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Coral recovery at Aldabra Atoll, Seychelles: five years after the 1998 bleaching event

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Changes in reef benthos were assessed at Aldabra Atoll following the mass coral bleaching event of 1998. Video transects were used to survey the benthos and analysed using the Australian Institute of Marine Science five-dot method. Comparison of coral cover data collected by the Cambridge Southern Seychelles Atoll Research Programme with data collected during this study revealed that mortality of coral at Aldabra following the bleaching event was approximately 66% at 10 m depth and 38% at 20 m depth. Five years on, there are signs of hard coral recovery at some locations, but in spite of several years of high coral recruitment (7–9 recruits per m^2 at 10 m depth, 4–6 recruits per m^2 at 20 m depth, where recruits are defined as any colony under 5 cm maximum diameter), recovery of hard coral has not occurred at a significant level. There has been a considerable increase in soft coral cover at some locations, which was dominated by the genus *Rhytisma*. Macro algal cover did not increase following the bleaching event, although, as would be expected, dead corals have been colonized by coralline algae. There have been no further events leading to large-scale coral mortality at Aldabra since 1998.

Keywords: bleaching; recovery; coral; Seychelles; recruitment; monitoring

1. Introduction

The mass coral-bleaching event of 1997–1998 is considered the most severe on record (Wilkinson 2002). The event led to the destruction of an estimated 16% of the world's coral reefs, with most of the damaged reefs located in the central-to-northern Indian Ocean, southeast and east Asia and the western Pacific (Wilkinson 2000, 2002). Bleaching was particularly severe in the Indian Ocean, with post-bleaching levels of mortality reaching as much as 90% in parts of eastern Africa and the Maldives and 50–90% over extensive areas of shallow reefs in the Seychelles, Comoros, Madagascar and Chagos (Souter *et al*. 2000).

One contribution of 24 to a Discussion Meeting 'Atmosphere–ocean–ecology dynamics in the Western Indian Ocean'.

Among the reefs exposed to these elevated temperatures were those of the large raised atoll of Aldabra in the southern Seychelles. Aldabra is a UNESCO World Heritage Site and has recently been identified as a marine biodiversity hotspot by Conservation International. A University of Cambridge expedition surveyed the marine community of Aldabra in 1998 and reported some 40% of all outer-reef scleractinians to be recently bleached or dead (Spencer *et al*. 2000). In response to this, the Aldabra Marine Programme (AMP) was formed in 1999 with the express purpose of monitoring, over the long term, the outcome of the bleaching perturbation and measuring the recovery of the reef community. The AMP has now established 11 permanent monitoring sites around Aldabra: eight on the outer reef and three lagoon sites. Baseline data have been obtained on the diversity and abundance of both corals and fishes at each of these sites (Downing *et al*. 2003). In addition, a coral recruitment study was initiated in February 2001 at all sites. Here we present results from the seven outer-reef sites established at Aldabra, the eighth site being omitted from analyses due to insufficient data.

2. Methods

At each permanent monitoring site, digital videography was used to record the benthic habitat along shallow (10 m) and deep (20 m) transect lines. Each transect line was 50 m long and marked by lead core line laid along the depth contour between two metal stakes marking the start and end. Video footage was recorded at 40 cm from the substrate, first along the shoreward side of the line and then back along the offshore side, with a pause every 25 m to give a total of four replicates. The imagery was later analysed using the Australian Institute of Marine Science five-dot method (Osborne & Oxley 1997). The point counts were made on approximately 35 non-overlapping frames per transect, from which benthic categories were recorded (sand, rock, rubble; encrusting algae; macro-algae; live hard coral; live soft coral; *Rhytisma*; dead coral). Repeated measures analysis of variance was used to examine differences in mean percentage cover of hard coral, soft coral, *Rhytisma*, macro-algae and coralline algae. Time (November 1999; February 2001, 2002 and May 2003), site and depth were treated as fixed effects. To satisfy normality and equality of variance assumptions for the analysis, all percentage data were expressed as proportions and then arcsine square-root transformed. Assumption of sphericity was tested using Mauchly's test. Huynh–Feldt correction was used where this assumption was not met. Data for November 1999 were not analysed for the categories soft coral and *Rhytisma*, as these were not separated in the original video analysis from that year.

Coral recruitment has been assessed at all permanent survey sites since February 2001. Recruits were defined as colonies with a maximum width of 5 cm. Counts were made in 1 m^2 quadrats, with up to nine randomly positioned sets of four 1 m quadrats at the 10 and 20 m survey depths. Where sea conditions (i.e. surge) allowed, some quadrats were positioned at 6 m depth.

3. Results

Comparison of coral cover data collected by the Cambridge Southern Seychelles Atoll Research Programme at Aldabra just after the bleaching, with data collected by AMP, indicates that most corals that bleached in shallow water died, leading

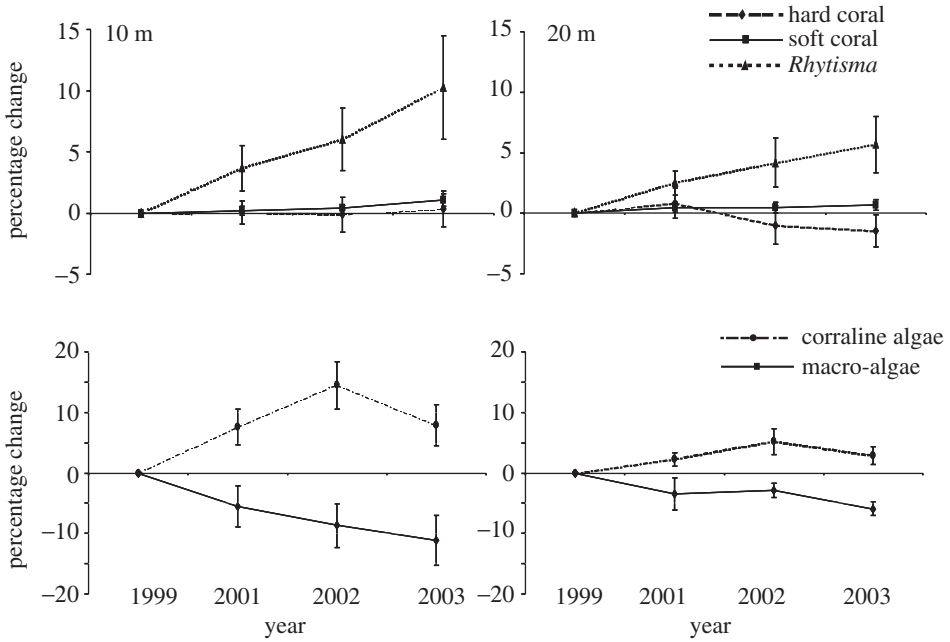

Figure 1. Percentage change in benthic cover (± standard error of the mean) at Aldabra Atoll between 1999 and 2003 in shallow (10 m) and deep (20 m) water. Figures are averages for all seven sites. Legend shows benthos type.

to at least 66% mortality. In deep water (20 m), about half of the bleached corals recovered, and therefore mortality was only 38% in spite of very severe bleaching in 1998.

Mean yearly change in live-coral cover for all sites combined indicates that, between November 1999 and May 2003, coral cover increased by 11.7% in shallow water and 4.9% in deep water. However, most of this growth can be attributed to the soft-coral genus *Rhytisma* (figure 1). Cover of *Rhytisma* increased significantly during the study period ($F_{2,84} = 61.79$, $P < 0.001$) and there were significant site and depth interactions ($F_{12,84} = 5.31$, $P < 0.001$ and $F_{2,84} = 6.8$, $P = 0.002$). Growth of *Rhytisma* was particularly prolific on the northwest coast of Aldabra. Live hard coral has only increased by 0.3% in shallow water and actually decreased by 1.5% in deep water during the study period (table 1). These differences were not significant ($F_{3,126} = 0.88$, $P < 0.45$), although there was a significant interaction between sites ($F_{18,126} = 2.28$, $P = 0.004$), reflecting differences in hard-coral growth that increased most at the sheltered northwestern point of the atoll and decreased most next to the research station on the western coast. Soft-coral cover other than *Rhytisma* has not changed significantly during the study period ($F_{2,84} = 1.91$, $P = 0.15$).

Although there was considerable coral mortality at Aldabra following the 1998 bleaching event, there has been no associated increase in macro-algae, which have declined during the study period ($F_{3,126} = 77.73$, $P < 0.001$). Cover of coralline algae increased during the study period ($F_{3,126} = 41.10$, $P < 0.001$), as it colonized coral that died during the bleaching event. Most of this increase occurred between 1999 and 2002, after which there has been a decline that can be attributed to the increased

Table 1. *Change in benthic composition at Aldabra between 1999 and 2003 shown as mean (± standard error of the mean) per cent cover of hard coral, soft coral, Rhytisma, coralline algae and macro-algae at* 10 *and* 20 m *depths*

(Means are calculated from per cent cover of categories at seven outer reef sites.)

	year			
depth/category	1999	2001	2002	2003
10 m				
hard coral	11.3 ± 2.8	11.3 ± 2.8	11.2 ± 2.7	11.6 ± 2.8
soft coral	1.8 ± 0.7	2.0 ± 0.9	2.3 ± 0.8	2.9 ± 1.2
Rhytisma		3.7 ± 1.8	6.0 ± 2.6	10.3 ± 4.2
coralline algae	12.3 ± 2.8	19.9 ± 4.1	26.8 ± 4.6	20.2 ± 4.0
macro-algae	15.6 ± 5.9	10.0 ± 5.2	6.9 ± 2.6	4.4 ± 1.9
20 m				
hard coral	20.3 ± 4.4	21.1 ± 4.6	19.3 ± 4.3	18.8 ± 4.2
soft coral	1.3 ± 0.6	1.8 ± 0.8	1.7 ± 0.9	2.0 ± 0.9
Rhytisma		2.5 ± 1.0	4.2 ± 2.0	5.7 ± 2.3
coralline algae	8.2 ± 2.1	10.5 ± 1.9	13.4 ± 3.2	11.2 ± 2.1
macro-algae	13.3 ± 5.3	9.9 ± 4.2	10.4 ± 6.1	7.4 ± 4.9

colonization by *Rhytisma* (figure 1). The increase was not as high in deep water, where coral mortality was lower, but the trend was the same.

Levels of recruitment at Aldabra have been consistently high in February 2001, 2002 and May 2003. During this period, average numbers of recruits were between 7 and 9 per m^2 at 10 m depth and 4 and 6 per m^2 at 20 m depth. Levels of recruitment in 2003 were higher than in previous years, although there was only a significant increase in recruit numbers at site 3 in shallow water and site 1 in deep water ($t_{0.05(2)} = 2.68$, df $= 45$, $P = 0.002$ and $t_{0.05(2)} = 2.72$, df $= 35$, $P = 0.003$, respectively).

4. Discussion

AMP results from 1999 support findings by the Cambridge Southern Seychelles Atoll Research Programme (Spencer *et al*. 2000), and suggest bleaching at Aldabra may not have been as severe as at other locations in the Seychelles. Since AMP started surveys at Aldabra in 1999, there has been little evidence of hard-coral recovery. However, coral recruitment at Aldabra is high and mortality of recruits is only 10–30% (personal observation), which should accelerate future reef regeneration (though see below). Furthermore, a steady decrease in the amount of dead coral recorded over the past three years indicates that no further perturbations likely to hinder coral growth have occurred since the study started. The decline in hard-coral cover in front of the Aldabra research station is noteworthy, and may be associated with anchoring of visiting boats.

There is no evidence of macro-algal blooms following the bleaching event. However, the increase in cover of the soft coral *Rhytisma* is likely to be an opportunistic bloom that has occupied empty space as would macro-algae. *Rhytisma* will most likely decline in abundance in future years as hard-coral recovery continues, although,

where present, it is likely to hinder hard-coral recruitment or out-compete established recruits, and thus delay recovery.

Levels of coral recruitment have been consistently high over the two-and-a-half-year study period, indicating a reliable source of recruits. The prevailing current at Aldabra is the South Equatorial Current that runs from east to west. It is therefore possible that recruitment originates from the nearby islands of Assomption, Astove or Madagascar. Aldabra may also be self-seeding, a possibility made likely by the formation of eddies on the northwestern side of the atoll (Heywood *et al*. 1996). The eddies could entrain coral larvae produced on the outer reef, and inside the lagoon, long enough to allow settlement on their reef of origin.

Reefs around Aldabra are essentially free from anthropogenic disturbance, yet so far recovery of corals has been poor. This raises serious concerns as to the speed at which reefs suffering from direct anthropogenic impacts may be able to recover from bleaching events. Aldabra is clearly a unique and valuable benchmark site from which to continue monitoring coral recovery. The AMP is committed to continuing long-term monitoring of the reef-recovery process at Aldabra, and other locations in the Seychelles.

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