Coral Reef Health and Status

Authors: Obura, David, and Oliver, Tom

Source: A Rapid Marine Biodiversity Assessment of the Coral Reefs of Northeast Madagascar: 56

Published By: Conservation International

URL: https://doi.org/10.1896/054.061.0108

Chapter 6

Coral reef health and status

David Obura and Tom Oliver

SUMMARY

To prioritize ecologically resilient reefs for conservation action, we evaluated the sites surveyed in the Northeast Madagascar Marine RAP using resilience assessment methods developed by IUCN and CORDIO East Africa. Overall the region showed high coral cover (mean of 48%), and coral populations that spanned the expected size range for the genus in question, including large, mature colonies. The common occurrence of large colonies suggests that there has been no catastrophic mortality in the past few decades. Coral recruitment was present, but relatively low.

Even after an extended heating event that ended immediately preceding the survey, coral bleaching was relatively low, showing a mean ~5% of colonies affected. This, and the low impact detected from the 1998 mass bleaching event, suggests that the corals in this region have largely resisted the negative effects of heating events, and supports the hypothesis that these reefs are thermally resistant. In general, the northern three locations (Ambodivahibe, Nosy Ankao, Loky Bay) showed greater coral cover, larger corals and fewer bleached colonies than the southern two sites (Andravina, and Vohemar). Coral recruitment was highest on the northern and southern extremes, in Ambodivahibe and Vohemar, though overall was comparatively low.

The generally intact structure of the reefs and apparent resistance to coral bleaching suggests that the region is a priority for conservation. We recommend conservation actions to enhance coral recruitment, a key factor for ecological resilience, through the targeted restriction of fishing pressure and watershed management to limit/reduce sedimentation.

INTRODUCTION

Coral reefs and their associated seagrass beds and mangrove habitats support the highest marine biodiversity in the world (Knowlton et al. 2010) as well as the livelihoods and economies of millions of coastal people (Moberg 2009). The coral reefs of Madagascar have long been recognized as a key asset in supporting the dual aims of biodiversity conservation and poverty alleviation.

An issue of primary concern for coral reefs is climate change, now recognized as one of the greatest threats to coral reefs worldwide (Hoegh-Guldberg et al. 2007). Mass coral bleaching remains one of the most immediate impacts of climate change on corals reefs, as abnormally high water temperatures trigger the breakdown of the coral-algal symbiosis and can lead to mass coral mortality (Coles and Brown 2003). Other factors that affect reefs in the region include cyclones, terrestrial sediment run-off, predator outbreaks such as crown of thorns seastars, and anthropogenic threats such as fishing, pollution, and nutrient additions (Wilkinson 2004).

Each of these factors affects the ecological state of reefs, and alone or in concert they can act to drive the reef from a highly diverse system capable of providing sustenance for many people to a degraded state that supports few species and sustains few people. The likelihood that a given reef will succumb to these factors and slide down this scale of "reef health" can be explained in terms of the reef's *ecological resilience* – i.e. its ability to resist threats and to recover to a healthy state when an impact does occur (Obura and Grimsditch 2009).

The natural resilience of reefs is being undermined by stresses associated with human activities and these local pressures reduce the resilience of the system by reducing its ability to cope with additional stresses, such as those presented by climate change (Hoegh-Guldberg et al. 2007). Increasingly, policy-makers, conservationists, scientists and the broader community are calling for management actions to restore and maintain the resilience of the coral reefs to climate change, and thus avoid worst-case scenarios. To assist management authorities in focusing management efforts on priority areas, the IUCN Climate Change and Coral Reefs working group (http://cms.iucn.org/cccr), led by CORDIO East Africa, has outlined a series of protocols to quantify basic resistance and resilience indicators for coral reefs.

We applied this resilience assessment method to the reefs surveyed in the Northeast Madagascar Marine RAP. This component of the RAP focuses on reef health and resilience, to more directly support conservation outcomes recommended by the species-oriented components.

Northeast Madagascar is a particularly interesting region for those interested in reef resilience in the face of climate change. To date, many regions in Madagascar have suffered from notable bleaching-induced mortalities (Quod et al. 2002, NOAA 2007, Maharavo et al. in press, Obura 2009), however, reefs in Northeast Madagascar have reportedly escaped major bleaching impacts (Webster and McMahon 2002, McKenna et al. 2005). Our survey aimed to critically evaluate these findings, and build a broader perspective on reef resilience in the region.

METHODS

The methods that we applied in this study were developed by the IUCN working group on Climate Change and Coral Reefs, as a rapid assessment of the resilience of coral reefs to climate change and its most immediate consequence, high seawater temperature. Consequently, its objectives and methodology are consistent with those of the marine RAPs, adding a component on reef health to the biodiversity assessment. Several components of the reef ecosystem were measured at varying levels of detail, as follows:

1. **Benthic cover –** provides the main overall indicators of reef state, and particularly the balance between corals and algae. Benthic cover was estimated by eye, and reported here. Benthic photo quadrats were also collected for future analysis and for verification of visual estimates if necessary.

2. **Fleshy algae** – provides information on the main competitors to corals on degrading reefs. Fleshy algae cover (%) and height (cm) were estimated.

3. **Coral community structure –** provides an overview of the relative abundance of coral genera, and that are susceptible or resistant to coral bleaching. The abundance of all coral genera was estimated during field visits along a five-point scale (0-absent, 1-rare, 2-uncommon, 3-common, 4-abundant, 5-dominat).

4. **Coral population structure –** the size class distribution of selected corals provides detailed information on their demography (including recruitment, growth and mortality). It includes sampling of small corals (<= 10cm) in 1 m^2 quadrats, and larger corals (> 10 cm) in belt transects of 1m width (the length of transect sampled is maximized, within the constraints of time and opportunity, with > 50m being desirable).

5. **Coral threats –** gives an indication of the current health of the coral community, and includes observations on coral bleaching, disease, and mortality, and presence of predators and threats such as crown of thorns stars.

6. **Fish herbivores and other functional groups –** fish exert primary control on the reef community, and on algae through herbivory, thus controlling competition between algae and corals. This data was collected and reported under the separate RAP component on fish biodiversity and biomass.

7. **Resilience indicators –** various additional factors that affect the resistance of corals to bleaching and the resilience or recovery potential of the reef community. A broad range of indicators in different classes is measured, including of aspects in 1-6 above, but at less quantitative levels. A detailed description of the methodology is available in Obura and Grimsditch (2009). The main classes of indicators are listed in Table 6.1.

RESULTS

Resilience Indicators

Indicators are summarized in Table 6.2 for benthic cover (%), site depth (m) and indicators of physical and coral community characteristics (1-5 scale). Detailed results follow.

Hard corals were the dominant cover at all the areas visited, confirming the healthy state of the coral reefs of the region. Coral cover averaged 48% throughout the area (Fig. 6.1), with highest cover in Vohemar (60%) and decreasing to 21% in Andravina.

Sites with the lowest coral cover (A17, A05, A20, etc) all showed high influence of sedimentation and/or wave energy, the low coral cover being a natural response to these factors. Soft corals were also abundant at ≈ 20% cover, at a similar level to algal turf. The high abundance of soft corals is consistent with the apparently high levels of nutrients in the area, as a result of freshwater runoff from land, and high levels of wave energy along the exposed coast. Turfs were the dominant algal form found on the reefs at an average of 20%, with macroalgae averaging < 5%. Vohemar had higher macroalgal abundance than the other areas, likely a result of eutrophication and heavy fishing pressure.

While sampling for resilience indicators focused on shallow sites about 10 m, we found that reef profiles were very shallow, with many sites having the main zone of coral development at <10 m (Table 6.2). In most cases, the reef maximum reef depth was at 12-18m, where the rocky substrate gave way to sand and rubble slopes. Given the accumulation of fine sediment and the relatively low light levels at these depths, it appears that coral growth may have been limited by sedimentation and/or high turbidity.

Physical characteristics of the areas are summarized in Fig. 6.2. Exposure of reefs to wave energy was generally moderate to high, though the most highly exposed sites in the region were not sampled due to accessibility problems. The fore reef at Vohemar was the most exposed site sampled and showed characteristics of this exposure, with strong development of reef spurs and pillars similar to structures found farther south in the Masoala peninsula. The most sheltered sites were within Loky Bay and showed characteristically high levels of fine terrigenous silt. Characteristics that contribute to cooling of surface waters (upwelling, proximity to deep water, mixing by wave energy) were found to be highest at Ambodivahibe and Vohemar. They were lower at the other three locations as these were either within bays, or on large platforms distancing them from cooler deep waters.

Aspects of coral community structure are summarized in Fig. 6.3. Bleaching was at moderately low levels throughout the region, reflecting a regional bleaching alert due to the presence of a moderate hotspot in the region (see NOAA and CORDIO alerts). Bleaching levels increased southwards, with highest levels recorded at the southern sites of Andravina and Vohemar, corresponding to up to 20% of corals showing some level of bleaching or paling. Mortality as a result of bleaching was not apparent, however. The lack of mortality observed so far may indicate that mortality from the moderate bleaching event may be limited, with no major impact on the coral communities in the short term. Repeat observations of some of the study sites, particularly at Ambodivahibe and Vohemar in mid-2010 could test this. Quantitative bleaching transect data is presented below (See *Coral Bleaching Data)*.

Disease and mortality levels for corals were low throughout the region, confirming the low impact of anthropogenic and disease-causing agents. Coral recruitment levels were

Table 6.1. Resilience Indicators

Group	Factor	Variable	Group	Factor	Variable
1-Cover	Coral	Coral cover	3-Coral community	Size/age	Largest corals (3)
	Algae	Fleshy Algae		Condition	Coral bleaching
		CCA			Mortality-new
	Substrate	Rubble			Mortality-old
2-Physical	Substrate	Topogr. Complex. - micro			Recovery-old
		Topogr. Compl. - macro			Coral disease
		Sediment texture	4-Coral associates		Obligate feeders
		Sediment layer			Branching residents
	Cooling & flushing	water movement			Competitors
		deep water (30-50m)			Bioeroders (urchins, nonfish)
		depth of reef base			Bioeroders (internal, spo)
		wave energy/ exposure			Corallivores (negative)
	Temperature	Temperature (oC)	5-Anthropogenic	Water	Nutrient input
	Shading & screening	depth (m)			Pollution (chemical)
		aspect		Substrate	Pollution (solid)
		slope (degrees)			Turbidity/ sedimentation
		phys. shading			Physical damage
		canopy corals		Fishing	Destructive fishing
		Visibility (m)/ turbidity			Fishing pressure
	Acclimatization	Exposed low tide			
		Ponding/pooling			

Table 6.2. Selected resilience indicators (Obura & Grimsditch 2009) for sites surveyed in Northeast Madagascar. Variable type is shown in the table, including percent cover (%),depth (m) and indicators on a 1-5 scale, where 1 is low and 5 is high for the individual indicator.

		Benthic community						Physical characeristics					Coral community characteristics				
	Variable	Hard Coral	Soft Coral	CCA	Macro algae	Turf Algae	Rubble	Depth	Exposure	Topographic Complexity	Estuarine influence	Cooling	Bleaching	Disease/mortality	Recruitment	Fragmentation	Mature corals
Location/Site	Type	%	%	%	%	%	%	m	1-5	1-5	1-5	1-5	1-5	1-5	1-5	1-5	1-5
Ambodivahibe	A01	30	10	0	30	10	5	10	2.0	2.5	3.3	3.1	2	2.5	2	2	5.0
	A01B/C	60	20	2	5	10	8	10	3.0	3.0	2.2	3.6	2	2.5	2	2	5.0
	A02/3	25	20	15	3	20	10	8	2.0	2.5	3.3	3.4	2	3.0	2	2	3.5
	A04	60	0	15	5	20	5	15	4.0	3.0	2.4	4.5	2	2.0	3	3	4.5
	A05	20	25	2	15	25	5	10	5.0	1.5	2.0	3.1	2	1.0	2	2	3.0
Loky	A06	60	20	5	1	13	0	7	2.0	4.0	2.1	3.8	2	1.0	3	2	4.5
	A07	40	5	0	2	30	5	8	1.0	2.5	4.6	3.7	2	1.5	2	2	5.0
	A08/9	25	30	2	5	30	5	10	3.0	1.5	3.3	3.3	3	1.0	2	2	4.0
	A10	30	20	0	2	40	5	10	4.0	2.0	2.4	3.1	2	1.0	3	2	4.5
	A11	85	2	3	0	5	0	1	1.0	3.5	2.2	2.1	4	1.0	2	3	5.0
	A12	80	1	5	0	10	2	5	3.0	3.5	3.6	2.4	3	1.0	3	2	5.0
Ankao	A20	70	20	0	0	5	3	6	2.0	2.0	2.8	2.3	2	1.5	2	2	5.0
	A21	40	10	5	2	20	5	5	2.0	3.0	2.0	2.7	2	2.0	3	2	4.5
	A22	20	50	0	5	20	2	10	3.0	2.5	2.8	3.1	2	2.0	1	2	4.5
	A23	45	35	2	2	10	5	5	2.0	3.0	3.0	2.4	3	1.0	2	2	4.5
	A24	55	20	0	0	20	5	5	3.0	3.0	4.6	2.4	3	2.5	2	2	5.0
Andravina	A17	15	10	0	3	60	5	6	2.0	2.5	4.5	2.8	3	1.0	1	1	4.5
	A18	30	15	0	5	30	5	6	4.0	3.5	3.7	2.0	3	1.5	2	2	3.5
Vohemar	A13	70	0	15	3	10	0	10	5.0	3.5	2.7	3.6	4	2.0	2	2	4.0
	A14	60	5	0	5	25	5	5	2.0	3.0	4.4	2.9	4	2.0	3	2	4.5
	A15	40	40	10	5	5	0	10	5.0	3.0	3.0	3.6	4	2.5	2	2	4.0
	A16	70	10	3	0	15	0	10	5.0	4.0	2.2	3.8	3	1.0	2	2	4.5

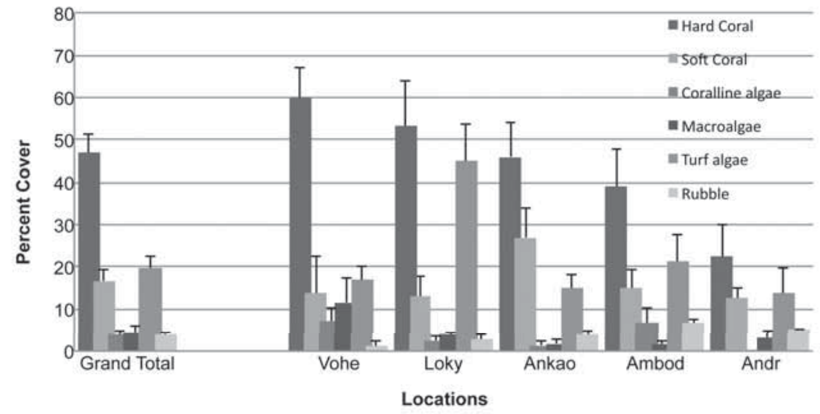

Figure 6.1. Benthic cover for Northeast Madagascar, and by sampling locations.

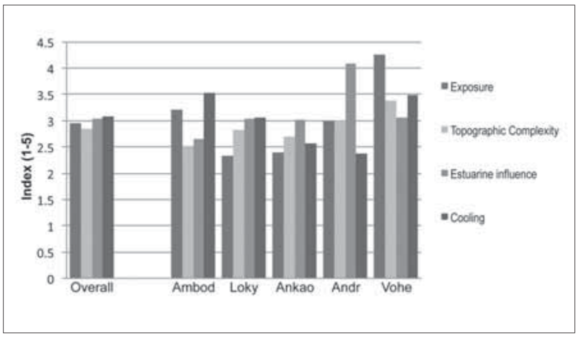

Figure 6.2. Physical indicators for reefs in Northeast Madagascar, on a scale of 1 (low) to 5 (high).

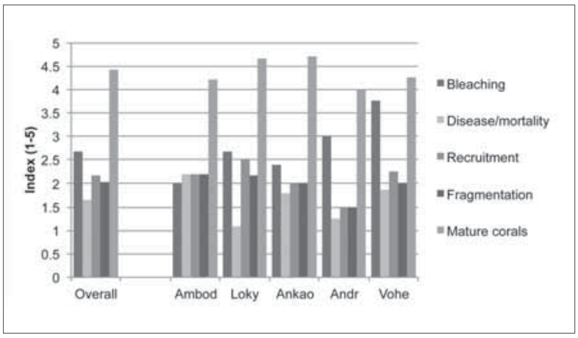

Figure 6. 3. Coral community characteristics for reefs in Northeast Madagascar, on a scale of 1 (low) to 5 (high).

relatively low; further results are presented below from the size class transects. Fragmentation of corals was relatively low, and mostly from natural causes such as wave energy. The reefs showed little to no evidence of anchor scars or boat strikes, and direct damage by people is limited as fishers operate from boats and there is no regular diving tourism. Mature corals dominated the survey sites, even where coral cover was relatively low, indicating no major mortality of corals in the recent past (1-2 decades) that would have eliminated large mature colonies and without sufficient time for them to grow back.

Coral Generic Abundance

The Northeast Madagascar RAP recorded fifty-eight coral genera on reefs (Fig. 6.4), ranging from the strongly dominant genera *Acropora* and *Porites*, to those present in only one or few instances – *Caulastrea, Micromussa, Sandalolitha* and *Scolymia*. In between these extremes, genera typical of East African reefs were found. Most interesting for regional biogeography, the monotypic genera that are endemic to the Western Indian Ocean, *Gyrosmilia interrupta* (36), *Horastrea indica* (45) and *Anomastrea irregularis* (52) were found at higher abundances than occur elsewhere in East Africa. The most significant sites for these genera were sites A8, 9 and 10 in Loky Bay and site A22 in Nosy Ankao for *Gyrosmilia*, and site A17 in Andravina for *Horastrea* and *Anomastrea*. The regional endemic *Craterastrea laevis* was not recorded during the surveys as it was confused with *Leptoseris* sp., though was

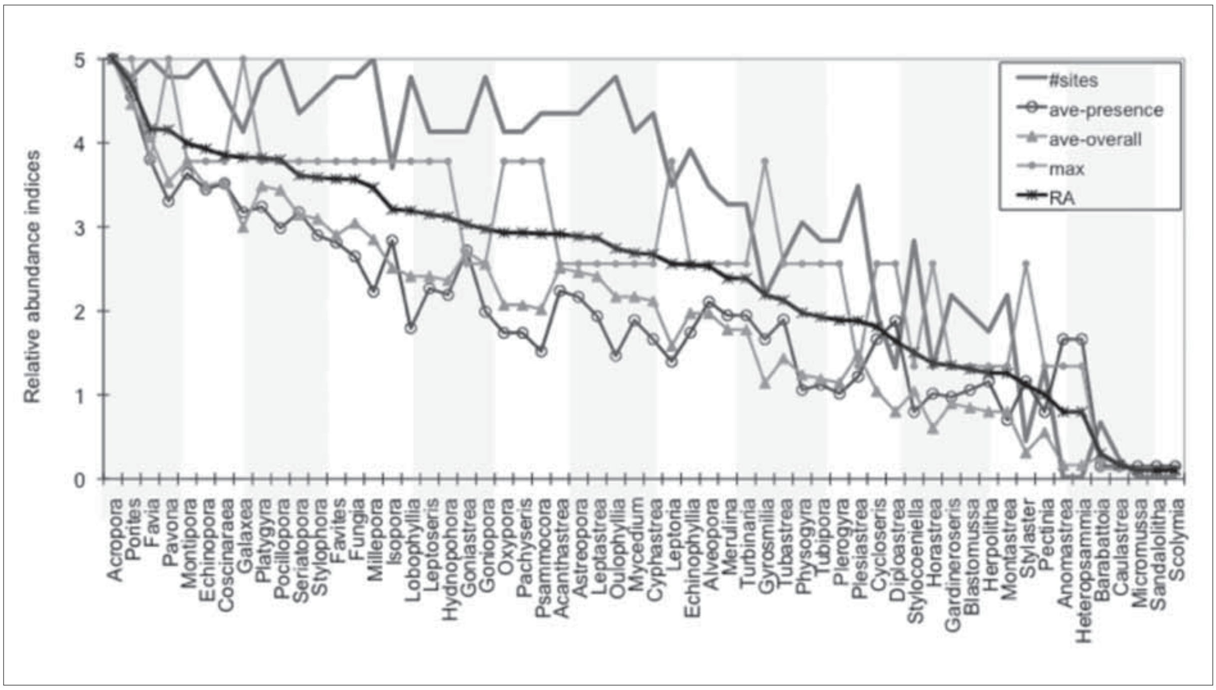

Figure 6.4. Ranked abundance of coral genera in Northeast Madagascar. Indices are scaled from 5 (highest) to lowest (0), and are the following: #sites - proportion of sites at which the genus was found; ave-presence - average of abundance index at sites at which the genus was present; ave-overall - average of abundance index for each genus, including absences; max - maximum abundance index across all sites; RA - average of all the preceding indices.

identified subsequently from photographs and was collected at Andravina.

Patterns of generic composition varied across surveyed locations. Examining only common genera in quantitative measures of colony size and total area (see next section), the competitively dominant genera *Acropora* and *Porites* (recorded in both massive and branching forms) were common everywhere, but locations differed greatly in the presence of the genera characterized by smaller colony size, like *Stylophora* and *Seriatopora. Galaxea* was common only at Ambodivahibe and Nosy Ankao, where *Galaxea* occurred in large stands, excluding other corals.

Coral Size Structure

Of these 58 genera, 23 representative and common genera were surveyed for coral population size structure (see IUCN Resilience assessment method manual). Here we present these size structure data two ways: (1) by geographic area for all genera pooled (Figs. 6.5 & 6.6), and (2) for the top 9 genera (with *Porites* being presented as branching and massive forms separately), pooled across the whole study area (Figs. 6.7 & 6.8). In both cases we present the size structure as (A) number of colonies counted in each size class (Figs. 6.5 & 6.7), and as (B) the total area of colonies in each size class (Figs. 6.6 & 6.7). In all cases, numbers are given per standard area of 100 m^2 to standardize for different levels of sampling at each dive site depending on time and logistics.

Size class data allow one to better understand both coral recruitment and coral maturity patterns. We did see evidence of recruitment, but regional recruitment levels appeared generally low. Recruitment size classes (coral diameter <= 10 cm) usually dominate size class distributions by colony number (Fig. 6.5, Obura in prep), but here we often found that the smallest size classes were a small fraction of colonies in most sites. Among geographic areas, the highest absolute recruitment levels were seen in Ambodivahibe and Vohemar. Among genera, we counted the highest number of the smallest size classes in the most common genera, i.e. *Acropora*, massive *Porites*, *Galaxea*, *Seriatopora*, and *Pocillopora* (Fig. 6.8). However, when normalized by relative abundance, *Pocillopora* shows the strongest recruitment signal, with *Seriatopora, Fungia,* and both massive and branching *Porites* close behind (Fig 6.7).

Noting the pattern among sites and genera in the largest size classes also allows us to discuss the potential disturbance dynamics in the region. Generally speaking, corals in Northeast Madagascar spanned their expected size class distribution, including the largest colonies expected for a given genus. The presence of all size classes, especially the largest, indicates a relatively low level of catastrophic disturbance over the past few decades. Among the locations, Ambodivahibe, Loky Bay, and Nosy Ankao all showed dominance by area of the largest size classes (note y-axis break in Fig. 6.6). Vohemar and Andravina on the other hand showed either lower dominance or absence of the larger size classes (respectively), suggesting a pattern of either ongoing disturbance or a previous severe disturbance to these coral communities. In the case of Andravina, this is most likely the heavy sediment loads tolerated by these reefs, and in the case of Vohemar, a combination of wave stress from extreme exposure on the reef crest, and anthropogenic stresses in the harbor. Among genera, the largest colonies were represented by staghorn *Acropora* thickets, large *Acropora* tables, large stands of *Galaxea*, and groups of plating *Montipora*. Unlike many other regions in the Indo-Pacific, very large massive *Porites* “bommies” were rare.

Coral Bleaching Data

The northeast monsoon season of 2010, from January to May, is the local summer season when bleaching risk is highest. In the months directly prior to our survey, the region of Northeast Madagascar showed a high temperature anomaly, leading to alerts through the NOAA “Hotspot” program, and a “High Risk Warning” from CORDIO/IUCN Western Indian Ocean Regional Bleaching Warning Network (CORDIO/IUCN March 29, 2010). The latter warnings, updated every 2 weeks, began with a “moderate” warning for Northeast Madagascar from January 15, until February 12, at which point it was upgraded to a “high risk” warning that ran until March 29. The warming event abated as the summer conditions cooled roughly 3-4 weeks early, and the strong SE monsoon/trade winds that signal the shift in seasons were already in force by the expedition’s start in the last days of March. This resulted in an early cooling and dissipation of the regional warm pool of water.

Over the heating period, sites across the region accumulated 4-7 Degree Heating Weeks (DHW), defined as the number of weeks over a 12-week window in which temperatures exceed long-term summer maxima by 1° C (Liu et al. 2005, Strong et al. 2002, Skirving et al. 2006). As a rule of thumb, corals are at risk for bleaching with as little as 1 DHW, and with moderate levels of bleaching at 4 DHW, and widespread bleaching with mortality by 8 DHW (Skirving et al. 2006). Our survey began immediately after the hotspot dissipated, maximizing our chances of finding maximal bleaching effects. As our study region reached a maximum of 7 DHW immediately before our survey, and previous work on east-coast Malagasy reefs in 2005 has shown that conditions of 6 DHW correlated with mean bleaching rates of 38% (+/- 3.0 SE) (McClanahan et al. 2007), we expected widespread bleaching, and the possibility of mortality.

We did observe bleaching throughout the range of the survey, but the overall extent of bleaching was low (Fig. 6.9). The mean bleaching extent across all transects was 5.1% (+/- 1.0% se) of colonies affected, with maxima in Andravina and Vohemar (9.7% +/- 4.0%, 9.5% +/- 2.1%, respectively, mean ± se). If we consider the effect by colony area, the overall mean estimate rises to 7.54% (+/- 2.3%se) of colony area per 100 m^2 primarily due to the common occurrence of large, partially bleached *Acropora* thickets (Fig. 6.10). These thickets were particularly common in Loky Bay, where there

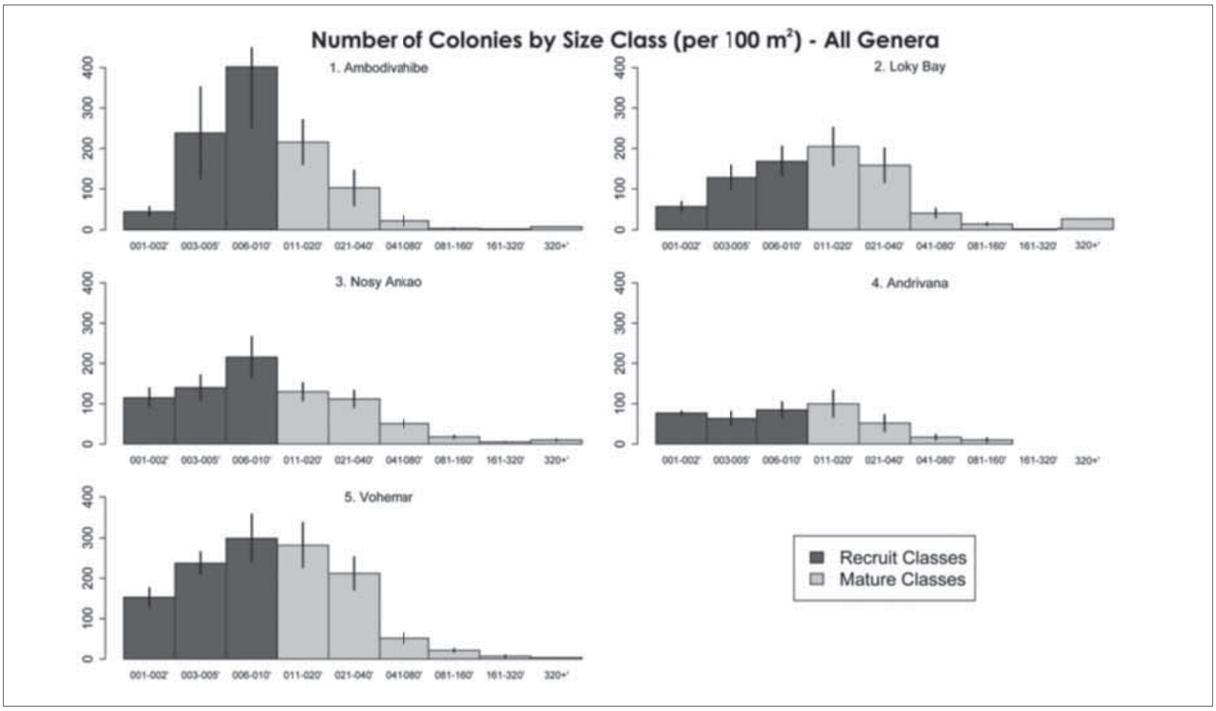

Figure 6.5. Coral size distribution by number of colonies counted per transect, grouped by area. In all graphs, size classes are shown in the x axis, the dark gray for recruit and juvenile sizes (0 - 10 cm diameter) and light gray for adult sizes (> 10 cm diameter). The x axis represents the size classes in cm - 001-002 is < 2.5 cm; 011-020 is 11-20 cm, etc.

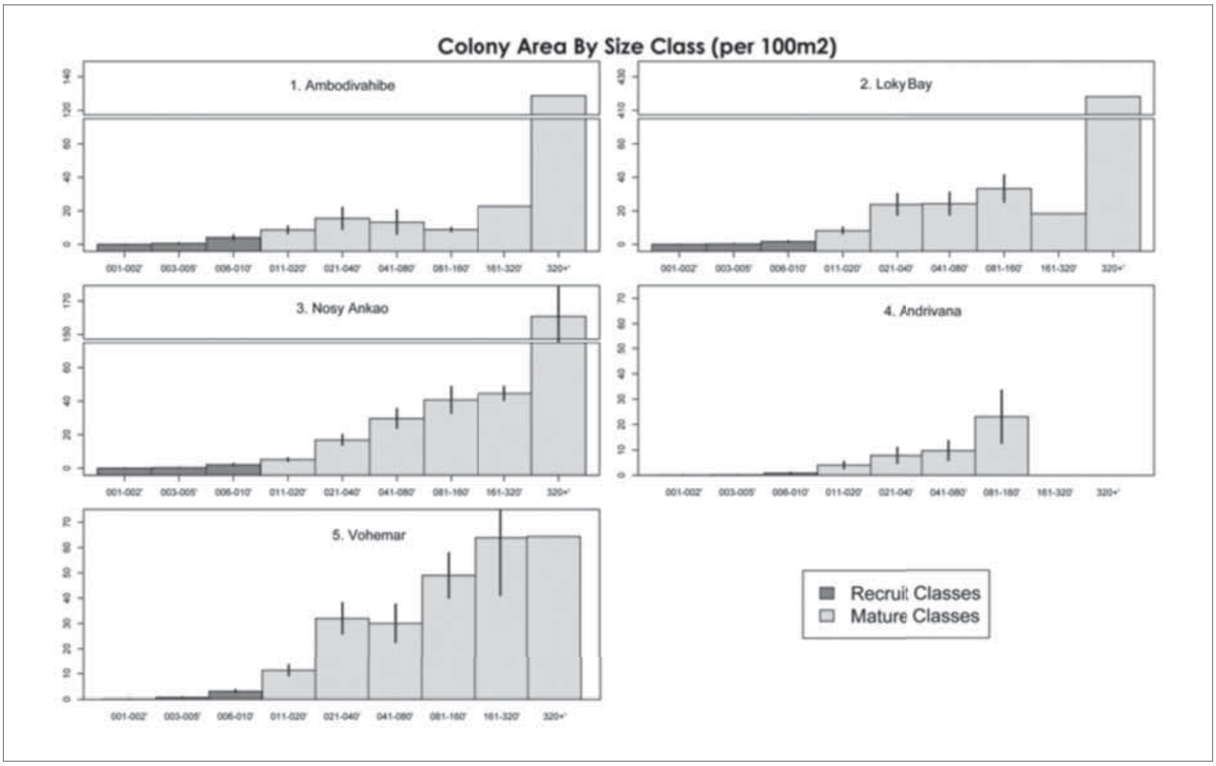

Figure 6.6. Coral size distribution by colony area surveyed per transect, grouped by area. Note break in y-axis for Ambodivahibe, Loky Bay, and Nosy Ankao, due to domination in area of vary large colonies.

is a clear distinction among per colony and per area estimates (Fig. 6.9, Fig. 6.10).

While bleaching was present throughout the area, we witnessed little to no bleaching-induced mortality, with overall means of affected colonies at <1% in a value statistically indistinguishable from zero (0.16% +/- 0.13%se). During our surveys in early-mid April, many of the colonies noted as "bleached" still retained portions of unaffected tissue, and were likely to recover without mortality. Upon returning to Ivovna in early June, 2-3 km north of Ambodivahibe, only 3 of 11 transects showed any bleaching at all, the overall bleaching extent was 0.6% of colonies affected (+/- 0.5%se), and no bleaching-induced mortality was apparent.

The low level of bleaching we witnessed during the RAP survey occurred across the whole size class distribution, which does not suggest that any particular life stage/size class was more or less susceptible to bleaching effects during this event (Fig. 6.11).

There were, however, major distinctions in bleaching extent among coral genera (Fig. 6.12). Many of these generic-level patterns followed expectations based on previous susceptibility measures, with "susceptible" genera like *Stylophora, Montipora,* and *Seriatopora* showing major effects, and more intermediate/resistant genera like *Pavona*, *Galaxea,* and *Hydnophora* showing more minor effects. However, certain patterns were more unexpected. The "massive" growth forms in genera like massive *Porites, Favia, Favites, Goniastrea,* and *Platygyra*, showed greater effects than the branching forms of *Porites*, *Acropora* and *Pocillopora,* even though these branching genera are generally considered to be more susceptible to bleaching and bleaching-induced mortality. It is nevertheless common in East African reefs to see relatively high levels of bleaching in massive Porites, though with low mortality, as found here.

These generic-level patterns can also help explain the distinctions in bleaching extent among the sampling locations. We recorded the greatest bleaching extent in Andravina and Vohemar, where 9.5-9.7% of colonies were affected, while the other three sites showed 1.6-5.0% of colonies affected (Figure 6.9). Examining the relative abundance of coral genera across locations (Figure 6.5), we can see that both Andravina and Vohemar are dominated by genera that showed the greatest effects of bleaching. In Andravina, over 20% of the corals sampled were *Stylophora*, while in Vohemar, over 20% were massive *Porites*. These two genera showed the greatest effects of bleaching in our survey, and their abundance in these populations contributes to the bleaching patterns we saw among locations.

CONSERVATION RECOMMENDATIONS

The reefs in Northeast Madagascar generally show very good coral cover for East Africa (average 48%) and colonies that span the expected size distributions, including large, old colonies. The common occurrence of these large colonies suggests that this region has not suffered a catastrophic mortality in the recent past (1-2 decades). This gives the area a high priority for conservation, as reef health, at least in terms of the benthic community) has not yet shifted far from baseline conditions before human disturbances became common.

Of the five locations, three are heavily sediment-affected bay systems: Ambodivahibe, Loky Bay and Andravina. Of these, the first two are large and deep enough to have areas within them that are less sediment-affected and allow for complex reef structure (i.e. A02/A04 in Ambodivahibe, A06/A11A in Loky Bay) while the small size of Andravina resulted in a very heavily sediment-affected system with low coral abundance and small corals. The southern end of our survey, Vohemar, has a very exposed fore-reef and heavily sediment- and human-influenced back-reef. Finally Nosy Ankao, on a seaward bank bathed by cleaner water and less influenced by sedimentation, is also the site of an intensive algal farming operation.

The second hottest thermal stress event in the region, after the El Niño of 1997-98 occurred during the time of the RAP surveys. Our findings of low bleaching levels, < 5%, suggest that the corals and reefs of Northeast Madagascar are surprisingly resistant to temperature stress. Total affected colonies (pale & bleached) were also low, 9.9 % (1.6 SE), especially as compared to estimates of 44.2% (2.9 SE)% affected corals in the southeast, at Andavadoaka and 62.9% (7.4 SE) at Belo Sur Mer during the same period (Sophie Benbow, Blue Ventures). We also found evidence of low impact of the 1997-98 and 2005 events by the abundance of large colonies several decades old. This pattern appears at sites across the region, including Ambodivahibe, Loky Bay, and Nosy Ankao.

While the mechanism for this apparent bleaching resistance requires further research, both the upwelling of cool water caused by flow of the South Equatorial Current onto the coastline and its deflection north over the tip of Madagascar, and of turbidity caused by terrestrial water, are likely to be significant factors. This finding supports the notion that the corals of Northeast Madagascar are more resistant to bleaching effects than other reefs in the region. Both the lack of recent bleaching in the face of warming and evidence of low historical levels of major disturbance suggest that the reefs of Northeast Madagascar should be high priority for conservation action.

Although the size structure data shows that the reefs have relatively high cover and a large percentage of mature corals, coral recruitment is generally low. This may be a matter of concern for the long-term overall resilience of these reefs, and should be prime target of management intervention. The low levels of recruitment may be due to a number of factors, including: (1) few sources of coral larvae: most reefs in this region have a narrow and shallow reef profile, limiting the total area of reef community and potential source colonies for reproduction; (2) low retention of dispersing larvae: strong currents that rip northward around the tip of Madagascar may deliver dispersing larvae to the East African mainland instead

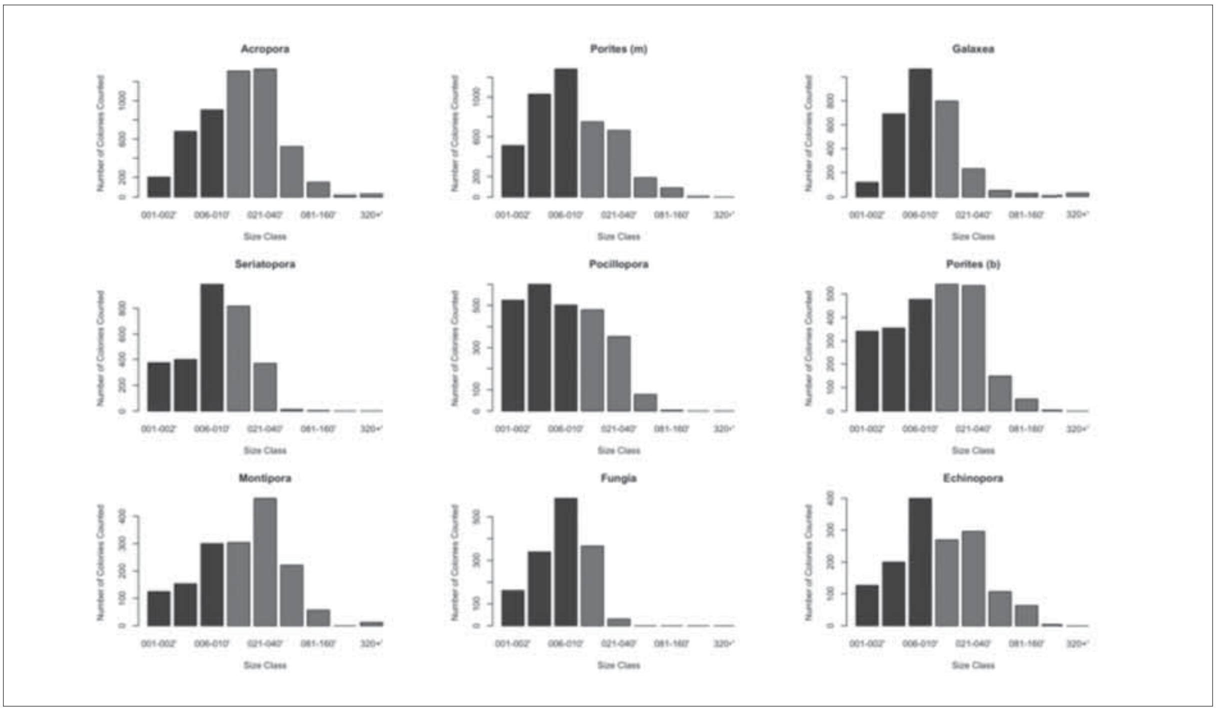

Figure 6.7. Coral size distribution by number of colonies counted for each of the most abundant 9 genera (by number of colonies).

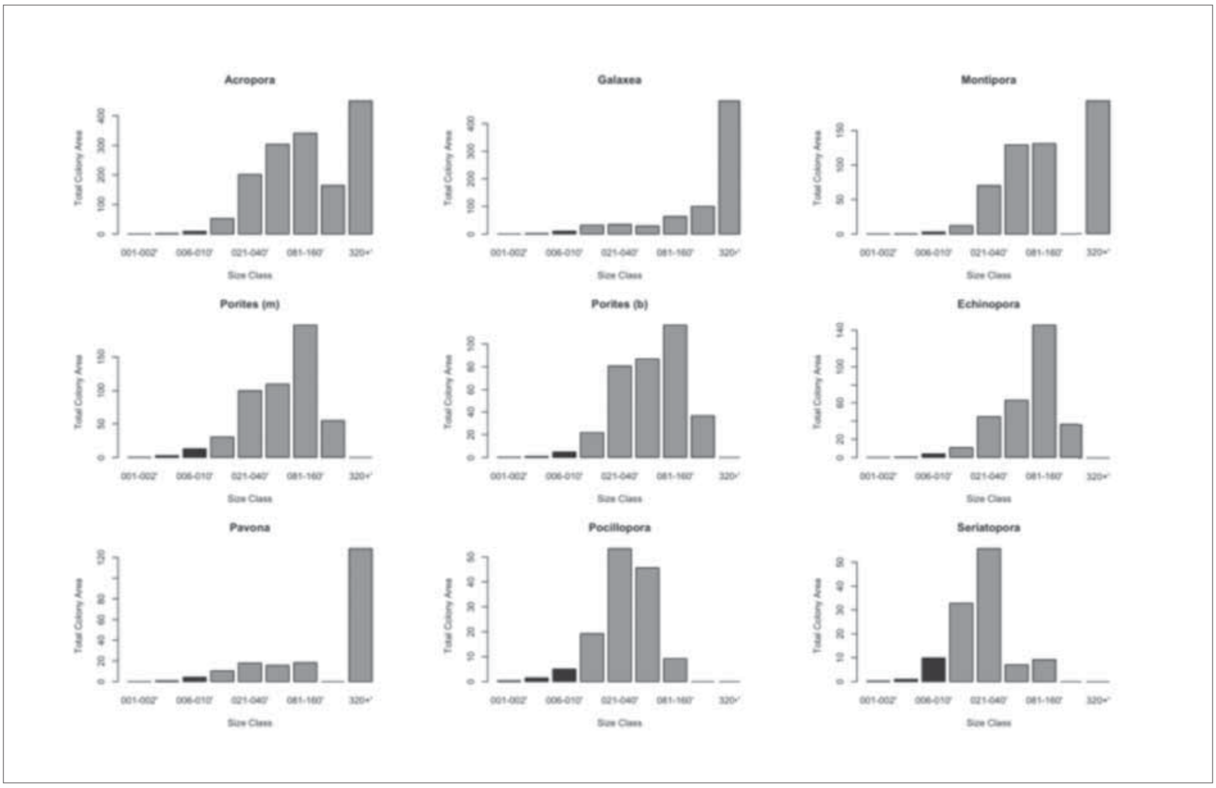

Figure 6.8. Coral size distribution by colony area surveyed for most abundant 9 genera (by area).

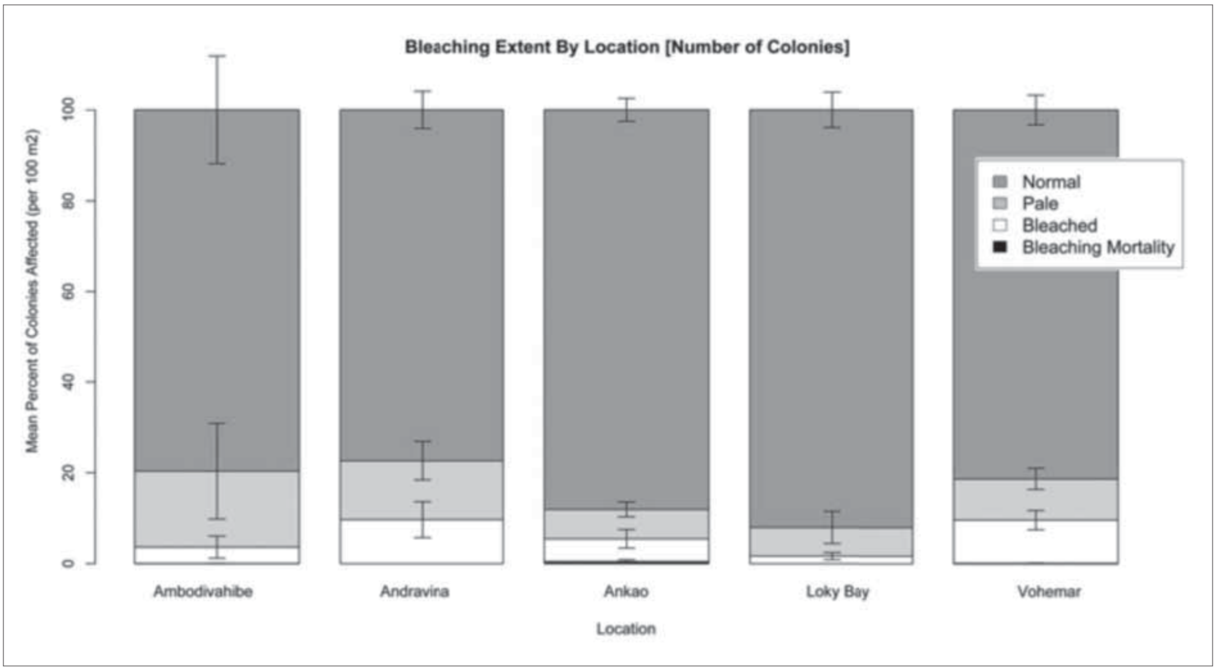

Figure 6.9. The extent of coral bleaching by location, expressed as the percentage of colonies affected per 100 m². Error bars are SE of each condition class (Normal, Pale, etc.).

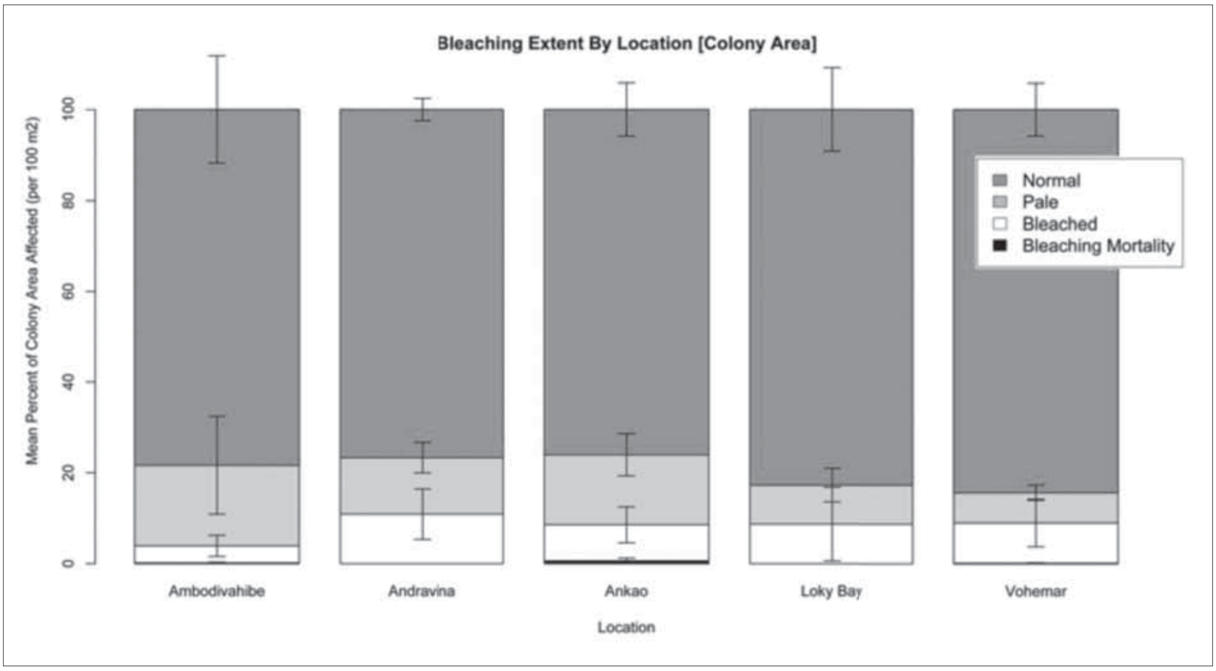

Figure 6.10. The extent of coral bleaching by location, expressed as colony area per 100 m² affected. Error bars are SE of each condition class (Normal, Pale, etc.).

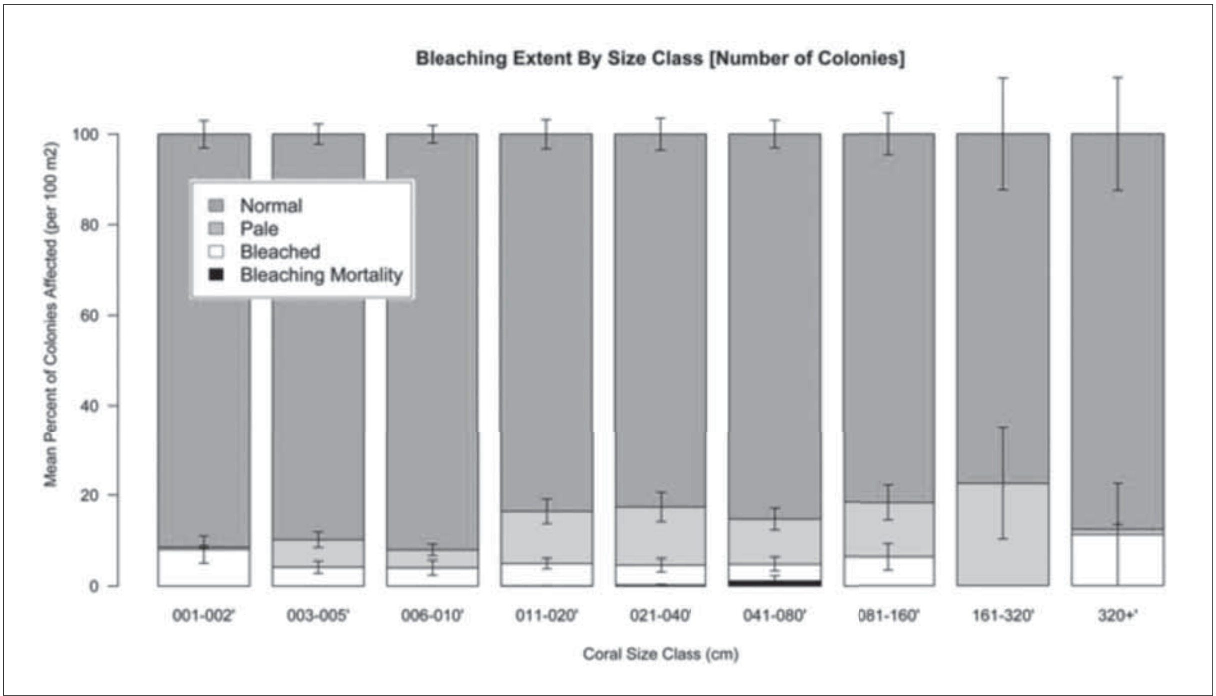

Figure 6.11. The extent of coral bleaching by size class, expressed as number of colonies per 100 m^2 affected. Error bars are SE of each condition class (Normal, Pale, etc.).

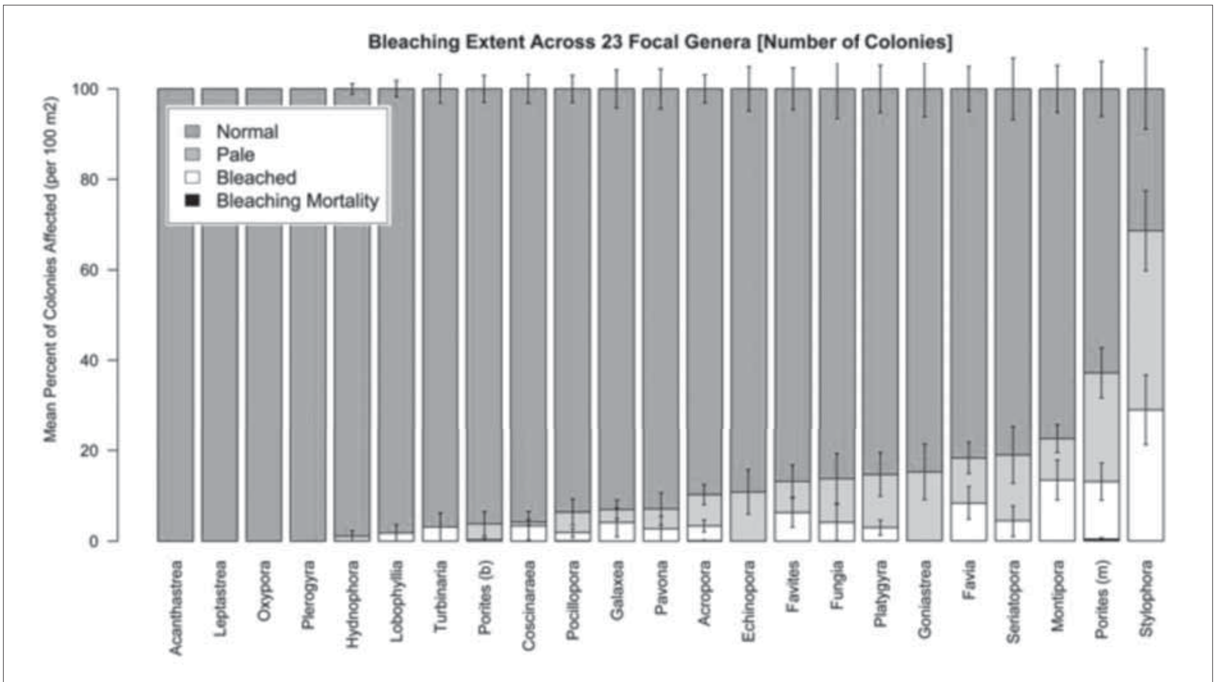

Figure 6.12. The extent of coral bleaching by genus across the 23 focal genera sampled in our methodology, expressed as number of colonies per 100 m^2 affected. Error bars are SE of each condition class (Normal, Pale, etc.), numbers above the bars indicate the number of transects in which the genus was found.

of retaining them locally; and (3) little good settlement substrate: most reefs showed a relatively low abundance of bare, hard substrate free of sediment, turf, soft coral or sponge.

While the first two of these factors are not likely to change due to conservation actions, these reefs can be managed to promote coral recruitment by ensuring good settlement substrate. This can be promoted by a) watershed management, to reduce sedimentation and smothering of surfaces otherwise suitable for coral settlement, and b) limiting fishing pressure, to promote herbivory and reduction of competition between turf/macroalgae and recruiting corals. Other components of the RAP also found sediment influence and fishing to be overwhelming anthropogenic factors affecting the region's reefs, reinforcing the need to manage both factors to sustain the reefs.

In terms of practical management actions therefore, we recommend the following:

1. limiting fishing pressure in priority sites to maintain a strong community of grazing fish;
2. managing upstream watersheds to minimize sediment delivery to the reefs;
3. monitoring fishing, watershed use and coral reef health to evaluate the effectiveness of these management actions; and
4. selecting additional management actions specific to individual sites and/or locations, such as
    a. partnership with the algae-farming company at Nosy Ankao,
    b. establishing community-based management areas in Ambodivahibe, Loky Bay and Andravina, and
    c. establishing solid and liquid waste and municipally-managed protected areas in Vohemar.

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