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

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ABSTRACT

In September 1998, with water temperatures at 31^0 Celsius, the initial bleaching event spread over the whole of the Visayas region. Bleaching reduced much of the live coral at Danjugan Island to dead coral covered with filamentous algae within six months. Acropora spp. corals associated with the Pavona colony were most susceptible to bleaching. This same colony suffered live tissue loss in shallow (6m) areas. The original live coral cover of 80% was reduced to approximately 5%, with dead coral heads subsequently covered by filamentous and macroalgae.

Over two years the team from the Coral Cay Conservation investigated the effects of coral bleaching on a single colony of *Pavona clavus* at three depths at Danjugan Island, Negros Occidental, Philippines. Repeat monitoring of the area showed considerable recovery of *Pavona clavus* at medium depths (around 12m) from totally bleached live coral tissue cover to 88% healthy pigmented tissue by August 2000. This study highlights the important effect that depth at one site can have on coral bleaching and subsequent recovery within a single species of massive 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/invertebrate 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 synthesize carbohydrates from photosynthesis and rely solely on predatory feeding by the coral polyps (Wilkinson *et al.,* 1999). This process normally results in significant stress for the coral colony as they lose around 80% of the photosynthetic product (sugar) and carbon acquisition provided for them by the zooxanthellae (Muscatine, 1990; Sebens, 1987). Inter- and intra-specific variability in zooxanthellate species and temperature tolerance levels result in different susceptibilities of coral species to bleaching, 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 kilometers during some bleaching events.

Depth has also been cited as having a significant impact on the severity of bleaching events within sites (Glynn *et al.,* 2001) as apparent thermoclines in the water column, and the lack of UV penetration to deeper waters can reduce bleaching effects on deeper corals. It has, however, been difficult to accurately test these hypotheses in the field, due to the patchy nature of coral communities, and geno- and phenotypic variances between colonies of the same species. This study is unique in that the experimental colony is the same (one large *Pavona clavus* colony), and may indeed be an individual of the same genotype as the framework appears to be contiguous throughout the area of the colony. If this indeed were an individual colony (approx 15m basal diameter by 15m height), the variable of genotypic separation between different individuals of the same species would be eliminated (Hoegh-Guldberg, 1999).

The global coral bleaching event of 1998 was a well-documented phenomenon (Hoegh-Guldberg, 1999; Wilkinson, 2000), and highlighted the effects of increased Sea Surface Temperatures (SSTs) on the susceptibility of different species of corals to bleach (Marshall and Baird, 2000). Some studies surveyed and monitored post-bleaching benthic community dynamics including competition between corals and 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 studies concerned with recovery since the initial bleaching took place in August 1998. One study carried out from Silliman 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 Sea Surface Temperatures (SSTs), with 80% of corals bleached (Divinagracia, 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 Tubbattaha, Bolinao, the northern Palawan shelf, and the Kalayaan Island group (west of Palawan) (Arceo *et al.,* 1999). Studies carried out at Apo Island after the 1998 bleaching event showed limited survival of established colonies (particularly *Galaxea fascicularis*), and that post-bleaching recruitment of this species has been limited. Branching *Acropora* has dominated shallow-water recruitment at Apo since the bleaching event (Raymundo and Maypa, 2002 & 2003). Findings from published literature revealed that members of the *Acroporidae* family were most susceptible to bleaching during 1998 in the Philippines (Arceo *et al.,* 1999).

It is important to quantify the recovery of the 1998 as well as the successive bleaching events that may occur on Philippine coral reefs. The unpredictable nature of both the spatial and temporal patterns of bleaching on these reefs makes assessment and monitoring of recovery that much more important (Westmacott *et al.,* 2000). Simple and effective monitoring methods can quantify these changes, while subsequent data can help with management decisions on how 'robust' a coral reef can be to withstand the effects of temperature increase. Resistance or otherwise to bleaching effects in the future may have a large part to play in determining zoning patterns in and around marine parks (Goreau *et al.,* 2000).

Methods

Our investigation recorded the effects of bleaching on one particularly large colony of *Pavona clavus* at Danjugan Island, Negros Occidental, Philippines (Fig. 1). Located west of Negros Occidental within the Western Visayas region of the Philippines, Danjugan Island supports extreme biodiversity of hermatypic corals (Fenner, pers. comm.), with 377 species recorded in eight months of subtidal survey work (Gill *et al.,* 1996).

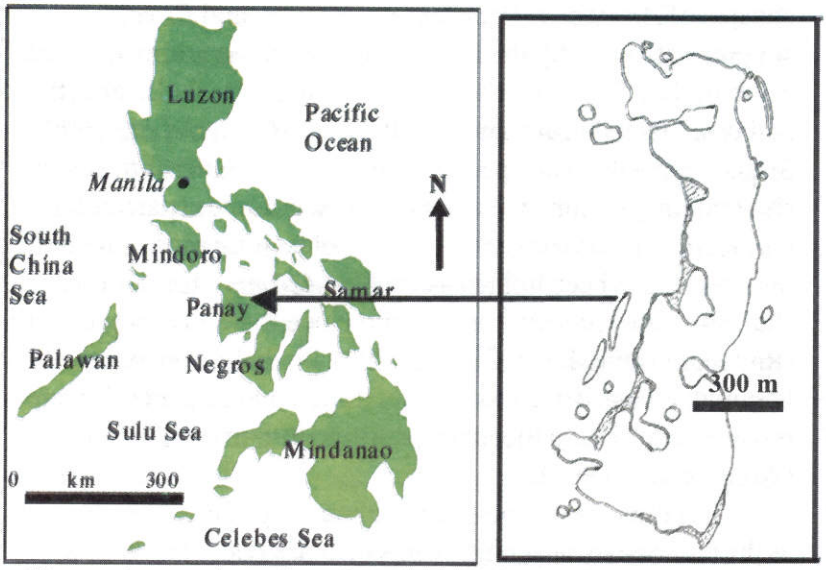


Figure 1. Location of Danjugan Island off the western coast of Negros Occidental, Philippines.

The *Pavona clavus* colony lies in waters between 6m and 22m depth. The basal diameter of this colony is estimated to be around 10m, tapering up to a pinnacle at 6m depth with a diameter of approximately 2-3 meters. The coral mound is not entirely monospecific and has other colonies growing over it, particularly near the upper surface where a large (1m wide at the base, and 1m tall) *Hydnophora pilosa* is dominant. There are also forms of the *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 extending vertically from the main colony interior.

Percent cover data were recorded in three replicate 1m^2 quadrats at three depths – 6, 12 and 18m (lowest low water below chart datum). Permanent quadrats (made of welded iron reinforcement bar) were placed on the reef in September 1998, two weeks after the onset of the bleaching at Danjugan Island was first witnessed (Harding, pers. obs.). Quadrats were attached to the substratum using plastic cable tied at each corner, which were attached to dead coral. The 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).

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 recorded *in situ* on waterproof slates. Volunteer divers collected quadrat information and water temperature. These surveyors were all trained in standard data collection techniques, and were tested in the classroom and *in situ* prior to collecting quadrat data (see Mumby *et al.*, 1995). Percent cover data were arcsin-transformed and subsequently analyzed (2-way ANOVA) for temporal and depth-related differences in cover.

Results

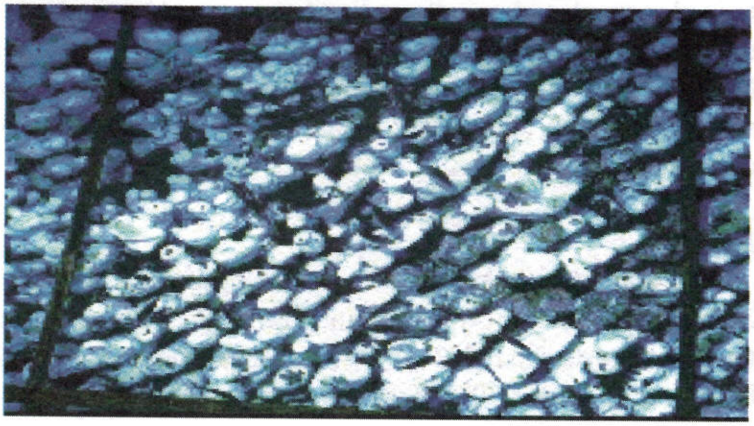
Coral and other cnidarians were bleached to a depth of 25m at a number of sites around Danjugan Island. Water temperatures reached 31^{0}C during August and September 1998, but never exceeded 30^0 C between October 1998 and August

2000 (temperature was recorded by calibrated thermometers). It appears that there was a mixed bleaching effect on hard corals around Danjugan Island which varied according to the species composition of sites coupled with the depth of the colonies (Table 1 and Fig. 2). During the bleaching event itself (August-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. 3).

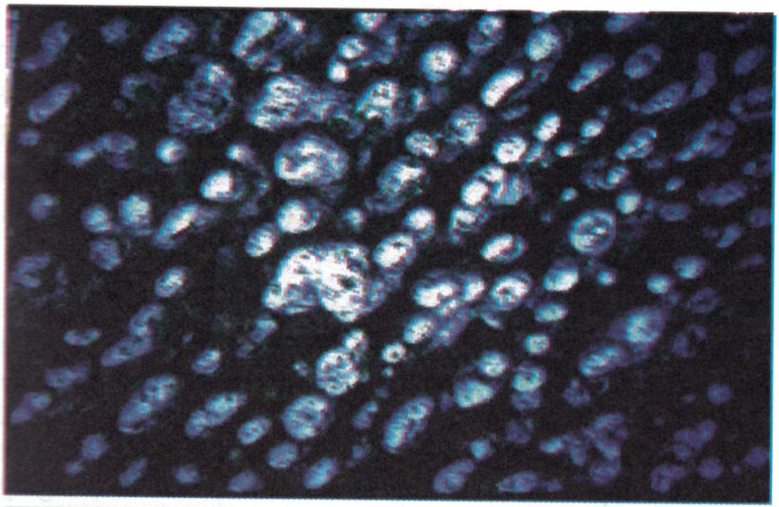
Furthermore, different areas of each individual *P. clavus* column showed different susceptibilities to bleaching at varying depths (Fig. 2). In the shallow areas (6m), all areas of the coral were bleached (Figs 2A and B). However, in deeper waters (12 and 18m), corals bleached on the upper most surface of the individual columns but remained healthy (pigmented) on vertical walls (Fig 2C and D).

Figure 2. *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 medium depth (12m) on the same colony (August 2000) – note the effect of bleaching only on the upper surface of colonies; and image (D) is of the bleaching effect on the colony at 18m (August 2000) – this photo shows the macroalgae community at this depth (*Lobophora variegata*), and bleaching only on upper surface of the *P. clavus* colonies.

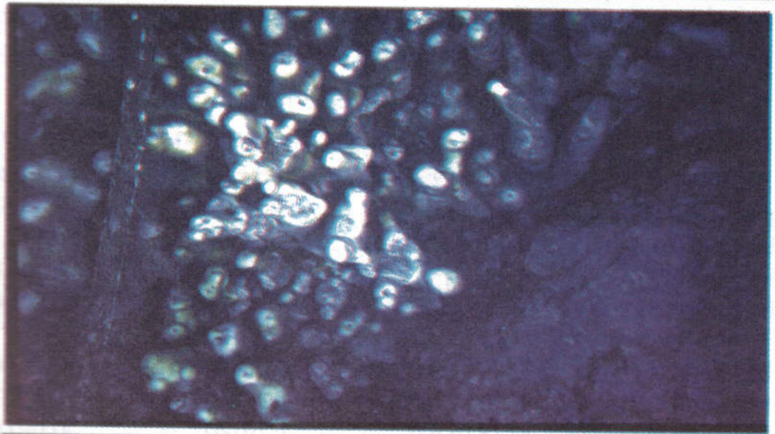
A.



B.



C.



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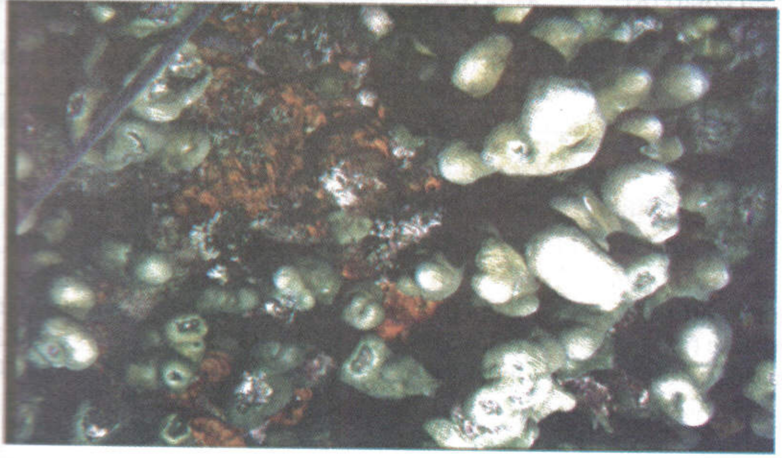


Depth was a significant factor in the post-bleaching recovery of the *Pavona clavus* colony. Areas of the colony at 12m and 18m were ultimately less affected by bleaching (from 85% healthy coral pre-bleaching, to 68.7% cover after 2 years at 12m) than areas in the upper 6m (from 80% healthy coral cover down to around 15%) (2-Way ANOVA, $F = 7.38$, $P < 0.024$).

Table 1. Mean percent cover (±SD) values of key benthic categories between time and depth after the initial bleaching event on the *P. clavus* colony. The relationship between depth and time and each benthic category was investigated using a 2-Way ANOVA on arcsin transformed percent cover data. * Indicates significant difference in percent cover over time for that particular category (ANOVA, $P < 0.05$). $^{\Psi}$ Indicates a significant difference in percent cover between depths (ANOVA, $P < 0.05$) for that category.

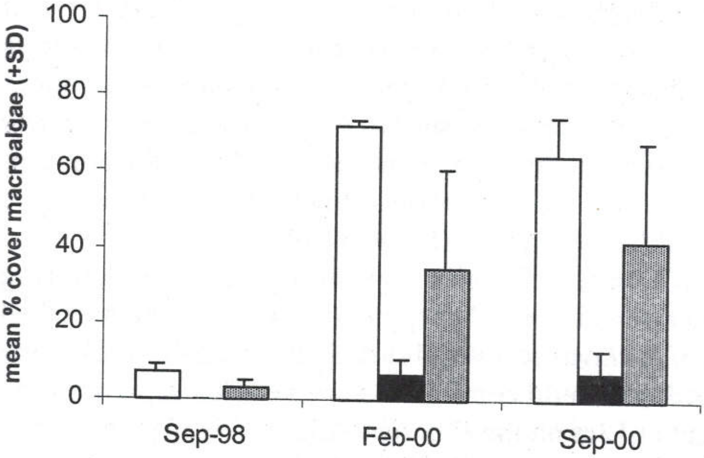
	TIME (post bleaching)		
	August 1998	February 2000	September 2000
Category (DEPTH)	%(±SD)	%(±SD)	%(±SD)
Healthy coral (6)	0.0(0.0) *$^{\Psi}$	2.5(0.7)* $^{\Psi}$	15.0(13.8)* $^{\Psi}$
Healthy coral (12)	4.0(3.5)* $^{\Psi}$	45.0(5.0)* $^{\Psi}$	68.7(8.1)* $^{\Psi}$
Healthy coral (18)	10(15.49)*	25.7(29.9)*	30.0(34.7)*
Bleached coral (6)	83.0(11.0)*	0.0(0.0)*	0.0(0.0)*
Bleached coral (12)	86.7(11.6)*	3.3(2.9)*	0.3(0.3)*
Bleached coral (18)	81.0(16.4)*	1.7(0.6)*	0.0(0.0)*
Bare rock (6)	2.0(1.0)*	7.5(1.0)*	20.0(10.0)*
Bare rock (12)	4.0(3.5)*	6.7(3.5)*	10.2(8.5)*
Bare rock (18)	1.7(2.9)*	3.0(2.7)*	11.0(10.2)*
Rubble (6)	0.0	0.0	0.0
Rubble (12)	0.0	0.0	0.0
Rubble (18)	0.0	3.7(6.4)	5.7(8.1)
Filamentous (6)	8.0(3.0)*	18.0(0.0)*	0.7(0.6)*
Filamentous (12)	5.3(4.6)*	11.3(10.3)*	0.2(0.3)*
Filamentous (18)	4.0(1.7)*	20.0(14.8)*	3.0(1.0)*

Macroalgae (6)	7.0(2.0)*$^{\Psi}$	72.0(1.7)*$^{\Psi}$	64.3(10.2)*$^{\Psi}$
Macroalgae (12)	0.0*$^{\Psi}$	6.7(3.8)*$^{\Psi}$	7.3(6.1)*$^{\Psi}$
Macroalgae (18)	3.0(2.0)	34.8(26.1)	41.7(26.0)

In September 1998, the deep (18m) sample site showed 80% bleached coral, with 11% remaining unaffected. Healthy coral cover from this depth increased from 11% in 1998 to 30% by August 2000.

The proportion of bare rock increased significantly over time at all depths, and particularly so in shallow depths. This is likely to have been caused by increased herbivorous fish grazing at shallow depths on this colony before and after bleaching (Table 1).

The relative tissue recovery of the *P. clavus* colony at different depths over the sampling period had a significant impact on the colonization of algae after the initial bleaching event (Fig. 3). At 6m, bleaching was succeeded by a 57% increase in macroalgae cover after two years. This resulted in macroalgae cover of 64.33% of the benthos (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), macroalgae cover increased from 3 to 41.67% over the 2-year sampling period while filamentous algae increased from 4% to 20% cover at 18m by February 2000, and then decreased considerably by August 2000, indicating either some form of succession within the benthic community or possible grazing effects.



Discussion

The severity of the bleaching event witnessed in this study was comparable to that observed in other areas of the Southeast Asian region and wider Indo-Pacific (Burke *et al.*, 2002; Wilkinson, 2000). However, the recovery of deeper (>10m) coral appears to be encouraging. Although significant areas were heavily bleached in the initial August event, deeper corals went on to regain pigmentation (zooxanthellae) by the end of the sampling period. Shallow branching, and even massive species such as *Diploastrea heliopora* and massive *Porites* spp. were almost totally bleached around Danjugan Island, yet much of the coral tissue regained zooxanthellae pigmentation in the early stages of the two year monitoring period (in fact, within the first four months).

Areas that had monospecific massive stands of corals, such as at shallow Hilary's reef on the east coast of the island (with *P. clavus* colonies being monospecific), showed overall bleaching patterns where both the apical and vertical surfaces of colonies were totally bleached. In deeper waters some of the sub-massive stems regained pigment almost immediately, but predominantly on the vertical surfaces. The pattern of bleaching on the apex of colonies, and not on the vertical walls, is likely a result of increased Ultra Violet (UV) light penetration during periods of very calm weather on coral reefs (Fisk and Done, 1985). 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 surfaces and polyps, making the former more susceptible to bleaching (Brown, 1997).

What appeared 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 at this depth could continue to survive. This is particularly evident at 12m on the *P. clavus* colony (Fig. 3). There was also some recruitment of coral at the 12 and 18m depth areas, principally of *Acropora* species, but also of *Galaxea fascicularis*, *Pocillopora*, *Seriatopora,* and some *Fungiid* species.

Other species of corals with more delicate growth structures, such as branching bottlebrush *Acroporaidae,* were more susceptible to bleaching at similar depths than the *P. clavus* colony (Solandt, pers. obs.). *Acropora* spp. fared worse after the bleaching event and have been observed to be more susceptible to bleaching than more massive species of the genera *Porites*, *Favia*, *Pavona,* and other massive species (Baird and Marshall, 1998).

Algae growing on bleached colonies increased in cover within the first year due to the free space available on the bleached coral. After one to two years, most of the algal species and biomass that had colonized the recently dead coral were absent. Fish herbivory increased as the quantity of ephemeral algae settling on the substratum increased (Solandt, pers. obs.). Consequently, there was a reduction in the cover of these species of algae and the recruitment and growth of more structurally complex macroalgae, such as *Halimeda* spp. or *Dictyota* spp (in some cases, these areas were colonized by coral recruits).

The observations and measurements within this study confirm that hard corals have different susceptibilities to bleaching from increased prolonged sea surface temperatures. *Porites lobata, Pavona clavus,* and other species (many faviids and fungiids) appear to recover zooxanthellae faster than the faster growing branching genera such as *Acropora*.

Since the start of the monitoring period on this *P. clavus* colony and surrounding reefs at Danjugan Island, it appears that this particular colony has recovered fairly well in terms of live tissue cover after the initial bleaching event. Managed by the Philippines Reef and Rainforest Conservation Foundation Inc., Danjugan Island was made a fully gazetted marine reserve on February 2000. Areas such as 'Hilary's reef' where this spectacular *Pavona clavus* coral is located are within one of the three designated and clearly marked no-take zones (fish sanctuaries) where fishing of any description is prohibited. Monitoring of the reefs of Danjugan Island is on-going (monitoring of bleaching recovery; Reef Check surveys; fish-tagging experiments by members of the University of the Philippines; a giant clam seeding project). It is hoped that the success of the reserve, recently voted Best Managed Philippine Reef, 2001, will help to provide marine resource conservation for this unique area of natural heritage for future generations of Filipinos.

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