Tanintharyi Conservation Programme

Assessment of the Myeik Archipelago Coral Reef Ecosystem

ReefCheck Surveys January 2013 to May 2014

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Cover image Surveying percentage coral cover in Myeik Archipelago. Credit: FFI (2014).

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1. ABSTRACT

Coral reefs play a critical role in the health of marine ecosystems and are an important source of protein and income to millions of people worldwide. This reliance on coral reefs has however come at a price with fish stocks on coral reefs declining from overexploitation. This is especially true for Myanmar's Myeik Archipelago in which overfishing and use of destructive fishing methods has led to a decline in fish numbers and degradation of reefs. Steps are therefore needed to identify key biodiverse areas within the archipelago and develop management strategies to conserve the ecosystem. Marine Protected Areas (MPAs) are promoted as one such strategy for the conservation and management of exploited fisheries and marine communities, however managers lack reliable and relevant data on the archipelago's marine ecosystems to implement such a tool. To address this issue assessments of coral reefs throughout the archipelago were undertaken to 1) ascertain the status of coral reefs within the archipelago; and 2) identify key biodiverse areas suitable for marine protected area designation. In total 180 sites were surveyed using Reef Check and visual analysis methods recording extent of coral cover, indicator fish and invertebrate abundance and diversity and anthropogenic impacts. Results from the surveys show that overall coral cover within the archipelago is less than 30% and heavily degraded, however there are still a number of individual sites which have a diverse and extensive coral cover falling within the Good (51-75%) to Very Good range (76-100%). Indicator fish species abundance was very low across the whole archipelago, although numbers were found to be higher on those reefs further from large city centres. No sharks, rays or turtles were observed. Invertebrate abundance was dominated by long-spined sea urchins (*Diadema sp.*) which were found in very high numbers across most of the surveyed reefs. Sea cucumbers were in very low numbers, which believed to be a result of over collection and no large aggregations of Crown of thorns starfish were observed. Most sites surveyed recorded some level of anthropogenic impact with dynamite fishing still found to be prevalent even though its use is banned. Anchor damage continues to cause heavy impacts on a number of reefs, most notably those close to the city centre of Myeik, as are discarded fishing nets which smother corals. Results of the surveys show that the archipelago shows clear signs of degradation and overfishing but has a number of sites where the coral habitat is still intact providing a chance of recovery for the ecosystem as a whole. These sites have been recommended as priority areas in terms of a marine protected area network including models of co-management with resource uses.

2. INTRODUCTION:

Coral reefs are worth almost 30 billion dollars in terms of the good and services they provide (Cesar et al. 2003) such as coastal protection, nursery habitat and feeding grounds for marine organisms and sustaining the livelihoods and protein sources of millions of people through fisheries (Moberg and Folke 1999; Burke 2012). They are, however, in decline world-wide (Burke 2012) and part of this degradation has been attributed to a rise in human population and increased migration to coastal areas (Lubchenco et al. 2003; Fabricius 2005) causing sedimentation through terrestrial runoff (Fabricius 2005), coastal pollution and declines in coral cover and fish stocks from overfishing (Hughes et al. 2007; Anthony et al. 2011). There is therefore a heightened need for more effective ways to conserve marine ecosystems, and although not able to mitigate all these threats, marine protected areas (MPAs) are seen as an effective tool in the management of coastal marine environments (Boersma and Parrish 1999; McClanahan and Arthur 2001; Lubchenco et al. 2003). MPAs take on various functions depending on their designation e.g. from allowing certain forms of resource extraction to total off limit areas (Boersma and Parrish 1999; Lubchenco et al. 2003) known as 'Closed' or 'No Take Zones', however their goals are essentially the same, that is, to provide protective refuges and habitat for exploited fish species while benefiting fished areas through exporting larvae and eggs through spillover (Gell and Roberts 2003); as well as conserving overall biodiversity and maintaining ecosystem services (Lubchenco et al. 2003).

The creation of MPAs however is not without its critics who argue that commercially targeted species are too mobile to be protected by MPAs and that closing off areas will reduce catches and increase travelling time (Harrison et al. 2012). Furthermore MPAs are noted as being unable to mitigate against other impacts such as introduced species (Boersma and Parrish 1999), coral bleaching or pollution (Jones et al. 2004). However, MPAs are not designed to be used in isolation and need to complement other conservation tools for managing marine environments (Lubchenco et al. 2003). The benefit to fisheries and management of exploited species however is well documented and MPAs have shown to increase the size and abundance of targeted fish species which mainly occupy the higher trophic levels as predators (Gell and Roberts 2003; Jones et al. 2004; Hawkins et al. 2006; Harrison et al. 2012; Raberinary and Benbow 2012). For coral cover however, although MPAs have been shown, through meta-analysis to be generally effective in reducing or preventing coral loss, their effects on reef heterogeneity, coral composition and richness are less known (Selig and Bruno 2010). However the study also found that older MPAs can increase the resilience of reefs. This may have important ramifications on the protection of coral reefs given the mounting threats including outbreaks of *Acanthaster planci*, the Crown of Thorns starfish (COT) (Brodie et al. 2012); runoff from intensified land clearing (Fabricius 2005; Diaz and Rosenberg 2008); chemical pollution and oil spills (Aronson and

Precht 2006); coral disease (Roff et al. 2011); human induced CO2 increase in the atmosphere causing ocean acidification and global warming (Anthony et al. 2011); and overfishing. Although MPAs may not be able to prevent these threats directly, except overfishing, a more resilient reef may be able to withstand these impacts. Furthermore, in terms of a multispecies fishery, where setting size and catch limits is near impossible, MPAs are considered a cost effective tool in sustainably managing the fishery whereby a range of targeted species have some form of protection in a fishery that is hard to regulate (Hilborn et al. 2004; Sumaila et al. 2000).

Worldwide however MPAs cover less than 2.8% of the oceans (UNEP-WCMC 2013). This is of particular concern for countries such as Myanmar which is considered both socially and economically vulnerable from reef loss given its reliance on marine habitats as a major food source (Burke et al. 2012). Situated in the east Andaman Sea the country has a coastline stretching over 2,200km and supports a rich variety of biodiverse marine habitats including coral reefs, mangrove forests, seagrass beds, mudflats and sand beaches (Cox et al. 2013). However, the country's marine ecosystems are under increasing pressure from unregulated fishing, destructive fishing techniques, sedimentation, pollution, increasing coastal populations and climate change (BANCA 2011; Rao et al. 2013; Obura 2014; Cox et al 2013). Fisheries surveys comparing catch per unit effort data from 1979-80 to 2013 found a six-fold decrease, and standing stock of pelagic fish estimates for 2013 approximately 10% of 1980 levels (Yin Yin Moe 2013). (For full review of Myanmar's marine ecosystems see Holmes 2013). In Myanmar MPAs are extremely under represented with only six protected areas existing which have marine components (Moscos Island, Thamihhla Kyun Wildlife Sanctuary, Lampi Marine National park and two Shark Protected Areas) (Holmes et al 2013, Cox et al 2013). In addition, institutions responsible for the management of these areas lack the resources and capacity for their implementation (Rao et al. 2013) and as such several remain as paper parks. This is further compounded by the fact that these institutions are lacking temporally and spatially reliable and relevant data on marine ecosystems, species, population dynamics, threats etc. in order to support the design and implementation of a marine protected area network.

Therefore, since 2013 a team of Myanmar marine biologists, trained in scuba diving and marine survey techniques, undertook broadscale surveys of the coral reefs within Myeik Archipelago using Reef Check methodology to 1) ascertain the status of coral reefs within the archipelago; and 2) identify key biodiverse areas suitable for marine protected area designation. These surveys were complimented by additional specialist surveys on the resilience of the archipelago's coral reefs (see Obura et al 2014). The following report provides the results of the Reef Check surveys only but combines the resilience information when discussing potential MPA sites.

3. METHODS:

Site Description and Selection

A total of 115 sites were surveyed within Myeik Archipelago between January 2013 and May 2014 (Figure 1, Appendix 1). The archipelago consists of over 800 islands and is within the Tanintharyi region of Myanmar (Cox et al. 2013). The reefs surveyed fall into three broad categories as described by Obura et al. (2014): 1. fringing reefs on outer islands characterised by coral covered boulder slopes of depths up to 15m in addition to shallower sandy bays; 2. Rock reefs, including pinnacles and steep slopes off islands down to 30m and noted for encrusting corals; and 3. Inner fringing reefs, sheltered islands closer to the mainland known for higher turbidity. In general, sites were characterised by a range of massive and branching corals species, few soft corals and algae elements, and home to a diverse, yet low in abundance, faunal assemblage. As the main objective behind these surveys was to find areas within the archipelago with the high conservation value in terms of coral reefs sites only those sites with an estimated coral cover of over 20% were surveyed. Snorkel surveys were therefore conducted at each site to visually estimate coral cover before a quantitative survey was performed.

Reef Check Surveys

To undertake the surveys Reef Check (Hodgson et al. 2006) methodology was employed which is a worldwide monitoring tool used to assess coral reef health and designed for the use by scientists and non-scientists including local community groups. This methodology focuses on the abundance of a set of readily identifiable indicator species (Table 1) that are used to gauge the health of a coral reef ecosystem. The standardised methodology is useful for comparing reefs and regions and therefore provide Myanmar marine decision makers with information on the relative status of their reefs. For the purpose of these surveys Reef Check was also used to provide a baseline of quantitative data on the archipelago's coral reefs and for the identification of key biodiverse areas.

Table 1 Key indicator species included in Reef Check methodology as 'early-warning' indicators of the general condition of coral reef ecosystems (from Cox et al 2013)

Indicator Species	Scientific Name	Warning if numbers are:	Indicator of:
Crown of thorns	*Acanthaster planci*	High	Heavily impacted and degraded ecosystem
Long-spined sea urchin	*Diadema antillarum*	High	Overfishing and heavily impacted/degraded ecosystem
Butterfly fish	*Chaetodon spp.*	Low	Overfishing and possible aquarium trade
Groupers (>30cm)	*Epinephelus spp.*	Low	Overfishing
Parrotfish (>20cm)	*Scaridae spp.*	Low	Overfishing
Lobster	*Nephropidae spp.*	Low	Overfishing
Pencil urchin	*Eucidaris tribuloides*	Low	Overfishing and curio trade
Giant clam	Tridacna gigas	Low	Overharvesting and aquarium/curio trade

Standard Reef Check methodology involves the use of four 20m transects (replicates) at each site at two depths of 2-6m and 6-12m. Given the scarcity of corals across different depth ranges in the archipelago the survey methodology was revised to carry out five 20m replicates at each site along one depth contour with a minimum five metre gap between each replicate (Figure 2 and 3). All transects ran parallel to the shoreline and depths averaged 6.8m (range 1.3-30.0m). For each surveyed site the following was recorded (from Cox et al 2013):

1. Site description – qualitative description of the survey site including GPS location, survey depth, visibility, surveyor details, survey conditions etc.
2. Substrate composition - point sample, substrate data at 0.50 m intervals along each replicate transect line.
3. Fish abundance, size and diversity (pre-selected indicators only) – abundance estimates along the belt transects - surveyors estimate the total number of indicator species seen within an imaginary area measuring 10 m wide x 5 m high along each 20 m transect line. Fish size was estimated for Groupers, e.g. *Epinephelus spp*.
4. Invertebrate abundance, size and diversity (pre-selected indicators only) - the total number of certain invertebrate species within the survey area (10m x 20m belt transect). Size estimates for giant clams.
5. Anthropogenic impacts, coral disease and bleaching - indicators of anthropogenic damage within the 10m x 20m belt transect area. Impacts were categorised in terms of severity:
    - 0 = no damage
    - 1 = low damage, 1 instance
    - 2 = medium damage, 2-4 instances
    - 3 = high damage, > 5 instances

A detailed description of each surveyed category is given in Appendix 1.

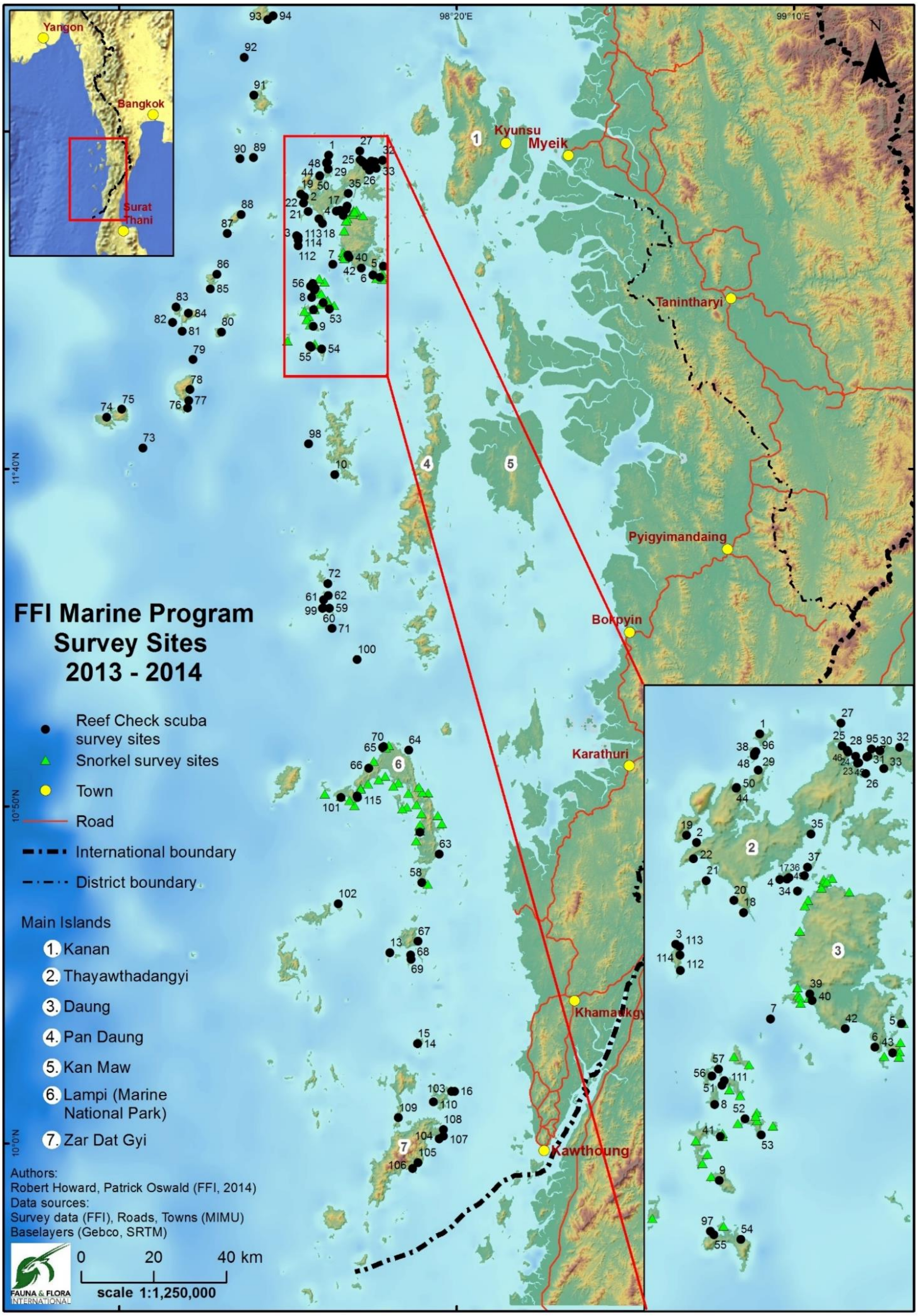


Figure 1 Reef Check and snorkel survey sites from January 2013 to May 2014 in Myeik Archipelago, Myanmar.

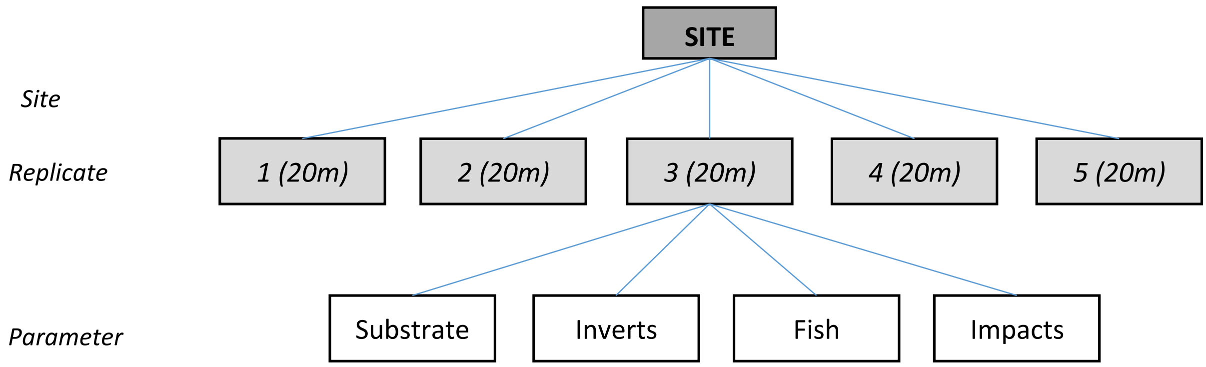


Figure 2 Sampling design for each Reef Check survey.

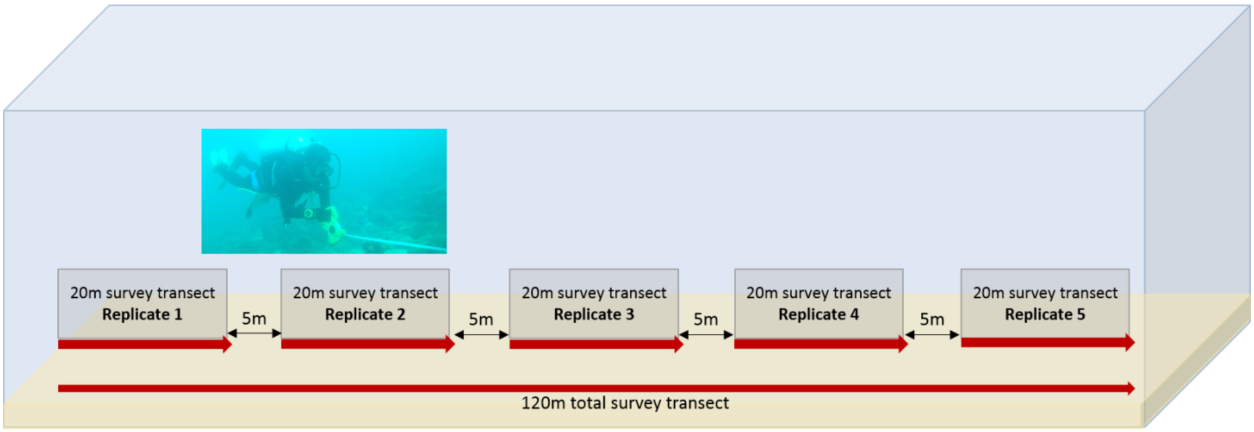


Figure 3 Reef Check methodology used. Five 20 m transects (replicates) surveyed at each site. Each replicate is spatially separated from the next by 5 m.

In addition to site level, data was grouped by five island groups (referred to as geographical areas) Figure 4.

1) Lampi Island Group (LMP) (inner reef, declared marine national park);
2) Pyin Sa Bu Island Group (PSB) (inner and rocky reefs);
3) Torres Island Group (TOR) (outer and rocky reefs);
4) Thawaythadangyi Island Group (TYT) (inner reefs); and
5) Zar Dat Gyi Island Group (ZDG) (inner reefs)

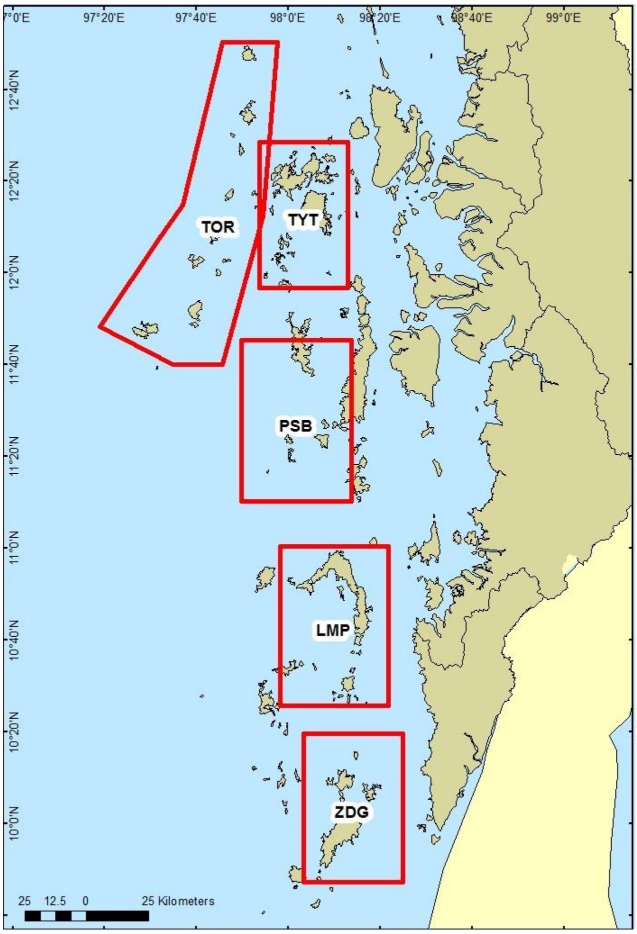


Figure 4. Five island groups surveyed Lampi Island Group (LMP); Pyin Sa Bu Island Group (PSB), Torres Island Group (TOR), Thawaythadangyi Island Group (TYT) and Zar Dat Gyi Island Group (ZDG).

Data analysis

The data for each transect was imported into individual Reef Check Excel spreadsheet templates and then into a master spreadsheet containing all sites in which the five replicates per transect could be averaged for analysis. For the Torres Island Group surveys only one replicate was performed per site due to time and depth constraints. As such caution must be exercised in the interpretation of this data. For sites 1-16 only benthic data, validated by an expert, were analysed as these were the first surveys conducted by the survey team. Coral cover was classed as per Habibi et al. (2007) with: Poor (0-25%), Average (26-50%), Good (51-75%) and Very Good (76-100%). Given that sites were not sampled randomly, statistical analysis was not performed on the data. Despite this, some useful conclusions can still be drawn using pivot tables and charts. Statistical significance was however assessed for urchin abundance versus coral cover and depth versus coral cover. In these cases a Pearson's correlation was used with a Shapiro Wilks test used to test for normality and Levene's test for homogeneity of variance. For all statistical tests performed an alpha level of 0.05 was used. N values are given for each analysis as not all variables were assessed at each site due to time constraints.

4. RESULTS:

Substrate composition

Across 115 surveyed sites hard coral cover dominated with a mean percentage of 51.2% (±2.5), with a range of 0% at Blundel Island (site 89) (which was dominated by soft coral) to 92% at That Pan Nyo (site 38) and Zar Dat Ngal (site 110) (Figure 5) (refer to Figure 1 for site locations). The second highest recorded substrate was dead coral with 19.1% (±1.3) followed by rubble at 11.7% (±1.5). The remaining substrates were all under 7%, the lowest being sponges at 0.14% (±.05).

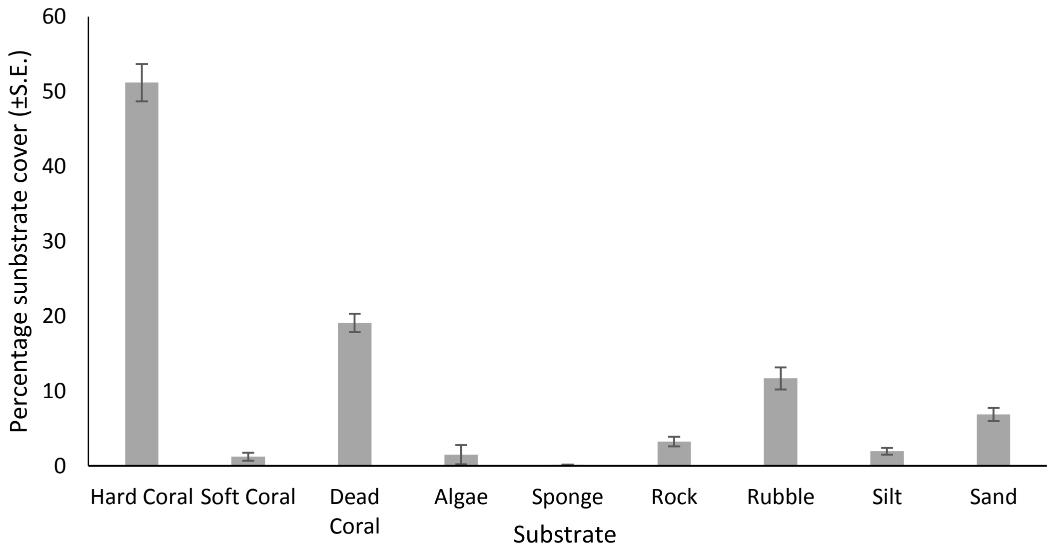


Figure 5 Mean percentage cover of nine categories of substrate (±S.E.) across Myeik Archipelago. (n = 115 except for algae where n=16).

This pattern was similar across the five geographical areas with hard coral dominating in TYT (64.3% ±2.8), ZDG (50.6% ±5.2), PSB (50.1% ±8.6) and LMP (40.2% ±5.7) (Figure 6). In TOR however percentage cover for hard coral, dead coral and rubble were very similar with 25.6% (±5.5), 24.1% (±4.3) and 24.7% (±5.4) respectively. For all locations dead coral coverage was similar (between 15-25%) while rubble, rock and sand, the next dominant substrates varied between sites but generally under 15% (Figure 6). In all five locations soft coral cover was low with the highest 4.2% (±2.6) at TOR. Likewise algae cover was limited with the highest coverage at TYT (2.3% ±2.3).

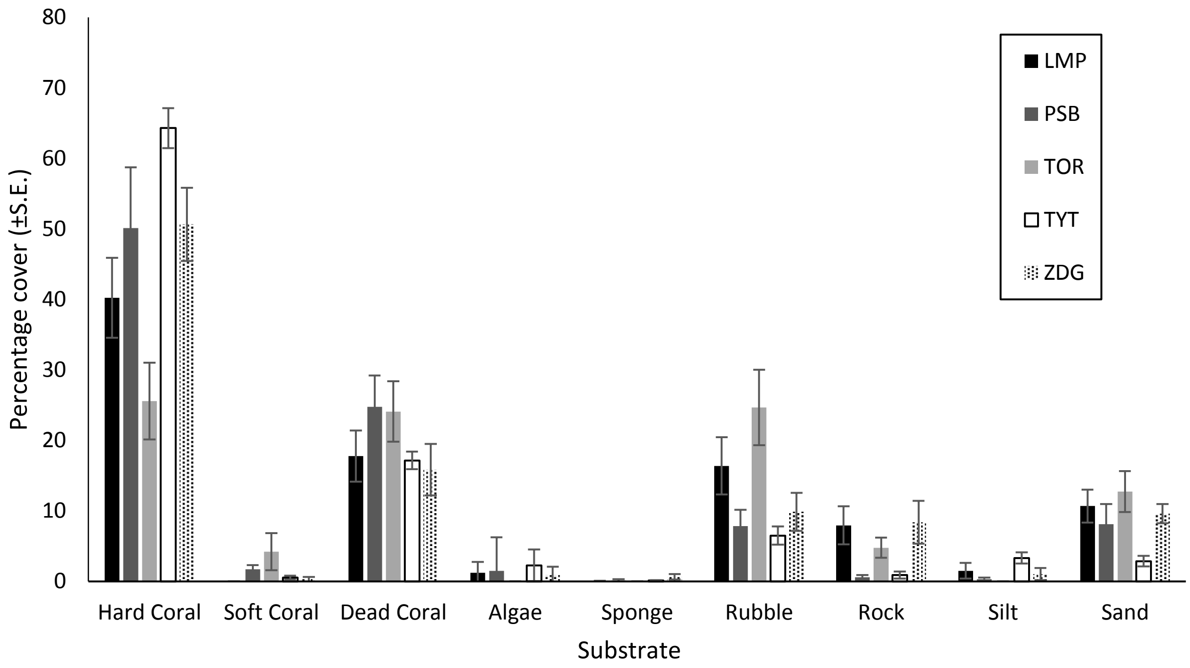


Figure 6 Mean percentage cover of nine categories of substrate (±S.E.) by geographical areas: Lampi (LMP, n=15 [algae n=3]), Pyin Sa Bu (PSB, n=10 [algae n=1]), Torres (TOR, n=22 [algae n=0]), Thawaythadangyi (TYT, n=57 [algae n=9]) and Zar Dat Gyi (ZDG, n=11[algae n=3]) Island Groups.

When surveyed hard coral is broken down into morphological types massive coral dominates with 22.5% (±1.8) and is almost 2.5 times more prevalent then the next dominant coral type acropora branching with 9.2% (±1.8) (Figure 7). The remaining categories are sparsely represented with less than 6% cover for each with the lowest of 0% for fire coral and *Tubipora* corals.

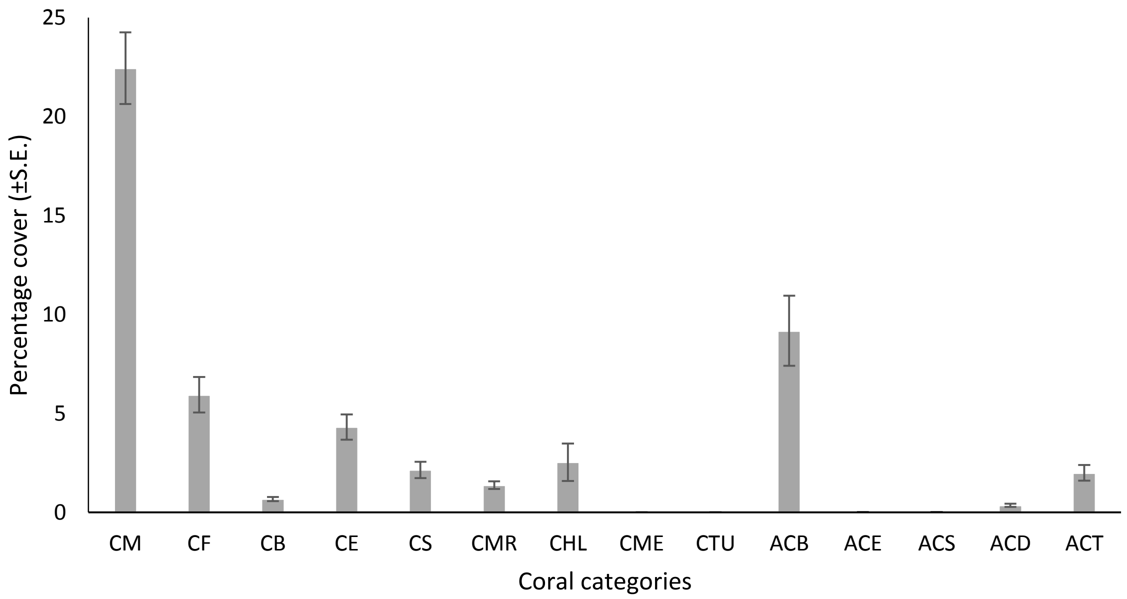


Figure 7 Mean percentage cover of 14 coral categories (±S.E.) across Myeik Archipelago (n = 115). (Codes: CM- Coral Massive; CF- Coral Foliose, CB- Coral Barnching; CE- Coral Encrusting; CS- Coral Sub-massive; CMR- Mushroom Coral; CHL- *Heliopora*; CME- Fire Coral; CTU- *Tubipora*; ACB- Acropora Branching; ACE- Acropora Encrusting; ACS- Acropora Submassive; ACD- Acropora Digitata; and ACT- Acropora Tabulate).

This pattern was not found to be universal across the five geographic areas with branching *Acropora* corals dominating in PSB, while in TOR massive and *Acropora* branching corals were found to have similar cover (Figure 8).

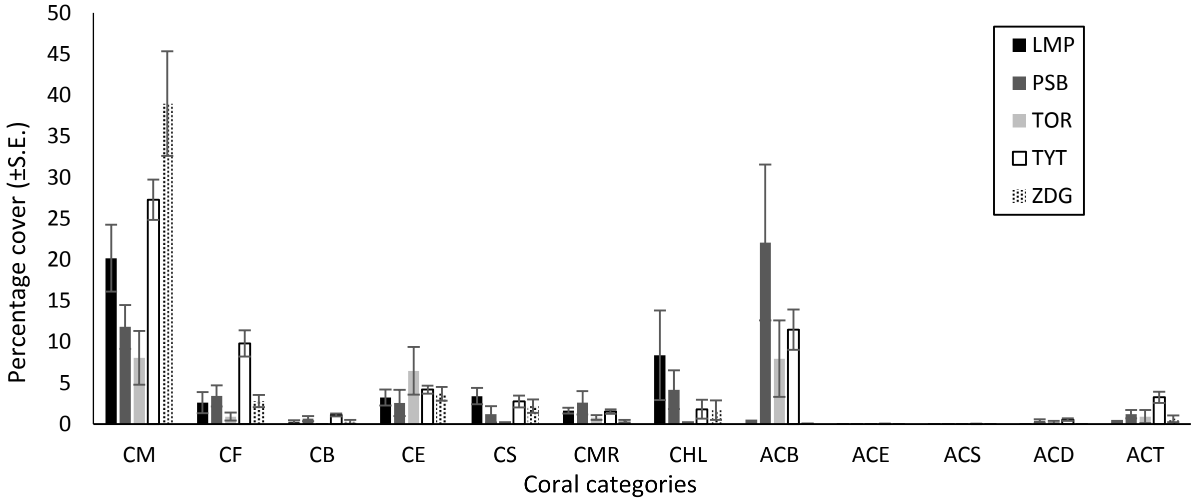
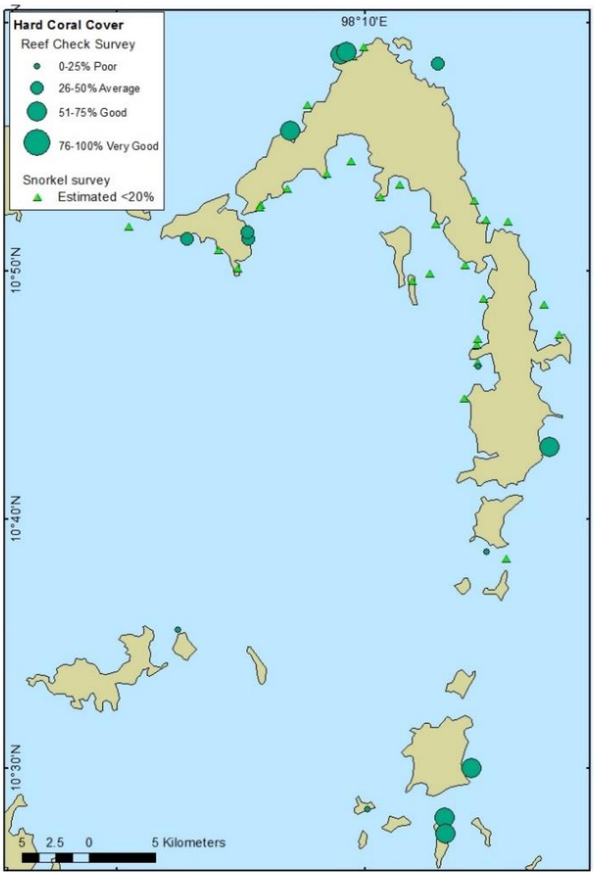


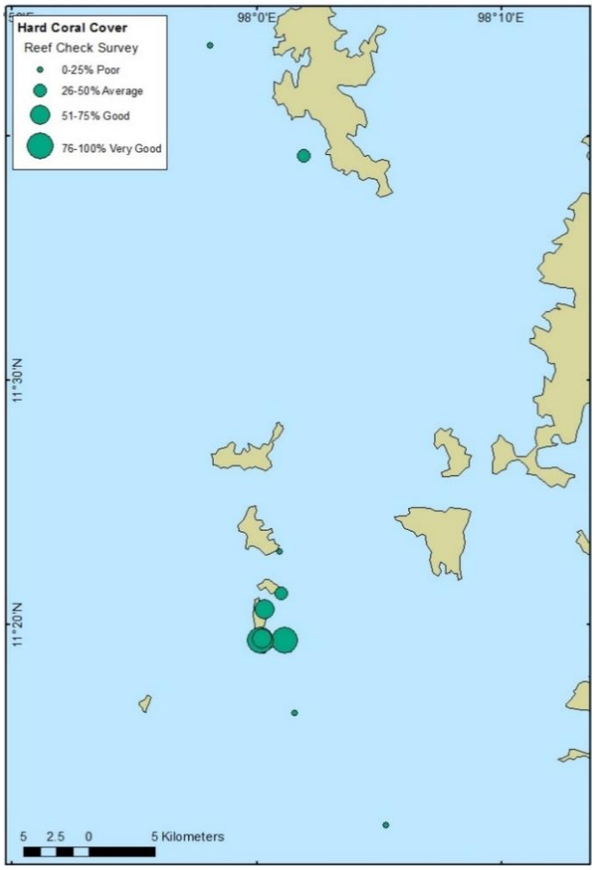
Figure 8 Mean percentage cover of 14 coral categories (±S.E.) by geographical area: Lampi (LMP, n=15), Pyin Sa Bu (PSB, n=10), Torres (TOR, n=22), Thawaythadangyi (TYT, n=57) and Zar Dat Gyi (ZDG, n=11) Island Groups. (Codes: CM- Coral Massive; CF- Coral Foliose, CB-Coral Barnching; CE- Coral Encrusting; CS- Coral Sub-massive; CMR- Mushroom Coral; CHL- *Heliopora*; CME- Fire Coral; CTU- *Tubipora*; ACB-Acropora Branching; ACE- Acropora Encrusting; ACS- Acropora Submassive; ACD- Acropora Digitata; and ACT- Acropora Tabulate).

Within the five geographical areas substrates varied across sites and hard coral cover ranged from under 10% to over 90% in some locations. In LMP hard coral cover varied from 7.5 to 71% (n= 15; Figure 9a); in PSB from 18.6 to 86% (n= 10; Figure 9b); TOR 0 to 80% (n= 22; Figure 9c); and ZDG 20 to 92% (n= 11; Figure 9d); and TYT 6 to 92% (n= 57; Figure 9e). Hard coral cover was not found to vary with depth with no significant correlation observed when only sites where all five replicates were surveyed were compared (t = -0.9604, df = 78, p-value = 0.3398).

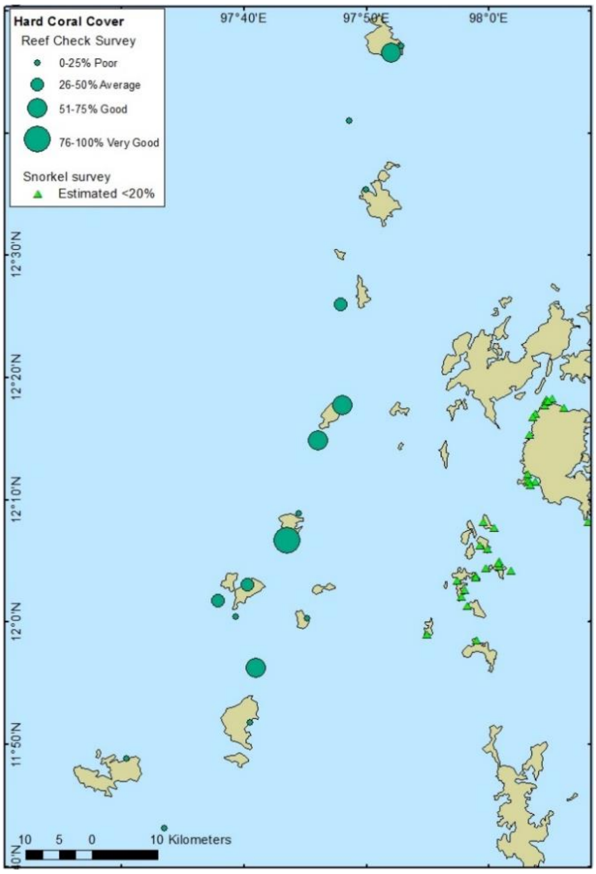
a. LMP



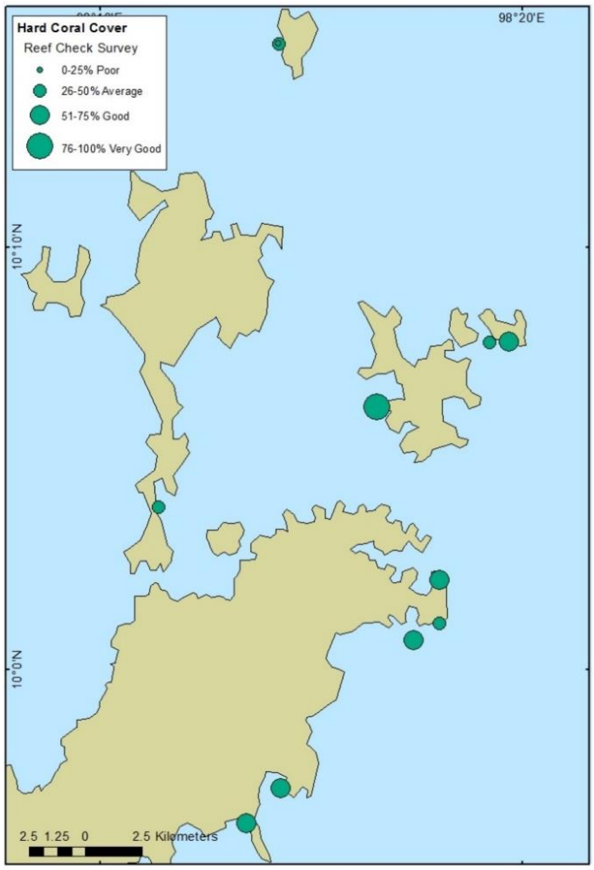
b. PSB



c. TOR



d. ZDG



e.

f.

e. TYT

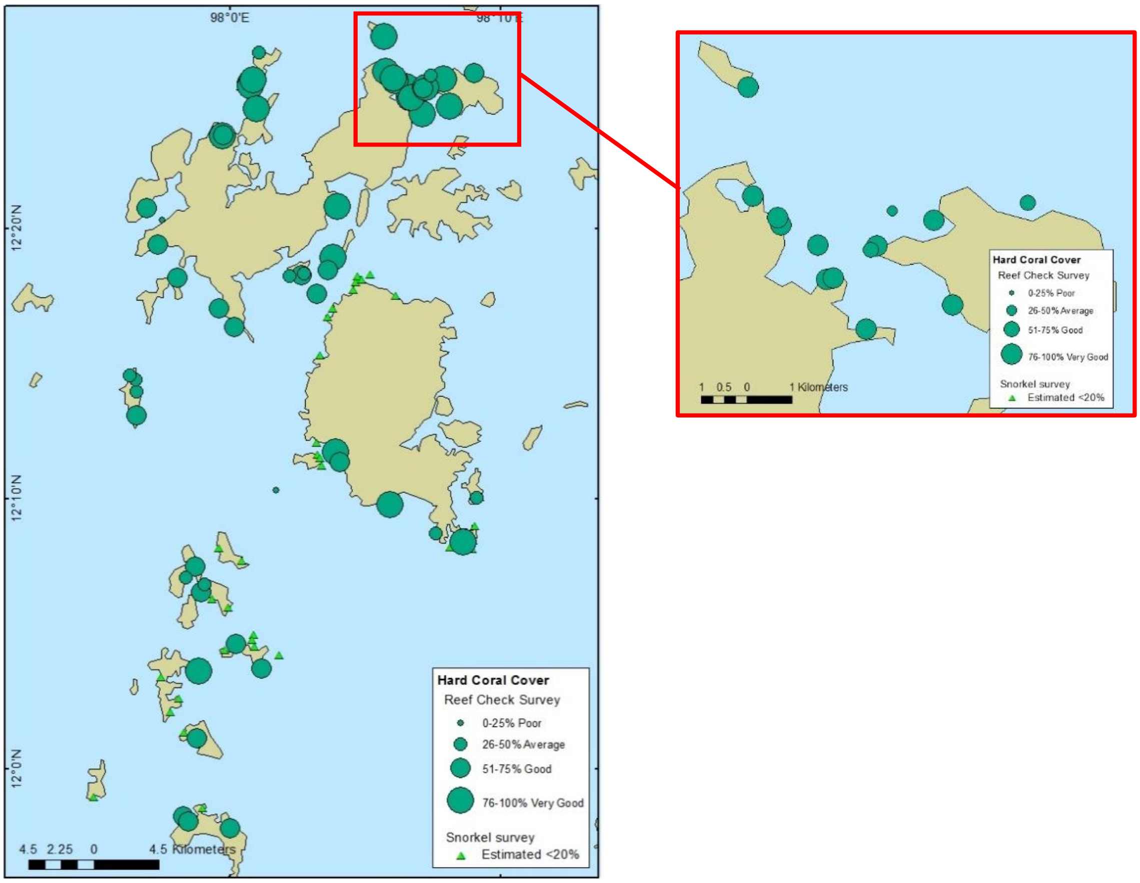


Figure 9 Mean percentage cover of Hard Coral by geographical area: a. Lampi (n=15); b. Pyin Sa Bu (n=10), c. Torres (n=22); d. Zar Dat Gyi (n=11); and e. Thawaythadangyi (n=57).

Fish abundance, size and diversity

The mean number of fish for all 9 categories across all surveyed sites were found to be low. Snapper numbers were highest, with an average of 9.0 (±2.7) fish across the 91 transects surveyed (Figure 10). This was followed by butterflyfish (4.2 (±0.8)), parrotfish (3.8 (±1.0)) and grouper (3.2 (±0.5)). The remaining fish were found to have less than one fish per transect for all surveyed sites (Table 2). For the groupers, the 30-40cm size class dominated with 96.2% of the total groupers recorded, almost 30 times the next highest category 40-50cm with only 3.2% of the total. Both the 50-60cm and >60cm categories recorded less than 1% of all grouper size classes with 0.5 and 0.1% respectively. No sharks, rays or sea turtles were recorded on any of the transects.

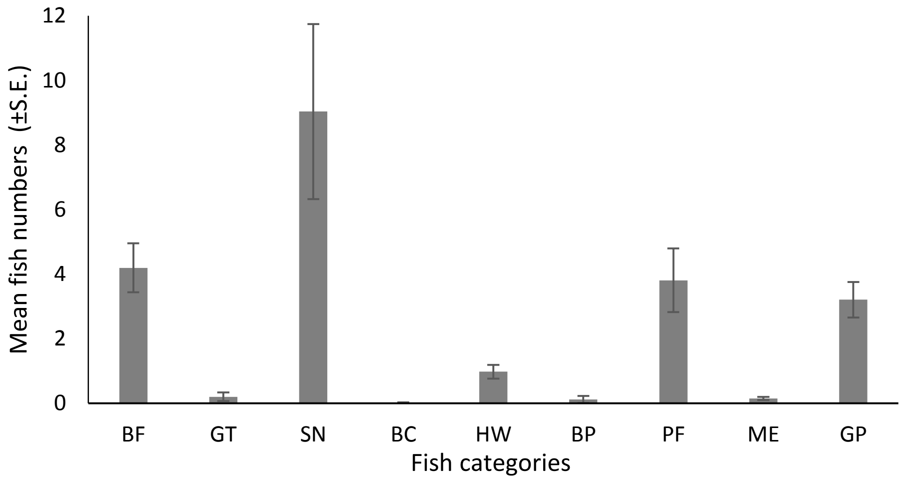


Figure 10 Mean fish numbers for 9 fish categories (±S.E.) per transect at 91 sites across Myeik Archipelago. (BF- Butterflyfish, GT- Haemulidae, Sweetlip, SN- Snapper, BC- Barramundi Cod, HW- Humphead Wrasse, BP- Bumphead Parrotfish, ME- Moray Eel and GP- Grouper).

Table 2. Mean fish numbers for 5 fish categories recording less than 1 (±S.E.) per transect at 91 sites across Myeik Archipelago

Code	Fish Group	Mean number of fish (±S.E.)
GT	Haemulidae, Sweetlip	0.20 (±0.1)
BC	Barramindi Cod	0.06 (±0.01)
HW	Humphead wrasse	0.98 (±0.2)
BP	Bumphead Parrotfish	0.12 (±0.1)
ME	Moray eel	0.51 (±0.1)

The mean number of fish per transect did, however, vary at the geographical area level, but butterflyfish, snapper, parrotfish and groupers dominated at all sites with the other categories recording very low numbers (Figure 11). When comparing the four main fish groups noted above TOR showed the highest abundance for most of these categories followed by PSB, LMP, ZDG then TYT (Table 3).

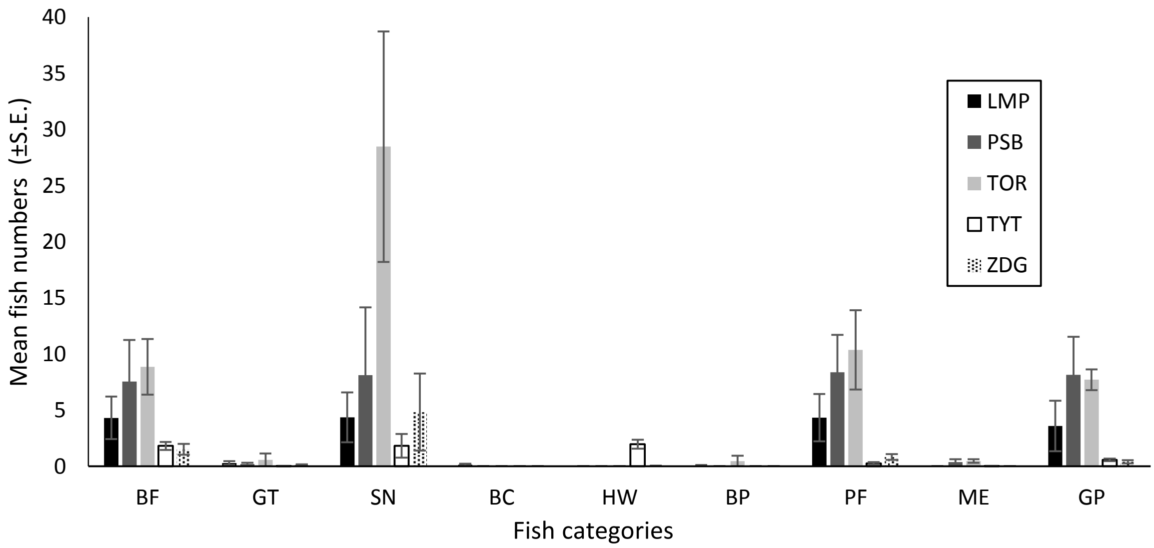


Figure 11 Mean fish numbers for 9 fish categories (±S.E.) per transect by geographical area: Lampi (LMP, n=10), Pyin Sa Bu (PSB, n=8), Torres (TOR, n=21), Thawaythadangyi (TYT, n=45) and Zar Dat Gyi (ZDG, n=7) Island Groups. (BF- Butterflyfish, GT- Haemulidae, Sweetlip, SN- Snapper, BC- Barramundi Cod, HW- Humphead Wrasse, BP- Bumphead Parrotfish, ME- Moray Eel and GP- Grouper).

Table 3 mean fish numbers for the four dominant fish categories (±S.E.) per transect by geographical area: Lampi (LMP, n=10), Pyin Sa Bu (PSB, n=8), Torres (TOR, n=21), Thawaythadangyi (TYT, n=45) and Zar Dat Gyi (ZDG, n=7) Island Groups. * Denotes highest value for each fish category and ‡ the lowest.

	Butterfly fish	Snapper	Parrotfish	Grouper
LMP	4.3(±1.9)	4.4(±2.2)	4.3(±2.1)	3.6(±2.2)
PSB	7.6(±3.7)	8.1(±6.0)	8.4(±3.3)	8.2(±3.4)*
TOR	8.9(±2.5)*	28.5(±10.3)*	10.4(±3.5)*	7.7(±0.9)
TYT	1.8(±0.3)	1.8(±1.1) ‡	0.3(±0.1) ‡	0.6(±0.1)
ZDG	1.5(±0.5)‡	4.8(±3.4)	0.8(±0.3)	0.4(±0.1) ‡

Within the five geographical areas the numbers of fish within the four main fish categories varied considerably across sites with the highest ranges per transect within TOR for snapper between 0 (sites 85 and 89) and 200 (site 80) (however as noted in the methods only one replicate was used for TOR surveys). Figure 13 a-d provide spatial results of this data.

Invertebrate abundance, size and diversity

Diadema were the most common of all the invertebrates recorded with 55.7 (±10.8) individuals per transect (Figure 12). Mean invertebrate numbers per transect were generally very low with all but banded coral shrimp (10.1±4.3) and *Diadema* recording means under one. The crown of thorns starfish (COT) was found in very low numbers with a mean of only 0.07 (±.03) and the maximum number recorded at any one site was three individuals at site 60 within PSB. For giant clams, with a mean of only 0.55 (±0.4) individuals per transect, records were dominated by those in the smallest size class, length <10cm, with means decreasing by half with each size class increase (Figure 14).

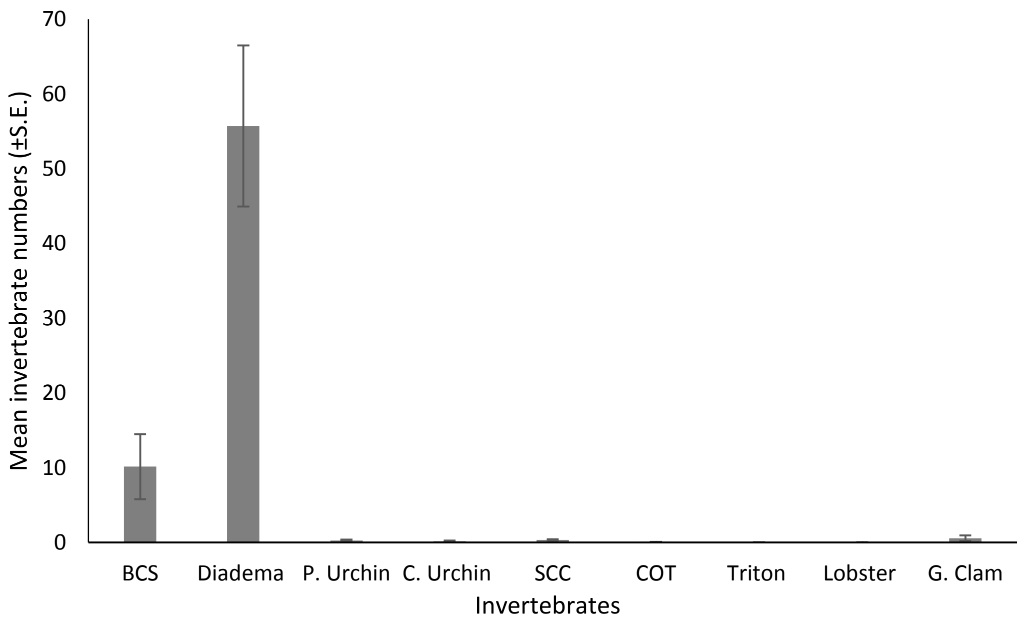
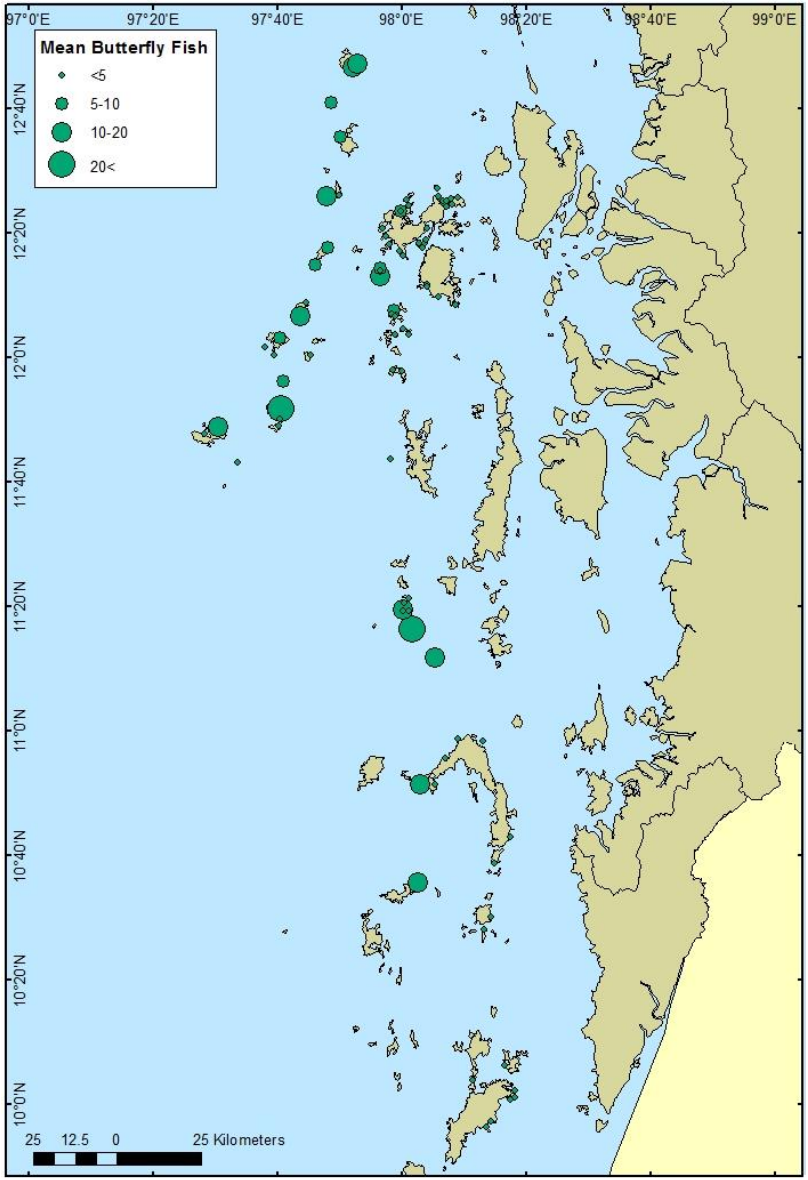
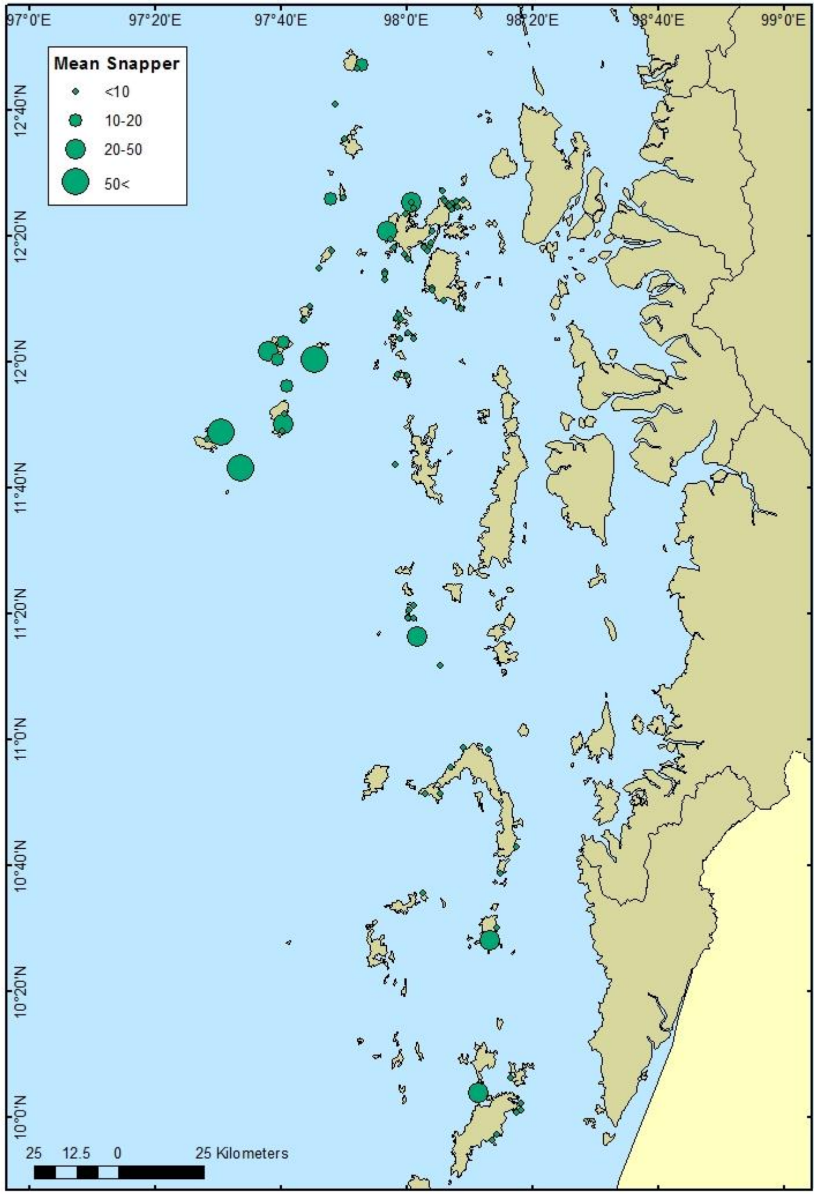


Figure 12 Mean invertebrate numbers for 9 categories (±S.E.) per transect at 94 sites across Myeik Archipelago. (Codes: BCS- Banded Coral Shrimp; P. Urchin- Pencil Urchin; C.Urchin- Collector Urchin; SC- Sea Cucumber; COT- Crown of Thorns; G. Clam- Giant Clam)

a.


Mean Butterfly Fish
<5
5-10
10-20
20<
97°0'E
97°20'E
97°40'E
98°0'E
98°20'E
98°40'E
99°0'E
12°40'N
12°20'N
12°0'N
11°40'N
11°20'N
11°0'N
10°40'N
10°20'N
10°0'N
25 12.5 0 25 Kilometers

b.


Mean Snapper
<10
10-20
20-50
50<
97°0'E
97°20'E
97°40'E
98°0'E
98°20'E
98°40'E
99°0'E
12°40'N
12°20'N
12°0'N
11°40'N
11°20'N
11°0'N
10°40'N
10°20'N
10°0'N
25 12.5 0 25 Kilometers

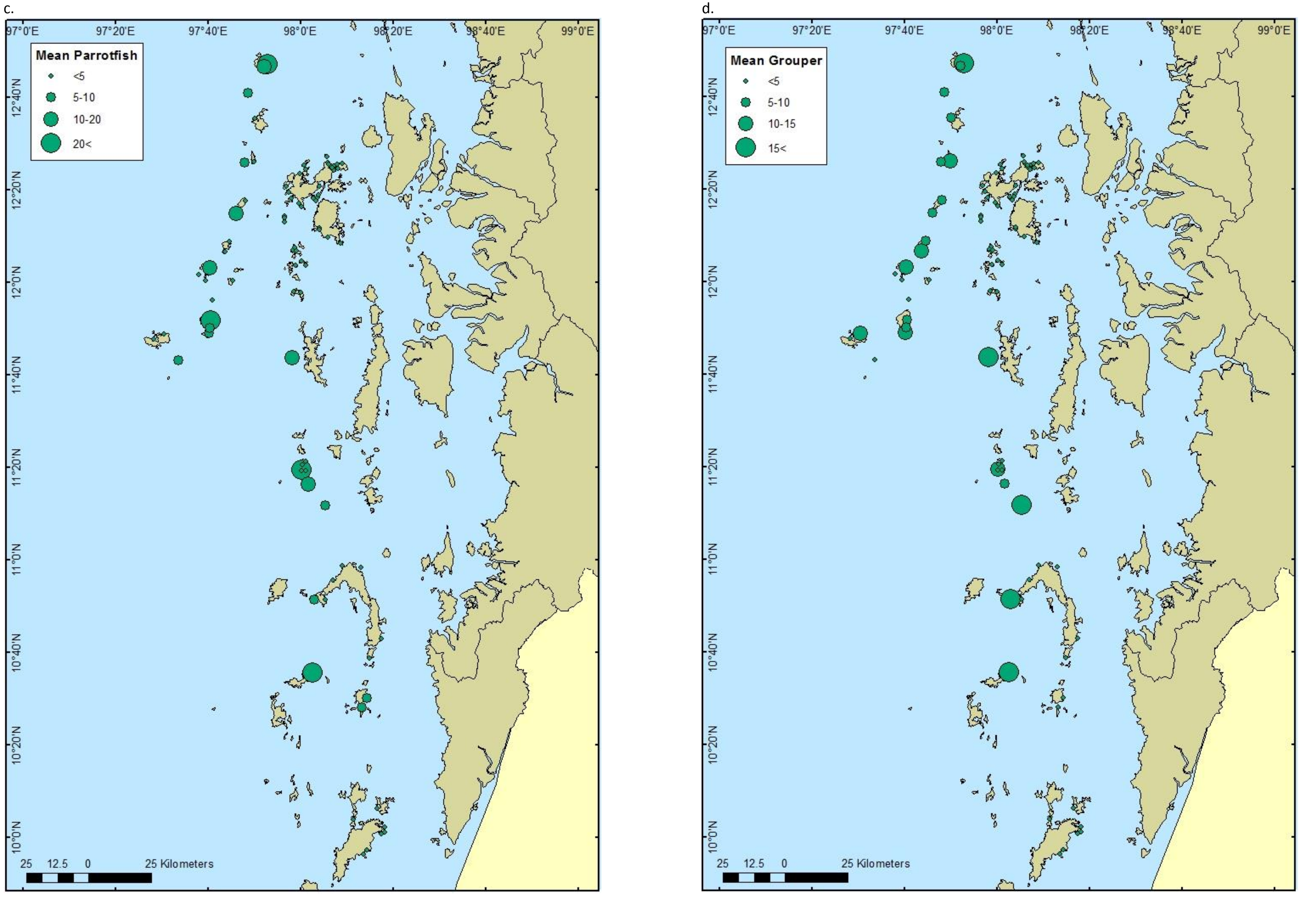


Figure 13. Mean fish numbers per site for the four dominant fish categories: a. Butterflyfish; b. Snapper; c. Parrotfish; and d. Grouper, within Myeik Archipelago. Note the different numbering classes used on each map.

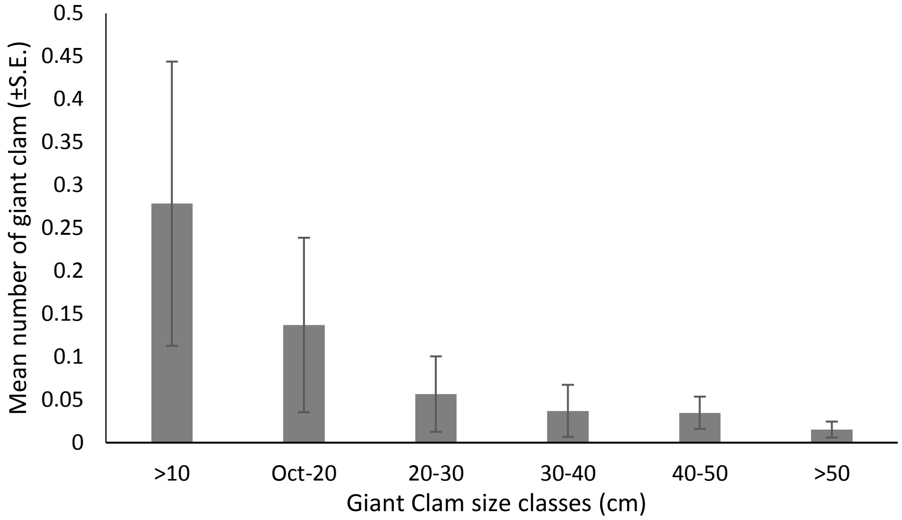


Figure 14 Mean numbers of Giant Clams per size class (±S.E.) per transect at 94 sites across Myeik Archipelago.

Given such low numbers of invertebrates, only *Diadema* data were analysed at the geographical area and site level. Across the five geographic locations mean *Diadema* numbers per transect were generally similar with 108.8 (±29.9) at TOR, 101.5 (±48.4) at PSB, 98.5 (±50.4) at LMP and 68.7(±25.5) at ZDG, although there was great variation within these locations as shown by the high standard error figures (Figure 15). TYT recorded much lower numbers with a mean of 10.25 (±3.4) per site. No significant correlation was observed when comparing hard coral cover with *Diadema*, when only sites where all five replicates were surveyed were analysed (t = -1.7498, df = 61, p-value = 0.0852).

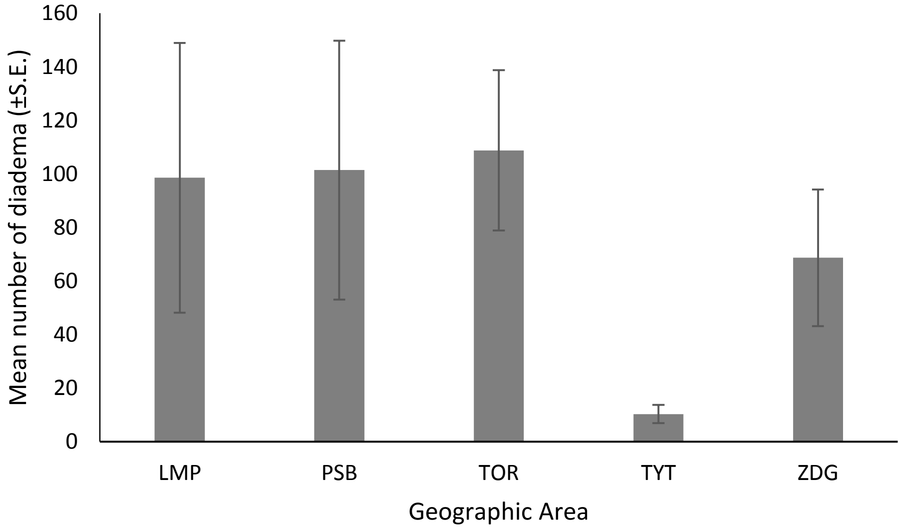
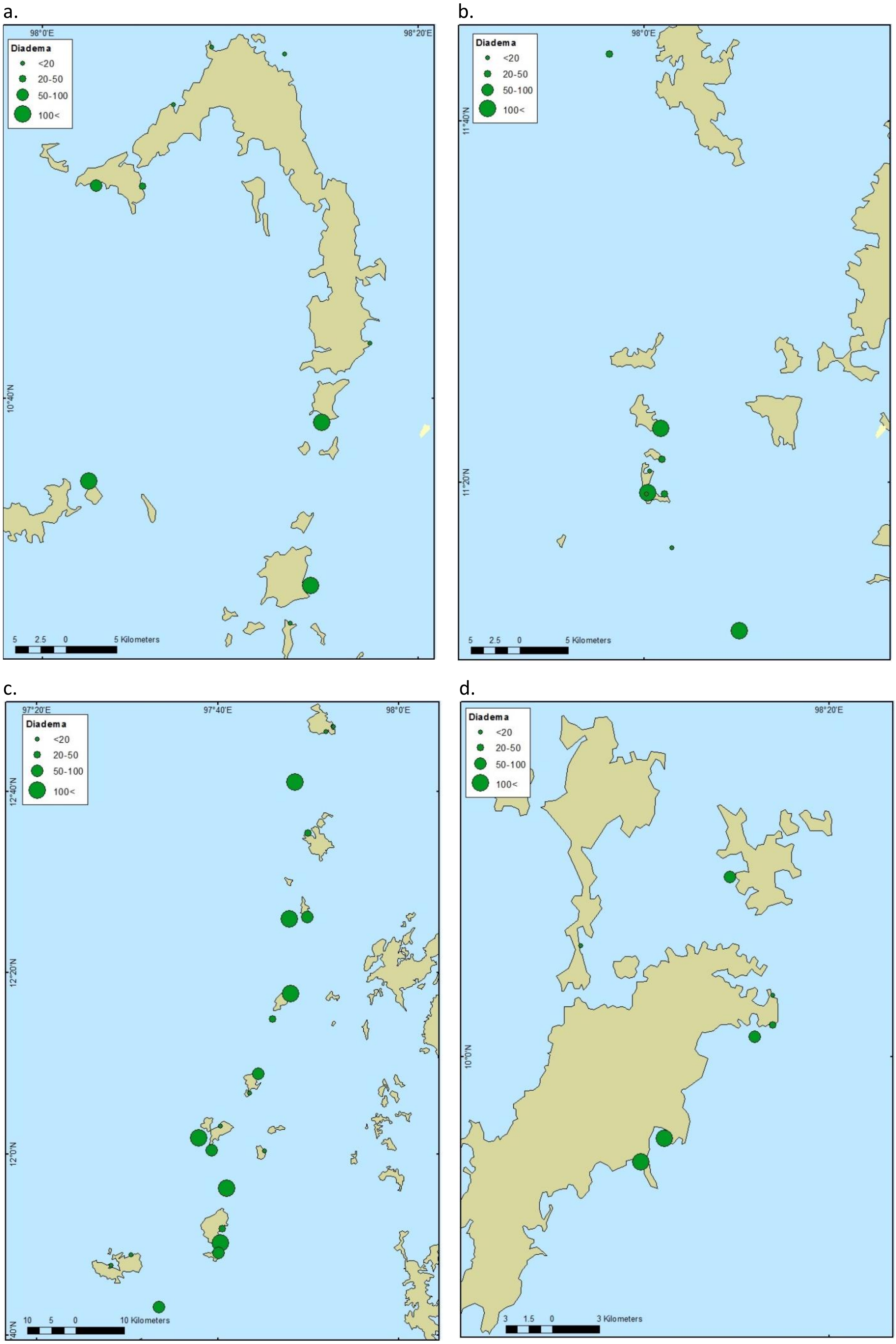


Figure 15 Mean number of *Diadema* individuals by geographical area: Lampi (LMP, n=9), Pyin Sa Bu (PSB, n=9), Torres (TOR, n=21), Thawaythadangyi (TYT, n=45) and Zar Dat Gyi (ZDG, n=7) Island Groups.

At the site level the highest mean number of *Diadema* recorded was within Lampi at site 102 with 465 individuals (although only one replicate was surveyed for this site). It should also be noted that for the 45 sites surveyed within TYT, 20 of these recorded zero *Diadema*. Figure 16 (a-e) provide spatial results of this data at the site level.


a.
98°0'E
98°20'E
10°40'N
Diadema
<20
20-50
50-100
100<
5 2.5 0 5 Kilometers
b.
98°0'E
11°40'N
11°20'N
Diadema
<20
20-50
50-100
100<
5 2.5 0 5 Kilometers
c.
97°20'E
97°40'E
98°0'E
12°40'N
12°20'N
12°0'N
Diadema
<20
20-50
50-100
100<
10 5 0 10 Kilometers
d.
98°20'E
10°0'N
Diadema
<20
20-50
50-100
100<
3 1.5 0 3 Kilometers

e.

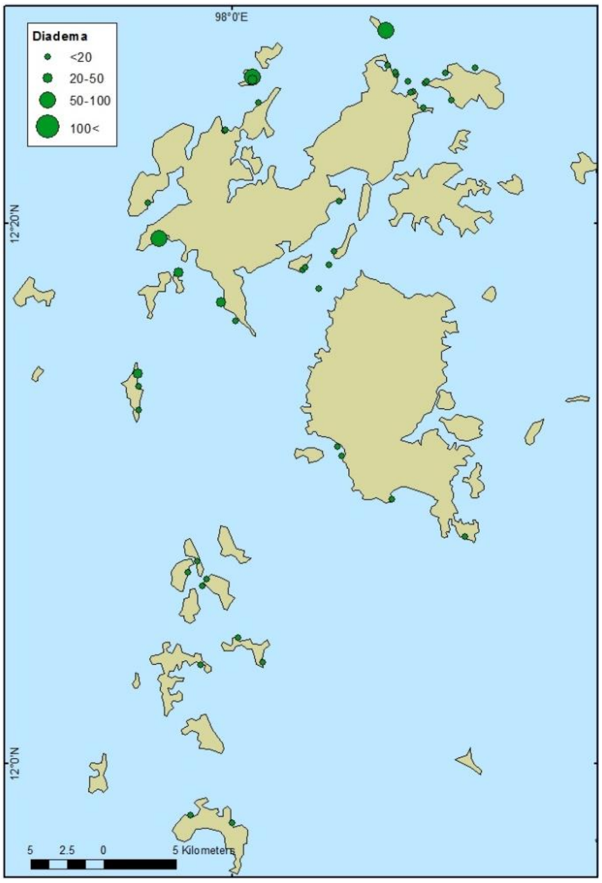


Figure 16 Mean number of *Diadema* individuals per site by geographical area: a, Lampi (LMP, n=9); b. Pyin Sa Bu (PSB, n=9), c. Torres (TOR, n=21); d. Zar Dat Gyi (ZDG, n=7); and e. Thawaythadangyi (TYT, n=45).

Anthropogenic impacts

Of the five categories of anthropogenic impacts assessed no one impact dominated, with a mean impact score of approximately one (low damage) for each (Figure 17). This level of damage was similar when comparing geographic locations with the highest levels of damage of just under 1.5 for dynamite at both LMP and TOR (Figure 18). At the site level however impacts varied from scores of 0 to those with 3, the highest level of damage. Table 3 provides a list of those sites with mean scores over 2 for each impact and Figure 19 and Figure 20 (a-e) provides a spatial view of these results.

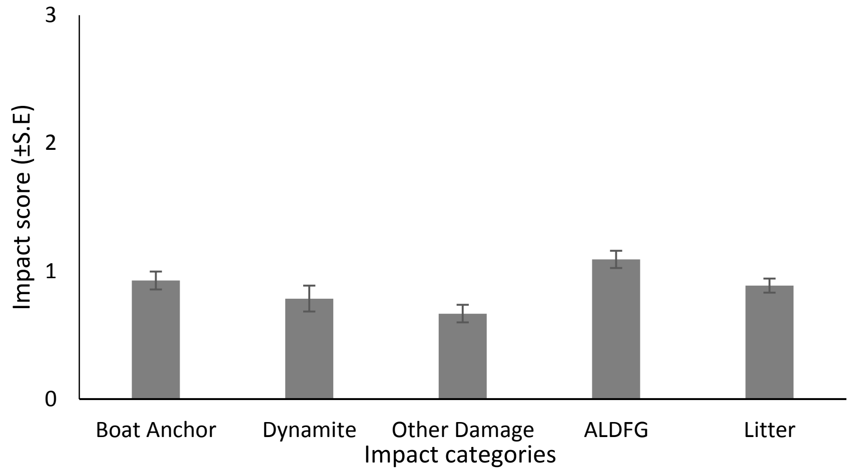


Figure 17 Impact score (0 no damage, 3 highest damage) for the five anthropogenic impacts assessed. (ALDFG- Abandoned, Lost or otherwise discarded fishing gear).

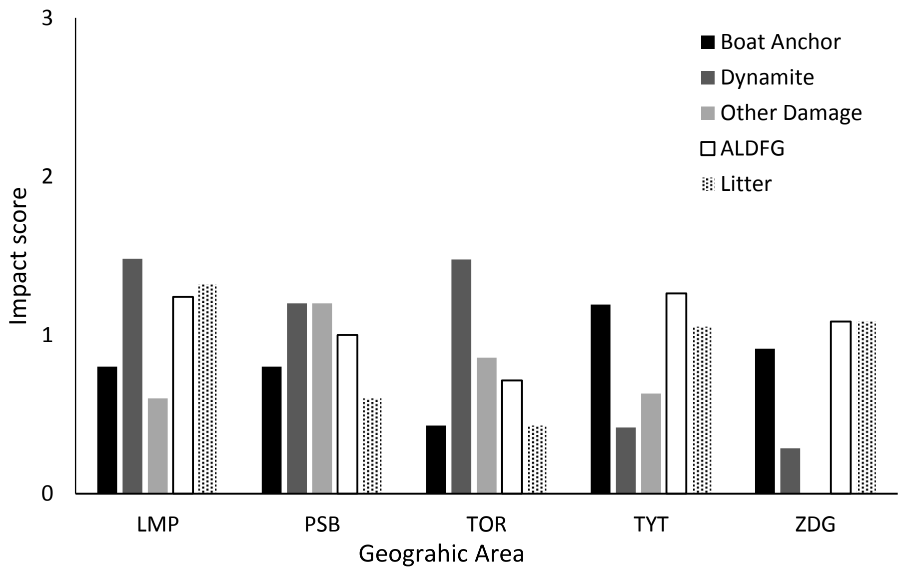


Figure 18 Impact score (0 no damage, 3 highest damage) for the five anthropogenic impacts assessed by geographical area: Lampi (LMP, n=15); Pyin Sa Bu (PSB, n=10), Torres (TOR, n=22); and Thawaythadangyi (TYT, n=57); and Zar Dat Gyi (ZDG, n=11). (ALDFG- Abandoned, Lost or otherwise discarded fishing gear).

Table 4 Surveyed sites with a mean impact score over 2 for each category. Underlined sites are those with a mean score over 2 for more than one category. (ALDFG- Abandoned, Lost or otherwise discarded fishing gear)

Boat anchor	Dynamite	Other	ALDFG	Litter
25	27	22	21	34
26	32	34	22	
27	36	71	26	
30	52	93	32	
36	67	102	33	
37	68		37	
50	71		44	
	73		50	
	74		84	
	75		102	
	76			
	77			
	80			
	82			
	84			

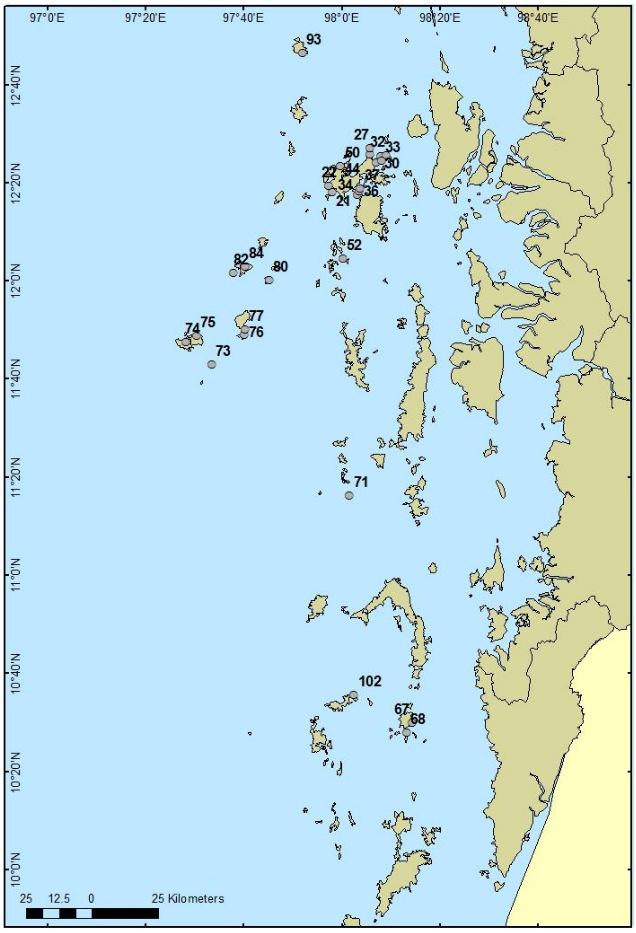
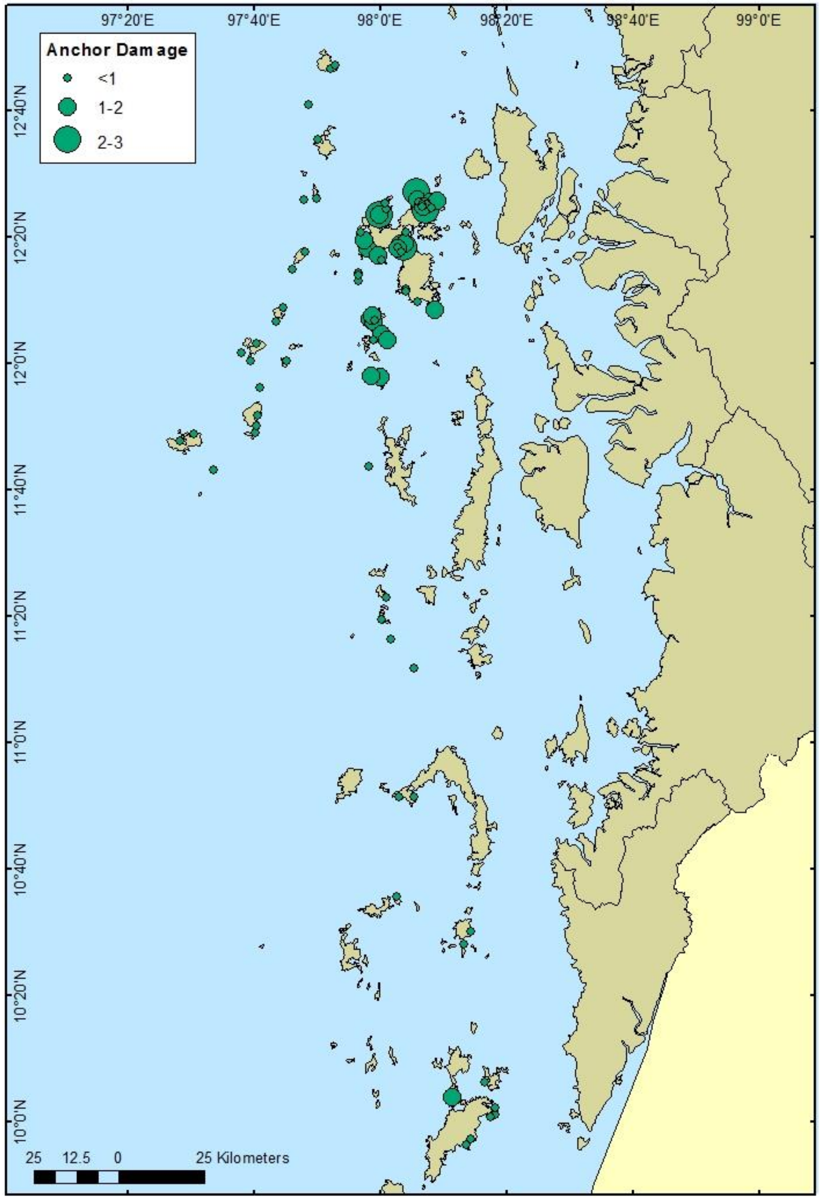
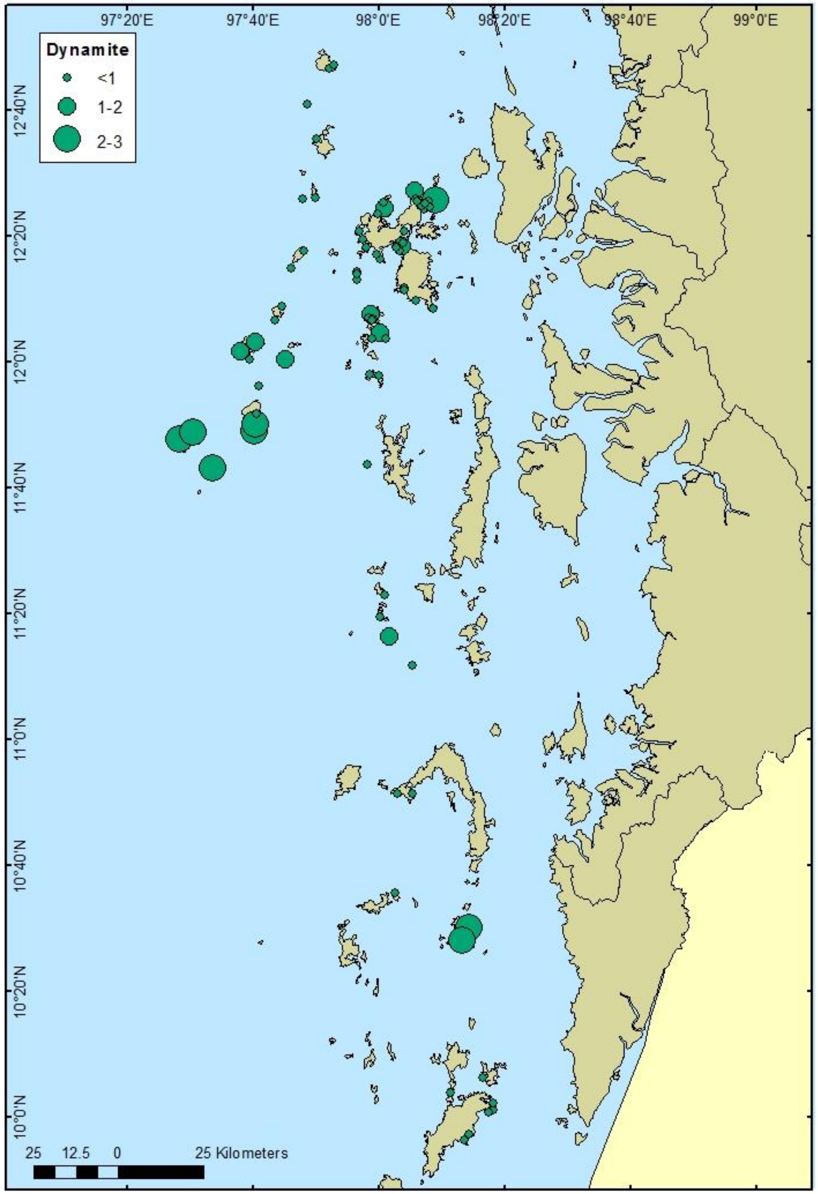


Figure 19. Surveyed sites with a mean impact score over 2 (medium to high impact).

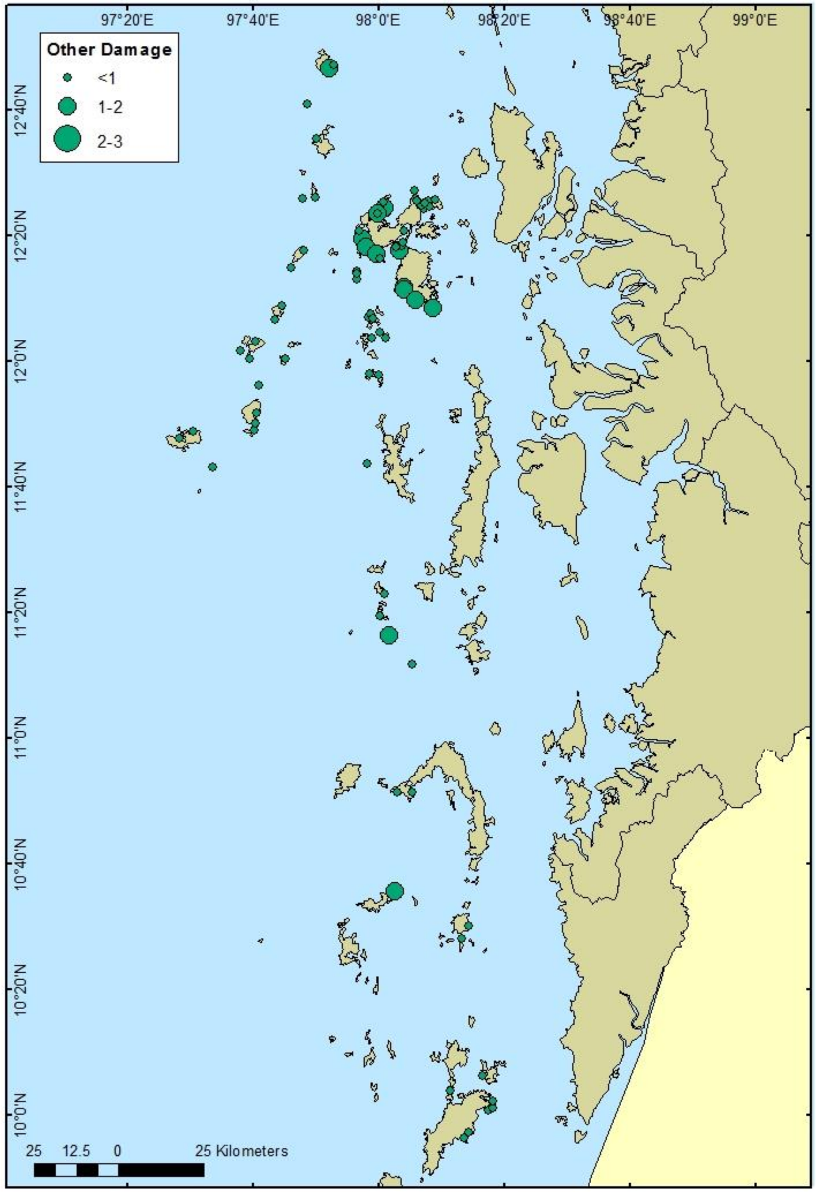
a.


Anchor Damage
<1
1-2
2-3
97°20'E
97°40'E
98°0'E
98°20'E
98°40'E
99°0'E
12°40'N
12°20'N
12°0'N
11°40'N
11°20'N
11°0'N
10°40'N
10°20'N
10°0'N
25 12.5 0 25 Kilometers

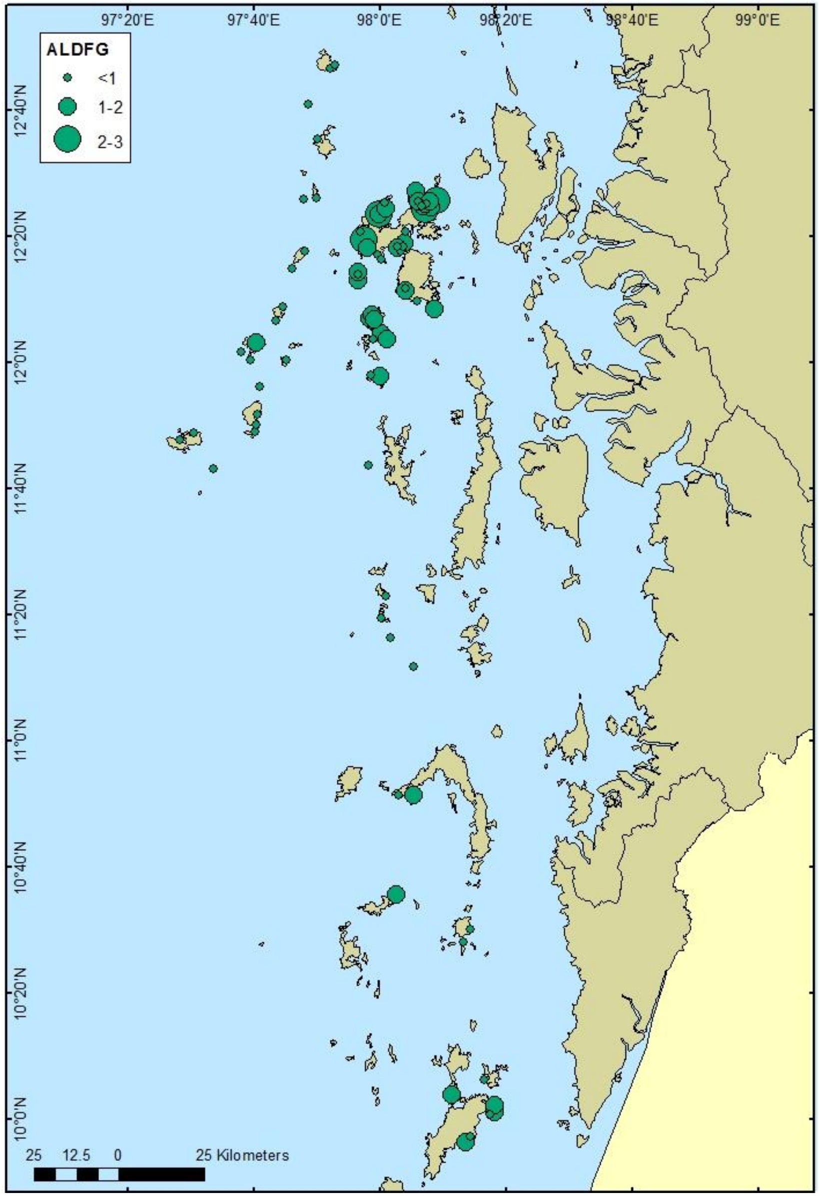
b.


Dynamite
<1
1-2
2-3
97°20'E
97°40'E
98°0'E
98°20'E
98°40'E
99°0'E
12°40'N
12°20'N
12°0'N
11°40'N
11°20'N
11°0'N
10°40'N
10°20'N
10°0'N
25 12.5 0 25 Kilometers

c.


Other Damage
<1
1-2
2-3
97°20'E
97°40'E
98°0'E
98°20'E
98°40'E
99°0'E
12°40'N
12°20'N
12°0'N
11°40'N
11°20'N
11°0'N
10°40'N
10°20'N
10°0'N
25 12.5 0 25 Kilometers

d.


ALDFG
<1
1-2
2-3
97°20'E
97°40'E
98°0'E
98°20'E
98°40'E
99°0'E
12°40'N
12°20'N
12°0'N
11°40'N
11°20'N
11°0'N
10°40'N
10°20'N
10°0'N
25 12.5 0 25 Kilometers

e.

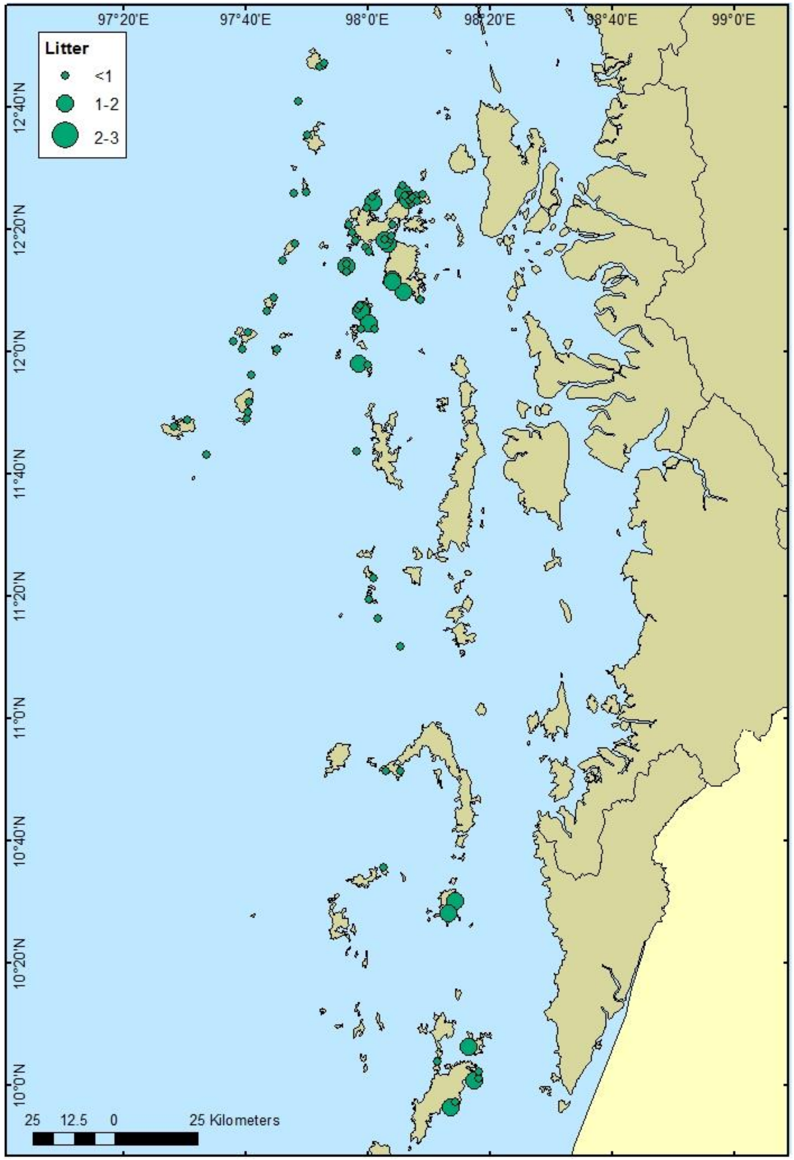


Figure 20 Impact score (0 no damage, 3 highest damage) for the five anthropogenic impacts assessed a. Boat Anchor; b. Dynamite; c. Other; d. ALDGF; and Litter. (ALDFG- Abandoned, Lost or otherwise discarded fishing gear).

5. DISCUSSION:

Substrate composition

The status of hard coral cover varies greatly across the archipelago from 0% to 92% and although the Reef Check surveys show an average of 51.2%, when the snorkel surveys are taken into account, which estimate coral cover below 20%, the average coral cover for the archipelago is estimated to be below 25%. Using Habibi et al's (2007) scale this puts the archipelago in the Poor range (0-25%). For comparison, Reef Check data from the region has Indonesia (surveys from 1997-2006, Habibi et al (2007)), Australia (surveys 2011-2013, Bauer (2013)), and Malaysia (surveys in 2012, Yewdall (2013)) all considered Average (26-50%). Myanmar does however show similarities with the Maldives which suffered greatly from the 1998 coral bleaching event with coral cover in 2008 estimated at 25.7% (Solandt 2008). Although Hard Coral dominated in many of the sites Dead Coral and Coral Rubble was recorded frequently indicating both past and current impacts on the reefs. Thermal stress in 2010 is considered to be a leading contributing factor to coral degradation at many of the sites, with those within TOR most effected while those on the inner reefs such as TYT may have been buffered from high temperatures by high turbidity and also recovered faster due to the dominance of branching *Acropora* (Obura et al 2014). More recently, however, the results show that the reefs have been further impacted by anthropogenic threats including dynamite fishing and boat anchor damage (discussed in detail below). Although overall coral cover for the archipelago is poor, encouragingly, there are still individual reefs considered quite healthy with 38 of the 180 reefs (including snorkelled sites) within the Good Range (51-75%) for hard coral cover and 26 sites in the Very Good range (76-100%) (see Figure 21 in conclusion).

In terms of coral morphology the archipelago is dominated by massive corals which is noted as an indicator of a reef in poor health (Cox et al. 2013) and may be a result of frequent but low impact disturbances across the archipelago. This pattern was most prominent in LMP and ZDG where massive corals were clearly dominant with very few branching corals observed. At LMP and ZDG both Dead Coral and rubble were similar to other sites and impacts were not found to be any more severe than at the other geographical areas. Recovery of impacted communities depends in part on the replenishment of corals by larvae which successfully settle on damaged reefs (Diaz-Pulido et al. 2009) and potentially LMP and ZDG are lacking a viable source of coral recruits to enable recovery. Further studies focused on recruits at the two regions would be needed to confirm this. Similarly there may be other low impact disturbances occurring at these sites which have not being picked up by these surveys such as coral disease. In TYT massive corals also dominated although both branching and foliose corals were frequent. As noted above, the inner reefs may have been less affected by the rising temperatures of 2010 and so have also shown better signs of recovery. However this recovery in the future in TYT may be jeopardised by the high incidences of anchor damage recorded. Unlike the above three geographical areas in TOR similar occurrences of both massive and branching corals were observed. This region had the lowest hard coral cover and some of the highest dead corals and rubble. Obura et al (2014) postulates that this is due high sea surface temperatures in 2010 in which damage was found to be more severe in the outer reefs which may be less accustomed to large temperature changes. In PSB it is branching corals which dominate the substrate followed by massive corals, although there is some overlap when standard errors are compared. The frequent occurrence of the branching corals in this region may indicate good recovery from previous disturbances, such as thermal stress, coupled with the ban on dynamite fishing which the local administrator has enforced to a certain degree around the islands.

Fish abundance, size and diversity

Results for the nine fish categories within the archipelago indicate an ecosystem heavily impacted by overfishing and the use of destructive fishing methods. For the butterflyfish, closely associated with coral reefs, only a mean of four individuals per site were recorded. This result is comparable to data from Malaysia (Yewah 2012) but below the 30 plus butterflyfish observed in Indonesia for 2006 (Habibi et al 2007). For all other fish however the results of this survey appear similar to the low numbers recorded in both Indonesia and Malaysia where overfishing is blamed for reduced fish populations. For example, schooling snapper and sweetlips (e.g. *Lutjanus bengalensis* and *Plectorhincus lineatus* (FishBase 2014)), were rarely seen in large groups, with only 25 of the 575 replicate transects recording numbers over 10 individuals for snapper and only two of the 575 replicate transects recording numbers over four individuals for sweetlips. Likewise for parrotfish only 12 out of 575 replicate transects showed groups over 10. Parrotfish play an important functional role on coral reefs keeping algae levels low allowing coral recruits to settle and flourish (Feitosa and Ferreira 2014). Taking these fish out of the system could lead to a phase shift within the archipelago where reefs could become algae dominated (Hughes, Rodrigues et al. 2007). However, as discussed below *Diadema* urchins appear to be filling this role, for now. For groupers, although not known for large aggregations on reefs, were found to be clearly dominated, albeit in low numbers, by those in the 30-40cm size class which maybe in part due to the finfish fishery within the archipelago where juvenile groupers are wild-caught and reared in cages (Holmes et al. 2013). This a concern for those species of grouper which only become sexually mature above this size range and take several years to reach reproductive age e.g. *Epinephelus coioides* which reaches maturity at 43.5 cm (Grandcourt et al. 2005) and a species targeted by Myanmar fishers (Holmes et al. 2013). This situation is similar to that recorded in the Maldives where 85% of groupers recorded were under 40cm and a need for reviewing landing sizes and protection of spawning sites has been advocated (Solandt 2014). The remaining surveyed fish, barramundi cod (Vu), humphead wrasse (En), bumphead parrot fish (Vu) and moray eels, like in Malaysia and Indonesia were recorded in very low numbers. Along with moray eels, these species are a draw for scuba divers and loss of these species is a conservation concern and could be detrimental to any tourism ventures. Likewise, no sharks, marine turtles or manta rays were recorded at any of the 115 survey sites, the loss of such marine species would be detrimental to the ecosystem. For example, sharks well known for their role as apex predators, have the potential to influence marine communities at both large temporal and spatial scales (Ferretti et al. 2010).

Within the five geographical areas butterflyfish, snapper, parrotfish and grouper, were recorded in the highest mean numbers at TOR, this is surprising giving that this area had the lowest coral cover. The distance of these islands from the mainland may be a factor with potentially less fishing activity, although given the amount of dynamite damage encountered here this trend may not last long. The fact however that only one replicate was taken at the surveys sites for this area the results must be interpreted with caution. Outside of TOR the highest recording for all of these four fish groups was at PSB. Like TOR its remoteness from the main cities, Myeik and Kawthong may mean less fishing pressure than LMP, ZDG or TYT, although dynamite fishing and ALDFG was comparable to these sites. The area with the lowest fish records was TYT which maybe a result of its closeness to Myeik and the high level of anchor damage here compared to the other sites may reflect a greater fishing effort around these islands. Interestingly, however, this area has some of the highest coral cover which means that with a well-managed fishery the fish populations in this area could recover given the habitat is still relatively intact.

Invertebrate abundance, size and diversity

The results from the invertebrate surveys showed a landscape dominated by long spined sea urchins and depauperate in the other invertebrates. These results are similar to Malaysia and Indonesia where only *Diadema* were recorded in high numbers whereas the other urchins, sea cucumbers, triton shells, lobsters and giant clams were rarely observed more than once per transect (Habibi et al. 2007, Yewdall 2013). Low numbers of these species have been blamed on overfishing for both the aquarium trade and as a food source. For the archipelago this was clearly observed by the survey team in Myeik town where a live lobster operation collects wild caught lobsters for export to Thailand, with many of the individuals observed adolescents. One operator from such ventures did however note the need for protection of spawning sites (pers. comm. U Maung Gyi). The trade in sea cucumbers to China is also prevalent within the archipelago and although this is a recent shift in target species as a result of fish populations declining, sea cucumber divers are already reporting reduced catches (Saw Han Shein 2013). Encouragingly, the surveys recorded low numbers of COTS, a species known for population outbreaks leading to heavily degraded coral reefs (Brodie et al. 2012). These echinoderms occur naturally on coral reefs and so the occasional observation of these starfish in the archipelago is not a cause for concern. Whether Myanmar reefs have ever been affected by large population booms of COTS is unknown due to the lack of underwater surveys in the area, therefore these surveys will provide a useful baseline to monitor against.

For *Diadema sp.* their abundance is often influenced by fishing pressure on their predators (McClanahan 2014). For example, McClanahan and Shafir (1990) in comparing closed to open reefs, found that urchin densities were negatively correlated with exploited predatory triggerfish, noting that numbers of urchin decreased as triggerfish abundance increased in closed areas and vice versa for open reefs. Although the surveys did not record specific urchin predators, humphead wrasse are known to feed on these echinoderms (Guardians 2012) and their low numbers in the archipelago may be one factor affecting urchin abundance. The high numbers of urchins recorded may also be why little algae was recorded during the substrate surveys when herbivorous parrotfish were in such low numbers. If the urchin numbers however are not kept in check their prevalence can lead to urchin barrens in which they remove large amounts of calcium carbonate from living coral and can also feed on coral recruits (Norström et al. 2009). Although *Diadema* were recorded in high numbers in most regions, in TYT the numbers were very low, along with overall fish numbers and algae cover. Potentially, given its closeness to Myeik the collection of urchins for consumption in TYT is higher than the other sites, while the numbers are at a level high enough to keep algae cover low or there are other herbivores filling this functional role not recorded in these surveys.

Anthropogenic Impacts

For impacts to the reefs, as a result of human actions, although the overall impact score for the archipelago for each variable was in the low damage category most sites recorded some level of damage and 25 of the 115 sites surveyed by Reef Check recording medium to high impacts. In comparisons to surveys from Malaysia, Myanmar reefs show higher incidences of damage especially in terms of dynamite fishing and discarded fishing nets but show similar impact scores across all categories with reefs in Indonesia (Habibi et al. 2007, Yewdall 2013). What is most concerning for the reefs in Myanmar is the continued use of dynamite fishing across the archipelago. This form of fishing, not only negatively effects the fish populations which the users are targeting but also smaller non target fish, invertebrates and can lead to declines in demersal plankton (Guard and Masaiganah 1997). The most lasting affect is however on the corals themselves, with recovery even after 40 years found to be minimal (Guard and Masaiganah 1997). Application of the law banning the use of this method needs to be strongly enforced to ensure recovery of the habitat on which so many species rely. Like dynamite, casting of boat anchors onto the coral reefs is also having a damaging impact within the archipelago and this is most prevalent in TYT which was the only area to have sites with an impact score over two for this variable (7 of 57 sites). This result may be due to TYT's close proximity to a large city, and therefore more boat traffic passing through these islands (it should also be noted that this area has been more intensely surveyed then the other areas). The islands around TYT are of great importance to the archipelago given the high coral cover observed here and therefore management interventions such as no anchoring areas or public moorings need to be established to ensure these reefs stay intact. As for the discarded fishing nets, most of the sites found to have impact scores over two for ALDFG were also at TYT, however as mentioned above this may also be a result of the higher sampling in this area. It's unknown if these nets were used for trawling over the reefs or whether they drifted onto the reefs once lost. Either way the mere presence of these nets over the reefs could have negative effects on coral growth and recruitment as many of them were observed covered in algae and smothering the substrate. Stopping these nets from being entangled in the reef will require both rigorous application of the law pertaining to trawling grounds and clean up divers removing the nets from the reef which could be done community groups involved in marine conservation.

Conclusion

Results of the surveys show that the archipelago shows clear signs of degradation and overfishing but has a number of sites where the coral habitat is still intact providing a chance of recovery for the ecosystem as a whole. These findings concur with reef resilience data from Obura et al. (2014) in which the overall picture for the archipelago was found to be average to below average levels, but for a number of key sites in a state of recovery. The most intact sites from the Reef Check surveys have been overlayed with recommended areas for protection by Obura et al (2014), either for their recovery potential or as larval sources for other sites, to provide a range of key biodiversity areas which either fit into a marine protected area network or are key in the overall marine spatial planning for the archipelago (Figure 22).

It is important to emphasise that the focus of this study was coral reefs and to ensure representatviness of all marine habitats within a marine protected area network critical areas of mangrove forests, seagrass beds and mudflats within the archipelago must also be included. Like coral reefs, many of the these habitats are under threat with sea grass beds are being damaged by 'baby trawlers' (Holmes et al. 2013) and mangrove forests along the Tanintharyi coast are heavily impacted by deforestation to supply the demand for charcoal and house construction (San Tha Tun 2014).

Key to the protection of these habitats and sustainable use of marine resources within the archipelago will be involvement of key stakeholders in decision making (e.g. fishing industry, both large scale commercial users and artisanal fishers, tourism operators etc.). It is now widely accepted that co-management is critical to achieving effective and equitable marine resource use. Co-managed MPAs are noted as a means to improve the economies of fishing communities by not only increasing catches but also through engagement in other non-consumptive use activities such as tourism, which can also help alleviate the reduction in fishing grounds from MPAs created for conservation purposes (Sanchirico 2000). It is therefore recommended that the next steps towards MPA establishment in Myanmar include developing a model of co-management known as Locally Managed Marine Areas or LMMAs.

LMMAs are used throughout the Indo-Pacific (Tan 2011) and involve an arrangement whereby local communities and the state work in partnership with NGOs and scientists to jointly manage marine resources (Van Beukering et al. 2007). LMMAs employ a range of tools to manage the fishery, including (Govan et al. 2008; FAO 2009; The et al. 2009):

- total no-take areas (MPAs)
- restoration of economically important species e.g. sea cucumbers
- alternative livelihood options
- operating rotational harvests of fished areas
- marine reserve awareness
- gear or seasonal restrictions
- species-specific refugia
- appointment of fisheries wardens

This form of co-management provides local communities with a greater sense of ownership as they are key to the planning, design, implementation and evaluation of the management strategies, including those noted above (Sivo 2011). These approaches must, of course, be tailored for the local context and fit into a wider marine spatial planning process for the archipelago which includes all users and not just small communities. As fisheries management takes into account a more ecosystem based approach, managing the human dimension becomes critical and the success of any management strategy relies heavily on the acceptance and adherence by the people (Agardy et al. 2003).

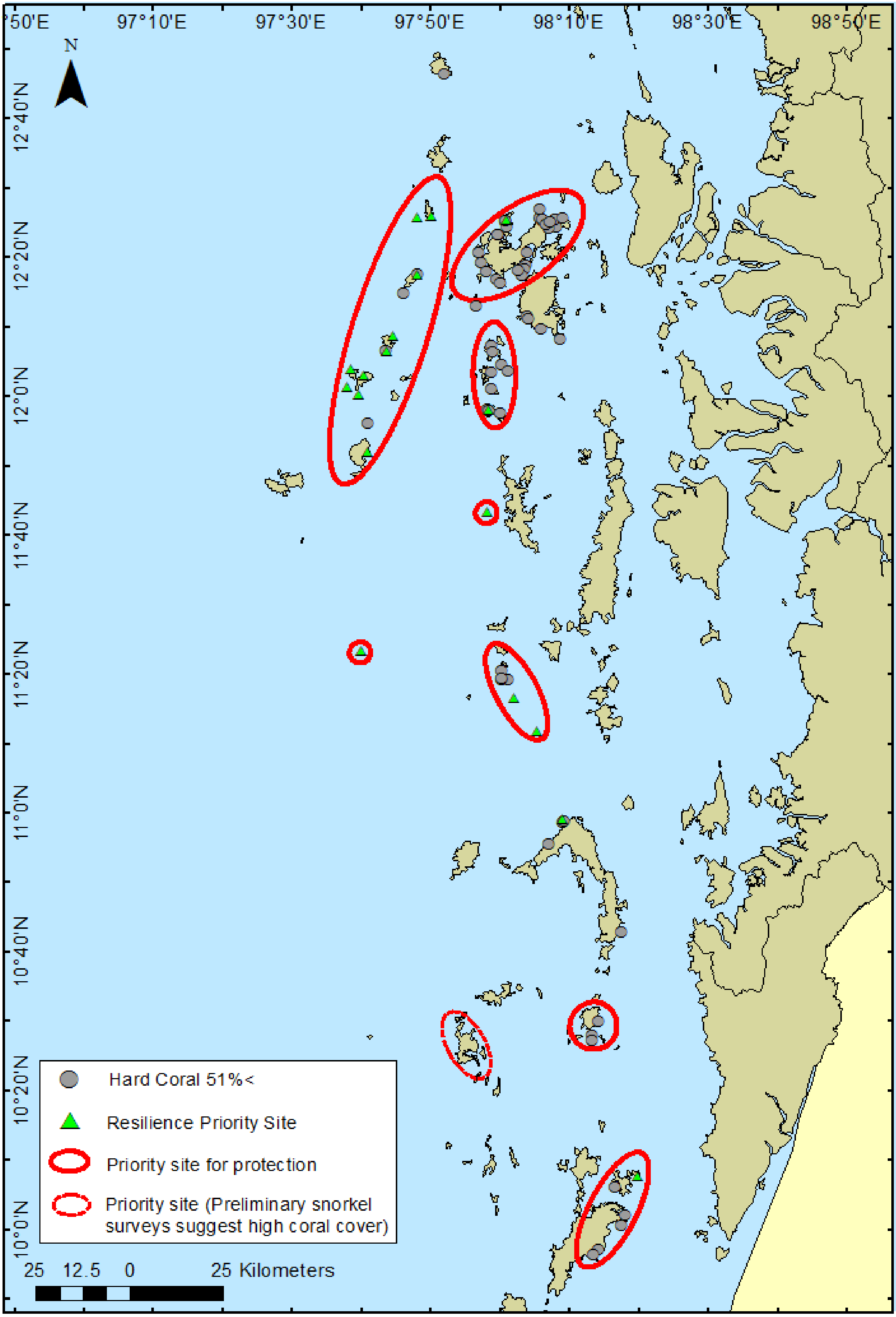


Figure 21 Priority sites for protection. Hard Coral data from Reef Check surveys and Resilience data from Obura et al 2014.

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7. APPENDIX

Appendix 1: Reef Check Survey Site Details

Site	Geo. Area	LatDD	LongDD	Site Name	Survey Depth (m)	Mean % Hard Coral Cover
1	TYT	12.44203	98.01769	Thawaythadangyi Kyun	7.3	35
2	TYT	12.33900	97.95778	Thawaythadangyi Kyun	4.7	13
3	TYT	12.24267	97.93814	Thawaythadangyi Kyun	5.2	42.5
4	TYT	12.30397	98.03683	Ba Gyee Kyunn Southwest	5.2	30
5	TYT	12.16753	98.15206	Wadi Kyunn Southeast	4.6	26.5
6	TYT	12.14542	98.12672	Daung Kyunn Southwest Tip	5.5	36.5
7	TYT	12.17211	98.02803	Ao Lei Kyunn Southwest Tip	7.3	20.5
8	TYT	12.09097	97.97506	Taung Kyun Pone	12.5	6
9	TYT	12.01889	97.97922	Kyet Paun Kyunn Northeast Bay	6.4	53
10	PSB	11.65306	98.03233	Pyin Sa Bu Kyunn Southwest	9.5	49
11	LMP	10.85931	98.08764	Wa Ale Kyunn East	12.2	31.5
12	LMP	10.76942	98.24247	Lampi	11	11
13	LMP	10.47208	98.16825	Nyaung Whee	4.6	17.5
14	ZDG	10.24697	98.23747	Shwe Kyun Gyi	8.2	43
15	ZDG	10.24703	98.23700	Pa Law Ka Kyan	5.8	20
16	ZDG	10.12939	98.32811	Thay Yae Kyunn	4.2	50.5
17	TYT	12.30578	98.04544	Za Latt	3	35
18	TYT	12.27286	98.00242	Pearl farm	3	53
19	TYT	12.34608	97.94833	Phalar Aw	3	53.5
20	TYT	12.28439	97.99325	Palu Palal Hill	7.3	59.5
21	TYT	12.30308	97.96714	Thit Lat Tan Aw	4	60
22	TYT	12.32369	97.95511	Thawaythadangyi Kyun	6.4	74
23	TYT	12.41425	98.11039	Tit Ti Tu Aw	4.3	90.5
24	TYT	12.42100	98.10864	Shar Aw	4.8	88
25	TYT	12.43067	98.09583	Palu Palal Aw	8.5	88
26	TYT	12.40447	98.11822	Sas Tit Aw	5.5	82
27	TYT	12.45219	98.09483	Palu Palal Hill	3.7	77.5
28	TYT	12.42639	98.10069	Shar Aw	14.3	81.5
29	TYT	12.40758	98.01611	Zat Latt East	5.5	80.5
30	TYT	12.42589	98.13167	Taung Pan Gyi	7.9	81.5
31	TYT	12.42003	98.11914	Taung Pan Gyi	7.6	74.5
32	TYT	12.42939	98.15019	Taung Pan Gyi	7.6	56
33	TYT	12.40922	98.13530	Taung Pan Gyi	6.1	88
34	TYT	12.29306	98.05336	Mee Kway Island	7.3	68
35	TYT	12.34708	98.06619	Zalwal	7.9	78
36	TYT	12.30769	98.06000	Dahaw	6.1	71.5
37	TYT	12.31569	98.06314	Dahaw	10.1	79.5
38	TYT	12.42342	98.01253	That Pan Nyo	5.1	92
39	TYT	12.19550	98.06517	Nyaung Hmine	4.3	90.5
40	TYT	12.18942	98.06750	Nyaung Hmine	4.6	72
41	TYT	12.06053	97.98050	Mee Kway Island	5.5	88
42	TYT	12.16294	98.09864	Dahaw	7.6	79
43	TYT	12.13997	98.14372	Dahaw	4.9	87
44	TYT	12.39050	97.99528	Taung Pan Gyi	3.4	85
45	TYT	12.41453	98.11167	Tit Ti Tu Aw	3.4	79.5
46	TYT	12.42500	98.10142	Shar aw	3.1	84

47	TYT	12.42083	98.12031	Taung Pan Gyi	3	79.5
48	TYT	12.42167	98.01250	That Pan Nyo	2.4	87
49	TYT	12.30447	98.04375	Bar Ge Mountain	2.7	61
50	TYT	12.39114	97.99583	Aw Wine	3.4	67.5
51	TYT	12.10911	97.98183	Kyun Pone	3.4	62
52	TYT	12.07728	98.00383	Salin Taung	2.5	73
53	TYT	12.06211	98.01906	Salin Taung	3.4	57
54	TYT	11.96306	97.99986	Mee Sein Is.	3.2	70.5
55	TYT	11.96758	97.97442	Mee Sein Is.	4.7	56.5
56	TYT	12.11789	97.97258	Kyun Pone	2.1	33
57	TYT	12.12456	97.97864	Kyun Pone	2	72.5
58	LMP	10.64517	98.24794	Lampi	3.7	11.5
59	PSB	11.32242	98.01889	La Ngan	4	86
60	PSB	11.32239	98.00253	La Ngan	4.7	84.5
61	PSB	11.34342	98.00536	La Ngan	4	72.5
62	PSB	11.35439	98.01664	La Ngan	2.4	49
63	LMP	10.71556	98.29050	Lampi	3.2	52
64	LMP	10.97242	98.21517	Lampi	3.8	30.5
65	LMP	10.97850	98.15028	Lampi	3.2	71
66	LMP	10.92739	98.11636	Lampi	3.5	51.5
67	LMP	10.49978	98.23775	Nyaung Whee	4	60.5
68	LMP	10.46631	98.22008	Nyaung Whee	3	65.5
69	LMP	10.45567	98.22061	Nyaung Whee	3	51.5
70	LMP	10.98061	98.15389	Lampi	5.5	67.5
71	PSB	11.27269	98.02614	Kyat Mi Thar Su Is.	11.3	22.5
72	PSB	11.38333	98.01581	Saw Pu Is.	11	25
73	TOR	11.71831	97.55844	Sular Nge Is.	18	7.5
74	TOR	11.79461	97.46953	West Sular Is.	10.4	2.5
75	TOR	11.81414	97.50667	West Sular, North Is.	12.2	10
76	TOR	11.81719	97.66856	Kon Thee Is.	7.9	5
77	TOR	11.83575	97.67144	East Sular Is.	9.5	5
78	TOR	11.86275	97.67511	East Sular	10	17.5
79	TOR	11.93703	97.68253	West Islet	10	65
80	TOR	12.00519	97.75297	Dana Theik Di Is.	10	7.5
81	TOR	12.00694	97.65561	South to Sular Kha Mouk Islet	10	15
82	TOR	12.02892	97.63161	Double Is.	17	27.5
83	TOR	12.06692	97.64028	Tower Rock	30	2.5
84	TOR	12.05125	97.67125	Sular Kha Mout	13	27.5
85	TOR	12.11192	97.72542	Bailey Is.	12	80
86	TOR	12.14792	97.74086	Bailey Is. (Jer Bout Is.)	11	17.5
87	TOR	12.24808	97.76731	West Spur	15	70
88	TOR	12.29519	97.80114	Metcalfe Is.	11	55
89	TOR	12.43631	97.83161	Blundell Is.	7	0
90	TOR	12.43278	97.79856	Chevalier Rock	15	37.5
91	TOR	12.59025	97.83269	Tanintharyi Is.	15	20
92	TOR	12.68386	97.80917	North Pinnacle	18	12.5
93	TOR	12.77703	97.86650	Kabuzya Is.	18	70
94	TOR	12.78606	97.88033	Kun Thee Is.	14	7.5
95	TYT	12.42772	98.12342	Thayawthatangyi Is.	3.5	42.5
96	TYT	12.42508	98.01425	Sack Is.	1	80
97	TYT	11.97078	97.97094	Mee Sein Is.	3.5	62.5
98	PSB	11.72864	97.96819	Hlwa Sar Gyi Is.	10	21.25
99	PSB	11.32392	98.00375	Khin Pyi Sone Is.	1.3	72.5
100	PSB	11.19619	98.08822	A Pha Is.	6.1	18.75

101	LMP	10.85514	98.04733	Wa Ale Is.	11.4	28.75
102	LMP	10.59272	98.04103	Bo Ywe Is	10.4	7.5
103	ZDG	10.12906	98.32050	Zar Dat Ngal Is	1.6	50
104	ZDG	10.01153	98.29047	Zar Dat Gyi	1.5	59
105	ZDG	9.95294	98.23811	Zar Dat Gyi	2.4	52
106	ZDG	9.93917	98.22444	Zar Dat Gyi	4	51
107	ZDG	10.01822	98.30078	Zar Dat Gyi	4	38
108	ZDG	10.03528	98.30075	Zar Dat Gyi	3.4	52.5
109	ZDG	10.06394	98.18992	Zar Dat Gyi	3	49
110	ZDG	10.10372	98.27603	Zar Dat Ngal	2.7	92
111	TYT	12.11367	97.98428	Kyun Pone	3.9	33
112	TYT	12.21793	97.94239	Kyun Gedway	5.7	66
113	TYT	12.24042	97.94181	Kyun Gedway	5.6	45
114	TYT	12.23269	97.94233	Kyun Gedway	4.6	46.5
115	LMP	10.85503	98.08842	Lampi	3.4	45.5

Appendix 2: Reef Check Variables Measured

1. Site Description

Survey_id
Site_id
Project_description
Reef_name
Reef_type
Date
Time
Reef_zone
Act_depth
Latitude
Longitude
Transect_orientation
Trans_length
Trans_width
No_replicates
Depth_seafloor
Dist_shore
Weather
Visibility
Why_site
Best_reef
Surveyors Length of transect tape used (m)
Total number of replicates

2. Substrate composition

Substrate	Code	Description
Acropora coral	ACB	*Acropora* Branching – coral colonies that have a tree-like formation, corals arranged in a series of fused horizontal branches. ACB shows 2nd branching with axial polyps. Their colour can vary bright to pale blue to brown.
Acropora coral	ACD	*Acropora* Digitata – coral colonies in the digitate category. These corals have thick, dome-shaped axial corollites. It has a solid base and branches that grow upright. Thay have many colours, but the most commons are brown, cream, blue and purple.
Acropora coral	ACE	*Acropora* Encrusting – coral that are formed by thick ridges, branches, columns or encrusting plates. These colonies are generally upright but can have irregular shape (depending upon wave action), very large and have distinct *Acropora* polyps. They have smooth, exert and rounded corallites, generally there are no axial corollites. The colour varies from brown to pale cream.
Acropora coral	ACS	*Acropora* Submassive – coral with irregular shape, encrusting base with columnar branches that show distinct acropora polyps. Their central branches are thick and conical whether prostrate branches are thinner with upturned. Their colour can vary from cream to bright green to yellow-brown.
Acropora coral	ACT	*Acropora* Tabulate – corals colonies that have flat table-like plate formation or aggregation of small plates. The base may be formed by a fused solid mass, branchlets have an upward projection. On the margin of the table profile ACT has axial polyps, radial corallites from a rosette and are cup-shaped. Their colour varies from grey or green to brown and cream.
Non-*Acropora* Coral	CB	Branching coral – corals that show uniform upright branches; 2nd branching with no axial polyps. Branches are compact and thick when found and wave-exposed environments; but when found in protected areas they have more open and

		thinner branches. This category is for all speciesthat show branching excluding *Acropora* corals.
Non-*Acropora* Coral	CE	Encrusting coral – species that attach itself to the hard substrate below taking the profile and shape of the substrate. Its margins are very thin and it can form plate like colonies. Their colour can vary from mottled brown or brown to white. During the day their white tentacles may be extended.
Non-*Acropora* Coral	CF	Foliose coral – coral colonies can be encrusting or laminar. Also called foliose corals, they often are plate like colonies with small polyps. The plate can be horizontal or vertical and the tentacles are normally only extended at night. They are usually are green, grey, brown or pink but sometimes they may have white, green or red oral discs. Some colonies may show a distinctive colour margin.
Non-*Acropora* Coral	CM	Massive coral – coral colonies that are very large, boulder or mound shapes. Those colonies have thick margin; septa are wiedly spaced and irregular. Even if their septa size varies, they all appear very similar in all dimensions. They show a wide colour variation, but mottled with pale calices is often shown.
Non-*Acropora* Coral	CMR	Mushroom coral - includes all members of the Fungiidae family, also called mushroom corals. These colonies are solitary marine organism that are not attached to the reef and are capable of benthic locomotion. Those are free-living organisms have solitary polyp which they extend to feed at night.
Non-*Acropora* Coral	CS	Sub-massive coral – indeterminate colonies that have various growth forms, often showing nodular surface, columns, hillocky, flat, thickened branches or massive rounded colonies. They can be several meters across and they tend to have green or brown colours.
Non-*Acropora* Coral	CHL	Heliopora – deep brown, smooth surface, blue on the inside and white fluffy polyps when extended.
Non-*Acropora* Coral	CME	Fire coral – all species belonging to the Millepora family. These corals have smooth surface but when the polyps are extended they have a fuzzy appearance; normally mustard yellow/brown in colour.
Non-*Acropora* Coral	CTU	Tubipora corals – unique coral family also called organ pipe coral. This coral have a hard calcium carbonate skeleton that has many stacked organ pipe-like tubes. Each tube contains the coral polyps. The skeleton is bright red, but often hidden by the polyps which are grey or green in colour.
Dead Coral	DC	Dead coral – include recently dead corals. Dead coral colonies may have a visible yellow or white skeleton with no algae. Their corollite walls, holes and growth forms holes will still be recognizable; the smaller structures could be eroded and there may be a very thin.
Dead Coral	DCA	Dead coral algae – includes corals that have been dead for a large period of time. Those colonies are covered with thick fleshy algae. The substrate close to those dead corals is normally covered with microscopic turf algae. The majority of those dead corals retain their coral structure.
Algae	AA	Algae – non-distinct algal mass usually made up of different types of algae. Their size is bigger than turf algae, but smaller than macro algae usually <5cm.
Algae	CA	Coralline algae – calcified coralline algae. Their colour can range from pink to dark burgundy; often encrusting but sometimes they appear like leaves.
Algae	HA	Halimeda – genus of green micro algae. This organism has a triangle-shaped, segmented, calcified stacked green body. Most herbivores do not eat these algae due to its calcareous skeleton.
Algae	MA	Macroalgae – non-district algae that are >5m in height. Generally, those do not have complex anatomical forms; their bodies are often erected. These can be brown, green and red in colour.
Algae	TA	Turf algae – multi-specific, but often those are uniform, short filamentous or mat of algae. Their size vary between >1cm & <5cm. This categories has a high diversity, including 30-50 species commonly occurring.
Other fauna	SC	Soft coral – this category includes all species of soft or leathery coral. Their colour range from dark shades of brown to very bright and colourful.
Other fauna	SP	Sponge – this category includes all animals from the Porifera Phylum. Sponges vary in shape, size and colour. These multicellular organisms have prominent openings and rough surface texture.

Other fauna	ZO	Zoanthids – those belong to a cnidarian order that is commonly found in coral reefs. Those are sea anemones that live in small colonies. These organisms usually have polyps joined together with two rings tentacles.
Other fauna	OT	Other – this category is for any other organism like gorgonians, anemones, sea squirt and sea grass.
Abiotic	S	Sand – normally composed by fine grains, their size range between >63mm and <2mm. When stirred it settles immediately.
Abiotic	SI	Silt – is normally composed by fine particles that when stirred, form a cloud where the particles remain suspended and settles very slowly.
Abiotic	RU	Rubble – broken unconsolidated pieces of coral; those can be dead or alive. Their size vary but generally <15cm in size.
Abiotic	WA	Water – in this category is included any crevice, crack or fissure deeper than 50cm.
Abiotic	RCK	Rock – hard substrate of non-carbonate origin. It can be made of stone or granites. Hard substrates that are covered by barnacles, oysters, encrusting turf or coralline algae also fall into this category.
Abiotic	DB	Debris – both natural (unconsolidated material) and manmade (marine litter, abandoned fishing gear etc.) When exposed to the marine environment, debris can be colonized by algae and sessile organisms (oysters, mussels, barnacles etc.)

3. Fish abundance, size and diversity (pre-selected indicators only)

Code	Fish
BF	Chaetodontidae, Butterflyfish
GT	Haemulidae, Sweetlip
SN	Lutjanidae, Snapper
BC	Barramindi Cod
HW	Humphead wrasse
BP	Bumphead Parrotfish
PF	Parrotfish (other)
ME	Moray eel
GP_30_40	Grouper 30 - 40 cm
GP_40_50	Grouper 40 - 50 cm
GP_50_60	Grouper 50 - 60 cm
GP_gt60	Grouper > 60 cm
Sharks	Sharks
Turtles	Turtles
Mantas	Mantas
OtherFauna	Other fauna

4. Invertebrate abundance, size and diversity (pre-selected indicators only)

Code	Invertebrate
BCS	Banded Coral Shrimp
Diadema	*Diadema* (long spined sea urchin)
PUrchin	Pencil Urchin
CUrchin	Collector Urchin

SC	Sea Cucumber
COT	Crown of Thorns
Triton	Triton
Lobster	Lob
GC_lt10	Giant Clam <10cm
GC_10_20	Giant Clam 10-20cm
GC_20_30	Giant Clam 20-30cm
GC_30_40	Giant Clam 30-40cm
GC_10_20	Giant Clam 40-50cm
GC_gt50	Giant Clam >50cm

5. Anthropogenic impacts, coral disease and bleaching

Code	Impact
Boat_Anchor	Damage - boat or anchor
Dynamite	Damage - dynamite
Other	Damage - other
ALDFG	Trash - Abandoned, Lost or otherwise discarded fishing gear
Litter	Trash - litter