BASELINE ASSESSMENT OF CORAL CONDITION IN TUBBATAHA REEFS NATURAL PARK: MONITORING SITES AND GROUNDING SITES

Submitted By:

Dr. Laurie J. Raymundo,
University of Guam Marine Laboratory
and
Dr. Alexander M. Kerr,
University of Guam Marine Laboratory

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EXECUTIVE SUMMARY

From April 24 to 28, 2015, surveys were conducted on Tubbataha to attempt to establish a baseline level of coral disease and to assess coral health condition. Such surveys had not been undertaken, to date. However, as coral diseases become an increasing threat to reef health worldwide, the Tubbataha Management Office deemed it important to determine whether this was a threat to the current health of the reef communities and to establish what would be considered a “normal” current level of disease against which to measure future levels. An additional goal was to assess coral health at two grounding sites, which had been damaged in 2015 from the grounding of the US Navy vessel, USS Guardian, and the Chinese fishing vessel Ming Pin Yu. In the five days of surveys, researchers from University of Guam Marine Lab, Dr. Laurie Raymundo and Dr. Alexander Kerr, and Silliman University Institute of Marine Science, Dr. Aileen Maypa, carried out surveys at the South Atoll (Site S6) and North Atoll (Site S2), as well as the two grounding sites. Due to weather constraints, Jessie Beazley Atoll was not visited. Replicate transects were read at both deep and shallow permanent monitoring sites and at control and impact sites within grounding areas. Mean total disease prevalence at the monitoring sites was 3.3%±2.2% and that within the grounding footprint, 7.7%±9.2%. This suggests that the corals damaged from the grounding event were rendered more susceptible to disease because of the physical damage to the colonies. Furthermore, this effect was visible a full two years after the event and despite signs of regrowth and recovery. White syndrome was, by far, the most commonly observed disease; present at all sites. Other diseases: black band disease, brown band disease, skeletal eroding band, growth anomalies and ulcerative white spots, were all very rare. Recommendations are presented for improved or continued management, based on our results.

INTRODUCTION

In April 2015, surveys were conducted at two monitoring sites and two grounding sites on the North and South Atolls, Tubbataha Reefs Natural Park (TRNP) (N 08°50'677, E 119°55'734), in the Sulu Sea, Philippines to establish baseline levels of prevalence of described Indo-Pacific coral diseases. This report summarizes this survey effort, presents a baseline disease prevalence level and an assessment of coral condition within the grounding site footprints, and suggests recommendations for improving management within the Park.

Infectious coral diseases are now considered a major threat to coral reefs globally (Harvell et al. 2004; Burge et al. 2014). While diseases caused by microorganisms are a natural component of all ecosystems, the recent increase in the prevalence of coral disease is thought to be symptomatic of degrading water quality and habitat, which affect a coral's ability to mount an adequate immunodefense response to stress (Mydlarz et al. 2006). As such, infectious disease is both an emerging cause of coral decline and a consequence of degrading environments for corals. However, there are many reef systems that have never been surveyed, so determination of how much of an impact disease is currently having—or may have in the future--is impossible. Hence, there is a need for assessments and monitoring for this threat.

The study of coral disease is a relatively recent science and one of the questions that researchers grapple with is "what constitutes a baseline level of disease on a reef?" (Ruiz et al. 2012). Pristine reefs worldwide offer the opportunity to determine what we predict might constitute a baseline amount of coral disease, given intact ecosystems and clean water. An additional impetus for establishing a "baseline" in a given location is to provide a reference metric against which to measure future change. As rising sea temperatures, increased frequency of bleaching events, ocean acidification and more severe storms are predicted as a consequence of climate change, it is essential to establish what is considered "normal" within a given reef community prior to major environmental change. Understanding what constitutes expected levels of a given attribute—such as disease prevalence—under a given set of environmental conditions increases predictive power and the efficacy of management efforts.

TRNP is a relatively pristine reef that has not been previously surveyed for coral disease. A strong management effort run by the Tubbataha Protected Area Management Board has resulted in the creation of a monitoring program, deployment of conservation officers that patrol the area to prevent harvesting and destructive activities, and guidelines for controlling the impacts of tourism. Given the expected increase in tourism activities and the constant threat of poaching, ship groundings, storms and bleaching events, it is important to include an assessment of coral condition (i.e., population size structure and impacts to health: disease, bleaching, predation, physical damage) in regular monitoring activities. While percent live coral cover and species diversity assessments can be important indicators of change, they do not reveal the cause of any change witnessed. By assessing, documenting and quantifying possible causes of mortality, management efforts can be better designed to protect these reefs.

This first effort, therefore, had two objectives: 1) to survey coral condition in as many of the permanently established monitoring sites as possible, given weather and time constraints, and 2) to survey two major grounding sites: the USS Guardian and the F/V Min Ping Yu, to look for evidence of recovery and test the hypothesis that physical damage to corals is associated with higher disease prevalence.

METHODS

Surveys took place over a 5-day period, April 24-28, 2015. One monitoring site on the south atoll: S6-B (N 08°45.103', E 119°49.660') and one on the north atoll: S2-A (N 08°56.126', E 120°00.763') were surveyed at both deep and shallow subsites. In addition, the F/V Min Ping Yu (N 08°51.091', E 119°56.200') and USS Guardian (N 08°48.543', E 119°48.516') were also surveyed see Figure 1). Shallow control sites adjacent to each grounding site, but outside of the damage footprint, were also surveyed. Weather constraints prevented us from surveying a site on Jessie Beazley atoll.

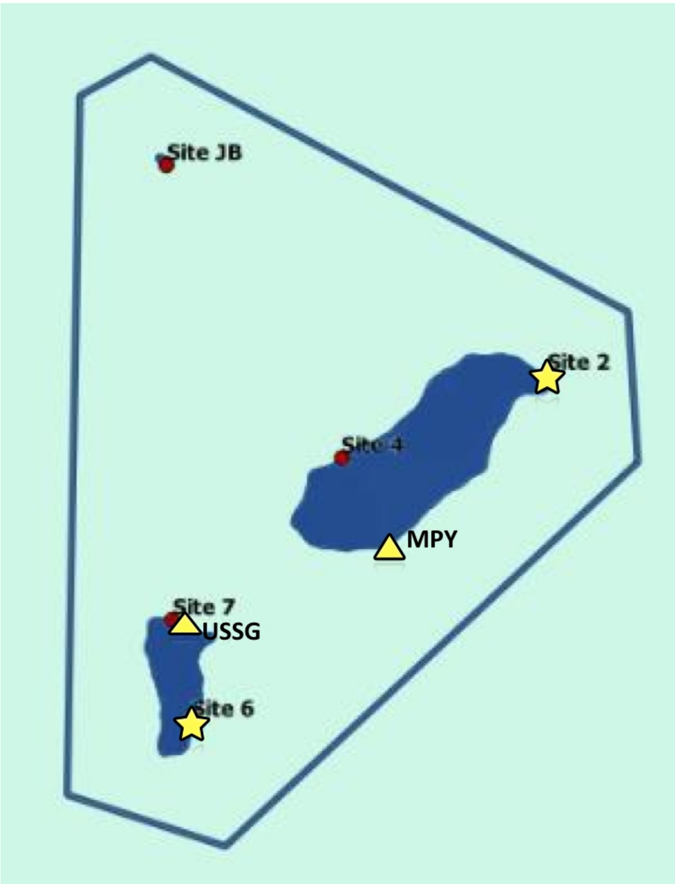

Figure 1. Map of TRNP showing unsurveyed monitoring sites (red dots) and monitoring sites surveyed during this trip (yellow stars), and surveyed grounding sites (yellow triangles).

At sites S6-B and S2-A, two 20m transects were laid at deep (10m) and shallow (5m) depths, following the reef contour, parallel to shore and approx-imately 10m apart. A one meter belt was read along each transect, for a total reef area surveyed of 80 m^2 per site. Within each belt, all coral colonies were counted, identified to the lowest taxon possible, size class was determined by estimating maximum colony diameter, and colonies were individually assessed for impacts to health. Size classes used were developed by Raymundo and have been applied adequately to Micronesian (Redding et al. 2013; Raymundo et al. 2013; Raymundo et al. in prep) and Philippine (Raymundo et al. 2011) reefs. They are listed in Table 1.

Disease assessments followed those described in Raymundo et al. (2009) and included all described diseases from Indo-Pacific reefs: white syndrome, black band disease, brown band disease, ulcerative white spot disease, growth anomalies, and skeletal eroding band. We also examined colonies for non-disease impacts that include: predation, bleaching, physical damage such as breakage or toppling, and aggressive algal overgrowth.

Table 1. Size classes used in coral population size structure assessments.

Size Class	Colony Maximum Diameter Range, cm
1	1 - 10 cm
2	11 - 30 cm
3	31 - 60 cm
4	61 cm - 1 m
5	1 - 2 m
6	> 2 m

At grounding sites, replicate parallel transects were laid along the length of the grounding footprint, to cover the entire area of the impact site as well as adjacent unimpacted control sites. We differentiated between two distinct zones affected by groundings: 1) *direct impact zones* (defined as the zone where the ships had rested on the substrate, determined by obvious scouring and carving of the pavement substrate) and 2) *impact border zones* (defined as the adjacent area affected by ship movement and shifting, determined by the absence of direct scouring and presence of rubble, dead structure, breakage and other signs of physical damage). Additional transects were laid in adjacent reef area outside the grounding footprint, to serve as unimpacted controls. Therefore, transect position varied according to the position of damaged area. The fishing boat Min Ping Yu struck the reef broadside, creating a scoured rectangular area approximately 3902 m^2 (estimated by Tubbataha Manage-ment Office (2014)), parallel to the reef crest ridge. To survey this site, four 30m x 1m belt transects were positioned as described by Figure 2, to cover the seaward border of the impact zone (B), the center of the direct impact zone (C), and the lagoonal crest border zone (D). The total estimated area surveyed was 875 m^2. This area, however, did not include the swath cut by the boat as it

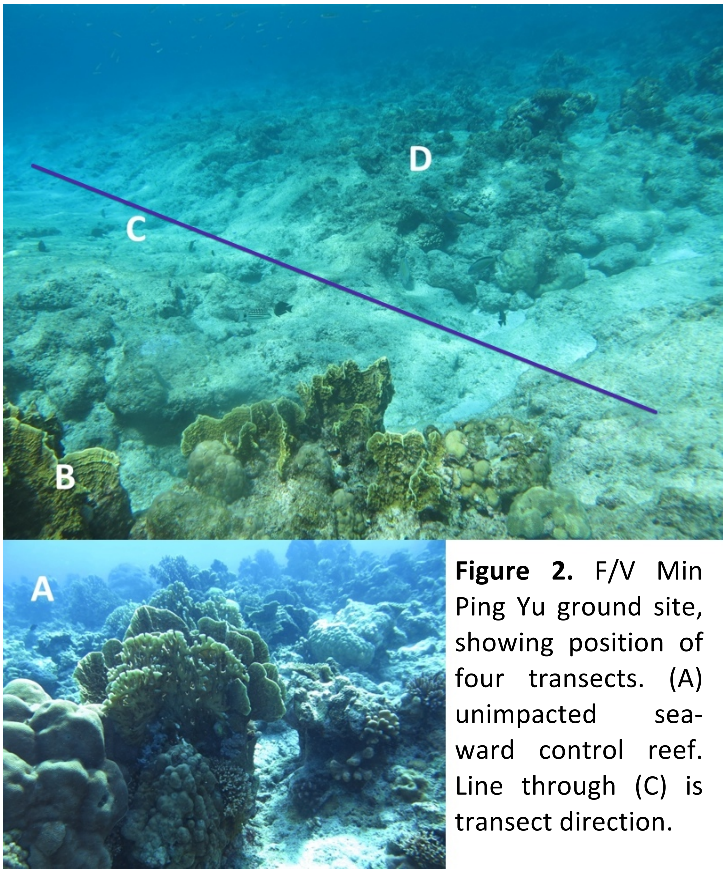

Figure 2. F/V Min Ping Yu ground site, showing position of four transects. (A) unimpacted sea-ward control reef. Line through (C) is transect direction.

approached the reef crest. Transect (A) was laid parallel to the impact zone within intact reef along the seaward edge. These long transects were subdivided into (3) 10m-long segments; each segment was considered a separate replicate for statistical analysis.

In contrast, the USS Guardian struck the reef perpendicular to the crest, creating an impact zone roughly 2345 m^2. Thus, to survey this site, we ran short (10m x 1m) replicate belt transects perpendicular to the crest, from the crest toward the lagoon, to cover both the primary direct impact zone (nine transects) and the impact border margins on either side (three and four transects, respectively). Transects were approximately 5m apart. The approximate area of reef substrate surveyed was, therefore, 975 m^2. Six 10 m x 1 m belt transects were likewise surveyed along intact reef adjacent to the impact zone, to serve as a control site (Figure 3).

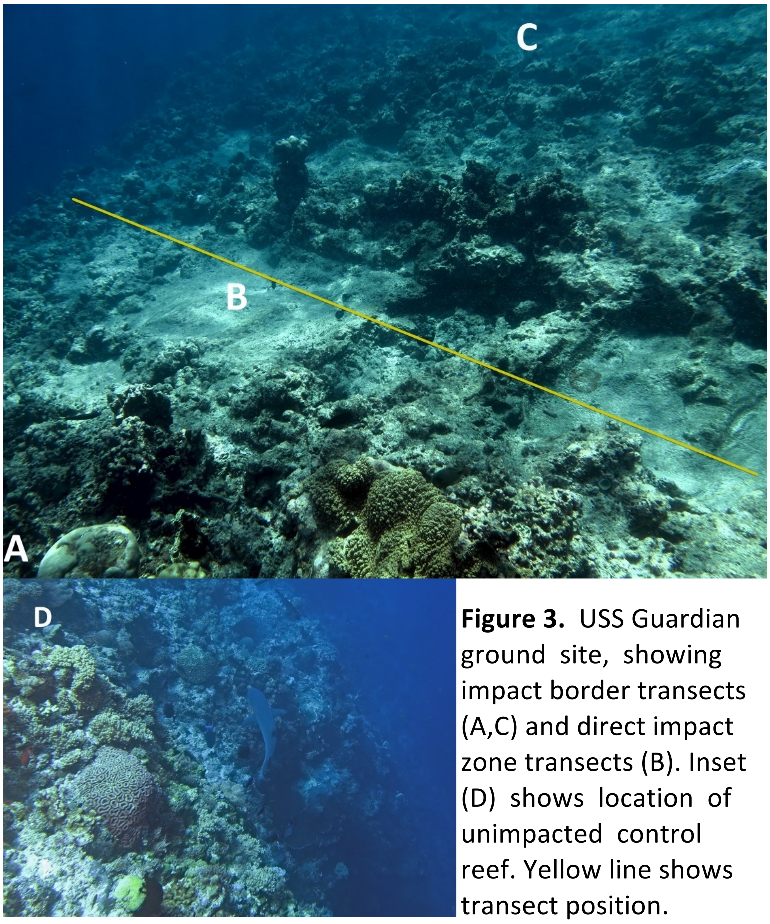

Figure 3. USS Guardian ground site, showing impact border transects (A,C) and direct impact zone transects (B). Inset (D) shows location of unimpacted control reef. Yellow line shows transect position.

Prevalence of disease, damage, and bleaching was calculated per transect as follows: (No. of colonies with impact N)/(Total no. of colonies) X 100. Means and standard deviations were calculated per site using standard statistical methods.

RESULTS

Of the described Indo-Pacific coral diseases, six were observed along our transects: white syndrome, black band disease, skeletal eroding band, brown band disease, growth anomalies, and ulcerative white spots (Figure 4). Mean total prevalence for all sites was 6.9% ± 8%, but when broken down by site type, total mean prevalence for diseases in the monitoring sites was 3.3% ± 2.2%, and in the grounding sites was 7.7% ± 9.2%. We present figures from other surveys within the Philippines for comparison in Table 2. This finding is consistent with other surveys; in general, despite high coral cover, reefs that are less impacted and have more intact communities tend to have lower disease prevalence (Raymundo et al. 2009). White syndrome was, by far, the most common disease and was observed on at least one transect at all sites, affecting 14

Table 2. Calculations of mean total disease prevalence taken from other surveys in the Philippines.

Total Mean Prevalence	Location	Reference
11.60%	Central Visayas	Raymundo *et al.* 2005
5.10%	Lingayen Gulf	Raymundo *et al.* 2005
2.80%	Central Visayas MPAs	Raymundo *et al.* 2009
4.50%	Central Visayas non-MPAs	Raymundo *et al.* 2009
4.65%	Central Visayas	Ruiz-Moreno *et al.* 2012
2.50%	Bantayan Is., Cebu	Raymundo *et al.* 2011
3.30%	Tubbataha monitoring sites	*This report*
7.70%	Tubbataha grounding sites	*This report*

genera (*Acropora, Isopora, Montipora, Pocillopora, Porites, Favia, Favites, Goniastrea, Platygyra, Cyphastrea, Echinopora, Leptoria, Hydnophora* and *Coeloseris*). White syndromes have broad host and geographic ranges and appear to have more than one cause (Bourne et al. 2015). Other diseases were very uncommon and limited to one or two cases per transect. Other impacts to coral health included bleaching, physical damage (breakage/ toppling) and corallivory from the snail *Drupella* spp. However, prevalence of these impacts was generally very low and we saw no direct evidence of corallivore (either *Drupella* or *Acanthaster planci*) outbreaks. In this report we also include a category for partial mortality (tissue loss) of unknown cause. In some cases, tissue loss is a product of a past insult and the cause is no longer evident. However, if the history if the site is known, as it is in this case, then records of partial mortality provide useful information even if the direct cause is not verified by actual observation. It is prudent, therefore, to track this sort of change, particularly when monitoring is infrequent. We recorded these observations as partial mortality. Examples of these impacts are presented in Figure 5. We discuss results of monitoring sites separately from the grounding site; please see below.

Permanent Monitoring Sites

A summary of descriptive characters of the coral communities in the monitoring sites is presented in Table 3. Colony density (i.e., numbers of colonies per $20m^2$) varied considerably between sites and depths but, interestingly, the total number of genera did not vary that widely. Overall total disease prevalence for monitoring sites was 3.3%±2.2%, which is fairly low. White syndrome accounted for most of the disease we observed, though there were a few cases of skeletal eroding band recorded. This disease is frequently observed colonizing wounds to coral tissue caused by physical damage or predation (Page and Willis 2008) and so it is not unusual to see it associated with predation wounds. Bleaching was very rare on all sites, as was unexplained partial mortality/tissue loss, and physical damage was limited to two cases observed on one transect in the shallow site at S6-B.

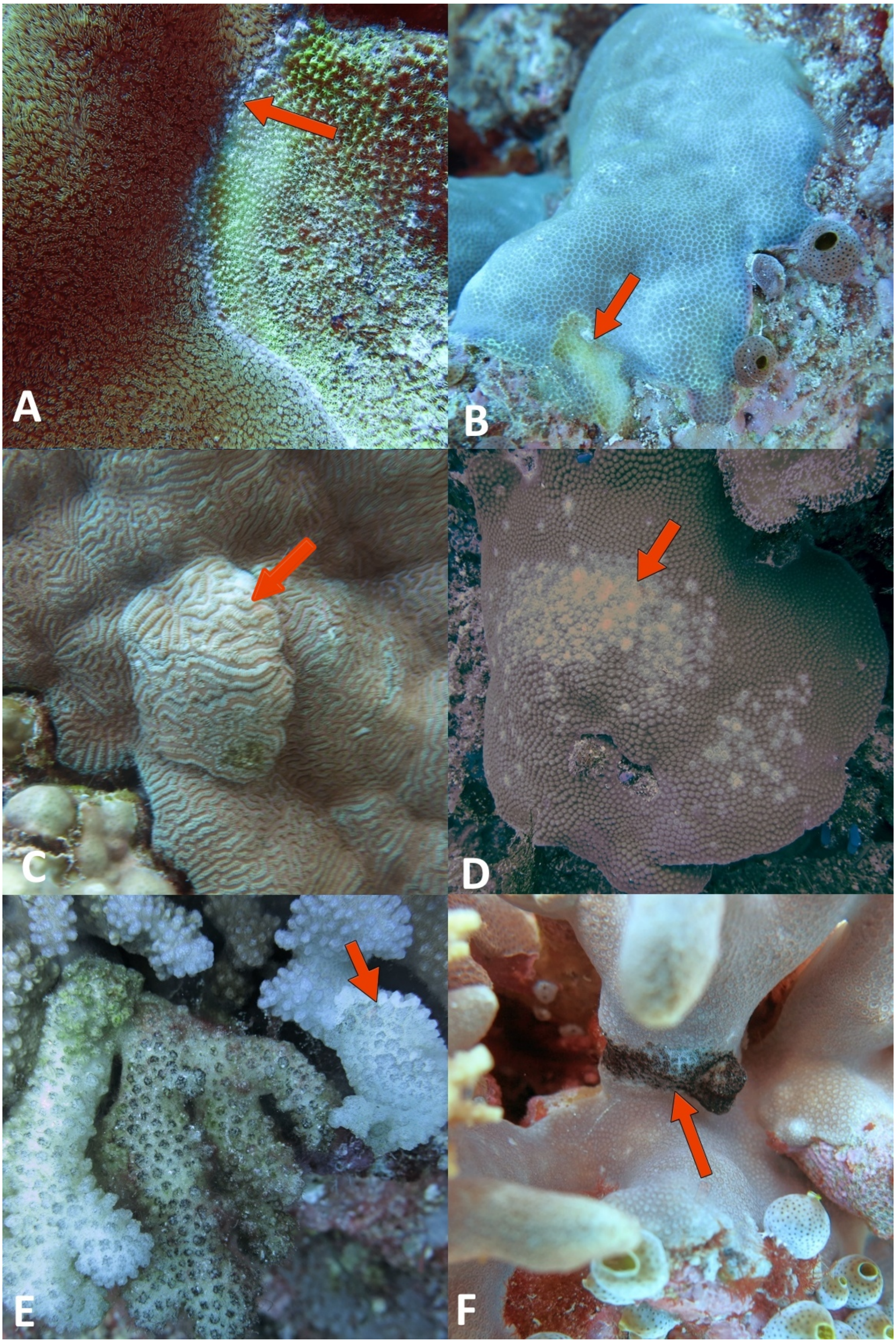

Figure 4. Coral diseases observed within surveyed sites in 2015. (A),(B): White syndrome affecting *Hydnophora pilosa* and *Porites* sp.; (C) a growth anomaly on *Leptoria phrygia;* (D): Ulcerative white spot disease affecting *Diploastrea heliopora;* (E): Skeletal eroding band on *Pocillopora* sp*;* and (F): Black band disease on *Porites cylindrica*. Red arrows indicate progressing front of each disease. Photos: L. Raymundo.

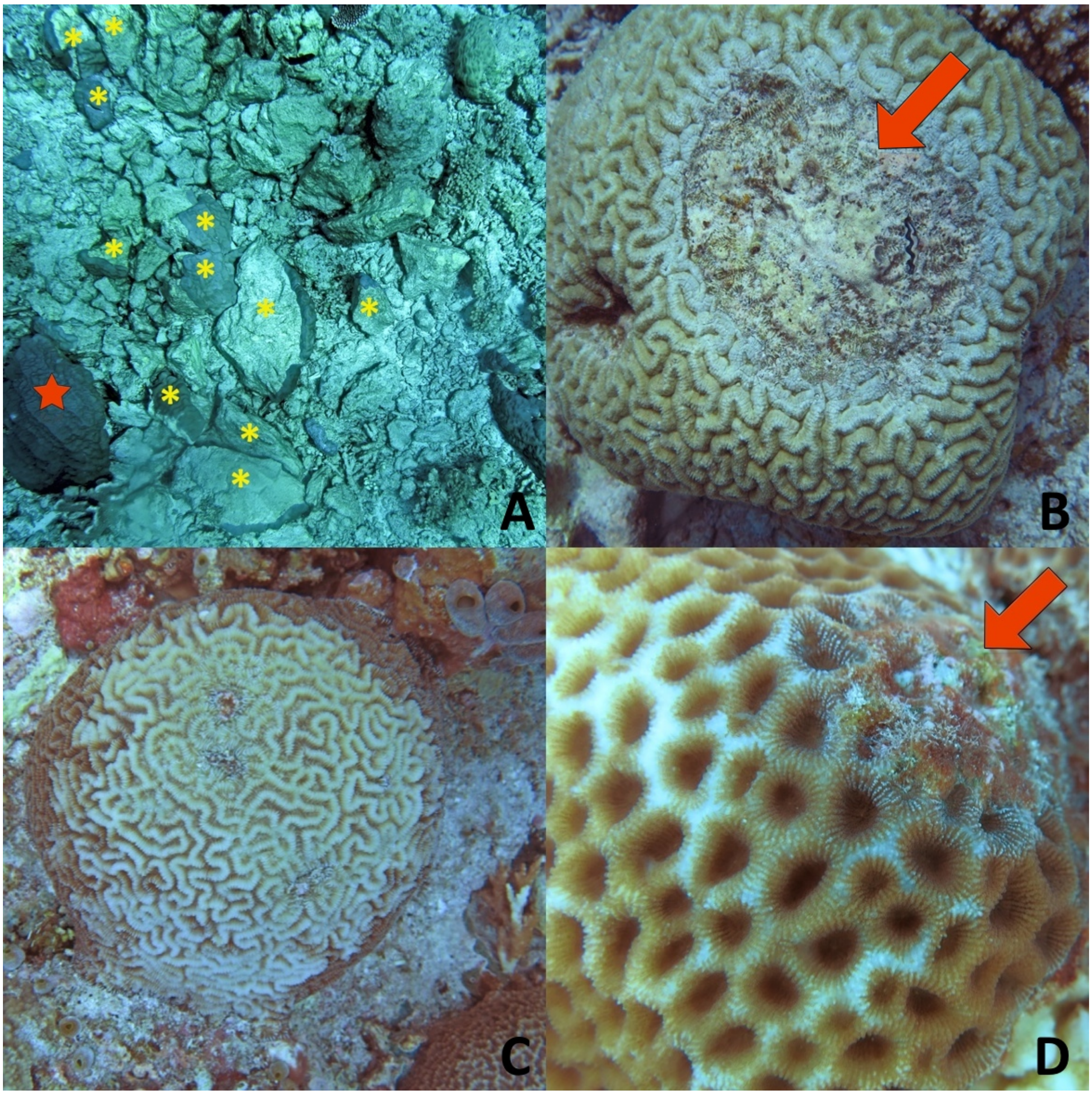

Figure 5. Impacts to corals that were not attributed to infectious diseases. (A) Breakage of a massive *Porites* colony as a result of the Min Ping Yu grounding two years prior. Red star denotes a portion of the original colony; yellow stars denote pieces of the colony broken off when the boat struck. (B) Surface abrasion (red arrow) of a *Symphyllia* colony in the same area, probably caused by damage from the boat hitting the top of the colony. (C) Bleaching in *Platygyra*; (C) Tissue loss of unknown origin in *Favites*. Photos: L. Raymundo.

Population size structure of the monitoring sites showed a dominance by colonies in size class 2 (11 -30cm maximum diameter) (Figure 6). This is not uncommon in reef zones regularly exposed to high wave energy; indeed most transects were dominated by robust growth forms. The highest colony density was seen in the site with the largest number of colonies in size class 1 (1-10cm); S2-A, Shallow. All three transects at this site encompassed a large number of caespitose *Acropora*, which is a growth form that tends to be smaller.

Table 3. Summary of surveyed attributes of coral communities in the permanent monitoring stations. Numbers in ( ) represent one standard deviation from the mean presented.

Site	Mean Colony No. / Transect	Total Genera Number	Mean Disease Prevalence					Other Health Impacts		
			WS	BBD	SEB	UWS	Total Disease	Bleaching	Partial Mortality	Physical Damage
S2-A North, Deep	244 ± 24	24	4.9 (0.09)	0.00	0.2 (0.3)	0.00	5.1 (0.2)	2.7 (2.6)	2.7 (2.6)	0.00
S2-A North, Shallow	670 ± 437	28	2.2 (0.02)	0.05 (0.07)	0.00	0.17 (0.04)	2.4 (0.1)	0.9 (1.1)	3.1 (1.2)	0.00
S6-B South, Deep	202 ± 0.7	29	3.7 (0.4)	0.00	1.2 (0.4)	0.00	5 (0.7)	0.5 (0.7)	0.2 (0.4)	0.00
S6-B South, Shallow	197 ± 164	25	1.5 (2.7)	0.00	0.3 (0.5)	0.00	1.6 (2.7)	1.4 (2)	1.9 (2.4)	0.3 (0.5)

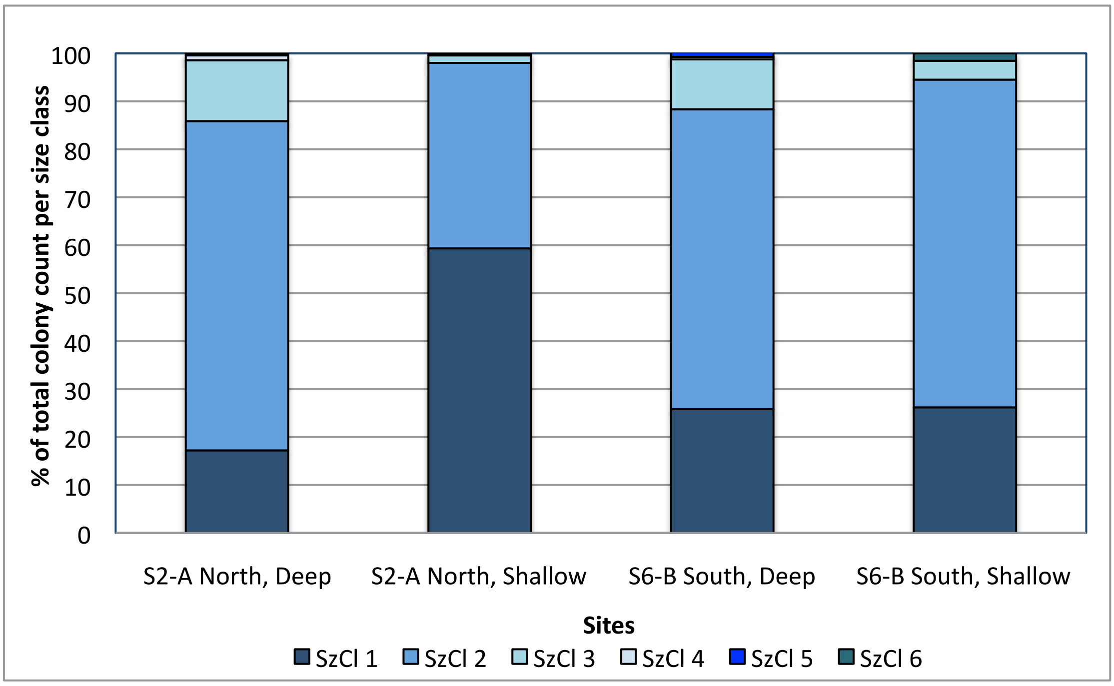

Figure 6. Coral population size structure summarized by sub-site, for monitoring sites surveyed in 2015. Colony counts are pooled across transects at each site. Size classes are defined in Table 1.

In summary, our surveys revealed a reasonably healthy coral community in good condition, with no indication of any major physical or biological damage or impact to the community in the recent past.

Grounding Sites

Our efforts at the grounding sites attempted to quantify visible impacts to the coral community two years after the events, in order to provide some ability to project the length of time for full recovery. In general, the scoured direct impact areas were visibly distinct from either the impact border zones or the adjacent unimpacted reef areas. Rubble that dominated directly after the incidents was absent, probably having been washed into deeper water by wave action. Direct impact zones were devoid of large colonies and the damage to substrate was still very prominent. Colonies within these zones appeared to be new recruits that probably appeared after the incidents; most were within the smallest size class. This indicates that recovery is beginning within these zones and will probably continue as long as the reef remains healthy, herbivory is high, and water quality remains high. However, it will likely take much longer for these areas to resemble the surrounding reef. We discuss each grounding site separately, below.

F/V Min Ping Yu

Table 4 and Figure 5 summarize coral community attributes that were measured at this site. The seaward control, immediately adjacent to the direct impact site, showed higher colony density, generic diversity and percentage of colonies in larger size classes than sites impacted by the ship grounding. The seaward border was

Table 4. Summary of surveyed attributes of two ship grounding sites and undamaged control areas within TRNP. Values in ( ) represent one standard deviation from the mean.

Site	Position in Impact Zone	Mean Colony No./ Transect	Total Genera Number	Disease Prevalence					Other Health Impacts Prevalence		
				WS	BrB	SEB	GA	Total Disease	Bleaching	Partial Mortality	Physical Damage
Min Ping Yu	seaward control	34 (15)	22	7.6 (0.6)	0	1.3 (2.3)	1.2 (2.1)	10.3 (1.8)	5.2 (4.5)	16 (11.6)	2 (2)
	seaward impact border	25 (2.5)	19	16.2 (8.5)	0	1.3 (2.3)	1.3 (2.3)	18.8 (12.)5	4 (6.9)	27.8 (7.4)	6.4 (3.8)
	impact zone	14 (9)	11	8.9 (10.2)	0	0	0	8.9 ±(10.)2	0	0	10.4 (8.4)
	lagoonal impact border	25 (17)	13	0	2.7 (1.6)	0	0	0.9 (1.6)	0.7 (1.7)	0	5.6 (9.6)
USS Guardian	impact border, west	31 (14)	19	13.6 (4.4)	0	0	0	13.6 (4.4)	10.7 (6.5)	33.7 (8.7)	11.5 (6.7)
	impact zone	7.8 (2.9)	8	2.9 (7.9)	0	0	0	2.9 (7.9)	0	0	7.8 (11.4)
	impact border, east	29.5 (4.2)	18	13.6 (6.7)	0	0	0	17.9 (3.2)	15.6 (7.6)	22 (15)	3 (2.4)
	control site	175 (99)	31	3.2 (0.8)	0	0.3 (0.4)	0	3.6 (1.2)	17.3 (7.6)	7.36 (0.7)	0.93 (1)

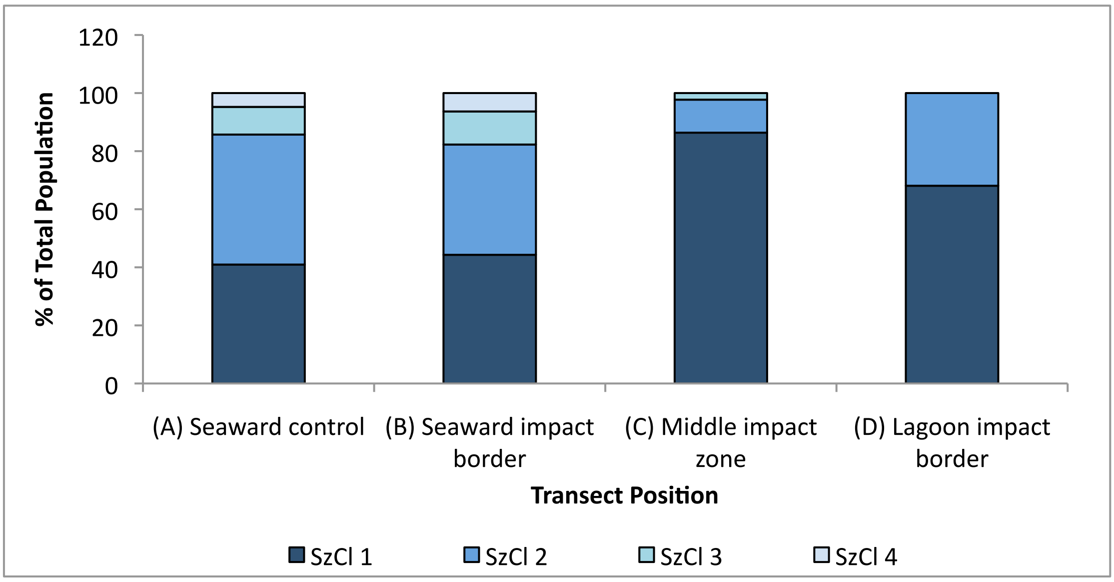

Figure 7. Coral population size structure in the F/V Min Ping Yu grounding site, two years after the incident. Numbers are summed per transect. Size classes are defined in Table 1.

similar to the control site, but showed numerous signs of past injury; many colonies were fractured or overturned; partial mortality and disease prevalence were highest in this zone. Both higher disease and partial mortality could be the direct result of the physical damage these colonies experienced. Several diseases are known to be associated with physical damage to the colony; damage creates entry wounds and stresses the colony, increasing its susceptibility to disease (Page and Willis 2008; Nicolet et al. 2013). However, many fractured colonies showed new growth and re-attachment to the substrate, a positive sign of recovery (Figure 6). The direct impact zone and lagoonal border were dominated by recent recruits of relatively low density and diversity, though disease and physical damage prevalence were still high.

Figure 8. Evidence of reattachment of an *Isopora palifera* colony along the seaward border of the Min Ping Yu grounding site.

USS Guardian

The grounding footprint pattern was most evident in the USS Guardian site. The area of direct impact was characterized by low colony density and generic diversity, high numbers of small colonies, the majority of which appeared to be new recruits (Figure 7), and low disease prevalence and partial mortality. Higher disease prevalence, physical damage, partial mortality and bleaching were all evident within the border zones. These contained a larger percentage of large colonies, higher colony density and generic diversity. However, the grounding footprint area was distinctly different from the control site adjacent to it, in all aspects. The undamaged control site showed a larger percentage of larger colonies, much higher colony density, generic diversity similar to that seen in monitoring sites, and very low disease prevalence, partial mortality and physical damage.

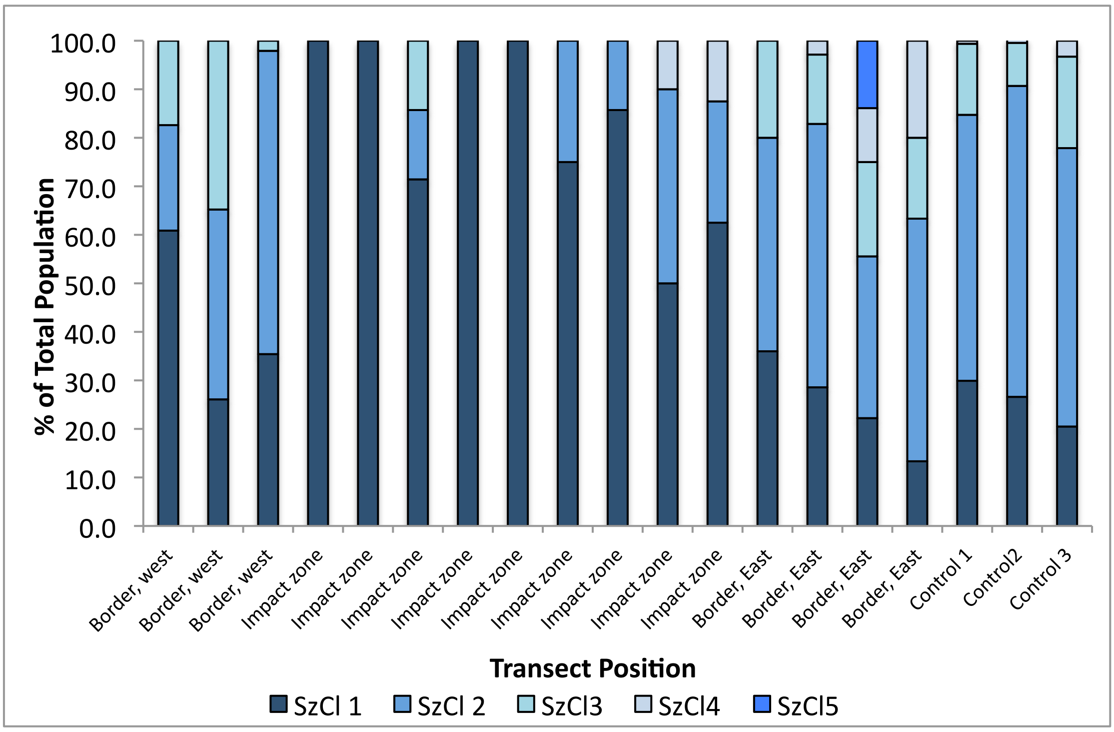

Figure 9. Coral population size structure within the USSG grounding footprint and in an adjacent control site. Numbers are summed per transect. Size classes are defined in Table 1.

In summary, impacts from the grounding sites showed similar patterns in both cases. The scouring effect of the ships resulted in bare substrate that was initially covered in rubble, but at the time of these surveys, the rubble had obviously been scatted by wave action. High herbivory prevented algal colonization of these areas, which made coral recruitment possible. Thus, the direct impact areas were dominated by few, juvenile coral colonies representing fewer genera than surrounding areas. Disease and damage to these colonies was low, as they recruited after the grounding and have suffered few impacts since the incidents. Persistent impacts of the grounding were more evident in the border zones. These contained coral populations with higher density and generic diversity, larger colonies, but also much higher total disease, physical damage and partial mortality. It is difficult to project how long it will take these areas to recover to the extent where they resemble the surrounding reef.

RECOMMENDATIONS

The following are recommendations to improve current management, based on the results of the surveys summarized in this report:

- Continue annual monitoring of benthic and fish communities. Establish a database or data repository that can be utilized to gauge management success.

- Include coral bleaching and disease severity and prevalence in monitoring efforts. If training of personnel is necessary to be able to accomplish this accurately, then invest in the training of key personnel.

- To assist and augment annual monitoring efforts, train resident conservation officers in basic monitoring techniques that would enable them to spot significant events (bleaching event, disease outbreak, COTS outbreak) and report them to the Management Board.

- Include the grounding sites in surveys, to monitor increases in percent live coral cover, as a proxy for recovery rate.

Studies have shown higher disease prevalence in reefs frequented by tourist divers than in adjacent reefs (Lamb and Willis 2011; Lamb et al. 2014), as well as higher disease severity in waters affected by sewage nutrient enrichment (Redding et al. 2013; Baker et al. 2010). It is hypothesized that divers cause breakage and damage to coral, creating entry wounds for pathogens and nutrients may stress coral defense mechanisms or favor pathogenic microbes. Therefore, management efforts should include the following:

- Establish monitoring stations within sites frequented by tourism dive boats. These can be short (10m) replicate transects but should be comparable in depth with the other monitoring sites, which could serve as control sites. Monitor for coral breakage, toppling, other physical damage and disease prevalence.

- Impose and enforce strict "no touch" rules for divers. Gear entanglement (including camera gear) and buoyancy control issues among new divers are also diver-related sources of coral breakage that should be discussed with divers and prevented by dive guides. Existing rules regarding the banning of gloves is to be supported and continued.

- Include information on the link between coral breakage and disease in all dive briefings.

- Monitor breakage and other forms of damage to corals and coral disease along permanent transects within dive sites.

At present the current regulations within the TRNP state that ships must dump sewage at least 1 nautical mile from the atoll. Work by Villanoy et al. (2003) on current dispersal patterns within TRNP suggested that dumping at the southwestern corner of the southern atoll would have the least impact on the reef, as most water would be deflected away from the atolls during much of the year. However, this is not, apparently, a consistent practice visiting dive ships. Stable isotope analysis, a novel tool that tracks nutrients sources in benthic organisms, is a useful tool to determine the concentrations and sources of molecules such as nitrogen and carbon in water and organisms. This tool demonstrated, for instance, that sewage-based nitrogen was still detectable in sea fans located 1 km offshore from a sewage outfall in the Caribbean (Baker et al. 2010).

- To address the impacts of ship sewage dumping and recommend a minimum distance and location acceptable for such activities, it would be beneficial to have a stable isotope analysis done on water samples. Although an analysis of biological tissue (such as fish, algae or soft corals) may provide more information, the permitting process is lengthy. Water sample analysis would provide an adequate risk assessment that could inform management decisions.

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