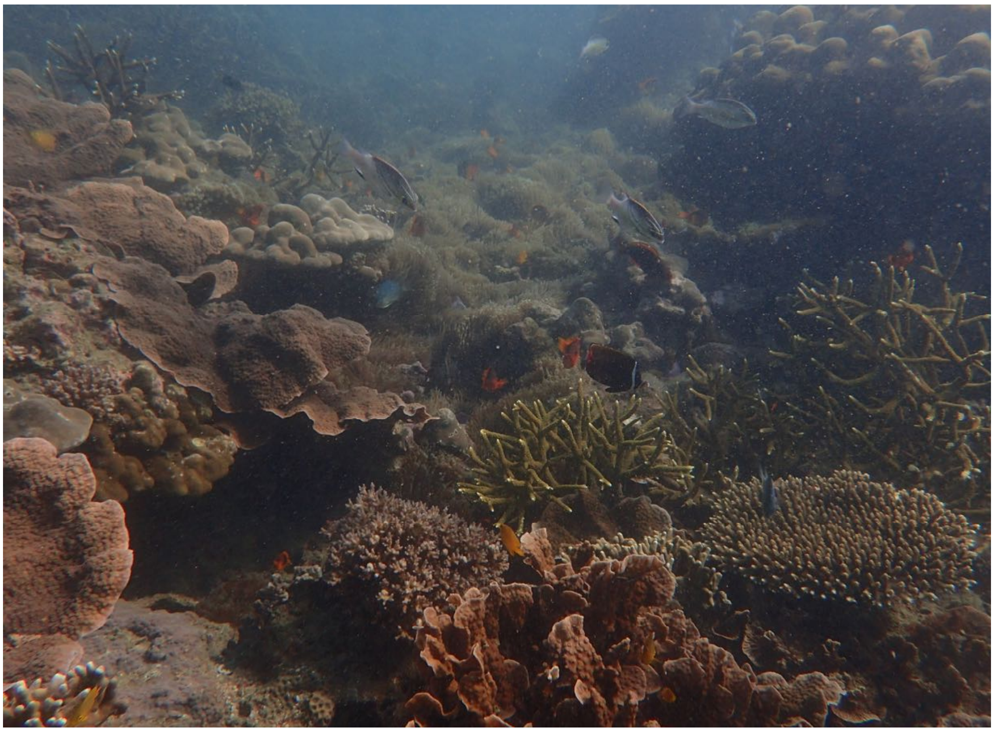
Tanintharyi Conservation Programme

CORAL DIVERSITY AND REEF RESILIENCE IN THE NORTHERN MYEIK ARCHIPELAGO, MYANMAR



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The program

The Tanintharyi Conservation Programme is an initiative of Fauna and Flora International (FFI) Myanmar Programme, implemented in collaboration with the Myanmar Forest Department and a number of local, national and international collaborators and stakeholders. FFI Myanmar operates the programme under a MoU with the Forest Department specifically for marine and terrestrial conservation activities in Tanintharyi Region.

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Cover image

Front cover: Coral reef La Ngann Island Group, Myeik Archipelago, Myanmar (Credit: Robert Howard/FFI).

Back cover: corals and coral reefs throughout Myeik Archipelago, Myanmar (Credit: Robert Howard/FFI)

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Abstract

Intensive surveys of coral community structure and reef resilience were conducted in the Myeik Archipelago, Myanmar in March 2014. Hard corals were dominant at 33% cover overall (maximum 80%), highest on inner reefs, then rock walls then outer reefs. A total of 287 hard coral species (68 genera, 17 families) were observed, giving a prediction of ≈ 309 species. Coral species diversity was highest on inner reefs due to dominance and high diversity of the genus *Acropora*, but overall, coral communities were dominated by *Porites*, particularly on outer fringing reefs. Coral community composition was similar to the Coral Triangle/Indonesian region, though some species characteristic of the west and northern Indian Ocean were present (including *Acropora roseni, A. rudis*, *Plesiastrea devantieri* and *Anomastrea irregularis)* emphasizing the character of the Andaman Sea as a transition zone between the west and eastern parts of the Indo-Pacific. Two coral species were listed as Endangered (*Acropora roseni* and *A. rudis*), and 36 as Vulnerable.

Overall reef resilience was scored at average to below average levels. Some sites, particularly those on outer fringing reefs, showed unmistakable evidence of past mortality consistent with the presence of high sea surface temperatures in 2010, likely due to a combination of El Nino and negative Indian Ocean Dipole (IOD) phases. Inner reefs may have been sheltered from thermal stress by high turbidity, and/or the dominance of fast growing *Acropora* resulting in faster recovery from past impacts. There was a general absence of fish, high presence of sea urchins, and high frequency of observed coral entanglement by fishing gears, suggesting high fishing pressure.

These results will be used to inform spatial planning for marine protection zones within the archipelago. We recommend an archipelago-wide participatory approach to management, to facilitate an understanding of the multiple goals for management at different reef sites.

Introduction

The Myeik Archipelago is situated in the north-eastern Andaman Sea, in the southernmost part of Myanmar. It contains approximately 800 islands, essentially the tops of several coastal ranges of hills, running parallel to the coast over some 3 degrees of latitude. The archipelago is coastal in nature, strongly influenced by river discharge from the coastline, and facing the Andaman Sea to the west. Administratively, it is part of the Tanintharyi region of Myanmar that stretches from the Gulf of Mottama in the north to the Pakchan River in the south. The archipelago is about 300 km long and 100 km wide, covering an area exceeding 34,000 km^2 (Figure 1).

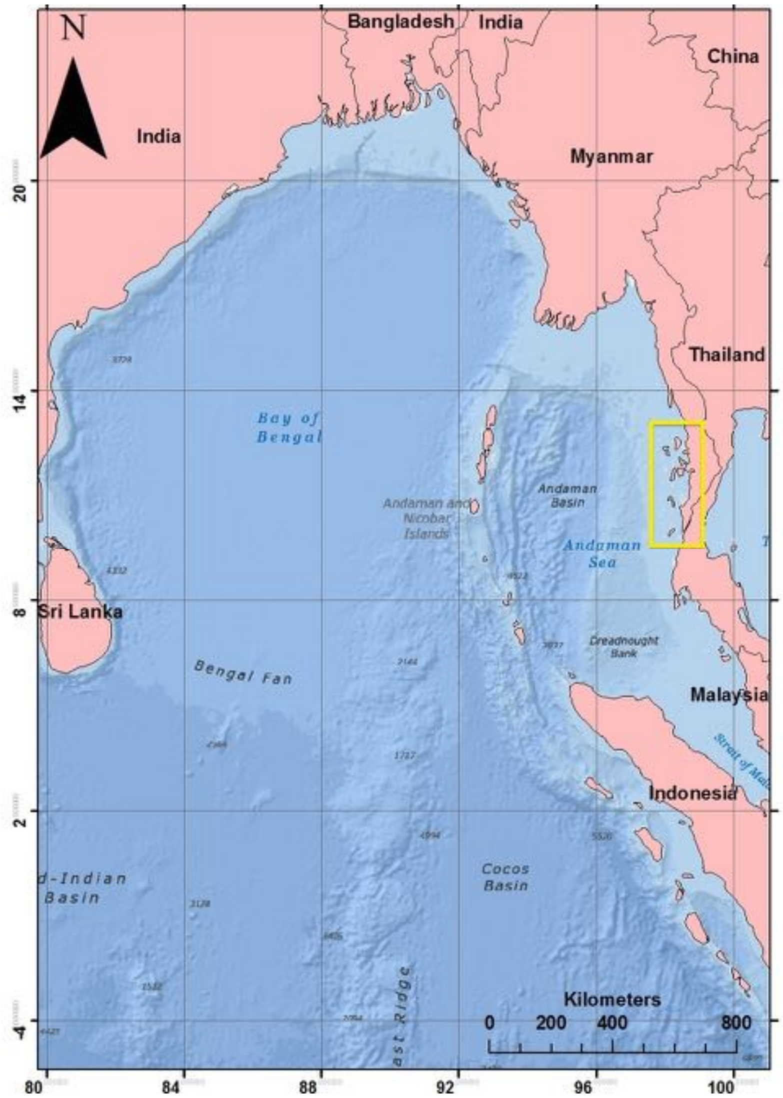

Figure 1. Map of the Andaman Sea and Bay of Bengal, showing the location of the Myeik Archipelago in southern Myanmar (yellow rectangle).

Prior reports from Fauna & Flora International (FFI) and the Wildlife Conservation Society present extensive background on the opportunity for international cooperation and support in marine management offered by the opening up of Myanmar in the last 5-10 years, early surveys conducted in this region, and justification for the marine programme established by FFI and BANCA (the Biodiversity and Nature Conservation Association) (Holmes et al. 2013, Cox et al. 2013, Tun 2013). Management areas already exist within the Myeik archipelago – the Lampi Marine National Park (274 km^2, established 1996), encompassing Lampi Island, several smaller nearby islands and the surrounding waters, and two large Shark Protected Areas of 1706 km^2 and 11,734 km^2, but with no clear management measures. A national exercise to identify Key Biodiversity Areas (KBA) for Myanmar in a broader KBA ‘corridor’ concept, named the Myeik Archipelago the Tanintharyi Marine Corridor.

Socio-economic dependence on the marine resources of the Myeik archipelago is high. There is a long history of in-migration from other regions of Myanmar which has created a growing fishing industry led by people without a history and culture of fishing. This is juxtaposed against a long culture of marine resource use among the local Moken or Salone and other 'sea gypsy' peoples, who have lived off the sea for centuries, and now rapidly growing commercial fisheries of both Myanmar and Thai origins. The range of fishing activities in the islands is extensive (Saw et al. 2013), and evidence of overfishing and destructive fishing is clear underwater (Tun 2013, Cox et al. 2013), especially in the inner islands of the archipelago where subsistence fishing is common. In the outer parts of the archipelago, trawling is the dominant fishing activity, on the extensive shallow platforms (40-70 m deep) between the islands.

Other drivers of coral reef condition include sedimentation and river discharge from the land – the Great Tenasserim (Tanintharyi River) river system, one of Myanmar's major rivers drains into the Andaman Sea at Myeik Township, has a river delta system that stretches over 32km of coastline (Cox et al. 2013). On a larger scale, the Irrawaddy river delta empties into the sea north of the archipelago, and its influence spreads across the western part of the Andaman Sea. Seawater warming and acidification are mounting threats, with temperature increases already impacting most of the world's reefs. Reports of coral bleaching from Myanmar are few, though evidence of past bleaching is clear (Cox et al. 2013, Tun 2013, and see results here, p. 16). The precise relationships between El Niño Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD) cycles and temperature variation in this region are unclear (See Appendix A), nevertheless, oscillations of ENSO and IOD and background warming result in thermal stress in most places at some point, and this also poses a significant threat to the Myeik coral reefs.

The two prior expeditions focused on the Thayawthadangyi Kyun and Daung Kyun islands, one from a liveaboard dive boat, the other during regular operations of the FFI staff and from islands/small-boat based. Nevertheless, the former surveyed some dive sites enroute between Kawthaung (in the south) and the main island group (in the north). To complement these two expeditions, a third liveaboard trip was organized in March 2014 which also surveyed some sites spread through the southern half of the archipelago, but focused on the outer northern island reefs, which had not previously been surveyed.

This expedition had a number of components to it, of which two elements are reported here (surveys of coral species diversity and reef resilience). Others included extending the ecological surveys using Reef Check methods by the FFI marine survey team, surveys for coral diseases, and building up a fish species list for the archipelago – these are to be reported separately.

Justification for the two foci of this report are presented below.

Coral diversity

Scleractinian corals are the architects of coral reefs, supporting the full range of biodiversity and ecosystem services that reefs sustain. The diversity of corals at a location is indicative of the diversity and robustness of other reef fauna, and corals have been the focus of biodiversity conservation and research for decades, such as in the delineation of the Coral Triangle (e.g. Roberts et al. 2002, Hoeksma 2007). The coral reefs of Myanmar have been very little studied over 50 years, and are among the gap regions in global databases of coral diversity (C. Veron, pers. comm.). The objective in this part of the survey was to develop a list of the coral species of the Myeik archipelago as a resource for conservation planning (e.g. in next steps in establishing KBAs, Holmes et al 2013), as well as to identify the biogeographic relationships and patterns of this region as a transition zone between the Indian Ocean (Spalding et al. 2007, Obura 2012) and the Coral Triangle (Hoeksma 2007, Rudi 2012).

Reef resilience

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.

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, and a number of studies increasingly focus on applications of resilience surveys to reef management (Obura and Grimsditch 2009, Maynard et al. 2010, 2012). Of immediate significance to government in Myanmar at local and national levels is the very high dependence on marine resources at multiple levels – small scale and subsistence fishing, large scale industrial fishing, and growing opportunities for tourism and economic diversification. An understanding of the different factors that affect the health of individual sites can contribute to the long term sustainability and growth in the region around Myeik archipelago.

To assist management authorities in focusing management efforts on priority areas, a method developed by the IUCN Climate Change and Coral Reefs working group (http://cms.iucn.org/cccr, Obura and Grimsditch 2009), was applied, to quantify basic resistance and resilience indicators for reefs in the Myeik archipelago.

Study sites

Thirty five sites were surveyed for corals and resilience indicators, spread across 11 days from 11 – 22 March 2014 (Table 1, fig. 2, Appendix A). Complementing earlier work in 2013 in two separate survey efforts (Tun 2013, Cox et al. 2013), this expedition targeted the more remote and harder to reach outer islands in the north of the archipelago.

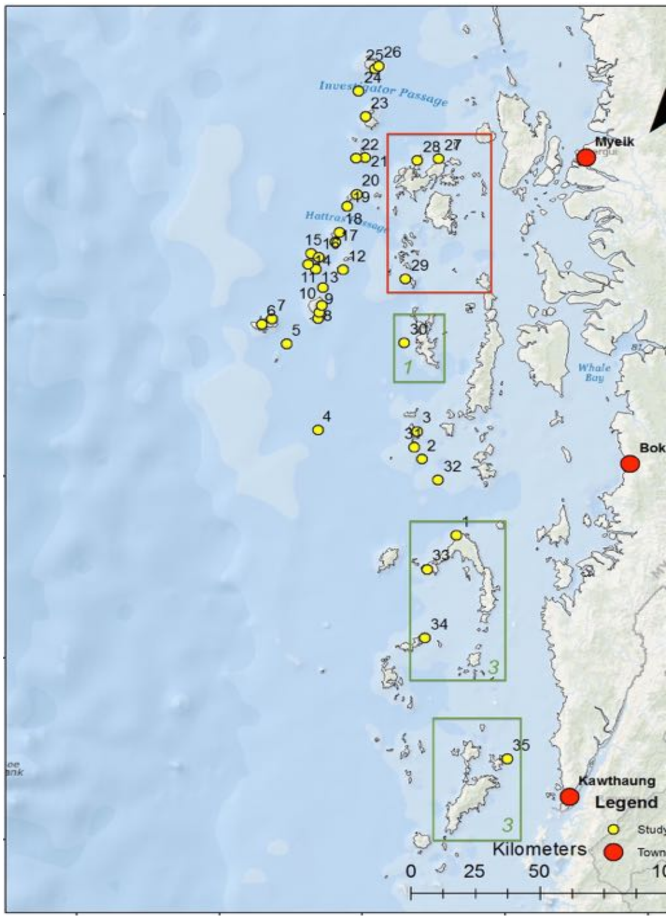

Figure 2. Survey sites in the Myeik archipelago sampled in this survey, and showing the extent of two prior expeditions January-June 2013 (Tun 2013, Cox et al. 2013). Both of them sampled mainly in the red box in the Thayawthadangyi Kyun and Daung Kyun islands, while Tun 2013 also conducted limited sampling in

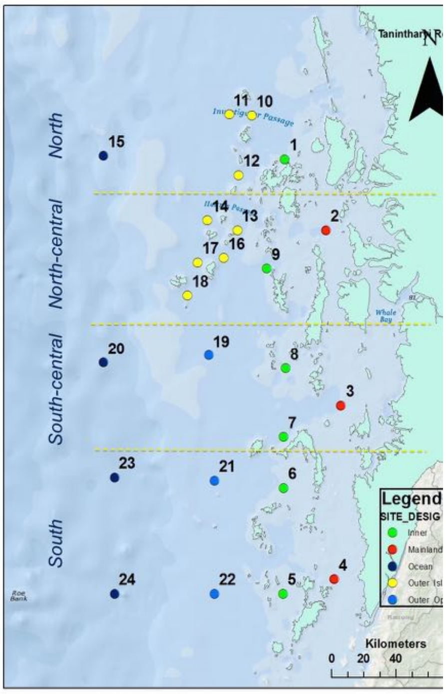

Figure 3. Sampling points for sea surface temperature and chlorophyll a from MODIS satellite data. N-S reef zones indicate by yellow lines; colour coded symbols show E-W reef zones: red – mainland, green – inner islands/reefs, yellow – outer islands/reefs,

the green boxes (number of sites shown in green italic text).

blue – open water comparable to outer islands, black – open ocean. Numbers do not correspond to study sites (fig. 2).

Descriptive categories were recorded for each site, to determine if characteristics of the reefs were influenced by the nature of the islands, in the following categories:

Reef type – three basic reef types were sampled:

1. Fringing reefs on outer islands (i.e. the string of islands in the NW of the archipelago, from sites 5 to 26 in fig. 2), in which the boulder slopes of the islands down to a base of 10-15 m were covered with corals, generally on sheltered sides of the islands. In addition, in bays, the sandy/shallow substrates could be covered with coral communities.
2. Rock reefs, typically vertical or steeply sloping surfaces of rock/island pinnacles, with encrusting corals, with the base of the reefs extending below 20-30 m into deeper water. Typically, these reefs were highly exposed to currents and waves, and often dominated by filter feeders and other invertebrates, particularly with increasing depth. These were interspersed among the inner and outer islands, with some isolated ones (e.g. site 4, fig. 2).
3. Inner fringing reefs, on islands close to the mainland and sheltered from high wave energy by the outer islands and bank systems – with high turbidity and strong currents through narrower channels. These are strongly influenced by terrestrial influences, including settlement in villages, small scale fishing, and river discharge.

A number of factors may affect reef structure and freshwater/groundwater features that influence coral reef health. These include the geological origin of the islands, and island size and vegetation. All of these may influence freshwater runoff and the degree to which it carries nutrients/humus/microbial community to adjacent reefs. These were recorded in the following categories:

- Island size – categorized descriptively into large, medium and small.
- Vegetation – the presence of vegetation on islands was strongly affected by island size, with the smallest islands and rocks typically having no or very minor vegetation cover. The type of vegetation – primary forest, degraded forest, or agricultural, was not recorded.

Table 1. Study sites visited during the expedition. Site numbers correspond to figure 1. See Appendix A for site descriptions.

Site #	Site name	Lat	Long	Depth	Reef type	Island size	Veg.
1	Katat Aw	10.9840	98.1525	6	fringe	Large	yes
2	Kyet mi thar su	11.2765	98.0331	21	rock	small	yes
3	Saw Pu I.	11.3833	98.0167	16	rock	small	yes
4	Black Rock	11.3891	97.6685	31	rock	tiny	no
5	Sular Nge	11.7193	97.5594	26	rock	small	yes
6	West Sular	11.7927	97.4726	18	fringe	large	yes
7	West Sular	11.8064	97.6537	21	fringe	large	yes
8	Kunn Thee Is	11.8174	97.6693	20	fringe	large	yes
9	East Sular	11.8386	97.6731	18	fringe	large	yes
10	East Sular	11.8658	97.6819	18	fringe	large	yes
11	West Islet	11.9347	97.6852	33	rock	small	yes
12	Dana Theik Di island	12.0034	97.7558	22	fringe	Large	yes
13	Prinsep Island (Sular Khamouk)	12.0057	97.6604	33	rock	small	no
14	Double island	12.0243	97.6341	33	rock	tiny	no
15	Tower Rock	12.0652	97.6440	31	rock	Large	yes
16	NW Bay, Sular Khamouk i. (Prinsep Island)	12.0502	97.6720	16	fringe	Large	yes
17	Bailey Island	12.1100	97.7286	12	fringe	medium	yes
18	Bailey Island, North shore	12.1463	97.7435	16	fringe	large	yes
19	West Spur	12.2463	97.7703	21	fringe	small	yes
20	Metcalfe I, (beach)	12.2929	97.8032	18	fringe	medium	yes
21	Blundell I, W (beach)	12.4342	97.8343	14	fringe	medium	yes

22	Chevalier Rock	12.4304	97.8019	24	rock	small	yes
23	Taninthary I. (W bay)	12.5910	97.8351	18	fringe	Large	yes
24	North Pinnacle	12.6892	97.8106	24	rock	tiny	no
25	Kabuzya Island, SW	12.7744	97.8687	14	fringe	large	yes
26	Kabuzya Island, E	12.7849	97.8809	25	fringe	large	yes
27	Sharr Aw, Thayawthadangyi Island	12.4292	98.0909	11	inner	Large	yes
28	Sack Island	12.4232	98.0169	10	inner	Large	yes
29	Mee Sein I.	11.9679	97.9747	18	inner	medium	yes
30	Hlwa Sar Gyi island	11.7226	97.9714	12	inner	medium	yes
31	Khin Pyi Son (I.)	11.3219	98.0060	21	inner	medium	yes
32	A Pha Island	11.1944	98.0893	24	inner	medium	yes
33	Wa Ale Kyunn	10.8534	98.0503	14	inner	medium	yes
34	Bo Ywe island	10.5905	98.0436	14	rock	medium	yes
35	Zardet Nge Kyunn	10.1282	98.3308	10	inner	medium	yes

Methods

Environmental parameters

Spot measurements of environmental parameters were not taken in the field, as point measurements of variables such as temperature or visibility give no indication of long term conditions and variability, and there are no historical data against which to compare spot measurements. Following observations in the field of the likely importance of temperature variability, exposure to upwelling/nutrients and sediment influence, sea surface temperature and chlorophyll (for nutrients and river influence) data were extracted from remote sensing data products. Because remotely sensed data are affected by proximity to land, rather than attempting to extract data for individual survey sites, a selection of 24 points was made (fig. 3) to sample both north-south and east-west (inshore-offshore) gradients in the archipelago, and a higher density of points around the outer northern islands to pick up any east/west exposures that may affect the survey sites.

Both sea surface temperature (SST) and chlorophyll (mg m^{-3}) were obtained from MODIS night time images at a spatial resolution of 4 km. Monthly mean raster images were extracted from July 2002 to June 2014. The grids were generated internally using SAGA GIS while the points were extracted using ARCGIS and imported to SAGA for further analysis. The mean, maximum and minimum of monthly data were obtained for each year (excluding minimum for chlorophyll, and data was only available up to 2010).

Coral community structure

Coral genera and species were identified in the field, and a full species list was developed based on field IDs using digital photography as a primary reference and references that include underwater photographs (see Obura 2012, Sheppard and Obura 2004). Note that for the purposes of this report, which is to assist management and planning, the familiar old genus names for corals are used, though some of them are superseded and replaced by new names. As the corrected names from systematic research in the last 5-10 years are largely only known in the coral species research community, and not yet in use in the general monitoring and management literature, they are not used here.

To derive an index of relative abundance at genus level, a 5-point scale was used to estimate relative abundance for each genus at the end of a dive, with 1- rare; 2- uncommon; 3- common; 4- abundant and 5- dominant. Using these scores three variables can be calculated for each genus: number of sites recorded, average abundance at each site (ignoring absences) and maximum abundance across all sites. Averaging these together provides an index of relative abundance of genera, ranging from 1 (rarest genus) to 5 (dominant and most abundant genus). Note that for four sites at the beginning of the trip (numbers 2-5), genus abundance was not sampled independently as initial effort focused on identifying species and reliability of resilience scores – thus these four were scored together, resulting in a higher number of genera that cannot be compared directly with the results from other sites.

While a full species list for each site is not possible to obtain from the data, indicative richness across sites with adequate time of sampling is presented, showing a total species richness recorded per site. Using species occurrence records from successive dives an accumulation curve for the survey trip is established that asymptotes towards a total species richness for the study area (see Obura 2012 for details). Michaelis-Menten enzyme kinetic equations provide a stable estimate of total species richness at the asymptote (Smax, Keating 1998), using the multivariate analysis software PRIMER v 6.0 (Clarke and Gorley 2006).

Reef resilience

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 (Obura and Grimsditch 2009). The purpose of the method is to provide an overview of multiple factors affecting reef health at a site, giving quick recommendations for prioritizing management actions across sites and to cope with different threats/factors at different sites. The full set of indicators estimated are shown in Table 2. Indicators were estimated either in the natural quantity (e.g. % cover, for the dominant cover types such as those analyzed in fig. 11), or on a semi-quantitative scale from 1 to 5. Indicators estimated on quantitative scales were transformed to the 5-point scale during analysis, and all indicators were transformed so that a score of 1 indicates poor conditions for corals, and 5 indicates good conditions for corals (see also Cox et al. 2013 for a similar approach).

Table 2: Resilience Indicators recorded in this survey, and their grouping into resilience factors

Factor	Variable
1-Coral population	Hard Coral
	Dominant size class
	Largest corals
2-Algal community	Fleshy Algae-cov
	Fleshy Algae-canopy
	Turf Algae
3-Interactions	Soft Coral
	Inverts-other
	Branching residents
	Competitors
	Bioeroders (external)
	Bioeroders (internal)
	Corallivores (negative)
4-Substrate condition	Rubble
	Consolidation
	Top. Compl. - micro
	Top. Compl. - mid
	Top. Compl. - macro
5-Cool	Currents
	Wave exposure
	Deep water (30-50m)
	Depth of reef base
	Ponding/pooling
6-Screen	Depth
	Visibility (m)
	Compass direction/ aspect
	Slope (degrees)
	Physical shading
	Canopy corals
7-Impacts on corals	Fragmentation
	Bleaching
	Mortality-recent
	Coral disease
	Mortality-old
8-Sediment infl.	Sediment texture
	Sediment layer
9-Recovery potential	Recruitment
	Recovery-old
	CCA

Several indicators and factors included in Obura and Grimsditch (2009) were omitted from sampling, with details given for this in Appendix A. In contrast to recommendations from McClanahan et al. (2012), the purpose of these surveys to give a direct to management planning at a coarse scale supports the inclusion of a broad range of semi-quantitative indicators, while more detailed scientific sampling can be developed in the future as resources allow.

Results and discussion

Broad scale environmental conditions

Temperature

Sea surface temperature across the archipelago is remarkably uniform. MODIS satellite data shows strong inter-annual differences (fig. 4), with a highest maximum temperature in 2005 and a second peak in 2010. Other than 2005, mean temperatures were relatively stable throughout the period 2002 to 2008, but showed a strong peak in 2010 and a sharp dip in 2009. The period from 2011 to 2014 has been uniformly cool.

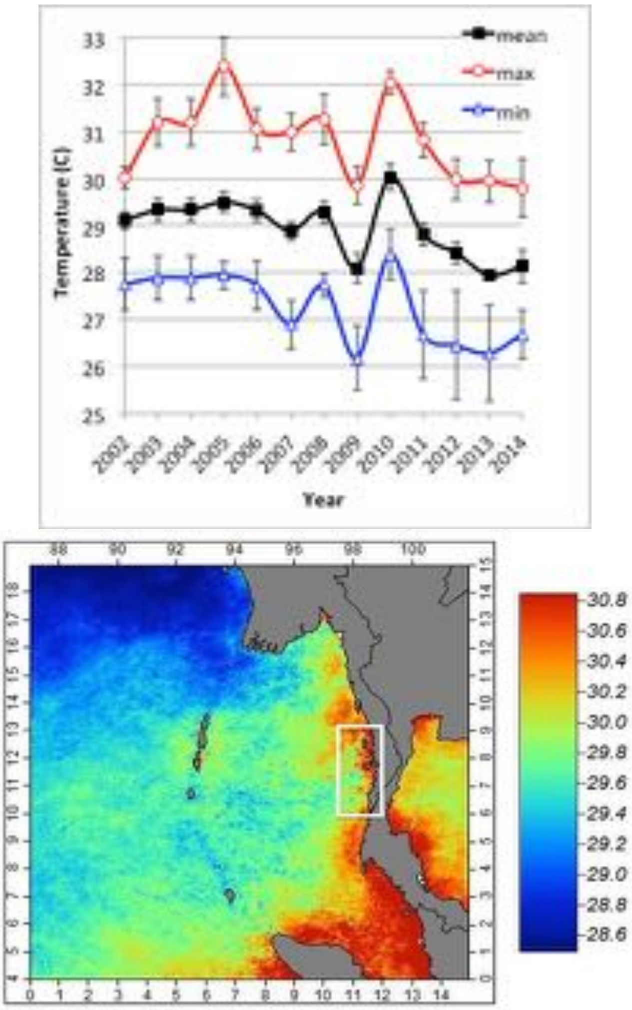

Figure 4. Left: Sea surface temperature in the Myeik archipelago, from 2002 to 2014, using MODIS 4 km resolution data, showing monthly mean, maxima and minima across 24 sampled points. Right: mean monthly temperatures for 2010. The approximate location of the archipelago and survey locations is shown by the white rectangle.

Detailed results are shown in Appendix A. Overall, the results suggest that temperature may not be a structuring variable within the archipelago – SSTs are similar across latitudinal and inshore-offshore gradients, and intra-annual variation (by month) is uniform across the region. However temperature is strongly structured by year, so the archipelago is uniformly exposed to thermal stress, and this occurred in 2005 and 2010. To a minor extent, during these warm conditions, there may be some greater stress to outer and inner island locations compared to more open exposed locations (i.e. the rock pinnacles and rocky reefs).

The relationship between SST patterns in this region and ENSO or IOD phases is complex. High temperatures in 2010 were associated with El Niño conditions in the Pacific, and negative conditions for the IOD – at least the latter is associated with high SST in the eastern Indian Ocean, and tele-connections of high SST in the western Pacific may have enhanced this in the eastern Indian Ocean. This suggests the hypothesis that mass bleaching and associated mortality likely happened during 2010, and the surveys here are recording mortality from that event, and subsequent recovery. Further, since temperature does not differ greatly within the archipelago, then any differences in site condition within the archipelago can be hypothesized to be due to some other structuring variable, either unrelated to thermal stress (e.g. fishing, sedimentation), or that alters exposure to thermal stress (e.g. through screening, cooling or acclimation; West and Salm 2003, Obura 2005).

Chlorophyll

Chlorophyll a concentration was strongly structured across the archipelago, with highest values at sites 2, 8 and 9 (fig. 5), the closest sites to the Tanintharyi River that flows into the waters around the Thayawthadangyi Island. There was a strong peak in chlorophyll levels in 2007, associated with river discharge (see Appendix B), most likely due to high rainfall due to La Niña conditions in that year.

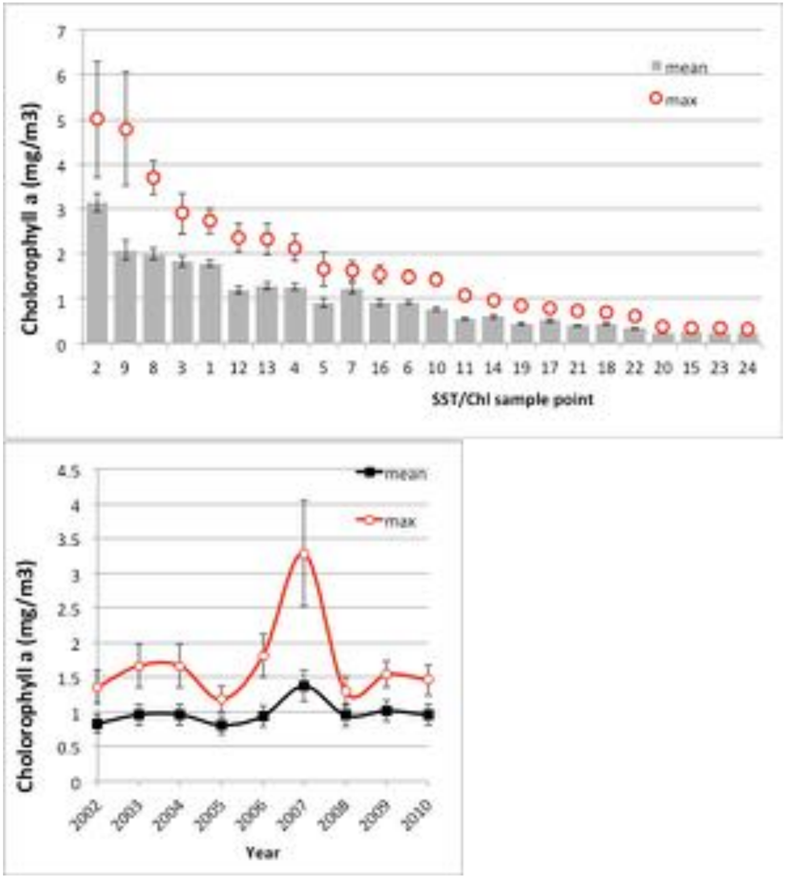

Figure 5. Left: Average and standard error bars for mean and maximum monthly chlorophyll concentration (mg m^{-3}) at 24 sample points in the Myeik archipelago, ordered from highest to lowest. Points 2, 9 and 8 are closest to the estuary of the Tanintharyi River (see fig. 3). Right: Annual mean and maximum chlorophyll concentrations across all sampled points.

Coral community structure

Genus diversity and abundance

Sampling of coral genera at each site yielded a total of 68 genera in 17 families (Appendix B). The most diverse site, East Sular (9) had 46 genera, while the least diverse, Double Island (14) had 29 genera (fig. 6). Between these extremes there were 4 sites with higher diversity then the rest, about half the sites with between 39 and 42 genera, and then a rapid decline from 37 genera down to the minimum of 29.

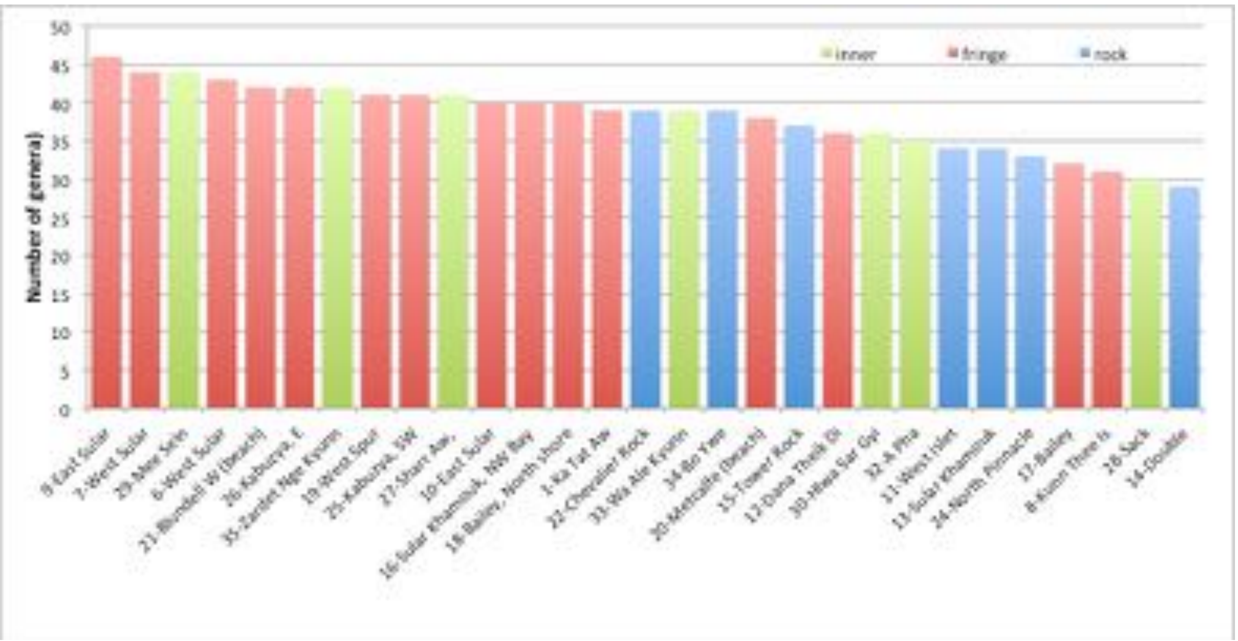

Figure 6. Coral genus diversity of study sites, separated by reef type – outer fringing reef, rock assemblages and inner reefs. Excluded from the graph are sites 2-5 (all rock assemblages) as their genus diversity was not recorded individually but as a group, so not comparable to the others (see methods).

Figure 7 distinguishes the three reef types from one another, showing that highest generic diversity was found on the outer fringing reefs. These reefs had a median of about 40 genera per site, with some low outliers (17-Bailey Rock and 8-Kunn Thee Island), inner reefs had comparatively high diversity with a median of about 39, while rock reefs had a median of about 36 genera per site.

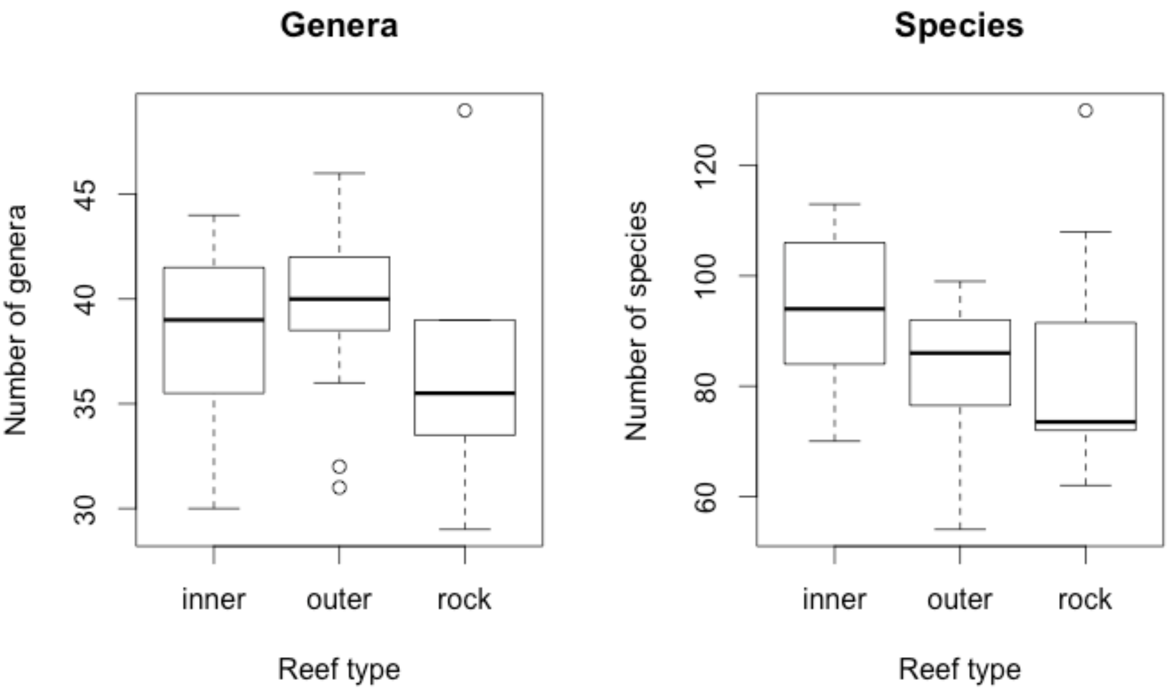

Figure 7. Boxplots of coral genus and species diversity by reef type. Differences in genus and species diversity between reef types was not significant (Kruskal Wallis rank sum tests: genera - p=0.2041, df=2; species - p=0.2613, df=2). The high outlier of sites 2-5 is shown for rocky reefs (see methods). The low outliers for genus diversity in outer fringing reef sites are Baily I. and Kun Thee (see summary of findings and Table 6).

The relative abundance of coral genera (fig. 8) showed a smooth decline from the dominant genus, *Porites*, to genera that were recorded as rare at just one site, including *Siderastrea, Alveopora, Caulastrea, Cynarina, Lithophyllon* and *Madracis*. *Porites* was clearly dominant as it was present at all sites with an average abundance > 4, and was dominant at more than one site. *Acropora* was also found at all sites and was dominant at more than one site, but its average abundance was lower (< 3), due to being uncommon or rare at a moderate number of sites. This finding matches patterns found in the Daung Islands (Cox et al. 2013), where massive corals were found to be common/abundant at most sites (most likely including and driven by *Porites*), while *Acropora* was rare at some sites while dominant in others. Following these two genera, *Favia*, *Platygyra* and *Pavona* led a list of some 20 genera which were all common at more than one site (green line). Interestingly, *Psammocora* was 6th in relative abundance, which is uncommon. This may reflect the high nutrient/sediment influence in the region, but is not a strong or common indicator of this.

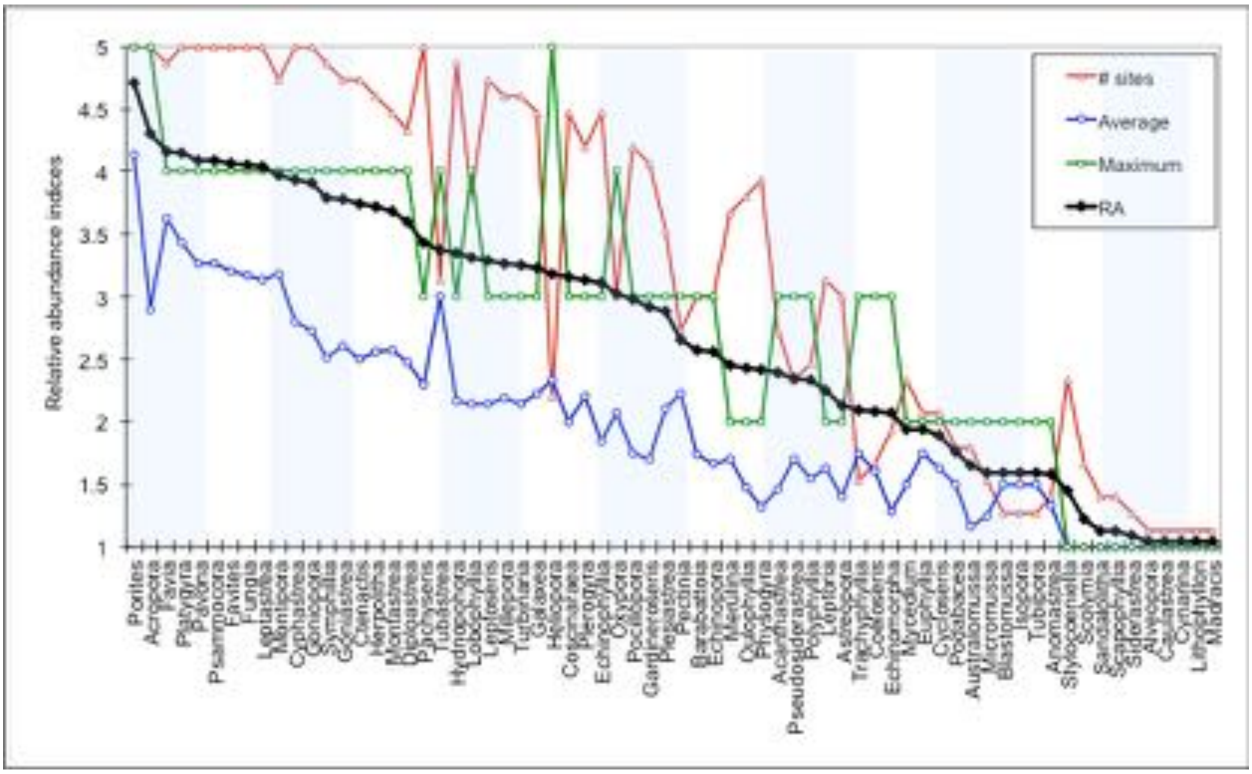

Figure 8. Relative abundance of coral genera with all indices scaled from 1 (minimum) to 5 (maximum). Three variables are shown: number of sites recorded, average abundance across sites in which found, maximum abundance at a site and RA = average across the three variables.

The high genus diversity and even slope of the Relative Abundance (RA) line (fig. 8) indicates coral communities of high consistency across the full range of sites, in spite of the differences in coral genus diversity between reef types shown in the earlier section. In fact, there was extremely high consistency in the relative abundance of genera among the three reef types, with the first absence of a genus from one reef type occurring for the 35th coral, *Pectinia*, being absent from rock wall assemblages (fig. 9) (*Pectinia* is a fine foliaceous genus found on sandy substrates, so this absence from rock walls is unsurprising).

This consistency in the coral assemblages likely reflects an abundant source pool of larvae for recruitment from the broader Andaman Sea, and potentially strong linkages with larval sources from the core regions of the Coral Triangle to the east.

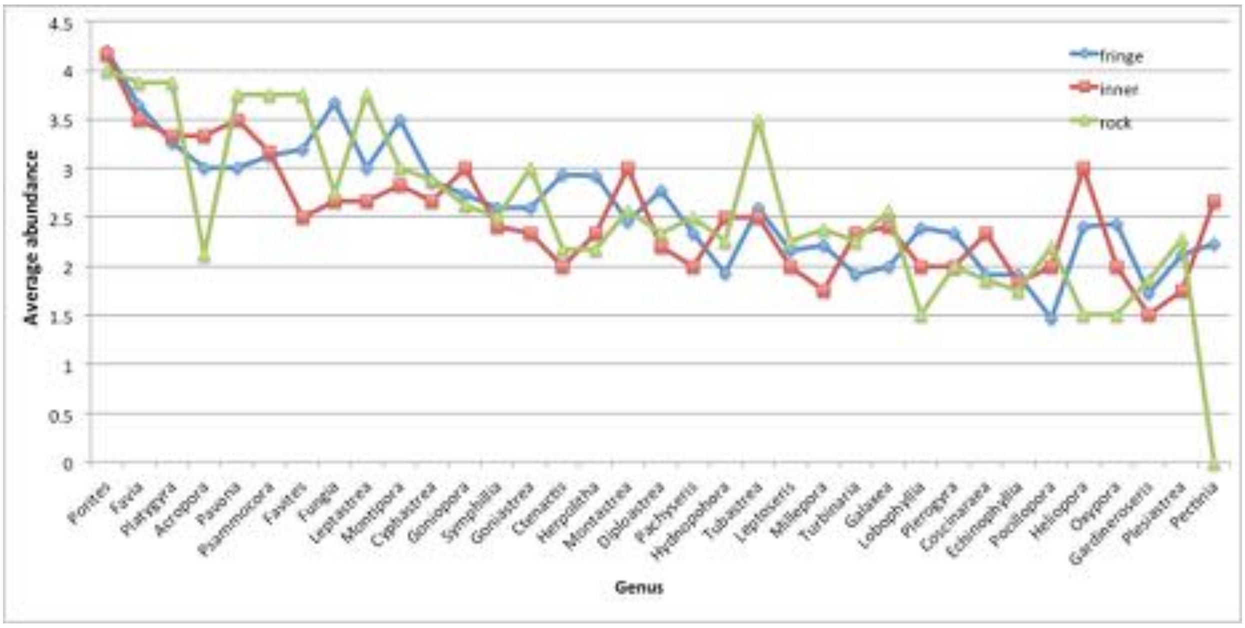

Figure 9. Average abundance of the top 35 genera at each reef type (fringing, inner, rock assemblage).

Coral species diversity

Two hundred and eighty seven coral species were recorded across all sites (Appendix B). This compares with numbers of 366 confirmed national? records and an additional 46 predicted occurrences of species for the Andaman sea region that contains the Myeik archipelago (i.e. the Andaman Sea, Gulf of Matarban, North Myanmar and Bangladesh, Andaman Islands, and Nicobar Islands ecoregions of Coral Geographic, C. Veron, unpublished data). Using a species accumulation curve method that predicts total richness if sampling is continued indefinitely, a prediction of 309 species is obtained (see Obura 2012 for methods), and it is likely that with more sampling of cryptic habitats and taxonomic methods, this species richness will be added to.

This species richness is as expected, on the slope from the richness of corals in the Coral Triangle region (Hoeksma 2007, Veron et al. 2009), where > 500 species may be reached in an area of similar size (and see Rudi 2012 for the western tip of Sumatra). The Andaman region has the highest species diversity of corals in the Indian Ocean (due to its proximity to the Coral Triangle) and diversity declines from here westwards, though an equivalent richness of corals is found in the highest diversity sub-peak in the Western Indian Ocean (Obura 2012).

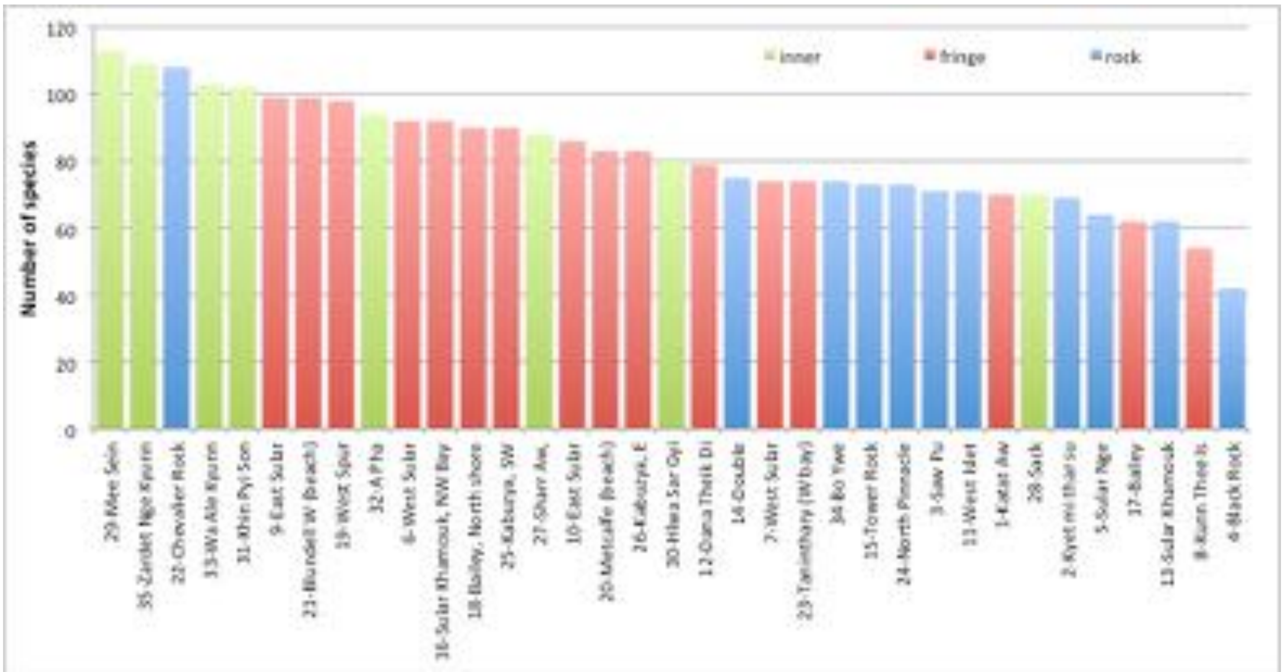

Figure 10. Species richness at individual sites, coded by reef type.

The most species rich site was Mee Sein (29) with 113 species (fig. 10), followed by 3 other inner reef sites and Chevalier Rock (22, a rock assemblage) with >100 species. By contrast with genus diversity, species diversity was higher in the inner reefs than the outer fringing reefs. This may be a result of two factors: a) the high diversity and abundance of the genus *Acropora* in the inner reefs results in low genus richness but high species richness; and b) with shallower reef bases in the outer reefs (generally ending at 12-15 m on sandy slopes), and apparent impact from coral bleaching in the recent years, species may have been lost from the outer reefs, or be present at very low abundance. As with the genus distributions, the rock assemblages showed low species diversity, with a minimum of 42 species at Black rock.

Table 3. Number of observed species in each IUCN Red List category.

Red List category	# species
Least Concern (LC)	125
Near Threatened (NT)	75
Vulnerable (VU)	36
Endangered (EN)	2
Data Deficient (DD)	4
Not filled	45
Total	287

Tabulation of the IUCN Red List status of each coral species (Table 3) shows that 2 species are classified as Endangered (*Acropora roseni* and *A. rudis*), and 36 as Vulnerable. *A. roseni* and *A. rudis* were recorded at 3 and 1 sites, respectively, and interestingly these are species in the basal clades of *Acropora* that are more commonly associated with the W and N Indian Ocean, and not the Indo-Australian region. Their rarity in this survey may indicate their being at the edge of their distribution, with implications on whether they should have prominent status in species protection interventions. Paralleling this pattern, other W&N Indian Ocean species were found:

- *Anomastrea irregularis*, constituting a large range extension (Veron 2000).
- *Plesiastrea devantieri,* only recently described from the Red Sea and thought to be endemic there (Veron 2002), but widespread throughout the WIO (Obura 2012).

Acropora branchi, a species previously only known from the W and N Indian Ocean, and recently recorded from the W tip of Sumatra (Rudi 2012) was searched for actively, but was not found. It is a very prominent and recognizable species, so its absence is likely a true absence given the amount of surveys done on this trip.

Other than the above W&N Indian Ocean species, other species found were typical of the Indo-Australian region (e.g. *Australomussa rowleyensis*, *Pectinia* spp), emphasizing that the reef fauna in the Andaman Sea is more Indo-Australian/SE Asian in composition than Indian Ocean.

Additional species of note:

- *Pseudosiderastrea tayami* was relatively common, as was a coral identified as *Pseudosiderastrea* sp. The possibility of this being *P. formosa* (Pichon et al. 2012), newly described based on samples from Taiwan, is being investigated. The latter's range was thought to be restricted to Taiwan, its type locality.

Reef health and resilience

Benthic description

Benthic cover data is reported from the estimated resilience indicators, to be compared with Reef Check data collected by other members of the team, in the future. Overall, the benthos was dominated by hard corals with an average cover of about 33% (fig. 11) with minima and maxima of 2% and 80%, followed by turf algae and other benthic invertebrates (excluding soft corals) at 17 and 16.5% respectively. Breaking these numbers down by reef type shows significant differences across all cover types except fleshy algae (ANOVA on square root-transformed data, $p < 0.05$). Inner reefs had the highest cover of corals at 55%, and 22-29% on fringing and rocky reef sites. The cover of soft corals and other invertebrates, and coralline algae, was highest on rocky reef sites (total of 52%) compared to 15-20% on fringing and inner reefs sites. This reflects strong wave/current conditions on the rocky reef sites, and likely also control of the fleshy algal community by herbivores. By contrast, cover of algal turf and rubble were both highest on fringing reef sites, (24% and 16%, respectively), reflecting mortality of corals and degradation of those reefs (see later discussion). Fleshy algal cover was low at all sites, indicative of some level of herbivory, though fish herbivore populations are generally low (Cox et al. 2013, Tun 2013), and sea urchins abundances high.

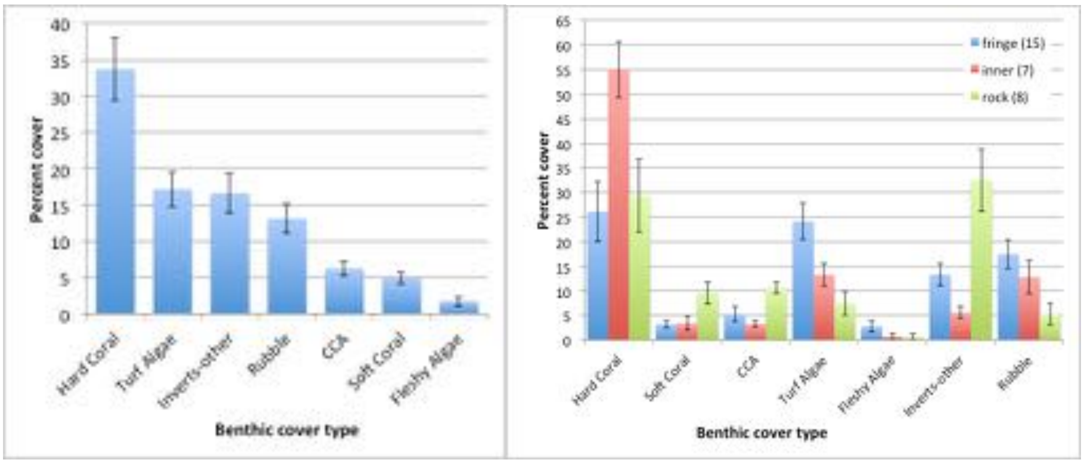

Figure 11. Percentage cover of the benthos by visual estimation, across all sites (left) and by reef type (right). Mean and standard errors, are shown, and the legend or reef type shows the number of sites in each category.

The overall relationship between benthic cover types and reef type is illustrated in the MDS plots (fig. 12), which emphasise the dominance of hard coral cover in structuring the reefs, the grouping of soft coral, invertebrates and CCA together independently of hard coral, and of the algal types (including fleshy algal height) and rubble in the opposite direction to coral, indicative of past impacts to a reef and incomplete recovery. While sites from each of the three reef types are mixed in the plot there is a tendency for segregation of rock reefs to the top (invertebrates, soft corals and CCA), inner reefs to the bottom right (hard coral) and outer fringing reefs to the left (flesh and turf algae, and rubble).

Overall, these results suggest a number of patterns:

- The dominance by corals of inner reefs influenced by high turbidity confirms findings from the previous two expeditions (Tun 2013, Cox et al. 2013), though in this case differences between massive corals and *Acropora* are not investigated. The high cover of corals indicates relatively low severe disturbance in the past, for example in relation to potential coral bleaching, which is in contrast to the outer fringing reefs.
- The outer fringing reefs were visibly in varied stages of degradation/recovery, with a massive impact likely to have occurred in the past. Dead coral skeletons and eroding framework were noted at many sites, for example at NW bay, Sular Khamouk (16) extensive dead thickets of staghorn *Acropora* blanketed the ground, at West Sular (7) the large dead colonies of reef-forming *Porites* and other reef-building corals were visually dominant, and at Kabuzya Island, SW (25) there was an even mix between these two assemblages. In contrast, some sites, such as Bailey Island (17) had a near-intact bed of staghorn *Acropora* over hundreds of meters across. It is likely that such widespread mortality on shallow fringing reefs was due to a thermal stress event at some point in the last ten years, most likely occurring in either 2010 or 2005 when thermal stress was highest (fig. 4). SST patterns indicate almost no differential exposure of sites to thermal stress, so the difference in part mortality between inner and outer reefs cannot be attributed to different thermal stress. Turbidity, as indicated by chlorophyll was markedly higher at some inshore reefs (fig. 5), so may have provided some protection to these reefs during a thermal stress event.
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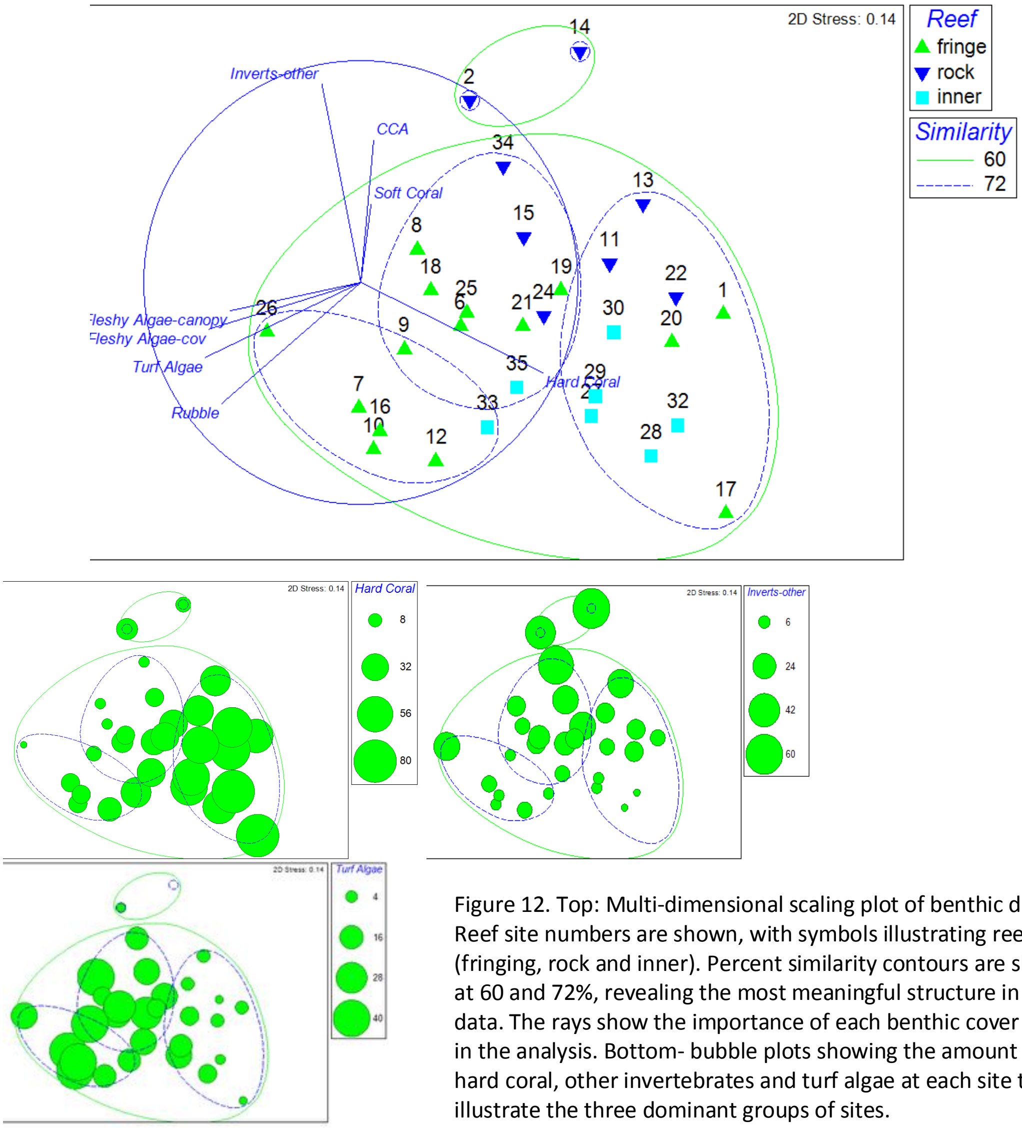


Figure 12. Top: Multi-dimensional scaling plot of benthic data. Reef site numbers are shown, with symbols illustrating reef type (fringing, rock and inner). Percent similarity contours are shown at 60 and 72%, revealing the most meaningful structure in the data. The rays show the importance of each benthic cover type in the analysis. Bottom- bubble plots showing the amount of hard coral, other invertebrates and turf algae at each site to illustrate the three dominant groups of sites.

- Comparing the inner and outer reefs, other surveys in East Africa have demonstrated a similar dynamic of high mortality on offshore reefs exposed to clear water, and low mortality on inshore reefs exposed to riverine turbidity and generally warmer conditions (Mafia-Songosongo area in Tanzania, Obura 2005).
- The rock wall/reef assemblages are more exposed to high wave energy and currents, and are steeply sloping to vertical, so develop little accumulation of large corals. With strong depth zonation, they may be dominated by soft corals and other encrusting invertebrates (ascidians, sponges, zoanthids, etc.) and are overall less responsive to thermal stress. In addition, the high levels of exposure tend to bathe them in cooler waters, so overall stress experienced may be less – though this may only occur at very localized levels – the overall patterns of SST do not indicate broader upwelling of cool waters in the more open waters near some of the rock reef assemblages in the south-central sector (see Appendix A).

Overall resilience

A process of selecting resilience indicators that show some correlation with coral community structure was undertaken for each resilience factor, and is presented in Appendix C. Experience has shown that indicators or factors often thought to be associated with resilience, or healthy corals, may not show such patterns in particular instances, so for a particular region, it is necessary to assess which indicators perform the best in 'predicting' the health of the coral community. This also helps to whittle the number of indicators down to manageable levels. The results of this exercise are summarized in Table 4.

Table 4: Resilience Indicators selected for each factor for multivariate analysis (see Appendix 4).

Factor	Variable	Notes
1-Coral population	Species richness Hard Coral Dominant size class	Three independently derived indicators, giving robust coverage of aspects of coral community structure.
2-Algal community	Fleshy Algae cover Turf Algae cover	The two most common algal indicators from monitoring transects. Broadly applicable to other studies
3-Interactions	Invertebrates-other Bioeroders (external)	Both indicate negative interactions for corals – competition from other benthic invertebrates, and disturbance/bioerosion from sea urchins. Also standard indicators from monitoring programmes.
4-Substrate condition	Topographic complexity – micro and mid scales	Other substrate variables didn't correlate positively, perhaps due to strong differences in substrate among the three reef zones. Micro- and middle-scale complexity are both relevant to coral dynamics, for recruitment and colony growth/structuring, respectively.
5-Cooling	n/a	None of the cooling indicators were correlated with coral health. A surprising result as these have been consistent in other (East African) studies, and expected by theory (West and Salm 2003, Obura 2005). Variation among the three reef zones, and unusual dynamics of Indian Ocean Dipole in this location may be factors in this.
6-Screening	Visibility (m) Canopy corals	Few of the screening indicators were correlated with coral health, and visibility only weakly. Canopy coral was correlated, but this is expected, as it is primarily an indicator of coral community structure.
7-Impacts on corals	Mortality-recent Mortality-old	No bleaching or other immediate stress to corals were noted, thus the lack of any correlation with coral health. Mortality, both old and recent, were correlated with coral health.
8-Sediment influence	Sediment texture Sediment layer	Only two simple indicators of sediment influence were estimated in situ, both correlated with coral health.
9-Recovery potential	Recruitment Recovery-old	CCA cover was negatively correlated with coral health, and recruitment was neutral, but included as it is a common measure in coral reef monitoring. The estimate of recovery from past bleaching was well correlated with coral community structure, which should be expected.

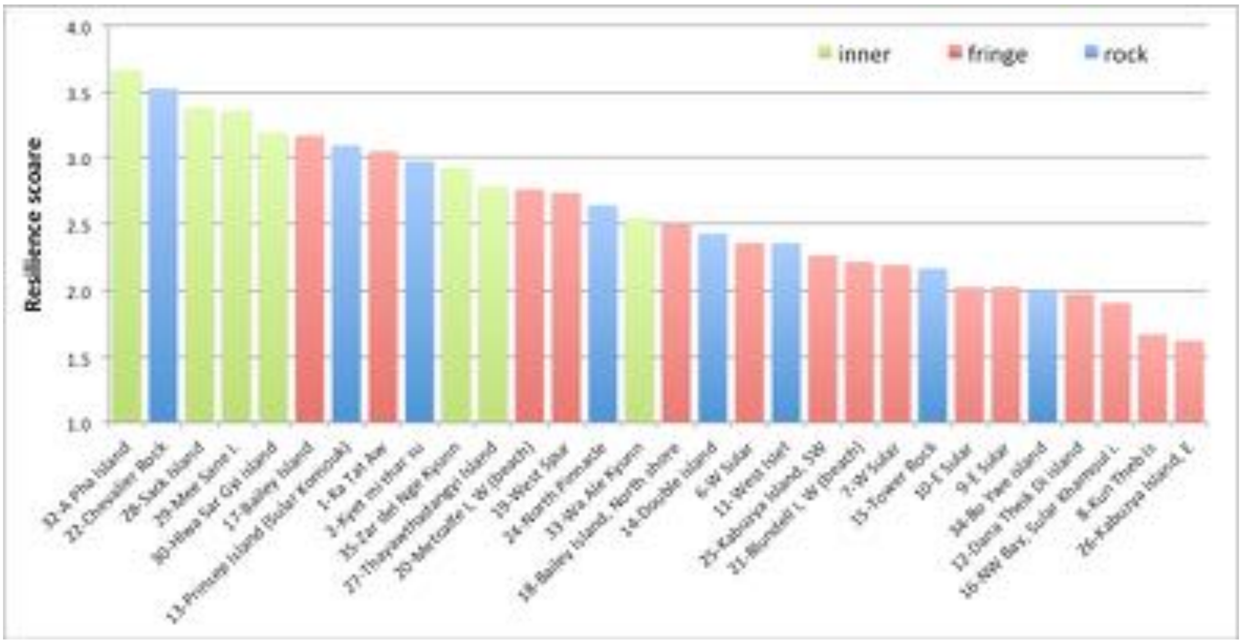


Figure 13. Resilience scores at survey sites, ordered from highest to lowest

On the basis of resilience factors averaged from the indicators selected (Table 4), overall site resilience scores varied from 3.7 to 1.6 (fig. 13). The higher coral cover and diversity of the inner reefs documented in earlier methods is reflected in their higher resilience scores, with 4 of the top 5 sites being inner reefs. A Pha (32), Chevalier rock (22), Sack (28) and Mee Sein (29) islands topped the list. Bailey Island (17) scored the highest for outer fringing reef sites. Rocky reefs were dispersed broadly throughout the range of resilience scores, while outer fringing reef sites scored the worst, with 9 of the 11 worst sites. Kun Theib Island (8) and Kabuzya (east side) scored the worst.

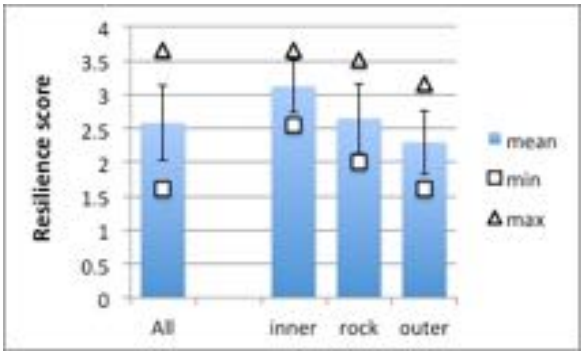


Figure 14. Resilience scores for all sites, and by reef type (mean, minimum, maximum and standard deviation).

The average score across all reefs was 2.6 (fig. 14), somewhat below a medium score of 3, indicating the degree of impacts to the reefs in general. Figure 14 also shows the mean and range of resilience scores for each reef type, with inner reefs having a mean of 3.1 versus 2.6 for rock reefs and 2.3 for outer reefs, though none of these were statistically significantly different from one another.

The contribution of individual resilience factors to overall site resilience is shown in a radar or spider plot, where each factor is a radius in a circular plot, with the score for each factor shown as the distance out along the radius (fig. 15, left). The resulting polygon illustrates how the factors rate against each other, and the overall shape and area give a visual depiction of the characteristics and overall resilience of the site – the larger the polygon, the higher the resilience.

Coral, algal community and recovery from past impacts scored the highest, with screening scoring the worst. Also useful is depiction of variability within each factor (fig. 15, right), which was also relatively uniform across the factors, though evidence of past impacts (old mortality) was the most variable factor, following by recovery from this old mortality (however, note that factors with only one indicator will have higher variability, as when two separate variables with similar ranges are averaged, the law of central tendency tends to reduce the range of extremes, and reduce variability in the combined variable).

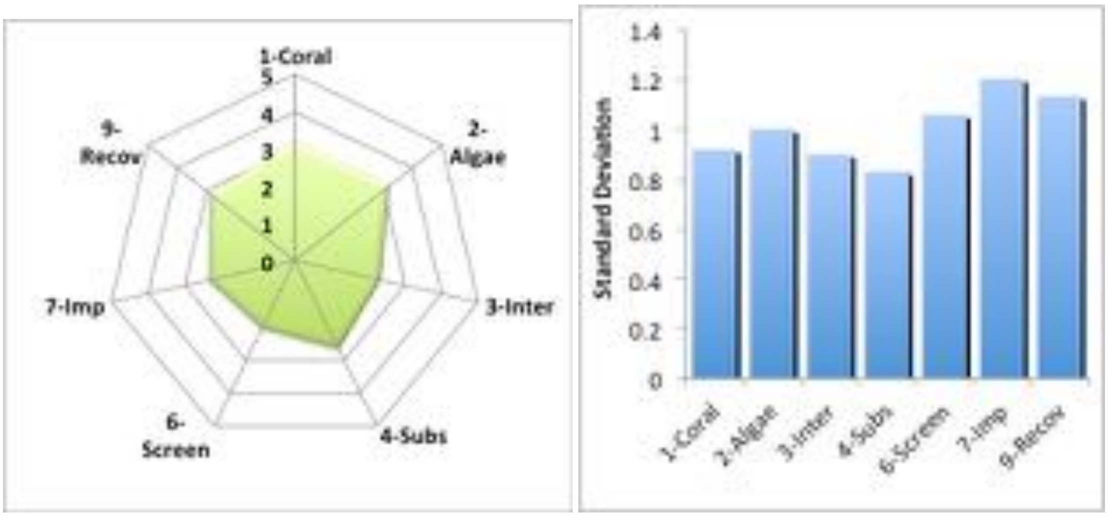


Figure 15. Average score for each resilience factor across all sites (left). Each factor (Table 4) is shown as a ray, scaling from 1 to 5, so the larger the overall shape, the higher the resilience of the site. Cooling (6) is excluded as no indicators within this factor correlated with coral community structure. Right- variability of each factor across survey sites.

Looking at how the resilience factors scored across the three reef types shows clearly how coral community structure is higher at inner reefs and lower at the other two reef types (fig. 16), screening is higher at inner reefs (which is as expected given the higher influence from river discharge, and tellingly, evidence of past impacts and degree of recovery from these score worse at the outer reefs than the inner and rock reefs.

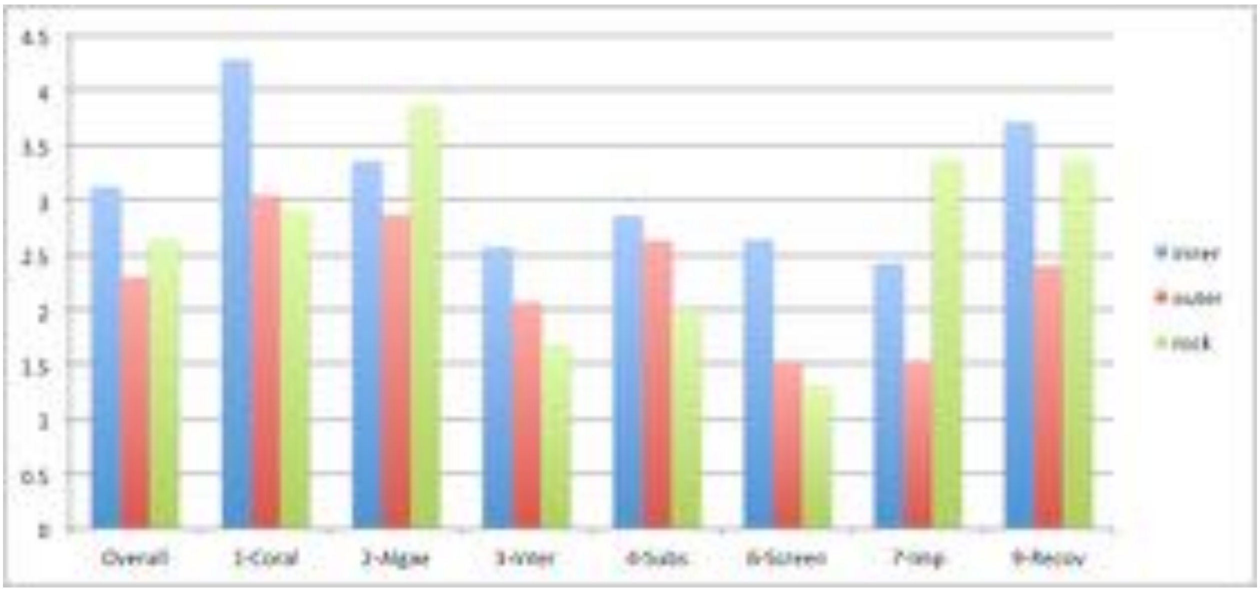


Figure 16. Resilience factors scores by reef type. *Note – I'll replace this with box plots for final*

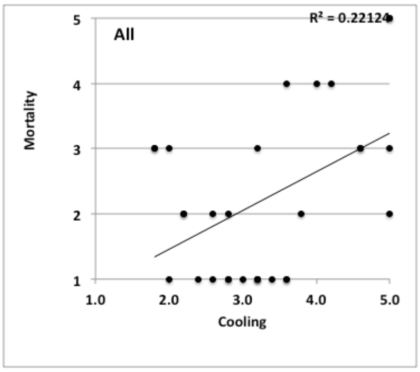
Table 5 breaks these down further to the site level, with sites ordered from highest to lowest (as in fig. 13). The colour coding shows clearly which factors contributed the most to structure among the sites. Thus the top 10 sites scored well for coral and algal community factors, as well as recovery. By contrast, scores for interactions, substrate and screening were uniformly lower, and screening in particular scored the lowest possible (1) for half the sites. The broad range of sites with good coral and algal communities is a good sign for future management, as they indicate the benthos is basically sound. Similarly, of the many sites that scored poorly for past impacts (all the bottom half of sites), a number were showed good level of recovery (scoring 3 or 4), providing a target for those that were showing no recovery. Interactions scored poorly across most sites, reflecting the high abundance of bioeroding sea urchins throughout (a sign of reef degradation, and also of fishing pressure that removes their predators), and abundance of other benthic invertebrates (that compete with corals).

Table 5. Matrix of resilience factors by site, sorted from highest to lowest overall (mean) score. Shading progressively from green through yellow to red. Same data as fig. 13.

Sites	Reef type	Mean	SD	1-Coral	2-Algae	3-Inter	4-Subs	6-Screen	7-Imp	9-Recov
32-A Pha Island	inner	3.7	1.2	4.7	4.5	3.0	2.5	2.0	4.0	5.0
22-Chevalier Rock	rock	3.5	1.0	4.7	4.5	2.5	3.0	2.0	4.0	4.0
28-Sack Island	inner	3.4	0.6	3.7	3.5	2.5	3.0	4.0	3.0	4.0
29-Mee Sein I.	inner	3.4	1.0	5.0	3.5	3.0	2.5	3.5	2.0	4.0
30-Hlwa Sar Gyi island	inner	3.2	1.0	4.3	3.5	2.5	3.5	1.5	3.0	4.0
17-Bailey Island	outer	3.2	0.8	3.7	4.5	3.5	2.5	2.0	3.0	3.0
13-Prinsep Island (Sular Komouk)	rock	3.1	1.6	2.7	4.0	1.5	1.5	2.0	5.0	5.0
1-Ka Tat Aw	outer	3.0	0.6	3.3	4.0	3.0	2.0	3.0	3.0	3.0
2-Kyet mi thar su	rock	3.0	1.7	3.3	3.5	1.5	1.0	1.5	5.0	5.0
35-Zar del Nge Kyunn	inner	2.9	0.9	4.0	3.0	1.5	3.5	3.5	2.0	3.0
27-Thayawthadangyi Island	inner	2.8	0.7	4.0	3.0	2.5	2.0	3.0	2.0	3.0
20-Metcalfe I, W (beach)	outer	2.8	1.3	4.3	4.0	1.5	2.5	1.0	2.0	4.0
19-West Spur	outer	2.7	1.1	3.7	3.0	1.5	3.0	1.0	4.0	3.0
24-North Pinnacle	rock	2.6	0.9	3.0	3.5	2.0	3.0	1.0	3.0	3.0
33-Wa Ale Kyunn	inner	2.5	1.2	4.3	2.5	3.0	3.0	1.0	1.0	3.0
18-Bailey Island, North shore	outer	2.5	1.2	3.0	3.5	2.0	3.0	1.0	1.0	4.0
14-Double island	rock	2.4	1.4	2.0	5.0	1.5	1.5	1.0	3.0	3.0
11-West Islet	rock	2.4	1.0	3.0	4.0	2.0	1.5	1.0	3.0	2.0
6-W Sular	outer	2.4	0.7	3.0	2.5	2.5	3.0	2.5	1.0	2.0
25-Kabuzya Island, SW	outer	2.3	1.0	3.3	3.0	1.5	3.0	1.0	1.0	3.0
21-Blundell I, W (beach)	outer	2.2	1.2	4.0	3.0	1.0	2.5	1.0	1.0	3.0
7-W Sular	outer	2.2	0.9	2.3	1.5	3.0	3.5	2.0	1.0	2.0
15-Tower Rock	rock	2.2	0.8	2.7	3.0	1.5	2.0	1.0	2.0	3.0
10-E Sular	outer	2.0	1.1	2.7	2.0	2.5	4.0	1.0	1.0	1.0
9-E Sular	outer	2.0	0.8	2.7	3.0	2.0	2.5	2.0	1.0	1.0
34-Bo Ywe island	rock	2.0	0.9	2.0	3.5	1.0	2.5	1.0	2.0	2.0
12-Dana Theik Di island	outer	2.0	0.7	2.3	2.5	1.5	2.0	1.5	1.0	3.0
16-NW Bay, Sular Khamoul i. (Prinsep Island)	outer	1.9	0.8	3.3	2.0	2.0	2.0	1.0	1.0	2.0
8-Kun Theb Is	outer	1.7	0.7	1.7	3.0	1.5	1.5	2.0	1.0	1.0
26-Kabuzya Island, E	outer	1.6	0.7	2.3	1.5	2.0	2.5	1.0	1.0	1.0

An alternative way to illustrate the resilience scores at each site is in individual radar/spider plots, shown in Appendix D10.

The exclusion of the two factors most commonly discussed in relation to bleaching resistance, cooling and screening (West and Salm 2003, Obura 2005, Obura and Grimsditch 2009) was somewhat surprising. However, given that there was no thermal stress or bleaching during the surveys, and conditions had been uniformly cool for a number of years (fig. 4) this might not be a surprise. Fig. 17 presents correlations between these factors and old mortality, showing the expected positive correlation (all indicators are scaled so that conditions/results good for corals are high).



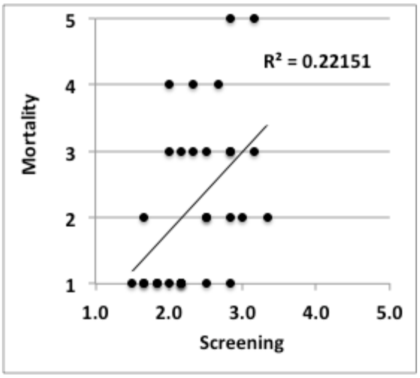


Figure 17. Correlation between old mortality and the bleaching resistance factors cooling and screening.

Results from the resilience indicators offer the following observations with respect to opportunities for improving reef condition:

- the healthy coral and algal communities, and high recovery potential, indicate reefs that may be responsive to improved conditions, i.e. be responsive to management;
- high recovery rates on some reefs, the uniform coral community across all sites (indicating a uniform larval pool and good recruitment throughout) and that recruitment was reasonably good across sites (showing no particular patterns) suggest good recovery ability;
- the importance of bioeroding sea urchins seems clear and confirms Tun (2013) and Cox et al.'s (2013) findings, indicating overfishing. Management to reduce overfishing will therefore likely have a positive impact on the reefs;
- there is an abundance of other invertebrates competing for space on the reefs (e.g. on some rocky reefs, corallimorphs were very abundant, and on some inner reefs, soft corals were abundant) so may provide a challenge to coral recovery on degraded reefs.
- the factors commonly associated with bleaching resistance on reefs (screening, cooling) appeared to play a minor role at the study sites, until analysed against apparent mortality in the past.

An interesting indicator of the role of localized recruitment was the presence of more *Acropora* staghorn species recruits at a highly impacted site on Baily Island, NW (18), adjacent to the only site with an intact mature staghorn bed in the outer islands (Bailey Island beach, 17). By contrast, other impacted sites appeared to have more limited recruitment of new corals. Thus while the overall coral community appears to reflect a regional species pool, on account of its uniformity (see comments related to fig. 9), short-term recruitment and recovery of reefs may be more dependent on localized recruitment.

Summary of findings

Coral communities were clearly structured by three main reef types: a) fringing reefs on relatively exposed boulder slopes of outer islands, from the surface to about 15 m depth where the boulders transitioned into sandy slopes; b) fringing reefs on relatively sheltered slopes of the inner islands with high turbidity and strong currents; and c) steeply sloping/vertical rock walls on small isolated rocks or outer island cliff faces, extending into deeper water over 20-30 m deep. Hard corals dominated the reefs at 33% average cover (max 80%), overall, with maximum cover on inner reefs, intermediate cover on rock walls and lowest cover on outer fringing reefs.

Coral reefs in the survey area showed high levels of hard coral diversity, with 287 species observed, in 68 genera and 17 families. Species accumulation curves predicted a total of 309 species would be obtained with the same method of sampling. Species diversity of corals was highest on inner reefs due to dominance and high diversity of the genus *Acropora*, which paradoxically meant that genus diversity on inner reefs was often lower than on others. Overall, coral communities were dominated by *Porites*, particularly on outer fringing reefs. *Acropora* was visually dominant on inner reefs, and below these two, a broad suite of faviids, *Psammocora* and *Fungia* (mushroom corals) were abundant. Genera very well mixed and uniform among all reef types, with the top 34 genera being present at all 3 reef types. Diversity levels were as expected for the Andaman Sea, with a community composition similar to the Coral Triangle/Indonesian region. Of all the species recorded, two coral species were listed as Endangered (*Acropora roseni* and *A. rudis*), and 36 as Vulnerable. A significant complement of species characteristic of the west and northern Indian Ocean was found, including two *Acropora* species from a basal clade (*A. roseni* and *A. rudis*), as well as *Plesiastrea devantieri* and *Anomastrea irregularis*. This emphasizes the character of the region (Andaman Sea) as a transition zone between the coral faunae of the West Pacific/Indonesian region (Coral Triangle) and the western and northern Indian Ocean.

The health of reefs in the region appeared compromised. The overall resilience or health of reefs was scored at average to below average levels (range 3.1 to 2.6 on a 1 (poor) to 5 (good) scale). While some sites had good coral communities, others showed unmistakable evidence of past mortality, shown by the presence of dead coral skeletons and eroding reef/rubble frameworks, and high cover of algal turf (17%). Outer fringing reefs showed the greatest evidence of mortality. Rocky reefs showed low evidence of past mortality, partly due to lower abundance of coral and dominance by other invertebrates, less buildup of reef framework due to steep slopes and community structure, strong currents, and colder conditions. Inner reefs were dominated by fast growing *Acropora*, so may have recovered faster if there had been past impact, but also may be sheltered from impacts by more turbid conditions. There was a general absence of fish and high presence of sea urchins, suggesting high fishing impacts and corroborating past findings (Cox et al. 2013, Tun 2013, Saw 2013). Though fishing was not directly observed on most sites, there was high evidence of past fishing with nets and fishing lines tangled in corals.

Corals at the survey sites had clearly suffered significant mortality in the recent past, though at differing levels. High sea surface temperatures occurred in 2010, likely due to combination of El Nino and negative IOD phases, so we hypothesize that the mortality of corals observable across the broad range of study sites was caused by mass bleaching in relation to thermal stress in 2010. SST did not differ significantly within the archipelago, thus the differences observed in site condition are most likely a result of some other structuring variable(s), either unrelated to thermal stress (e.g. fishing, sedimentation), or that altered exposure to thermal stress. The principle findings in relation to bleaching impacts were:

- Chlorophyll patterns show strong spatial patterning within the archipelago, with high turbidity influence near the Tanintharyi River and in the inner islands, suggesting significant influence of this factor in the limited mortality of corals on inner fringing reefs.
- While SST detectable from satellites showed no structuring, *in situ* observations on rocky/wall reefs suggested lower temperatures and an influence of upwelling/currents did reduce thermal stress. However for outer islands, influence of cooling factors did not appear to provide any protection, with the screening influence of turbidity being a stronger protection factor.
- At the smaller scale among sites, estimates of screening and cooling factors did not show any influence on current resilience scores, indicating there is no finer scale structuring of these indicators than between the three classes of islands. Thus it is not clear what local dynamics may alter the degree to which sites are sheltered from thermal stress, e.g. in the case of Baily Island (17) where no mortality of Acropora occurred, compared to e.g. the NW side of the island (18) and all the degraded outer sites, where high mortality occurred.

Resilience factors show that coral and algal state of the sites was relatively good, and recovery from past impacts has been good at some sites (at inner and rock reefs) but other factors scored worse (e.g. lack of complex interactions among species and poor substrate quality, Table 5). This suggests a degree of responsiveness/recovery potential in the coral community, but if other factors are scoring poorly, recovery from subsequent impacts may be undermined. If a repeat major impact occurs in the near future (e.g. from thermal stress, a cyclone or direct damage from people), it will be interesting to see if recovery is slower than has occurred to date. The importance of localized recruitment at one site highlights the importance of maintaining refuge populations throughout the archipelago, to promote recovery at impacted sites immediately adjacent to them.

The impact of fishing on the reefs was clearly important, in the lack of large fish, and from past studies (Cox et al. 2013, Saw 2013, Tun 2013), though little fishing pressure was seen on the reefs. It is possible that reef fishing is strongly seasonal in nature (just not being observed during this expedition), and/or that the pelagic/trawler fisheries that were abundantly observed also impact on reef fish – whether through indirect pathways, or additional fishing pressure on reefs by crews (for their own food, or personal income on return to port). Fishery data from historical sources, and establishment of more nuanced fishery monitoring is urgently needed to assess levels of fishing and the health of fish stocks, to improve management. In this regard, spatial planning to control fishing effort is essential, and should be based on different reef/community types, fishing types (Saw et al. xxx) and other factors.

Between-site comparisons

The condition of individual sites varied considerably, but was strongly grouped by reef type (Table 6). Accordingly, prioritization of sites is divided among the three reef types – outer, inner and rock reefs.

Outer fringing reefs - in general, these showed the highest impact of past mortality and poor recovery, with 10 out of the 16 sites showing poor recovery and low resilience scores. Five sites had high coral genus richness scores, and Bailey island had the highest resilience score for all outer islands.

- The most highly impacted sites, by resilience scores, 6-12, 21, 25 and 26, were spread throughout the outer islands, and were typically the shallow (<10 m) boulder slopes in sheltered locations and embayments. As a result of their shallow profile, and being accustomed to more oceanic conditions, it is likely that the warm pool of water in 2010 caused severe mortality at these locations.
- Only a few outer sites were in good condition, having escaped high mortality. Two stood out in particular – Bailey I (17), which had an unbroken stand of staghorn *Acropora* (4 species) over several 100s of meters, from 3-9 m depth. Localized currents and circulation were likely important in sheltering it from mortality. The second site, Metcalfe I. (20) had an unusual dominance of *Porites* species in the shallows, thus was less susceptible to thermal stress, with diverse corals on rocky spurs extending into deeper waters. Ka Tat Aw (1), was also in good condition, being somewhat intermediate in nature between the outer and inner reef sites.
- With such high impact from past mortality, supporting the recovery of reefs is an important target for management. In this regard, recovery potential is important, which is indicated by appropriate substrate, evidence of regrowth of corals that likely suffered partial mortality, recruitment of new corals, and relative lack of current threats/stresses. Of the highly degraded sites, East Sular (10) stood out with very high topographic complexity and potential recovery, and the NW side of Bailey I (18), with some evidence of recruitment of staghorn corals, likely from the mature community nearby (site 17). Metcalfe (20) and Blundell (21) islands also had complex topography with regrowth of a mixed community of corals, though they clearly were still at very early stages of recovery from a massive impact in the past.
- The NW Bay at Sular Khamouk (16), adjacent to a settlement supplying freshwater and produce to fishing boats, and therefore with high visitation by boats anchoring nearby, had the highest incidence of disease in the outer islands and evidence of rubble/physical damage. This is an indication of the need for management of localized impacts at this site, as well as at new supply sites that will proliferate in the outer islands as settlers and fishers inevitably intensify their activities in the outer islands.
- Because of the importance of protecting the least impacted sites, and supporting recovery of the most impacted sites, the sites mentioned here should be targeted for specific management objectives, with general control of activities across the outer islands, in particular limiting unplanned expansion of settlement and migrant fisher bases in sheltered locations.

Inner fringing reefs - these reefs showed the highest diversity levels as well as best condition of coral communities and resilience scores, due to low overall mortality in the past. Because of their higher resilience/better condition, combined with their proximity to villages and human settlements in the inner islands and mainland, they are among the most important reefs for subsistence and commercial resource use.

- Different inner reefs stood out for different reasons – 4 sites had very high genus and/or species diversity of corals, while 4 sites showed strong indicators of recovery and resilience paired with good coral community structure. Mee Sein I. (29) and Zardet Nge Kyunn (35) stood out for their diversity of corals, though the latter was a narrow fringe of corals around an island, and adjacent to a heavily used anchorage for fishing vessels. A Pha (32) and Sack (28) islands had the highest resilience scores, followed by Mee Sein I., then Hlwa Sar Gyi I. (30). Mee Sein I. had the highest score for overall condition of the coral community.
- The endangered species, *Acropora roseni* and *A. rudis*, were found at sites 2, 22 and 27, but are likely also distributed elsewhere, and only site 22 (Chevalier Island) stands out for other reasons for protection. Species classified as Vulnerable were distributed across a broad range of sites.
- Khin Pyi Son (31) and A Pha (32) Islands had the most complex and deepest profiles of the inner fringing reefs, the former along a channel by Langan village, the latter on the eastern (sheltered) side of an island. However they did not score well for condition, due to impacts

from the village for the former, and the steep slopes and fishing activity on the latter result in a broken up reef framework.

- Prioritization of sites for management needs to consider use and proximity to villages as a primary factor, as well as practicality of management/enforcement. In contrast to the outer islands, where key sites could be identified because of the high impact from past bleaching, inner sites should be managed through a more representation-oriented principle, identifying key sites for protection (including tourism reasons) but emphasizing the proportion of overall reef area under different management regimes.

Rock/wall reefs – these sites are not classic reef habitats, with co-dominance of soft corals and other heterotrophic invertebrates alongside hard corals. They are more similar to colder/high nutrient rocky reef habitats. As a result, the condition of the benthic community was generally good, but resilience scores focused on coral reef health were not average to poor.

- Among all the rocky reef sites, Chevalier Rock (22) stood out as the most diverse, as well as having the largest *Acropora* colonies, good coral/algal condition and minimal evidence of past impacts. Like the inner reefs, its high diversity is due to dominance by *Acropora*, with correspondingly low genus diversity. This similarity to 'normal' reefs is likely due to its topography (rubble slopes, small cliffs in the shallows and complex rocks/buttresses, as opposed to vertical cliffs) it was the closest in structure and condition to a 'normal' reef community.
- Though generally in good condition, the sites were clearly impacted by fishing gear, particularly of nets likely set in more open waters or adjacent to the rocks, but getting caught on the rocks. They are likely important aggregation points for pelagic fish, as productivity around them is likely enhanced by interaction between them and turbulent flow around them.
- The rocky reefs are also highly valuable for dive tourism, providing the most spectacular experience for divers on account of their vertical and steep profiles, strong currents and large fish communities. The most spectacular sites for tourism included Black Rock (4) for its vertical relief, whip corals and encrusting fauna, Sular Khamouk (13) for a complex structure, good coral community and field of blue anemones in the shallows,
- Accordingly, management should focus on a small number of key sites for high levels of protection to maintain the presence of large fish, as well as buffer zones for application of fishing gear, that take into account local currents and likelihood of entanglement.

Table 6. Summary of sites characteristics for management recommendations, based on coral diversity and resilience results (above) and observations (see site descriptions, Appendix A). Good characteristics are shown in green text, bad characteristics in red text, neutral in black. Sites without characteristic patterns are excluded from the table.

Site	Site name	Coral diversity	Resilience factors	Observations
Outer fringing reefs				
1	Katat Aw			Good condition, intermediate between outer & inner reefs
6	West Sular	High genus	poor recovery/high impact	
7	West Sular	High genus	poor recovery/high impact	
8	Kunn Thee Is	Low genus/species	Poor scores throughout	
9	East Sular	High genus	poor recovery/high impact	
10	East Sular		poor recovery/high impact	Good topography for recovery
12	Dana Theik Di island		Poor scores throughout	
16	NW Bay, Sular Khamouk		Poor scores throughout	Local impacts from boats/ settlement on island
17	Bailey Island	Low genus diversity		Unimpacted staghorn *Acropora*
18	Bailey Island, North			Recruitment seeded from 17
19	West Spur		Coral good, other factors bad	
20	Metcalfe I, (beach)		Coral good, other factors bad	Unusual *Porites* community, good topography for recovery
21	Blundell I, W (beach)	High genus	poor recovery/high impact	Good topography for recovery
25	Kabuzya Island, SW		poor recovery/high impact	

26	Kabuzya Island, E	High genus	Lowest scores overall	
Inner fringing reefs				
27	Sharr Aw, Thayawth. I		Coral good, other factors bad	
28	Sack Island	Low genus	Coral, algae, recovery good	
29	Mee Sein I.	High genus/high species	Coral, algae, recovery good	Good reef structure and depth profile
30	Hlwa Sar Gyi island		Coral, algae, recovery good	
31	Khin Pyi Son (I.)	High species		Good depth profile, but close to village/high impacts
32	A Pha Island		Highest scores, recovery good	Good reef structure and depth profile
33	Wa Ale Kyunn	High species		
35	Zardet Nge Kyunn	High genus/species	Coral good, other factors bad	
Rock walls				
2	Kyet mi thar su		Recovery strong	
4	Black Rock	Low species		Spectacular dive
11	West Islet		Very poor recovery	
13	Sular Khamouk		Recov v. strong	Spectacular dive
14	Double island	Lowest genus		Spectacular dive
15	Tower Rock			Spectacular dive
22	Chevalier Rock	High species	Coral, algae, recovery good	Top rocky reef, all values, Spectacular dive
34	Bo Ywe island		Poor scores throughout	

Recommendations

Management considerations should include the following:

- Key sites vs. representation – for some features, key sites are clearly identified (see previous section) while for others, representation through a proportional area under effective management should be the priority.
- Overall condition of reefs in the Myeik archipelago is average, as a result of diverse impacts, including thermal stress and coral bleaching, fishing for reef fish, and trawler/pelagic fishing on the banks surrounding the islands. While population density in the islands is generally low and concentrated on a very small number of islands, penetration of boats into the entire archipelago for fishing is very high, providing a significant challenge for managing intensification of fisheries in the future.
- The coral community throughout the islands is relatively uniform, so details of reef condition are more important than of species composition for management.
- Reef communities were clearly differentiated into three classes – inner fringing reefs, outer fringing reefs and rocky reefs, and management decisions for these reef types should be made independently.
    - Inner reefs are the most diverse and in the best condition due to protection from bleaching impacts, but also the most vulnerable to fishing pressure and of highest immediate value for food security.
    - Outer reefs were intermediate in diversity and in the worst condition due to impacts from past bleaching events (likely in 2010), but with lower impacts from fishing, and will become of increasing value for food security with increasing human population growth and expansion of fishing in the future. As a result of past impacts, key sites can be identified to prevent losses to the best sites, and promote recovery of the most impacted sites with highest recovery potential. Management for recovery and maintaining resilience should be a top priority.
    - Rocky reefs have the lowest diversity and least-typical coral reefs, have low vulnerability to bleaching impacts and also to fishing – but have a particularly vulnerability to entanglement of gear from fisheries in adjacent open waters. They have among the

highest value for dive tourism due to their spectacular topography and potential for large fish.

Direct threats to reefs to the coral reefs of the Myeik archipelago are already high, and clearly differentiated into two types:

- Fishing imposes an immediate threat in multiple ways across all island types, and to the banks/pelagic zones between the islands. Management and monitoring of fishing effort are two of the strongest tools for reducing impacts to coral reefs and other habitats, and establishment of nuanced monitoring, in partnership between fisheries authorities, all relevant fishery sectors and the conservation/management community is essential. Alongside this establishment of regulations to protect sensitive sites to replenish fished ones, for protection of biodiversity and for other users (e.g. tourism) is necessary. An archipelago-wide spatial management approach is necessary to address this sufficiently, and projecting forwards 20 or more years to expected population levels on the coastline/islands and in the fishery sector is essential.
- Coral bleaching as a result of thermal stress has already impacted the outer islands, and the threat will increase to all three classes of islands. The spatial management system established for fishery management should also include vulnerability to future thermal stress and its impacts on the reefs, both for general reef resilience and recovery dynamics, as well as for impacts to fishery replenishment and recovery potential.

For a whole-archipelago spatial management system, best practice for Marine Spatial Planning (Grantham et al. 2013, Sale et al. 2014) and managing for reef resilience (Anthony et al. 2014) should be considered.

References

Anthony K.R.N, Marshall, P.A. et al. (2014) Operationalizing resilience for adaptive coral reef management under global environmental change. Global Change Biology (2014), doi: 10.1111/gcb.12700

Clarke & Gorley 2006 (PRIMER User manuals/Tutorials) www.primer-e.edu

Coles, S., Brown, B., 2003. Coral bleaching capacity for acclimati- zation and adaptation. Advances in Marine Biology 46, 183–224.

Cox T, Fanari I, Zau Lunn, Cameron A & Benbow S (2013) Preliminary assessment of the Myeik Archipelago coral reef ecosystem, Myanmar. Fauna & Flora International, Cambridge. Pp 28.

Grantham HS, Agostini VN, Wilson J et al. (2013) A comparison of zoning analyses to inform planning of a marine protected area network in Raja Ampat, Indonesia. Marine Policy, 38, 184-194.

Hoegh-Guldberg, O. et al. Coral reefs under rapid climate change and oceanacidification. Science 318, 1737–1742 (2007).

Hoeksma B (2007) Delineation of the Indo-Malayan Centre of Maximum Marine Biodiversity: The Coral Triangle. Biogeography, Time and Place: distributions, Barriers and Islands. pp. 117–178.

Holmes, K.E., Tint Tun and Kyaw Thinn Latt. 2013. Marine Conservation in Myanmar - The current knowledge of marine systems and recommendations for research and conservation. Yangon, WCS and MSAM. 204 pp.

Keating KA (1998) Estimating species richness: the Michaelis-Menten model revisited. Oikos 81: 411–416.

Maynard J, Wilson J, Campbell S, Mangubhai S, Setiasih N, Sartin J, Ardiwijaya R, Obura D, Marshall P, Salm R, Heron S, and Goldberg J. 2012. Assessing coral resilience and bleaching impacts in the Indonesian archipelago. Technical Report to The Nature Conservancy with contributions from Wildlife Conservation Society and Reef Check Foundation Indonesia. 62 pp.

Maynard JA, Marshall PA, Johnson JE, Harman S (2010) Building resilience into practical conservation: identifying local management responses to global climate change in the southern Great Barrier Reef. Coral Reefs 29: 381–391. doi:10.1007/s00338-010-0603-8.

McClanahan TR, Donner SD, Maynard JA, Macneil MA, Graham NAJ, et al. (2012) Prioritizing Key Resilience Indicators to Support Coral Reef Management in a Changing Climate. PLoS ONE 7: e42884. doi:10.1371/journal.pone.0042884.t003.

Meyers, G.A., P.C. McIntosh, L. Pigot and M.J. Pook, 2007: The years of El Niño, La Niña and interactions with the tropical Indian Ocean. J. Climate, 20, 2872-2880.

Obura D (2005) Resilience and climate change: lessons from coral reefs and bleaching in the Western Indian Ocean. Estuarine, Coastal and Shelf Science 63: 353–372. doi:10.1016/j.ecss.2004.11.010.

Obura D (2012) The Diversity and Biogeography of Western Indian Ocean Reef-Building Corals. PLoS ONE 7: e45013. doi:10.1371/journal.pone.0045013.

Obura, D.O. and Grimsdith, G. (2009). Resilience Assessment of coral reefs – Assessment protocol for coral reefs, focusing on coral bleaching and thermal stress. IUCN working group on Climate Change and Coral Reefs. IUCN, Gland, Switzerland. 70 pages

Pichon M., Chuang Y-Y., and Chen C.A. (2012) *Pseudosiderastrea formosa* sp. nov. (Cnidaria: Anthozoa: Scleractinia) a new coral species endemic to Taiwan. Zoological Studies 51(1): 93-98.

Rudi E, Campbell SJ, Hoey AS, Fadli N, Linkie M, et al. (2012) The Coral Triangle Initiative: what are we missing? A case study from Aceh. ORX 46: 482–485. doi:10.1017/S0030605312000178.

Sale PF, Agardy T, Ainsworth CH, Feist BE, Bell JD, & 20 others. (2014) Marine Pollution Bulletin. Marine Pollution Bulletin: 1–16. doi:10.1016/j.marpolbul.2014.06.005

Saw Han Shein, Antt Maung, Salai Mon Nyi Nyi Lin and Zau Lunn (2013) Development of a Marine Protected Area Network in Myanmar. Myanmar Marine Programme Report No. 1/2013 Fauna & Flora International.

Sheppard and Obura 2004

Tun K (2013) FFI Myeik Archipelago Coral Reef Survey Expedition 2013. Fauna & Flora International, Cambridge. Pp 197.

Veron, J.E.N., Devantier, L., Turak, E., Green, D.H., Kinnmonth, S., Stafford-Smith, M. & Peterson, N. (2009) Delineating the Coral Triangle. Galaxea, 11, 91–100

West, J., Salm, R., 2003. Environmental determinants of resistance and resilience to coral bleaching: implications for marine protected area management. Conservation Biology 17, 956–967.

Appendix A – Site Descriptions and notes on Resilience method applied

Notes on resilience observations

A number of resilience factors normally collected in surveys were not done. The reasons for this were several:

- unfamiliarity with the region. With extensive experience in the Western Indian Ocean, I have felt comfortable recording observational data on factors such as connectivity, fishing impacts, management impacts, etc. But with no prior experience in Myanmar and the eastern Indian Ocean, I felt unprepared to estimate many of these indicators, so excluded them.
- Some factors, such as for fish are difficult to collect while focusing on benthic and coral work. Being unfamiliar with the reefs, I therefore also decided not to collect these.

Resilience factors outlined in Obura and Grimsditch (2009) that were not collected:

- Fish groups – herbivore and predator populations, and overall biomass
- Connectivity
- Anthropogenic influences, on water quality, substrate quality, and fishing effort
- Management effectiveness, in fisheries aspects, biodiversity conservation (MPAs) and ICZM/land based impacts.

These datasets can be compiled more effectively by the local team from *in situ* data, but also from background information and studies. This could be done as part of management planning work.

Site descriptions

Table 7. Detailed site descriptions

Site #	Site name	Lat	Long	Depth	Description
1	Katat Aw	10.98403	98.152528	6	Fringing reef around the side of a bay, very turbid and turbidity-resistant species, dominated by *Heliopora coerulea* especially in shallows. High diversity of Hard Coral.
2	Kyet mi thar su	11.27653	98.033056	21	Highly exposed, rubble/boulder strewn, dominated by filter feeders (fans, crinoids) with encrusting corals and some but broken up Acropora etc. in shallows. Very high diversity in cryptic/encrusting forms
3	Saw Pu I.	11.38325	98.016667	16	Like 2 but less exposed, high cover of filter feeders, whip corals, fans, etc. and very high cover of encrusting corals in the shallows
4	Black Rock	11.38911	97.6685	31	Vertical rock pinnacle in current, granite surfaces encrusting with corals in <15 m, Rhodactis dominant deeper, with fans, high mussels, etc. Transition to coral dominance/encrusting Leptoseris/psa/etc at 10-4 m, then macroalgae/turfs/crustose coralline algae (cca) shallower. Strong currents normally, planktivorous fish. Depauperate coral community, mostly in shallows.
5	Sular Nge	11.71931	97.559361	26	Exposed rock, sloping on all sides, swam around. Similar high current/N community, with few corals at depth, but veruy high encrusting cover in the shallows. Nets (3) entangled in several places. Similar fauna to 2-4
6	West Sular	11.79267	97.472639	18	Shelter fringing reef within channel between islands. Fine sand at shallows, and flat slope at 18. High turbidity/low energy community with *Porites cylindrica* at 6 m, *Acropora echinata* at 12-16m, high bioturbation in sand. Very diverse backreef assemblage, showing bioerosion and strong bleaching/fishing (?) impacts - could easily be an East Africa reef community
7	West Sular	11.80644	97.653694	21	Sheltered sand/rocky slope with dead staghorn thickets and large bommie structure down to 13-15m on sandy slope. Very high mortality, likely from bleaching and dynamite >90%, but surviving and quite robust-looking large corals in the shallows. Low diversity in staghorn thickets, dominated by *Lophophora*, high diversity of scattered colonies in bommies/rocky reef substrates. Greatest carbonate accretion seen so far (sites to #9), with bommies/carbonate layer on granite boulders, and some photos of the carbonate/coral skeletons being removed by bioerosoin. Very highly impacted - would be a fantastic site from its bommie topography and diversity otherwise. So far, of the sites, looks like

					the one with the greatest potential. High potential for recovery due to 3D f/w in bommies and boulders
8	Kunn Thee Is	11.81736	97.66925	20	Sandy slope from small beach, total mortality of staghorn beds and corals on granite boulders, but v. little carbonate accretion - the community is really one on granite boulders. In current from inner waters, strong current at 10-20 m and out towards headland -> *Tubastrea micrantha* habitat and oysters/mussels on rock, not great for corals. Marginal environment for corals, and high mortality following bleaching/dynamiting most likely.
9	East Sular	11.83856	97.673083	18	similar to 8 - sandy slope from beach with dead staghorn in front, towards rocky coast more boulders with corals, interspersed with v. extensive staghorn thickets from 2-10 m. 100% dead staghorn, and 95% + mortality in others, with only large *Diploastrea heliopora* and *Porites lutea/australensis* remaining. Moderately high div of corals in stag framework and on rocks, but clearly very impacted. Staghorn thickets dead perhaps >3-4 years? to 2010 bleaching, and many corals growing on them up to 10 cm size (3 yrs?)
10	East Sular	11.86575	97.681917	18	Gentle slope out from shore, mixed sand/granite substrate and bommies, with dead staghorn on most of the sandy substrate (5-12m) merging to extensive 90% (dead) *Oxypora crassispinosa* framework (more live down from rocky shore than sandy). Reef base at 15-16 m, onward sloping sand. >95% mortality overall, but reasonable framework on dead bommies (eroding) and granite, stag/oxy framework not yet collapsed, with some juveniles, abundant (small) *Lobophora*. High potential for recovery due to 3D f/w in bommies and boulders
11	West Islet	11.93469	97.685222	33	Isolated pinnacle/small island with near-vertical granite faces. More horizontal/sloping substrate than 2-5 but predominately similar communities, with more coral growth. At 25-35 m, large *Tubastrea micrantha* on boulders, slope 30, with fungiids and others, high CCA. Changing to encrusting corals from 18-5 m, high dominance of *Leptastrea pruinosa*, *Psammocora*, *Pavona*, etc. Like other pinnacles, low evidence of mortality/some mortality visible, but very high cover of corals and recovery.
12	Dana Theik Di island	12.00336	97.755833	22	Fringe of boulders around island, on sloping sand. Most of corals a rubbly/sandy community going down to sand at 20 m - coralliths, etc. Some scattered HS on slope, but otherwise only boulders in <3 m provide hard substrate, with *Porites* dominated community encrusting the rocks. *Siderastrea savignyana* in one small HS patch at 12-14 m. Bed of *Montipora digitata*, about 10*30 m on part of slope, 7-10 m. Did not do resilience indicators, as hard to classify this as 'reef community', but should note that this is probably typical of some/many shorelines. Should manage to minimize impacts etc., rather than as 'coral reef' habitat?
13	Prinsep Island (Sular Khamouk)	12.00569	97.660389	33	Isolated rock pinnacle w/t vegetation, off Prinsep I. Vertical wall to 20m, then boulder-strewn slope to >33 m. from 25 m very thick forest of whip corals, with juvenile snappers schooling. Encrusting Corals abundant but small, mostly CCA and inverts at this depth. Drifted E and upwards, to sloping shelf around island from 24-8 m, progressively increasing cover of corals and 'normal' assemblage. Finished with garden of blue condylactis in <8 m in shelter of rock.
14	Double island	12.02428	97.634111	33	Very vertical faces with canyons/massive boulders, and shelves at about 10 and 20 m, bottoming out at 30+m on sloping sand. Very high current and energy, corals predominantly at 8-20 m, but relatively low cover, much higher cover of carpeting/thing sponge/ascidian, tubastrea, fans, etc. High energy shown by growth forms of Pocilloporidae. Largest *Acropora* tables so far seen, *Acropora hyacinthus* and sol, at 10 m shelf on lee side. Coral community less developed than on other pinnacles. Very complex surge and currents, and pelagic fish/predators/planktivores abundant.
15	Tower Rock	12.06517	97.644	31	Wall dive, to 25 m base, changing to large 5-10 m boulders to N, and a more complex site with canyons and strong reversing currents. Horizontal/sloping surfaces with more diverse coral community, and debris from larger shallows above, showing intermediate corals between the fringing reefs and deep walls.
16	NW Bay, Sular	12.05017	97.672028	16	Fringing reef at the edge of the bay with the supply village. Very degraded - mortality from bleaching and fishing likely, w. highest

	Khamouk i. (Prinsep Island)				incidence so far of disease/competitive interactions with corals - e.g. on diphel (see photos), and COTs pred. Base of reef rubble at 12 m on sand - above this, dead staghorn and Pectinia paeonia, grading into boulders in shallows, w encrusting community dominated by Porites in shallowest (Porites monticulosa, lut, enc). *Diploastrea heliopora* the largest colonies, but with significant disease and COTS predation.
17	Bailey Island	12.10997	97.728611	12	Entered about 300 m N of beach, scrappy staghorn/*Montipora digitata* framework with some mortality in past. Sand slope at 12 m. Within 50 m, started into near-unbroken staghorn bed from 3-9 m depth, to S end of beach and headland (where *Porites* on boulder community started abruptly). Undisturbed staghorn that survived the 2010 bleaching, perhaps 4 species - *Acropora muricata, intermedia, horrida* and one other.
18	Bailey Island, North shore	12.14633	97.7435	16	Fringe of boulders around island, in some places to 4 m, in others to 16-18 m depth. On sand, low development of corals, with scrappy fungidae/*Montipora digitata*/*Acropora* stands. In one place development of acropora staghorn thickets of 1-3 m size, clearly due to recruitment from stag community on sheltered side of island. Where bommies extend down to 18 m, highcover of encrusting corals (Leptoseris, *Psammocora* etc) and some *Tubastrea micrantha*, just like rock dives. Observations suggest the fringing reef sites are essentially substrate limited - the natural rockfall/sediment platform dynamics mean that the sandy slope starts at about 4-6m deep, limiting good HS to the wave/high T zone in the shallows, so after bleaching, limited to hardy *Porites* and some others. Where good substrate does penetrate deeper, like here, abundant corals are found. Also recruitment limited - the high development of *Acropora* and *Montipora digitata* on this site is due to supply from the healthy community on the leeward side (site 17)
19	West Spur	12.24628	97.77025	21	Rocky islet close to deeper water, so sand does not start till 16-18 m. Bommies at all depths w high cover of encrusting corals (*Leptoseris, Psammocora, Montipora*, Faviidae, etc), and with *Acropora* in shallows (*lutkeni, humilis, robusta)* in robust growth forms. Confirms observation from S18 on substrate limitation. The greater supply of acropora may be due to this and perhaps more leeward communities, but also, is there a S-N increase in acropora? Perhaps screening closer to the Irrawaddy occurred in 2010. Requires further investigation.
20	Metcalfe I, (beach)	12.29292	97.803194	18	Boulders to 4-5 m, very heavily grown with *Porites* community (*lobata, lutea, solida, monticulosa*), below this, mostly sandy with low coral, but occasional boulder to 16+m, heavily encrusted with mixed community (as above). Very dense *Pseudosiderastrea* zp1 (cf. *formosa*), with *Pseudosiderastrea tayami* and cos colonies. Did resilience measures on *Porites* community in the shallows, excluded the sandy bottoms, as hard to do the two together
21	Blundell I, W (beach)	12.43422	97.834278	14	Same as previous, very scrappy on sand, some patches of *Goniopora* -dominated, Soft coral, and *Pectinia paeonia*. At sides of beach among boulders in <4 m, high development of *Porites* bommies - young colonies on boulders, with diverse community around them, encrusting, some acropora, plus urchins. Did resilience measures on *Porites* community in the shallows, excluded the sandy bottoms, as hard to do the two together.
22	Chevalier Rock	12.43044	97.801889	24	Boulder slope from 0 to about 15 m, then gives way to smaller rubble on a gentler slope down to 25 m and beyond. Lower slope very mobile, few corals (some encrusting, fungiids, etc). Main slope from 14-8 m very high coral cover - encrusting on boulders, with highest diversity of *Acropora* and small *Pocillopora* so far seen, in 4-6m on vertical walls. Largest *Acropora* tables seen anywhere - *cytherea, bifurcata, hyacinthus*, up to 2 m. A cave with high surge, into the island.
23	Taninthary I. (W bay)	12.59103	97.835083	18	Started within the lagoon, on sandy bottom with varied patches of staghorn, a stand of loose *Porites cylindrica* on sand and open spaces. Drifted to SW edge of bay and the rock substrate, with a debris slope of large rubble and *Tubastrea micrantha* trees, then finished in fast drift on the outside - all rock face and large boulders 3-8 m in size, almost nothing but encrusting corals due to direct wave energy.

24	North Pinnacle	12.68919	97.810556	24	Pinnacle with 45o slope to base at 20 m, large boulder-strewn slope, varying in size from 1 -8 m or so. Very high encrusting cover as in other wall locations. Rubble/sand base at 20 m with relatively low diversity, large *Tubastrea micrantha*, etc.
25	Kabuzya Island, SW	12.77439	97.868694	14	Enclosed bay, started halfway to beach on N side, and drifted outwards. Sandy substrate with patchy *Acropora* staghorn thickets (*Acropora muricata, A. horrida*) and lobophytum patches, some in very good shape transitioning to base of island rock/bommies at 7-8 m. High mortality from bleaching, with patchy regrowth/recovery, very varied - *Diploastrea heliopora, Lobophyllia corymbosa, Lobophyllia robusta, Porites* spp., etc. Staghorn patches continue at base of slope. High diversity coral community.
26	Kabuzya Island, E	12.78494	97.880917	25	Sheltered fringing reef against a beach/rocky shore. Very high mortality and complex bommie structure in <5 m, to dead staghorn collapsed rubble (with corallimorph encrusting) to 8-10 m, then sandy slope. Very low coral recruitment, high abundance of vase sponges, COTS and *Padina* - all indicative of higher nutrient/freshwater flow. The collapsed staghorn in contrast to S08, where the framework was still standing - i.e. higher internal bioerosion/fw influence here.
27	Sharr Aw, Thayawtha dangyi Island	12.42919	98.090944	11	Inner reef fringing a point/channel between islands. Very high current (spring tides) and low visibility (1m) made a challenging dive. High diversity and cover *Acropora* community from MLW to 4m, then quick transition through some deeper corals to bare boulders at 10 m. Fast drift dive
28	Sack Island	12.42319	98.016917	10	Similar to 27, but low-flow location, so dominated by staghorn beds from MLW to 5-8 m, with patches of bommies (*Porites*) with diverse corals on them. Very low visibility.
29	Mee Sein I.	11.96786	97.974722	18	Fringing reef around island, very low visibility. *Acropora* thickets in shallowest depths, transitioning to mixed community at 3-6 m, then rubble/sand slope from 8-10 m. Very poor visibility. Structure similar to other fringing reefs today.
30	Hlwa Sar Gyi island	11.72261	97.971361	12	Fringing reef around edge of island, like other inner reefs, *Acropora* thickets from lowest spring to about 8 m, as water clarity very good (20 m). Some boulders in shallows with encrusting community from low/moderate wave energy. Shallows also dominated by *Heliopora coerulea*, with diversity mixed assemblage from 4-12 m, and rubble/deep community below, on a sandy sloping bottom
31	Khin Pyi Son (I.)	11.32186	98.006	21	Fringing reef in channel between islands, opposite Mokan village. Shallow *Acropora* thickets, exposed at spring low, with *Porites* bommies and other corals, transitioning to a rubble/HS/silt slope from 3-5 m, continuing down to 18-20 m with deep water corals/whips etc. from 10 m and below. Very silty environment, but high diversity. Coral in shallows in good condition in spite of proximity to village, though clearly some acropora tables/heads overturned (they apparently use hook and line).
32	A Pha Island	11.19444	98.089306	24	Fringing reef on sheltered (E) side of N-S island. *Porites*-dominated from 2-10 m (*lutea, monticulosa, lobata, deformis, horizontalata, cylindrica, silimaniana*, etc) with near-90% cover, with some mixed community (i.e. instead of the staghorn belt of other inner sites). Where HS goes deeper, becomes more like deeper communities in other fringing reefs. Steep sandy slope starts at 4-5 m, with rocky spurs to 17/18 m, and continues past 25 m. Wave zone in <3m with encrusting rocky community like Chevalier - *Montipora, Pocillopra, Acropora*, etc.
33	Wa Ale Kyunn	10.85339	98.050333	14	Sheltered coral community on gentle slope - hard substrate in shallows developing to bommies in 5-9 m, then staghorn beds and sand, the staghorn between about 8 and 12 m depth. High mortality in shallows and mid-depths, but not catastrophic (perhaps 50-80%?), energetic recruitment and regrowth of corals happening, with largest populations of small *Pocillopora, Isopora palifera* and small *Acropora* yet seen. High coral diversity. Very good recovery in progress, partly due to available substrate (though bioerosion is active) and likely a larval supply from islands a little farther north
34	Bo Ywe island	10.59047	98.043639	14	Vertical wall, spurs and fallen bommies to 12 m, then sand/rubble plain. Encrusting community on the rock surfaces dominated by corallimorphs (rhodactis) and soft corals (dendronephthya), with

					abundant *Tubastrea micrantha*, whip corals. Urchins (*Diadema*) in v. high abundance on all except vertical faces, resulting in CCA and bare rock surfaces. Small corals in rubble (Coscinaraea wellsi, *Anomastrea*) all indicative of high upwelling/nutrients and flow. very like outer rock pinnacles, but with more insure/high turbidity community
35	Zardet Nge Kyunn	10.12819	98.33075	10	*Porites* and *Pavona* fringing reef community, extending to about 5 m deep, very broken up by past mortality (including fishing, nets, potentially dynamite), then a rubble slope with many fragments, to sandy/silty slope at 10 m. High turbidity community, with *Echinomorpha, Diploria* and small mixed colonies. Quite high diversity. Very high *Diadema* abundance, so broken up coral heads/bommies, but clear regrowth underway.

Appendix B – Environmental conditions

Sea Surface Temperature (SST)

Sea surface temperature across the archipelago is remarkably uniform. MODIS satellite data (fig. B1) show strong inter-annual differences (fig. B2), with a highest maximum temperature in 2005 and a second peak in 2010. Other than 2005, mean temperatures were relatively stable throughout the period 2002 to 2008, however, showed a strong peak in 2010. 2009 was a very cool year, with strong minima in all three variables – maximum, minimum and mean monthly temperatures, and from 2011 to 2014, all three temperature indicators are again remarkably stable, and lower than in the earlier stable years of the record.

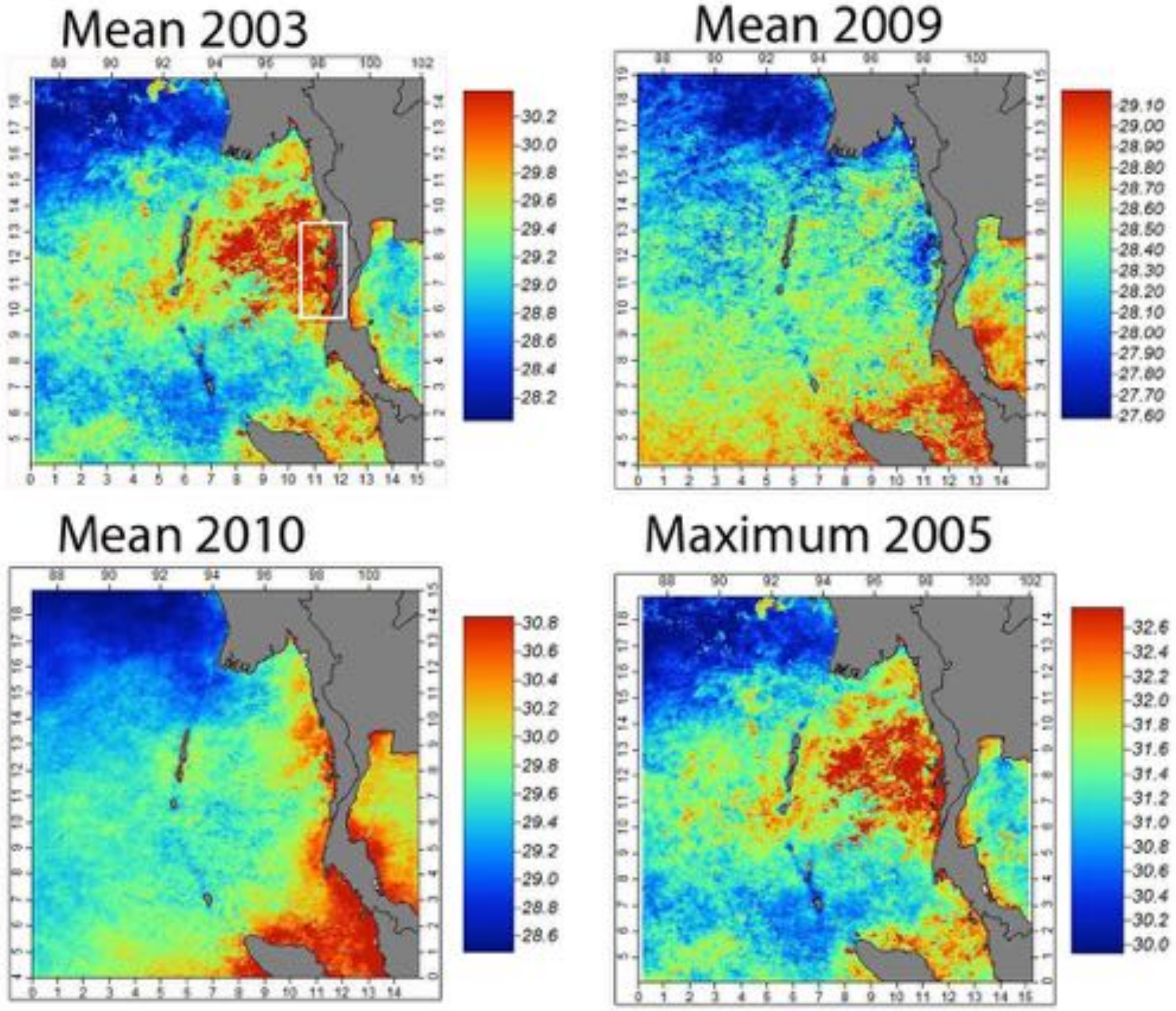


Figure B1. Annual summaries of SST in the Myeik archipelago, showing monthly mean SST for a typical year (2003), the coldest year (2009) and a hot year (2010); and maximum monthly temperature for 2005. Note that colour coding for each map is different. The approximate survey area is shown by the white rectangle.

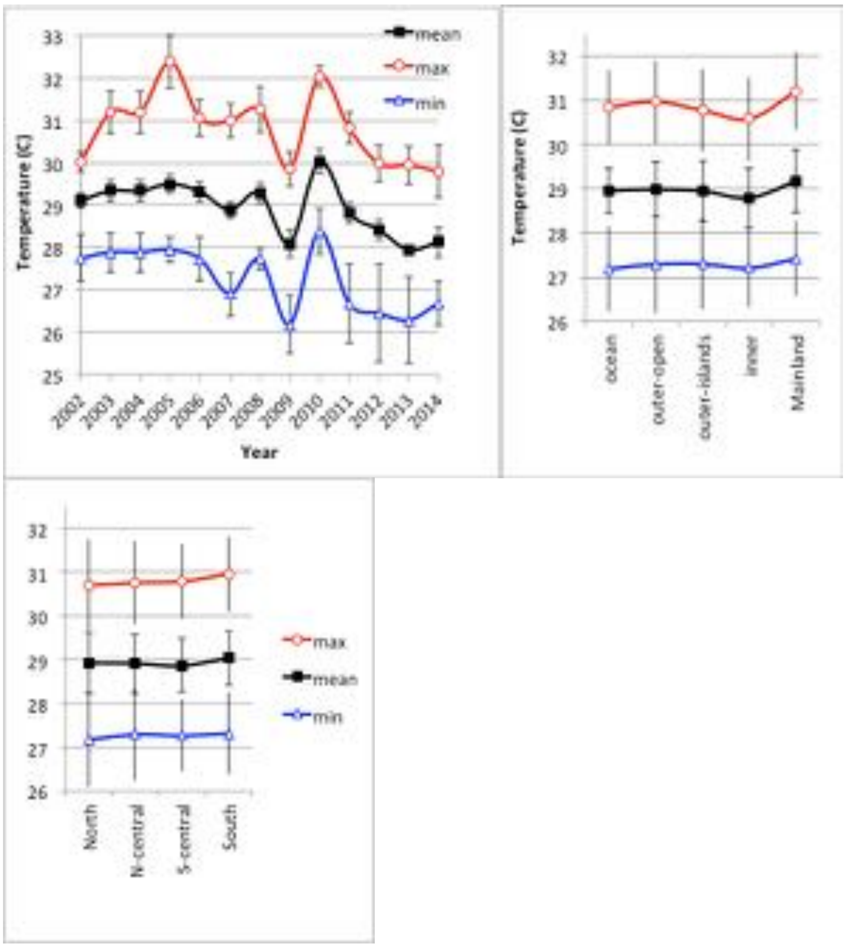


Figure B2. Sea surface temperature patterns in the Myeik archipelago, from 2002 to 2014, using MODIS 4 km resolution data. Twenty four points were selected representative of major regions and water masses in the archipelago (see methods, fig. 3) and SST at each of these points were sampled from MODIS for each month from 2002 to 2014. Left – annual patterns in monthly mean, maxima and minima across sampled points; Center – longitudinal grouping of sites from open ocean to adjacent ot the mainland; Right; latitudinal grouping of sites from north to south.

Consistency in temperatures across the archipelago are shown in the middle and right graphs (fig. B2) in which there is almost no trend in SST from east to west or north to south. If anything, a small dip in temperature is noted in the inner waters of the archipelago. Interestingly, this dip in temperature is just visible on the SST charts (fig. B1), particularly in the cool year 2009 just offshore of Thayawthadangyi island, suggesting there may be persistent upwelling here that may drive cooler waters into the inner islands system. Northern locations are very slightly cooler than southern locations, perhaps as a result of this feature. However, none of these differences are statistically significant, by inspection of the error bars in the figures.

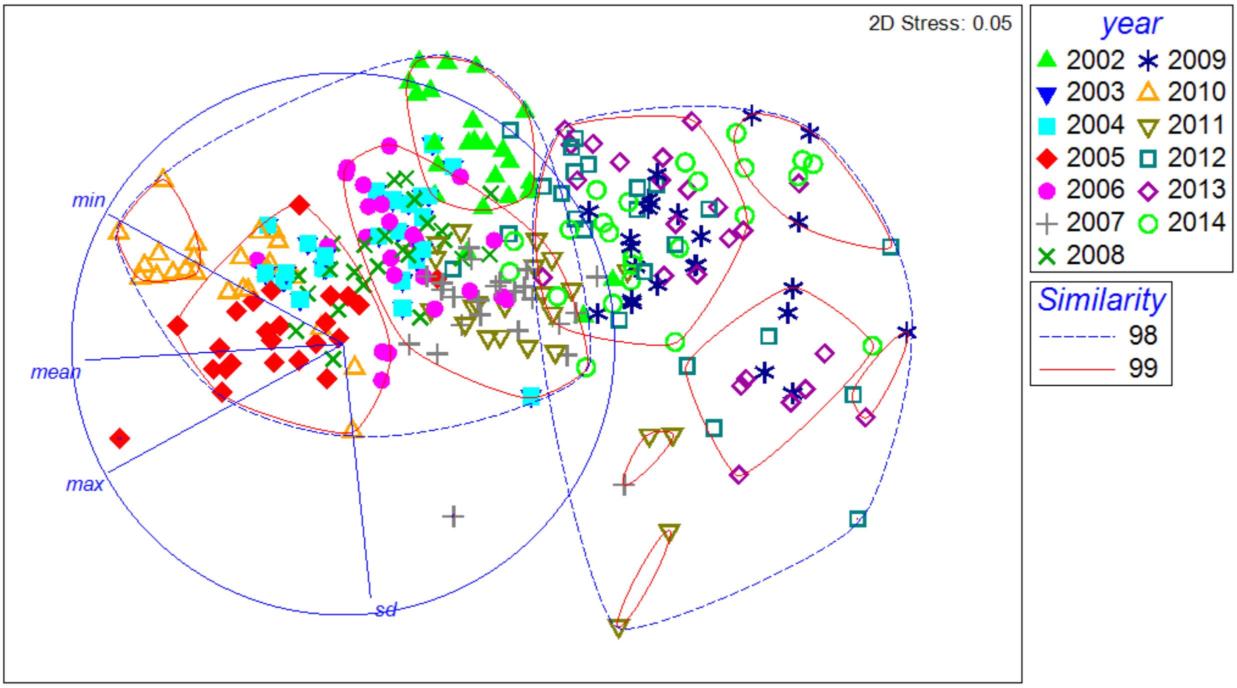


Figure B3. Multi-Dimensional Scaling (MDS) plot of MODIS SST sampling of monthly mean, maximum, minimum and standard deviation at 24 points from 2002-2014. See methods for the sampled locations. Cluster similarity at 98 and 99% is shown, with points coded by year

These patterns are confirmed in the MDS analysis of SST at each sample point by month from 2002 – 2014 (fig. B3). The figure shows a broader horizontal spread of sites, with minimum, mean and maximum SST vectors aligned (meaning that month-site combinations with higher temperatures are to the left) and standard deviation orthogonal to these and pointing down (month-site combinations with higher variation in temperature are to the bottom). Fig. B3 codes the points by year, with 2005 and 2010 clearly aggregated to the left (warmer conditions), 2009 to the right (cooler conditions) and 2011 to 2014 to the center/upper/right (cooler and less variable conditions). Coding the points by east-west, north-south and by site (from 1-24) revealed no clear clustering of points. There was a single outlier site in 2005 with the highest maximum monthly temperature. This was point 15 (see fig. 3, methods), the northernmost oceanic point, suggesting the region is exposed to maximum temperatures in the northern Andaman sea, which is shown in the charts for 2003 (mean) and 2005 (maximum). The pattern of points also suggests that in 2010 minimum temperatures were unusually warm across a broad range of sites.

Fig. B4 recreates fig. B2 but just for 2010. This shows higher and very stable minimum temperatures in mainland, inner and outer island locations (all inner and outer fringing reef survey sites were in these categories), with slightly lower temperatures and very high variability at the outer-ocean points (most similar in behavior to waters around the rock pinnacles). This is shown in the SST chart (mean 2010, fig. B1) as a narrow warm band in the inner part of the archipelago, and a sharp transition to cooler conditions in the outer islands and farther into

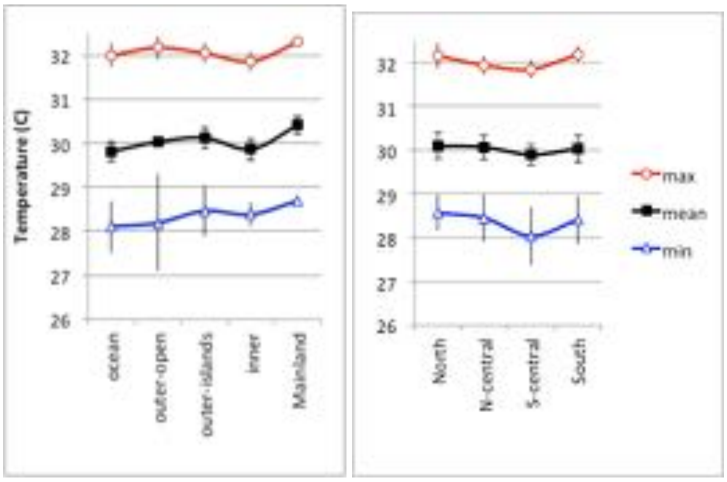


Figure B4. . Sea surface temperature patterns in the Myeik archipelago, for 2010. Left- longitudinal grouping of sites from open ocean to adjacent to the mainland; Right; latitudinal grouping of sites from north to south.

the Andaman Sea. No particular pattern is shown from north to south, except for slightly cooler condition in the central regions than the northern or southern extremities in 2010. The inshore-offshore pattern suggests stable warm conditions for a large period of time in 2010, on inner and outer fringing reefs but less so on rock pinnacles, which could result in significant thermal stress at the former.

Chloropyll a

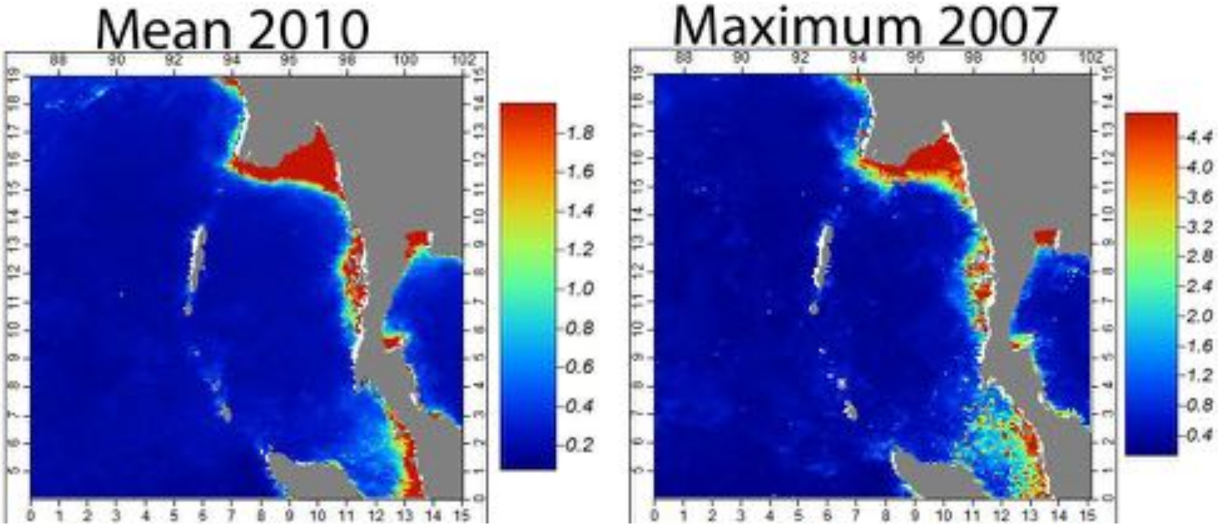


Figure B5. Chlorophyll a in the Andaman Sea (mg m-3), showing mean monthly concentrations in 2010 (left) and maximum monthly concentrations in 2007 (right). Note each map has a different legend.

Chlorophyll a concentration was strongly structured across the archipelago, as would be expected, with significantly higher values on inshore sites than offshore ones (fig. B6, B7), and with higher levels in the north-central region. Chlorophyll levels at individual sites show very distinctly that river flow to the north-central region, from the Great Tenasserim (Tanintharyi River) river system, one of Myanmar's major rivers that runs through the Tanintharyi Region before draining into the Andaman Sea at the Myeik Township, and into the waters around the Thayawthadangyi Kyun and Daung Kyun islands, is the source of the cholorophyll, and that it dilutes rapidly out from this point. Both maximum and mean chlorophyll levels peaked strongly in 2007, likely as a results of heavy rainfall, perhaps due to monsoon conditions, or a cyclone. No signal of upwelling-related chlorophyll peaks could be seen.

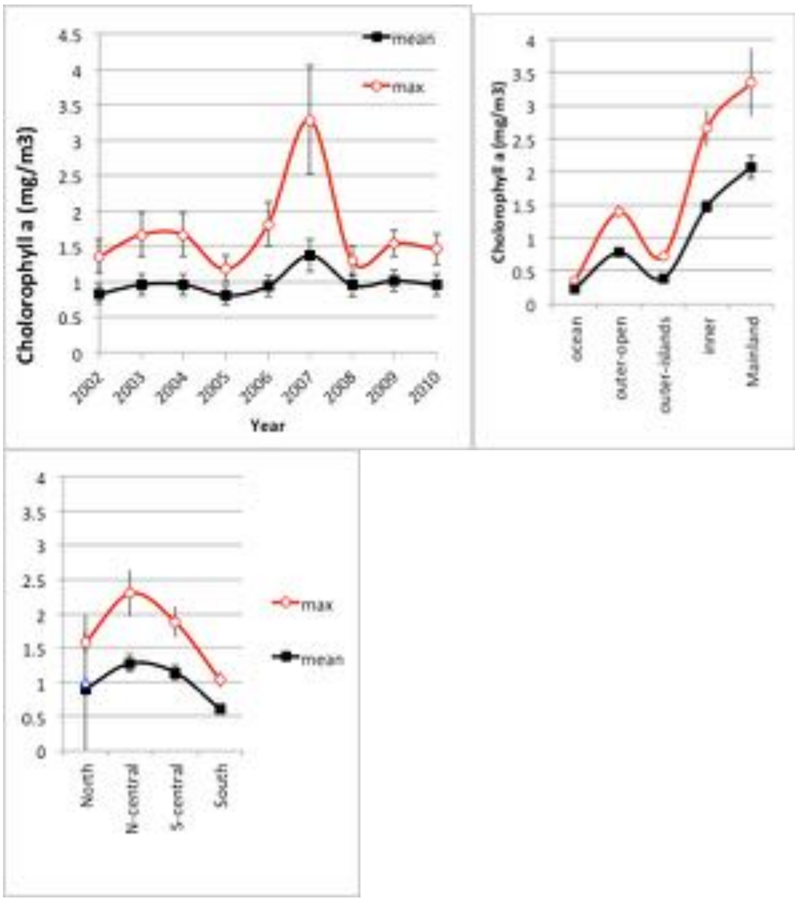


Fig. B6. Cholorophyll a concentration (mg m^{-3}) in the Myeik archipelago from 2002 to 2010 (left), and on an west-east (offshore-onshore) gradient (middle) and north-south gradient (right). Mean and maximum monthly values and standard errors are shown.

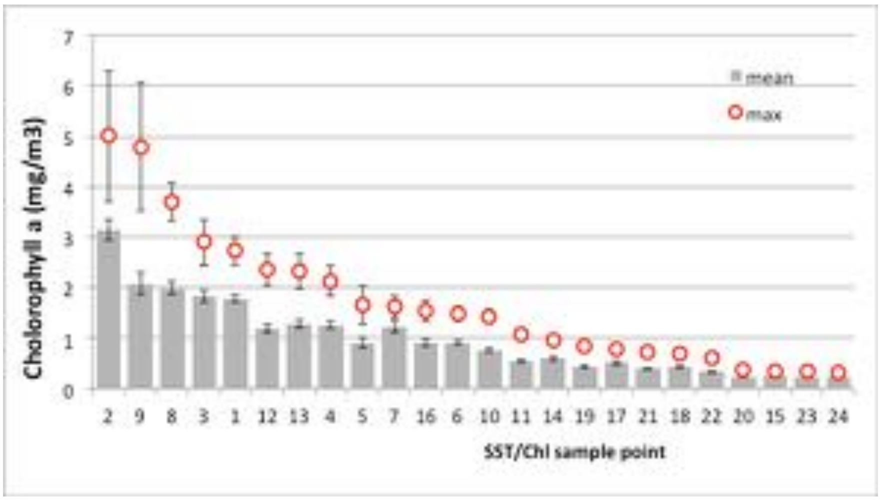


Figure B7. Average and standard error bars for mean and maximum monthly chlorophyll concentration (mg m-3) at 24 sample points in the Myeik archipelago, ordered from highest to lowest. Points 2, 9 and 8 are closest to the estuary of the Tanintharyi river (see fig. 3).

ENSO/IOD oscillations

This part of the Eastern Indian Ocean is somewhat protected from high seawater temperature events, as, similar to the Ecuador/Peruvian coastline in the Pacific, is at the cool end of the see-saw of hot and cold water that drives ENSO cycles. Thus while most reef regions in the Indian Ocean suffer higher temperatures and coral bleaching during El Niño and positive Indian Ocean Dipole phases, the Andaman Sea is generally cooler at these times.

Determining whether a year was classified as positive or negative phases of ENSO or IOD cycles varies with the methods of different groups, and a useful matrix of +/- combinations of these was developed up until 2009 (see Meyers et al. 2009, and http://www.marine.csiro.au/~mcintosh/Research_ENSO_IOD_years.htm). This table was extended using other sources to estimate whether years from 2009 to 2014 were positive or negative for ENSO and IOD, shown in Table 8.

According to this, key years shown for temperature and chlorophyll events were:

2005 – high maximum temperatures – neutral for both ENSO and IOD.

2007 – high chlorophyll – la Niña conditions, associated with high rainfall in this region, neutral IOD.

2009 – low temperatures – neutral for both ENSO and IOD.

2010 – high overall temperatures – El Niño conditions in the Pacific, negative IOD, at least the latter enhancing high temperatures in the eastern Indian Ocean.

Table 8. Tabulation of positive, neutral and negative phases of the El Niño Southern Oscillatoin (ENSO) and Indian Ocean Dipoles, for the period 1997 to 2014. Years up to 2008 are taken from the http://www.marine.csiro.au/~mcintosh/ Research_ENSO_IOD_years.htm, those from 2009 are inferred from other sources to less certain, and indicated in red italics font.

		IOD		
		-ve	**neutral**	**+ve**
ENSO	**-ve**		1998, 1999, 2000, 2007, *2011*	
	neutral		2001, 2002, 2003, 2005, 2006, 2008, *2009, 2012, 2014*	2004, *2013*
	+ve	*2010*		1997

Appendix C – Coral species lists

Genera

Sixty eight genera recorded in 17 families, during the FFI Myeik archipelago cruise, March 10-21, 2014.

Acanthastrea
Acropora
Alveopora
Anomastrea
Astreopora
Australomussa
Barabattoia
Blastomussa
Caulastrea
Coeloseris
Coscinaraea
Ctenactis
Cycloseris
Cynarina
Cyphastrea
Diploastrea
Echinomorpha
Echinophyllia
Echinopora
Euphyllia
Favia
Favites
Fungia
Galaxea
Gardineroseris
Goniastrea
Goniopora
Heliopora
Herpolitha
Hydnophora
Isopora
Leptastrea
Leptoria
Leptoseris
Lithophyllon
Lobophyllia
Madracis
Merulina
Micromussa
Millepora
Montastrea
Montipora
Mycedium
Oulophyllia
Oxypora
Pachyseris
Parasimplastrea
Pavona
Pectinia
Physogyra
Platygyra
Plerogyra
Plesiastrea
Pocillopora
Podabacia
Polyphillia
Porites
Psammocora
Pseudosiderastrea
Sandalolitha
Scapophyllia
Scolymia
Siderastrea
Stylocoeniella
Symphyllia
Trachyphyllia
Tubastrea
Turbinaria

Species

Preliminary species list collected by David Obura during the FFI Myeik archipelago cruise, March 10-21, 2014.

The red list status (RL) is given for some of the species, the others are to be filled in in due course.

Totals= 288 species, 68 genera, 17 families.

Family	**Genus**	**Species**	**RL**
Acroporidae	*Acropora*	*acuminata*	VU
	Acropora	*appressa*	NT
	Acropora	*aspera*	VU
	Acropora	*austera*	NT
	Acropora	*bifurcata*	DD
	Acropora	*cerealis*	LC
	Acropora	*clathrata*	LC
	Acropora	*cytherea*	LC
	Acropora	*digitifera*	NT
	Acropora	*divaricata*	NT
	Acropora	*echinata*	VU
	Acropora	*gemmifera*	LC
	Acropora	*granulosa*	NT
	Acropora	*horrida*	VU
	Acropora	*humilis*	NT
	Acropora	*hyacinthus*	NT
	Acropora	*inermis*	DD
	Acropora	*intermedia*	LC
	Acropora	*kosurini*	
	Acropora	*latistella*	LC
	Acropora	*loripes*	NT
	Acropora	*lutkeni*	NT
	Acropora	*macrostoma*	DD
	Acropora	*microphthalma*	LC
	Acropora	*muricata*	NT
	Acropora	*nana*	NT
	Acropora	*nasuta*	NT
	Acropora	*retusa*	VU
	Acropora	*robusta*	LC
	Acropora	*roseni*	EN
	Acropora	*rudis*	EN
	Acropora	*samoensis*	LC
	Acropora	*secale*	NT
	Acropora	*selago*	NT
	Acropora	*spicifera*	VU
	Acropora	*subulata*	LC
	Acropora	*tenuis*	NT
	Acropora	*valida*	LC
	Acropora	*zp1*	XX
	Alveopora	*tizardi*	LC
	Astreopora	*expansa*	NT
	Astreopora	*gracilis*	
	Astreopora	*incrustans*	VU
	Astreopora	*listeri*	LC
	Astreopora	*myriophthalma*	LC
	Astreopora	*ocellata*	LC
	Isopora	*palifera*	NT
	Montipora	*aequituberculata*	LC
	Montipora	*calcarea*	VU
	Montipora	*confusa*	VU
	Montipora	*cryptus*	NT
	Montipora	*digitata*	LC
	Montipora	*efflorescens*	NT
	Montipora	*effusa*	NT
	Montipora	*floweri*	LC
	Montipora	*foveolata*	NT
	Montipora	*hispida*	LC
	Montipora	*informis*	LC
	Montipora	*monasteriata*	LC
	Montipora	*nodosa*	NT
	Montipora	*spongodes*	LC
	Montipora	*stilosa*	VU
	Montipora	*tuberculosa*	LC
	Montipora	*undata*	NT
	Montipora	*verrucosa*	LC
Agariciidae	*Coeloseris*	*mayeri*	LC
	Gardineroseris	*planulata*	LC
	Leptoseris	*amitoriensis*	NT
	Leptoseris	*foliosa*	LC
	Leptoseris	*glabra*	LC
	Leptoseris	*incrustans*	VU
	Leptoseris	*mycetoseroides*	LC
	Leptoseris	*scabra*	LC
	Leptoseris	*solida*	LC
	Pachyseris	*rugosa*	VU
	Pachyseris	*speciosa*	LC
	Pavona	*cactus*	VU
	Pavona	*clavus*	LC
	Pavona	*decussata*	VU
	Pavona	*duerdeni*	LC
	Pavona	*explanulata*	LC
	Pavona	*maldivensis*	LC
	Pavona	*varians*	LC
	Pavona	*venosa*	VU

Astrocoeniidae	*Stylocoeniella*	*armata*	LC
	Stylocoeniella	*guentheri*	LC
Coscinaraeidae	*Anomastrea*	*irregularis*	VU
	Coscinaraea	*columna*	LC
	Coscinaraea	*crassa*	NT
	Coscinaraea	*exesa*	XX
	Coscinaraea	*monile*	LC
	Coscinaraea	*wellsi*	LC
	Coscinaraea	*zp1*	
Dendrophylliidae	*Tubastrea*	*micrantha*	XX
	Tubastrea	*zpp*	XX
	Turbinaria	*frondens*	LC
	Turbinaria	*irregularis*	LC
	Turbinaria	*mesenterina*	VU
	Turbinaria	*peltata*	VU
	Turbinaria	*stellulata*	VU
Euphyllidae	*Euphyllia*	*ancora*	VU
	Euphyllia	*glabrescens*	NT
	Physogyra	*lichtensteini*	VU
	Plerogyra	*sinuosa*	NT
Faviidae	*Barabattoia*	*amicorum*	LC
	Caulastrea	*connata*	VU
	Cyphastrea	*chalcidicum*	LC
	Cyphastrea	*microphthalma*	LC
	Cyphastrea	*serailia*	LC
	Diploastrea	*heliopora*	NT
	Echinopora	*gemmacea*	LC
	Echinopora	*lamellosa*	LC
	Echinopora	*pacificus*	
	Favia	*danae*	LC
	Favia	*favus*	LC
	Favia	*helianthoides*	NT
	Favia	*lizardensis*	NT
	Favia	*maritima*	NT
	Favia	*matthai*	NT
	Favia	*maxima*	NT
	Favia	*pallida*	LC
	Favia	*rosaria*	
	Favia	*rotumana*	LC
	Favia	*speciosa*	LC
	Favia	*stelligera*	NT
	Favia	*truncatus*	LC
	Favia	*veroni*	NT
	Favia	*vietnamensis*	NT
	Favites	*abdita*	NT
	Favites	*acuticolis*	NT
	Favites	*bestae*	
	Favites	*chinensis*	NT
	Favites	*complanata*	NT
	Favites	*halicora*	NT
	Favites	*pentagona*	LC
	Favites	*russelli*	NT
	Favites	*spinosa*	VU
	Favites	*vasta*	NT
	Goniastrea	*aspera*	LC
	Goniastrea	*australensis*	LC
	Goniastrea	*edwardsi*	LC
	Goniastrea	*minuta*	NT
	Goniastrea	*palauensis*	NT
	Goniastrea	*pectinata*	LC
	Goniastrea	*retiformis*	LC
	Leptastrea	*aequalis*	VU
	Leptastrea	*pruinosa*	LC
	Leptastrea	*purpurea*	LC
	Leptastrea	*transversa*	LC
	Leptoria	*irregularis*	VU
	Leptoria	*phrygia*	NT
	Montastrea	*annuligera*	NT
	Montastrea	*curta*	LC
	Montastrea	*magnistellata*	NT
	Montastrea	*salebrosa*	XX
	Montastrea	*valenciennesi*	NT
	Oulophyllia	*crispa*	NT
	Oulophyllia	*levis*	
	Parasimplastrea	*sheppardi*	EN
	Platygyra	*acuta*	NT
	Platygyra	*carnosus*	NT
	Platygyra	*daedalea*	LC
	Platygyra	*lamellina*	NT
	Platygyra	*pini*	LC
	Platygyra	*ryukyuensis*	NT
	Platygyra	*sinensis*	LC
	Platygyra	*verweyi*	NT
	Platygyra	*yaeyamaensis*	
	Plesiastrea	*versipora*	LC
	Plesiastrea	*zp1*	
Fungiidae	*Ctenactis*	*echinata*	LC
	Cycloseris	*costulata*	LC
	Cycloseris	*erosa*	XX
	Cycloseris	*patelliformis*	XX
	Cycloseris	*somervillei*	LC
	Fungia	*concina*	LC

	Fungia	*corona*	XX
	Fungia	*danai*	XX
	Fungia	*fungites*	NT
	Fungia	*granulosa*	LC
	Fungia	*moluccensis*	LC
	Fungia	*paumotensis*	LC
	Fungia	*repanda*	LC
	Fungia	*scabra*	LC
	Fungia	*scruposa*	LC
	Fungia	*scutaria*	LC
	Fungia	*seychellensis*	VU
	Herpolitha	*limax*	LC
	Herpolitha	*weberi*	XX
	Lithophyllon	*undulatum*	
	Podabacia	*crustacea*	LC
	Podabacia	*lankaensis*	
	Polyphillia	*novaehiberniae*	
	Polyphillia	*talpina*	LC
	Sandalolitha	*dentata*	
	Sandalolitha	*robusta*	LC
Hydrozoa	*Heliopora*	*coerulea*	VU
	Millepora	*exesa*	LC
	Millepora	*platyphylla*	LC
	Millepora	*tenaera*	XX
Merulinidae	*Hydnophora*	*exesa*	NT
	Hydnophora	*microconos*	
	Hydnophora	*rigida*	LC
	Merulina	*ampliata*	LC
	Scapophyllia	*cylindrica*	
Mussidae	*Acanthastrea*	*brevis*	VU
	Acanthastrea	*echinata*	LC
	Acanthastrea	*hemprichii*	VU
	Acanthastrea	*regularis*	XX
	Acanthastrea	*rotundoflora*	NT
	Acanthastrea	*subechinata*	NT
	Australomussa	*rowleyensis*	
	Blastomussa	*merletti*	LC
	Cynarina	*lachrymalis*	NT
	Lobophyllia	*corymbosa*	LC
	Lobophyllia	*flabelliformis*	XX
	Lobophyllia	*hataii*	LC
	Lobophyllia	*hemprichii*	LC
	Lobophyllia	*pachysepta*	NT
	Lobophyllia	*robusta*	LC
	Micromussa	*amakusensis*	NT
	Scolymia	*australis*	XX
	Symphyllia	*agaricia*	LC
	Symphyllia	*radians*	LC
	Symphyllia	*recta*	LC
	Symphyllia	*valenciennesi*	LC
Oculinidae	*Galaxea*	*fasicularis*	NT
	Galaxea	*paucisepta*	
Pectiniidae	*Echinomorpha*	*nishihira*	
	Echinophyllia	*aspera*	LC
	Echinophyllia	*echinata*	LC
	Echinophyllia	*echinoporoides*	LC
	Echinophyllia	*patula*	
	Echinophyllia	*taylorae*	
	Mycedium	*elephantotus*	LC
	Mycedium	*robokaki*	
	Oxypora	*crassispinosa*	LC
	Oxypora	*lacera*	LC
	Pectinia	*africana*	VU
	Pectinia	*alcicornis*	
	Pectinia	*lactuca*	VU
	Pectinia	*paeonia*	
Pocilloporidae	*Madracis*	*kirbyi*	LC
	Pocillopora	*damicornis*	LC
	Pocillopora	*danai*	VU
	Pocillopora	*eydouxi*	NT
	Pocillopora	*indiania*	VU
	Pocillopora	*ligulata*	LC
	Pocillopora	*verrucosa*	LC
	Pocillopora	*woodjonesii*	LC
	Pocillopora	*zelli*	LC
Poritidae	*Goniopora*	*albiconus*	VU
	Goniopora	*columna*	NT
	Goniopora	*djiboutiensis*	LC
	Goniopora	*lobata*	NT
	Goniopora	*minor*	NT
	Goniopora	*pendulus*	
	Goniopora	*planulata*	VU
	Goniopora	*somaliensis*	LC
	Goniopora	*stokesi*	NT
	Goniopora	*stutchburyi*	LC
	Goniopora	*zp.*	XX
	Porites	*annae*	NT
	Porites	*aranetai*	
	Porites	*australensis*	LC
	Porites	*cylindrica*	NT
	Porites	*deformis*	
	Porites	*horizontalata*	

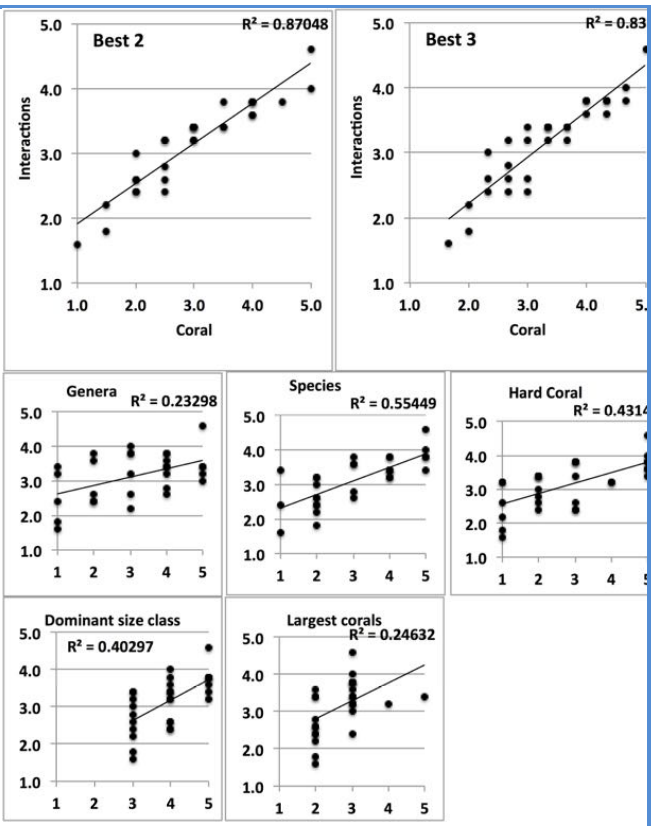
	Porites	*lichen*	LC
	Porites	*lobata*	NT
	Porites	*lutea*	LC
	Porites	*monticulosa*	LC
	Porites	*nigrescens*	VU
	Porites	*profundus*	LC
	Porites	*rus*	LC
	Porites	*silimaniana*	
	Porites	*solida*	LC
	Porites	*stephensoni*	
Siderastreidae	*Psammocora*	*albopicta*	DD
	Psammocora	*digitata*	NT
	Psammocora	*explanulata*	LC
	Psammocora	*niestraazi*	LC
	Psammocora	*obtusangula*	NT
	Psammocora	*profundacella*	LC
	Pseudosiderastrea	*tayami*	NT
	Pseudosiderastrea	*zp1 (cf. formosa)*	
	Siderastrea	*savignyana*	LC
Trachyphylliidae	*Trachyphyllia*	*geoffroyi*	NT

Appendix D – Resilience factors and indicators

Coral community

Five variables for coral community structure were used: number of genera and number of species, from genus and species surveys, (see methods), and hard coral cover, dominant size class and largest coral estimates. The table and figure below show the relationships among them.

Site	Coral-all	Best 2	Best 3	Genera richness	**Species richness ****	**Hard Coral ****	**Dominant size class ****	Largest corals
My01	3.2	3.0	3.3	3	2	4	4	3
My02	3.4	3.5	3.3	5	5	2	3	2
My06	3.4	3.0	3.0	5	4	2	3	3
My07	3.0	2.0	2.3	5	2	2	3	3
My08	1.6	1.0	1.7	1	1	1	3	2
My09	3.2	2.5	2.7	5	4	1	3	3
My10	2.8	2.5	2.7	4	3	2	3	2
My11	2.6	2.5	3.0	2	2	3	4	2
My12	2.4	2.0	2.3	2	2	2	3	3
My13	2.4	2.0	2.7	2	1	3	4	2
My14	1.8	1.5	2.0	1	2	1	3	2
My15	2.6	2.0	2.7	3	2	2	4	2
My16	3.4	3.0	3.3	4	4	2	4	3
My17	3.4	3.0	3.7	1	1	5	5	5
My18	3.2	2.5	3.0	4	4	1	4	3
My19	3.4	3.5	3.7	4	4	3	4	2
My20	3.8	4.0	4.3	3	3	5	5	3
My21	3.8	3.5	4.0	4	4	3	5	3
My22	4.0	5.0	4.7	3	5	5	4	3
My24	2.4	2.5	3.0	1	2	3	4	2
My25	3.4	3.0	3.3	4	4	2	4	3
My26	2.6	2.0	2.3	4	3	1	3	2
My27	3.6	4.0	4.0	4	3	5	4	2
My28	3.2	3.0	3.7	1	2	4	5	4
My29	4.6	5.0	5.0	5	5	5	5	3
My30	3.6	4.0	4.3	2	3	5	5	3
My32	3.8	4.5	4.7	2	4	5	5	3
My33	3.8	4.0	4.3	3	5	3	5	3
My34	2.2	1.5	2.0	3	2	1	3	2
My35	3.8	4.0	4.0	4	5	3	4	3



Figure/table D1 – Individual values for resilience indicators in the right hand side of the table. The three columns to the left show overall mean, for all coral indicators, and average for the best 2 and best 3. The figures show overall coral on the x axis, plotted against the individual indicators (below, see graph titles), and in the top two, against the best 2 (species number and hard coral cover), and best 3 (species number, hard coral cover and dominant size class). The selected indicators are highlighted in yellow with bold red typeface.

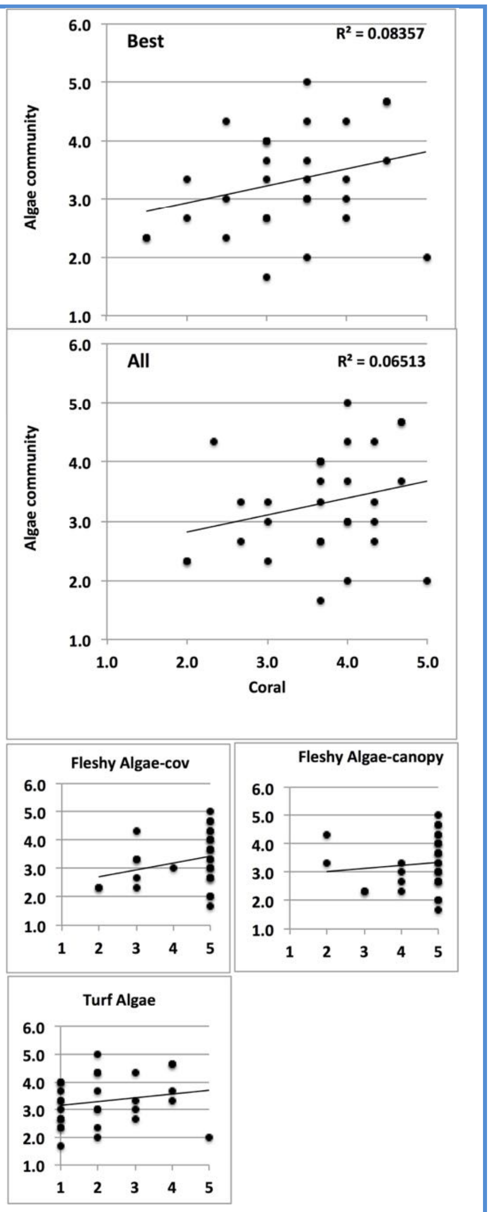
Data from multiple methods was pulled together to obtain the best indicator of coral community health, using both genus and species richness by site (as these showed slightly different patterns, see results section) and three indicators from the resilience indicator estimates. Correlating each indicator against their average indicated highest correlation for species richness (r^2=0.554), then hard coral cover (r^2=0.431) then dominant size class (r^2=0.403). After these both genus richness and largest coral size showed much lower levels of correlation.

Exploring the behavior of correlations using just the best 2 and best 3 indicators, while overall correlations were slightly lower using three (explainable because of its lower value), nevertheless, because each of the three indicators presents a different aspect of coral community structure, it was decided to use the best 3. This indicator of coral community health (***species richness, hard coral cover and dominant size class***) was used as the basis for all subsequent analysis of resilience indicators.

Algal community

Three variables for algal community structure were used: fleshy algal cover, fleshy algal height, and turf algal cover. The table and figure below show the relationships between these and the coral community (best 3 indicators).

Site	**Coral**	**Best**	**All**	**Fleshy Algae-cover ****	**Fleshy Algae-canopy**	**Turf Algae cover ****
My01	3.3	4.0	4.3	5	5	3
My02	3.3	3.5	3.0	3	2	4
My06	3.0	2.5	3.0	4	4	1
My07	2.3	1.5	2.0	2	3	1
My08	1.7	3.0	3.7	5	5	1
My09	2.7	3.0	3.7	5	5	1
My10	2.7	2.0	2.7	3	4	1
My11	3.0	4.0	4.3	5	5	3
My12	2.3	2.5	3.0	3	4	2
My13	2.7	4.0	4.3	5	5	3
My14	2.0	5.0	5.0	5	5	5
My15	2.7	3.0	3.7	5	5	1
My16	3.3	2.0	2.7	3	4	1
My17	3.7	4.5	4.7	5	5	4
My18	3.0	3.5	4.0	5	5	2
My19	3.7	3.0	3.7	5	5	1
My20	4.3	4.0	4.3	5	5	3
My21	4.0	3.0	3.7	5	5	1
My22	4.7	4.5	4.7	5	5	4
My24	3.0	3.5	4.0	5	5	2
My25	3.3	3.0	3.7	5	5	1
My26	2.3	1.5	2.0	2	3	1
My27	4.0	3.0	3.7	5	5	1
My28	3.7	3.5	4.0	5	5	2
My29	5.0	3.5	4.0	5	5	2
My30	4.3	3.5	4.0	5	5	2
My32	4.7	4.5	4.7	5	5	4
My33	4.3	2.5	2.3	3	2	2
My34	2.0	3.5	4.0	5	5	2
My35	4.0	3.0	3.7	5	5	1



Figure/table D2 – Individual values for algal resilience indicators in the right colour coded columns. The three columns to the left show the coral community factor (best 3), then the mean of the best 2 algal indicators and mean for all algal indicators. The figures on the right show the coral community factor on the x axis, plotted against the individual indicators (below, see graph titles), and in the top two, against the best 2 (fleshy algal cover and turf algal cover), and all 3. The selected indicators are highlighted in yellow with bold red typeface.

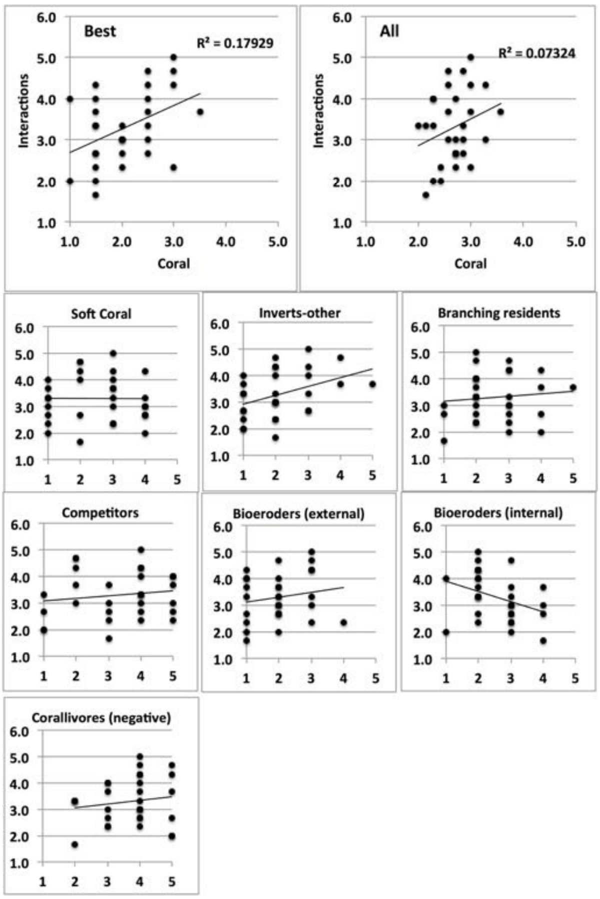
The coral community structure is marginally positively correlated with each of the algal indicators, though only slightly. Correlation between the fleshy algal cover and canopy height is clear from the table, and the skewed distribution of points in their two graphs. Combining turf algal cover and fleshy algal cover gave the highest correlation with coral community structure, higher than all three algal indicators together (shown) and higher than algal turf with fleshy algal canopy and then with the two fleshy algal indicators averaged together.

The algae resilience factor will be indicated by the average of turf and fleshy algal cover.

Interactions

Seven variables for interactions were used: soft coral, invertebrates-other, branching residents, competitors, bioeroders (external), bioeroders (internal), corallivores (negative).

Site	Coral	Best	All	Soft Coral	Invertebrates-other **	Branching residents	Competitors	Bioeroders (external) **	Bioeroders (internal)	Corallivores (negative)
My01	3.3	2.5	2.9	1	2	3	4	3	3	4
My02	3.3	1.5	2.0	4	1	2	1	2	2	2
My06	3.0	2.5	3.3	4	2	3	4	3	3	4
My07	2.3	3.0	3.0	3	2	2	4	4	3	3
My08	1.7	1.5	2.1	2	2	1	3	1	4	2
My09	2.7	2.0	2.7	2	3	2	4	1	3	4
My10	2.7	2.5	2.9	1	3	3	5	2	2	4
My11	3.0	2.0	2.7	4	2	1	2	2	4	4
My12	2.3	1.5	2.7	3	2	3	3	1	3	4
My13	2.7	1.5	2.7	4	1	1	3	2	3	5
My14	2.0	1.5	2.3	1	1	3	1	2	3	5
My15	2.7	1.5	2.7	4	1	4	1	2	4	3
My16	3.3	2.0	2.1	1	3	2	4	1	2	2
My17	3.7	3.5	3.6	3	5	5	3	2	4	3
My18	3.0	2.0	2.9	1	2	3	5	2	3	4
My19	3.7	1.5	2.6	3	1	2	2	2	3	5
My20	4.3	1.5	2.6	2	2	3	4	1	2	4
My21	4.0	1.0	2.3	3	1	2	4	1	2	3
My22	4.7	2.5	2.9	2	2	3	2	3	3	5
My24	3.0	2.0	2.6	3	2	2	3	2	3	3
My25	3.3	1.5	2.3	3	1	2	4	2	2	2
My26	2.3	2.0	2.4	1	1	2	5	3	2	3
My27	4.0	2.5	2.7	1	3	2	5	2	2	4
My28	3.7	2.5	3.0	1	4	4	5	1	2	4
My29	5.0	3.0	3.0	3	3	2	4	3	2	4
My30	4.3	2.5	3.0	4	2	4	2	3	2	4
My32	4.7	3.0	2.6	2	4	2	2	2	2	4
My33	4.3	3.0	3.3	3	3	3	4	3	2	5
My34	2.0	1.0	2.4	4	1	4	1	1	1	5
My35	4.0	1.5	2.3	2	2	2	5	1	1	3



Figure/table D3 – Individual values for interaction indicators are in the right colour coded columns. The three columns to the left show the coral community factor (best 3), then the mean of the best 2 indicators (invertebrates-other, and external bioeroders) and mean for all seven indicators. The figures on the right show the coral community factor on the x axis, plotted against the individual indicators (below, see graph titles), and in the top two, against the best 2 indicators, and all indicators. The selected indicators are highlighted in yellow with bold red typeface.

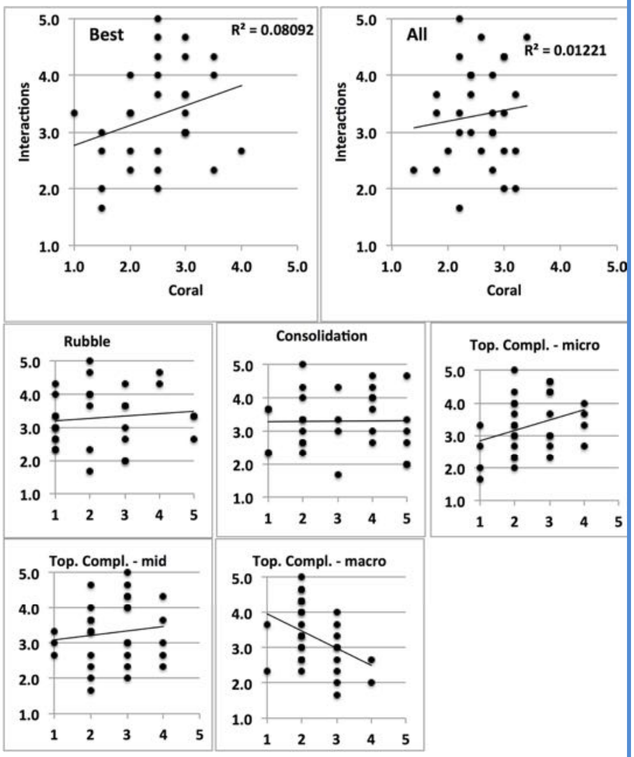
Not all the interactions indicators correlated positively with coral community structure. Soft coral cover, presence of branching residents, competitors and corallivores were either very weakly positive, and internal bioeroders were negatively correlated (i.e. more internal bioerosion was observed in more developed coral communities, which is not surprising give greater coral abundance in the inner reefs where nutrients and sediment influence are higher, supporting internal bioeroders. The percent cover of other invertebrates and abundance of external bioeroders were most strongly correlated with coral community structure, most likely because the former compete for space, and the latter are a direct stress to corals, so their inverse indicators should show positive correlation, as found here.

The Interactions resilience factor will be indicated by the average of invertebrates (other), and external bioeroders.

Substrate condition

Five variables for substrate condition were used: rubble, consolidation, topographic complexity at micro (coral recruitment), middle (coral colonies/fish crevices) and macro (reef structure) scales. The table and figure below show the relationships between these and the coral community.

Sites	1-Coral	Best	All	Rubble	Consolidation	**Top. Compl. – micro ****	**Top. Compl. – mid ****	Top. Compl. - macro
My01	3.3	2.0	3.0	5	3	2	2	3
My02	3.3	1.0	2.8	5	5	1	1	2
My06	3.0	3.0	2.2	1	2	3	3	2
My07	2.3	3.5	2.8	2	2	3	4	3
My08	1.7	1.5	2.2	2	3	1	2	3
My09	2.7	2.5	2.0	1	2	3	2	2
My10	2.7	4.0	2.6	1	2	4	4	2
My11	3.0	1.5	2.8	3	5	2	1	3
My12	2.3	2.0	1.4	1	1	2	2	1
My13	2.7	1.5	3.2	5	5	2	1	3
My14	2.0	1.5	3.0	3	5	1	2	4
My15	2.7	2.0	3.0	3	4	1	3	4
My16	3.3	2.0	1.8	1	2	2	2	2
My17	3.7	2.5	1.8	2	1	3	2	1
My18	3.0	3.0	2.4	1	3	3	3	2
My19	3.7	3.0	3.2	3	4	2	4	3
My20	4.3	2.5	3.0	4	4	2	3	2
My21	4.0	2.5	2.8	2	4	2	3	3
My22	4.7	3.0	3.4	4	5	3	3	2
My24	3.0	3.0	2.8	1	4	2	4	3
My25	3.3	3.0	2.2	1	2	4	2	2
My26	2.3	2.5	1.8	1	1	2	3	2
My27	4.0	2.0	2.4	2	4	2	2	2
My28	3.7	3.0	2.4	3	1	4	2	2
My29	5.0	2.5	2.2	2	2	2	3	2
My30	4.3	3.5	3.0	3	3	3	4	2
My32	4.7	2.5	2.6	2	4	3	2	2
My33	4.3	3.0	2.2	1	2	3	3	2
My34	2.0	2.5	3.2	3	5	2	3	3
My35	4.0	3.5	2.4	1	2	4	3	2



Figure/table D4 – Individual values for substrate indicators are in the right colour coded columns. The three columns to the left show the coral community factor (best 3), then the mean of the best 2 indicators and mean for all five substrate indicators. The figures on the right show the coral community factor on the x axis, plotted against the individual indicators (below, see graph titles), and in the top two, against the best 2 (micro and medium scale topographic complexity), and all indicators. The selected indicators are highlighted in yellow with bold red typeface.

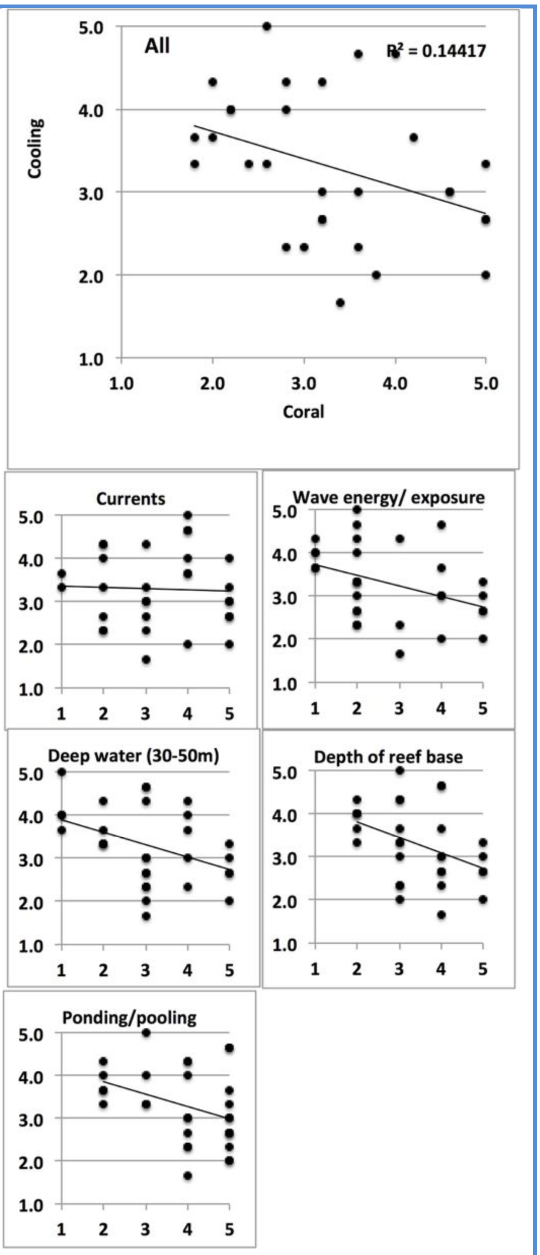
Substrate indicators were poorly correlated with coral health, even for the best two – micro and medium scale topographic complexity. Macro scale complexity was strongly negatively correlated with coral community structure, as the most topographically complex reefs, the rock pinnacles, had the poorest coral diversity and development. They were also the most consolidated reefs. The amount of rubble was not correlated at all with coral community structure, likely because many reefs with high rubble also had good coral cover or diversity (recovering), as well as poor coral development. The importance of micro and mid-scale complexity for corals is related to the need for shelter recruitment space in the former, and that corals create much of the mid-level complexity.

The substrate resilience factor will be indicated by the average of micro and mid-scale topographic complexity.

Cooling

Five variables for cooling were used: currents, wave energy/ exposure, deep water (30-50m), depth of reef base, ponding/pooling. The table and figure below show the relationships between these and the coral community (best 3 indicators).

Sites	1-Coral	Best	All	Currents	Wave energy/ exposure	Deep water (30-50m)	Depth of reef base	Ponding/pooling
My01	3.3		1.8	1	2	2	2	2
My02	3.3		5.0	5	5	5	5	5
My06	3.0		3.2	3	2	3	4	4
My07	2.3		3.0	2	2	3	4	4
My08	1.7		3.4	3	3	3	4	4
My09	2.7		3.2	3	2	3	4	4
My10	2.7		3.2	2	2	3	4	5
My11	3.0		4.6	5	4	5	5	4
My12	2.3		3.6	3	3	4	3	5
My13	2.7		5.0	5	5	5	5	5
My14	2.0		5.0	5	5	5	5	5
My15	2.7		5.0	5	5	5	5	5
My16	3.3		2.4	2	2	2	3	3
My17	3.7		1.8	1	1	2	3	2
My18	3.0		3.6	3	4	3	3	5
My19	3.7		4.2	4	4	4	4	5
My20	4.3		2.8	3	2	3	2	4
My21	4.0		2.8	2	2	4	2	4
My22	4.7		4.0	4	4	3	4	5
My24	3.0		4.6	5	5	4	4	5
My25	3.3		2.6	3	2	2	3	3
My26	2.3		2.8	2	2	3	3	4
My27	4.0		2.2	5	1	1	2	2
My28	3.7		2.0	4	1	1	2	2
My29	5.0		2.6	4	2	1	3	3
My30	4.3		3.2	2	3	4	3	4
My32	4.7		3.6	4	2	3	4	5
My33	4.3		2.0	2	1	2	3	2
My34	2.0		3.8	4	4	3	3	5
My35	4.0		2.2	4	1	1	2	3



Figure/table D5 – Individual values for cooling indicators are in the right colour coded columns. The two columns to the left show the coral community factor (best 3), and the mean of the all the cooling indicators. The figures on the right show the coral community factor on the x axis, plotted against the individual indicators (below, see graph titles), and in the top graph, against the mean of all indicators. No indicators are selected.

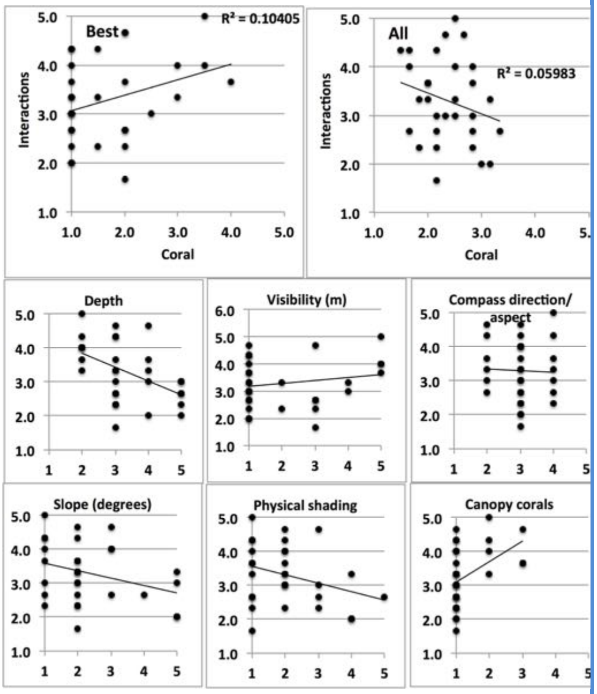
Currents were not correlated with coral community structure, but all other indicators of cooling of the water column were negatively correlated with coral community structure. This is as a result of the strong differentiation between the rock pinnacles and wall habitats, exposed to strong waves, upwelling and deeper water, but that also had less developed coral communities because of the vertical faces, cooler higher nutrient conditions and exposure. Unlike many other areas where cooling indicators are correlated with coral health after bleaching events, this is not the case for the Myeik archipelago. It is worth noting that depth of the reef base and wave energy/exposure show the strongest relationship (though negative) with coral community structure (as well as proximity to deep water). This is comparable to other comparisons in East Africa, though the relationship is opposite. Even with the rock reefs a relationship between the cooling indicators and coral community was absent.

Thus the cooling resilience factor will not be represented in overall analyses.

Screening

Six variables for screening were used: depth, visibility (m), compass direction/ aspect, slope (degrees), physical shading, canopy corals. The table and figure below show the relationships between these and the coral community.

Sites	1-Coral	Best	All	Depth	**Visibility (m)**	Compass direction/ aspect	Slope (degrees)	Physical shading	**Canopy corals**
My01	3.3	3.0	2.5	2	4	3	2	2	2
My02	3.3	1.5	3.2	4	2	3	5	4	1
My06	3.0	2.5	2.5	3	4	3	2	2	1
My07	2.3	2.0	2.8	5	3	3	2	3	1
My08	1.7	2.0	2.2	3	3	3	2	1	1
My09	2.7	2.0	2.2	3	3	3	2	1	1
My10	2.7	1.0	1.7	3	1	3	1	1	1
My11	3.0	1.0	2.8	5	1	2	5	3	1
My12	2.3	1.5	2.2	3	2	4	2	1	1
My13	2.7	2.0	2.8	5	3	2	3	3	1
My14	2.0	1.0	3.2	5	1	3	5	4	1
My15	2.7	1.0	3.3	5	1	4	4	5	1
My16	3.3	1.0	2.0	3	1	4	2	1	1
My17	3.7	2.0	2.0	3	1	3	1	1	3
My18	3.0	1.0	2.2	4	1	4	1	2	1
My19	3.7	1.0	2.0	4	1	2	2	2	1
My20	4.3	1.0	1.7	2	1	3	2	1	1
My21	4.0	1.0	1.7	2	1	3	1	2	1
My22	4.7	2.0	2.3	4	1	2	2	2	3
My24	3.0	1.0	2.3	5	1	3	2	2	1
My25	3.3	1.0	1.8	3	1	2	2	2	1
My26	2.3	1.0	1.8	3	1	3	1	2	1
My27	4.0	3.0	2.5	2	5	3	3	1	1
My28	3.7	4.0	2.8	2	5	4	2	1	3
My29	5.0	3.5	2.5	2	5	4	1	1	2
My30	4.3	1.5	2.2	3	1	4	1	2	2
My32	4.7	2.0	2.7	3	3	3	3	3	1
My33	4.3	1.0	1.5	3	1	2	1	1	1
My34	2.0	1.0	3.0	4	1	3	5	4	1
My35	4.0	3.5	2.8	2	5	3	3	2	2



Figure/table D6 – Individual values for screening indicators are in the right colour coded columns. The three columns to the left show the coral community factor, then the mean of the best 2 indicators and mean for all six indicators. The figures on the right show the coral community factor on the x axis, plotted against the individual indicators (below, see graph titles), and in the top two, against the best 2 (visibility and canopy corals), and all indicators. The selected indicators are highlighted in yellow with bold red typeface.

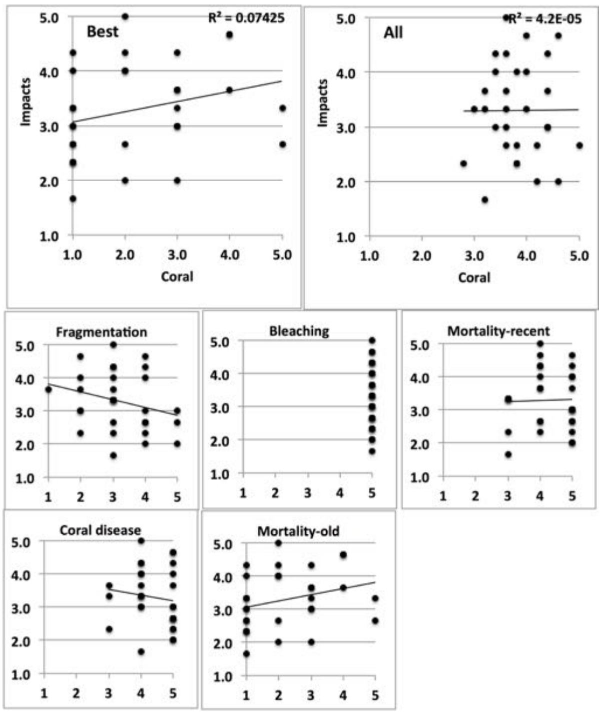
Screening indicators were on the whole negatively correlated with coral community structure, apart from visibility, which had a very slight positive relationship. The existence of a canopy structure has been hypothesized to give some screening from light, and therefore thermal stress (West and Salm 2003, Obura 2005), however, it is also auto-correlated with the coral community structure – a more structure coral community will tend to have some degree of canopy formation. So it must be used with caution.

The screening resilience factor will be indicated by the average of visibility and canopy corals.

Historical impacts

Five variables for historical impacts were used: fragmentation, bleaching, mortality (recent), coral disease and mortality (old). The table and figure below show the relationships between these and the coral community.

Sites	1-Coral	Best	All	Fragmentation	Bleaching	Mortality-recent	Coral disease	**Mortality-old**
My01	3.3	3.0	3.6	3	5	3	4	3
My02	3.3	5.0	4.0	3	5	3	4	5
My06	3.0	1.0	3.4	2	5	5	4	1
My07	2.3	1.0	3.8	4	5	4	5	1
My08	1.7	1.0	3.2	3	5	3	4	1
My09	2.7	1.0	3.6	3	5	4	5	1
My10	2.7	1.0	3.8	4	5	4	5	1
My11	3.0	3.0	4.4	5	5	5	4	3
My12	2.3	1.0	2.8	2	5	3	3	1
My13	2.7	5.0	5.0	5	5	5	5	5
My14	2.0	3.0	4.6	5	5	5	5	3
My15	2.7	2.0	4.2	4	5	5	5	2
My16	3.3	1.0	3.0	3	5	3	3	1
My17	3.7	3.0	3.2	1	5	4	3	3
My18	3.0	1.0	3.6	2	5	5	5	1
My19	3.7	4.0	4.4	3	5	5	5	4
My20	4.3	2.0	3.6	3	5	4	4	2
My21	4.0	1.0	3.8	3	5	5	5	1
My22	4.7	4.0	4.6	4	5	5	5	4
My24	3.0	3.0	4.4	4	5	5	5	3
My25	3.3	1.0	3.2	3	5	3	4	1
My26	2.3	1.0	3.8	3	5	5	5	1
My27	4.0	2.0	4.0	4	5	5	4	2
My28	3.7	3.0	3.6	2	5	4	4	3
My29	5.0	2.0	3.6	3	5	4	4	2
My30	4.3	3.0	4.4	4	5	5	5	3
My32	4.7	4.0	4.0	2	5	4	5	4
My33	4.3	1.0	3.4	3	5	4	4	1
My34	2.0	2.0	4.2	4	5	5	5	2
My35	4.0	2.0	3.4	2	5	4	4	2



Figure/table D7 – Individual values for impact indicators are in the right colour coded columns. The three columns to the left show the coral community factor, then the mean of the 2 best indicators and mean for all 5 indicators. The figures on the right show the coral community factor on the x axis, plotted against the individual indicators (below, see graph titles), and in the top two, against the best indicator (old mortality), and all indicators. The selected indicator is highlighted in yellow with bold red typeface.

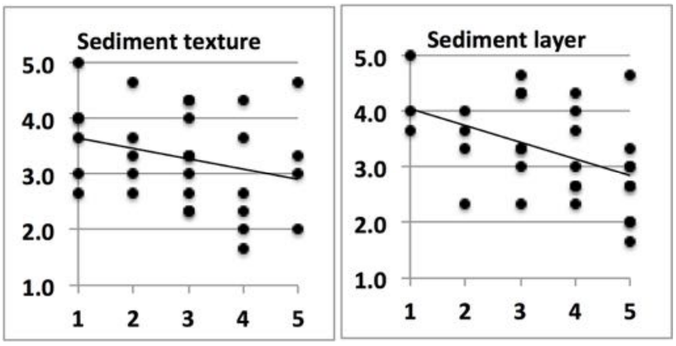
There was no current bleaching during the surveys, and only minimal incidence of some coral diseases or conditions, principally 'purple spot' and a red rust on *Porites* (which is in fact a sponge), and of recent mortality of corals. Thus these are expected to show no meaningful relationship with coral community structure. Fragmentation, while evidence of some disturbance, is also a reproductive strategy for many corals, particularly branching ones and staghorn *Acropora*, and the negative relationship shown here suggests it is not having a detrimental impact. The incidence of old mortality showed the only positive correlation (i.e. low incidence of old mortality was associated with coral community structure) though even this was at very low levels of significance.

The historical impacts resilience factor will be indicated by the level of old mortality.

Sedimentation influence

Two variables for sedimentation influence were used: sediment texture and sediment layer thickness. The table and figure below show the relationships between these and the coral community.

Sites	1-Coral	None	**Sediment texture**	**Sediment layer**
My01	3.3		2	3
My02	3.3		5	5
My06	3.0		2	3
My07	2.3		3	4
My08	1.7		4	5
My09	2.7		4	4
My10	2.7		2	5
My11	3.0		1	5
My12	2.3		4	2
My13	2.7		1	5
My14	2.0		5	5
My15	2.7		3	4
My16	3.3		3	2
My17	3.7		2	2
My18	3.0		3	4
My19	3.7		4	4
My20	4.3		3	4
My21	4.0		3	4
My22	4.7		5	5
My24	3.0		5	5
My25	3.3		3	3
My26	2.3		3	3
My27	4.0		1	2
My28	3.7		1	1
My29	5.0		1	1
My30	4.3		4	3
My32	4.7		2	3
My33	4.3		3	3
My34	2.0		4	5
My35	4.0		1	1



Figure/table D8 – Individual values for sediment influence indicators in the right colour coded columns. The two columns to the left show the coral community factor. The figures on the right show the coral community factor on the x axis, plotted against the individual indicators (below, see graph titles), and in the top two, against all indicators. The selected indicators are highlighted in yellow with bold red typeface.

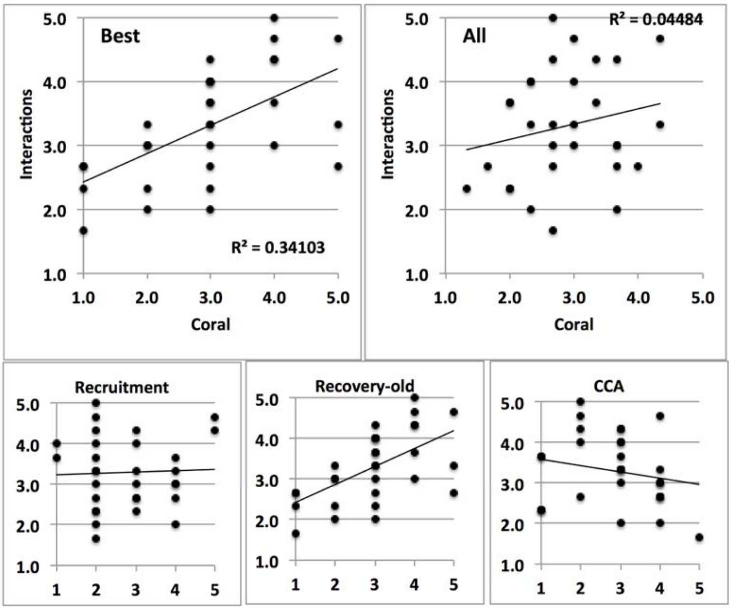
Only two indicators were collected for sedimentation influence, and both of them showed similar levels of negative correlation with coral community structure – indicating that high levels of fine terrestrial sediment were associated with high levels of coral development. This is because the inner reefs were the most developed, thus having a stronger influence on the results than any effect of stress of terrestrial sediments on corals. Because of this, sediment influence can't be used as a negative factor affecting coral development.

The sedimentation resilience factor will not be represented by any indicators

Recovery potential

Three variables for recovery potential were used: recruitment rate, recovery from earlier impacts (old) and cover of crustose coralline algae (CCA). The table and figure below show the relationships between these and the coral community.

Sites	1-Coral	Best	All	**Recruitment**	**Recovery-old**	CCA
My01	3.3	3.0	3.0	3	3	3
My02	3.3	5.0	4.3	4	5	4
My06	3.0	2.0	2.7	2	2	4
My07	2.3	2.0	2.0	3	2	1
My08	1.7	1.0	2.7	2	1	5
My09	2.7	1.0	2.7	3	1	4
My10	2.7	1.0	1.7	2	1	2
My11	3.0	2.0	3.0	3	2	4
My12	2.3	3.0	2.0	2	3	1
My13	2.7	5.0	4.0	3	5	4
My14	2.0	3.0	3.7	4	3	4
My15	2.7	3.0	3.7	4	3	4
My16	3.3	2.0	2.3	2	2	3
My17	3.7	3.0	2.0	2	3	1
My18	3.0	4.0	3.7	4	4	3
My19	3.7	3.0	3.3	4	3	3
My20	4.3	4.0	2.7	2	4	2
My21	4.0	3.0	3.0	3	3	3
My22	4.7	4.0	4.3	5	4	4
My24	3.0	3.0	3.7	4	3	4
My25	3.3	3.0	2.7	2	3	3
My26	2.3	1.0	1.3	2	1	1
My27	4.0	3.0	2.3	1	3	3
My28	3.7	4.0	2.0	1	4	1
My29	5.0	4.0	2.7	2	4	2
My30	4.3	4.0	3.3	3	4	3
My32	4.7	5.0	3.0	2	5	2
My33	4.3	3.0	3.7	5	3	3
My34	2.0	2.0	2.3	2	2	3
My35	4.0	3.0	2.3	2	3	2



Figure/table D9 – Individual values for recovery indicators in the right colour coded columns. The three columns to the left show the coral community factor, then the mean of the best 2 indicators and mean for all recovery indicators. The figures on the right show the coral community factor on the x axis, plotted against the individual indicators (below, see graph titles), and in the top two, against the best 2 (recruitment and old recovery), and all indicators. The selected indicators are highlighted in yellow with bold red typeface.

Against expectations, estimated recruitment of corals was not correlated with coral community structure, and neither was the cover of crustose coralline algae. Estimated level of recovery from old impacts was strongly correlated with coral structure.

The recovery resilience factor will be indicated by the estimated level of recovery (from old impacts).

Resilience radar plots by site

Figure D10. Radar plots of resilience factors per site. All details are the same as in Fig. 15. Polygons are shaded to show those in the upper (green), middle (yellow) and bottom (red) thirds of resilience scores across all sites. Same data as Table 5.