ARTICLE IN PRESS

Marine Environmental Research xxx (2017) 1–10

Contents lists available at ScienceDirect

Marine Environmental Research

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

Variation in size frequency distribution of coral populations under different fishing pressures in two contrasting locations in the Indian Ocean

G. Grimsditch [a, *], C. Pisapia [b], M. Huck [c], J. Karisa [d], D. Obura [e], M. Sweet [c]

[a] International Union for the Conservation of Nature, Merryrose 2nd Floor, Malé 20006, Maldives
[b] ARC Centre of Excellence for Coral Reef Studies, James Cook University, Townsville, Queensland 4811, Australia
[c] Aquatic Research Facility, Environmental Sustainability Research Centre, College of Life and Natural Sciences, University of Derby, Derby DE22 1GB, UK
[d] Kenya Marine and Fisheries Research Institute, PO Box 81651-80100, Mombasa, Kenya
[e] CORDIO East Africa, #9 Kibaki Flats, Kenyatta Beach, Bamburi, Mombasa 80101, Kenya

A R T I C L E I N F O

Article history:
Received 5 November 2016
Received in revised form
17 September 2017
Accepted 21 September 2017
Available online xxx

Keywords:
Coral reefs
Fisheries
Ecosystem management
Coastal waters
Effects-population

A B S T R A C T

This study aimed to assess how the size-frequency distributions of coral genera varied between reefs under different fishing pressures in two contrasting Indian Ocean locations (the Maldives and East Africa). Using generalized linear mixed models, we were able to demonstrate that complex interactions occurred between coral genera, coral size class and fishing pressure. In both locations, we found *Acropora* coral species to be more abundant in non-fished compared to fished sites (a pattern which was consistent for nearly all the assessed size classes). Coral genera classified as 'stress tolerant' showed a contrasting pattern i.e. were higher in abundance in fished compared to non-fished sites. Site specific variations were also observed. For example, Maldivian reefs exhibited a significantly higher abundance in all size classes of 'competitive' corals compared to East Africa. This possibly indicates that East African reefs have already been subjected to higher levels of stress and are therefore less suitable environments for 'competitive' corals. This study also highlights the potential structure and composition of reefs under future degradation scenarios, for example with a loss of *Acropora* corals and an increase in dominance of 'stress tolerant' and 'generalist' coral genera.

1. Introduction

Many biological processes associated with clonal animals such as corals have been argued to be related to size rather than age (Connell, 1973; Loya, 1976; Hughes and Jackson, 1980; Hughes and Connell, 1987; Szmant, 1991; Soong, 1993). In corals, survival, growth and fecundity are strongly size-dependent (Hughes and Jackson, 1980, 1985) and consequently the size structure of coral populations is an important driver of their dynamics (Bak and Meesters, 1998). Assessing size structures of coral populations can provide information about important ecological processes such as coral survivorship, recruitment, fecundity, mortality and community responses to various stress events such as mass coral bleaching or *Acanthaster plancii* outbreaks (Meesters et al., 2001; McClanahan et al., 2008). Records of coral size class distributions and frequencies can provide an in-depth understanding of trends in the condition and resilience of reef ecosystems, rather than the data offered from more simplified metrics such as coral cover or diversity (Bak and Meesters, 1998; de Barros and Pires, 2006; Meesters et al., 2001).

Indeed, numerous studies have already started to take coral size class distribution into account, for example when surveying reefs subjected to variable stressors such as in areas with high human population densities, increased urbanization and higher fishing pressures (Meesters et al., 2001; Vermeij and Bak, 2003; Adjeroud et al., 2007; McClanahan et al., 2008). For example, Meesters et al. (2001) showed that reefs closer to heavily urbanized coastal areas contained relatively fewer colonies in smaller size classes but more colonies in larger size classes. Coral reefs in such areas are often classed as degraded due to the higher levels of pollution and sediment loads coupled with an increase in fishing pressure. In

* Corresponding author.
E-mail addresses: gabriel.grimsditch@iucn.org (G. Grimsditch), chiara.pisapia@my.jcu.edu.au (C. Pisapia), M.Huck@derby.ac.uk (M. Huck), jkarisa@kmfri.co.ke (J. Karisa), dobura@cordioea.net (D. Obura), M.Sweet@derby.ac.uk (M. Sweet).

https://doi.org/10.1016/j.marenvres.2017.09.017
0141-1136/© 2017 Published by Elsevier Ltd.

contrast to Meesters et al. (2001), McClanahan et al. (2008) illustrated that in areas where fishing pressure increased, a reduction in coral size across all genera was observed. In this instance, the findings were linked with increased rates of partial mortality or through the removal of functionally important herbivorous fish that are a key resource in regulating coral-algal competition and in maintaining resilience of coral populations against disturbances and mortality events (McClanahan et al., 2008).

Both studies illustrate the role of herbivorous fish in influencing coral population demographics. Herbivorous fish have been shown to be beneficial to coral populations as they provide key ecosystem functions that influence benthic communities (Folke et al., 2004), principally by reducing levels of macroalgae and promoting benthic organisms such as turf algae and crustose coralline algae that in turn provide suitable substrate for the settlement and growth of coral larvae (Harrington et al., 2004). Loss of herbivorous fish can result in an increase in macroalgae, which can out-compete corals for space and light and lead to reduced chances of survival for coral recruits (Birrell et al., 2005; Mumby et al., 2007; Hughes et al., 2007). The literature, highlighted above, illustrates that we still do not fully understand the true impacts fishing activity can have on coral size class frequencies and coral species with varying life history strategies.

Here we aimed to assess how the size-frequency distributions of coral genera varied between reefs under different fishing pressures in two contrasting locations in the Indian Ocean. We surveyed reef sites in East Africa (Kenya and Tanzania) and compared them to reef sites in Maldives (North Ari Atoll). Together they represent distinct biogeographical regions (Obura, 2012), with varying levels of anthropogenic pressures (McClanahan, 2011). East African fringing reef systems are subject to a high-pressure subsistence fishery, with moderately-sized and well-enforced non-fished Marine Protected Areas (McClanahan, 2011). Such fishing practices are routinely carried out using basket traps, hand lines, spear guns, beach seines and gill nets. Commonly targeted species include Lethrinidae, Scaridae and Siganidae. In contrast, Maldivian atoll reef systems are subject to lighter reef fishing and bait fishing pressure on community reefs with smaller de facto no-take areas in the reefs surrounding tourist resort islands (Jaleel, 2013; Pisapia et al., 2017a,b; Moritz et al., 2017). 'Bait fishing' is defined as the targeting of species of reef fish that are captured and kept alive to be used as live bait for pelagic tuna fishing and is carried out using nets to capture schools of bait fish species, for example Spratelloides, Caesonidae, Pomacentridae and Apogonidae (Adam, 2006). In contrast, reef fishing (targeting Serranidae, Carangidae and Lutjanidae among others) in the Maldives is generally carried out using handline. Differing fishing regimes in the Maldives and East Africa could potentially affect coral demographics in both regions.

Under 'healthy' reef conditions, it would be expected that coral reefs harbour a population structure consisting of many small colonies and fewer large colonies (Bak and Meesters, 1998). In this study, we hypothesized that coral size class frequencies and distributions would vary between the different fishing regimes studied i.e. 'fished' and 'non-fished' areas. More specifically, it was expected that lower densities of larger coral size classes would be found in fished areas, especially in East Africa where fishing pressure is generally higher, compared to non-fished areas where larger coral size classes were expected to be more frequent (Adam, 2006; McClanahan, 2011; Samoilys et al., 2017). Intraspecific and interspecific variation in size-structure responses to fishing pressure were also expected, with some taxa being more susceptible to changes in coral size class frequencies and distributions than others, especially when taking coral life history strategies into account. Corals can be classified as having 'competitive' life-history strategies when they grow quickly, shade out other genera and can dominate communities in ideal non-stressed environments, for example tabular and branching *Acropora* coral species (Darling et al., 2012). However, these corals are also usually highly sensitive to breakage, thermal stress and other local stressors on the reef. Corals classified as 'stress tolerant' include species that have massive domed morphologies, large corallites, high fecundity, slow growth rates and are usually broadcast spawners - all advantageous traits for conserving energy and surviving in more stressed environments (Darling et al., 2012). Corals classified as 'weedy' tend to be small, have brooding reproductive strategies, fast growth rates and high population turnover. Corals classified as 'generalists' exhibit traits of all the previous three life-history strategies (Darling et al., 2012). In this study, it was expected that coral genera categorized as 'stress tolerant' would exhibit a higher frequency of colonies, of larger sizes, in higher fishing pressure reefs when compared to non-fished reefs. In contrast, coral genera categorized as being 'competitive' would exhibit the opposite trend i.e. a lower frequency of colonies of larger sizes in areas with higher fishing pressure.

2. Materials and methods

2.1. Study sites

The study was conducted in two distinct biogeographic locations: North Ari Atoll, in the central Maldivian archipelago, and along the East African coast from Mombasa in Kenya, to Pemba in Tanzania (Fig. 1). Overall, 31 sites were surveyed (Table 1). In 2009, 10 sites in East Africa were selected and surveyed. These included four in Marine Protected Areas (MPAs), that are closed to fishing and heavily enforced, three sites open to fishing and therefore potentially subjected to high levels of subsistence fishing, and three sites open to fishing but with gear restrictions in place (classified as marine reserves). In 2015, 21 sites in North Ari Atoll were also surveyed. These included nine in resort islands, which were classed as 'de facto' marine protected areas as they are effectively 'closed' from fishing activities, and 12 sites associated with community islands, where the reefs are open to light subsistence reef fishing pressure and the practice of bait fishing.

2.2. Survey methodology

At each reef site, three replicate 10 m $\times$ 1 m belt transects were laid lengthwise along the reef slope at 10 m depth, with a minimum of 3 m separating each transect. All living corals within the belt transect were identified to genus level and for each colony the longest diameter was recorded. A total of 6178 coral colonies of 11 genera were counted in the Maldives and a total of 2693 coral colonies of the same 11 genera were counted in East Africa. These 11 genera were chosen as they were the most abundant across the sites in both regions. The colonies were classified in predetermined size classes: 0–5 cm, 6–10 cm, 11–20 cm, 21–40 cm and >40 cm following Obura and Grimsditch (2009). The corals sampled here have contrasting morphologies and life history strategies, and therefore were classed in different categories following Darling et al. (2012): *Acropora* sp. was categorized as 'competitive'; *Porites* massive sp., *Favia* sp., *Favites* sp., *Galaxea* sp., *Goniastrea* sp., and *Platygyra* sp. as 'stress tolerant'; and *Echinopora* sp. and *Pavona* sp. as 'generalist'. There are, however, some genera which do not easily fit into these three main categories and as such were given proportional values to account for the different life history strategies they exhibit. This is calculated from the number of species that is 'typical' for any given site; see Keith et al. (2013). Thus, *Pocillopora* was classed as being 25% 'weedy' and 75% 'generalist' and *Montipora* was classified as being 25% 'competitive', 58% 'generalist' and 17% 'stress tolerant'. For these two genera any total frequencies