results support the growing body of research on how heat stress and disease are shaping the trajectory of Caribbean coral communities.

2. Materials and methods

2.1. Study area

This study was conducted on three of Tobago's major reef systems: Buccoo Reef, Culloden Reef and Speyside (Fig. 1). Tobago is a hilly 300 km^2 island of volcanic origin covered mostly by forest and shrublands, though the south-western part of the island has undergone significant urbanization and agricultural development. The island's fringing coral reefs developed under the influence of nutrient and sediment outflow from the Orinoco and Amazon Rivers of nearby South America. Consequently, Tobago's coral communities have lower species diversity than other Caribbean reefs (Laydoo, 1991).

Buccoo Reef is composed of five large, sloping reef flats covering about 4 km^2 and is Tobago's only official marine protected park (since 1973). In the last three decades, the adjacent land has experienced rapid urbanization; untreated sewage and uncontrolled storm waters drain into Buccoo Bay (Potts et al., 2004; Lapointe et al., 2010; Parkinson, 2010). The horseshoe shaped reef of Culloden covers ~0.05 km^2 and is located in a remote bay surrounded mostly by forested hills (Laydoo, 1991). Human activities in the area are limited to occasional recreational divers, artisanal fishing and boat anchorage. Speyside, on the north-eastern side of the island, features a large network of fringing reefs along small islands and rocky outcrops. Like Culloden, Speyside's coastline remains relatively undeveloped apart from Speyside village (a fishing community) and a few medium-sized hotels.

Two study sites were established at each reef system. The Buccoo sites (Western Reef and Outer Reef) represented systems exposed to land pollution from runoff and sewage. The Culloden sites (Culloden East and Culloden West) experience similar marine conditions but less land-based pollution. The Speyside sites (Black Jack Hole and Angel Reef) are more exposed to the Atlantic Ocean and less affected by mainland terrestrial runoff. All surveys were conducted between 8 and 12 m depth at all sites using SCUBA from mid-May to late June of 2013.

2.2. Coral size surveys

At each reef site, 10 transects were conducted, and the length of all adult corals (colonies ≥5 cm) that lay within 50 cm on each side of a 10 m transect tape were measured following the protocol outlined by Done et al. (2010). All measured colonies were identified to the species level, except for the genus *Agaricia*. Only colonies with >50% of the living tissue within the belt transect area were recorded in the survey. Colonies that exhibited partial mortality or fission such that separate patches of living tissue were >3 cm apart from each other were considered independent colonies and were measured individually (Adjeroud et al., 2007; McClanahan et al., 2008; Done et al., 2010). To identify changes in the coral community and population structure over time, we used unpublished data collected in September 2010 (before bleaching induced coral mortality) and in March 2011 (after bleaching induced coral mortality) at all sites except Angel Reef by the Trinidad and Tobago Institute of Marine Affairs (IMA). As the IMA surveyed both length and width of each living colony along four 10 m × 2 m belt transects, the mean dimension was employed in this analysis. The IMA surveys covered a total of 80 m^2 per reef. So that a balanced statistical comparison could be made between the IMA and 2013 assessments, eight transects were randomly subsampled from the 2013 assessment.

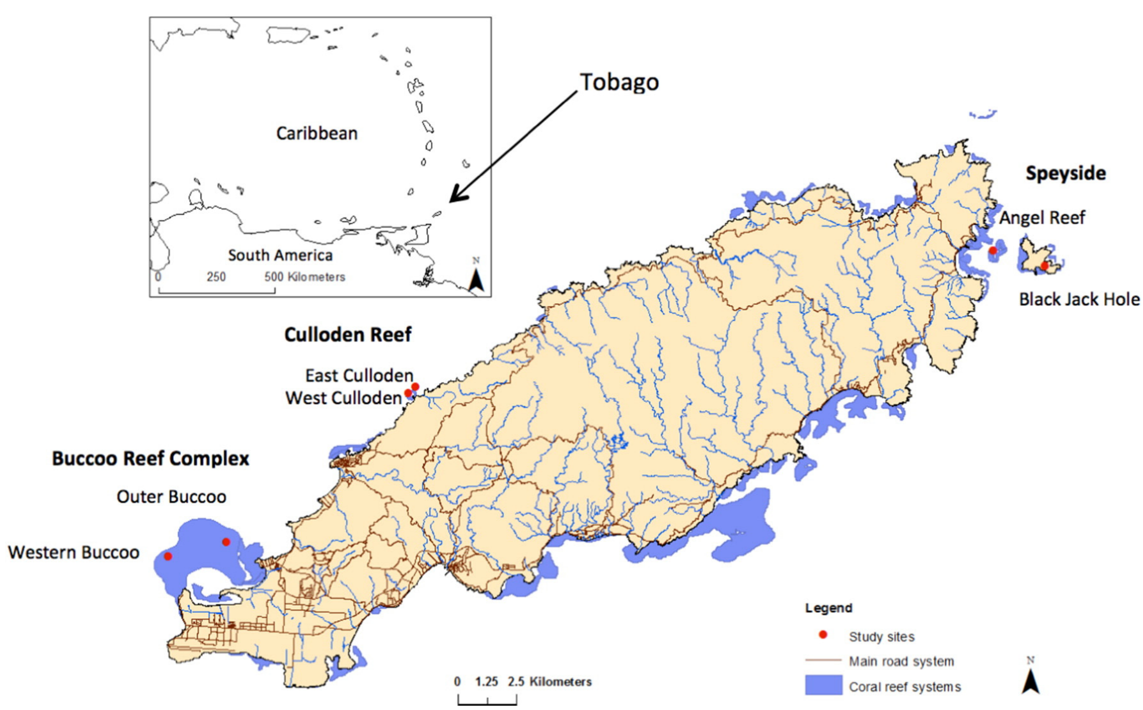

Fig. 1. Map of Tobago and location of study sites.