

## The effects of habitat on coral resistance and resilience to bleaching

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### Abstract

Coral bleaching related to climate change is one of the major threats to coral reefs today. This study examines bleaching responses of scleractinian corals at four Kenyan sites (Kanamai, Vipingo, Mombasa and Nyali) representing shallower and deeper lagoon habitats. Bleaching incidence was monitored for the whole coral community, while zooxanthella densities and chlorophyll levels were monitored for selected species (*Pocillopora damicornis*, *Porites lutea* and *Porites cylindrica*) during non-bleaching and mild-bleaching years. The objective was to determine whether corals in different habitats display varying resistance and resilience to bleaching and to indicate which habitat characteristics are responsible. Differences in bleaching responses between shallower and deeper lagoons were observed, with shallower sites Kanamai and Vipingo exhibiting lower bleaching incidence than deeper sites Nyali and Mombasa. Shallower lagoons also displayed higher fluctuations in light and temperature than deeper sites, with higher maximums, lower minimums, higher standard deviations and higher diel variation. This suggests that corals in the shallower lagoons have acclimatized to become more resistant to bleaching because of the fluctuating conditions they endure daily. In sites with higher bleaching incidence, it was found that coral recovery occurred more quickly in the protected area (Mombasa) compared to the reserve (Nyali).

### Keywords

Coral bleaching, coral acclimatization, resilience, Kenya

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### Introduction

Coral colonies have been observed to acclimatize or adapt to fluctuating temperature and irradiance levels, and this prior experience might make the colonies more able to resist unexpected bleaching events (Brown et al. 2002a, Brown et al. 2002b). Acclimatization can be defined as the ability of an organism to undergo phenotypic changes in response to stress in the natural environment that result in the readjustment of the organism's resistance levels to that stress (Coles and Brown 2003). Adaptation occurs over the long-term when the more stenotopic members of a population are eliminated by environmental stress, leaving the more resistant organisms to reproduce and recruit to available habitat (Coles and Brown 2003). Threshold temperatures that induce coral bleaching-related mortality vary worldwide due to selective adaptation and according to the maximum water temperatures that are normal in the area, implying a capacity of corals and/or zooxanthellae to survive higher temperatures for a certain period of time. Furthermore, corals that are regularly exposed to stressful environmental conditions have been shown

to acclimatize and exhibit physiological resistance to elevated temperatures and UV-radiation that exceed normal thresholds (Brown et al. 2000; Brown et al. 2002a; Brown et al. 2002b, Coles and Brown 2003).

In order to combat the worst effects of climate change and to conserve this valuable ecosystem, it is important to determine which factors affect coral reef bleaching resistance and resilience and to apply this knowledge in management plans. Although bleaching events cannot be prevented by managers, by implementing appropriate management responses it is possible to help a coral reef recover from bleaching and to mitigate the worst effects.

This study examines the bleaching responses of corals at four sites (Nyali, Mombasa Marine Park, Kanamai and Vipingo) representing two distinct lagoon habitats on the Kenyan coast (deeper and shallower lagoons). The sites were characterized using environmental parameters such as depth, water flow, light and temperature. Bleaching responses were monitored for the general coral community and zooxanthella densities and chlorophyll levels were monitored for target species (*Pocillopora damicornis*, *Porites lutea* and *Porites cylindrica*)

during a non-bleaching year (2006) and a mild bleaching year (2007). The objective of this study is thus to determine whether corals in different habitats display different bleaching responses (i.e. resistance and resilience) and to indicate which environmental characteristics are responsible for the variation in response.

### Materials and Methods

Five large and healthy coral colonies for each target species (*Pocillopora damicornis*, *Porites cylindrica* and *Porites lutea*) were mapped in two shallower lagoons (Kanamai and Vipingo, 0.4 m depth and 0.6 m at low tide respectively) and two deeper lagoons (Mombasa Marine Park and Nyali, 1.4 m and 1.8 m depth at low tide respectively) along the Kenyan coast. Target species were chosen according to general abundance and bleaching susceptibility, with one highly susceptible (*Pocillopora damicornis*), one moderately susceptible (*Porites cylindrica*) and one resistant (*Porites lutea*) target species. Coral size class and line intercept transect data were also collected for two fixed 25x2 m transects at each site.

The bleaching season in Kenya occurs during the late northeast monsoon from mid March when doldrum conditions become most intense to late April when the first storms of the southeast monsoon induce cooling of surface waters. In the two years of the study, sampling began before bleaching during the northeast monsoon (February and early March), continued during bleaching season of the northeast monsoon (late March and April) and finished during the recovery period of the southeast monsoon (May, June and July).

Coral fragments were collected from the mapped colonies using a hammer and chisel. The fragments were transported to the laboratory submerged in seawater in small plastic bottles and were held in an aerated seawater tank for less than 24 hours. Coral tissue was removed from the skeleton using a water jet. Seawater was then added to the tissue to make up a fixed volume of 500 ml. The tissue slurry was homogenised using a hand-held homogenizer and 1.0 ml of homogenate was loaded into a Sedgwick-Rafter chamber. Using a compound binocular microscope and a magnification of x400, the number of zooxanthellae in 10 random quadrats was recorded. The counting chamber was then reloaded and another 10 random quadrats were counted. The area of the coral skeleton was measured using the aluminium foil method (Marsh 1970); the area/weight ratio of aluminium foil was determined and coral skeletons were then wrapped in this foil. The foil was then trimmed to fit the skeleton area and weighed. Using the weight of the trimmed foil

and the area/weight ratio for the foil, the skeleton area could be determined.

To measure chlorophyll *a* levels, a known volume of the homogenate was filtered through a GF/F filter paper and the filtrate was dissolved in 10 ml of 90% acetone. It was then centrifuged for 10 minutes at 2000 rpm and the chlorophyll absorbance was read using a Whatman spectrophotometer.

If it was observed, bleaching incidence was recorded in the water using a random swim method. This consists of noting the size class, genus and bleached/pale/dead percentages of each bleached colony in 20 haphazard 2 m<sup>2</sup> areas at each site.

Water temperature was monitored using underwater Hobo temperature loggers that were left at each site during the entire duration of the study. Light was monitored using a Hobo light meter for only 24-hour periods on the same day and time at each site to avoid theft and overgrowth of the light meter. Water flow was measured using a clod card method (McClanahan et al. 2005). Plaster-of-Paris clod cards were made in an ice-cube tray, dried and weighed before being deployed in the field in small net bags that were tied to the substrate. They were collected 24 hours later, dried and weighed again in order to determine how much had dissolved. Current speed in g d<sup>-1</sup> (24 h) was obtained by dividing weight loss by deployment time. Weight loss [g] was then converted to flow speed ( $V_w = \text{cm s}^{-1}$ ) using the equation  $V_w = (DW_{\text{clod}} - 0.932)/2.357$ , which was obtained by studies of clod dissolution in a flume with controlled water flow (Anzai 2001).

Statistical analyses were performed using the program Minitab (version 10.1). Differences in zooxanthella density were investigated using the Man-Whitney U test with Bonferroni corrections and the Kruskal-Wallis test.

### Results

#### Depth

Nyali and MMP are deeper lagoons (1.8 m depth and 1.4 m depth at mean low tide respectively) while Kanamai and Vipingo are shallower lagoons (0.4 m depth and 0.6 m at mean low tide respectively).

#### Temperature

The shallower lagoons Kanamai and Vipingo displayed the most fluctuating temperature conditions, with higher standard deviations ( $\pm 1.9^\circ\text{C}$  and  $\pm 1.5^\circ\text{C}$  respectively), higher maximum temperatures ( $36.2^\circ\text{C}$  and  $33.8^\circ\text{C}$  respectively), lower minimum temperatures ( $24.0^\circ\text{C}$  and  $23.7^\circ\text{C}$  respectively) and bigger differences between diurnal and nocturnal temperatures ( $+0.9^\circ\text{C}$  and  $+0.4^\circ\text{C}$  respectively) than the deeper lagoons. Between the

two, Kanamai displayed larger fluctuations, as well as the highest average temperature overall (27.8°C).

The deeper lagoons of MMP and Nyali displayed less pronounced temperature variations with lower standard deviations (both  $\pm 1.4^\circ\text{C}$ ) as well as smaller maximum-minimum (+8.9°C and +8.1°C respectively) and diurnal-nocturnal (both +0.2°C) differences than the shallower lagoons. However, the deeper lagoons displayed bigger temperature increases from the 2006 to 2007 northeast monsoon bleaching seasons, with a +0.9°C increase in Nyali and a +0.8°C increase in MMP compared to a +0.7°C increase in both Kanamai and Vipingo (fig. 1).

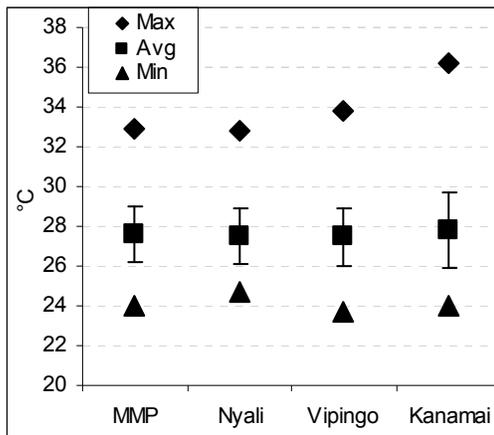


Figure 1. Average, standard deviation, minimum and maximum temperatures for all sites.

### Light

As expected, the shallower lagoons Kanamai and Vipingo also displayed more fluctuating light regimes than the deeper lagoons Kanamai (4913 $\pm$ 14,315 lux) and Vipingo (4758 $\pm$ 10,489 lux) both displayed much higher average light levels, higher standard deviations and higher maxima (70,846 lux and 110,223 lux respectively) than MMP (average of 518 $\pm$ 879 lux, maximum of 5167 lux). Although light data are unavailable for Nyali, it is likely that light levels are similar to MMP given the depth and sediment levels of the site.

### Water flow

There was no clear trend between water flow at deeper and shallower lagoons. MMP consistently displayed the highest average water flow during both neap (6.4 cm/s) and spring tide cycles (9.0 cm/s). Kanamai (5.4 cm/s) displayed similar water flow to Nyali (5.5 cm/s) and Vipingo (5.6 cm/s) during neap tide and it appears that MMP stands out as the site displaying highest water flow.

### Substrate cover

MMP and Kanamai displayed higher hard coral cover (28.4% and 23.0% respectively) while Nyali and Vipingo displayed lower hard coral cover (14.7% and 10.6% respectively). Macroalgal cover was higher in deeper sites MMP (25.5%) and Nyali (21.0%) than in shallower sites Vipingo (8.3%) and Kanamai (3.7%).

### Coral cover

All sites are dominated by massive and branching *Porites* colonies. 90.5% of MMP, 80.3% of Kanamai, 59.9% of Nyali and 42.2% of Vipingo coral cover was massive and branching *Porites*. The highest relative coral cover of the more bleaching-susceptible genera *Acropora* and *Pocillopora* is found in Vipingo (10.2%) and Nyali (8.3%). *Acropora* and *Pocillopora* only accounted for 3.7% of Kanamai's coral cover and 0.7% of MMP's coral cover.

### Bleaching and mortality incidence

Bleaching was first observed during late April of 2007. The shallower lagoons Kanamai and Vipingo exhibited lower levels of combined paling, bleaching and mortality (4.4% and 6.3% of total coral area respectively) than the deeper lagoons Nyali and MMP (35.1% and 26.9% of total coral area respectively). During the recovery period, MMP still exhibited relatively high bleaching incidence (9.8%) but low mortality (0.9%). Nyali exhibited the highest mortality (11.7%) and also relatively high bleaching (4.5%). In July, mortality increased to 13.1% in Nyali and 2% in MMP, but bleaching incidence in MMP decreased to 6.0%, indicating recovery (fig. 2).

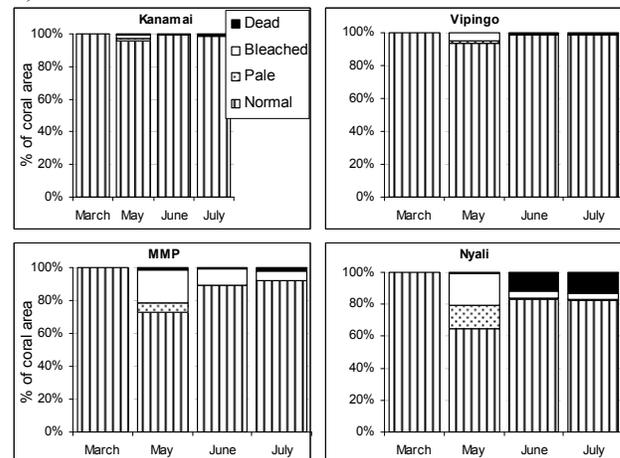


Figure 2. Bleaching and mortality incidence for all for sites from March to July 2007. Nyali and MMP exhibited higher bleaching than Kanamai and Nyali. Corals in MMP recovered better than in Nyali.

*Pocillopora* and *Porites* accounted for the highest proportion of bleached colonies, but differed greatly

in their mortality rates. In MMP, Nyali and Vipingo, *Pocillopora* accounted for 37%, 47.1% and 33.3% of bleached colonies respectively. In Kanamai, MMP and Nyali, *Porites* accounted for 47.2%, 28.3% and 13.8% of bleached colonies respectively. However, during the recovery period of June and July, *Porites* experienced low bleaching-related mortality while *Pocillopora* experienced highest mortality in all sites (from 37.5% in Vipingo to 90% in MMP). Of the three target species only *Pocillopora damicornis* suffered significant mortality in both 2006 (50% overall mortality) and 2007 (47% overall mortality) with colonies in Kanamai experiencing the lowest mortality rate in both years.

#### *Zooxanthella densities*

Average zooxanthella densities for marked colonies (*Pocillopora damicornis*, *Porites lutea* and *Porites cylindrica*) were higher for all species at all sites in 2006 than in 2007 (Man-Whitney U test,  $p < 0.05$ ). Average zooxanthella densities were also higher in shallower sites than in deeper sites for all species (Man-Whitney U test  $p < 0.001$ ). In general, Kanamai exhibited the highest average zooxanthella densities while MMP displayed the lowest. *Porites lutea* colonies exhibited the highest zooxanthella densities while *Pocillopora damicornis* (Kruskal-Wallis,  $p < 0.001$ ).

#### *Chlorophyll a levels*

Chlorophyll *a* concentrations were generally higher in shallower than in deeper sites, and Kanamai exhibited the highest chlorophyll *a* concentrations while MMP exhibited the lowest (Man-Whitney U test,  $p < 0.05$ ).

### **Discussion**

Considerable differences in bleaching responses between shallower and deeper lagoon sites were observed, with shallower sites Kanamai and Vipingo exhibiting much lower bleaching incidence than deeper sites Nyali and MMP in both haphazard sampling and marked colonies. These results suggest that corals in the shallower lagoons have acclimatized and/or adapted to the more fluctuating environmental conditions they endure on a daily basis and have become more resistant to thermal stress than corals in the deeper lagoons. McClanahan et al (2005) found similar responses and concluded that 'that benign or stable environments will produce communities that are less resilient to rare climatic disturbances but if disturbances are sufficiently infrequent, they will maintain high numbers of species. Variable or stressed environments will maintain dominant organisms capable of

withstanding climatic disturbances but will lose those rare members of the community that cannot adapt to the stressful conditions.'

Shallower sites Kanamai and Vipingo displayed more fluctuating temperature and light regimes than deeper sites Nyali and MMP with higher maxima, lower minima, larger standard deviations and larger diel variations. The smaller volumes of water in the shallower lagoons probably explain the difference in temperature and light regimes; shallower lagoons absorb but also lose heat more quickly and attenuate less light than in the deeper lagoons.

Differences in temperature and light regimes could also explain differences in bleaching responses between similar-depth sites. Kanamai displayed lower bleaching incidence and bleaching-related mortality than Vipingo and is also a shallower site with higher average temperatures, standard deviations, differences between maximums and minimums, diel variations, maximum light levels and standard deviation in light levels. Similarly, MMP displayed higher average temperatures and difference between maximum and minimum temperature than Nyali and also suffered lower bleaching incidence,

On the other hand, water flow did not correlate well with bleaching incidence, and although corals in Nyali suffered much higher bleaching incidence than Kanamai and Vipingo, all these sites displayed very similar water flow velocities. It therefore appears that light and temperature histories were more influential than water flow in determining the bleaching responses of corals.

Studies have shown that corals with higher zooxanthella densities are more resistant to bleaching (Grimsditch et al. 2008), a hypothesis that is further confirmed by this study. *Porites lutea* displayed the highest densities and was the most resistant to bleaching. *Porites* colonies made up a large proportion of bleached corals but they exhibited very little mortality. *Pocillopora damicornis* exhibited the lowest densities and was the most susceptible to bleaching, accounting for most bleaching-related mortality in all sites. Zooxanthellae population dynamics could thus partly explain bleaching responses of different genera.

All sites were dominated by massive and branching *Porites* corals, discounting the possibility that large variations in coral community compositions determined bleaching responses. However, differences in community composition could partially explain varying bleaching responses between similar-depth sites. Nyali exhibited higher bleaching incidence than MMP and also a higher proportion of area covered by bleaching-susceptible

genera (i.e. *Pocillopora* and *Acropora*). The same applies to Vipingo compared to Kanamai.

During the recovery period, colonies in Nyali displayed higher mortality than those in MMP, while a higher proportion of corals in MMP remained bleached but did not die. It is possible that colonies in Nyali were being overgrown by algae more quickly than those in MMP, which remained in a bleached state longer. This could be due to the protected status of MMP and that herbivory levels could be higher than in Nyali, which is subject to high fishing pressure. Populations of important herbivores such as parrotfish and surgeonfish have been shown to be significantly higher in protected areas than in non-protected areas along the East African coast (McClanahan and Arthur 2001).

In conclusion, this study shows that during the 2007 bleaching season, corals in the shallower lagoons of Kanamai and Vipingo were more resistant to bleaching stress than corals in the deeper lagoons of MMP and Nyali, probably due to a history of higher light and temperature extremes and variation at the shallower sites. Whether this acclimatization is due to short-term phenotypic changes or due to a longer-term process of adaptation through natural selection is a question that begs further research. *Pocillopora* was the genus most susceptible to mortality and *Porites* displayed high resistance to mortality. Among all these patterns of bleaching susceptibility, it is not clear whether the acclimatization is host-based or symbiont-based, and monitoring of the genetic identity of the zooxanthellae in corals at these sites could help in answering this question. Finally, bleached corals in MMP suffered lower levels of mortality than in Nyali, maybe associated with the possibility that rates of herbivory are higher in MMP due to its protected status. While herbivory is often related to resilience of reefs and the influence of herbivores assisting recovery by coral recruits, this result suggests herbivory may also mediate interactions between algae and bleached corals, and assist in the survival of bleached corals.

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#### References

- Anzai R (2001) The effects of coral morphology and waterflow rates on rates of coral growth and passive diffusion. MSc thesis, University of the Ryukyus.
- Brown BE, Dunne RP, Goodson MS, Douglas AE (2000) Bleaching patterns in reef corals. *Coral Reefs* 404:142-143.
- Brown BE, Downs CA, Dunne RP, Gibbs SW (2002a) Exploring the basis of thermotolerance in the reef coral *Goniastrea aspera*. *Mar Ecol Prog Ser* 242:119-129.
- Brown, BE, Dunne, RP, Goodson, MS and Douglas, AE (2002b) Experience shapes the susceptibility of a reef coral to bleaching. *Coral Reefs* 21:119-126.
- Coles SL, Brown BE (2003) Coral bleaching – capacity for acclimatisation and adaptation. *Adv Mar Biol* 46:183-223.
- Grimsditch GD, Mwaura J, Kilonzo J, Amiyo N, Obura D (2008) High zooxanthellae densities and turnover correlate with low bleaching tolerance in Kenyan corals. In: Obura, D, Tamelander, J and Linden, O (eds) CORDIO Status Report 2008. CORDIO, Mombasa, pp235-236.
- Marsh JA (1970) Primary productivity of reef-building calcareous red algae. *Ecology* 51:255-263.
- McClanahan TR, Arthur R (2001) The effect of marine reserves and habitat on populations of East African coral reef fishes. *Ecol Appl* 11:559-569.
- McClanahan TR, Maina J, Moothien-Pillay R, Baker AC (2005) Effects of geography, taxa, water flow, and temperature variation on coral bleaching intensity in Mauritius. *Mar Ecol Prog Ser* 298:131-142.