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Executive Summary

Coral reefs are severely threatened by climate change and human activities that challenge the natural resilience of these systems to resist and recover from disturbances. Managers, conservationists and policymakers are all working to tackle the challenges of giving reefs the best chance of coping with projected climate change impacts. Recently, reef resilience has received added research attention because disturbance frequencies are expected to increase under climate change scenarios. For this reason, many have been working to develop frameworks that enable reef resilience to be assessed and compared among sites. Identifying sites with high resilience potential can inform a range of management decisions to support and maintain coral reefs. Presently, a framework has been published that suggests 11 variables be evaluated to compare the resilience potential of coral reef sites. These are: coral diversity, bleaching resistance, recruitment, herbivore biomass, macroalgae cover, temperature variability, nutrient input, sedimentation, fishing access, coral disease, and anthropogenic physical impacts (McClanahan et al. 2012).

This report presents the results of the first field-based implementation of the McClanahan et al. (2012) framework from 35 sites around Saipan. This applied research was funded by the NOAA Coral Reef Initiative and is a collaboration of representatives of the following agencies: CNMI DEQ, NOAA, DFW, CRM, PMRI, and TNC. The resilience scores calculated are the average of the scores for 9 variables included in the analysis (the variables above minus coral disease and anthropogenic physical impacts, which were not observed). The relative categories high, medium and low were used to describe the scores for all independent variables and the resultant resilience scores. The report presents the results of the resilience analysis, including resilience rankings and maps, and presents suggestions for managers as well as our working group’s plans to continue and advance the research presented here in 2013/14.

23 sites were found to have high relative resilience; 9 sites have medium, and 3 have low. Principal Components Analysis revealed that all 9 variables contributed to differentiating the sites but rankings were most strongly driven by coral diversity, bleaching resistance and macroalgae cover. Without exception, sites with the highest resilience, relative to other sites surveyed, have high coral diversity, high bleaching resistance and low macroalgae cover. Low resilience sites have low coral diversity, low bleaching resistance, and high or at least some macroalgae cover. High and medium resilience sites are located throughout all of Saipan’s reef habitats while the low resilience sites are all in the Saipan lagoon.

Some of the suggestions for managers presented include: considering additional management and enforcement at four of the top ten high resilience sites that are not currently in protected areas, giving the sites with high resilience and high coral cover special attention to facilitate tourism opportunities, and monitoring and maintaining herbivory at sites especially vulnerable to coral bleaching.

Scoring for all independent variables and the final resilience scores are all relative to the sites surveyed only. Thus, the data can be re-analyzed and assessed when CNMI-wide results and recommendations become available in 2014 following surveying around Rota and Tinian. Follow-up work to that presented here is being planned and is described in the report’s concluding ‘Next steps’ section. The planned advancement of this work has already been partially funded. This applied research from Saipan is amongst only a few examples of operationalizing resilience as a concept to inform tractable informed management decisions. This work will continue to benefit from the high level of engagement amongst local and collaborating international agencies that has been characteristic of the project thus far.

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1. Introduction and objectives

Climate change is now widely regarded as the single greatest long-term threat to coral reef ecosystems; the world's most diverse marine ecosystems (review in Hoegh-Guldberg et al. 2007). Climate change impacts projected for reefs include a greater frequency and severity of coral bleaching events. These 'mass' bleaching events are caused by anomalously warm sea temperatures and have already impacted many of the world's reefs (reviews in Hoegh-Guldberg 1999, and Hoegh-Guldberg et al. 2007). Other climate-related impacts include increased ocean acidification (Anthony et al. 2011). As the oceans absorb more and more carbon dioxide, they acidify, which weakens coral skeletons, reducing growth rates and increasing susceptibility to damage from storms (review in Kleypas et al. 2006). Further, severe tropical storms are expected to increase in frequency and sea levels are rising (IPCC 2007). Changed rainfall and ocean circulation patterns are also expected on a range of spatial scales. These changes could increase freshwater input to some coral reef areas and affect source-sink recruitment dynamics for corals, other reef invertebrates, and reef-associated fish (Munday et al. 2009).

Despite the severity of the threats posed by climate change, for most reef locations stress caused by human activities is an even more imminent concern (Burke et al. 2011). Coastal development, dredging, construction, and coastal land management and use all affect water quality on reefs (Burke et al. 2011). The dominant framework builders on reefs, the stony corals, have to compete for space and light with algae. Algae grow faster than corals, especially in nutrient-rich waters, so algae sometimes out-competes corals when water quality is poor (McCook 1999). This is a competition made tougher for corals as coastal populations target and extract the herbivorous fish that help control algal growth (McCook 1999). Reefs have always faced natural and man-made disturbances and have always been dynamic systems (Nystrom and Folke 2001). Now though, increasing levels of anthropogenic stress and the projected effects of climate change pose unprecedented challenges to the resilience of reef systems (review in Hoegh-Guldberg et al. 2007). Resilience is the capacity to resist and recover from disturbances to maintain or return to a state that provides the goods and services upon which, for reefs, hundreds of millions of people depend (Resilience Alliance). That reef resilience is being challenged is supported by observations from around the world of declining coral cover on reefs in recent decades (examples; Bruno and Selig 2007; De'Ath et al. 2012).

Managing coral reefs in the face of local and global-scale stressors requires tackling the issues from several angles (Marshall et al. 2006). The condition of a coral reef can be likened to a patient with acute and chronic illnesses and both need to and are being addressed (Anthony and Maynard 2011). Policymakers and others are working to reduce greenhouse gas emissions and slow the rate of climate change. At the local-scale, managers and conservationists are working to support the resilience of reefs by reducing anthropogenic stress (examples: Maynard et al. 2010, 2011). Reef managers have a range of tools at their disposal to reduce stress. Tools such as protected areas reduce stress at a smaller scale, while others like watershed restoration efforts can affect large areas of reef habitat. Though most managers have at least some options for reducing stress on reefs, the areas to be managed are often large and resources to establish and enforce actions to reduce stress on reefs are usually scarce. For this reason, many managers benefit from knowing the actions they could take, and the areas they could implement these actions, to maximize their capacity to support reef resilience (Maynard et al. 2010).

Researchers have been working to identify the key characteristics of resilient reefs and through collaboration with managers and conservationists are developing ways to evaluate these 'resilience indicators'. In the most recent review, McClanahan and colleagues (2012) present a resilience assessment framework based on 11 key indicators that an expert panel believed to be of the greatest importance, and have the strongest empirical evidence (as conferring resistance or resilience).

> "Identifying the top-ten ranked factors for resilience independently for perceived importance and scientific evidence, showed some overlap in factors, but produced a total list of 13 factors (Table 2). From this list, we only included factors that were considered feasible to assess (average feasibility scores .5), which resulted in a final list of 11 key factors for resilience management and conservation, ranging from the presence of stress-resistant corals to areas of reduced fishing pressure. Using only this final list of 11 key factors, we developed a site-selection framework for management." – From McClanahan et al. 2012

The 11 recommended indicators are thus not necessarily *all* the indicators that may drive resilience potential at a site and differences in resiliency among sites. Rather the 11 are among the most important and have the greatest scientific evidence as influencing resilience. Further, the relative importance of each indicator to a final resilience score is diluted with each indicator added. We use the 11 recommended indicators here and recognize that other indicators could be important in Saipan and that this field of research is still growing and advancing. Definitive global or regional guidance for reef managers in the area of assessing resilience potential in the field has yet to become available. The 11 indicators recommended in McClanahan et al. 2012 and used here are: coral diversity, recruitment, bleaching resistance, temperature variability, herbivore biomass, macroalgae cover, nutrient input, sedimentation, fishing pressure, coral disease and anthropogenic physical impacts. The relative resilience potential of reef sites can be calculated and compared by measuring and assessing the recommended indicators at surveyed sites.

The research and work presented was conceptualized by some in the team at a workshop chaired by The Nature Conservancy in Guam in 2009. The aim initially was to develop and improve on the capacity within CNMI to respond to coral bleaching events. This became the basis of a proposal funded by the Coral Reef Initiative of NOAA to gather baseline information from reefs rarely or never visited around Saipan. The vision for the work expanded during the funding process. Collecting baseline information from infrequently visited sites as well as sites that have never been surveyed remained a priority. In total, 21 sites not visited annually by the Marine

Monitoring Team of CNMI's Division of Environmental Quality were surveyed (35 sites in total). In addition to collecting baseline information, the resilience assessment framework put forward by McClanahan et al. (2012) was completed. Undertaken in March of 2012, this was the first field-based implementation of this resilience assessment framework. Specific suggestions were developed on the back of the results to support reef resilience in CNMI.

The four specific objectives of the applied research we have conducted and will continue are:

1) To assess and measure the benthic community composition, key resilience indicators and anthropogenic stress at reef sites throughout CNMI.

2) To determine the relative resilience potential of sites we survey, to map and spatially interpolate the results, and to present findings in combination with assessments of combined anthropogenic stress.

3) To develop defensible suggestions for managers as action options to consider such that the natural resilience of reefs in CNMI can be supported and so that resilience can increasingly inform local management decisions.

4) To share our results with the broader scientific and management community in a two-way exchange such that others can benefit from our efforts and lessons learned and that our work can benefit from the efforts of others.

Objectives 1 and 2 are covered in the methods and results, and the report concludes with overviews of Objectives 3 and 4. As above, work towards all objectives is ongoing.

2. Methods

2.1 Data collection

Eleven variables were included in the resilience analysis, based on the site selection framework described in McClanahan et al. (2012). Data were collected and compiled on all 11 in Saipan from March 1 to May 20 of 2012 at a total of 35 sites (Fig. 1). Appendix 1 contains the survey site coordinates and Figure 1 shows the site locations. Survey and assessment methodologies used for each variable are described below with variables categorized as having been assessed in the field or via a desktop analysis. In addition to the 11 variables included in the resilience analysis, benthic community composition was assessed, using 3 x 50 m point-intercept transects (0.5 m intervals, 100 points per transect) at each site. In addition to the methods used to assess coral community structure (described below), a list of all species seen at the site was recorded. The resultant species list was used to tally all coral species seen at each site that were among the 82 species petitioned for endangered species listing in 2009 and the 66 of those proposed for listing by NMFS in December of 2012.

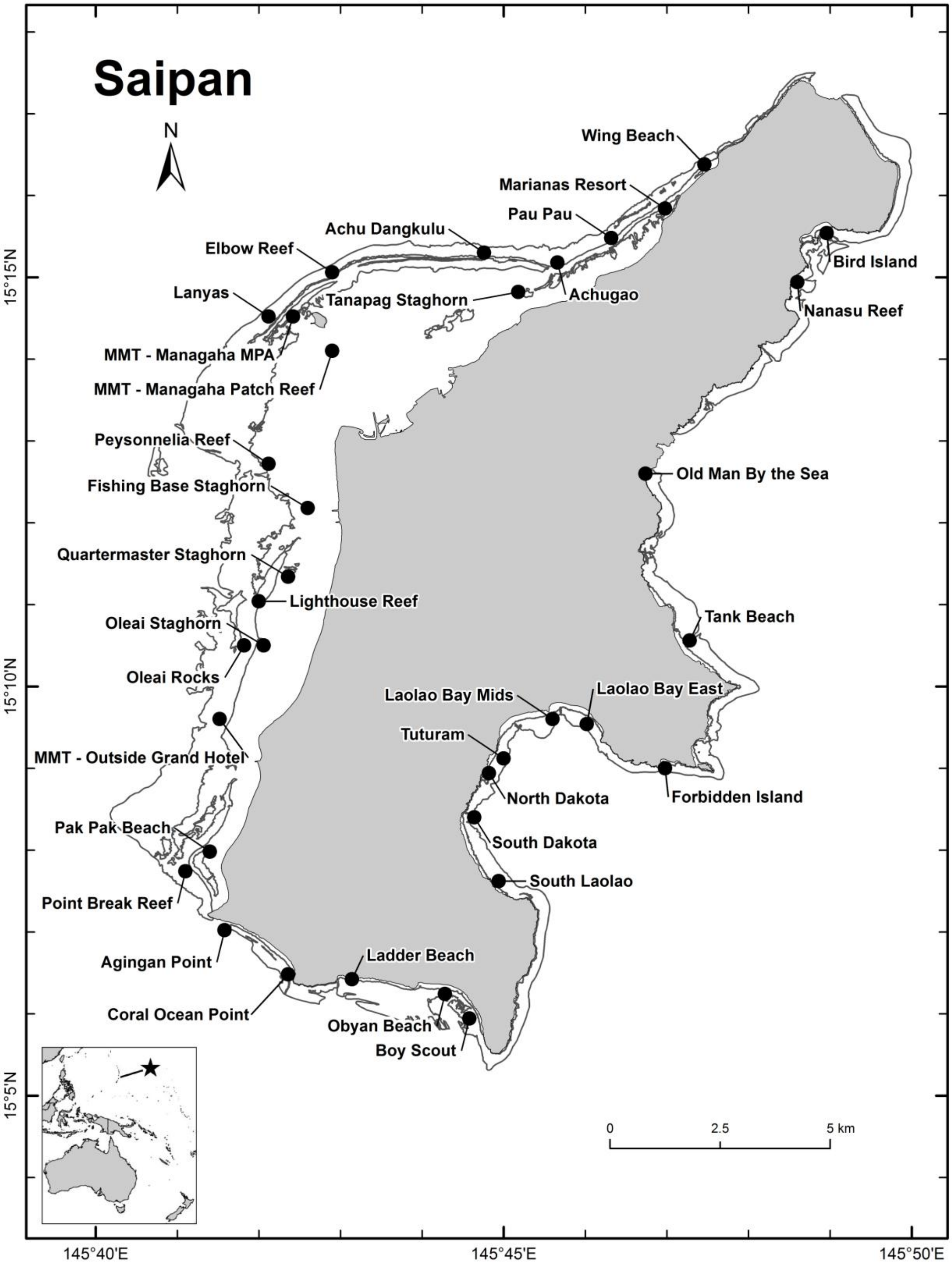


Fig. 1. Locations of the 35 sites surveyed between March and May of 2012 for the resilience analysis.

2.2 Fieldwork; variables measured

Variables assessed in the field include: coral diversity, recruitment, bleaching resistance, herbivore biomass, macroalgae cover, coral disease, and anthropogenic physical impacts (i.e., anchor and fin damage). Survey methodologies and units for each are described below.

Coral diversity

All corals were identified to species within 16, 0.25 m^2 quadrats haphazardly tossed along three 50 m line transects laid sequentially with 2-10 m gaps along the same depth (8-10 m for reef sites, 2-4 m for lagoon sites). A checklist of species encountered at the site was made (species richness), and the abundance of each species encountered in the quadrat tosses was derived. Simpson's Index of Diversity (unitless, ranging from 0 to 1) was calculated. This index asks the likelihood that two randomly sampled individuals will ***not*** be of the same species; the greater the likelihood (closer to 1) the higher the diversity. The formula for Simpson's Index is given below, where n = the total number of organisms of a particular species, and N = the total number of organisms of all species observed.

$$D = \frac{\sum n(n-1)}{N(N-1)}$$

Recruitment

The geometric mean (two longest lengths averaged) of all corals within 16, 0.25 m2 quadrats (see Coral diversity for transect information) was calculated. Recruits were considered to be corals with a geometric mean <4cm. The density of recruits was calculated for each site and became the final recruitment measure; sum total of recruits across all quadrats divided by 4 (for meters) yielding 'recruits/m^2'.

Bleaching resistance

Every coral species identified during the surveys was given a bleaching susceptibility score from 0 to 10; the higher the score the more susceptible the species to thermally-induced bleaching. Rankings were produced using an expert focus group that reviewed the literature, as well as data from the only well documented bleaching event in Saipan – the 2001 event (see Appendix 2). Species with a susceptibility score of 4 or less were considered resistant for this analysis. The proportion (%) of the community made up of bleaching resistant corals was then calculated for each site. The community of corals at each site was considered to be the species identified using the quadrats described for 'coral diversity' above.

Herbivore biomass

Three 3-minute 5-meter radius stationary point counts (SPC's) were performed along each of three different 25m transect lines at each site, for a total of nine SPC's at each location. The transect lines and SPC's were set over hard bottom habitat at a depth of approximately 30-feet. SPC areas never overlapped and there were typically 5 to 10-meters of space between each count. The SPC counts were performed prior to any other activities at each site to minimize diver influence and most counts were done while rolling out the initial transect lines which provided a precise distance with which to reference SPC boundaries. All herbivorous fish and all other fish larger than 10 cm in body length were identified to species, and their length was estimated to the nearest cm. The weight of each fish in grams was then calculated using the standard equation – $W = aL^b$, where W is weight, L is length, and a and b are coefficients specific to each species. The coefficients used were sourced from NOAA's Coral Reef Ecosystem Division, are up-to-date and are mostly standard across the globe for all of the fish species identified. Species were classified as herbivores using IUCN's classification for these species (Green and Bellwood 2009) and when not available were classified as herbivores if known to be herbivorous in Saipan and/or elsewhere. Herbivore biomass was calculated for each SPC at each site following summing, and converting to kg/100 m^2. The average herbivore biomass was used here and is based on averaging across all nine SPCs.

Macroalgae cover

Three 50 m point-intercept transects were laid as described in the Coral diversity section. At 50 cm intervals (100 per transect, 300 per site) the benthos was categorized as live coral, dead coral, soft coral, sand, rubble, crustose coralline algae (CCA), pavement (bare hard substrate without CCA), macroalgae, turfing algae, and other invertebrates (i.e., sponges and sea stars). Macroalgae cover was calculated as the average (across transects) percent of the points identified classified as macroalgae.

Coral disease

All observations of coral disease were to be identified and described within 1 meter either side of the three 50-m transects (see Coral diversity section), so three 100 m2 belt transects. ***No coral disease was identified or described at any of the sites during these surveys so coral disease is not included in the resilience analysis.*** At many sites non-normally pigmented tissue was seen on many *Porites* spp. (pink and blue tissue mostly), which is known to be an inflammatory-like response caused by interactions between the coral tissue and many organisms (see Palmer et al. 2008). This is not a disease per se, but warrants ongoing attention.

Anthropogenic physical impacts

All instances of anchor or diver damage were to be documented, described and photographed but no such damage was observed at any of the sites.

In the field, the SPC surveys for herbivore biomass were completed first by a 2-diver team over the course of 1 hour. The quadrat portion of the benthic surveys (for bleaching sensitivity, and species diversity) were completed by one in the first diver team within sight but behind the diver counting and identifying fish. A second two-diver team entered the water 45 minutes after the first team to conduct the remaining benthic surveys. Total time at each site ranged from 90-120 minutes.

2.3 Desktop; variables assessed

Variables assessed using remote sensing and GIS software include: temperature variability, nutrient input, sedimentation, and fishing access. The methodologies used to assess each are described below.

Temperature variability: Observed sea surface temperature (SST) data for the period 1982-2010 was obtained from NOAA AVHRR Pathfinder Version 5.2, which has a resolution of 4 km (Casey et al. 2010). The data was quality screened; only data with a quality flag of 4 or greater was used. For each pixel the maximum monthly mean (MMM) was calculated – this is the month of the year with the highest average temperatures during the 28-yr period. The month with the MMM and one month either side was considered the 12 week summer period. During similarly stressful events, reefs with high variability in temperatures during the summer period have been observed to bleach less severely than reefs with low temperature variability (recent example in Guest et al. 2010). It is unknown, however, how variable temperatures need to be for an increase in temperature tolerance to be noted. Variability is calculated here as the standard deviation of the summer temperatures.

Pollution and Sedimentation Proxies: A proxy for pollution loading was developed using geographic information system (GIS) layers pertaining to watershed size, topography, and discharge flow direction. Digital elevation models (i.e., topographic data) were first used to define watershed boundaries and likely flow patterns for discharge waters. Subsequently, each site was attributed to an adjacent watershed. The proxy for pollution loading was then calculated as a continuous variable by measuring the watershed size. Thus, it was assumed that watershed size was a disproportional contributor to overall pollution loading. A proxy for sedimentation was generated by incorporating United States Forest Service GIS layers pertaining to land use (http://www.fs.usda.gov/r5). Land use categories were simplified into three classes: 1) barren land/urbanized vegetation/highly developed, 2) shrubs, and 3) vegetation with canopy cover. The sedimentation proxy was estimated by the percent cover of class 1 within each watershed.

Fishing access: Several proxies were considered to accurately depict fishing pressure: 1) wave exposure, 2) distance to shoreline access, 3) distance to nearest large population center, and 4) number of people in the nearest population center. We examined several combinations of these variables for their ability to match an expert survey on perceived differences in relative fishing pressure, whereby local fishers and fishery managers were asked to evaluate fishing pressure at our survey sites as being ranked low, medium or high. Our preliminary analysis found that wave exposure alone most closely matched the results of the manager's survey and created a direct rank match for approximately 70% of the sites. When we ran the same comparison including distance to shore or population centers the results were a much poorer match, with less than a 50% of the sites lining up with the manager's survey in both cases. Most sites were within short drives from population centers and short swims from shore which could explain why attempts to add those metrics created such deviation from the manager's survey. Reef fishing is driven by accessibility, which is mostly driven by average wave height and wave heights are higher on the eastern shore due to prevailing winds. Fishing 'access' from wave height alone is thus used here as a proxy for fishing pressure.

Wave exposure was estimated by using long-term wind datasets, and GIS layers pertaining to varying angles of exposure for each survey site. For each site, fetch (i.e., distance of unobstructed open water) was first estimated for each site within 16 quadrants (i.e., 0 to 360 degrees, equally distributed into 16 bins). Fully develop sea conditions were considered if unobstructed exposure existed for 20 km or greater. Ten-year long-term windspeed averages were calculated from Saipan airport data (www7.ncdc.noaa.gov/), and used as inputs to calculate wave height following Ekebom et al. (2003). Specifically, mean height was calculated by:

$$\mathrm{Hm} = 0.019\ \mathrm{U1.1}\ \mathrm{F.45} \tag{1}$$

Hm is the wave height (m) for each quadrant, U is the windspeed at an elevation of 10m, and F is the fetch (km). Windspeed corrections for varying elevations were made following Ekebom et al. (2003). Last, wave height was converted to energy following:

$$\mathrm{E} = (1/8)\rho g \mathrm{H2} \tag{2}$$

Where ρ is the water density (kg/m3), g is the acceleration due to gravity (9.81 m/s2), and H is the wave height (m). This process resulted in continuous data on wave exposure (in terms of wave energy), used here to describe 'access' to the fishery.

Fishing access was considered to be '0' for all protected areas, irrespective of wave energy at the site, thus giving no-take MPA sites the best possible score (1) to account for the restricted access and perceived enforcement.

2.4 Data analysis

Resilience potential

Nine variables were used to calculate resilience potential - coral diversity, recruitment, herbivore biomass, bleaching resistance, temperature variability, macroalgae cover, nutrient input, sedimentation and fishing access. To calculate resilience potential (the final output), values for each variable were first anchored to the maximum value for the variable among the pool of sites and then normalized to a 0 to 1 scale. For each variable, the site with the maximum value is given a score of 1. All other values for that variable - all of the sites with less than the max value - are normalized to the score of 1 by dividing by the maximum value. For example, if the maximum bleaching resistance value is 64%, the site with 64% receives a 1 and the site with 60% receives a 0.94 (or 60 divided by 64). Anchoring values to the max value helps make clear exactly how different one site's value is from others.

To produce a composite score, the scale for the anchored and normalized scores must always the same (0-1) and be uni-directional; i.e., here, a high score is always a good score. This requires subtracting the anchored score from 1 for macroalgae cover, nutrient input, sedimentation and fishing access since high levels of these are a negative rather than a positive for reef resilience.1 minus the anchored score results in the same 0 to 1 scale and ensures that the sites with low values for macroalgae cover, nutrient input, sedimentation and fishing access receive the best possible scores (i.e., 0% macroalgae cover would receive a 1).

Normalizing to a standard scale ensures the scores can all be combined into the composite resilience score, which is the average of all of the anchored and normalized scores. That score is one final ‘resilience potential score’. An alternate is also produced by using the anchoring and normalizing procedure again whereby the site with the highest resilience score receives a 1 and so on. Both values are shown in summary tables. Sites are ranked from highest to lowest anchored resilience score. Rankings, from 1 to 35 – are the numbers used to identify the sites throughout all of the results tables and on all of the mapping outputs. Sites with an anchored resilience score of 0.8 to 1 are considered to have high (relative) resilience potential, 0.6-0.79 medium, and <0.6 is low; these are green, yellow and red, respectively, in the relevant mapping outputs. These same ranges are used to describe high, medium and low scores for all of the variables used in the resilience analysis except macroalgae cover, nutrient input, sedimentation and fishing access. For those four, high scores or good scores are higher than 0.4 (equivalent to 1-0.6), medium scores are 0.21-0.4, and low scores are 0-0.2 (equating to 1 minus 0.8-1).

A principal components analysis (PCA) was undertaken to test whether differences between sites in final resilience scores are consistently driven by a few rather than all of the variables examined.

Resiliency scores for sites are not indicative of the health or condition on their own. In the framework used, a site can have a high resilience score relative to other sites due to a range of different combinations of high, medium and low scores for the variables. Further, state variables likely to be useful in assessing condition, like coral cover, are not included. Information on condition at the survey sites is presented in the results in the form of current levels of anthropogenic stress and Appendix 3 describes the benthic community composition at the survey sites.

Anthropogenic stress

A composite score was produced for anthropogenic stress by averaging the anchored scores for fishing access, nutrient input and sedimentation. For consistency, such that the composite score for resilience potential can be calculated, high scores are good scores for these variables, so a high score equals low stress. As with resilience potential, scores from 0.8 to 1 are high scores or good scores (low stress), 0.6-0.79 medium, and scores of <0.6 are low and equate to high stress. The larger numbers signifying low stress is counterintuitive and an unfortunate effect of needing all anchored scores to be uni-directional for a composite score to be produced. The figure captions help with interpretation of the maps that describe the anthropogenic stressors and the colors used remain intuitive in that red denotes the sites with high stress.

Mapping outputs

Maps have been produced using ArcGIS for resilience potential, anthropogenic stress, and for each of the nine variables. Spatial interpolation of the resilience analysis results was completed using the kriging process in ArcGIS, excluding the lagoon sites, which are portrayed as circular areas with ~500 m diameter. Nearest neighbor results are used for the interpolation, except in cases where the nearest neighbor is on the other side of the island (i.e., Bird Island). Interpolation results for resilience potential are contained to known reef area based on locally sourced habitat maps held by CNMI DEQ and PMRI.

Anchored scores are presented on the maps as 0 to 100 (to reflect percentage of max value) for ease of interpretation, but are from 0 to 1 in Table 2.

3. Results and Discussion

Results for the nine variables used in the resilience analysis are described first, then the resilience analysis and kriging outputs, followed by a summary of benthic community composition at the survey sites. The section concludes with a summary of the coral species petitioned for endangered species listing in 2009 and the 66 of those proposed for listing by NMFS in December or 2012.

3.1 Individual variables

For each of the individual variables included in the resilience analysis, all of the following are described and presented: the maximum value, the minimum value, the range, the number of sites with high (relative, see methods), medium and low scores, and any evident spatial patterns in the data. Bracketed [ ] numbers refer to final resilience rankings out of 35 and form the site labels on all maps shown.

3.1.1 Coral Diversity

The maximum Simpson's Index of Diversity value is 0.96 at Ladder Beach [21], Coral Ocean Point [25], Elbow Reef [23], and Tank Beach [31], and the minimum value, 0.0, at Fishing Base Staghorn [35]; a range of 0.96 (Table 1). The great majority of sites surveyed (31 of 35) have high relative coral diversity, 1 has medium (Oleai Staghorn [24]), and 3 have low relative diversity (Marianas Resort [33], Quartermaster Staghorn [34] and Fishing Base Staghorn [35]). The large range in diversity values found (Fig. 15, Table 1) is due to differences in the coral community compositions between some of the lagoon sites and the outer reef sites. The Three sites with the three sites with low relative diversity are all lagoon sites (Fig. 2).

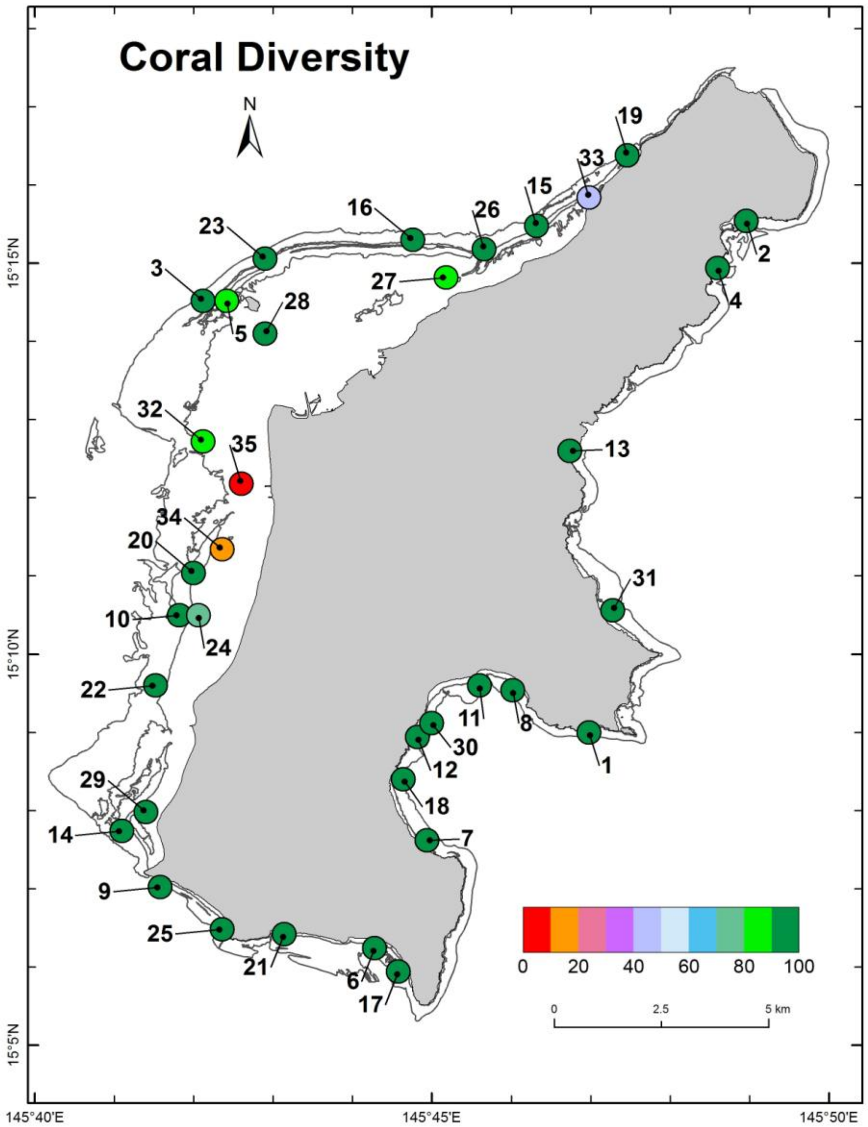


Fig. 2. Anchored coral diversity (Simpson's Index of Diversity) scores for the survey sites.

Note on maps: From here forward, number labels on the maps refer to resilience rankings (Table 1). The ten-bin color bar forming this legend represents the anchored score as 0 to 100 (instead of 0-1 as in Table 2), to reflect the percentage of the max value across surveyed sites.

3.1.2 Recruitment

The highest recruit density was found at LaoLao Bay East [8], 14.31 recruits/m^2, and the lowest at Fishing Base Staghorn [35] where no recruits were observed. In the case of coral diversity (section 3.1.1) nearly all (31 of 35) sites had scores within 20% of the maximum value. In contrast, recruit densities observed at the survey sites are spread throughout the 0-14.31 recruits/m^2 range (Figs. 3 & 14, Table 1). Three sites have high relative recruitment: LaoLao Bay East [8], Agingan Point [9], and Obyan Beach [6] (Fig. 3). 13 sites have medium recruitment and 19 sites have low recruitment. Spatial patterns in recruit densities are weak; recruit densities are generally lower at lagoon sites and highest in the southern outer reefs and parts of LaoLao Bay (Fig. 3). Recruits (geometric mean <4 cm) are the most common coral size class observed when all sites are pooled (Fig. 4); recruits were observed within sampling quadrats as commonly as all four of the largest coral size classes (8-16, 16-32, 32-64 and > 64 cm) combined (Fig. 4).

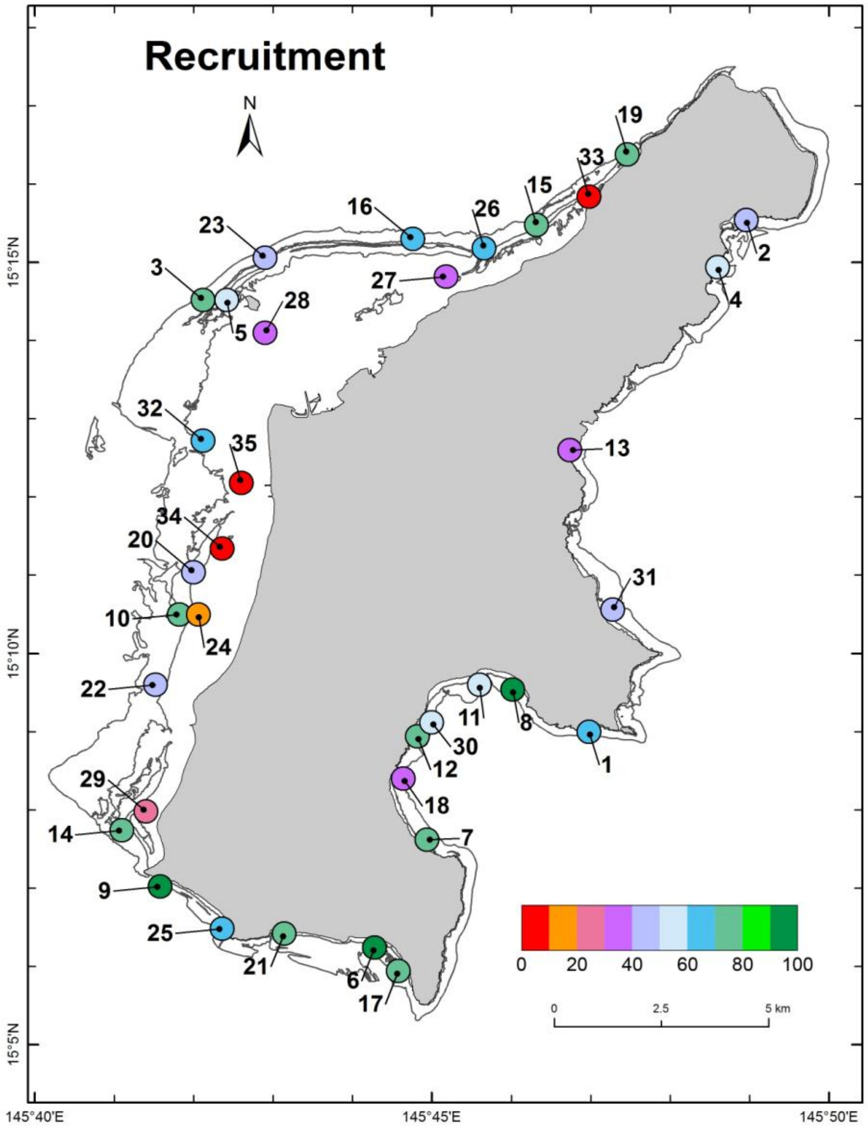


Fig. 3. Anchored recruitment scores for the survey sites.

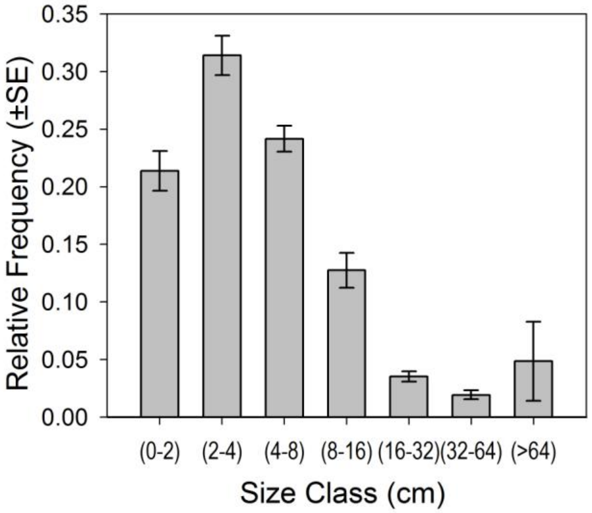


Fig. 4. Size-class frequency histogram of coral colonies observed within sampling quadrats with all survey sites pooled.

3.1.3 Bleaching Resistance

The three highest bleaching resistance values (% of coral community) are all at lagoon sites with coral communities of medium diversity (Fig. 2): Oleai Staghorn (88.46% [24]), Peysonnelia Reef (85.95% [32]), and Tanapag Staghorn (82.67% [27]) (Fig. 5, Table 1). The three lowest bleaching resistance values are also at lagoon sites and are the three sites with the lowest coral diversity: Quartermaster Staghorn (20% [34]), Marianas Resort (20%, [33]), and Fishing Base Staghorn (0% [35]). Therefore, the full range of bleaching resistance seen among the 35 survey sites can be found in the lagoon with some sites highly susceptible to bleaching and some amongst the most bleaching resistant (Fig. 5). There are 9 sites with high relative bleaching resistance, 19 with medium, and 7 with low (Fig. 15, Fig. 5). Spatial patterns in bleaching resistance are weak excepting that all of the sites with high relative bleaching resistance are in the lagoon and LaoLao Bay. Most outer-reef sites have medium bleaching resistance (Fig. 5).

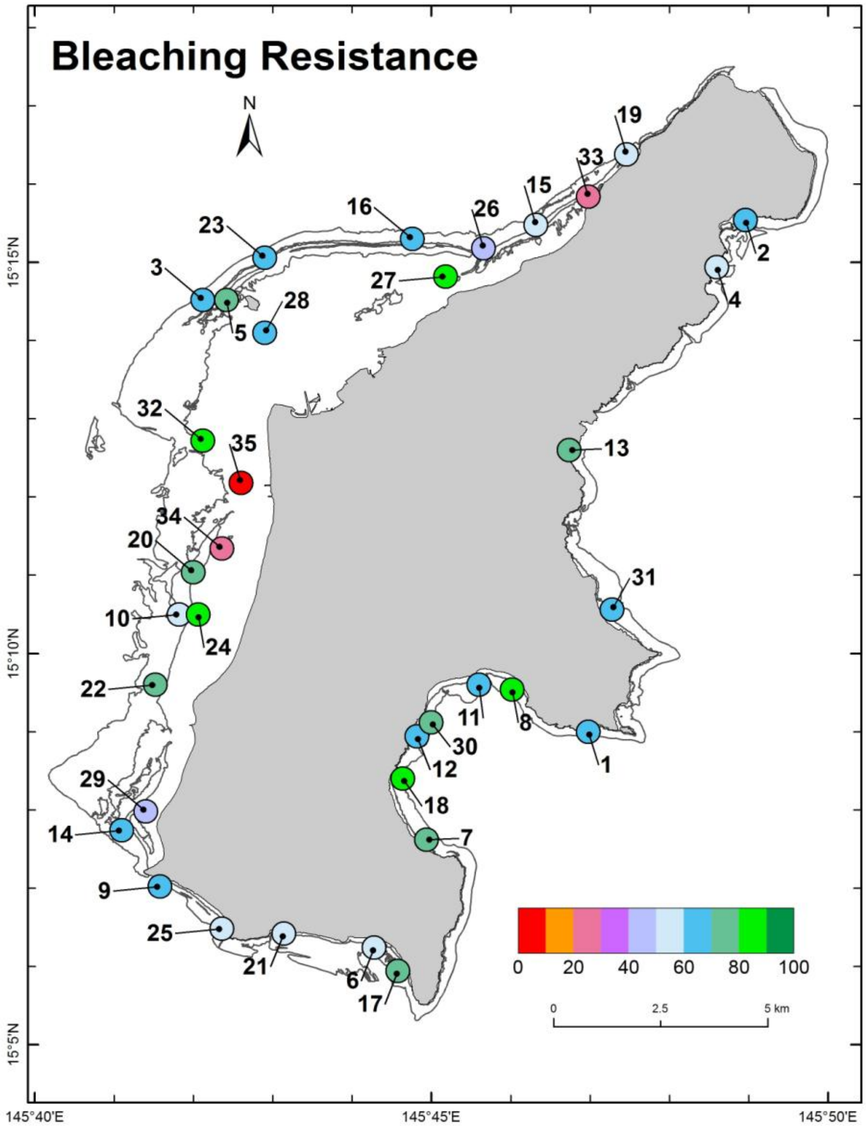


Fig. 5. Anchored scores for bleaching resistance for all survey sites.

3.1.4 Temperature variability

Summertime temperature variability, as measured by the standard deviation in temperatures during summer months from 1982-2005, is roughly 1°C for all survey sites (Table 1). The site with the highest summertime temperature variability is Nanasu Reef [4] with 0.98 °C, but the lowest is only 0.05 °C lower: Old Man By the Sea (0.94 °C [13], Fig. 15). All sites have high relative temperature variability; summertime temperatures vary no more or less at lagoonal sites than outer-reef or the more exposed eastern sites (Fig. 6).

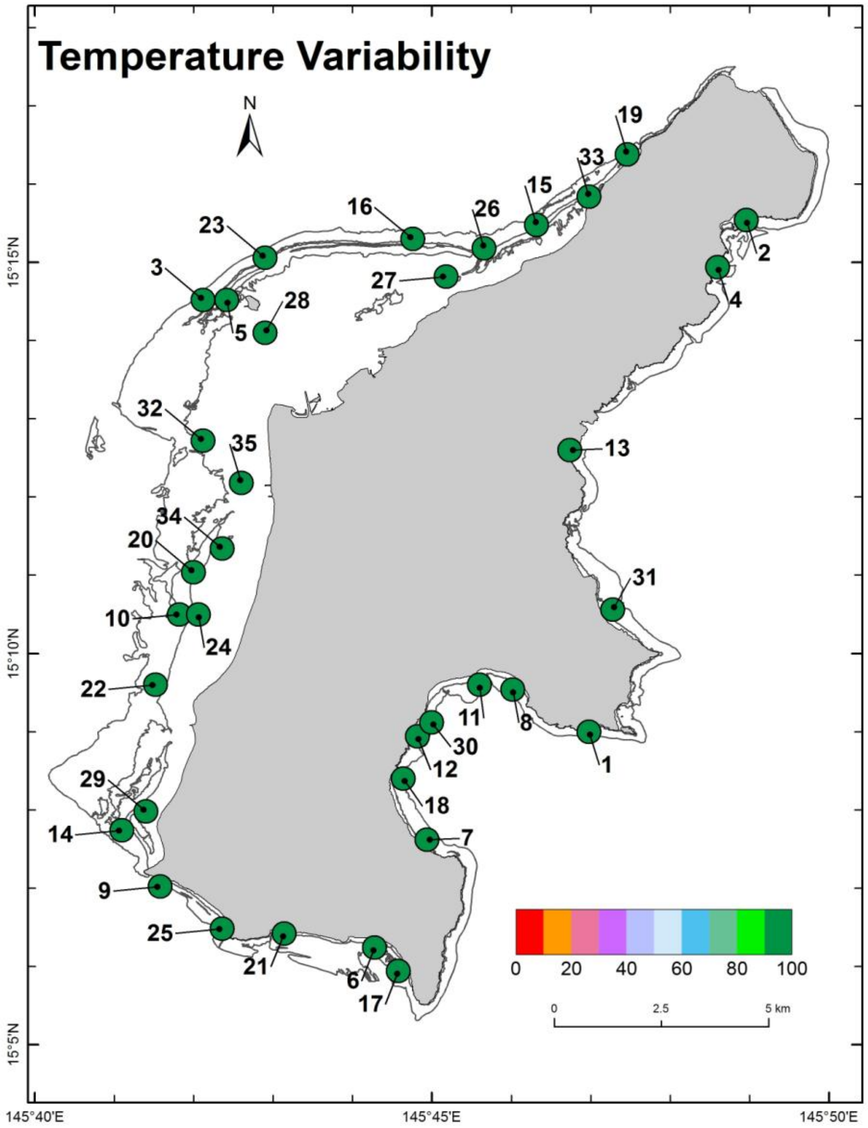


Fig. 6. Anchored scores for summer temperature variability for all survey sites.

3.1.5 Herbivore biomass:

There are four sites with herbivore biomass values that exceed 2 kg/100 m^2: Bird Island (3.33 kg/100 m^2 [2]), Nanasu Reef (3.01 kg/100 m^2 [4]), Obyan Beach (2.65 kg/100 m^2 [6]), and Oleai Staghorn (2.06 kg/100 m^2 [24]). Bird Island is a no-take marine protected area and amongst the sites with greatest wave exposure (Fig. 14) so it was not suprising to find a high (relative) herbivore biomass there. The herbivore biomass at most survey sites is far lower than that seen at Bird Island (Fig. 7). Throughout the report, sites with ‘low’ relative scores either for resilience or individual variables are those with <60% of the maximum value. For herbivore biomass, 31 of the 35 survey sites have <60% of the biomass seen at Bird Island, or ‘low’ relative biomass (Table 2, Fig. 15). There are 11 sites with less than 0.50 kg/100 m^2 (<15% of that seen at Bird

Island); the lowest of these is Pak Pak Beach (0.13 kg/100 m^2 [29]). Herbivore biomass is not correlated to fishing access ($p=0.39$, $t_{33}=0.258$ at $r=0.04$).

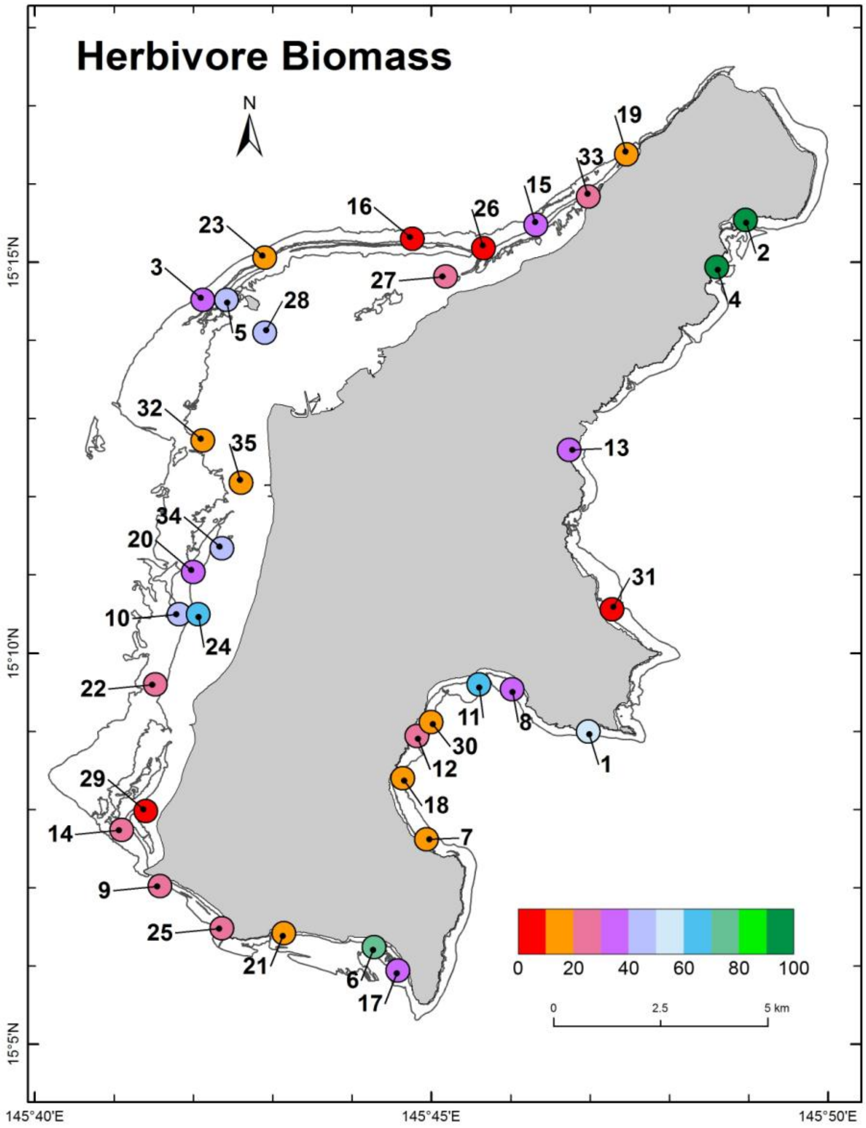


Fig. 7. Anchored scores for herbivore biomass at all survey sites.

3.1.5.1 Herbivorous Fish Communities

When all sites are pooled nearly half of the herbivorous fish biomass is made up of grazers/detritivores (i.e., fish that do both, Fig. 8). The remaining half is made up in near equal parts detritivore (i.e., exclusive detritivores) and scrapers/small excavators (both ~20%), and ~10% browsers, with less than 3% planktivores. For the common herbivorous fish families, Scaridae and Acanthuridae, Scarids observed were slightly larger on average than Acanthurids (Figs. 9 & 10). More than 30% of the observed Scarids were 11-15 cm, and another 30% 16-20 cm (Fig. 9). In contrast, >50% of the

Acanthurids were 11-15 cm, and less than 15% were 16-20 cm. No Acanthurids were observed larger than 30 cm (Fig. 10); a few Scarids were observed between 31 and 35 cm, and between 36 and 40 cm (Fig. 9).

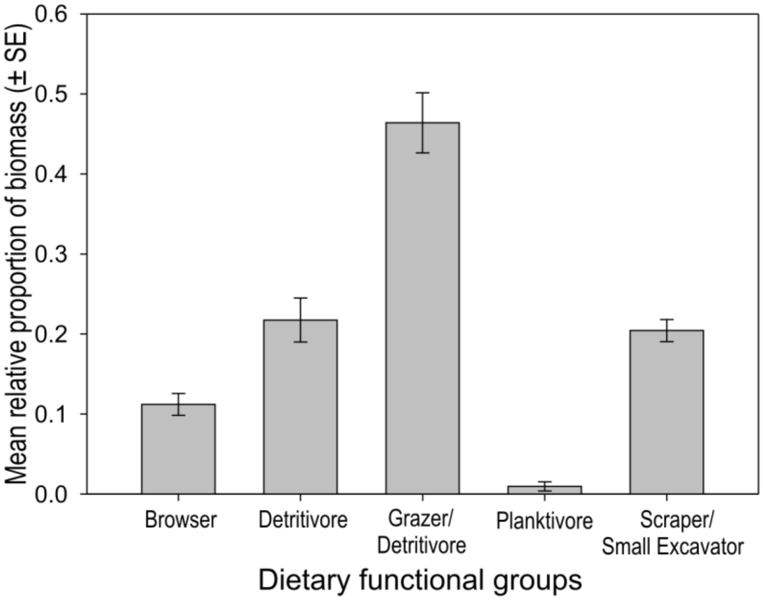


Fig. 8. Mean relative proportion across all survey sites of IUCN/NOAA designated dietary functional groups for fish species observed during the 2012 surveys. This study did not count non-herbivorous fish below 10cm in length.

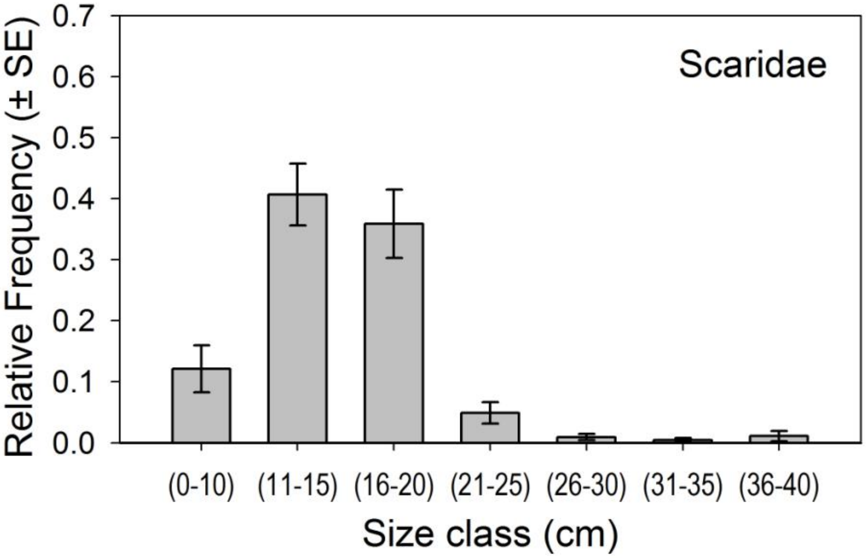


Fig. 9. Size-class frequency histogram for fish within the Scaridae family observed during the 2012 surveys, pooled across all 35 survey sites.

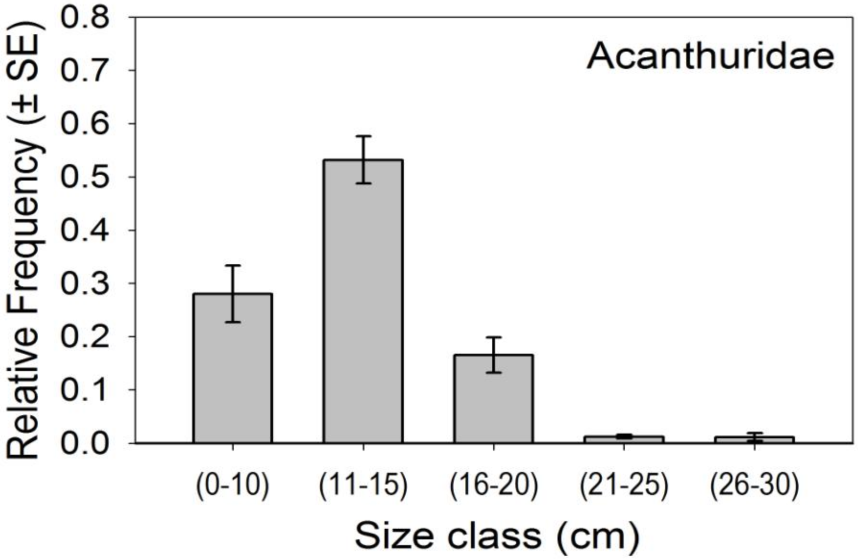


Fig. 10. Size-class frequency histogram for fish within the Acanthuridae family observed during the 2012 surveys, pooled across all 35 survey sites.

3.1.6 Macroalgae cover

Macroalgae was observed at less than half (16) of the 35 survey sites (see all circles *not* dark green in Fig. 11, and see Fig. 15). Only 10 of those sites have macroalgae cover that exceeds 5% of the substrate, and only five sites have macroalgae cover that exceeds 20% of the substrate. These five are: Tuturam (72.44% [30]), South Dakota (33.67% [18]), Quartermaster Staghorn (32.33% [34]), South LaoLao (24.61% [7]), and Marianas Resort (22.33% [33]). For this and the upcoming three variables (nutrient input, sedimentation and fishing access), lower values (i.e., lower macroalgae cover) are better for reef resilience. Keeping the normalized scale of 0-1 uni-directional means all values for macroalgae cover are still anchored to the maximum value (72.44% at Tuturam [30]) but then this is subtracted from 1 (see methods for more detail). Sites with less than 60% of the max value (so, once reversed, all anchored scores >0.4, Table 2), have low relative macroalgae cover. All remaining (34) sites have low relative macroalgae cover relative to Tuturam. Without exception, the highest levels of macroalgae cover (8 sites with anchored scores <0.9, sites *not* dark green in Fig. 11) are in LaoLao Bay, or in lagoon sites in western Saipan.

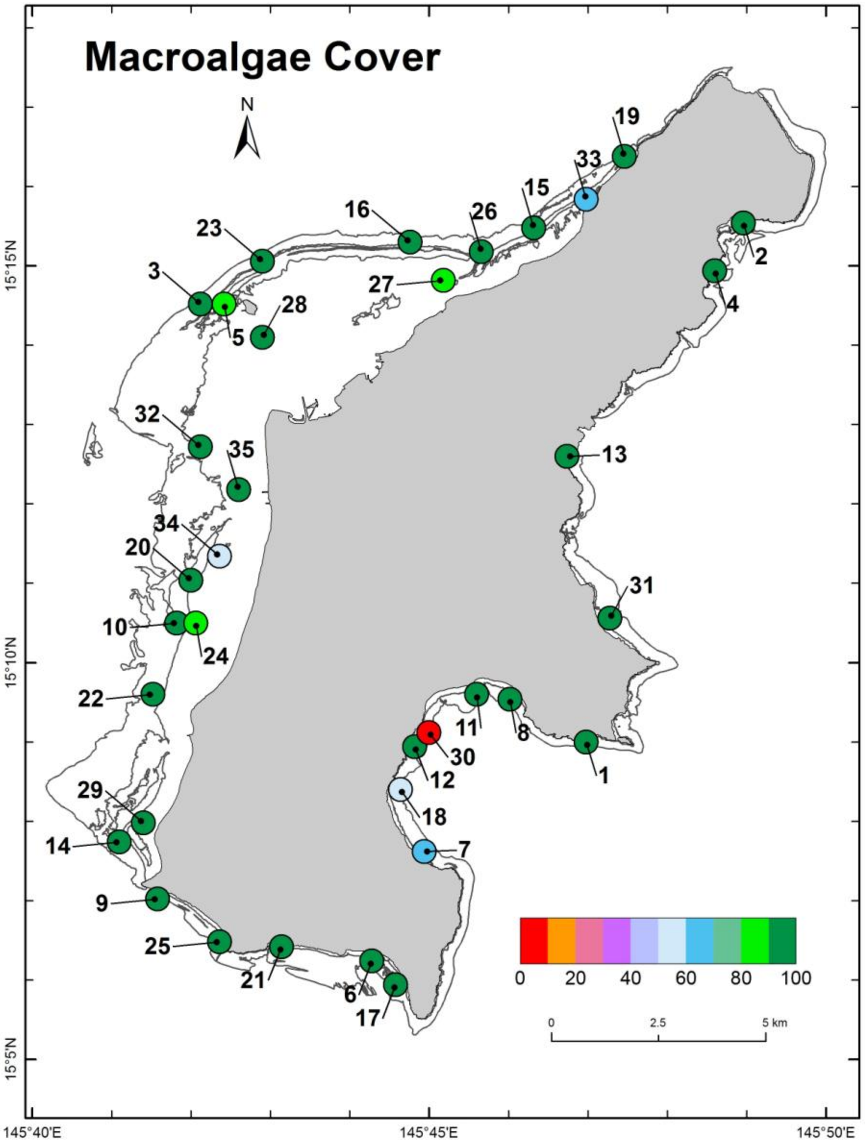


Fig. 11. Anchored scores for macroalgae cover at all survey sites. Low scores here mean high macroalgae cover.

3.1.7 Nutrient input & Sedimentation

Nutrient input was assumed to be directly proportional to watershed size, and sedimentation is the percentage of land made up by ‘barren land/urbanized vegetation/highly developed’ (see methods for more detail). The three highest nutrient input and sedimentation levels are at Tank Beach [31], MMT – Managaha Patch [28], and Peysonnelia Reef [32] (Figs. 12 & 13). Relative to the maximum levels seen, the great majority of sites have low nutrient input and sedimentation (32 of 35 sites, Table 1). The highest levels seen are at the sites geographically closest to Garapan in west Saipan, and to the large watershed adjacent to Tank Beach in the east.

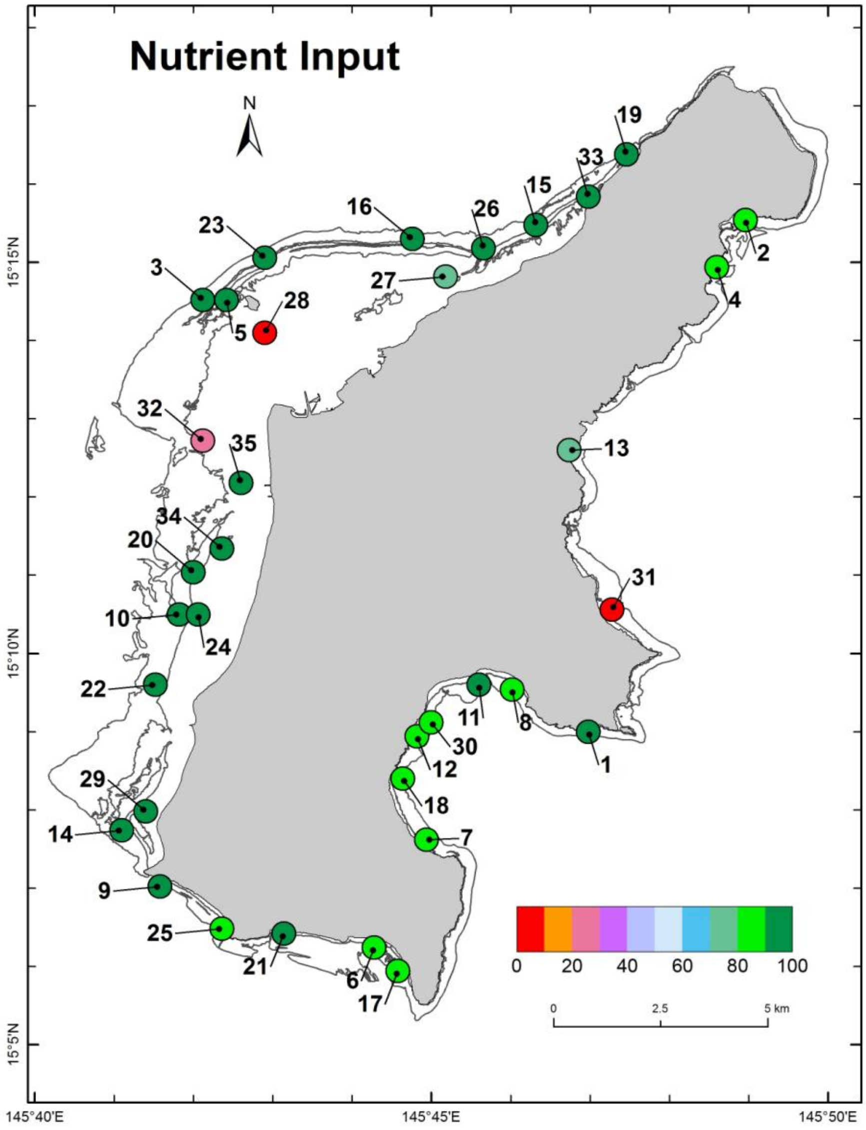


Fig. 12. Anchored scores for nutrient input at all survey sites. Low scores here mean high nutrient input.

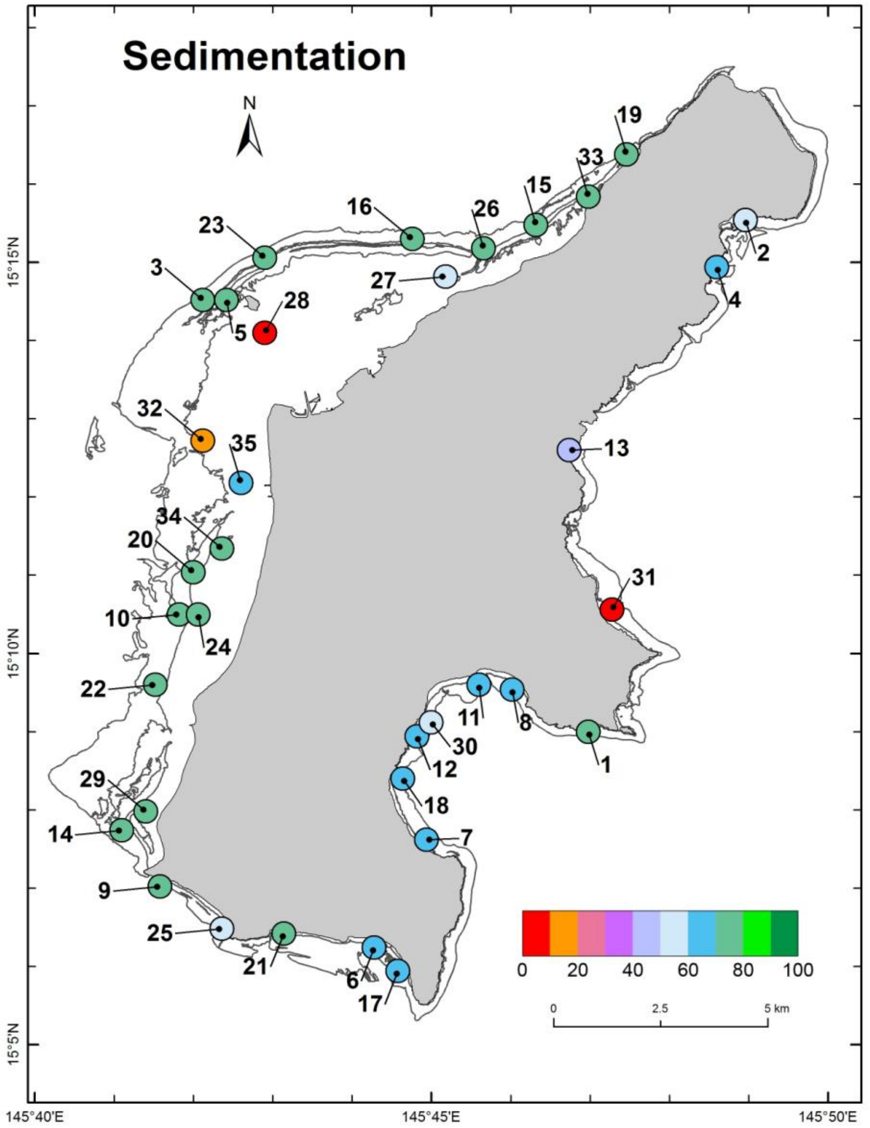


Fig. 13. Anchored scores for sedimentation at all survey sites. Low scores here mean high sedimentation.

3.1.8 Fishing access

There are strong spatial patterns in access to the fishery based on wave exposure and energy (Fig. 14). All sites that are not protected areas that have low fishing access (high wave exposure) are in the north east or in the exposed (central to southern) portions of LaoLao Bay; the four protected areas are all considered here to have low fishing access (Forbidden Island [1], Bird Island [2], Lanyas [3] and MMT Managaha MPA [5]). There are six sites with wave energies determined to be higher than 1000: Tank Beach [31], South LaoLao [7], Forbidden Island [1], Nanasu Reef [4], South Dakota [18], and Old Man By the Sea [13] (Table 1). There are 26 sites with wave energies lower than 500 (Table 1, Fig. 15). Overall, this results in 9 sites with low fishing access (high wave energy >80% of max observed at Tank Beach), 1 site with medium access, and 25 with high fishing access (low wave energy >60% of max observed) (Table 1, Fig. 15). All but two of the sites with high fishing access, both of which are in northern LaoLao, are in southern or western Saipan (Fig. 14).

Fishing access had one of the greatest ranges of all of the variables examined in this report. This range created a distinction between sites that was not achieved within most of the other metrics and allowed fishing access to stand out as an important driver in the overall resilience scoring. Three decisions were made during the development of this data that should be kept in mind:

1. No-take sites were set to the best possible score (lowest level of access)
2. The correlation achieved between the manager's survey scores and wave exposure scores was the best, so we did not include distance from shore or populations center within the final metric
3. It was assumed that sites with limited fishing access would also experience less fishing pressure

Improvements to the data collected for this metric or changes regarding the decisions and assumptions above could have a significant influence on the relative importance of the fishing pressure metric. Once real fishing effort data is available this metric should be run again to establish new relative resilience scores and evaluate the accuracy of the fishing access proxy.

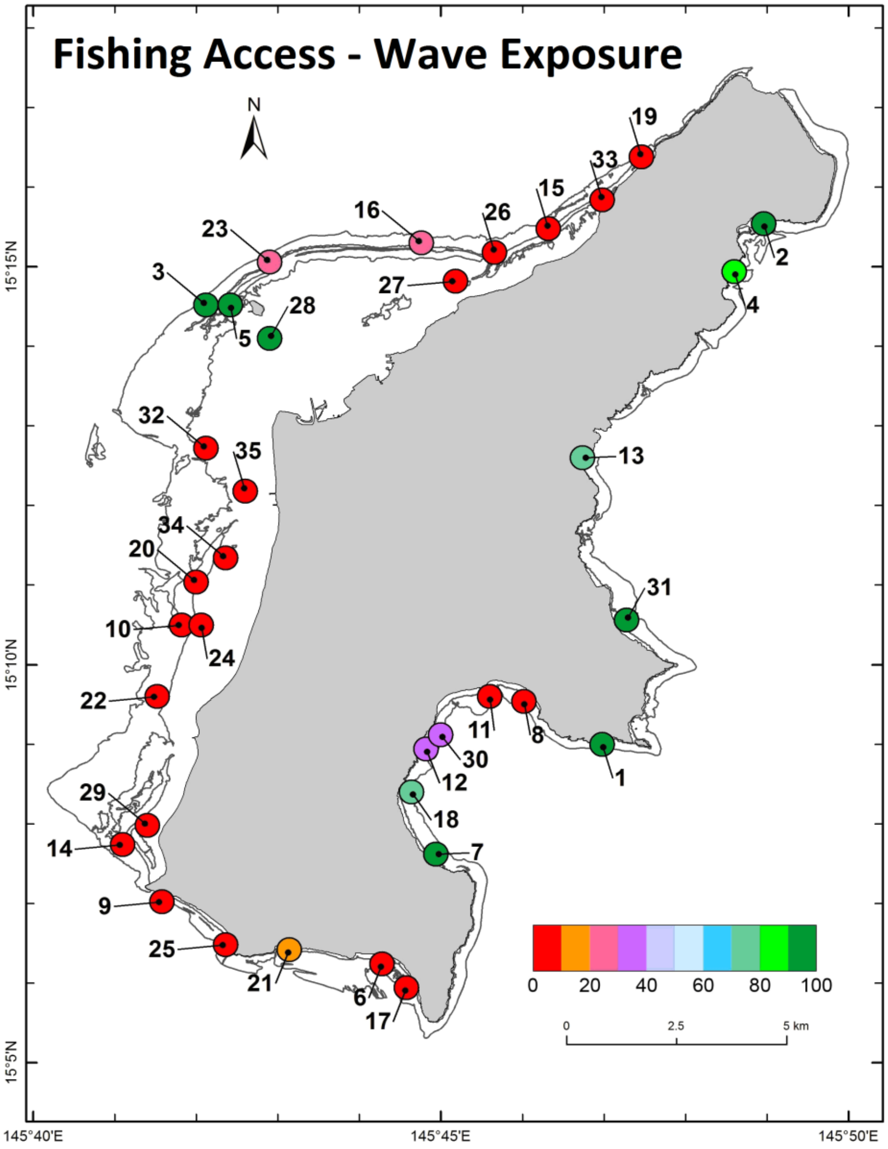


Fig. 14. Fishing access based on wave exposure at all survey sites. Low scores here mean high fishing access due to low wave exposure/energy.

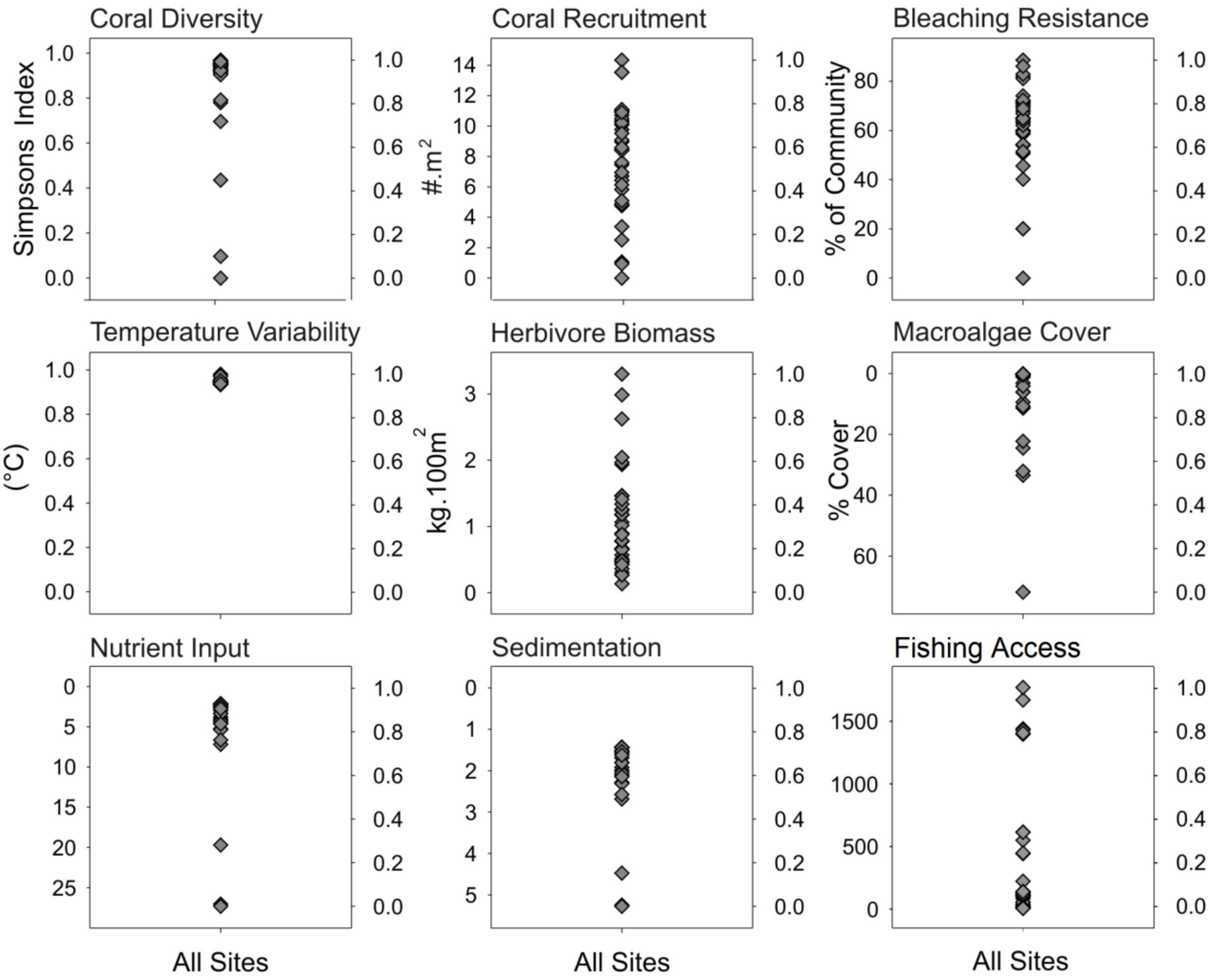


Fig. 15. Raw data values for all variables for all sites. Nutrient input, sedimentation and fishing access are all unit-less values. The values for each of the 9 variables included in the resilience analysis are also presented within Table 1 of each of the 35 site summaries that form Appendix 5.

3.2 Resilience Analysis

Raw data values for all variables are shown in Table 1 and referred to throughout sections within 3.1. The anchored (to the max value) and normalized (0-1 scale) scores are shown in Table 2. The resilience scores are the average of the anchored and normalized scores for all 9 variables and ranged from 0.84 (Forbidden Island) to 0.45 (Fishing Base Staghorn) (Table 2). High resilience scores were found for 23 sites (~65% of sites ranged between 0.8 and 1.0, based upon anchored resilience scores), 9 sites have medium resilience scores (26% of sites ranged between 0.6 and 0.79), and 3 sites have low resilience scores (9% of sites scored <0.59) (Table 1). Spatial patterns in the anchored resilience scores show that outer-reef sites in the west are not very different from one another in terms of resilience potential but are very different from lagoon sites (Fig. 16). Anchored scores vary somewhat within LaoLao Bay with the central portion of the Bay having a lower resilience score than the rest of the Bay (around Tuturam [30]). Spatial patterns are easier to discern in Fig. 17, which shows high, medium, and low resilience scores in green, yellow and red, respectively. All outer reef sites in the south and west have high (relative) resilience potential (Fig. 17). Lagoon sites in the west have medium or low resilience potential. Sites in the east are a mix of high and medium; high in the northeast where reef development is limited and medium there near Tank Beach, and high throughout LaoLao Bay excepting around Tuturam [30] (Fig. 17).

Principle components analysis (PCA) indicated that high and medium resilience sites were distinguished from low resilience sites by having higher coral diversity, recruitment, and bleaching resistance (Figure 17). Conversely, low resilience sites were characterized by high fishing access, nutrient input and sedimentation, and low coral diversity (Figure 17). This can be seen in the spatial patterns in resilience potential around Saipan (Figs. 16 & 17). Most outer reef sites have similar resilience scores and the low resilience sites are all in the lagoon where fishing access is greatest and coral diversity lowest (see sites numbered 33, 34 and 35; Figs. 17 & 17). The PCA results do not suggest that coral diversity is a more important driver of resilience potential in Saipan than fishing access (as an example). Rather the PCA results show that variability is greater for some indicators than for others (Fig. 18). Since all indicators are weighted equally in the analysis here, the indicators with the greatest variability (in anchored scores) have a greater influence on the differences in resilience scores seen. Variability, as measured by the standard deviation, is lowest for temperature variability (stdev=0.01). Standard deviation values for all other variables excepting fishing access are between 0.19 (Sedimentation) and 0.25 (Recruitment); Fishing access has a standard deviation of 0.40. In this analysis, fishing access is driving differences in the final resilience scores to a greater extent than the other variables.

More details on the resilience analysis results for each site can be found in the site summaries that form Appendix 5.

Table 1. Raw data values for all 9 variables used in the resilience analysis. Survey sites are presented in ascending order by resilience ranking (see Table 2). Asterisks denote variables that are reversed in the resilience analysis such that high values for those variables mean low scores once anchored/normalized to the 0-1 scale (see Table 2, and methods for more detail).

Resilience Score:
🟩 = High
🟨 = Medium
🟥 = Low

Site Names	Rank	Coral Diversity	Recruitment	Bleaching Resistance	Temperature variability	Herbivore biomass	Macroalgae cover*	Nutrient input*	Sedimentation*	Fishing access
Forbidden Island	1	0.93	9.75	64.99	0.96	1.95	0.00	2.46	1.57	1440
Bird Island	2	0.95	5.81	59.91	0.98	3.33	0.00	5.18	2.28	550
Lanyas	3	0.94	11.00	59.66	0.96	1.18	0.00	2.04	1.43	142
Nanasu Reef	4	0.92	7.44	53.85	0.99	3.01	6.00	3.97	1.99	1429
MMT - Managaha MPA	5	0.79	7.58	71.23	0.96	1.48	9.33	2.04	1.43	12
Obyan Beach	6	0.95	13.50	59.27	0.95	2.65	0.00	4.41	2.10	54
South Laolao	7	0.95	10.46	73.95	0.95	0.47	24.61	3.22	1.80	1671
Laolao Bay East	8	0.93	14.31	81.79	0.96	1.25	1.00	3.67	1.92	20
Agingan Point	9	0.91	13.50	66.80	0.97	0.67	0.00	2.28	1.51	130
Oleai Rocks	10	0.92	10.69	58.52	0.94	1.47	0.00	2.04	1.43	100
Laolao Bay Mids	11	0.91	8.44	63.76	0.96	1.98	0.50	2.83	1.68	85
North Dakota	12	0.94	10.31	64.53	0.96	0.65	0.00	3.97	1.99	616
Old Man By the Sea	13	0.94	4.75	69.79	0.94	1.27	6.00	7.16	2.68	1397
Point Break Reef	14	0.92	10.92	61.98	0.95	0.90	0.00	2.04	1.43	119
Pau Pau	15	0.94	11.06	54.07	0.96	1.07	0.00	2.04	1.43	107
Achu Dangkulu	16	0.94	8.94	67.74	0.96	0.30	0.00	2.04	1.43	443
Boy Scout	17	0.94	10.06	70.68	0.95	1.19	0.00	4.20	2.05	57
South Dakota	18	0.95	4.81	80.95	0.95	0.51	33.67	3.25	1.80	1405
Wing Beach	19	0.94	10.88	50.59	0.98	0.57	0.00	2.04	1.43	139
Lighthouse Reef	20	0.95	6.42	71.85	0.94	1.02	0.00	2.04	1.43	38
Ladder Beach	21	0.96	10.19	54.15	0.95	0.48	0.00	2.34	1.53	223
MMT - Outside Grand Hotel	22	0.95	6.93	69.66	0.95	0.77	0.00	2.04	1.43	113
Elbow Reef	23	0.96	6.69	62.98	0.96	0.36	0.00	2.04	1.43	448
Oleai Staghorn	24	0.69	2.50	88.46	0.94	2.06	11.33	2.04	1.43	7
Coral Ocean Point	25	0.96	9.50	51.36	0.95	0.65	0.00	5.30	2.30	103
Achugao	26	0.94	9.06	40.07	0.95	0.26	0.00	2.04	1.43	107
Tanapag Staghorn	27	0.78	4.88	82.67	0.96	0.78	10.67	6.59	2.57	7
MMT - Managaha Patch Reef	28	0.92	5.08	64.71	0.95	1.34	4.00	27.45	5.24	30
Pak Pak Beach	29	0.90	3.38	45.45	0.95	0.13	3.00	2.04	1.43	16
Tuturam	30	0.95	8.38	72.17	0.95	0.45	72.44	4.57	2.14	614
Tank Beach	31	0.96	6.13	68.75	0.95	0.26	0.35	27.72	5.26	1771
Peysonnelia Reef	32	0.79	8.56	85.95	0.94	0.48	0.33	19.95	4.47	137
Marianas Resort	33	0.43	0.94	20.00	0.96	0.88	22.33	2.34	1.53	7
Quartermaster Staghorn	34	0.10	1.06	20.00	0.94	1.42	32.33	2.04	1.43	10
Fishing Base Staghorn	35	0.00	0.00	0.00	0.95	0.42	0.00	2.62	1.62	13

Table 2. Final resilience scores and rankings for the survey sites. Anchored (to the max value) and normalized (uni-directional 0-1 scale) scores for all 9 variables are shown to the right. Resilience scores are the average scores for all variables, then anchored to the highest resilience score (column right of rank). High relative resilience potential includes the range (0.8-1.0), medium (0.6-0.79), and low (<0.6).

Resilience Score:
🟩 = High
🟨 = Medium
🟥 = Low

Site Names	Rank	Anchored Resilience Score	Resilience Score	Coral Diversity	Recruitment	Bleaching Resistance	Temperature variability	Herbivore biomass	Macroalgae cover*	Nutrient input*	Sedimentation*	Fishing access
Forbidden Island	1	1.00	0.84	0.96	0.68	0.73	0.97	0.59	1.00	0.91	0.70	1.00
Bird Island	2	0.99	0.83	0.98	0.41	0.68	0.99	1.00	1.00	0.81	0.57	1.00
Lanyas	3	0.98	0.82	0.98	0.77	0.67	0.97	0.35	1.00	0.93	0.73	1.00
Nanasu Reef	4	0.95	0.80	0.95	0.52	0.61	1.00	0.90	0.92	0.86	0.62	0.81
MMT - Managaha MPA	5	0.94	0.79	0.82	0.53	0.81	0.97	0.44	0.87	0.93	0.73	1.00
Obyan Beach	6	0.90	0.76	0.98	0.94	0.67	0.96	0.79	1.00	0.84	0.60	0.03
South Laolao	7	0.90	0.76	0.99	0.73	0.84	0.96	0.14	0.66	0.88	0.66	0.94
Laolao Bay East	8	0.89	0.75	0.96	1.00	0.92	0.97	0.37	0.99	0.87	0.64	0.01
Agingan Point	9	0.86	0.72	0.94	0.94	0.76	0.98	0.20	1.00	0.92	0.71	0.07
Oleai Rocks	10	0.86	0.72	0.96	0.75	0.66	0.95	0.44	1.00	0.93	0.73	0.06
Laolao Bay Mids	11	0.85	0.72	0.95	0.59	0.72	0.97	0.60	0.99	0.90	0.68	0.05
North Dakota	12	0.85	0.71	0.98	0.72	0.73	0.97	0.20	1.00	0.86	0.62	0.35
Old Man By the Sea	13	0.84	0.71	0.97	0.33	0.79	0.95	0.38	0.92	0.74	0.49	0.79
Point Break Reef	14	0.84	0.71	0.95	0.76	0.70	0.96	0.27	1.00	0.93	0.73	0.07
Pau Pau	15	0.84	0.71	0.97	0.77	0.61	0.97	0.32	1.00	0.93	0.73	0.06
Achu Dangkulu	16	0.84	0.70	0.98	0.62	0.77	0.97	0.09	1.00	0.93	0.73	0.25
Boy Scout	17	0.83	0.70	0.98	0.70	0.80	0.96	0.36	1.00	0.85	0.61	0.03
South Dakota	18	0.82	0.69	0.98	0.34	0.92	0.96	0.15	0.54	0.88	0.66	0.79
Wing Beach	19	0.82	0.69	0.98	0.76	0.57	0.99	0.17	1.00	0.93	0.73	0.08
Lighthouse Reef	20	0.82	0.69	0.99	0.45	0.81	0.95	0.31	1.00	0.93	0.73	0.02
Ladder Beach	21	0.82	0.69	1.00	0.71	0.61	0.96	0.14	1.00	0.92	0.71	0.13
MMT - Outside Grand Hotel	22	0.82	0.68	0.98	0.48	0.79	0.96	0.23	1.00	0.93	0.73	0.06
Elbow Reef	23	0.82	0.68	1.00	0.47	0.71	0.97	0.11	1.00	0.93	0.73	0.25
Oleai Staghorn	24	0.79	0.66	0.72	0.17	1.00	0.95	0.62	0.84	0.93	0.73	0.00
Coral Ocean Point	25	0.77	0.65	1.00	0.66	0.58	0.96	0.20	1.00	0.81	0.56	0.06
Achugao	26	0.77	0.65	0.97	0.63	0.45	0.96	0.08	1.00	0.93	0.73	0.06
Tanapag Staghorn	27	0.72	0.60	0.80	0.34	0.93	0.97	0.24	0.85	0.76	0.51	0.00
MMT - Managaha Patch Reef	28	0.71	0.60	0.95	0.36	0.73	0.96	0.40	0.94	0.01	0.00	1.00
Pak Pak Beach	29	0.70	0.59	0.93	0.24	0.51	0.96	0.04	0.96	0.93	0.73	0.01
Tuturam	30	0.70	0.58	0.98	0.59	0.82	0.96	0.13	0.00	0.84	0.59	0.35
Tank Beach	31	0.69	0.58	0.99	0.43	0.78	0.96	0.08	1.00	0.00	0.00	1.00
Peysonnelia Reef	32	0.66	0.55	0.82	0.60	0.97	0.95	0.14	1.00	0.28	0.15	0.08
Marianas Resort	33	0.57	0.48	0.45	0.07	0.23	0.97	0.26	0.69	0.92	0.71	0.00
Quartermaster Staghorn	34	0.53	0.44	0.10	0.07	0.23	0.95	0.42	0.55	0.93	0.73	0.01
Fishing Base Staghorn	35	0.49	0.41	0.00	0.00	0.00	0.96	0.13	1.00	0.91	0.69	0.01

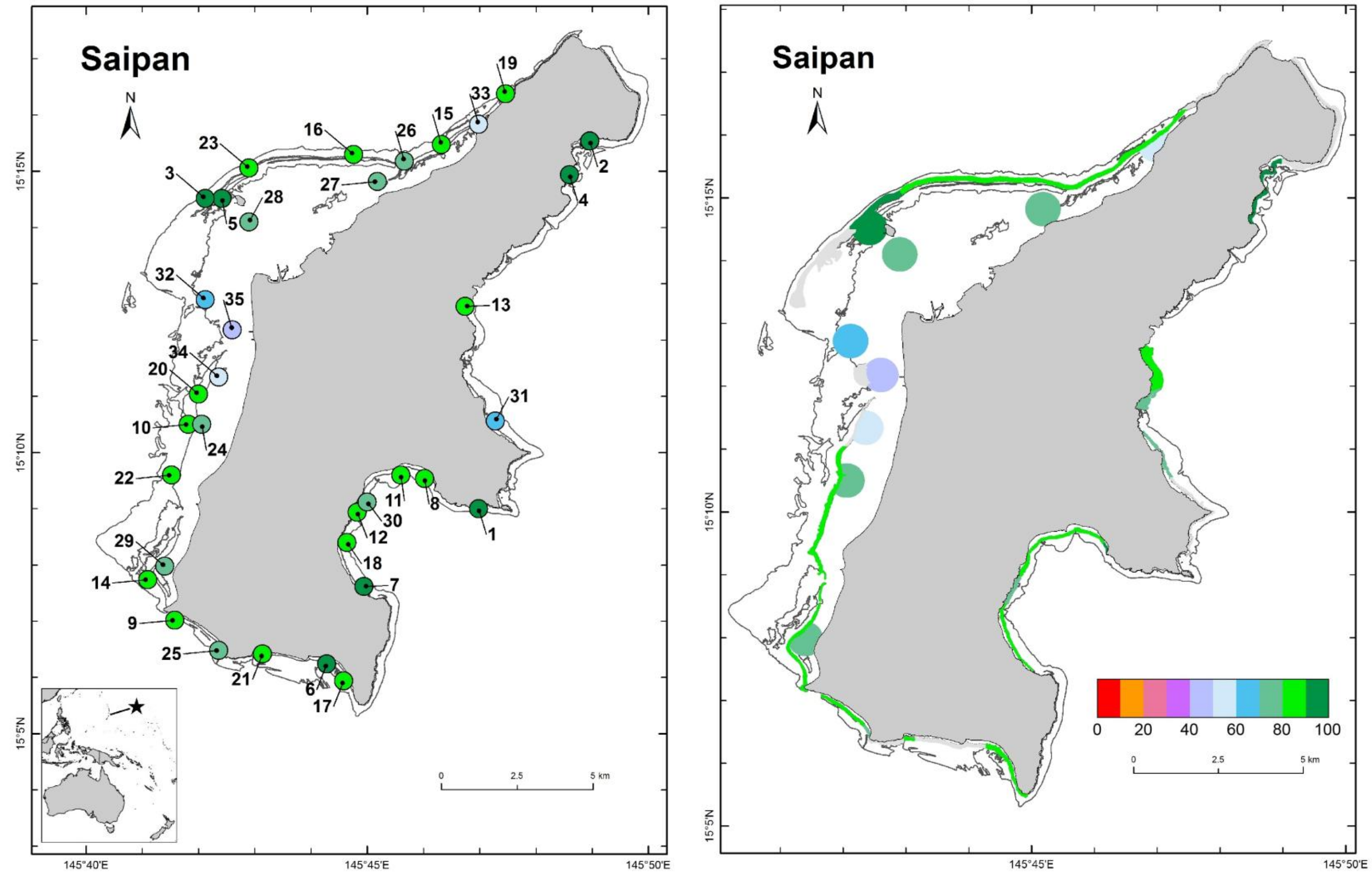


Fig. 16. Anchored resilience scores for all survey sites are shown by site on the left, and following spatial interpolation via kriging in ArcGIS on the right. Lagoonal sites are assumed to have a circular habitat area ~500 m^2 in diameter.

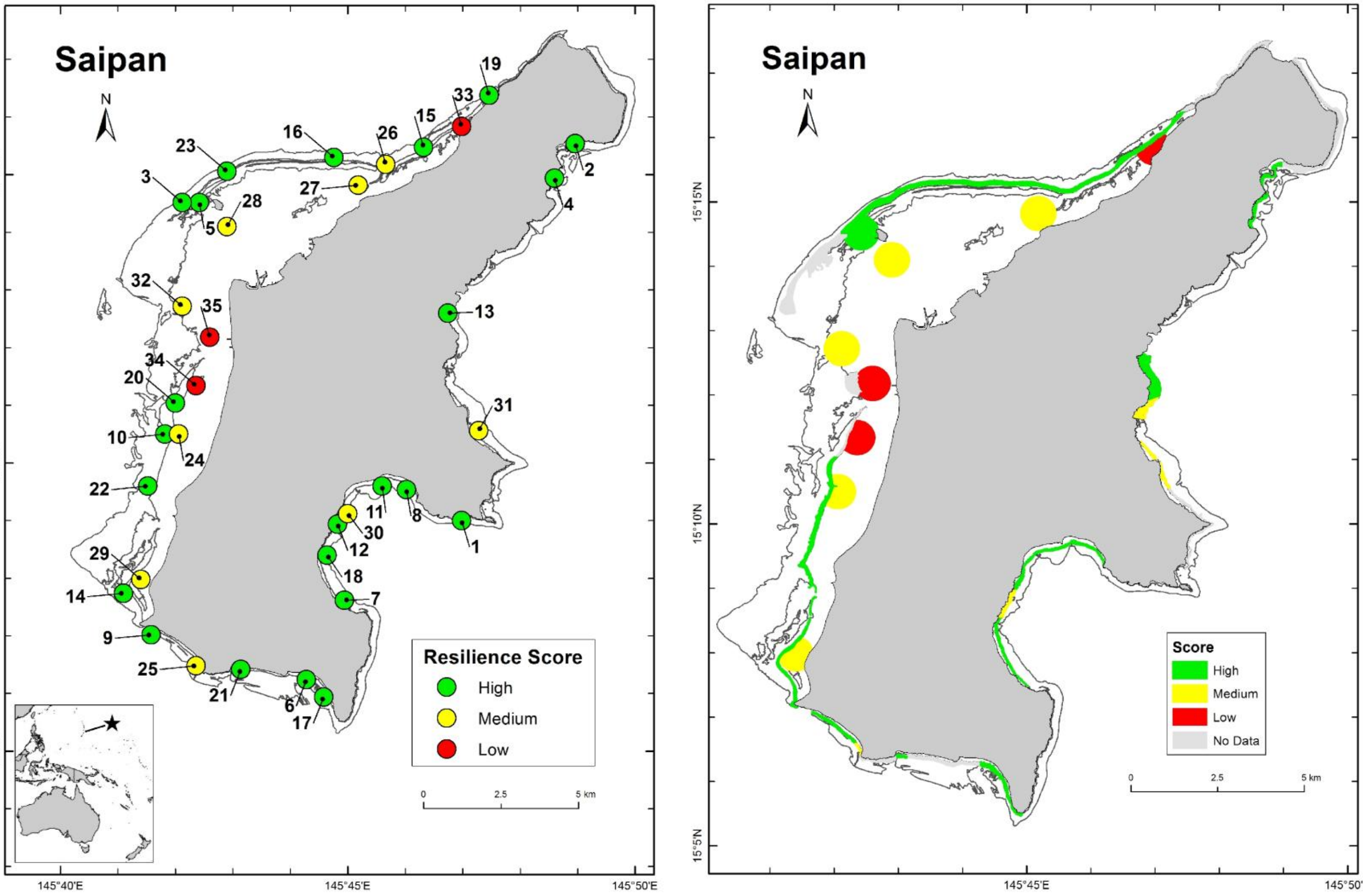


Fig. 17. High, medium and low resilience scores are shown by site on the left and refer to anchored scores between 0.8 and 1, 0.6-0.79, and >0.6, respectively. Spatial interpolation via kriging in ArcGIS is shown on the right. Lagoonal sites are assumed to have a circular habitat area ~500 m^2 in diameter.

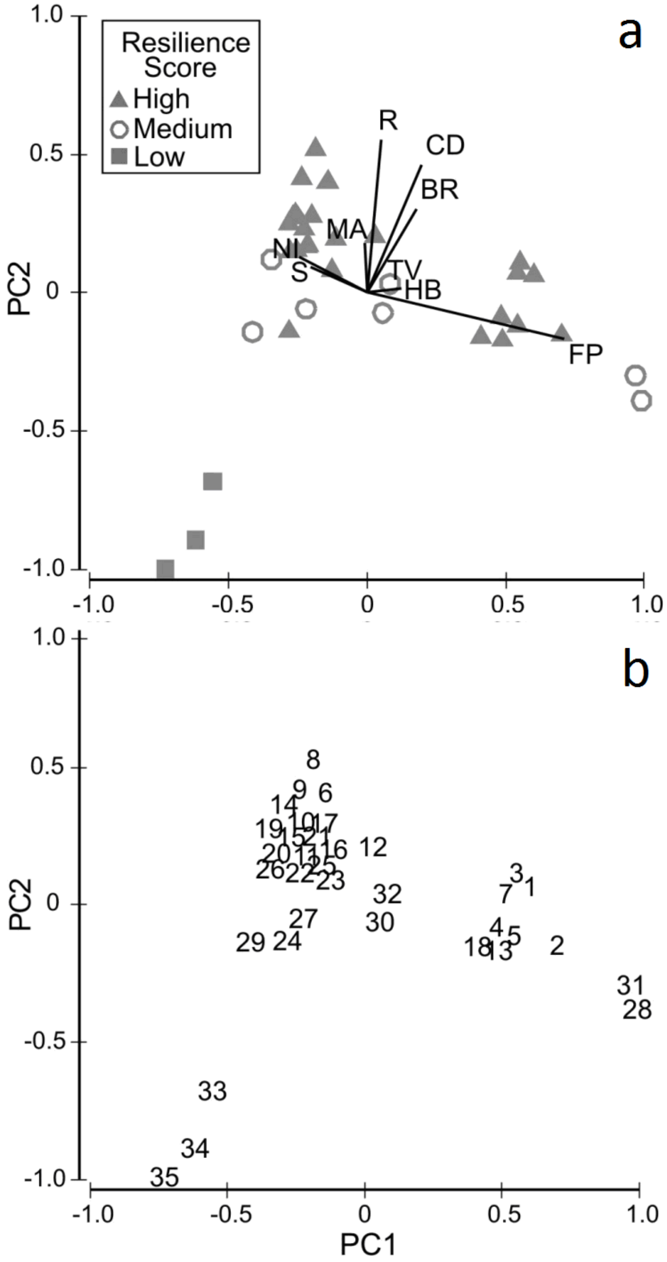


Figure 18. Both PC1 (38.7% of variation) and PC2 (22.5% of variation) were informative in understanding differences between sites. Fishing pressure (0.853) was the main driver of PC1; high fishing pressure characterized low resilience sites but there was a gradient of medium and high resilience sites along the axes in demonstrating that a range of fishing pressures scores characterized those sites. Low resilience sites were also characterized by high nutrient input (-0.296) and high sedimentation (-0.245). On the PC2 axis, high scores in coral diversity (0.556), coral recruitment (0.662), and bleaching resistance (0.211) distinguish the medium and high resilience sites from the low resilience sites.

3.3 Combined Anthropogenic Stress

Anthropogenic stress scores were produced by averaging anchored scores for nutrient input (section 3.1.7), sedimentation (section 3.1.7) and fishing access (section 3.1.8). Then anchoring these scores allowed us to describe anthropogenic stress at each site relative to the site assessed as having the lowest anthropogenic stress of all of the surveyed sites (Fig. 19). This process yielded 7 sites with low anthropogenic stress (1.0-0.8), 20 with medium (0.79-0.6), and 8 with high (<0.6); these are shown as green, yellow and red respectively in Table 3 and Figure 12. High levels of combined anthropogenic stress (nutrient input, sedimentation and fishing access; red in Table 3 and Figure 18) are found at locations exposed to run-off that are easy to access due to low wave exposure (Fig. 19). There are 8 of these locations: Obyan Beach [6], LaoLao Bay East [8], Boy Scout [17], Coral Ocean Point [25], Tanapag Staghorn [27], Managaha Patch Reef [28], Tank Beach [31], and Peysonnelia Reef [32]. Three of these sites – Obyan Beach [6], LaoLao Bay East [8] and Boy Scout [17] – have high resilience so can be considered priorities for local-scale actions to reduce one or all of the three anthropogenic stressors (see also section 4).

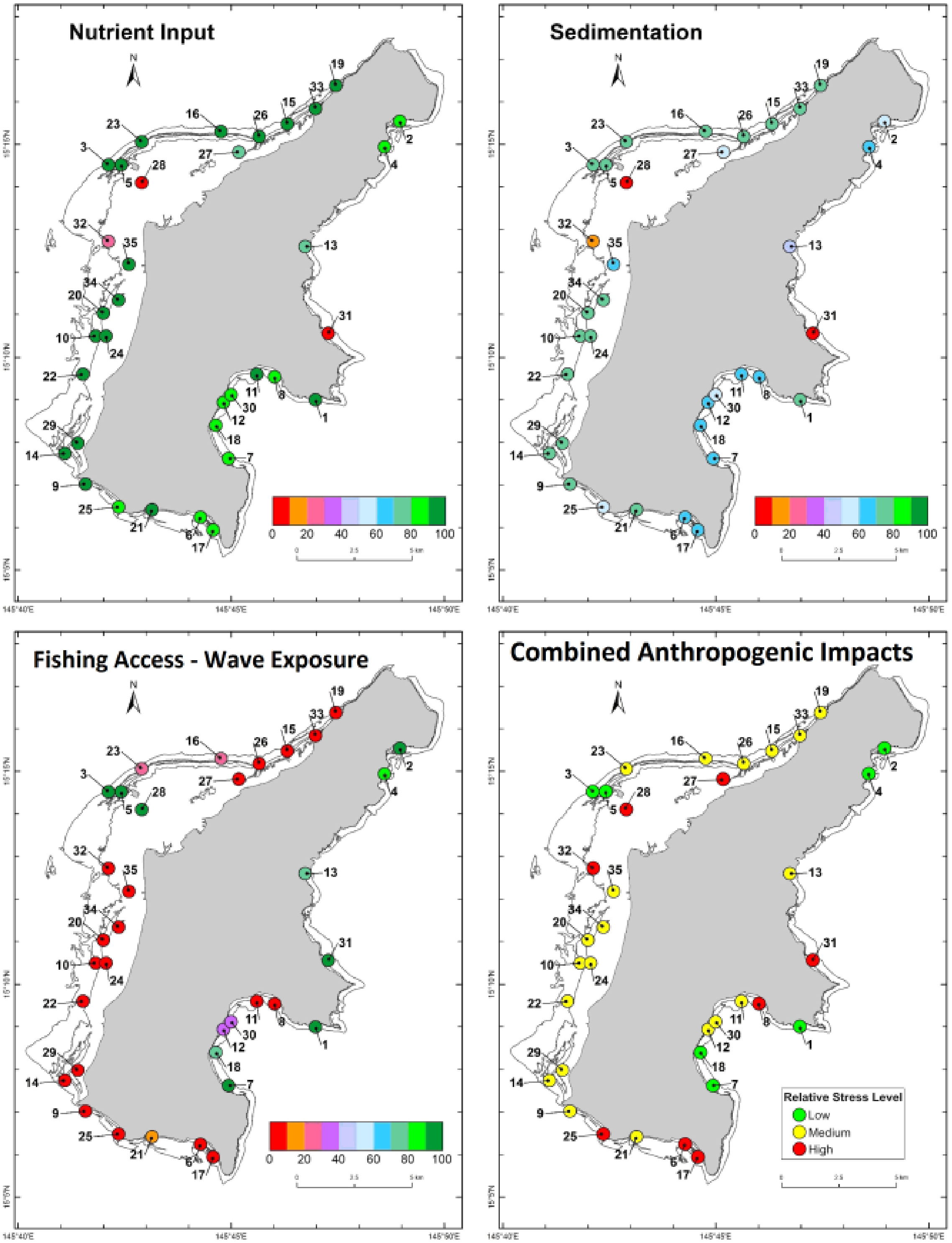
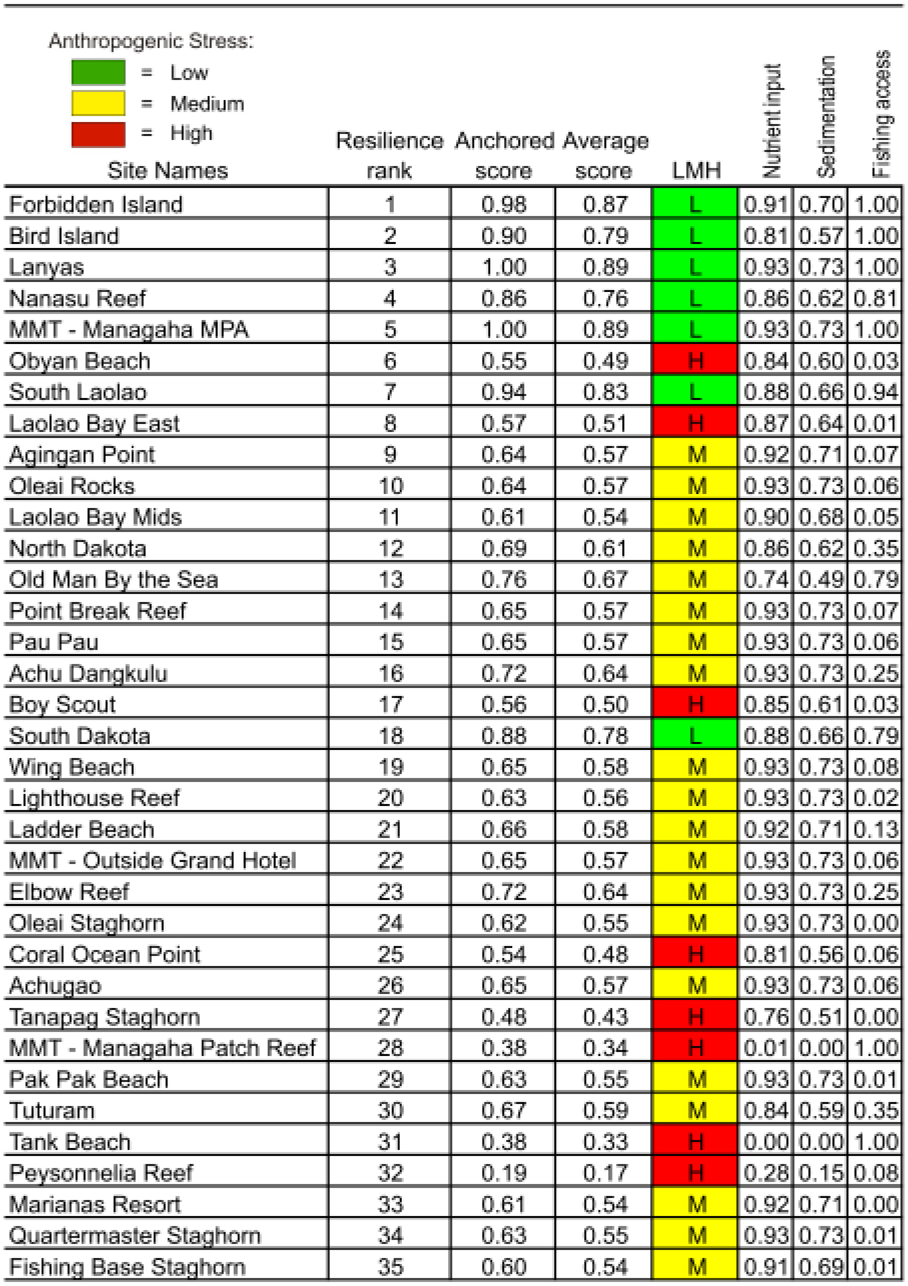


Figure 19. Anchored scores for nutrient input (see also Fig. 12), sedimentation (see also Fig. 13), and fishing access (see also Fig. 14), and all anthropogenic stressors combined. High, medium and low relative stress in the bottom right refers to <0.6, 0.6-0.79, and 0.8-1.0, respectively, in the anchored scores column of Table 3.

Table 3. Combined anthropogenic stress scores for all sites; the average of the anchored scores for nutrient input, sedimentation and fishing access (also shown in

Table 3. High, medium and low relative stress in the colored column is based on <0.6, 0.6-0.79, and 0.8-1.0, respectively, in the anchored score column.



Anthropogenic Stress:
🟩 = Low
🟨 = Medium
🟥 = High

Site Names	Resilience rank	Anchored score	Average score	LMH	Nutrient input	Sedimentation	Fishing access
Forbidden Island	1	0.98	0.87	L	0.91	0.70	1.00
Bird Island	2	0.90	0.79	L	0.81	0.57	1.00
Lanyas	3	1.00	0.89	L	0.93	0.73	1.00
Nanasu Reef	4	0.86	0.76	L	0.86	0.62	0.81
MMT - Managaha MPA	5	1.00	0.89	L	0.93	0.73	1.00
Obyan Beach	6	0.55	0.49	H	0.84	0.60	0.03
South Laolao	7	0.94	0.83	L	0.88	0.66	0.94
Laolao Bay East	8	0.57	0.51	H	0.87	0.64	0.01
Agingan Point	9	0.64	0.57	M	0.92	0.71	0.07
Oleai Rocks	10	0.64	0.57	M	0.93	0.73	0.06
Laolao Bay Mids	11	0.61	0.54	M	0.90	0.68	0.05
North Dakota	12	0.69	0.61	M	0.86	0.62	0.35
Old Man By the Sea	13	0.76	0.67	M	0.74	0.49	0.79
Point Break Reef	14	0.65	0.57	M	0.93	0.73	0.07
Pau Pau	15	0.65	0.57	M	0.93	0.73	0.06
Achu Dangkulu	16	0.72	0.64	M	0.93	0.73	0.25
Boy Scout	17	0.56	0.50	H	0.85	0.61	0.03
South Dakota	18	0.88	0.78	L	0.88	0.66	0.79
Wing Beach	19	0.65	0.58	M	0.93	0.73	0.08
Lighthouse Reef	20	0.63	0.56	M	0.93	0.73	0.02
Ladder Beach	21	0.66	0.58	M	0.92	0.71	0.13
MMT - Outside Grand Hotel	22	0.65	0.57	M	0.93	0.73	0.06
Elbow Reef	23	0.72	0.64	M	0.93	0.73	0.25
Oleai Staghorn	24	0.62	0.55	M	0.93	0.73	0.00
Coral Ocean Point	25	0.54	0.48	H	0.81	0.56	0.06
Achugao	26	0.65	0.57	M	0.93	0.73	0.06
Tanapag Staghorn	27	0.48	0.43	H	0.76	0.51	0.00
MMT - Managaha Patch Reef	28	0.38	0.34	H	0.01	0.00	1.00
Pak Pak Beach	29	0.63	0.55	M	0.93	0.73	0.01
Tuturam	30	0.67	0.59	M	0.84	0.59	0.35
Tank Beach	31	0.38	0.33	H	0.00	0.00	1.00
Peysonnelia Reef	32	0.19	0.17	H	0.28	0.15	0.08
Marianas Resort	33	0.61	0.54	M	0.92	0.71	0.00
Quartermaster Staghorn	34	0.63	0.55	M	0.93	0.73	0.01
Fishing Base Staghorn	35	0.60	0.54	M	0.91	0.69	0.01

For locations highly susceptible to bleaching, factors such as herbivore biomass and fishing access are particularly important. Herbivory is important at locations with high susceptibility to bleaching (relative to other sites in the area) because herbivores can reduce the cover of macroalgae; a major competitor of corals for space on reefs (review in Hughes et al. 2007). Healthy herbivore populations can help facilitate the recovery of coral populations following bleaching or other disturbance events that cause coral mortality (McCook 1999).

Seven locations (20% of those surveyed) are highly susceptible to bleaching (i.e., sites where the bleaching resistance (anchored) score is less than 0.60; Table 4). Bleaching resistance here is the percentage of the community made up by coral species that are generally resistant to bleaching. These bleaching susceptible locations will recover more slowly if processes like herbivory are not intact. Herbivore biomass is less than 50% of that seen at the site with the max herbivore biomass (anchored scores <0.5, Table 2). Further, fishing access based on wave exposure is high at all seven of these locations. These locations are likely to be amongst the most vulnerable surveyed given their sensitivity to bleaching and their accessibility to fishers, which may lengthen recovery timeframes between disturbance events. These sites warrant special attention during management and conservation planning.

Table 4. Vulnerable sites with low scores for bleaching resistance, low herbivore biomass and high fishing access based on wave exposure.

Rank	Site name	Bleaching resistance	Herbivore biomass	Fishing Access
35	Fishing Base Staghorn	0	0.13	0.01
33	Marianas Resort	0.23	0.26	0
34	Quartermaster Staghorn	0.23	0.42	0.01
26	Achugao	0.45	0.08	0.06
29	Pak Pak Beach	0.51	0.04	0.01
19	Wing Beach	0.57	0.17	0.08
25	Coral Ocean Point	0.58	0.2	0.06

The benthic community composition at the time of surveys can be found for all sites in Appendix 3. Appendix 4 contains the full list of coral species seen at the survey sites that were listed as potentially endangered on a petition in 2009 and given proposed classifications by NMFS in December of 2012.

4. Suggestions for managers

Based on the resilience analysis above, our team has made a number of suggestions to coral reef and coastal managers working in CNMI. These suggestions, detailed below, are based on the following approaches and rationale:

1. Climate change projections suggest that reef condition will decline through this century as disturbance frequencies increase. Managers should invest some resources in protecting high resilience sites if it can take many years or even decades for the benefits to manifest (as reported in McClanahan et al. 2013). This is because maximizing the number of healthy reefs in the long-term requires protecting the 'strong', or 'higher resilience potential' sites, if you expect most reefs to be in a degraded state (as we do, in the longer-term; Game et al. 2008). In our analysis, scores for resilience potential are partially driven by anthropogenic stressors. This creates the possibility that sites in the analysis could only differ in levels of anthropogenic stress but otherwise have the same resilience potential. We do not separate resilience indicators relating to anthropogenic stress from the other indicators. This is because we cannot defensibly quantify what the legacy of past anthropogenic stress will be. For management actions that result in benefits that take many years or decades to manifest – like marine protected areas – we suggest that sites shown here as having higher relative resilience potential deserve greater consideration. Further, we suggest reducing anthropogenic stress to the extent possible at the sites assessed as having the highest resilience potential.
2. Sites with greater coral diversity and low macroalgae cover deserve special consideration from managers as these may be high tourism value sites.
3. Actions resulting in improved water quality on reefs will affect the resilience potential of the greatest number of sites (versus other actions).
4. Protecting herbivorous fish populations is especially important at locations with greater relative vulnerability to coral bleaching.
5. Anchoring to the local maxima means this analysis of relative resilience potential for Saipan would change if sites were included from more remote locations in CNMI. This feature of the analysis highlights the importance of continuing and advancing the research and work presented here.

The suggestions for managers include:

- Obyan Beach, LaoLao Bay East, Agingan Point, and Oleai rocks are the four sites with resilience scores in the top ten that are currently not part of a marine protected area, and have high fishing access based on wave exposure. These are strong candidates for fishing pressure studies, focused enforcement presence or area based management since they have high resilience potential and are not protected from fishing by wave exposure. Further, coral diversity is extremely high at these locations. Another benefit of protecting these sites is that they are also likely to create positive growth opportunities for local dive and snorkel-based tourism operations.

- There are three sites with high resilience scores that have high anthropogenic stress: Obyan Beach, LaoLao Bay East, and Boy Scout. These warrant special consideration from managers as they represent priorities for targeted actions to reduce anthropogenic stress, specifically reducing nutrient input, sedimentation, and implementing studies to better understand the relationship between fishing access, fishing pressure and what is actually being harvested from these locations.

- There are five sites with high resilience potential, higher than average coral cover (>38%), and medium combined anthropogenic stress scores: Agingan Point [8], Point Break Reef [14], Wing Beach [19], Lighthouse Reef [20], and Elbow Reef [23]. These sites could warrant special attention to managers given their high relative resilience potential and that they might be of great present or future importance to dive and tour operators.

- The most resilient sites typically had low fishing access based on wave exposure, high herbivore biomass and low macroalgae cover. Suites of actions that address these issues on a broader scale, like the existing gillnet and scuba-spear ban, help to increase resilience potential at many sites around Saipan and need to be an ongoing management consideration as does the successful enforcement of these regulations.

- All of the sites assessed as having low or medium resilience have very low scores for one or more of: nutrient input, sedimentation, and fishing access. Scores for all of the other variables vary less among the pool of sites than these three anthropogenic stressors. Whole-of-island and local-scale targeted actions to reduce these stressors will maximize the number of healthy reef sites around Saipan as the frequency of climate-related disturbances increases.

- The three sites with low relative resilience – Marianas Resort, Quartermaster Staghorn, and Fishing Base Staghorn – are all highly vulnerable to temperature-induced bleaching. This is also true for Achugao, Pak Pak Beach, Wing Beach, and Coral Ocean Point. At all seven of these locations, bleaching resistance is low (<0.6), herbivore biomass is less than half of that seen at the site with the max biomass, and fishing access is high. These are vulnerable locations that warrant special consideration from managers. Three of these – Marianas Resport, Quartermaster Staghorn and Fishing Base Staghorn - are also critical lagoonal nursery habitats for fish. These areas could be a focus of community monitoring programs, like CoralWatch, given their vulnerability and accessibility. People participating in the monitoring can help keep trash off these reefs, and provide early warnings of bleaching impacts at these sites if bleaching is observed.

- The analysis approach of anchoring scores to local maxima means the analysis results are sensitive to the pool of sites included in the analysis; including more sites may raise the maxima, meaning sites with current high relative scores may have medium or low relative scores and vice versa. This is critically important in CNMI where most of the territory’s population resides on one island, Saipan. Surveying the reefs around the lesser populated islands, like Tinian and Rota, is an important next step. To that end, 2013-2014 funding was recently secured through the NOAA Internal call to fund a continuation of this work on Tinian.

These additional surveys have the potential to reveal the extent to which habitat condition and reef resiliency differ between Saipan and other locations with lower anthropogenic stress (see next steps section below).

5. Next steps

The lead investigator, J. Maynard, will continue to work closely with managers from CNMI’s Division of Environmental Quality and the local NOAA fisheries field office for at least 18 months from this report’s submission date. The team will work together to provide guidance for local managers based on the implications of the findings from the resilience analysis. Over the next several months, the project team will share project results in relevant conservation meetings. The project team is also preparing a manuscript on the resilience analysis for a conservation journal. This manuscript will address a critical science gap for conservation managers by providing much needed case studies of the development and implementation of coral reef resilience assessments.

In mid-2013 (May and June), the project team is planning further fieldwork in CNMI. A research proposal was submitted to NOAA’s Coral Reef Conservation Program in September of 2012 to increase the geographic extent of the fieldwork and resilience analysis described here. This proposal was successful and the new project funds will cover surveying 30-40 sites around the islands of either Tinian or Rota (FY13). The same field and desktop methodologies will be applied as presented in this report, and the approach will be updated to include recommendations, observations and advances in our understanding of how to best analyze the data. Following the fieldwork, the project team will be able to re-assess the maxima for each variable used to anchor scores in the present analysis. This will increase our understanding of the effects of anthropogenic stressors on relative resilience potential in CNMI since anthropogenic stress is far lower on the reefs surrounding Rota and Tinian than Saipan. For example, a site currently thought to have high herbivore biomass (when the Saipan biomass maxima is used) may have low biomass relative to that found on reefs around Tinian and/or Rota. Expected outcomes of the proposed 2014 fieldwork and analysis include: 1) a revised analysis of the relative resilience potential of sites throughout CNMI that is inclusive of sites near populated and unpopulated areas; 2) a report containing management recommendations to all local government agencies regarding actions to reduce stress on reefs and support recovery processes; 3) a publication on resilience analysis methodologies focusing on ways to maximize distinguishing sites at the local-scale while also being able to compare results between geographically disparate areas; and 4) user-friendly tools for practitioners based on (3).

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Appendices

Appendix 1 – Survey Site Waypoints

The latitude and longitude coordinates for all survey sites are shown below in decimal degrees, sorted in ascending order by resilience ranking.

Resilience rank	Site name	Latitude (N)	Longitude (E)
1	Forbidden Island	15.15	145.783
2	Bird Island	15.259	145.816
3	Lanyas	15.242	145.702
4	Nanasu Reef	15.249	145.81
5	MMT - Managaha MPA	15.242	145.707
6	Obyan Beach	15.104	145.738
7	South Laolao	15.127	145.749
8	Laolao Bay East	15.159	145.767
9	Agingan Point	15.117	145.693
10	Oleai Rocks	15.175	145.697
11	Laolao Bay Mids	15.16	145.76
12	North Dakota	15.149	145.747
13	Old Man By the Sea	15.21	145.779
14	Point Break Reef	15.129	145.685
15	Pau Pau	15.253	145.761
16	Achu Dangkulu	15.255	145.746
17	Boy Scout	15.099	145.743
18	South Dakota	15.14	145.744
19	Wing Beach	15.273	145.791
20	Lighthouse Reef	15.184	145.7
21	Ladder Beach	15.107	145.719
22	MMT - Outside Grand Hotel	15.16	145.692
23	Elbow Reef	15.251	145.715
24	Oleai Staghorn	15.175	145.701
25	Coral Ocean Point	15.108	145.706
26	Achugao	15.248	145.754
27	Tanapag Staghorn	15.247	145.753
28	MMT - Managaha Patch Reef	15.235	145.715
29	Pak Pak Beach	15.133	145.69
30	Tuturam	15.152	145.75
31	Tank Beach	15.176	145.788
32	Peysonnelia Reef	15.212	145.702
33	Marianas Resort	15.264	145.783
34	Quartermaster Staghorn	15.189	145.706
35	Fishing Base Staghorn	15.203	145.71

Appendix 2 – Bleaching Susceptibility Ratings

The table below shows the names of all of the species observed during these surveys, between March and May of 2012. Bleaching susceptibility is rated from 1-5 with 5 being the most susceptible. These ratings come from a focus group that reviewed available literature as well as field observations from the only known bleaching event on reefs in Saipan in 2001. Coral species were considered resistant at ratings ≤3 (see methods for more detail). Habitat classifications are as follows, and refer to the types of habitat(s) the species is known to occur in CNMI: Lf = loose framework reef, P = patch reef, Rf = reef flat, SG = spur and groove reef.

Species name	Growth Form	Bleaching Susceptibility	Habitat
Acanthastrea brevis	Encrusting	2	P, Sg
Acanthastrea echinata	Encrusting	2	Lf, P, Rf, Sg
Acanthastrea hillae	Encrusting	2	P, Sg
Acropora aspera	Staghorn	5	P, Rf
Acropora teres	Staghorn	5	P
Acropora copiosa	Staghorn	5	P
Acropora formosa	Staghorn	5	P
Acropora azurea	Digitate/corymbose	4	Lf, Sg
Acropora cuneata	Arborescent	2	P
Acropora digitifera	Digitate/corymbose	3	Lf, P, Sg
Acropora gemmifera	Digitate/corymbose	3	Lf, Sg
Acropora humilus	Digitate/corymbose	3	Lf, Sg
Acropora juv.	Digitate/corymbose	3	Lf, P, Sg
Acropora monticulosa	Arborescent	3	Lf, Rf, Sg
Acropora nasuta	Digitate/corymbose	5	Lf, Sg
Acropora palifera	Arborescent	2	Lf, P, Sg
Acropora secale	Digitate/corymbose	3	Lf, Sg
Acropora surculosa	Digitate/corymbose	3	Lf, P, Sg
Acropora tenuis	Digitate/corymbose	5	Lf, P, Rf, Sg
Acropora vaughani	Digitate/corymbose	3	Lf, Rf, Sg
Acropora verweyi	Digitate/corymbose	4	Lf, P, Sg
Astreopora listeri	Massive	4	Lf, P, Sg
Astreopora myriophthalma	Massive	4	Lf, P, Sg
Astreopora randalli	Massive	4	Lf, P, Sg
Cyphastrea chalcidicum	Massive	3	Lf, Sg
Cyphastrea japonica	Massive	3	Sg
Cyphastrea ocellina	Massive	3	Lf, Sg
Cyphastrea serailia	Massive	3	Lf, Sg

Cyphastrea sp. 1	Massive	3	Rf
Echinopora lamellosa	Plate	2	Lf, P, Sg
Favia favus	Massive	3	Lf, P, Sg
Favia matthaii	Massive	3	Lf, P, Sg
Favia rotumana	Massive	3	P
Favia speciosa	Massive	3	Lf, P, Sg
Favia stelligera	Massive	4	Lf, Sg
Favites abdita	Encrusting	2	Lf, P, Sg
Favites flexuosa	Massive	2	Lf, P
Favites russelli	Encrusting	1	Lf, P, Rf, Sg
Fungia scutaria	Free-living	2	Lf, P, Sg
Galaxea fascicularis	Encrusting	3	Lf, P, Sg
Goniastrea aspera	Massive	4	P
Goniastrea edwardsi	Massive	4	Lf, P, Rf, Sg
Goniastrea pectinata	Massive	3	Lf, P, Sg
Goniastrea retiformis	Massive	4	Lf, P, Rf, Sg
Goniopora fruiticosa	Massive	1	Lf, Sg
Goniopora minor	Massive	1	P
Heliopora coerula	Columnar	1	Lf, P, Rf
Hydnophora microconos	Massive	4	Lf, P, Rf, Sg
Leptastrea bottae	Encrusting	2	P, Sg
Leptastrea purpurea	Encrusting	2	Lf, P, Sg
Leptastrea transversa	Encrusting	2	Lf, Sg
Leptoria phrygia	Massive	3	Lf, P, Rf, Sg
Leptoseris mycetoseroides	Encrusting	3	P
Lobophyllia corymbosa	Massive	3	Lf, Sg
Lobophyllia hemprichii	Massive	3	Sg
Millepora platyphyllia	Columnar	1	Lf
Millepora sp. 1	Columnar	1	Sg
Millepora tuberosa	Encrusting	1	Lf, P, Sg
Montastrea curta	Massive	3	Lf, P, Sg
Montipora caliculata	Encrusting	4	Lf, P, Sg
Montipora efflorescens	Encrusting	4	Lf, P, Sg
Montipora floweri	Encrusting	4	Lf, Sg
Montipora grisea	Encrusting	4	Lf, Sg
Montipora hoffmeisteri	Encrusting	4	Sg
Montipora monasteriata	Encrusting	4	Lf, P, Sg
Montipora nodosa	Encrusting	4	Lf, P, Rf, Sg
Montipora sp. # 1	Encrusting	4	Lf

Montipora tuberculosa	Encrusting	4	Lf, P, Sg
Montipora verrilli	Encrusting	4	P, Sg
Pavona cactus	Foliose	3	P
Pavona divaricata	Foliose	3	Lf, P, Rf, Sg
Pavona duerdeni	Massive	4	Lf, P, Sg
Pavona varians	Encrusting	1	Lf, P, Sg
Platygyra daedalea	Massive	3	P, Sg
Platygyra pini	Massive	3	Lf, P, Sg
Pocillopora ankeli	Digitate/corymbose	4	Lf, Sg
Pocillopora damicornis	Digitate/corymbose	2	Lf, P, Rf, Sg
Pocillopora danae	Digitate/corymbose	3	Lf, Sg
Pocillopora elegans	Digitate/corymbose	4	Lf, P, Sg
Pocillopora eydouxi	Digitate/corymbose	4	Sg
Pocillopora juv.	Digitate/corymbose	4	Lf, P, Sg
Pocillopora meandrina	Digitate/corymbose	4	Lf, Sg
Pocillopora verrucosa	Digitate/corymbose	4	Lf, Sg
Pocillopora woodjonesi	Digitate/corymbose	4	Sg
Porites australiensis	Massive	1	Lf, Sg
Porites juv.	Massive	1	Lf, Sg
Porites lichen	Encrusting	1	Lf, P, Sg
Porites lobata	Massive	1	Lf, P, Sg
Porites lutea	Massive	1	Lf, P, Rf, Sg
Porites rus	Columnar	1	Lf, P, Sg
Porites vaughani	Encrusting	1	Lf, P, Sg
Psammacora haimeana	Encrusting	1	Lf, Sg
Scolymia australis	Encrusting	1	P
Stylocoeniella armata	Encrusting	1	Lf, P, Rf, Sg
Stylophora mordax	Digitate/corymbose	5	Lf, P, Rf, Sg

Appendix 3 – Benthic Community Composition

The benthic community composition varies widely among the survey sites. Coral cover ranges from 3 to 100%, bare substrate (minor turf algae if any on coral pavement) 0-81%, and macroalgae cover from 0-72% (Fig. Ap3.1 below). Benthic community composition is only included in the resilience analysis explicitly in the form of macroalgae cover, though the community make-up drives two other variables included; coral diversity and bleaching resistance. For this reason, sites with lower than average (38% across all survey sites) coral cover can and are classified as having high (relative) resilience potential in the resilience analysis (section 3.2, and Table 2, main report). Differences in the proportion of the substrate made up by common groups (i.e., live coral, macroalgae, etc.) provide an indication of habitat condition. Such information complements the resilience rankings and classifications (Table 2, main report) and the combined anthropogenic stress scores (Table 3, and Fig. 17, main report). The piechart panel that forms Fig. Ap3.1 below shows the resilience rankings and classifications (High/Medium/Low, see also Tables 1 and 2, main report), the benthic community composition, and the combined anthropogenic stress classification (from Table 3, main report). The panel graphic (Fig. Ap3.1 below) reveals that there are five sites with high resilience potential, higher than average coral cover (>38%), and medium combined anthropogenic stress scores: Agingan Point [8], Point Break Reef [14], Wing Beach [19], Lighthouse Reef [20], and Elbow Reef [23]. These sites could warrant special attention to managers given their high relative resilience potential and that they might be of great present or future importance to dive and tour operators.

More details on benthic community composition at the survey sites can be found in the site summaries that form Appendix 5.

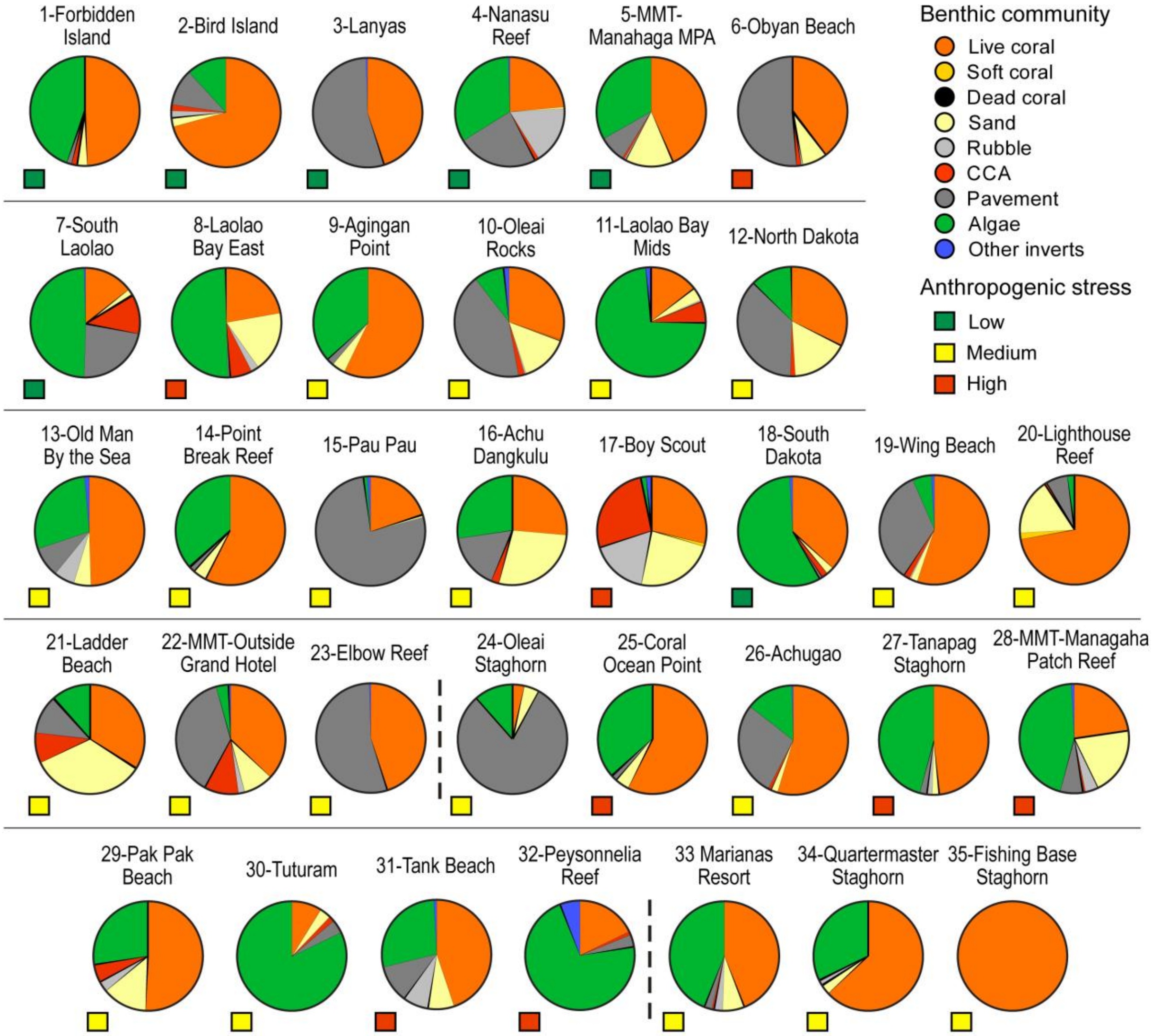

Fig. Ap3.1. The proportion of the substrate made up by 9 groups, at all survey sites. Sites are presented in ascending order based on resilience rankings (left to right); dashed lines separate high and medium (sites ranked 23/24) and medium and low (sites ranked 32 and 33) resilience sites. Boxes left and below each pie-chart denote combined anthropogenic stress as low, medium and high (see Table 3, main report).

Appendix 4 – ESA Listings of Coral Species by the NMFS

In 2009, 82 coral species were petitioned for listing under the Endangered Species Act by the Center for Biological Diversity. 40 of those species are known to occur on reefs within the borders of CNMI. On November 30th 2012, the NMFS released their proposed ruling on the petition, which recommended 66 of the initial 82 species be listed as either threatened or endangered. Of the 40 petitioned species known to be in CNMI, 28 were proposed by NMFS to be classified as ‘threatened’, 1 as ‘endangered’ (*Millepora foveolata*), and 11 as ‘not warranted’. A total of 23 of the 40 petitioned species known to be in CNMI were observed during these surveys (March-May, 2012) or during surveys conducted by the Marine Monitoring Team in 2009 (Table 1 below). 14 of these 23 have now been proposed by NMFS as ‘threatened’ (left-side of Table 1 below, grey shade), and 9 are proposed as ‘not warranted’.

The threatened coral species seen at the greatest number of sites are *Acropora verweyi* and *Pocillopora danae*, 21 and 18 sites, respectively. At least one coral species proposed as threatened was seen at all but one of the survey sites; South LaoLao. The coral species listed in the original 2009 petition that we observed at each survey site are listed again in Table 2 within each of the 35 site summaries that form Appendix 5.

Table 1. Coral species petitioned in 2009 for listing under the Endangered Species Act. The threatened and not warranted classifications are those proposed by the NMFS in November of 2012. X's denote locations where the coral was observed during these or surveys conducted by the Marine Monitoring Team in 2009.

Resilience Score:
🟩 = High
🟨 = Medium
🟥 = Low

Proposed NMFS Status		Threatened														Not Warranted								
Site Name	Rank	*Acropora verweyi*	*Pocillopora danae*	*Millepora tuberosa*	*Pocillopora elegans*	*Acropora vaughani*	*Montipora caliculata*	*Acropora aspera*	*Acanthastrea brevis*	*Acropora aculeus*	*Montipora lobulata*	*Acropora paniculata*	*Acropora palmerae*	*Alveopora fenestrata*	*Pavona diffluencs*	*Cyphastrea ocellina*	*Heliopora coerulea*	*Leptoseris incrustans*	*Turbinaria reniformis*	*Turbinaria stellulata*	*Cyphastrea agassizi*	*Pavona venosa*	*Pavona bipartita*	*Pavona cactus*
Forbidden Island	🟩 1	X		X		X										X								
Bird Island	🟩 2		X	X	X		X		X		X		X			X	X			X	X			
Lanyas	🟩 3	X	X			X										X								
Nanasu Reef	🟩 4	X	X	X	X	X									X		X							
MMT - Managaha MPA	🟩 5	X	X	X	X		X					X					X							
Obyan Beach	🟩 6	X	X	X	X		X		X		X					X		X						
South Laolao	🟩 7															X								
Laolao Bay East	🟩 8	X			X		X									X		X	X	X				
Agingan Point	🟩 9	X	X		X																			
Oleai Rocks	🟩 10						X																	
Laolao Bay Mids	🟩 11		X		X				X							X				X			X	
North Dakota	🟩 12			X		X	X									X								
Old Man By the Sea	🟩 13	X	X	X	X	X											X							
Point Break Reef	🟩 14		X				X																	
Pau Pau	🟩 15	X	X	X																				
Achu Dangkulu	🟩 16	X	X			X	X																	
Boy Scout	🟩 17	X	X	X	X	X				X	X					X	X	X	X					
South Dakota	🟩 18	X	X													X								
Wing Beach	🟩 19	X	X	X	X	X				X						X			X			X		
Lighthouse Reef	🟩 20	X	X	X	X	X	X																	
Ladder Beach	🟩 21	X	X	X		X	X									X								
MMT - Outside Grand Hotel	🟩 22	X	X	X	X					X						X								
Elbow Reef	🟩 23	X		X			X																	
Oleai Staghorn	🟨 24							X																
Coral Ocean Point	🟨 25	X	X	X	X		X			X	X	X		X			X	X	X			X		
Achugao	🟨 26	X				X											X							
Tanapag Staghorn	🟨 27							X	X								X							X
MMT - Managaha Patch Reef	🟨 28	X		X	X						X						X							
Pak Pak Beach	🟨 29		X	X	X	X		X	X							X	X				X			
Tuturam	🟨 30															X								
Tank Beach	🟨 31	X	X	X	X	X	X			X						X	X							
Peysonnelia Reef	🟨 32					X																		
Marianas Resort	🟥 33							X																
Quartermaster Staghorn	🟥 34							X																
Fishing Base Staghorn	🟥 35							X																
Number of Sites		21	20	18	16	14	13	6	5	5	5	2	1	1	1	16	11	4	4	3	2	2	1	1

Appendix 5 – Site Summaries

Summaries are presented for each survey site. Within each summary, a representative photograph is shown with a map showing the site location in red. All of the following are described in the text.

- The site's location.
- Scores for all 9 variables used in the resilience analysis and the final resilience score and rank. Descriptions of the methods for each variable can be found in the main report, section 2; temperature variability refers to variability (standard deviation) in the summertime temperatures (between 1982 and 2011).
- The benthic community composition.
- The diversity of stony corals.
- the number of species of corals observed that: (a) were on the list of 82 in the October 2009 petition for endangered species status (23 of the 40 known to be in CNMI were observed during these surveys), and (b) were proposed by the NMFS in November, 2012 as 'threatened' (14 of 23) or 'listing status not warranted' (9 of 23). The one species known to be in CNMI listed as endangered, *Millepora foveolata*, was not seen during our surveys.
- The biomass of herbivorous fish and the most common functional groups of herbivorous fish observed.
- The size-class distribution of stony corals.
- The size-class distribution of two key herbivorous fish families – Scaridae and Acanthuridae.

Methods for calculating the resilience scores are contained in the report methods, including anchoring and normalizing the continuous values measured in the field and using desktop analysis. Within the summaries the relative terms high, medium and low refer to anchored scores of 0.8-1.0, 0.6-0.79, and <0.6, respectively. This means scores are high if values are >80% of the max value, medium if between 60 and 79% of the max value, and low if less than 60% of the max value. Tables and figures are presented to complement the text and support statements therein; these are standard for all summaries presented and are as follows:

Table 1 shows the raw and anchored scores for all resilience variables, the final resilience score and the rank out of 35.

Table 2 contains a list of the coral species observed that were on the original 2009 petition for endangered species status with the NMFS. A superscript 'T' and 'NW' are used for the classifications released in November of 2012 for '*threatened*' and 'endangered species listing *not* warranted'. This table is only shown if one of the relevant coral species was observed.

Figure 1 presents the benthic community composition as a pie chart.

Figure 2 is the size-class frequency distribution of hard corals.

Figure 3 shows the mean biomass of herbivorous fish functional groups designated by IUCN.

Figure 4 shows herbivore biomass at the site relative to all other sites.

Figures 5 and 6 are size-class frequency distributions for Scaridae and Acanthuridae, respectively.

The site summaries are presented in the order of highest to lowest resilience score – Forbidden Island’s summary is shown first and the summary for Fishing Base Staghorn is presented last.

The site summary appendix is a separate document. The following contents list shows the page number for each of the respective site summaries.