Marine Environmental Research 67 (2009) 189–198

Contents lists available at ScienceDirect

Marine Environmental Research

journal homepage: www.elsevier.com/locate/marenvrev

Scleractinian coral population size structures and growth rates indicate coral resilience on the fringing reefs of North Jamaica

M.J.C. Crabbe *

Institute for Research in the Applied Natural Sciences, Faculty of Creative Arts, Technologies and Science, University of Bedfordshire, Park Square, Luton, LU1 3JU, UK

ARTICLE INFO

Article history:
Received 26 August 2008
Received in revised form 18 January 2009
Accepted 30 January 2009

Keywords:
Demographics
Tropical storms
Hurricanes
Cyclones
Bleaching
Climate change
Global warming
Coral growth
Recruitment
Discovery Bay

ABSTRACT

Coral reefs throughout the world are under severe challenges from many environmental factors. This paper quantifies the size structure of populations and the growth rates of corals from 2000 to 2008 to test whether the Discovery Bay coral colonies showed resilience in the face of multiple acute stressors of hurricanes and bleaching. There was a reduction in numbers of colonies in the smallest size class for all the species at all the sites in 2006, after the mass bleaching of 2005, with subsequent increases for all species at all sites in 2007 and 2008. Radial growth rates (mm yr^{-1}) of non-branching corals and linear extension rates (mm yr^{-1}) of branching corals calculated on an annual basis from 2000–2008 showed few significant differences either spatially or temporally. At Dairy Bull reef, live coral cover increased from 13 ± 5% in 2006 to 20 ± 9% in 2007 and 31 ± 7% in 2008, while live *Acropora* species increased from 2 ± 2% in 2006 to 10 ± 4% in 2007 and 22 ± 7% in 2008. These studies indicate good levels of coral resilience on the fringing reefs around Discovery Bay in Jamaica.

1. Introduction

Coral reefs throughout the world are under severe challenges from a variety of environmental factors including overfishing, destructive fishing practices, coral bleaching, ocean acidification, sea-level rise, algal blooms, agricultural run-off, coastal and resort development, marine pollution, increasing coral diseases, invasive species, and hurricane/cyclone damage, (Gardner et al., 2003; Bellwood et al., 2004; Crabbe et al., in press). The fringing reefs around Discovery Bay in Jamaica constitute one of the best documented areas of reef decline in the Caribbean, where loss of corals and macroalgal domination has been due to hurricanes (Woodley et al., 1981; Crabbe et al., 2002), overfishing (Jackson, 1997; Hawkins and Roberts, 2004), die-off of the long-spined sea urchin *Diadema antillarum* in 1983–84 (Hughes, 1994), and coral disease (Aronson and Precht, 2001). Nutrient enrichment does not appear to have been a causal factor in the development of the reef macroalgal communities (Greenaway and Gordon-Smith, 2006).

Maintaining coral reef populations in the face of large scale degradation and phase-shifts on reefs depends critically on recruitment (Hughes and Tanner, 2000; Coles and Brown, 2007), maintenance of grazing fish and urchin populations (Mumby et al., 2007), clade of symbiotic zooxanthellae (Stat et al., 2008) and management of human activities related to agricultural land use and coastal development (Mora, 2008). To manage coral reefs it is important to have an understanding of coral population demography – structure and dynamics (Soong, 1993; Meesters et al., 2001; Smith et al., 2005). Ideally, this involves the quantification of numbers of individual colonies of different size classes – the population structure-through time, in addition to quantifying coral growth rates, recruitment and survival. The fringing reefs around Discovery Bay have seen a number of climate-related challenges in recent years, notably several hurricanes as well as a mass bleaching event in the Caribbean in 2005 (Jones et al., 2004; 2008). Despite all these negative factors, there is evidence that prior to 2005 some Discovery Bay reefs were recovering (Idjadi et al., 2006), although a study subsequent to the 2005 bleaching event is not so positive (Quinn and Kojis, 2008). Healthy reefs have a high proportion of small size-classes that include new recruits and juveniles (Meesters et al., 2001), and the smallest size class of corals can be a good indicator of reef resilience (Loya, 1976; Connell, 1978). This study set out to quantify the size structure of populations and the growth rates of a number of corals over time in order to test whether the Discovery Bay coral colonies were exhibiting resilience in the face of multiple acute stressors of hurricanes and bleaching. I take the definition of resilience as the ability of the system to recover from disturbance and change, while main-

* Tel.: +44 0 1582489265; fax: +44 0 1582489212.
E-mail address: james.crabbe@beds.ac.uk.

0141-1136/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.marenvres.2009.01.003

taining its function (Carpenter et al., 2001; Grimsditch and Salm, 2006); for example a coral reef's ability to recover from a bleaching event. Resilience is a multi-faceted concept (Nyström et al., 2008), and factors that can improve coral reef resilience to a mass bleaching event include good species and functional diversity, good connectivity to larval sources, appropriate substrates for larval settlement and protection from other anthropogenic impacts.

2. Methods

2.1. Data on storms, hurricanes and bleaching events impacting Discovery Bay

Data on storm severity as it impacted the Discovery Bay sites was obtained from UNISYS (http://weather.unisys.com/hurricane/atlantic/) and the NOAA hurricane site (http://www.nhc.noaa.gov/pastall.shtml).

Information on bleaching was obtained from the NOAA coral reef watch site: (http://coralreefwatch.noaa.gov/satellite/current/sst_series_24reefs.html) and from Jones et al. (2008).

2.2. Sites and sampling

Four haphazardly located transects, each 15 m long and separated by at least 5 m, were laid at between 5–8.5 m depth at each of five sites [Rio Bueno (18° 28.805' N; 77° 27.625' W), M1 (18° 28.337' N; 77° 24.525' W), Dancing Ladies (18° 28.369' N; 77° 24.802' W), Dairy Bull (18° 28.083' N; 77° 23.302' W) and Pear Tree Bottom (18° 27.829' N; 77° 21.403' W)] along the fringing reefs surrounding Discovery Bay, Jamaica (Fig. 1). GPS coordinates were determined using a hand-held GPS receiver (Garmin Ltd.). Corals 2 m either side of the transect lines were photographed for archive information, and surface areas measured with flexible tape as described previously using SCUBA (Crabbe et al., 2002; Crabbe and Smith, 2005; Crabbe et al., 2008). For non-branching corals, this was done by measuring the widest diameter of the coral and the diameter at 90° to that. For branching corals (*Acropora palmata* and *Acropora cervicornis*), linear extension rates were measured using digital photography and image analysis, validated by measurements with flexible tape (Crabbe et al., 2002; Crabbe and Smith, 2005; Crabbe, 2007). Depth of samples was between 5–8.5 m, to minimise variation in growth rates due to depth (Huston, 1985). To increase accuracy, surface areas rather than diameters of live non-branching corals were measured (Crabbe et al., 2002; Crabbe and Smith, 2005). Sampling was over as wide a range of sizes as possible. Colonies that were close together (<50 mm) or touching were avoided to minimise age discontinuities through fission and altered growth rates (Hughes and Jackson, 1980; Foster et al., 2007; Elahi and Edmunds, 2007).

In this study we ignored *Montastrea annularis* colonies for demographic analyses, because their surface area does not reflect their age (Hughes and Jackson, 1980), and because hurricanes can increase their asexual reproduction through physical damage (Foster et al., 2007) although we included this species in growth rate measurements.

Radial growth rates of non-branching corals and linear extension rates of branching corals were calculated for each year from 2000–2008 as described previously (Crabbe et al., 2002; Crabbe and Smith, 2005). Overall, over 8000 measurements were made on over 1500 coral colonies, equally distributed between the sites for species and numbers of colonies.

This work was conducted at Discovery Bay during July 15–31 and December 19–30 in 2000, March 26–April 19 in 2002, March 18–April 10 in 2003, July 23–August 21 in 2004, July 18–August 13 in 2005, April 11–18 in 2006, December 30 in 2006–January 6 in 2007, and July 30–August 16 in 2008. Surveys were made at the same locations at the same sites each year.

Computer digital image analysis for coral linear extension rates was undertaken using the UTHSCSA (University of Texas Health Science Center, San Antonio, Texas, USA) Image Tool software (Crabbe and Smith, 2005). One or two-factor ANOVA was used to compare coral data among sites; ± error values represent standard errors of the data. The skewness coefficient (sk) (Zar, 1999) was used to quantify the relationship between the number of large and small corals within each population. The skewness for a normal distribution about the mean is zero, and any symmetric data should have skewness near zero. Negative values for the skewness indicate data that are skewed left (more small colonies than in a normal distribution) and positive values for the skewness indicate data that are skewed right (more large colonies than in a normal distribution). Water quality measurements at the sites have been reported previously (D'Elia et al., 1981; Greenaway and Gordon-Smith, 2006).

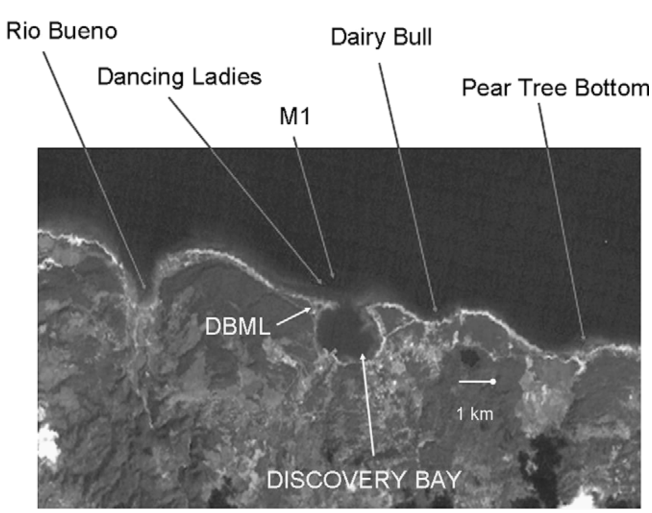

Fig. 1. Satellite image showing the location of fringing reef sites in this study (Rio Bueno, M1, Dancing Ladies, Dairy Bull and Pear Tree Bottom) around Discovery Bay, Jamaica. DBML, Discovery Bay Marine Laboratory. The horizontal line shows 1 km distance. See text for GPS coordinates.

3. Results

3.1. Environmental climate stressors-tropical storms and bleaching events

Hurricanes that had the potential to impact the reef sites during the study period are shown in Fig. 2, with their paths of travel. Only one of these storms resulted in any significant damage on the reefs, Ivan in 2004, a category 4 hurricane as it passed south of the island. Visually, the damage was minimal as far as reef destruction was concerned, with some *A. palmata* colonies being fragmented and overturned, notably at Pear Tree Bottom (personal observation). Although hurricane Emily in 2005 was also a category 4 hurricane, the eye passed sufficiently south of the island so that the impact involved sediment transfer owing to the high winds and rain (Crabbe and Carlin, 2007). Tropical storms Iris (category 1 hurricane, 2001), Lili (tropical storm, 2002), Bonnie (tropical wave, 2004), Charley (category 1 hurricane, 2004), Dennis (category 3 hurricane, 2005), Olga (tropical storm, 2007) and Dean (hurricane category 4, 2007) did not result in significant damage to the reef sites.

The only bleaching event that significantly impacted the reef sites during the study period was the mass Caribbean bleaching