

Coral Reef Bleaching at Danjungan Island, Negros Occidental, Philippines

A two year monitoring programme

Beger, M., Solandt, J-L, Dacles*, T

Coral Cay Conservation (CCC) 154 Clapham Park Rd, London SW4 7DE, UK. ccc@coralcay.org

*The Philippines Reef and Rainforest Conservation Foundation Inc. (PRRCFI)

#3 Dona Ceferina building, Mandallagan, Bacolod City, Negros Occidental, 6100 Philippines.

gll@mozcom.com

Abstract

The coral reef bleaching episode of 1998 was the most severe on record. However, it appears that there has been little description in the literature of rates of recovery of coral communities since 1998. This study was undertaken at Danjungan island marine reserve between September 1998 and August 2000 in order to reveal coral community changes since the bleaching event. *Pavona clavus* dominated the substrate at one site, and showed differences in susceptibility with depth and structural anatomy to the initial bleaching event. Tips of this species were more likely to be bleached, and remained dead two years after the bleaching event. There was evidence that *Porites* sp. were able to recover zooxanthellae at deeper (>10m) depths than those colonies from shallower depths, along with some fungiids. *Acropora* sp. were not found to be resistant to the bleaching, and did not recover, even down to 18m

Introduction

Coral bleaching results in the partial or complete loss of symbiotic zooxanthellae that live within the gastrodermal tissue of the coral host (Glynn 1993). There are a variety of abiotic factors that lead to bleaching in any coral (for a recent review, see Brown, 1997). Factors causing bleaching in scleractinian corals on a national/continental scale have been historically related to global sea surface temperature rise combined with periods of unusually intense UV irradiation (Brown, 1997). Other factors that may be contributory to bleaching events are low diffusion rates at the surface of the coral itself causing a lack of gaseous exchange between the host coral and the surrounding water that stresses the delicate symbiosis (Hoegh-Guldberg, 1999). Other anthropogenic and natural factors such as sedimentation, salinity and increased ambient pollution levels have all resulted in bleaching in the past (Glynn, 1993).

The phenomenon of coral bleaching has become more wide spread, and more damaging to coral reefs since the early 1980's (Salvat, 1991, Hoegh-Guldberg and Salvat, 1995). Indeed, the regularity of worldwide bleaching events is increasing (1991 and 1994 saw recent bleaching events), with the latest bleaching event in 1998 regarded as one of the most serious (Goreau *et al.*, 2000). Corals died in east Africa, the Maldives (with up to 100% mortality), The Andaman sea, across Indonesia and the South China Sea. The bleaching event then spread on to the south Pacific Islands and Great Barrier Reef of Australia (Wilkinson, 2000). The recovery rate of coral after bleaching depends on a number of variables in any one location, such as water quality, balance of the ecosystem, amount of herbivory, and the extent to which the coral colony bleached in the first place (Quinn and Kojis, 1999).

Recovery of corals after initial bleaching is fundamental to examining the stresses that coral reefs can tolerate regarding persistently damaging events. As sea surface temperature (SST) rise looks set to continue into the future (Brown, 1997), it is important to assess the longer-term impacts that bleaching episodes have on discrete coral communities. Repeat recording in isolated

environments at long distances from university academic establishments and marine laboratories has made the type of study documented here difficult to carry out over mid- to long-term time scales. This experiment yields continuous information from an isolated coral population, and describes the mid-term recovery rates of a coral reef in a region known for its biodiversity (the Visayas group in the central Philippines). The study focuses on one area that is dominated by the massive coral *Pavona clavus*, and another area that has a much greater species diversity of scleractinian coral species.

Study site

The bleaching recovery study documented here was established on Danjugan Island, Negros Occidental, Philippines as part of the Philippines Reef and Rainforest Project led by the Philippines Reef and Rainforest Conservation Foundation Inc. (PRRCFI) in collaboration with Coral Cay Conservation (CCC). The study was carried out between 1998 and 2000 by PRRCFI and CCC scientists with the assistance of trained volunteers. This experiment describes the mid-term recovery rates of a coral reef in a biodiverse region of the Philippines.

Danjungan Island (9 52 38.2 N, 122 22' 44.6 E) lies 1.5 km off the south west coast of Negros Occidental in the Visayas region of the Sulu Sea (Fig. 1). Danjugan Island was stated as a fully gazetted marine reserve in February 2000. It is surrounded by fringing coral reefs and some patch reefs. Most reefs possess a shallow horizontal reef front, extending to a depth of approximately 3m. From this depth, the reef slope drops off steeply to a near-horizontal sea bed at a depth of approximately 30m.

The bleaching recovery study was conducted at two different locations on the east coast of Danjugan Island; Hilarys Rock (HL) and Convention Reef (CV) (Fig. 1). Hilarys Reef was almost entirely composed of *P. clavus* above 20m depth. CV is a large rise in the sea bed, 200m to the south east of Hilarys, and is composed of a greater variety of corals including bottlebrush *Acropora* species. These two areas were principally chosen because of their dissimilarity of coral diversity.

Methods

Location of quadrats

Data was recorded from 3 replicate 1m² quadrats at three depths – 18, 12 and 6m (lowest low water). Quadrats were placed in two different locations – Hilary's and Convention reef (Fig. 2) along a 50m depth contour (Fig. 2). Quadrats were placed on the reef in September 1998, two weeks after the onset of the bleaching at Danjungan Island was first witnessed. Quadrats were surveyed and photographed at the following time intervals:

September 1998 (2 weeks post-bleaching);

August 1999 (12 months);

February 2000 (18 months);

August 2000 (24 months).

These time intervals coincided with periods of important community change within each quadrat on the shallow reefs of Danjungan Island.

Categories recorded from each quadrat included healthy coral, bleached coral, rock, rubble, sand, other, algae (divided into groups – filamentous, cyanobacteria and macroalgae). All percent cover estimates were validated from photographs after being written down on waterproof slates *in situ*. Volunteer data collectors were all standardised in their data collection techniques, and tested in the classroom and *in situ* prior to being allowed to collect quadrat data (see Mumby *et al.* 1995).

Deployment of quadrats and surveying

Quadrats were surveyed by a combination of both photographic and *in situ* recording of benthic characters inside the frame of the 1m² areas. Dives were conducted to record changes in the benthic community over a 2-year span. These data record the long-term patterns of community change within the boundary of the quadrats.

Quadrats were placed on the reef on September 9, 1998, one month after the initial recording of bleaching at Danjungan Island. Quadrats were surveyed at the following time intervals: September 1998 (1 month), August 1999 (12 months), February 2000 (18 months),

Data analysis

Percent cover estimates were arc-sin transformed prior to analysis so that they assumed a normal distribution of data. Consequently, non-parametric ANOVA (Kruskal-Wallis test due to heteroscedascity of variance in sample means) was used to find significant changes for benthic communities within depth zones over the two year study period.

Results

Physical measurements

Water temperatures at the two sampled sites increased to 31 degrees for at least one month around the bleaching period. SST satellite records of the movement of the hot water revealed that the central area of the Philippine archipelago was bathed in this hot water for approximately two months (NOAA satellite information). The earliest recording of bleaching in the Philippine archipelago was in June (Wilkinson, 2000). In this study, the bleaching was recorded over August to September, and was more severe at Danjungan Island on the sheltered and shallow eastern side. Temperatures from 1999 to 2000 (30°C maximum) did not reach as high as they did in 1998, and there was no record of an intense bleaching event during this time period.

Initial bleaching event

Corals were affected to a depth of 18m (Fig. 3d). Percentage of bleached corals was seen to range from 35 to 90% between 0 and 25m depth around the whole island (see Fig. 3a and 4a for the results of initial bleaching).

HL was more seriously affected than CV, with all depths being bleached above 80%. This was partly due to the density of live *P. clavus* being extremely high prior to the bleaching event at HL. During the bleaching period, the horizontal faces of the sub-massive *P. clavus* colonies were killed, and by the end of September, had already been colonised by filamentous algae (an average of $8 \pm 2\%$ for HL and $12.7 \pm 10.0\%$ for CV) (Fig. 4). Bleaching appeared less at Convention due to the fact that much of the substrate comprised filamentous algae prior to the bleaching event, especially at the 6m.

Recovery

The reduction in percent corals bleached at all depths over the first year of observation was dramatic. All sites had less than 10% bleached coral in August 1999 (Fig. 4). There was practically no bleaching recorded in February 2000 and August 2000. Healthy corals showed a tendency to recover at all sites and depths. However, there is a distinct difference between HL and CV at different depths.

The sub-massive colonies (*P. clavus*) on HL were very badly affected and died off completely at 6m. Therefore, healthy coral recovery appeared poor at this location (due to the 90% + dominance of *P. clavus* at this locality). Macroalgae and red calcareous algae became dominant at this location after the initial coral die-off (Fig. 4). At deeper depth of 12 and 18 m, much of the coral regained its zooxanthellae by April 1999, and had regained levels between 25 to 50% live (pigmented) cover after 12 months (Fig. 4). This change was significant for 12 m depth. Here, healthy corals recovered from below 5% in September 1998 to over 60% cover by August 2000. At these depths, the *P. clavus* died at the horizontal and upper surfaces of the colonies, and remained intact on the sides of the columns. This can be visualised by the photographs in Figure 3a-c. The results at 18 m are slightly biased by one quadrat located on branching *Acropora* spp. which bleached more readily than the *P. clavus*.

Corals at CV showed different recovery patterns at different depths. At a shallow (6m) depth a steady recovery occurred, resulting in a mean coral cover of 50% in August 2000 (Fig. 4). At 12 m and 18 m many of the fine branching *Acropora* spp. died and were overgrown by macroalgae, especially at the base of the branches, but regained healthy pigmented coral at the branch tips. Figure 4 demonstrated a decrease of filamentous algae as macroalgal cover increased (at 12 and 18m depths). There was a slow recovery process, reaching a healthy coral cover of approximately 25% by August 2000 for both depths (Fig. 4). Much of the branching coral was broken up into rubble, which constituted around 40% of total cover in 2000 (Fig. 4).

Algal colonisation of substrate after bleaching

A percentage of the coral that died as a result of the initial bleaching became a settlement substratum for algae (Fig. 4). Algal cover increased to its greatest extent 12 months after the bleaching event. This was evident at the medium to deep depths (Hilarys 18m, Convention 12 and 18m, see Fig. 4). Increase in algal cover was almost always succeeded by a reduction in cover (all sites and depths apart from Convention Reef 6m). Shallow Hilarys showed a distinctively high algal cover even two years after the bleaching event, where other sites appear to have recovered.

Discussion

The severity of the bleaching event witnessed in this study was comparable to that observed in other areas of the south east Asian region, and wider Indo-Pacific (Wilkinson, 2000). However, the recovery of many of the deeper (>10m) colonies appears to be encouraging, as many of them were heavily bleached in the initial August event, but went on to regain pigmentation (zooxanthellae), and subsequently recovered.

Shallow branching, and even massive species such as *Diploastrea heliopora* and *P. clavus* were almost totally bleached at Convention and at Hilarys, yet much of the coral tissue regained some zooxanthellae in the early stages of the two year monitoring period. Areas that had monospecific massive stands of corals, such as shallow Hilarys (with *P. clavus* colonies being dominant), showed bleaching patterns where the apex of colonies were more susceptible to bleaching than the vertical sides. Although these colonies were not representative of Danjungan coral fauna as a whole, they do provide a model of bleaching for the more massive colonies, and these patterns are exhibited in other massive species such as *Porites* sp.. Here bleaching continuously affects the apex of the colonies during extreme low tides, and high temperatures, leaving the sides of the colonies free from bleaching. This pattern on the apex of colonies may relate to the increased apparent UV penetration during times of very calm weather (Fisk and Done, 1985), as in August 1998 at Danjungan. In these circumstances, the upper tips of rounded colonies such as *P. clavus*, and larger *P. lobata* colonies are more exposed to UV than the adjacent vertical walls and polyps in this area are therefore more susceptible to bleaching (Brown, 1997). What did appear to change throughout the monitoring period (at medium and deep depths), was that the bleached areas of *P. clavus* recovered sufficiently, such that the colony regenerated in areas that were previously bleached. This is particularly evident at the 12m quadrats at Hilarys rock (Fig. 6-8).

Other species of corals, with more delicate growth structures, such as branching bottlebrush *Acroporid* spp.. These fared worse after the bleaching event, and are generally known as being more susceptible to bleaching than more massive species such as *P. lobata* (Baird and Marshall, 1999).

Algae growing on bleached colonies increased in percent cover within the first year to high levels due to the free space available on the bleached coral. After one to two years, much of the macroalgae that had colonised the habitats appeared to be converted back to bare rock. In some cases, these areas were colonised by coral recruits. Herbivory increased as the quantity of primary succession algae settling on the substrate increased (personal observation). Herbivory reduced these early colonising species of algae prior to the settlement and growth of more toxic macroalgal species such as *Halimeda* spp. or *Dictyota* spp. which were not apparent in the quadrats.

The recovery of corals during this study was cause for optimism as the bleaching event in 1998 was widely regarded as the most severe on record. There was significant recovery of corals from medium to deep depths.

Within this data, there is confirmation in the results of different susceptibilities of corals to bleaching from high sea surface temperatures. *P. lobata*, *P. clavus* and other species (many faviids and fungiids) appear to recover zooxanthellae better than the faster growing branching genera such as *Acropora*.

With effective management of the Danjungan Island Marine Reserve, corals will have a greater chance of recovery from bleaching episodes in the future, as these areas will be closed off to particular anthropogenic impacts, such as destructive fishing and logging.

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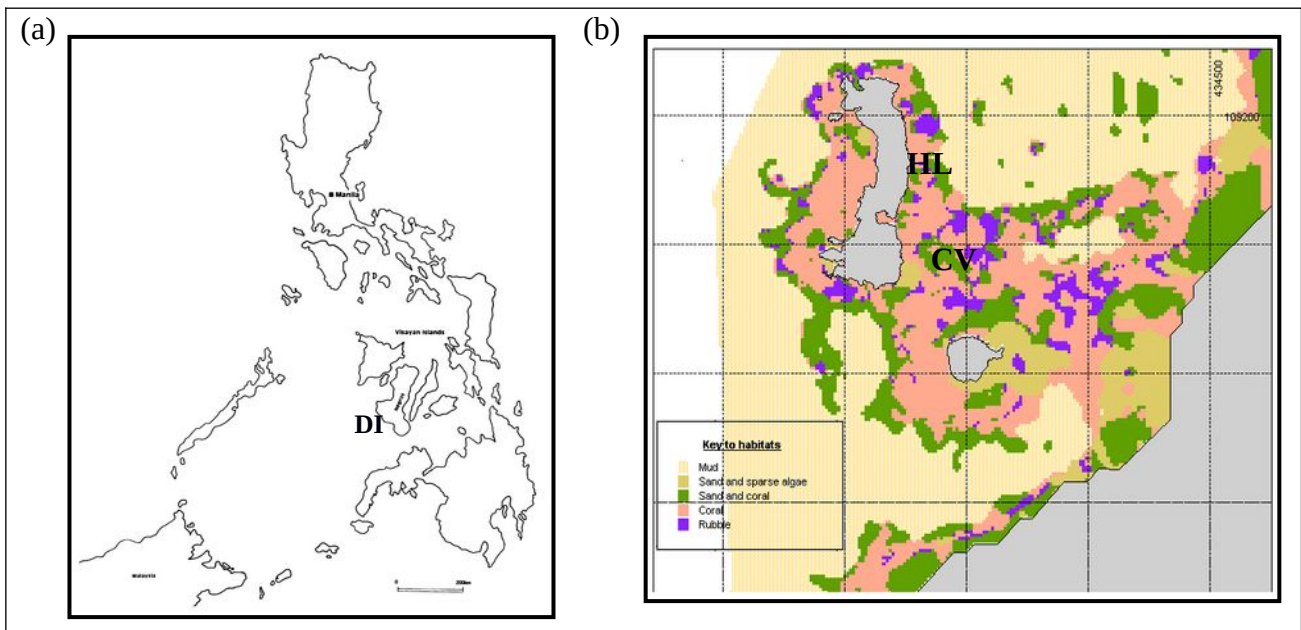


Figure 1. Map of the Philippines (a) and Danjungan Island (b). Danjungan Island lies off the west coast of Negros Occidental. The diagram on the right is taken from a RoxAnn sonar scanned-image of the major habitat classes in this section of coastline where the grey areas indicate land, and the other colours represent different benthic habitats (White and Harborne, in press).

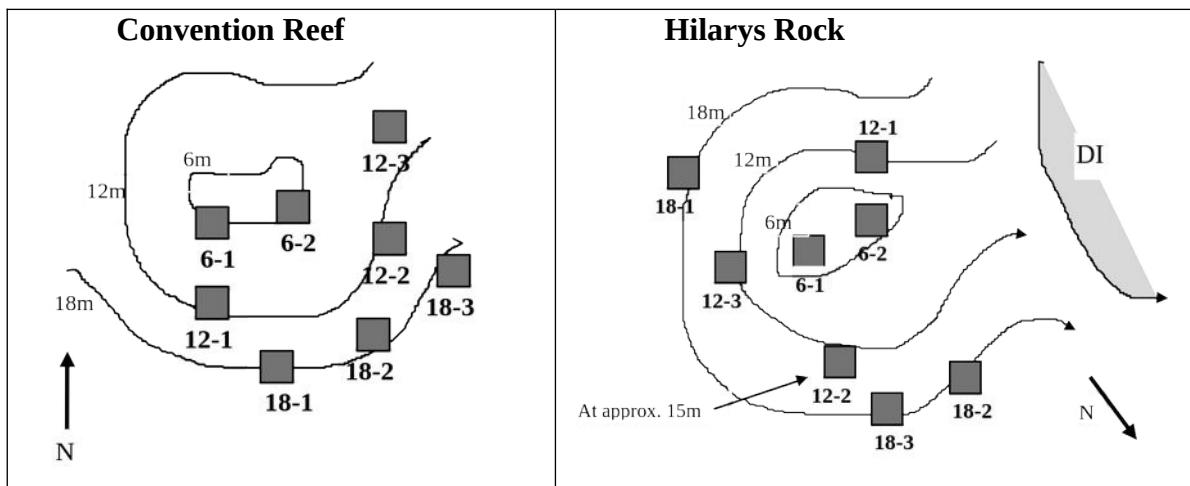


Figure 2. Schematic map showing the positions of permanent quadrates established for the monitoring of coral bleaching on HL and CV. Numbers indicate the depth that the quadrats were set, and the replicate number (therefore 12-1 represents the first quadrat at the 12m depth contour).

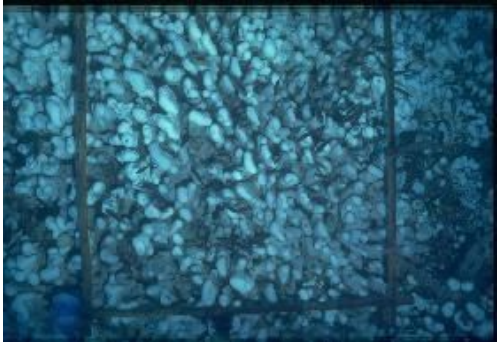
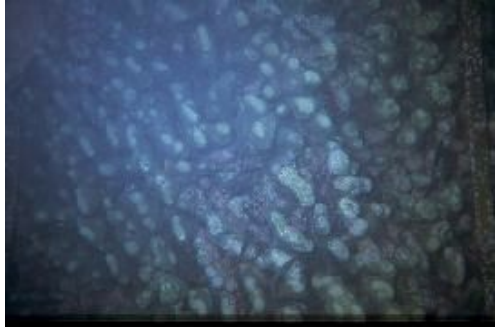
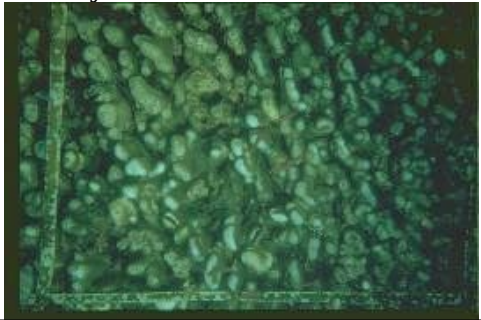
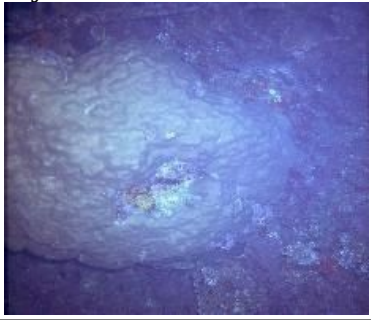
Hilary's Rock	Convention Reef
(a) September 1998 	(d) September 1998 
(b) August 1999 	(e) August 1999 
(c) February 2000 	(f) February 2000 

Figure 3. Examples for reef community changes after coral bleaching in 1998. a, b, c show 12 m quadrat 2 at HL; d,e,f show 18 m quadrat 1 at CV.

Figure 4. Mean $\pm$ SD % benthic cover estimates within 3 quadrats from 6,12 and 18m depth zones at Hilary's and Convention Reef monitoring stations from August 1998 to August 2000. * - Designates a significant change (K-W test, $P < 0.05$) in community between 1998 and 2000.

