Assessing resistance and recovery in CNMI during and following a bleaching and typhoon event to identify and prioritize resilience drivers and action options

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Project background: This proposed project builds upon the first CNMI resilience assessment (Maynard et al. 2015). The resilience indicators and the relative weighting of those indicators within the 2012-2015 assessment were based entirely on resilience theory. Consequently, the final resilience assessment results and relative classes for resilience describe ‘resilience potential’. This project (and award from NOAA CRCP) created the opportunity to re-visit sites initially surveyed in Saipan, CNMI in 2012 (so, 5 years ago by time this project started). Since 2012, reefs in CNMI have experienced four bleaching events and an intense typhoon. By documenting 2012-2018 changes in resilience and condition, we can evaluate ‘demonstrated resilience’ and hence develop recommendations based on reality rather than theory. This represents the critically needed first opportunity to undertake a follow-up resilience assessment using the methodology our team developed. Therefore, this project enables us to: 1) better ground resilience-based recommendations and the eventual prioritized actions in the reality of resistance and recovery patterns in CNMI, and 2) refine the publicly available guidance on resilience assessments and follow-on RBM actions.

Introduction:

Healthy coral reefs are highly resilient ecosystems. This resilience gives them the potential to resist and/or recover from local impacts like reduced water quality or a lack of herbivory and after major disturbances such as hurricanes and mass bleaching events. Coral reefs are being exposed to these potentially devastating events with greater frequency as the climate changes, making resilience an increasingly important property. Through the cumulative impacts of human use and the activities associated with human settlements, coral reefs are losing their resilience. As a consequence, protecting and restoring resilience is now a major focus of most coral reef management around the world. Resilience-based management (RBM) has emerged as the best way to reduce the vulnerability of coral reefs to the pervasive and inexorable changes in global climate (Norstrom et al. 2016). A focus on resilience gives us options – and hope - in the face of these new and often daunting challenges. RBM is ecosystem-based management that is future-looking, allowing decision makers to anticipate future change, and to focus efforts on improving the ability of the system to cope with future threats and unpredictable surprises.

Underpinning resilience-based management is the idea that local actions can positively influence the future of coral reefs, despite powerful external forces like climate change (Anthony et al. 2015). However, the application of resilience theory to the day-to-day business of coral reef management has been challenging. A key stumbling block has been the lack of a robust and easily implementable method for assessing coral reef resilience in a way that can inform marine spatial planning and support implementation of management strategies (McClanahan, Maynard et al. 2012). Fortunately, our ability to assess resilience of coral reefs has advanced greatly over the last decade - a feasible and useful protocol has been developed and is being applied in all of the US jurisdictions where reefs exist (Maynard et al. 2017; Maynard et al. 2015).

With support from the Coral Reef Conservation Program (CRCP) and others, we led a resilience assessment in the Commonwealth of the Northern Mariana Islands (CNMI) from 2012-2015 that included surveying 78 forereef sites near the islands of Saipan, Tinian, Aguijan, and Rota (results in Figure 1). We: assessed or measured resilience indicators, produced raw and relative resilience scores, assessed anthropogenic stress, developed criteria to help target management actions to support resilience and used the criteria to identify target sites, and compiled connectivity data as a lens through which to view/interpret our resilience results and prioritize from among the identified management action options (all summarized in Maynard et al. 2015). This first resilience assessment in CNMI informed a range of local management actions and activities and helped the U.S. Navy in their efforts to identify and prioritize mitigation alternatives for proposed future actions in the region.

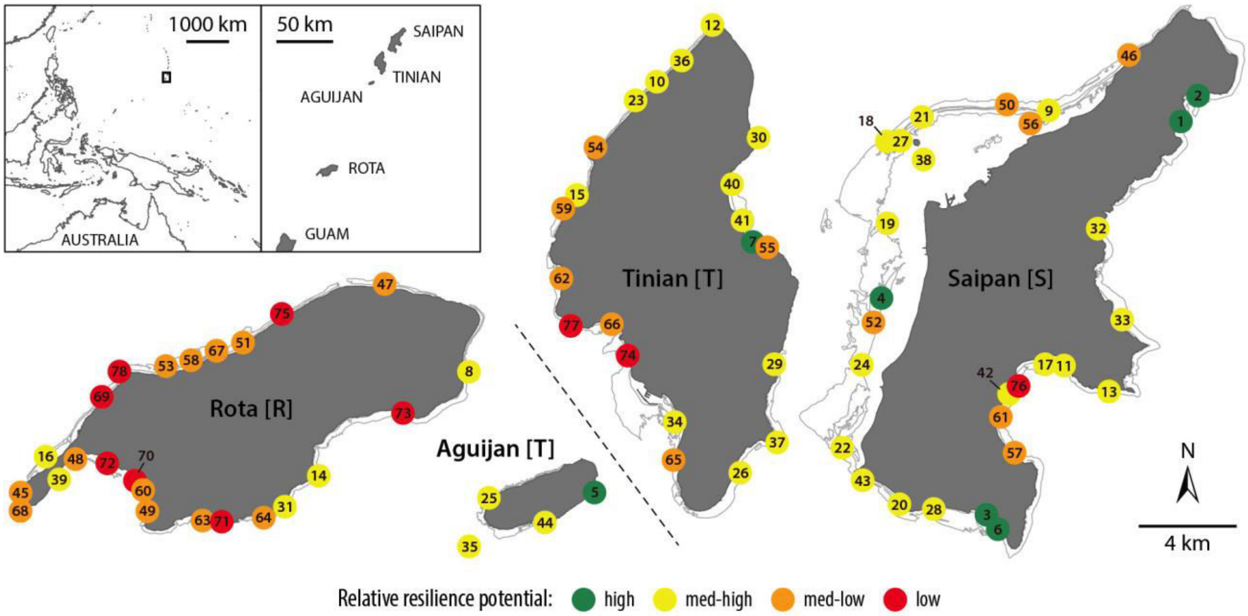


Figure 1. Inter-island resilience assessment results from the first CNMI resilience assessment, based on reef monitoring/surveys undertaken in 2012 (Saipan) and 2014 (other islands). Numbers refer to site names (see similar figure in Maynard et al. 2015 for site names).

This project built upon the first CNMI resilience assessment, completed in 2012 (in Saipan) and in 2014-2015 for Tinian and Aguijan and Rota and then reported on in Maynard et al. (2015). The resilience indicators and the relative weighting of those indicators within our first assessment were based entirely on resilience theory. Consequently, the final resilience assessment results and relative classes for resilience describe ‘resilience potential’. In the spring of 2018 we re-visited sites initially surveyed in Saipan, CNMI in 2012. Since 2012, reefs in CNMI have experienced bleaching events in 2013, 2014, 2016 and 2017 (see Figure 2) and two typhoons (Soudelor in 2015 and Yutu in 2018).

A review on recent bleaching from project manager partners in CNMI: *The CNMI has experienced extensive and unprecedented thermal stress and coral bleaching events over the last five years. The first of these major bleaching events occurred in 2013 when bleaching was observed in 85% of coral taxa on Saipan and Guam (Reynolds et al. 2014). This was followed in 2014 by a second mass bleaching event that impacted the entire archipelago (Heron et al. 2016). These consecutive annual bleaching events resulted in over 90% loss of staghorn Acropora spp. corals in Saipan Lagoon (BECQ-DCRM, Long-Term Monitoring Program, unpub. data) and high mortality of shallow water coral communities throughout the island chain (Heron et al. 2016; NOAA Coral Reef Ecosystem Program (CREP) unpub. data). In 2015, the Marianas experienced El Niño Southern Oscillation (ENSO)-related extreme low tides that exposed reef flats for prolonged periods during the dry season as well as a direct hit from the Category 4 Typhoon Soudelor. In 2016, mild bleaching occurred throughout the region and a dramatic increase in coral disease was recorded in Guam (Raymundo 2017). In 2017, the most severe mass bleaching event on record occurred across the region. On Saipan, nearly all coral taxa were impacted down to at least 20 m depth (BECQ-DCRM unpub. data) and preliminary data indicated that 90% of Acropora spp. corals and 70% of Pocillopora spp. corals died on shallow (<10 m) reefs (based on data presented within* ***this*** project report*).*

The accumulated thermal stress that preceded severe bleaching in CNMI in 2013, 2014, 2016, and 2017 is shown below as Figure 2, from NOAA Coral Reef Watch. This project represented the critically needed first opportunity to undertake a follow-up resilience assessment using the methodology our team developed. By documenting 2012-2018 changes in resilience potential (i.e., assessed resilience) and condition, we can: present and examine spatial patterns in coral cover loss and increases in macroalgae cover, assess whether bleaching resistance or resilience scores from 2012 predict changes in coral cover, re-assess spatial patterns in resilience and identify resilience class groupings, and set and use criteria to identify target sites for management actions.

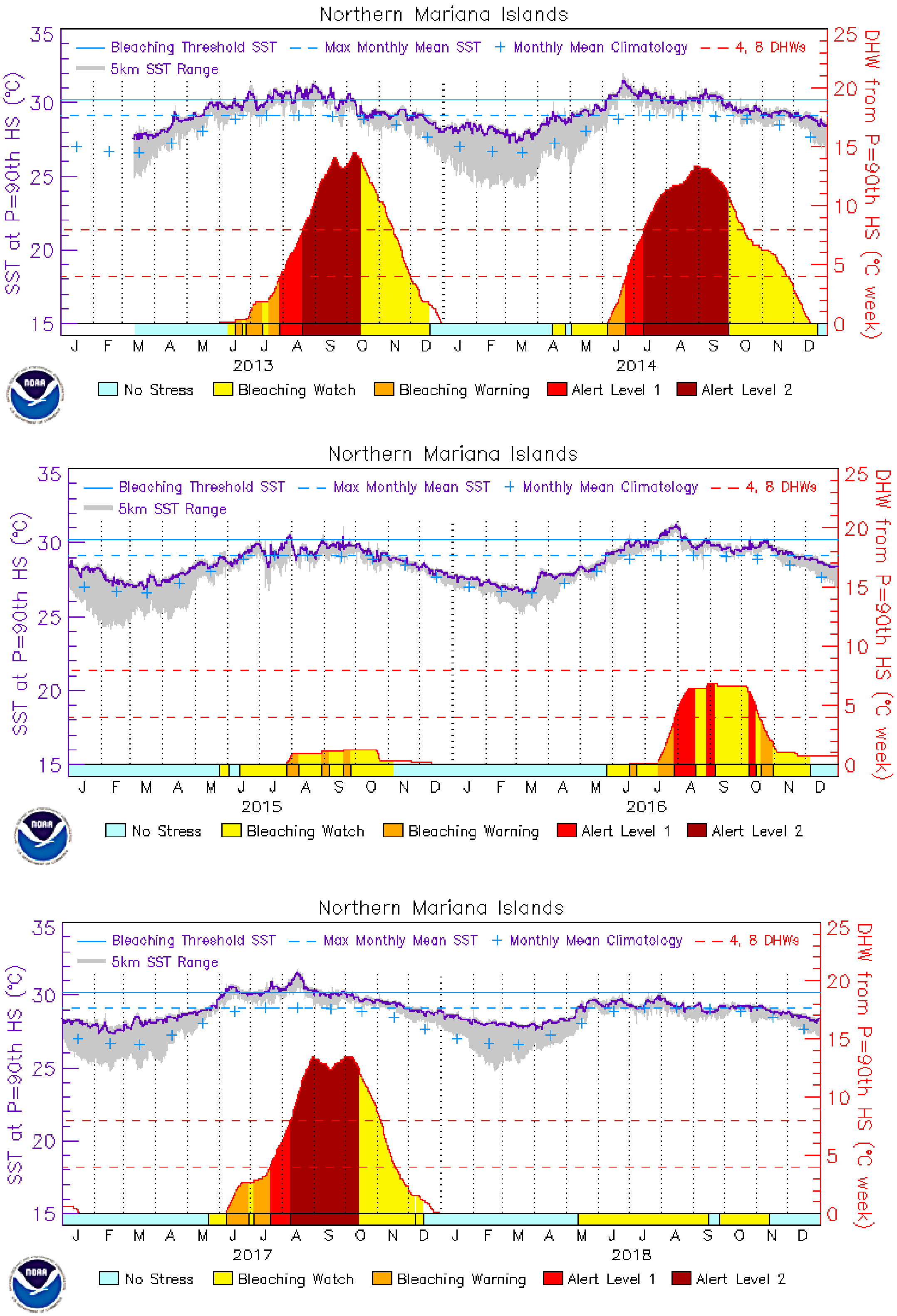


Figure 2. Regional virtual coral bleaching station for CNMI from NOAA Coral Reef Watch for 2013-2018, showing thermal stress exceeded Alert Level 1 on several occasions in 2016. Severe bleaching occurred during and after the thermal stress. Changes in coral cover due to the severe bleaching that occurred in 2013, 2014, 2016 and 2017 are presented within this report.

The project objectives for this study in Saipan, CNMI, directly from our submitted grant proposal, included:

(1) Map ESA-listed species distributions and training managers and community members to ID listed species.

(2) Assess changes in coral cover due to recent coral bleaching and cyclone events in Saipan and describe notable bleaching observations.

(3) Re-assess resilience in Saipan and evaluate capacity of resilience and resilience indicator scores to predict ecosystem change (2012-2017).

(4) Develop resilience-based management recommendations that account for spatial variation in resilience and the distribution of ESA-listed corals.

Methods

Our field and resilience assessment methods for the 2018 surveys (see **Appendix** for site coordinates) follow our methods from 2012 and 2014-2015, which are described within CRCP TM 22 and Maynard et al. 2015:

Maynard, J., S. McKagan, L. Raymundo, S. Johnson, G. Ahmadia, L. Johnston, P. Houk, G. Williams, M. Kendall, S. Heron, R. van Hooidonk, R., and E. McLeod. 2015. Assessing relative resilience potential of coral reefs to inform management in the Commonwealth of the Northern Mariana Islands. Silver Spring, MD: NOAA Coral Reef Conservation Program. NOAA Technical Memorandum CRCP 22. 153pp. doi:10.7289/V5H41PFM

Maynard, J. A., McKagan, S., Raymundo, L., Johnson, S., Ahmadia, G. N., Johnston, L., Houk, P., Williams, G.J., Kendall, M., Heron, S.F., and van Hooidonk, R. (2015). Assessing relative resilience potential of coral reefs to inform management. *Biological Conservation*, *192*, 109-119.

Methods specific to this study that differ from our research from 2012-2015 include that we:

- Examined cyclone and bleaching impacts on reef condition by subtracting 2018 cover estimates for corals from 2012 cover estimates;

- Used inverse distance weighted (IDW) interpolation to interpolate absolute and relative coral cover change between 2012 and 2018 as well as the resilience assessment results (IDW assumes each measured point has an influence that diminishes with distance, About from ArcGIS Pro);

- Assumed all resilience indicators to be of equal importance; they are not weighted in the 2018 resilience assessment presented here, as is recommended in Maynard et al. 2017.

- Used herbivore biomass (average biomass of all herbivorous fish seen among our stationary point counts) as a resilience indicator rather than average functional group biomass (see CRCP TM 22).

- Completed an analysis that separates resilience indicators between those that confer resistance (i.e., bleaching resistance) and those that indicate recovery potential, and then ranked sites based on resistance and recovery.

- Included data on land-based sources of pollution for each survey site including the number of sources and the number of water quality guideline exceedances from *Total Maximum Daily Loads for Coastal Waters Impaired by Bacteria on Saipan*, submitted to the US-EPA by Paradigm Environmental.

Results

Objective 1 - Map ESA-listed species distributions and train managers and community members to ID listed species.

During the 2012 benthic surveys performed as part of the resilience study on Saipan, *Acropora globiceps* was not identified at any sights. Our assumption is that the species was present during those surveys that occurred prior to the coral listing, but that benthic surveyors were confounding it with one of the other *Acropora* species that look very similar. . For that reason, we cannot compare locations we observed *A. globiceps* in 2018 to locations from 2012. Coral taxonomy experts, such as Laurie Raymundo at Guam, could reliably identify *Acropora globiceps* by 2014 and trained and worked with staff from the local monitoring program at CNMI-BECQ. By the time this project started, staff could reliably identify *Acropora globiceps* and did not need further training in its identification. Our team in 2018, which included coral taxonomists Doug Fenner and Lyza Johnston, observed the ESA-listed *Threatened* species *Acropora globiceps* at 10 of the survey sites and *Pavona diffluens* at 7 of the survey sites. *Pavona diffluens* is listed throughout its range but had not been reported in the CNMI or other parts of the Pacific at the time of the ESA listings. No other ESA-listed coral species (NMFS 2014 ESA listings) were observed during the 2018 resilience and reef condition surveys we conducted in Saipan, CNMI.

Some graphics within this report have also been provided to our local manager partners as single page PDFs enabling easy sharing among local agencies and use in other reports. We will place an asterisk after the figure number in the caption if we prepared the figure as a single page PDF and will upload those with this report as well.

Observations of coral species listed as *Threatened* in the NMFS Endangered Species Act coral species listings of 2014 (*Acropora globiceps* and *Pavona diffluens*). No coral species currently listed as *Endangered* are known to occur in CNMI.

Figure 3*. Observations of ESA-listed (Threatened) coral species *Acropora globiceps* and *Pavona diffluens* during reef condition and resilience surveys conducted in May, 2018 in Saipan, CNMI. Sites are numbered based on their 2018 resilience rank (see Figure 6). The surveys were led by Steven McKagan and were funded by the NOAA Coral Reef Conservation Program under a domestic grant to the Marine Applied Research Center (www.symbioseas.org). For further information contact: steven.mckagan@noaa.gov

Objective 2 - Assess changes in coral cover due to recent coral bleaching and cyclone events in Saipan and describe notable bleaching observations.

Coral cover change 2012-2018

The project team is certain that the great majority of the change in reef condition between 2012 and 2018 can be attributed to bleaching events between 2013 and 2017, rather than Typhoon Soudelor in 2015. Super Typhoon Yutu crossed Saipan five months after our surveys, in October of 2018. Yutu was a more severe storm than Soudelor and may have had major impacts on the coral reefs of Saipan and other islands within CNMI. This means that the coral cover estimates provided here from May of 2018 might be overestimates given coral cover at many locations might have declined further during Yutu. The nature and extent of impacts to the coral reefs of Saipan and other islands in CNMI from Super Typhoon Yutu are unknown and the subject of a number of efforts to raise funding for near-future surveys and research. The data collected during these surveys provide excellent pre-Yutu baselines.

The impacts of the 2013, 2014, 2016 and 2017 bleaching events (see thermal stress in Figure 2) were severe in Saipan.

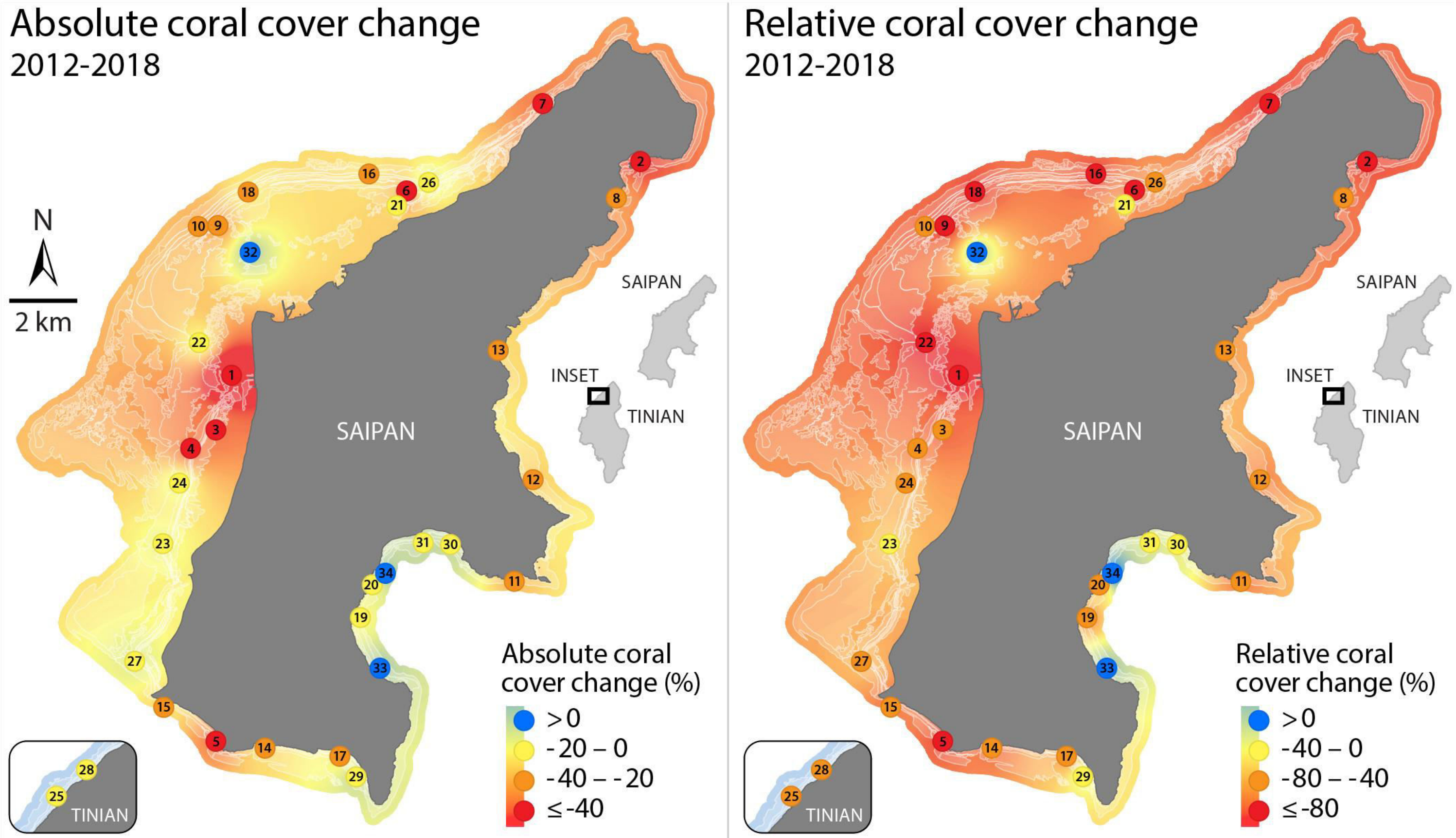
When all sites are combined (lagoon and forereef), the average coral cover at the 35 survey sites was 38% in 2012 and only 13% in 2018; an absolute loss of 24% and relative loss of 67%.

At the lagoon sites, average coral cover was 62% in 2012 and 17% in 2018; an absolute loss of 45% and relative loss of 73%.

At the forereef sites, average coral cover was 35% in 2012 and only 13% in 2018; an absolute loss of 22% and relative loss of 63%.

The coral reefs that we surveyed at 30ft of Saipan, CNMI lost 2/3rds of their coral cover during the 6-year period between 2012 and 2018 (Figure 4, Table 1). There were only three sites where cover did not decline or slightly increased – Laolao South (from 13.5 to 16%), Tuturam (from 8.8 to 15.33%), and Managaha Patch Reef (22.7% to 23.33). We did not survey fixed points and used different observers during each of our two survey years – cover estimates within 5% can be considered as similar or the same. Given that, these three sites should be seen as having the same coral cover in 2012 as in 2018 rather than be seen as locations where cover increased.

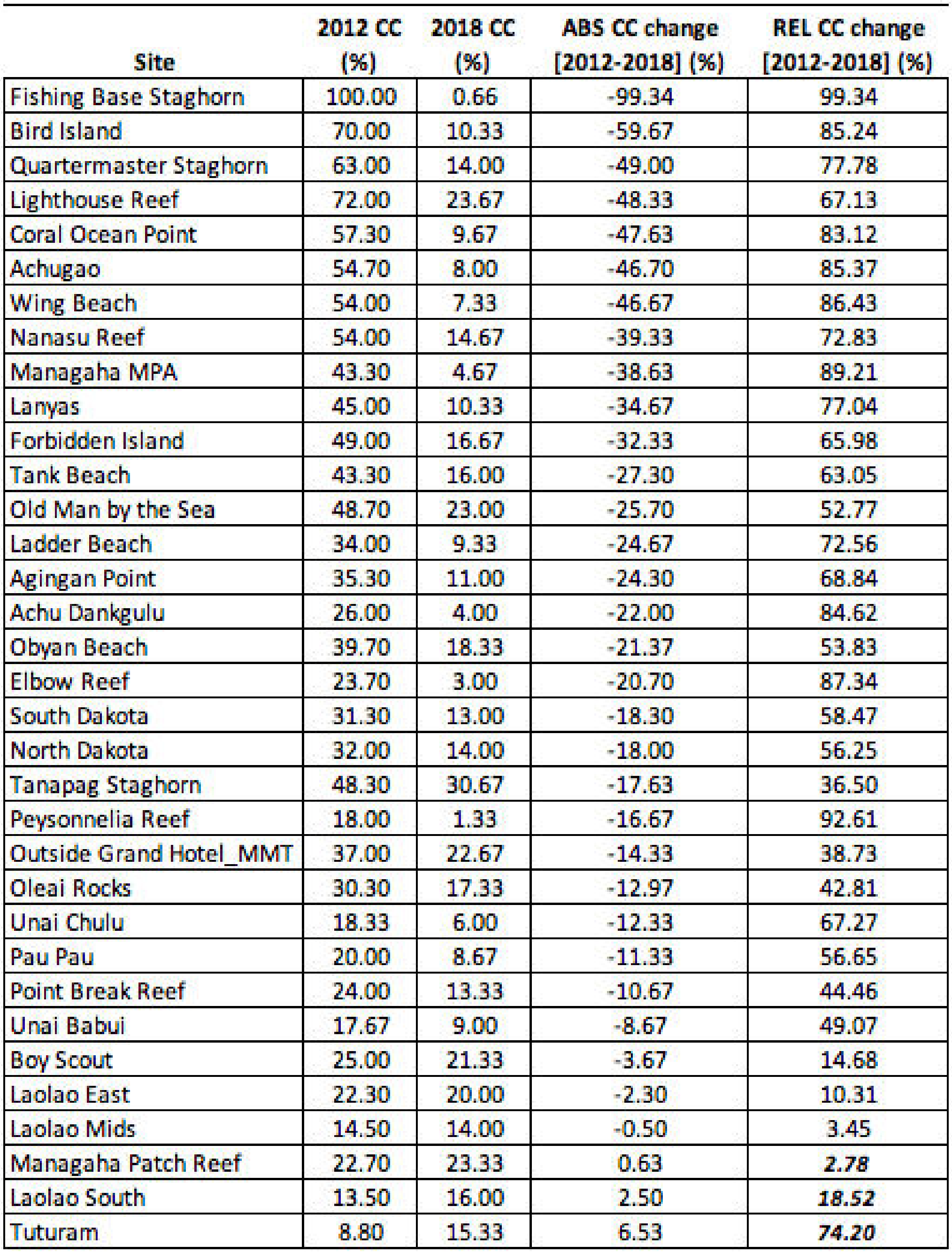
There were 12 sites where absolute coral cover loss exceeded 30% (see Table 1); the biggest losses were in the locations that had the highest coral cover in 2012. The mono-specific bleaching-susceptible stands of branching *Acropora* at Fishing Base Staghorn and Quartermaster Staghorn in the lagoon near Garapan bleached very severely – Fishing Base had 99% coral cover in 2012 and <1% in 2018 and Quartermaster had 63% coral cover in 2012 and 14% in 2018. Most of this loss occurred during the 2013 and 2014 (mostly 2014) bleaching events (CNMI-BECQ unpubl. data). The MPAs of Bird Island and Forbidden Island also suffered major losses of coral cover. Coral cover declined 32% at Forbidden Island (49% in 2012 to 17% in 2018) and coral cover declined 60% at Bird Island (70% in 2012 to 10% in 2018). The spatial patterns in coral cover loss reveal greatest losses in the lagoon near Garapan and in the sites east and west of the northern end of Saipan. Losses were generally lower on the exposed eastern side of the island and in Laolao Bay than on the sheltered western side (Figure 4).



1 – Fishing Base Staghorn [-99.3, -99.3]
2 – Bird Island [-59.7, -85.2]
3 – Quartermaster Staghorn [-49.0, -77.8]
4 – Lighthouse Reef [-48.3, -67.1]
5 – Coral Ocean Point [-47.6, -83.1]
6 – Achugao [-46.7, -85.4]
7 – Wing Beach [-46.7, -86.4]
8 – Nanasu Reef [-39.3, -72.8]
9 – Managaha MPA [-38.6, -89.2]
10 – Lanyas [-34.7, -77.0]
11 – Forbidden Island [-32.3, -66.0]
12 – Tank Beach [-27.3, -63.0]
13 – Old Man by the Sea [-25.7, -52.8]
14 – Ladder Beach [-24.7, -72.6]
15 – Agingan Point [-24.3, -68.8]
16 – Achu Dankgulu [-22.0, -84.6]
17 – Obyan Beach [-21.4, -53.8]
18 – Elbow Reef [-20.7, -87.3]
19 – South Dakota [-18.3, -58.5]
20 – North Dakota [-18.0, -56.3]
21 – Tanapag Staghorn [-17.6, -36.5]
22 – Peysonnelia Reef [-16.7, -92.6]
23 – Grand Hotel_MMT [-14.3, -38.7]
24 – Oleai Rocks [-13.0, -42.8]
25 – Unai Chulu [-12.3, -67.3]
26 – Pau Pau [-11.3, -56.7]
27 – Point Break Reef [-10.7, -44.5]
28 – Unai Babui [-8.7, -49.1]
29 – Boy Scout [-3.7, -14.7]
30 – Laolao East [-2.3, -10.3]
31 – Laolao Mids [-0.5, -3.4]
32 – Managaha Patch Reef [0.6, 2.8]
33 – Laolao South [2.5, 18.5]
34 – Tuturam [6.5, 74.2]

Figure 4*. Coral cover change between 2012 and 2018. Sites are numbered and listed from greatest to least absolute loss of coral cover during the study period. Change values are estimated using IDW interpolation for areas between survey sites. Site names are followed with bracketed values for the absolute change in percent coral cover (losses are negative values, see also Table 1). The May 2018 surveys were led by Steven McKagan and were funded by the NOAA Coral Reef Conservation Program under a domestic grant to the Marine Applied Research Center (www.symbioseas.org). For further information contact: steven.mckagan@noaa.gov

Table 1. Coral cover in 2012 and 2018, and absolute and relative coral cover change, listed from greatest to least absolute coral cover loss during the study period (see also Figure 4 to see a map of these data). All values for cover and cover change are percentages.



Site	**2012 CC (%)**	**2018 CC (%)**	**ABS CC change [2012-2018] (%)**	**REL CC change [2012-2018] (%)**
Fishing Base Staghorn	100.00	0.66	-99.34	99.34
Bird Island	70.00	10.33	-59.67	85.24
Quartermaster Staghorn	63.00	14.00	-49.00	77.78
Lighthouse Reef	72.00	23.67	-48.33	67.13
Coral Ocean Point	57.30	9.67	-47.63	83.12
Achugao	54.70	8.00	-46.70	85.37
Wing Beach	54.00	7.33	-46.67	86.43
Nanasu Reef	54.00	14.67	-39.33	72.83
Managaha MPA	43.30	4.67	-38.63	89.21
Lanyas	45.00	10.33	-34.67	77.04
Forbidden Island	49.00	16.67	-32.33	65.98
Tank Beach	43.30	16.00	-27.30	63.05
Old Man by the Sea	48.70	23.00	-25.70	52.77
Ladder Beach	34.00	9.33	-24.67	72.56
Agingan Point	35.30	11.00	-24.30	68.84
Achu Dankgulu	26.00	4.00	-22.00	84.62
Obyan Beach	39.70	18.33	-21.37	53.83
Elbow Reef	23.70	3.00	-20.70	87.34
South Dakota	31.30	13.00	-18.30	58.47
North Dakota	32.00	14.00	-18.00	56.25
Tanapag Staghorn	48.30	30.67	-17.63	36.50
Peysonnelia Reef	18.00	1.33	-16.67	92.61
Outside Grand Hotel_MMT	37.00	22.67	-14.33	38.73
Oleai Rocks	30.30	17.33	-12.97	42.81
Unai Chulu	18.33	6.00	-12.33	67.27
Pau Pau	20.00	8.67	-11.33	56.65
Point Break Reef	24.00	13.33	-10.67	44.46
Unai Babui	17.67	9.00	-8.67	49.07
Boy Scout	25.00	21.33	-3.67	14.68
Laolao East	22.30	20.00	-2.30	10.31
Laolao Mids	14.50	14.00	-0.50	3.45
Managaha Patch Reef	22.70	23.33	0.63	***2.78***
Laolao South	13.50	16.00	2.50	***18.52***
Tuturam	8.80	15.33	6.53	***74.20***

Predicting bleaching-induced mortality using 2012 resilience indicator data

Our team did not expect that the 2012 resilience scores (see Figure 1) would predict bleaching-induced mortality following a major bleaching event. The resilience index developed in 2012, and developed and presented again here for 2018, only included one indicator that measured bleaching resistance. The ‘bleaching resistance’ indicator is the percentage of the coral community made up by bleaching resistant taxa. We classified all coral species we observed on a scale of 1-5 from least to most sensitive. Species with scores of 1, 2 or 3 were considered resistant. Tables showing bleaching susceptibility scores for all observed taxa are in Maynard et al. 2015 (NOAA CRCP TM22). The bleaching resistance score developed in 2012 was a good predictor of spatial variation in coral cover loss following the four recent bleaching events (simple linear regression – R^2 of 0.5254, Figure 5).

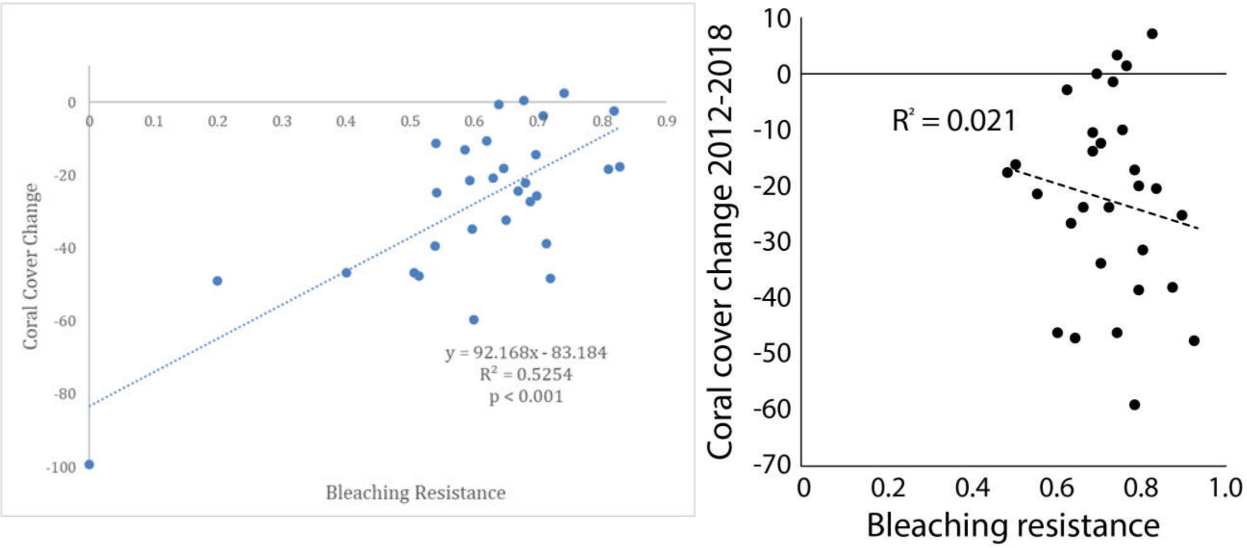


Figure 5. Simple linear regression between 2012 bleaching resistance scores and coral cover change 2012-2018. The plot on the left includes all sites surveyed in 2012 (n=35), including lagoon sites that were dominated by mono-specific highly bleaching-susceptible stands of branching *Acropor*a.

However, there is no discernible relationship between bleaching resistance and coral cover change 2012-2018 when only the Saipan forereef sites are included in the analysis (29).
This is probably mostly explained by (***1***) bleaching susceptibility scores largely coming from observations of bleaching susceptibility from the late 1990’s to early 2000’s or 2010. Looking back now, thermal stress events in that period, even the major global bleaching event of 1998, were less severe than many reefs experienced during the third global bleaching event of 2014-2017. Differences in susceptibility matter less when thermal stress is very severe – if thermal stress levels are high enough all or nearly all coral species experience bleaching. This seems to be the case for the recent bleaching events in CNMI. Thermal stress was very severe (see Figure 1) – or at least far more severe than has been typical of even warm summers in the last 10 years and many coral species bleached, but taxa considered relatively resistant had lower mortality rates. Other partial explanations for bleaching resistance scores in 2012 not predicting coral cover change between 2012 and 2018 at the forereef sites are: the other causes of coral mortality between 2012 and 2018 – (***2***) Typhoon Soudelor, coral disease and predation, and other natural

mortality, and (***3***) that we re-visited sites using waypoints rather than returning to transect start and endpoints defined by pins or stakes (we have returned close to where we surveyed in the past but did not survey exactly the same transect area). The three partial explanations are numbered in bold italics just above; our best estimate is that explanation 1 is at least 80%, while explanations 2 and 3 certainly also played a small part.

The bleaching resistance indicator is used within the 2018 resilience assessment presented here: (1) to enable direct comparisons with our 2012 resilience assessment results; and, (2) because the bleaching resistance indicator still may predict inter-species differences in bleaching severity during low and moderate thermal stress events.

Notable bleaching observations from Dr. Douglas Fenner

In addition to duplicating the benthic survey methods used in the previous 2012 and 2014 resilience studies on Saipan, Tinian and Rota, we were able to: develop a more comprehensive coral species list at each site (available upon request – steven.mckagan@noaa.gov), conduct a more comprehensive search for ESA-listed species, collect site data for corals >50cm (a size that are often missed within quadrat tosses but are of high ecological importance), and determine a ratio of live vs. dead corals for the genera *Acropora* and *Pocillopora* to estimate mortality associated with the 2017 bleaching event. These additional observations were made by Dr. Douglas Fenner; an experienced reef ecologist added to the 2018 survey team thanks to generous support from NOAA PIRO's Protected Resources Division. Key observations from Dr. Fenner’s surveys include:

- 109 coral species were identified across all sites in Saipan at 20-30 ft (vs 246 reported by Randall and Myers (1983) and 278 confirmed or strongly predicted by Veron et al. (2019) for the region across all depths)
- 9 Acropora species were observed across all sites at 30ft (vs 38 reported by Randall and Myers (1983) and 41 reported by Veron et al. (2019) for the region across all depths).
- 5 Pocillopora species were observed across all sites at 30ft (vs 10 reported by Randall and Myers (1983) and 12 reported by Veron et al. (2019) for the region across all depths)
- Acropora globiceps was the only listed species observed because P. diffluens listed status is geographically limited to only those organisms found in the Indian Ocean, but it was observed at 7 sites around Saipan during the 2018 study.
- 12 species were observed that do not appear in Randall and Myers (1983) or in Veron et al. (2019) and could potentially be new records.

Astreopora cucullata
Echinopora gemmifera
Echinophyllia orpheensis
Favia truncatus
Goniastrea favulus
Goniastrea minuta
Leptastrea bewickensis

Montipora capitata
Montipora meandrina
Montipora turgescens
Oulophyllia bennettae
Porites evermanni
Porites heronensis

- 795 corals of a size >50 cm length were recorded within belt transects (2m x 30m belt, 3 per site) across all of the survey sites. There were 3 sites where no corals >50 cm in length were observed
- Upright live vs dead corals of the genera *Acropora* and *Pocillopora* were assessed at 17 sites based on visual cues that strongly suggested the dead corals were the result of the 2017 bleaching event (Only 17 sites because we decided to record this information halfway through the field effort). These coral skeletons were covered in algae but the branch and corallite structures were still distinguishable, indicating that they died relatively recently.
    - 124 of 1217 *Acropora* spp. observed were alive, indicating approximately 90% mortality from the 2017 bleaching. This suggests bleaching in 2017 was the major driver of coral loss since 2012 (67% coral cover lost since 2012).
    - 344 of 1285 *Pocillopra* spp. observed were alive, indicating approximately 73% mortality from the 2017 bleaching

Objective 3 - Re-assess spatial variation in resilience potential in 2018.

2018 assessment of relative resilience for forereef sites in Saipan

Relative resilience varied greatly around Saipan in 2018, as assessed using our resilience index comprised of six resilience indicators. There were five high resilience sites (Grand Hotel (MMT), Lanyas, Oleai Rocks, Lighthouse Reef, Laolao Bay Mids) – these five have high relative coral recruit densities and/or have high relative cover of the bleaching-resistant massive coral *Porites rus.* There were 8 med-high resilience sites, 12 med-low resilience sites, and 4 low resilience sites (South Dakota, Achu Dangkulu, Peysonnelia Reef, Wing Beach). The high resilience sites ranked 1-4 are all on the sheltered western side of Saipan and the high resilience site ranked 5th, Laolao Bay Mids, is on the more exposed eastern side (Figure 6). The low resilience site ranked 26th, South Dakota, is also in Laoloa Bay, a couple kilometers south of the high resilience site Laolao Bay Mids, highlighting the great variation in reef condition and resilience within Laolao Bay. The other low resilience sites are on the sheltered western side of the island. The spatial patterns in relative resilience are shown within Figure 6, and normalized scores for the resilience indicators that comprise the resilience index are shown below within Table 2 (with raw scores for indicators in Table 3).

For this 2018 resilience assessment, macroalgae cover, coral recruitment, and herbivore biomass were by far the most important determinants of differences among sites in resilience scores (Figure 7, and see also Figures 8-11). Macroalgae cover, though higher everywhere in 2018 than in 2012, varied greatly among sites, which is likely partially attributable to difference among observers in classification of turfing versus macroalgae. The sites ranked 1-4 for resilience potential in 2018 all had relatively low macroalgae cover (high scores are good scores, meaning low macroalgae cover, see Table 2). Further, high resilience sites had high scores for either herbivore biomass (Grand Hotel (MMT) and Laolao Bay Mids) or coral recruitment (Lanyas and Oleai Rocks), or medium-high scores for coral recruitment and herbivore biomass (Lighthouse Reef). In summary, high resilience sites resisted the bleaching events or are recovering more quickly, have greater relative herbivore biomass, and lower relative macroalgae cover. In contrast, and without exception, the low resilience sites have relatively high macroalgae cover and relatively low herbivore biomass. The low resilience sites are recovering more slowly and with less herbivory occurring have experienced macroalgae blooms (Table 2).

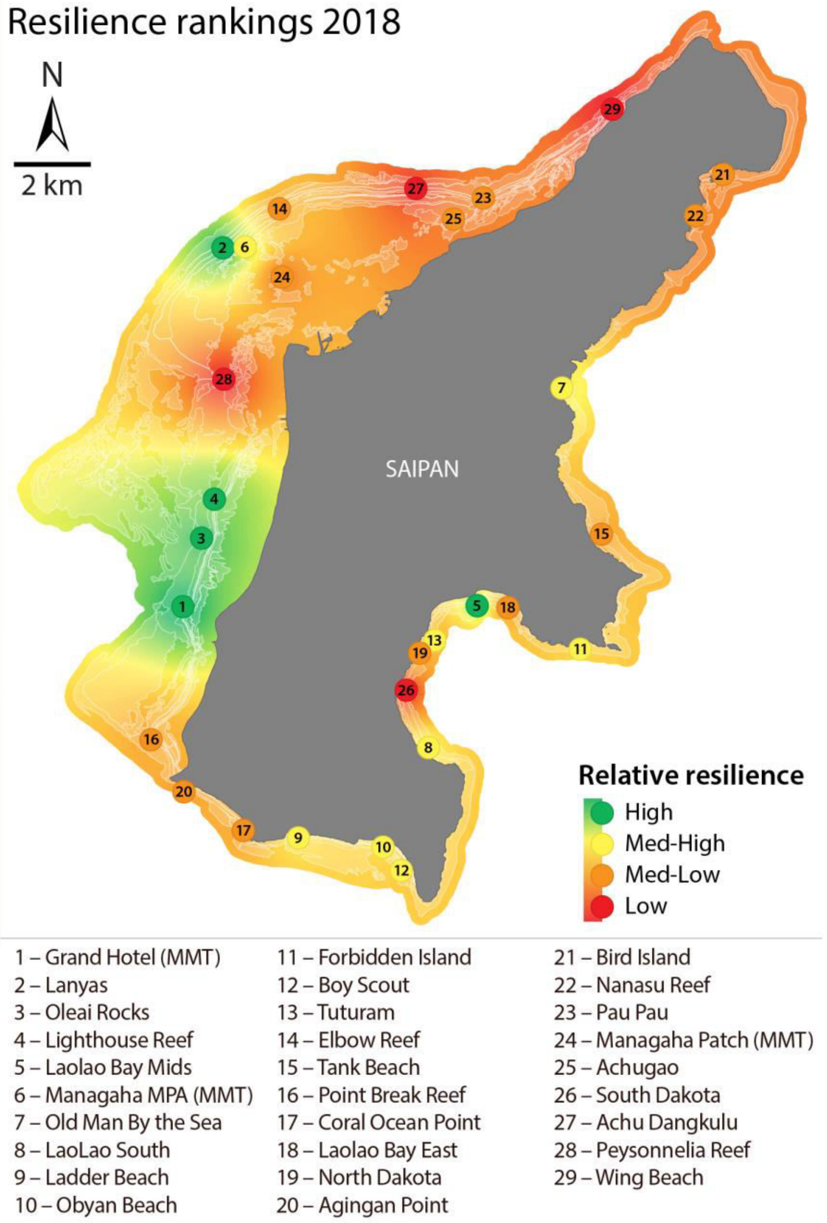
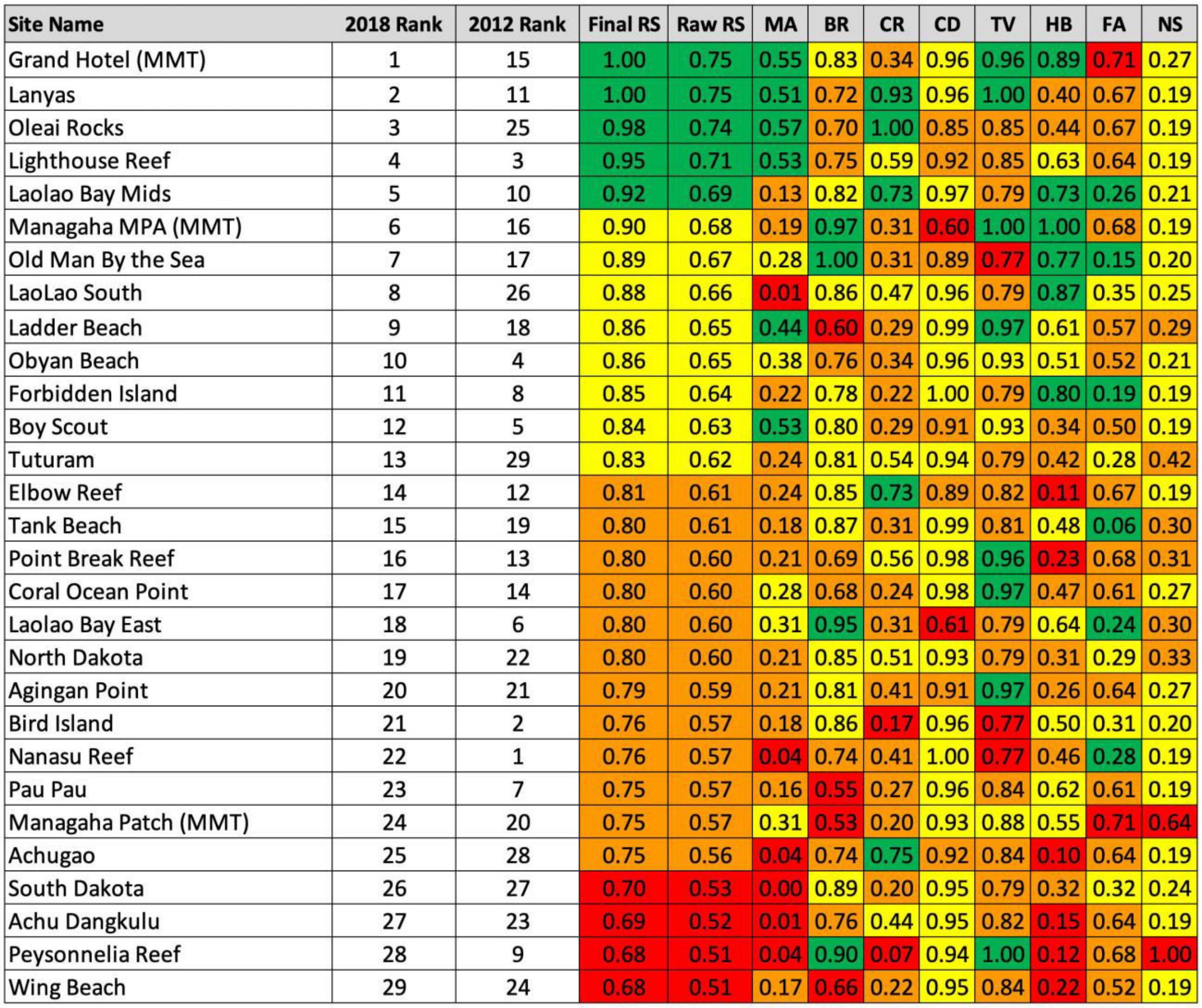


Figure 6. Relative resilience in 2018 in Saipan, CNMI, using a resilience index comprised of macroalgae cover, bleaching resistance, coral recruitment, coral diversity, temperature variability, and herbivore biomass. There are 5 high resilience, 8 med-high, 12 med-low, and 4 low resilience sites. Normalized scores for the resilience indicators that make up the resilience index are shown within Table 2. Map figures showing spatial variation in the six resilience indicators are presented as Figures 8-11. Color codes are as follows: high – green (>avg+1 stdev [avg=average, stdev = standard deviation]), med-high – yellow (<avg+1 stdev and >avg), med-low – orange (<avg and >avg-1stdev), low – red (<avg-1stdev). The May 2018 surveys were led by Steven McKagan and were funded by the NOAA Coral Reef Conservation Program under a domestic grant to the Marine Applied Research Center (www.symbioseas.org). For further information contact: steven.mckagan@noaa.gov

Table 2. Normalized scores for the resilience indicators used for our resilience index (MA, BR, CR, CD, TV, and HB) and for fishing access (FA) and nutrients and sediments (NS). Resilience indicator codes are: MA – macroalgae cover, BR – bleaching resistance, CD – coral diversity, TV – temperature variability, HB – herbivore biomass. Raw values for the resilience indicators, shown in Table 3, are normalized by dividing by the maximum value, and inversed for macroalgae cover, to set all scoring as uni-directional from 0-1 with 1 being the best score. Indicator scores are averaged to produce the raw resilience score (Raw RS), then normalized to produce the final resilience score (Final RS). Our methods for fishing access and nutrients and sediments were published in NOAA CRCP TM22. Color codes are as follows: high – green (>avg+1 stdev [avg=average, stdev = standard deviation]), med-high – yellow (<avg+1 stdev and >avg), med-low – orange (<avg and >avg-1stdev), low – red (<avg-1stdev).



Site Name	2018 Rank	2012 Rank	Final RS	Raw RS	MA	BR	CR	CD	TV	HB	FA	NS
Grand Hotel (MMT)	1	15	1.00	0.75	0.55	0.83	0.34	0.96	0.96	0.89	0.71	0.27
Lanyas	2	11	1.00	0.75	0.51	0.72	0.93	0.96	1.00	0.40	0.67	0.19
Oleai Rocks	3	25	0.98	0.74	0.57	0.70	1.00	0.85	0.85	0.44	0.67	0.19
Lighthouse Reef	4	3	0.95	0.71	0.53	0.75	0.59	0.92	0.85	0.63	0.64	0.19
Laolao Bay Mids	5	10	0.92	0.69	0.13	0.82	0.73	0.97	0.79	0.73	0.26	0.21
Managaha MPA (MMT)	6	16	0.90	0.68	0.19	0.97	0.31	0.60	1.00	1.00	0.68	0.19
Old Man By the Sea	7	17	0.89	0.67	0.28	1.00	0.31	0.89	0.77	0.77	0.15	0.20
LaoLao South	8	26	0.88	0.66	0.01	0.86	0.47	0.96	0.79	0.87	0.35	0.25
Ladder Beach	9	18	0.86	0.65	0.44	0.60	0.29	0.99	0.97	0.61	0.57	0.29
Obyan Beach	10	4	0.86	0.65	0.38	0.76	0.34	0.96	0.93	0.51	0.52	0.21
Forbidden Island	11	8	0.85	0.64	0.22	0.78	0.22	1.00	0.79	0.80	0.19	0.19
Boy Scout	12	5	0.84	0.63	0.53	0.80	0.29	0.91	0.93	0.34	0.50	0.19
Tuturam	13	29	0.83	0.62	0.24	0.81	0.54	0.94	0.79	0.42	0.28	0.42
Elbow Reef	14	12	0.81	0.61	0.24	0.85	0.73	0.89	0.82	0.11	0.67	0.19
Tank Beach	15	19	0.80	0.61	0.18	0.87	0.31	0.99	0.81	0.48	0.06	0.30
Point Break Reef	16	13	0.80	0.60	0.21	0.69	0.56	0.98	0.96	0.23	0.68	0.31
Coral Ocean Point	17	14	0.80	0.60	0.28	0.68	0.24	0.98	0.97	0.47	0.61	0.27
Laolao Bay East	18	6	0.80	0.60	0.31	0.95	0.31	0.61	0.79	0.64	0.24	0.30
North Dakota	19	22	0.80	0.60	0.21	0.85	0.51	0.93	0.79	0.31	0.29	0.33
Agingan Point	20	21	0.79	0.59	0.21	0.81	0.41	0.91	0.97	0.26	0.64	0.27
Bird Island	21	2	0.76	0.57	0.18	0.86	0.17	0.96	0.77	0.50	0.31	0.20
Nanasu Reef	22	1	0.76	0.57	0.04	0.74	0.41	1.00	0.77	0.46	0.28	0.19
Pau Pau	23	7	0.75	0.57	0.16	0.55	0.27	0.96	0.84	0.62	0.61	0.19
Managaha Patch (MMT)	24	20	0.75	0.57	0.31	0.53	0.20	0.93	0.88	0.55	0.71	0.64
Achugao	25	28	0.75	0.56	0.04	0.74	0.75	0.92	0.84	0.10	0.64	0.19
South Dakota	26	27	0.70	0.53	0.00	0.89	0.20	0.95	0.79	0.32	0.32	0.24
Achu Dangkulu	27	23	0.69	0.52	0.01	0.76	0.44	0.95	0.82	0.15	0.64	0.19
Peysonnelia Reef	28	9	0.68	0.51	0.04	0.90	0.07	0.94	1.00	0.12	0.68	1.00
Wing Beach	29	24	0.68	0.51	0.17	0.66	0.22	0.95	0.84	0.22	0.52	0.19

Table 3. Raw values for the resilience indicators with sites listed by 2018 ranking for the resilience assessment. Resilience indicator codes are: MA – macroalgae cover, BR – bleaching resistance, CD – coral diversity, TV – temperature variability, HB – herbivore biomass. Coral diversity and temperature variability are unitless. These raw values are normalized by dividing by the maximum value, and then inversed for macroalgae cover, to produce the uni-directional scores ranging from 0-1 shown within Table 2.

Site name	2018 Rank	MA (%)	BR (%)	CR (#/m^2)	CD	TV	HB (g/m^2)
Ladder Beach	1	39.67	0.56	4.53	0.94	0.94	17.62
Tuturam	2	53.67	0.75	8.53	0.89	0.76	12.05
Forbidden Island	3	55.33	0.73	3.47	0.95	0.76	23.09
Elbow Reef	4	53.67	0.79	11.47	0.85	0.79	3.21
Coral Ocean Point	5	51.00	0.63	3.73	0.93	0.94	13.37
Oleai Rocks	6	30.33	0.65	15.73	0.81	0.82	12.68
Bird Island	7	58.33	0.80	2.67	0.91	0.74	14.40
Tank Beach	8	58.33	0.81	4.80	0.94	0.78	13.90
Nanasu Reef	9	68.00	0.69	6.40	0.95	0.74	13.07
Lanyas	10	34.67	0.67	14.67	0.91	0.96	11.41
Obyan Beach	11	44.00	0.71	5.33	0.91	0.89	14.65
Boy Scout	12	33.67	0.74	4.53	0.86	0.89	9.72
Lighthouse Reef	13	33.33	0.70	9.33	0.87	0.82	18.18
Agingan Point	14	56.00	0.75	6.40	0.86	0.94	7.60
Old Man By the Sea	15	51.00	0.93	4.80	0.85	0.74	22.19
LaoLao Bay East	16	49.33	0.88	4.80	0.58	0.76	18.35
Grand Hotel_MMT	17	32.00	0.77	5.33	0.91	0.92	25.56
LaoLao South	18	70.00	0.80	7.47	0.91	0.76	25.12
North Dakota	19	56.33	0.79	8.00	0.88	0.76	8.91
Peysonnelia Reef	20	68.00	0.84	1.07	0.89	0.96	3.56
MMT - Managaha MPA	21	57.33	0.90	4.80	0.57	0.96	28.72
Achu Dangkulu	22	70.33	0.71	6.93	0.90	0.79	4.23
Achugao	23	68.00	0.69	11.73	0.87	0.81	2.76
Pau Pau	24	59.33	0.51	4.27	0.91	0.81	17.73
LaoLao Bay Mids	25	62.00	0.76	11.47	0.92	0.76	21.06
Managaha Patch	26	48.67	0.49	3.20	0.88	0.85	15.88
Point Break Reef	27	56.00	0.64	8.80	0.93	0.92	6.59
South Dakota	28	71.00	0.83	3.20	0.90	0.76	9.29
Wing Beach	29	59.00	0.61	3.47	0.90	0.81	6.33

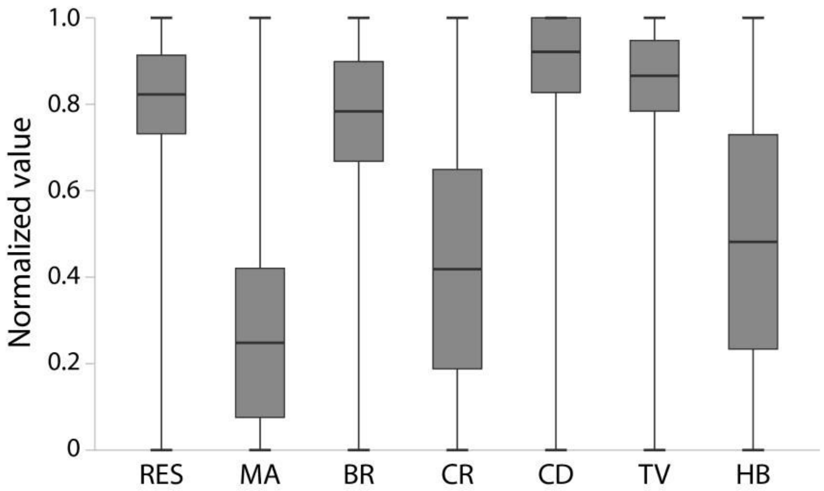


Figure 7. Box and whisker plot showing the average (box mid-point) and one standard deviation (top and bottom of box) and range (tails) for the normalized values for the six resilience indicators and the final resilience scores. Resilience indicator codes are: MA – macroalgae cover, BR – bleaching resistance, CD – coral diversity, TV – temperature variability, HB – herbivore biomass. The variance (width of the box determined by the standard deviation values) in scores is very low for bleaching resistance, coral diversity and temperature variability. The variance is far greater for macroalgae cover, coral recruitment, and herbivore biomass; these are the primary determinants of differences among sites in resilience scores for the 2018 analysis (see Tables 2 and 3, and Figure 6).

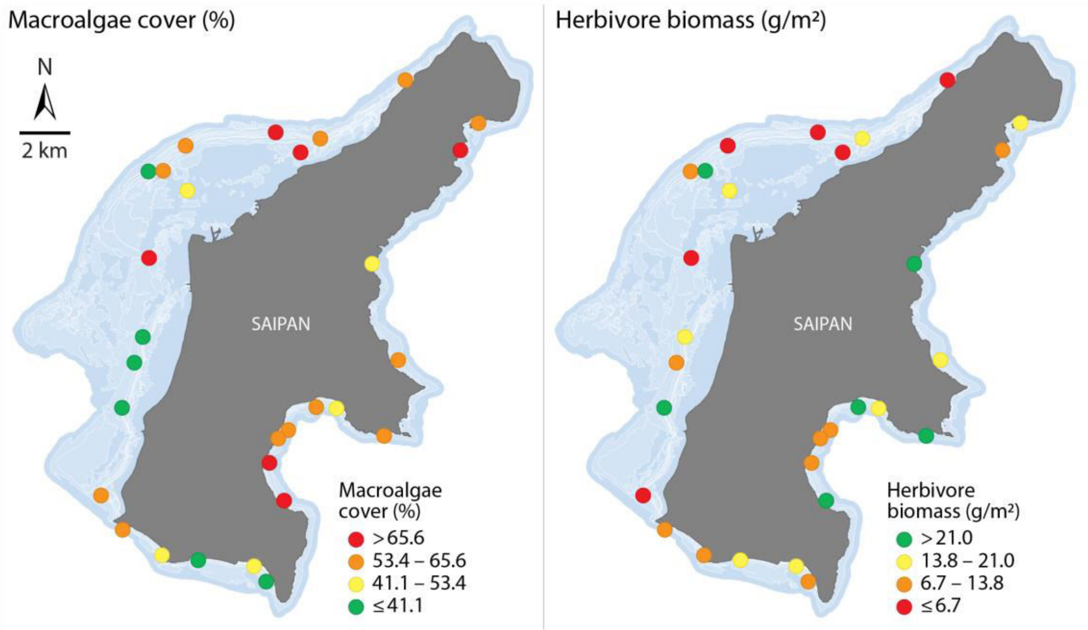


Figure 8. Macroalgae cover and herbivore biomass raw data values from surveys conducted in Saipan, CNMI in May of 2018. With coral recruitment, these indicators were the primary determinants of differences in resilience scores in 2018. Color codes are as follows: high – green (>avg+1 stdev [avg=average, stdev = standard deviation]), med-high – yellow (<avg+1 stdev and >avg), med-low – orange (<avg and >avg-1stdev), low – red (<avg-1stdev). Raw data values for all indicators are presented within Table 3.

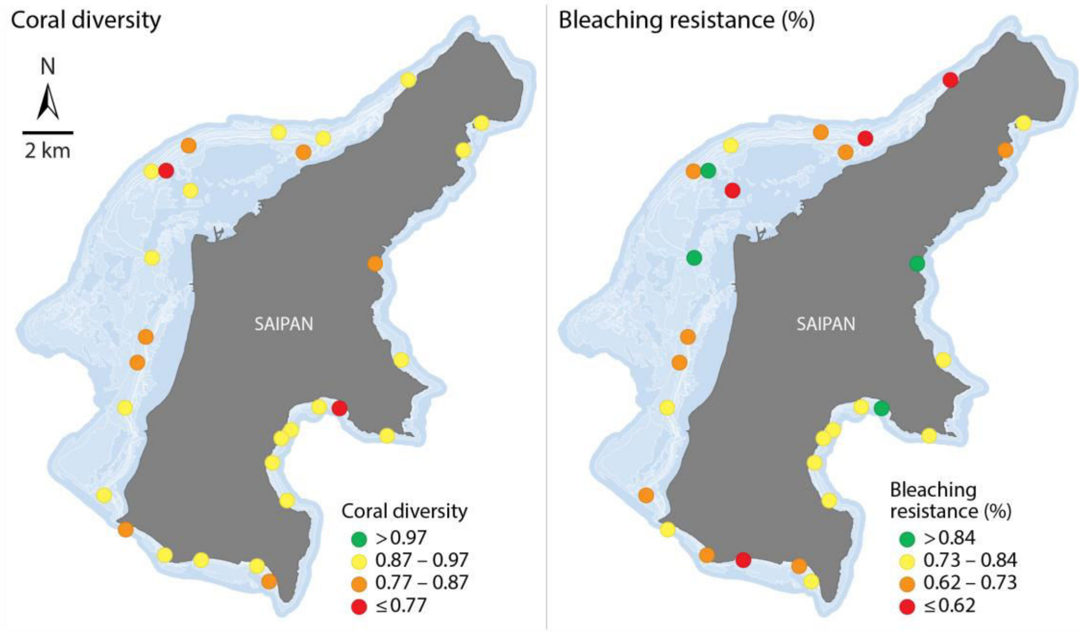


Figure 9. Coral diversity and bleaching resistance raw data values from surveys conducted in Saipan, CNMI in May of 2018. Color codes are as follows: high – green (>avg+1 stdev [avg=average, stdev = standard deviation]), med-high – yellow (<avg+1 stdev and >avg), med-low – orange (<avg and >avg-1stdev), low – red (<avg-1stdev). Raw data values for all indicators are presented within Table 3.

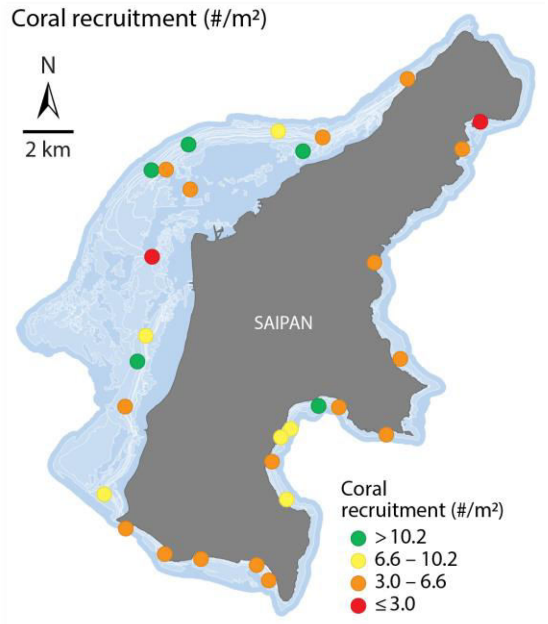


Figure 10. Coral recruitment raw data values from surveys conducted in Saipan, CNMI in May of 2018. Color codes are as follows: high – green (>avg+1 stdev [avg=average, stdev = standard deviation]), med-high – yellow (<avg+1 stdev and >avg), med-low – orange (<avg and >avg-1stdev), low – red (<avg-1stdev). Raw data values for all indicators are presented within Table 3.

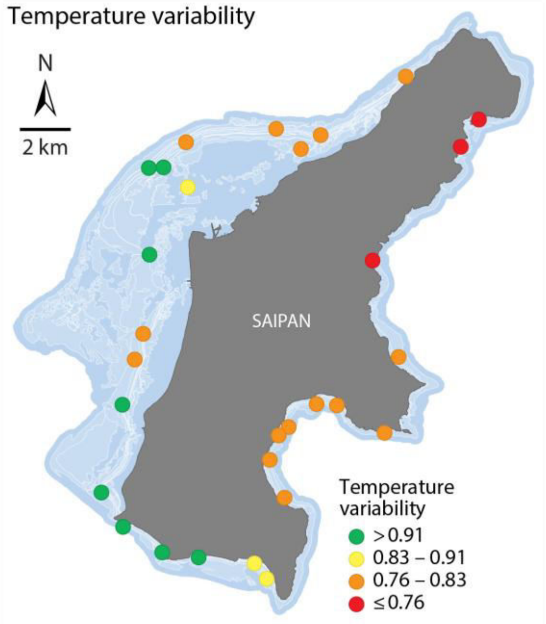


Figure 11. Temperature variability values from remotely sensed sea surface temperature data (the standard deviation of temperatures during the warmest 3 months). Color codes are as follows: high – green (>avg+1 stdev [avg=average, stdev = standard deviation]), med-high – yellow (<avg+1 stdev and >avg), med-low – orange (<avg and >avg-1stdev), low – red (<avg-1stdev). Raw data values for all indicators are presented within Table 3.

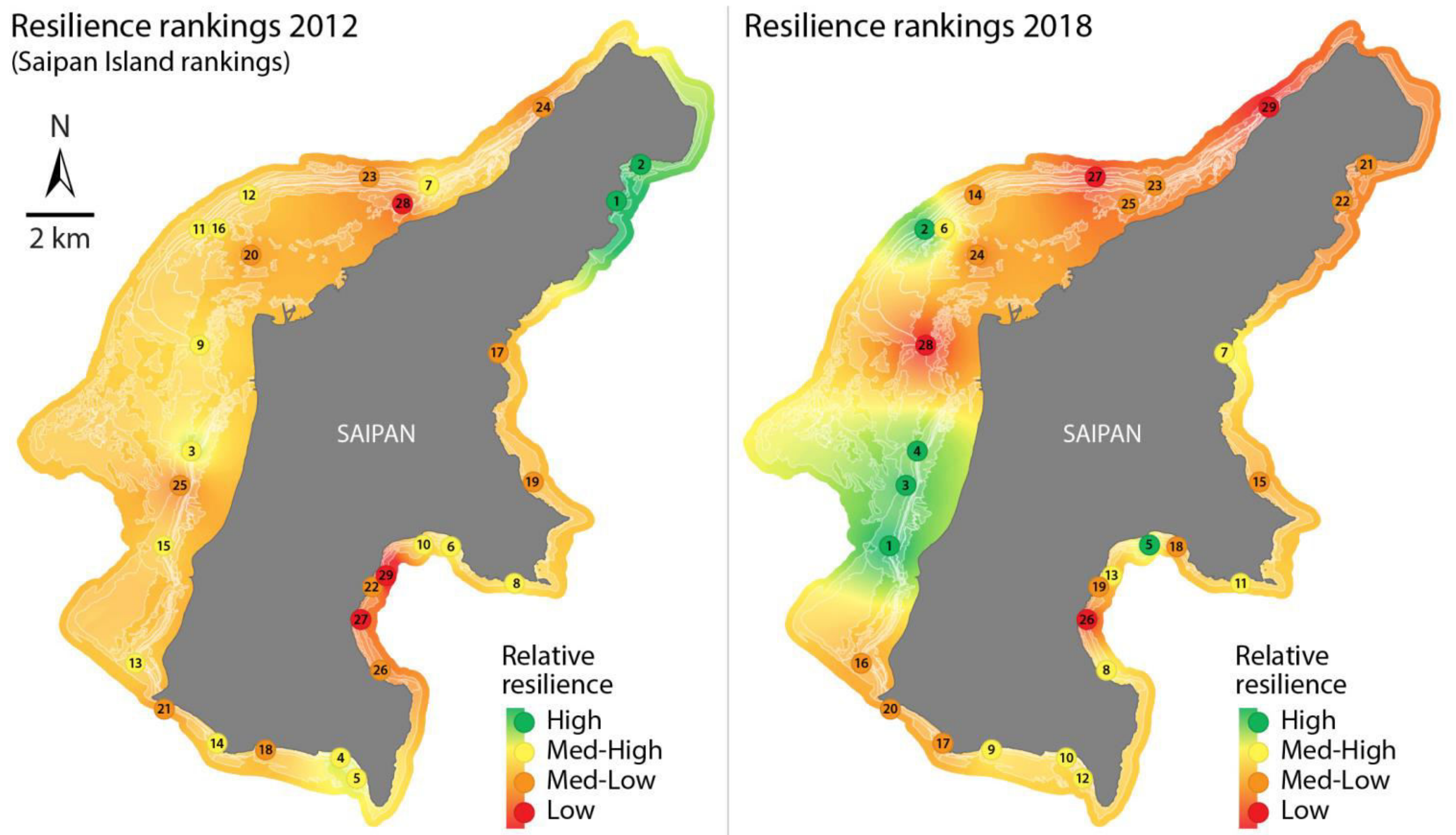
Comparing the 2018 and 2012 resilience assessment results

We found that resilience rankings were similar (within 10 ranking points) for 18 of the 29 survey sites when comparing our 2018 results with 2012 results (Figure 12). There were changes in ranking order that exceeded 10 ranking points at 11 of the 29 survey sites. Six of these changes were sites with lower relative resilience in 2012 that had higher relative resilience in 2018, including: Grand Hotel_MMT (from 15 in 2012 to 1 in 2018), Laolao South (from 26 to 8), Managaha MPA (MMT) (from 16 to 6), Old Man By the Sea (from 17 to 7), Oleai Rocks (from 25 to 3), and Tuturam (from 29 to 13). Five of the changes that exceeded 10 ranking points were sites with higher relative resilience in 2012 that had lower relative resilience in 2018, including: Laolao Bay East (from 6 in 2012 to 18 in 2018), Nanasu Reef (from 1 to 22), Pau Pau (from 7 to 23), and Peysonnelia Reef (from 9 to 28, see Figure 12).

The range in raw values for resilience scores in 2012 was 0.3 and the range in 2018 was 0.24. This means that sites were more different from each other in 2012 than was the case in 2018. That reefs were more similar in 2018 is a critically important result, and reflects that nearly all reefs suffered significant coral mortality due to bleaching, and that nearly all reefs have far higher levels of macroalgae cover than was the case in 2012. Reefs were only just beginning to recover during the 2018 surveys and will continue to differentiate as they recover, depending on future disturbance frequencies. A key take-away from the 2012 to 2018 comparisons, much more important than any rank change at any individual site, is that there was a far clearer distinction between the low and high resilience sites in 2018 than in 2012.

Resilience is the capacity to resist and recover from disturbances. The 2018 resilience assessment results were largely driven by differences in impact resistance. Given the recent history of severe disturbance and recovery just prior to the 2018 surveys, coral reef sites had little to no time to recover by the time our team completed surveys in May of 2018. In contrast, the 2012 resilience assessment results were likely largely driven by differences in recovery potential as sites had time to recover from disturbance events that occurred in the preceding 5-10 years.

In 2012, high resilience sites had a mix of all relative classes (low to high) for scores for indicators as did low resilience sites – this indicates high resilience sites were not very different from med-high resilience sites, and low resilience sites were not very different from med-low resilience sites. In statistics, this is referred to as the data having a more central distribution (picture a bell curve with a wider peak with short tails). In ecological terms, this means that sites became more and more like one another as they recovered from disturbances in the 5-10 years that preceded 2012. In 2018, there were 5 high resilience sites and 4 low resilience sites and these were distinctly different (to continue the statistics explanation, picture a bell curve with a narrower peak and longer and taller tails). High resilience sites had high or med-high coral recruitment and herbivore biomass and relatively low macroalgae cover. Low resilience sites had low or med-low coral recruitment and herbivore biomass and relatively high macroalgae cover. These are signs that sites with high resilience in 2018 may recover more quickly than sites with low resilience; whether this is true will be discernible over the coming 3-5 years if we can avoid additional disturbance events (which seems unlikely with bleaching now occurring biannually in the region) .

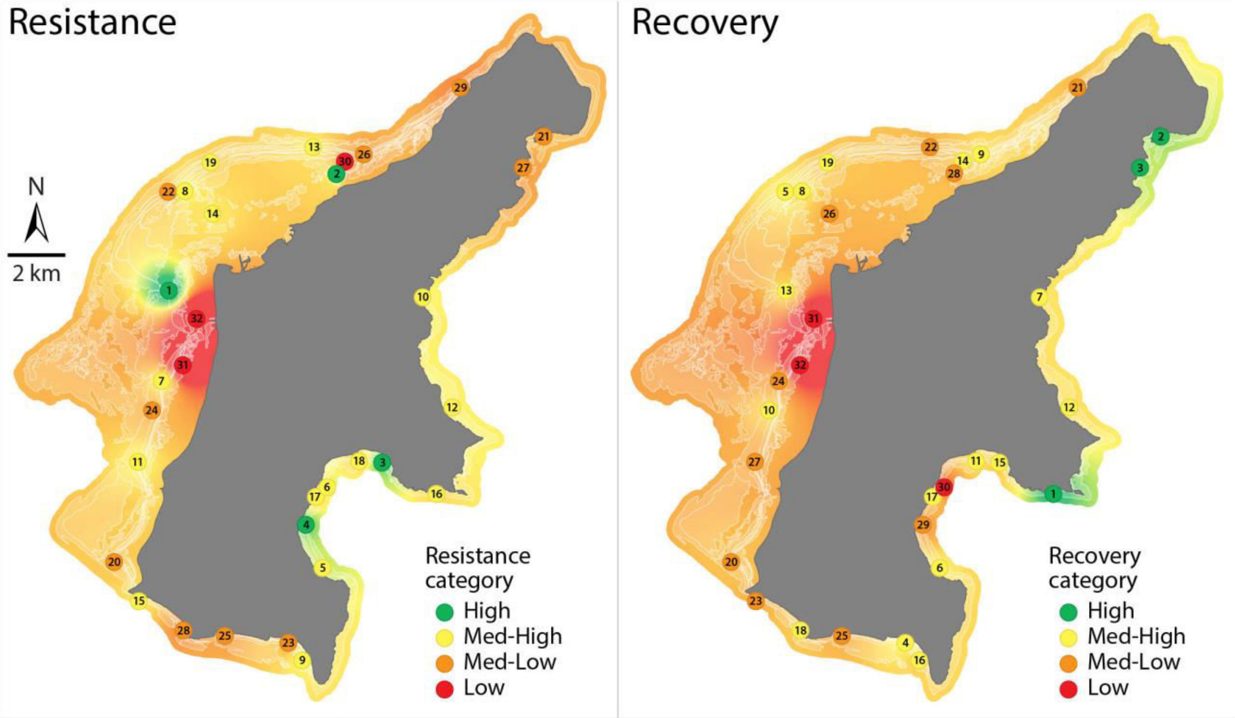


[1\22] Nanasu Reef
[2\21] Bird Island
[3\4] Lighthouse Reef
[4\10] Obyan Beach
[5\12] Boy Scout
[6\18] Laolao Bay East
[7\23] Pau Pau
[8\11] Forbidden Island
[9\28] Peysonnelia Reef
[10\5] Laolao Bay Mids
[11\2] Lanyas
[12\14] Elbow Reef
[13\16] Point Break Reef
[14\17] Coral Ocean Point
[15\1] Grand Hotel (MMT)
[16\6] Managaha MPA (MMT)
[17\7] Old Man By the Sea
[18\9] Ladder Beach
[19\15] Tank Beach
[20\24] Managaha Patch (MMT)
[21\20] Agingan Point
[22\19] North Dakota
[23\27] Achu Dangkulu
[24\29] Wing Beach
[25\3] Oleai Rocks
[26\8] LaoLao South
[27\26] South Dakota
[28\25] Achugao
[29\13] Tuturam

Figure 12. 2012 and 2018 resilience rankings based on surveys in May and June of 2012 and May of 2018. 2012 rankings were published in CRCPTM22 and Maynard et al. 2015 in *Biological Conservation.* IDW interpolation is used to estimate relative resilience for reef areas not surveyed. Numbers shown in brackets next to site names are 2012 rank and then 2018 rank. Color codes are as follows: high – green (>avg+1 stdev [avg=average, stdev = standard deviation]), med-high – yellow (<avg+1 stdev and >avg), med-low – orange (<avg and >avg-1stdev), low – red (<avg-1stdev).

Assessing resistance and recovery separately

Our team re-analyzed resilience using the 2018 survey data following separating resilience indicators into those that confer resistance (bleaching resistance) and those that indicate recovery capacity (coral recruitment, coral diversity, macroalgae cover, and herbivore biomass). Coral species differ less in the capacity to resist thermal stress as thermal stress increases; with sufficient thermal stress, all coral species will bleach. Given this, recovery capacity is likely the more important driver of differences among sites in likely resilience to climate change. The maps in Figure 13 show the results of separating resistance and recovery indicators and then normalizing, summing to create an aggregate score, and re-normalizing to compare sites (following the methods for the resilience assessment results presented in Figure 4.). These maps show greatest recovery potential within the marine protected areas by Forbidden Island, Bird Island and Nanasu Reef (see 1, 2 and 3 on Recovery map), which were among the high and med-high resilience sites in the 2012 analysis.



1 – Peysonnelia Reef [13]
2 – Tanapag Staghorn [28]
3 – LaoLao Bay East [15]
4 – South Dakota [29]
5 – LaoLao Bay South [6]
6 – Tuturam [30]
7 – Lighthouse Reef [24]
8 – Managaha MPA (MMT) [8]
9 – Boy Scout [16]
10 – Old Man by the Sea [7]
11 – Grand Hotel (MMT) [27]
12 – Tank Beach [12]
13 – Achu Dangkulu [22]
14 – Managaha Patch (MMT) [26]
15 – Agingan Point [23]
16 – Forbidden Island [1]
17 – North Dakota [17]
18 – LaoLao Bay Mids [11]
19 – Elbow Reef [19]
20 – Point Break Reef [20]
21 – Bird Island [2]
22 – Lanyas [5]
23 – Obyan Beach [4]
24 – Oleai Rocks [10]
25 – Ladder Beach [25]
26 – Pau Pau [9]
27 – Nanasu Reef [3]
28 – Coral Ocean Point [18]
29 – Wing Beach [21]
30 – Achugao [14]
31 – Quartermaster Staghorn [32]
32 – Fishing Base Staghorn [31]

Figure 13. 2012 and 2018 resilience rankings based on surveys in May and June of 2012 and May of 2018. 2012 rankings were published in CRCPTM22 and Maynard et al. 2015 in *Biological Conservation.* IDW interpolation is used to estimate relative resilience for reef areas not surveyed. Numbers shown in brackets next to site names are 2012 rank and then 2018 rank. Color codes are as follows: high – green (>avg+1 stdev [avg=average, stdev = standard deviation]), med-high – yellow (<avg+1 stdev and >avg), med-low – orange (<avg and >avg-1stdev), low – red (<avg-1stdev).

Objective 4 - Develop resilience-based management recommendations that account for spatial variation in resilience and the distribution of ESA-listed corals.

The 2018 resilience assessment results indicate demonstrated differences among sites in the capacity to resist disturbance. Sites were only just starting to recover when surveyed so the resilience scores are unlikely to be a good indication of differences among sites in recovery capacity – further surveys will be required in the coming years to assess recovery. These 2018 surveys provide the most up-to-date information available on differences among reef sites in Saipan in resilience. Resilience can and should be an important consideration in making management decisions; management actions are likely to have a greater long-term effect on ecosystem condition and service provisioning if implemented at sites with greater relative resilience.

Our team developed seven sets of criteria for using the resilience assessment and our field survey results to inform or target management actions. These match the sets of criteria used in 2012, but now include Reef Restoration, the presence of ESA-listed coral species *Acropora globiceps*, and a more rigorous assessment of land-based sources of pollution (see Figure 14). The sets of criteria we developed to inform or target management actions are shown within Table 4, with the numbers of sites (out of our 29 survey sites) that met the criteria, and examples of relevant management actions. The sites that met the various criteria are then shown in Figure 15. A total of 9 out of 29 sites met one of the sets of criteria – 12 met more than one of the criteria sets. A total of 8 out of 29 sites did not meet any of the criteria but may warrant management action for a great range and large number of other reasons not accounted for within our criteria sets.

Table 4. Criteria established to use resilience assessment and field survey results from May, 2018 in Saipan, CNMI to inform or target management actions. Locations of sites that met and did not meet the various criteria sets are shown in Figure 13.

Informing or targeting management action	Criteria (*n* of 29)	Relevant management actions
Priority **C**onservation Areas	Above average resilience potential and are currently outside established no-take MPAs (11)	Any of the actions described below (as appropriate)
ESA-listed coral species	ESA-listed coral species *Acropora globiceps* was observed at the site (9).	Ensure ESA guidelines/restrictions are met for all uses and visitation at or near the site.
Reef **R**estoration	Above average resilience potential and med-high or high herbivore biomass and coral cover less than 20% (6)**	Priority coral nursery and transplantation area, artificial reef installation
Land-based sources of pollution reduction	High resilience potential and above average values for land-based sources of pollution (4)	Afforestation, stream bank stabilization, riparian restoration, road and storm drain improvement, other erosion control practices, wetland enhancement and sewage treatment upgrades (reviews in ref)
Fishery access	Above average resilience potential and above average accessibility due to wave exposure (5)	Increased enforcement, marine protected areas[1], temporary closures[1], LMMAs, size regulations and bag and catch limits, moorings and no-anchoring areas, fish stocking, marine debris removal
Bleaching vulnerability	Low or med-low bleaching resistance and low or med-low herbivore biomass (2)	Increased monitoring during warm seasons, shading or other cooling measures, supporting recovery processes using place-based management
High **T**ourism potential	Above average coral diversity and above average coral cover and high fish biomass and above average accessibility due to wave exposure (0*) *This criteria is not shown on the map in Figure 13.	Establish moorings, undertake targeted outreach, develop stewardship and/or citizen science programs, marine debris removal

1 – there are no current plans in CNMI for adding marine protected areas or temporary closures.

***This criteria for Restoration was developed to get the conversation started locally in CNMI on using data like these to develop maps that can be used to target restoration efforts. Other potential criteria include sites with lower relative resilience that have thermally tolerant corals as these may not recover without restoration but provide important ecosystem services, such as fisheries habitat and coastal protection. Numerous NOAA projects are in the pipeline over the coming years to establish guidelines/criteria for parent colony harvesting and for coral colony outplanting. Development of these criteria were out of the scope of this current project and will need to include much data and information not collected during this such as spatial variation around Saipan in the economic and cultural value of coral reefs.*

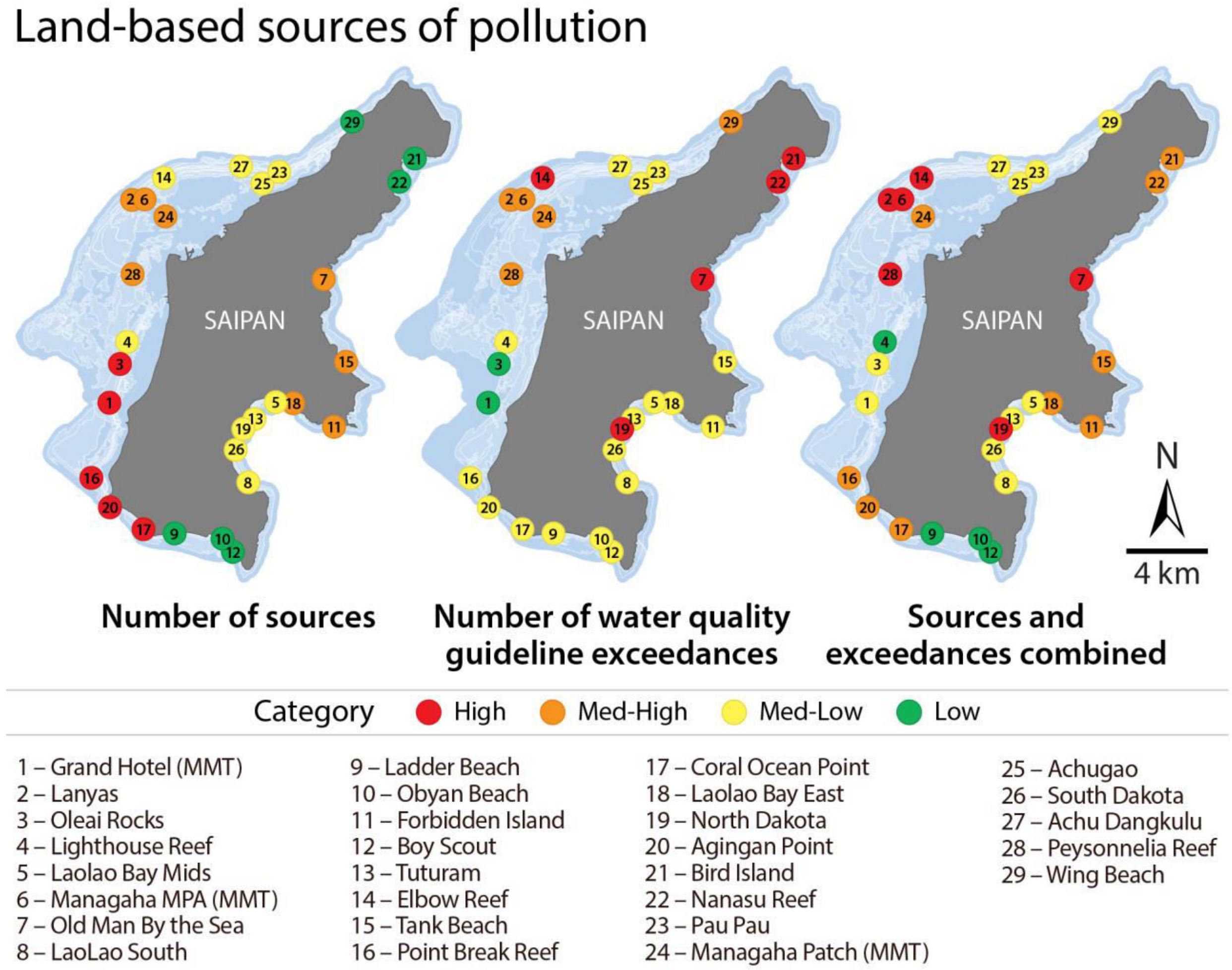


Figure 14. Data on land-based sources of pollution for each survey site including the number of sources and the number of water quality guideline exceedances from *Total Maximum Daily Loads for Coastal Waters Impaired by Bacteria on Saipan*, submitted to the US-EPA by Paradigm Environmental. Color codes are as follows: high – green (>avg+1 stdev [avg=average, stdev = standard deviation]), med-high – yellow (<avg+1 stdev and >avg), med-low – orange (<avg and >avg-1stdev), low – red (<avg-1stdev).

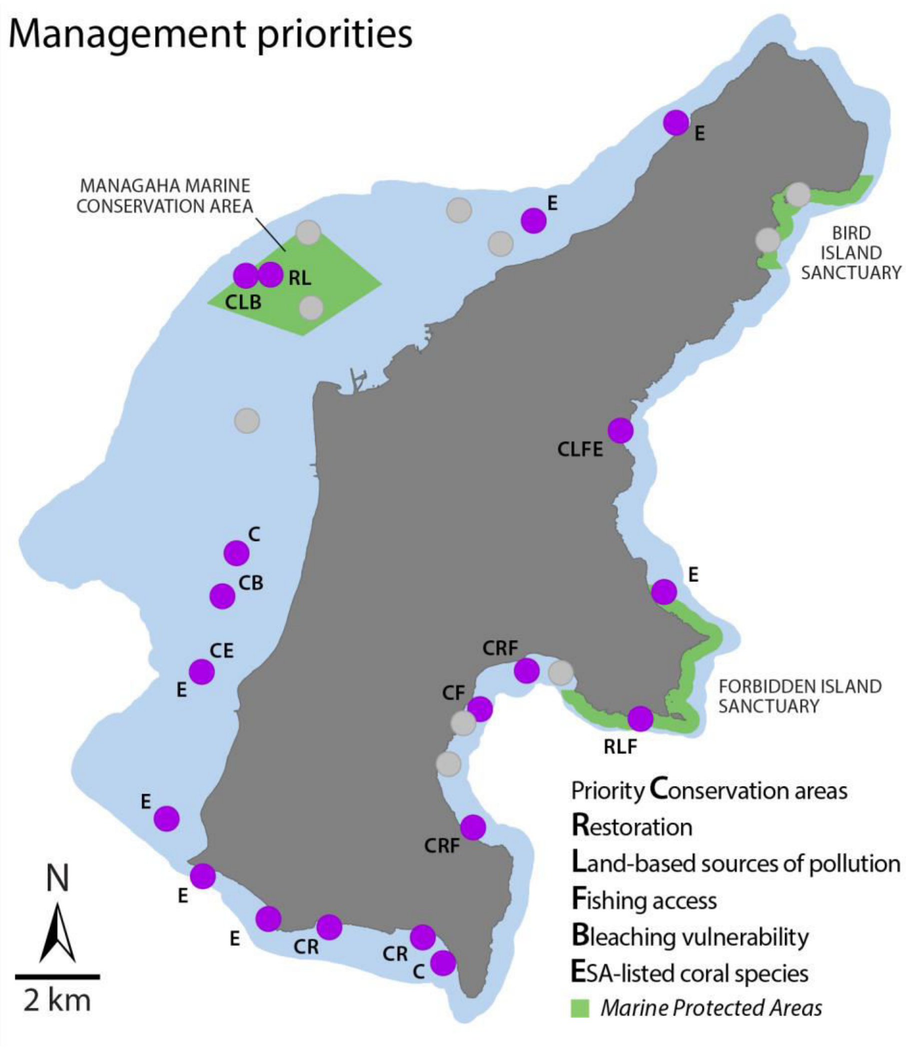


Figure 15. Locations of sites that met the various sets of criteria for informing or targeting management actions.

Coral reef condition versus resilience

Coral reef resilience is the capacity to resist and recover from disturbances, while maintaining provision of essential services. As assessed here, relative resilience is a combination of scores for six indicators of the capacity to resist or recover. The resilience index we developed and presented based on our 2018 survey data is not an indicator of spatial variation in coral reef *condition.* An aggregate index for condition was not developed as part of this project but could be with project data by combining indicators of status/condition, such as coral cover and total fish biomass. It is important to ensure resilience is not interpreted as condition and vice versa. A map of 2018 coral cover is provided below as Figure 14, to aid readers in understanding reef condition in Saipan during time of surveys in May, 2018. Super Typhoon Yutu may have impacted the coral reef habitats around Saipan just months after our surveys were completed; the coral cover data presented may not represent coral cover around Saipan at time of posting of this report to the NOAA CoRIS website. The data collected during these surveys provide excellent pre-Yutu baselines.

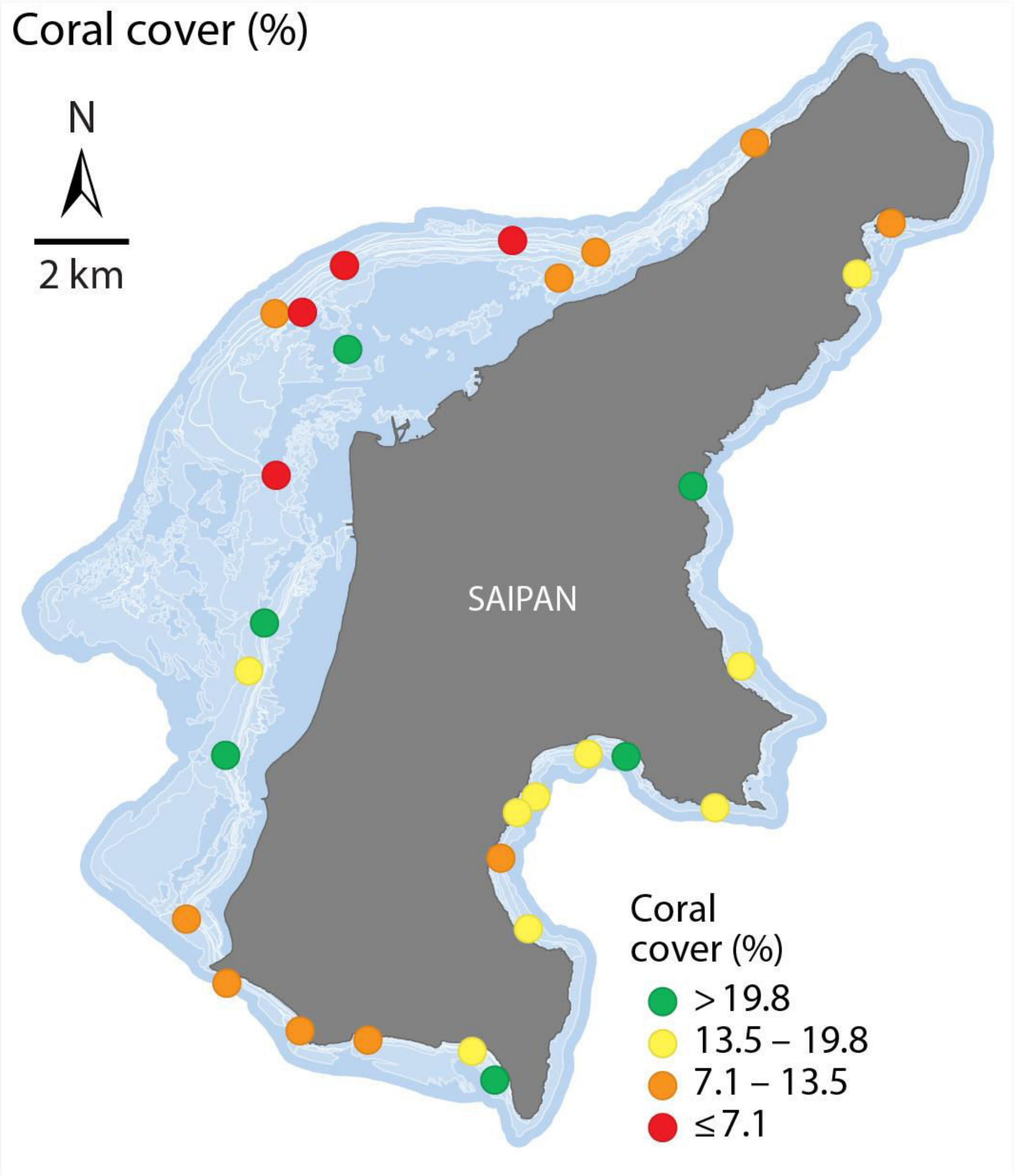


Figure 14. Coral cover at time of surveys in May, 2018 at forereef sites in Saipan, CNMI.

Management Applications and Next Steps

At time of reporting, our team was just starting the years-long process of sharing these results among reef and fisheries managers working in CNMI. Over the coming months and years, the results will continue to be shared and discussed, and then incorporated within management planning and decision-making.

Specifically, data and results from this project will be used for regulation, in keeping with NEPA, ESA, EFH, USACE Permits, and BECQ APC consultations. Other management applications include the large range of actions presented within Table 4 (the most topical being Restoration and LBSP reduction), the development of management plans, development of new reef regional priority guidance documents, and the refinement of fisheries management plans.

The results of this project will be included within a 2019 NOAA Science Seminar on assessing coral reef vulnerability to climate change.

Developing a coral reef condition metric for Saipan, described in the section just above, represents a potential next step. The project team has also identified another potential high-impact follow-up studies:

> Managers in CNMI may greatly expand upon the criteria shown within Table 4 and Figure 13 for Reef Restoration, which is and will increasingly be a priority in CNMI and other regions if/when reefs are severely impacted by disturbances. We presented just one way of using our field survey and resilience assessment results to identify potential restoration targets – others include: using coral diversity and cover information for species of interest to identify appropriate sites for the collection of corals and coral fragments to grow in future nurseries, and developing a range of ways to identify where to transplant nursery-grown corals that include, as examples, access, economic and cultural value, anthropogenic stress, and connectivity. The NFWF Emergency Coastal Resilience Fund (ECRF) 2019 has funds earmarked for coastal communities impacted by Typhoon Yutu. The Fund's second priority is to Address Barriers to Coastal Resilience and example projects NFWF mentions include: conducting rigorous evaluations of potential project sites, assessing alternatives for restoration and protection activities, determining site-specific characteristics that influence project and activity success, assessing potential improvements in risk reduction, applying existing decision-support tools to inform project design and site selection, and conducting cost-benefit analyses. In the months that follow finalization of this grant report, this project team will submit a grant to the NFWF ECRF 2019 to rigorously assess and compare restoration need and likely success among coral reef sites in Saipan, CNMI.

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Appendix

Table S1. Geographic coordinates of forereef survey sites on the fringing reefs near the islands of Saipan (surveys 2012, 2014 and 2018), Tinian/Aguijan (2014), and Rota (2014). Bracketed numbers refer to resilience rankings from the inter-island analysis to aid in finding site locations within Figure 1.

Site Name	Island Name	Lat (°N)	Lon (°E)
Achu Dangkulu [50]	Saipan	15.26	145.75
Achugao [56]	Saipan	15.25	145.75
Agingan Point [43]	Saipan	15.12	145.69
Bird Island [2]	Saipan	15.26	145.82
Boy Scout [6]	Saipan	15.10	145.74
Coral Ocean Point [20]	Saipan	15.11	145.71
Elbow Reef [21]	Saipan	15.25	145.71
Forbidden Island [13]	Saipan	15.15	145.78
Grand Hotel_MMT [24]	Saipan	15.16	145.69
Ladder Beach [28]	Saipan	15.11	145.72
Lanyas [18]	Saipan	15.24	145.70
Laolao Bay East [11]	Saipan	15.16	145.77
Laolao Bay Mids [17]	Saipan	15.16	145.76
Lighthouse Reef [4]	Saipan	15.18	145.70
Managaha Patch_MMT [38]	Saipan	15.24	145.72
Managaha_MMT [27]	Saipan	15.24	145.71
Nanasu Reef [1]	Saipan	15.25	145.81
North Dakota [42]	Saipan	15.15	145.75
Obyan Beach [3]	Saipan	15.10	145.74
Old Man By the Sea [32]	Saipan	15.21	145.78
Oleai Rocks [52]	Saipan	15.18	145.70
Pau Pau [9]	Saipan	15.25	145.76
Peysonnelia Reef [19]	Saipan	15.21	145.70
Point Break Reef [22]	Saipan	15.13	145.69
South Dakota [61]	Saipan	15.14	145.74
South Laolao [57]	Saipan	15.13	145.75
Tank Beach [33]	Saipan	15.18	145.79
Tuturam [76]	Saipan	15.15	145.75
Wing Beach [46]	Saipan	15.27	145.79
Asiga Point [30]	Tinian	15.06	145.66
Atgidon [62]	Tinian	15.01	145.59
Barangka [29]	Tinian	14.98	145.66
Barcinas Bay_MMT [66]	Tinian	14.99	145.61
Dynasty_MMT [34]	Tinian	14.96	145.63
Lamanibot [15]	Tinian	15.04	145.59
Leprosarium [74]	Tinian	14.98	145.61
Long Beach_MMT [41]	Tinian	15.03	145.65
Masilok Beach Wall [55]	Tinian	15.02	145.66
P. Lamanibot Sampapa [59]	Tinian	15.03	145.59
P. Lamanibot Sanhilo [54]	Tinian	15.06	145.60
Puntan Diapblo [77]	Tinian	14.99	145.59
Puntan Kastiyu [37]	Tinian	14.95	145.67
South Point_MMT [65]	Tinian	14.94	145.63
Suicide Cliff [26]	Tinian	14.94	145.65
Tahgong Point [12]	Tinian	15.10	145.64
Unai Asiga [40]	Tinian	15.04	145.65
Unai Babui_MMT [10]	Tinian	15.08	145.62
Unai Chulu 23]	Tinian	15.07	145.61
Unai Lamlam [36]	Tinian	15.09	145.63
Unai Masilok [7]	Tinian	15.02	145.66
Aguijan Island_MMT [25]	Aguijan	14.85	145.54
East Aguijan Falls [5]	Aguijan	14.85	145.58
Happy Days [44]	Aguijan	14.84	145.56
Naftan Rock [35]	Aguijan	14.83	145.53
Agatasi [31]	Rota	14.12	145.22
As Dudo_MMT [8]	Rota	14.17	145.29
Cave Museum_MMT [69]	Rota	14.16	145.15
Coconut Village [51]	Rota	14.18	145.20
Coral Gardens_MMT [49]	Rota	14.12	145.17
East Wedding Cake [39]	Rota	14.13	145.14
Haina Point [14]	Rota	14.13	145.23
Harnom Point [68]	Rota	14.12	145.12
Honey Gardens [60]	Rota	14.13	145.17
Iota Salvage_MMT [58]	Rota	14.17	145.18
Joanne's Reef [72]	Rota	14.14	145.15
Malilok Point [64]	Rota	14.12	145.21
Mochong [47]	Rota	14.20	145.26
Okgok_MMT [63]	Rota	14.11	145.19
Rota Resort_MMT [75]	Rota	14.19	145.22
Sailigai Point [78]	Rota	14.17	145.16
Sasanhaya_MMT [48]	Rota	14.14	145.14
Senhanom Wall [45]	Rota	14.12	145.12
South I Ch. Park [73]	Rota	14.15	145.26
Sunset Villa_MMT [53]	Rota	14.17	145.17
Takta Sagua [70]	Rota	14.13	145.16
Talakhaya_MMT [71]	Rota	14.11	145.20
Teteto [67]	Rota	14.18	145.19
West Harbor_MMT [16]	Rota	14.14	145.13