

EFFECTS OF 1998 BLEACHING EVENT ON LARGE *PAVONA CLAVUS* COLONY IN A PHILIPPINE MARINE PROTECTED AREA

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Abstract

The incidence of coral bleaching was investigated over two years at Danjungan Island, Negros Occidental, between September 1998 and August 2000. Tissue damage as a result of bleaching was dependent on the depth of the dominant coral, *Pavona clavus* on Hilarys reef, Danjungan Island. Water temperatures of 31⁰ Celsius accompanied the initial bleaching event in the vicinity of Negros Occidental, which was widespread over the whole of the Visayas region. Bleaching reduced much live coral of Danjungan Island to dead coral covered with filamentous algae within six months of the initial heating event. *Acropora* spp. corals were most susceptible to initial bleaching. Repeat monitoring of the area showed considerable recovery of *Pavona clavus* in the medium depths (around 12m) from totally bleached live coral tissue cover to 88% healthy pigmented tissue by August 2000. This same colony suffered live tissue loss in shallow (6m) areas from original live coral cover of 80% reduced to around 5%, with dead coral heads subsequently covered by filamentous and macroalgae. This study highlights the important effect that depth at one site can have on bleaching and subsequent recovery, within a singular species of coral.

Introduction

Bleaching has been described as the whitening of corals (and other invertebrates) as a result of the loss of zooxanthellae from the coral/invert host, or a decrease in photosynthetic pigment concentration residing in the host animal (Glynn, 1993). Post-bleaching is the most critical period for corals, as they lose the ability to synthesise carbohydrates from photosynthesis, and solely rely on predatory feeding by the coral polyps (Wilkinson *et al.*, 1999). This process normally results in significant stress for coral, as they lose around 80% of the photosynthetic product (sugar) and carbon acquisition provided for them by the zooxanthellae (Muscantine, 1990; Sebens, 1987). Inter- and intra-specific variability in zooxanthellae species and temperature tolerance levels results in different susceptibilities for coral species to bleach, given the same environmental parameters (Marshall and Baird, 2000; Jones, 1997). Different tolerance regimes within the coral host and zooxanthellae can lead to disparate patterns of bleaching on a spatial scale of kilometres during some bleaching events. Depth has also been attributed as having a significant impact on the severity of bleaching events within sites (Glynn *et al.*, 2001), as apparent thermoclines in the water, and the lack of UV penetration to deeper depths can cause considerably less bleaching to deeper corals.

The global coral bleaching event of 1998 was an internationally well-documented phenomenon (Hoegh-Guldberg, 1999, Wilkinson, 2000), and highlighted effects of increased Sea Surface Temperatures (SSTs) on the propensity of different species of corals to bleach (Marshall and Baird, 2000), and post-bleaching benthic community dynamics including competition with marine algae (Diaz-Pulido and McCook, 2002). However, the Philippines has seen little published material on the effects of bleaching at both national and local levels, and especially concerning recovery since the initial bleaching took place in August 1998 (Fig. 1). One study carried out from the Siliman University in Negros Oriental, revealed that bleaching in and around Bolinao in the central Visayas was nationally seen to be one of the worst areas affected by the increased SSTs with 80% of corals bleached (Divinaracia, 2000 in Burke *et al.*, 2002). A study over a wide range of locations in the Philippines revealed that species of *Acropora*, *Pocillopora*, *Porites* and *Pavona* were severely affected by the bleaching in areas as widespread as Tubattaha, Bolinao, the northern Palawan shelf and the Kalaayan Island group (west of Palawan) (Arceo *et al.*, 2001). Findings from this study revealed that members of the *Acroporidae* family were most susceptible to bleaching during 1998.

It is important to quantify the recovery of this, and successive bleaching events that may occur in Philippine reefs. The unpredictable nature of both the spatial and temporal patterns of bleaching on reefs makes assessment and monitoring of recovery that much more important (Westmacott *et al.*, 2000). Simple and effective monitoring methods can quantify these changes, and subsequent data can help with management decisions on how 'robust' a coral reef can be to the effects of temperature increase. Resistance or otherwise to bleaching effects in the future may have a large part to play in determination of zoning patterns in and around marine parks (Goreau *et al.*, 2000).

Methods

Our investigation recorded the effects of the bleaching on one particularly large colony of *Pavona clavus* at Danjungan Island, Negros Occidental, Philippines (Fig. 2). Danjungan Island lies to the west of Negros Occidental within the Visayas region of the Philippines, and supports extreme biodiversity of hermatypic corals (Fenner, pers. comm.), with around 377 species recorded in eight months of subtidal survey work (Harborne, 1996).

The *Pavona clavus* colony lies in waters between 22m and 6m deep. The basal diameter of this colony is estimated to be around 10m. The colony is not entirely monospecific, and has other colonies associated with it, particularly near the upper surface, where a large (1m wide at base, and 1m tall) *Hydnophora pilosa* is dominant. There are also forms of *Acroporidae*, *Montiporidae*, *Faviidae* and *Poritidae* families attached to this colony. Most of this *P. clavus* colony can be described as massive in overall structure, with columnar sub-massive fists of between 2 and 20cm radius (see Fig 3).

Percent cover data was recorded from 3 replicate 1m² quadrats at three depths – 18, 12 and 6m (lowest low water). Quadrats (made of welded iron reinforcement bar) 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 into the bleaching event);
February 2000 (18 months post-bleaching);
August 2000 (24 months post-bleaching).

These time intervals coincided with periods when surveys were carried out by CCC staff at these remote locations.

Categories recorded from each quadrat included healthy coral, bleached coral, rock, rubble, sand, other, algae (divided into groups – filamentous and macroalgae). All percent cover estimates were validated from photographs after being written down on waterproof slates *in situ*. Volunteer divers were used to collect quadrat information. These surveyors were all standardised in data collection techniques, and tested in the classroom and *in situ* prior to being allowed to collect quadrat data (see Mumby *et al.* 1995). Percent cover data was arcsin transformed and subsequently analysed (2-way ANOVA) for difference in cover between three depths (6;12 and 18m) and over time (September 98; February 2000 and August 2000).

Results

Danjungan Island was considerably impacted with coral and other cnidarians bleached down to a depth of 25m at some sites. Water temperatures reached 31⁰ C during august and September 1998, but never reached 30⁰ C from October 1998 up until August 2000.

It appears that there was varying response of the corals to the initial bleaching event related to species composition around Danjungan Island, coupled with the depth of the colonies (Table 1 and Fig. 4). Depth was similarly apparent in its effect on the recovery (or otherwise) of the *Pavona clavus* colony, with areas of the colony at around 12m seemingly better able to recover from the bleaching (from 85% healthy coral cover to 75% cover after 2 years) than areas in the top 6m (from 80% healthy coral cover down to around 3-5% in 2 years) (2-Way ANOVA, $F = 7.38$, $P < 0.024$). The deep (18m) sample site showed bleached coral of 80% with 11% healthy coral cover remaining unaffected. Healthy coral cover from this depth increase from 11% in 1998 to 30% by August 2000. During the bleaching event itself (July-September 1998), it was evident that increased depth resulted in a greater cover of remaining healthy coral (6m – 0% healthy corals; 12m – 4% healthy corals; 18m – 11% healthy corals Fig. 4) at the time of the bleaching event.

Different areas of each of the columnar form of *P. clavus* had different susceptibilities to bleach at different depths (Fig. 3). In the shallow areas (6m), all areas of the coral were bleached, however, in deeper waters (12 and 18m), corals bleached on the upper most surface of the individual columns but remained healthy (pigmented) on vertical walls (Fig 3).

The relative recovery of the *P. davus* colony over the sampling period had significant influence on the colonisation of algae after the initial bleaching event (Fig. 4). At 6m, bleaching was succeeded by a 819% rise in macroalgal cover over the two years. This resulted in macroalgal cover of 64.33% (August 2000) compared to an original cover of 7% (September 1998) at 6m. At medium (12m) depths, the cover of macroalgae increased from 0 to 7.33% over the whole sampling period, which was significantly less than at shallow depths (2-Way ANOVA, $F = 5.91$, $P < 0.0001$). At the deep site (18m), macroalgal cover increased from 3 to 41.67% over the sampling period, representing an increase of 1289% from September 1998 to August 2000. At all depths, filamentous algae increased between 114 and 400% to February 2000, and then decreased considerably by August 2000, indicating some form of succession within the benthic community.

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 (Burke *et al.*, 2002; Wilkinson, 2000). However, the recovery of deeper (>10m) coral 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 massive *Porites* spp. were almost totally bleached around Danjungan Island, yet much of the coral tissue regained some zooxanthellae in the early stages of the two year monitoring period (within the first four months). Areas that had monospecific massive stands of corals, such as shallow Hilarys (with *P. clavus* colonies being monospecific), showed overall bleaching patterns where both the apex and vertical walls of colonies were equally bleached in 1998. In deeper waters, some of the colonies regained pigment almost immediately, but predominantly in the vertical walls. This pattern of bleaching 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 *Porites lobata* colonies are more exposed to UV than the adjacent vertical walls and polyps and 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. 3).

Other species of corals, with more delicate growth structures, such as branching bottlebrush *Acropora* spp., were more susceptible to bleaching at similar depths than the *P. clavus* colony (pers. Obs) at Hilarys reef. *Acropora* sp. Coral in general fared worse after the bleaching event, and have been observed as more susceptible to bleaching than more massive species such as *Porites* and other massive species (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.

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

Since the start of the monitoring period on this colony, and surrounding reefs in Danjungan, it appears that this particular colony has come back fairly well in terms of

live tissue cover after the initial bleaching event. Danjungan Island is managed by the Philippines Reef and Rainforest Conservation Foundation Inc., and was made a fully gazetted marine reserve in February 2000. Areas such as 'Hilarys reef' where this spectacular *Pavona clavus* coral is located are within one of the three designated and buoyed no-take zones, where fishing of any description is restricted. Monitoring of the reefs of Danjungan Island is on going (bleaching recovery work is still being monitored, and Reef Check dives carried out, as are fish-tagging experiments by members of The University of the Philippines, and a giant clam seeding project). It is hoped that the success of the reserve (recently voted 'Best managed Philippine reef, 2002') will help to provide protection for this unique area of natural heritage for future generations of Filipinos. They will also benefit from observing one of the largest *Pavona clavus* colonies in part due to it's ability to considerably resist the deleterious consequences of the recent 1998 bleaching event at depths greater than 10m.

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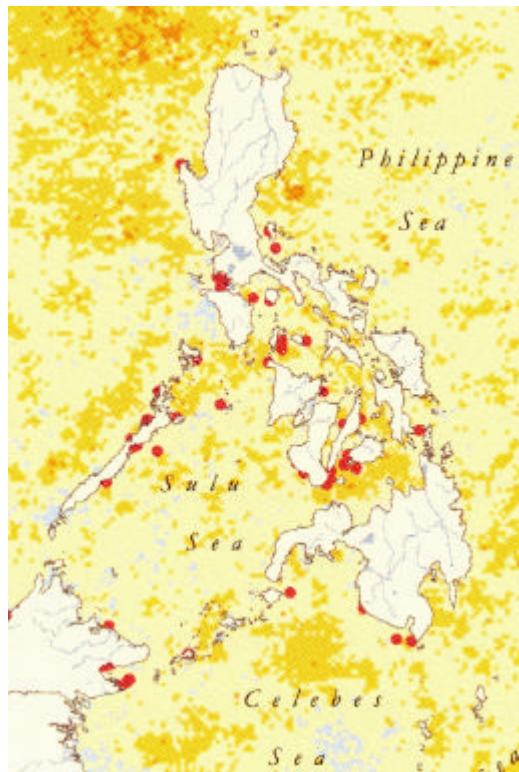


Figure 1. Image of the degrees of 'heating weeks' over SE Asia between August and September 1998. This map highlights areas of the Philippines where the Sea Surface Temperatures were at least 1⁰ C above the normal means for that time of year for 1-2 weeks (light yellow), and 2-3 weeks (dark yellow). The red dots designate confirmed sightings of bleaching during the event. In western Negros, the number of degree heating weeks was seen to be between 1 and 2. Source – 'Reefs at Risk' (edited by Burke *et al.* 2002).

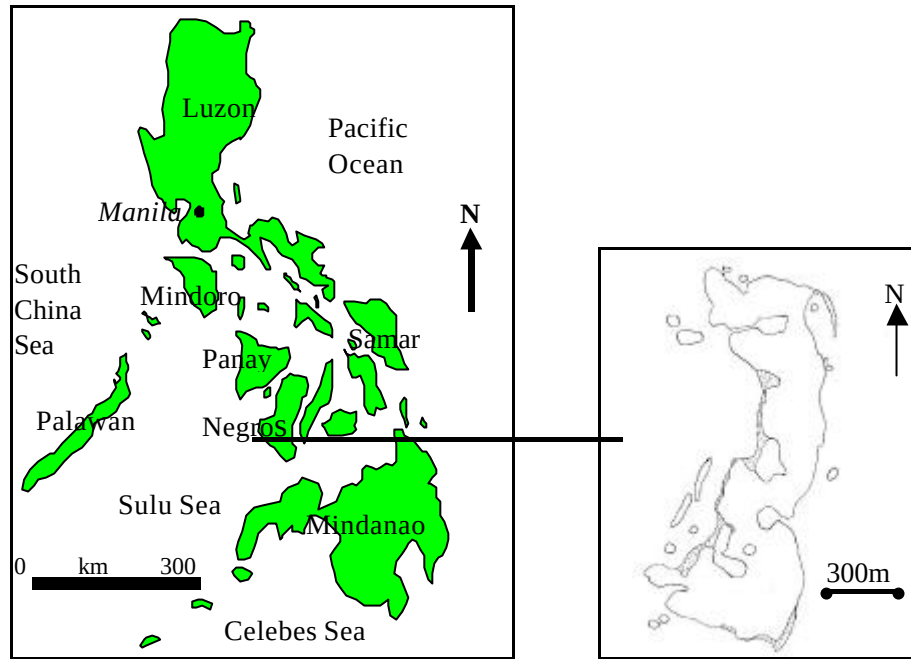


Figure 2. Danjugan Island is located at Negros Occidental, Philippines.

Table 1. Mean % cover ($\pm$ SD) values of key benthic categories between time and depth. The relationship between depth and time and each benthic category was investigated using a 2-Way ANOVA on arcsin transformed percent cover data. * designates significant difference in time between that particular category over the three sampling years (ANOVA, $P < 0.05$). Ψ designates a significant difference in percent cover between depths (ANOVA, $P < 0.05$) for that category.

category/depth	Aug-98	Feb-00	Sep-00
hard coral 6	0(0) * Ψ	2.5(0.71)* Ψ	15(13.75)* Ψ
hard coral 12	4(3.46)* Ψ	45(5.00)* Ψ	68.67(8.08)* Ψ
hard coral 18	10(15.49)*	25.67(29.93)*	30(34.70)*
bleached 6	83(11.00)*	0(0)*	0(0)*
bleached 12	86.67(11.55)*	3.33(2.89)*	0.33(0.31)*
bleached 18	81(16.37)*	1.67(0.58)*	0(0)*
rock 6	2(1)*	7.5(1)*	20(10)*
rock 12	4(3.46)*	6.66(3.46)*	10.17(8.46)*
rock 18	1.67(2.89)*	3(2.65)*	11(10.15)*
rubble 6	0	0	0
rubble 12	0	0	0
rubble 18	0	3.67(6.35)	5.67(8.14)
Filamentous 6	8(3)*	18(0)*	0.67(0.577)*
Filamentous 12	5.33(4.62)*	11.33(10.26)*	0.16(0.29)*
Filamentous 18	4(1.73)*	20(14.8)*	3(1)*
Macroalgae 6	7(2)* Ψ	72(1.73)* Ψ	64.33(10.21)* Ψ
Macroalgae 12	0* Ψ	6.67(3.79)* Ψ	7.33(6.11)* Ψ
Macroalgae 18	3(2)	34.8(26.09)	41.67(26.03)

* significant difference between time (ANOVA, $P < 0.05$)

Ψ significant difference between depth (ANOVA, $P < 0.05$)

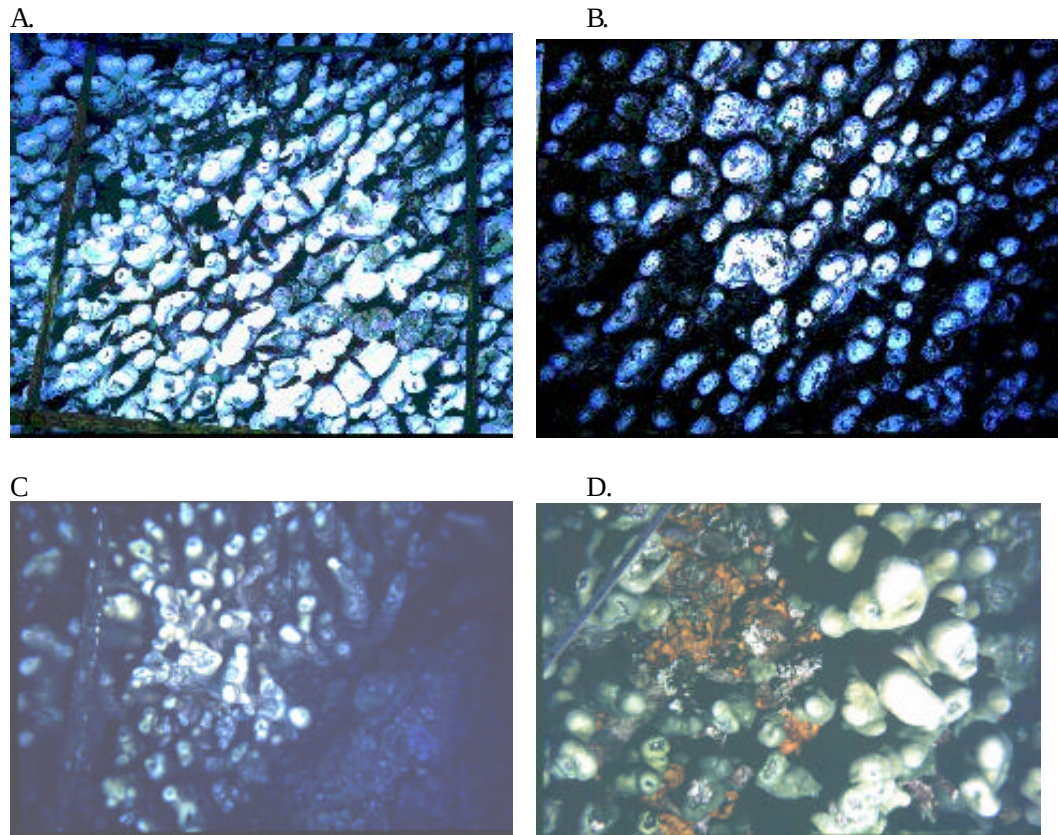


Figure 4. *Pavona clavus* at 6m in September 1998 (A), and the same quadrat August 2000 (B) – shows the change from bleached coral to dead coral covered by filamentous and macroalgae; image (C) shows the effect of bleaching at 12m on the same colony (August 2000) – note the effect of bleaching on the upper surface of colonies in medium depth waters; and image (D) is of the bleaching effect on the colony at 18m (August 2000) – this photo highlights the macroalgal community at this depth (*Lobophora variegata*), and the bleaching on the upper surface of the *P. clavus* colonies.

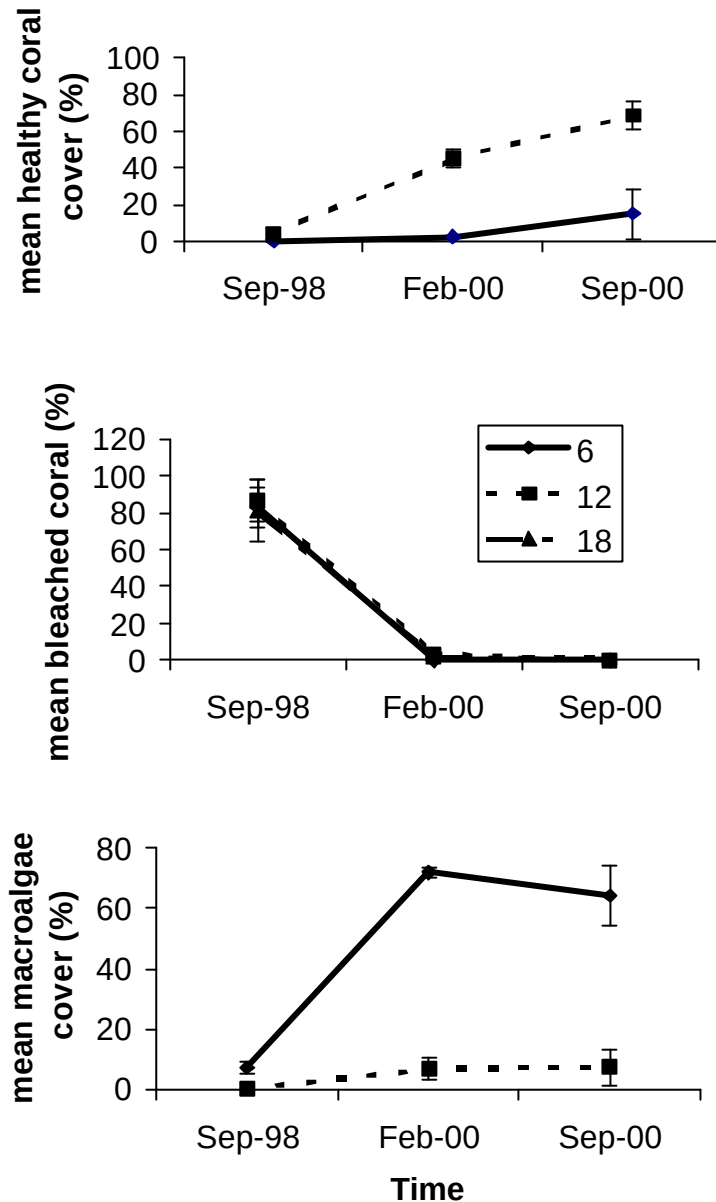


Figure 3. Significantly different relationships between depth and time for three benthic categories. **Healthy coral** recovered at a greater rate at 12m depths than at 6m (2-Way ANOVA, $F = 7.38$, $P < 0.024$). There was also a significant relationship over time, with significantly greater healthy coral cover seen in 2000 than in 1998 (2-Way ANOVA, $F = 15.21$, $P < 0.001$). There was a significant decrease in **bleached coral** between 1998 and 2000 at all depths (2-Way ANOVA, $F = 164.9$, $P < 0.0001$). The *Pavona clavus* colony was dominated by **macroalgae** more significantly at 6m than at 12m during the sampling period (2-Way ANOVA, $F = 5.91$, $P < 0.038$). Macroalgae colonisation and growth was also significantly greater in 2000 than in 1998 for both depths (2-Way ANOVA, $F = 46.14$, $P < 0.0001$).