Recovery of Caymanian Reefs after a coral bleaching event; can Marine Parks help?

Jessica Campbell

Bangor University

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Supervisor: Dr John R. Turner, Bangor University

Co-Supervisor: Croy McCoy, Department of Environment, Government of the Cayman Islands

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J.L Campbell

School of Ocean Sciences, Bangor University, Wales, United Kingdom

In Collaboration with the Department of Environment, Government of the Cayman Islands, George Town, Grand Cayman

Abstract

Coral Reefs are under threat from a growing number of environmental impacts and have already entered a period of decline and degradation, with especially severe loss of coral cover in the Caribbean. Reefs in the isolated Cayman Islands, encompassed by a long established network of protected areas, have however, fared better than most. Despite low levels of direct anthropogenic impacts, the Caymans suffered a severe coral bleaching event in September 2009. Bleaching was observed down to 60 metres. This thesis is the first to document the state of Caymanian reefs after the disturbance, and to examine to what extent recovery has occurred within and outside Marine Parks. Fifty five sites were surveyed by underwater visual census between June and August 2010. Macro algal and hard coral cover, coral community composition and incidence of bleaching and disease were recorded and compared between protection levels, islands and aspects. The effectiveness of Marine Parks in aiding recovery was found to be highly variable between islands, with more success on Grand and Little Cayman than on Brac. Mean hard coral cover was highest on Little Cayman (14.17%) with significantly higher cover found within Marine parks (17.71%) than outside parks (10.63%). Macro algal cover was significantly lower inside Marine Parks on Grand Cayman (30.65%) than outside parks (44.86%) and was close to significance on Little Cayman. The opposite was true on Brac, with higher macro algal cover inside Marine Parks (60.00%) than outside (48.47%). It is hypothesised that impacts in addition to those that can be mitigated by the implementation of protected areas are having negative effects on Caymanian reefs. Therefore it is suggested that while Marine Parks can be beneficial, alone they may not be sufficient to allow full recovery from bleaching events and prevent further decline in coral reef health.

Photo- Jessica Campbell

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Symbols & units

cm - Centimetre
m - Metre
Km - Kilometre
km^2 - Kilometre squared
% - Percent
< - Less than
> - Greater than

Acronyms & Abbreviations

ACoP - Approved Code of Practise
ANOSIM - Analysis of Similarities
ANOVA - Analysis of Variance
CB - Cayman Brac
DoE - Department of Environment, Government of the Cayman Islands
GCM - Grand Cayman
LC - Little Cayman
MDS - Multi-dimensional Scaling
MPA(s) - Marine Protected Area(s)
n - Number
PRIMER - Plymouth Routines In Multivariate Ecological Research
SCUBA - Self-Contained Breathing Apparatus
Sd - Standard deviation
SE - Standard Error
SST - Sea Surface Temperature

1 Introduction

Coral Reefs are one of most fragile and critical ecosystems on the planet (Crabbe, 2009). As the most bio-diverse marine ecosystems, containing an estimated one third of all marine species (Veron *et al.*, 2009), they are important to many people around the world as a source of protein, income generation and protection from wave erosion/ storm damage (Crabbe, 2009a). They are however, under threat from a growing number of environmental impacts and have already entered a period of decline and degradation (Crabbe, 2009a). Threats include sedimentation, nitrification, overfishing, destructive fishing techniques, and the coral eating Crown of Thorns (Jackson *et al.,* 1997, Gardner *et al.,* 2003, Bellwood *et al.,* 2004, Hawkins & Roberts, 2004, Crabbe, 2009b). Climate change however, has now taken over as the most urgent concern. Rising sea surface temperatures (SSTs) mean that the thermal limits of corals are now exceeded on a regular basis in many areas, causing the expulsion of symbiotic zooxanthellae (single celled algae) and paling of the coral skeleton termed coral bleaching. First observed in 1911 by L.R. Cary, coral bleaching has since come to the forefront of coral reef research. Particularly since the 1980's it has had devastating effects across the globe. In September 2009, the reefs of the Cayman Islands suffered a severe bleaching event (Gall, unpublished 2009) that will be at the centre of this thesis.

Such has been the global significance of bleaching that an extensive body of literature has accumulated on its causes and consequences (Baker *et al.,* 2008). Perhaps the most significant questions to be answered in research are how coral reefs can respond to and recover from bleaching and whether they can persist in the face of the ever increasing SSTs predicted for the future. Research has often aimed to address management issues such as what can be done to help corals recover after natural and anthropogenic disturbances. This study will accordingly examine the ability of Marine Protected Areas to help promote recovery after a coral bleaching event.

1.1 Bleaching impacts and subsequent recovery

Although mass bleaching is highly correlated with severe El Nino events (Sotka & Thacker, 2006) many other environmental stressors, which may act synergistically (see Buddemeir & Fauntin, 1993, Obura, 2009) can also bring about a bleaching response. The response is not identical in all corals however; while branching corals tend to show high levels of bleaching and mortality, encrusting and massive forms may often be more robust (Buddemeir & Fauntin, 1993). Bleaching tends to be most prevalent in species showing high rates of recruitment and more rapid growth (often referred to as r-selected or weedy species) (Buddemeir & Fauntin, 1993). Such species invest relatively less in stress tolerance, which comes at the cost of lower bleaching thresholds and higher mortality following bleaching (Obura, 2009). *Stylophora, Pocillopora* and *Acropora* for example are highly sensitive to heat stress, while *Cyphastrea, Goniopora, Galaxea* and *Pavona* are more resistant (Baird *et al.,* 2008). It may be expected therefore, that species composition on reefs having previously suffered severe bleaching events, may shift in favour of these more robust species. This may be offset against the fact that weedy species are more able to rapidly colonise an area and recover after bleaching.

For any coral colony to recover after bleaching, it clearly must re-acquire symbiotic algae in order to meet its energy budget requirements. For this to happen there must be sufficient numbers of zooxanthellae in the surrounding water. This is especially true since it is known that the rate of re-acquisition is influenced by zooxanthellae density (Kinzie *et al.,* 2001). Recovery from bleaching may therefore be facilitated when zooxanthellae are abundant in the environment, which is more likely to be the case if the reef in question has a high number of coral species and is well connected to other reefs that can potentially act as a supply source of new symbionts. Since crustaceans and fish may be important vectors of zooxanthellae (Buddemeir & Fauntin, 1993), this further suggests that recovery may be enhanced by diverse and well populated fish and invertebrate assemblages. It may be hypothesised therefore that recovery from bleaching will occur more rapidly on reefs that are healthy and diverse.

1.2 Reef resilience

Recovery from bleaching depends not just on re-acquisition of symbionts however; additionally corals must remain healthy enough to deal with a variety of other stressors. Recently bleached corals show increased stress levels which can lead to a reduction in their ability to fight disease and infection (Carpenter & Patterson, 2007). Disease outbreaks are often therefore facilitated by positive temperature anomalies and previous bleaching (Baker *et al.,* 2008). The devastation caused by disease in the Caribbean in recent decades (see Croquer & Weil, 2009) is testament to why it is essential that corals are given every chance of avoiding disease after a bleaching event. Reducing anthropogenic stresses is the main way in which further degradation can be avoided; indeed in the absence of severe human impacts reefs do readily reassemble themselves after routine disturbances (Bellwood *et al.,* 2004). Problems in recent decades are largely a result of a combination of many simultaneous stressors acting on corals. Such stressors can act in multiplicative rather than additive ways meaning that the sum of two stressors can exceed a threshold that a single stressor alone would not reach (McClanahan *et al.,* 2002).

The persistence of reefs over geological time scales (Veron *et al.,* 2009), shows that reefs are in fact, quite resilient. Resilience may be defined as the magnitude of disturbance that can be absorbed by a system before it shifts from one stable state to another (Nystrom *et al.,* 2000). The term is most often applied to refer to the ability of a coral reef to resist a phase shift (a move to algal domination) after a disturbance. Possibly the single most important factor in determining whether a reef can resist a phase shift after a disturbance such as bleaching, is whether overfishing has taken place. Jackson *et al.,* (2001) accordingly report that overfishing is very often a precondition for other factors to have major impacts upon the reef. Fishing has such a large effect since it alters the functional groups on a reef (a group of species with similar ecological roles, for example herbivores are a functional group, with their role being to remove algae from the reef (Nybakken, 2001)). Given that abundance of herbivores is the main limit to primary production (and algal growth) on coral reefs (McClanahan *et al.,* 2002) the implications are clear. Herbivory is a crucial process that ultimately prevents fast growing algae from increasing in abundance and outcompeting corals. If herbivore populations have been reduced by fishing to such an extent that they can no longer keep algal growth in check, corals will quickly be outcompeted; algal settlement on the reef will further prevent coral larvae attachment in the future making recovery unlikely.

1.3 Marine protected areas

Notwithstanding the many problems often faced by MPAs (see, Kaiser, 2005, Mora *et al.,* 2006, Mascia, 2007, Campbell, unpublished 2008 & Le Quesne, 2009,) it is becoming increasingly clear that when well managed, they can have numerous benefits. There are now multiple examples of reported increases in abundance, biomass and individual fish size inside protected areas (McClanahan & Kaunda-Arara, 1996, McClanahan & Mangi, 2000, McClanahan & Arthur, 2001, Roberts *et al.,* 2001, Gell & Roberts, 2003, Russ & Alcala, 2003, Unsworth *et al.,* 2007) with Halpern & Warner, (2002) finding that on average fish population densities were 91% higher, biomass 192% higher and individual fish size 20-30% higher inside protected areas. Clearly a healthier and more numerous fish population will be better able to control algal populations and help to resist a phase shift following a bleaching event.

MPAs often have additional benefits since not only is fishing banned, but other destructive practises (such as coral mining, boat anchoring) are prohibited and SCUBA divers are frequently encouraged to avoid touching the reef. The coral framework inside MPA's may therefore be in better physical condition with colonies able to grow to larger sizes. Since larger corals represent older corals, the age structure within MPAs may as a consequence, be in a more natural state than that found in more degraded areas. This is significant in light of the fact that bleaching can shift the age distribution towards juvenile and smaller colonies. Because the reproductive output of many corals is size dependant, such smaller colonies may have lower fecundity or may even be incapable of reproducing (Baker *et al.,* 2008).

Reproduction and recruitment to the reef are clearly essential for recovery after any disturbance (Mumby & Steneck, 2008). Even in the absence of shifts in age distribution however, bleaching events are often accompanied by a reduction in reproductive effort due to a decrease in the size and number of eggs and/or reproductive polyps produced (Ward *et al*., 2000, van Woesik, 2001). Low population densities, asynchronous reproduction and low reproductive output per individual can ultimately lead to total reproductive failure of a taxon; a classic example of the Alee effect (Knowlton, 2001). Accordingly recovery after bleaching is not a certainty and will be heavily dependent upon larval supply from nearby reefs containing healthy corals that are still able to reproduce. Even a reef with a low percentage of live coral cover remaining could regenerate if herbivore populations are sufficient to prevent algal dominance, and larval supply from nearby reefs is adequate. Larval supply is especially important given that many of the reef framework building corals are broadcasting species that spawn only once or twice per year, and are not generally capable of self fertilisation (Knowlton, 2001). It is for this reason that Crabbe (2009b) states that in addition to high functional diversity, good connectivity to larval sources, appropriate substrates for larval settlement and protection from other anthropogenic impacts can all help improve resilience after mass bleaching.

1.4 Caribbean Reefs

Even in a pristine state, Caribbean reefs are much less diverse than their Indo Pacific counterparts, containing only a fraction of the number of species of fish and corals (Nybakken, 2001, Bellwood *et al.,* 2004). While the functional groups present are broadly the same, the species richness within each group and taxonomic composition of groups is markedly different. Lower functional diversity can make reefs more vulnerable after disturbance and may in part help to explain the severe degradation that has occurred on Caribbean reefs in recent decades. Loss of coral cover has been severe since the 1970's with Gardner *et al.* (2003) reporting a reduction from approximately 50% hard coral to around 10% in 2003. Many reefs have become dominated by fleshy algae and have in addition undergone shifts in species composition.

Although with hind-site, it is now clear that for many years, coral reefs in the Caribbean were on a trajectory to collapse (Bellwood *et al*., 2004); no-one at the time realised the sheer scale and implication of changes that were taking place. Even as early as the 1950's overfishing was occurring such that fish stocks began to dwindle. Combined with this was increased nutrient run off from terrestrial sources. On relatively undisturbed reefs, both fish and urchins contribute to maintenance of hard coral cover and recruitment by suppressing algal biomass (McClanahan *et al.,* 2002). As fish stocks in the Caribbean continued to decline however there became an increasing reliance on the sea urchin *Diadema* to act as the principle grazer keeping algal blooms under control. With their main fish competitors and predators removed by fishing, densities of the urchin increased tenfold (Jackson *et al.,* 2001) such that by the 1970's there were an estimated ten *Diadema* per square meter (Bellwood *et al.,* 2004). Disease and mass mortality swept through the urchin population across the whole region in the early to mid 1980s (possibly facilitated by such high densities thus aiding transmission

(Jackson *et al.,* 2001)). After impacts such as bleaching and hurricanes, reefs were unable to display resilience. With very few herbivores remaining, algae increased in abundance unchecked; reefs underwent a phase shift, becoming dominated by fleshy algae (Gardner *et al.,* 2003). High incidence of white band disease in *Acroporids* further contributed to massive declines in coral cover; both *A. palmata* and *A. cervicornis* suffered mass mortality on reefs throughout the region. Such has been the extent of *Acroporid* mortality that paleontological evidence suggests it is without precedent in the late Holocene (Aronson & Precht, 2001, Wapnick *et al.,* 2004).

1.5 The Cayman Islands

1.5.1 Background

The Cayman Islands are home to what are widely regarded as some of the best reefs in the Caribbean. They are relatively isolated, surrounded by deep water, and have no rivers or industrial development. Located 240km south of Cuba, they are composed of Grand Cayman, Little Cayman and Cayman Brac. They have an estimated total population of just under 52,000 (Cayman Islands government, 2006), with the majority of residents living on the largest island, Grand Cayman. With an international airport in the capital Georgetown, Grand Cayman receives hundreds of thousands of visitors each year (1,856,000 arrivals in 2008, Gall unpublished) and is home to many large hotel resorts, condominiums and dive-operators (Manfrino *et al.,* 2003). Little Cayman is the least populated of the islands with less than 150 permanent residents, yet the five small to medium size hotels (Coelho & Manfrino, 2007) are very popular with SCUBA divers. Although population has since increased considerably, Cayman Brac had around 2000 permanent residents at the last census in 1999, with a large majority of residents located on the northern shore. Brac is additionally home to a number of dive resorts, though diving pressure is much lower than on either Grand Cayman or Little Cayman.

In contrast to many other Caribbean Islands, fishing pressure in the Caymans is considered to be relatively low (though it does remain an important cultural tradition on Cayman Brac in particular) (Creary *et al*., 2008). Even on Grand Cayman, despite the presence of numerous large resorts, private homes and corporate development (Creary *et al*., 2008) anthropogenic impacts on the reefs are not considered to be as severe as in most other parts of the region.

This is at least in part due to the committed work and vision of the Department of Environment (Cayman Islands government). Since a Marine Conservation Law (1979) was passed, the islands have had a long established and rigorously enforced (John Turner pers. comm.) network of protected areas (enforced since April 1986). The protected areas (herein Marine Parks) were established with the aim of protecting coral reefs and their associated communities, restoring fish stocks and replenishing fish in the surrounding areas (McCoy et al., 2009).

Despite the absence of impacts such as over fishing, nutrient run off and sedimentation to any large degree, lying within the hurricane belt, the Cayman Islands nevertheless frequently suffer physical damage from storms. Tompkins (2005) estimates that between 1887 and 1987 a tropical cyclone passed within 100 miles of Grand Cayman once every 2.7 years, and passed directly over it once every 12.5 years. Gilbert (1989) and Ivan (2004) were particularly significant in recent years, with Gilbert decimating *Acropora* populations and Ivan stripping sand and soft corals from shallower reefs, most notably round Grand Cayman (Croy McCoy pers. comm.) Tropical storms are common in both the wet (summer) and dry (winter) seasons (Blanchon, 1995). However, while hurricanes often strike in late summer, winter storms are often associated with cold northerly fronts. High frequency and severity of storms leads Blanchon (1995) to suggest that severe storms are the primary physical agent impacting the marine environment in the Cayman Islands.

1.5.2 Coral bleaching

The mass bleaching event of summer 2009 was the response to a hot deep water gyre that stretched all the way from the surface down to 460m, with temperature loggers at the time (see appendix one) recording elevated sea temperatures of over 30 degrees Celsius around Grand Cayman. This was accompanied by a period of calm weather and absence of cloud cover (Croy McCoy pers. comm.) meaning that solar radiation was additionally high. The mass bleaching of coral colonies that followed was particularly severe on Grand Cayman where the hot water gyre was centred. Bleaching occurred but to a less severe degree on Little Cayman, which was on the periphery of the gyre. Astonishingly, being situated just a few km away, Cayman Brac almost escaped the coral bleaching event.

From observations made at the time, it is clear that bleaching was much more severe on deeper reefs than on shallower ones. Colonies at depth rapidly expelled all zooxanthellae, turned bright white and remained so for several months. In contrast, many coral colonies situated much closer to the surface appeared to regain at least some degree of pigmentation much more rapidly (Croy McCoy pers. comm.) thus indicating re-colonisation by zooxanthellae. Figure 1.5-1 clearly shows several bleached colonies at depths down to 60m making this bleaching event highly atypical when compared to most solar induced bleaching events.

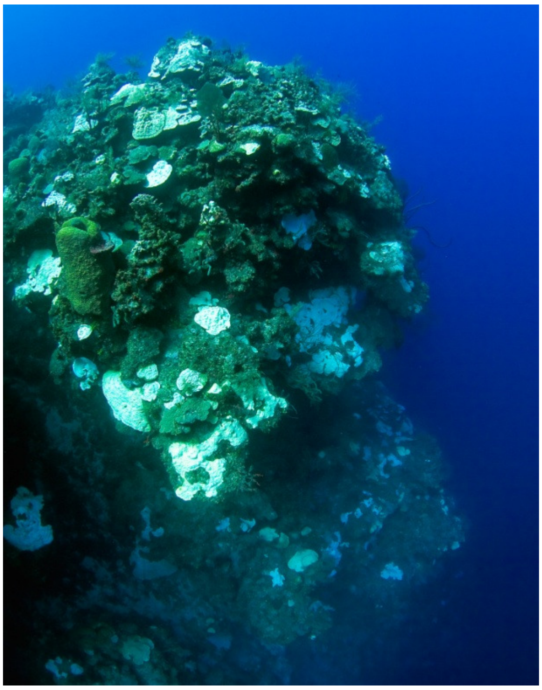

Figure 1.5-1 Image of reef wall on Grand Cayman, October 2009. Colonies at the bottom of the wall (60m) can clearly be seen to be bleached. Photo courtesy of Croy McCoy, photography Patrick Weir.

1.5.3 Project rationale

With frequent storm damage and bleaching, reef resilience and the ability to resist phase shifts after disturbances are crucial for the survival of Caymanian reefs. This is exemplified by predictions that the length of cyclone free periods will shorten in the future due to climate change. All sea surface temperature (SST) projections also predict that frequency of bleaching is set to rise rapidly in the coming years with the most rapid global increases predicted for the Caribbean, South East Asia and the Great Barrier Reef (Crabbe, 2008). In most oceans bleaching is predicted to become an annual event by 2040 but in the Caribbean this could be even sooner; likely by 2020 due to seasonal changes in seawater temperature (Crabbe, 2008). Again, how Caymanian reefs respond to and recover from bleaching is therefore of crucial importance. Despite the urgent need to respond to climate change however, until very recently, government agencies suggest that there has been inadequate information about the global consequences and localised impacts in the Cayman Islands (Tompkins, 2005). Climate change has typically not been considered as an immediate or significant threat and there has been little recognition of the need to implement response measures (Tompkins, 2005). Thankfully the on-going development of a national climate change response policy has begun to change this (John Turner, pers. comm.) It is however still vital that more work is done addressing the likely impacts of global change and ways in which reefs can be managed to help protect them against such impacts.

This thesis will therefore attempt to examine recovery from bleaching and document the current status of the reefs inside and outside Marine Parks around Grand Cayman, Little Cayman and Cayman Brac. This will more broadly address the question of whether protected areas can be beneficial in increasing reef resilience, helping reefs to overcome bleaching events and resist phase shifts to algal domination. Reefs will therefore be assessed in order to document differences in live coral cover, algal cover, species composition and incidence of bleaching and disease between areas within and outside of Marine Parks.

1.5.4 Hypothesise

H_0 Recovery of corals after the 2009 bleaching event will not be significantly different between reefs within and outside Marine Parks.

H_1 Recovery from bleaching will have occurred to a greater degree inside Marine Parks than outside.

Specifically this leads to three further hypotheses:

1) Percent live coral cover will be higher inside Marine parks than outside parks
2) Incidence of coral disease will be lower inside Marine parks

3) Remaining signs of bleaching/ occurrence of new bleaching will be lower inside Marine parks than outside parks

H_0 Species composition will not be significantly different within and outside of Marine parks

H_1 There will be significant differences between the species composition of reefs within Marine parks when compared to reefs not within parks

Specifically:

1) Marine Parks will have greater coral richness and diversity than areas outside of Parks
2) Areas outside parks will be characterized by faster growing, more weedy coral species and fewer important framework builders compared to areas within Marine parks

H_0 Recovery of corals after the bleaching event will not be significantly different between reefs facing differing aspects

H_1 Degree of recovery from bleaching will vary with reef aspect.

1.5.5 Objectives

Objective one

To assess the extent of recovery after the bleaching event of 2009 on reefs within and outside Marine parks on Grand Cayman, Little Cayman and Cayman Brac. This will involve determining the percentage of live coral cover, incidence of coral disease and any remaining or new coral bleaching. Additionally the percentage cover of macro algae will be determined in order to assess the likelihood of a phase shift.

Objective two

To assess the species composition on reefs within and outside Marine parks on Grand Cayman, Little Cayman and Cayman Brac. This will involve addressing the coral species richness, diversity, and evenness and also comparing the coral community composition using multivariate methods.

Objective three

To assess the degree of recovery from bleaching on reefs orientated towards different aspects around Grand Cayman, Little Cayman and Cayman Brac. This will be in terms of percentage live coral cover, incidence of coral disease and incidence of any remaining/new coral bleaching.