Long-Term Marine Monitoring Program
Final Report: NA13NOS4820010

Award period:
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SUMMARY

Despite multiple transfers of personnel within the monitoring program throughout this award period, the marine monitoring team (MMT) continues to collect ecological data for the CNMI. During this reporting period the MMT managed to conduct 59 biological surveys at 52 long-term monitoring sites across Saipan, Tinian, Aguigan, and Rota (Table1). Standardized surveys collect data on coral, fish, algae, non-coral macroinvertebrate, and seagrass assemblages across the various marine habitats and management areas of the CNMI, including marine protected areas, species reserves, and priority watersheds. In addition to the standard long-term monitoring efforts, the MMT has conducted over 100 additional surveys in support of related projects including a study on coral reef resilience, , and participated in three expeditions to the remote northern islands. Finally, with the increase of development in the CNMI, the data collected by this program is an essential baseline to monitor the effects these activities have on our marine resources.

In this report we briefly summarize size-class diversity, abundance and biomass data for coral, algae, benthic and fish measures collected throughout the CNMI. We also present current data at three of the CNMI's priority watersheds; Talakhaya, Laolao, and Garapan. The data collected and analyzed by the MMT provides crucial information on the environmental and anthropogenic causes of reef decline, the factors contributing to reef resilience and vulnerability, and the effectiveness of these management activities. This information then feeds back to support adaptive management strategies, in hopes of improving these watersheds.

INTRODUCTION

The MMT is truly a product of multiple agencies leveraging capacity, to achieve the goal of providing marine resource information to local managers for proper decision making. In 1980, the Division of Coastal Resources Management (DCRM) took initial steps towards documenting reef state by conducting site based ecological surveys in the CNMI. The MMT was initially created by the Division of Environmental Quality (DEQ) in 1997, in response to a large land clearing event at Laulau Bay. In 2001, the current program goals were defined through a partnership among DCRM, DEQ, and the Division of Fish and Wildlife (DFW). A formal long-term monitoring plan was developed in 2008, which outlined the program goals, methods, data handling, and other logistics (Houk and Starmer 2008). In 2014, CRMO and DEQ merged to form the Bureau of Environmental and Coastal Quality (BECQ). Currently, the marine monitoring team (MMT) consists primarily of BECQ staff, with periodic support from DFW, local NGOs, the local NOAA field office, and faculty and students from the Northern Marianas College and the University of Guam.

The overarching goals of the program are to gain a better understanding of how and why marine resources are spatially distributed across the CNMI, what their current status is, how they change through time, and how they are affected by natural and human disturbances and management actions. This information then feeds back to support sound management and policy decisions that promote sustainable development and the conservation of natural resources and environmental integrity.

Over the last decade, the MMT has mapped and characterized nearshore coral reef and lagoon habitats across the CNMI (Houk and van Woesik, 2008; Houk and van Woesik, 2010; Houk and Camacho, 2010) and collected baseline data on coral, macro-invertebrate, fish, algae, and seagrass assemblages, with respect to natural environmental regimes. This foundation provides a basis for partitioning out natural variance in order to effectively evaluate the influences of local (land-based sources of pollution, fishing, etc.) and global (i.e. climate change) stressors and management actions on coral reef health and resilience. For instance, the data generated from this program have been used to evaluate the interactive effects of watershed pollution and natural disturbance cycles on the integrity of seagrass beds across Saipan lagoon (Houk and Camacho 2010). Building upon this study, the integrity of seagrass habitats across the entire Saipan lagoon was evaluated and ranked. These rankings continue to be used for prioritizing watershed management planning needs. Another recently published study, based on twelve years of monitoring data, examined differential disturbance and recovery dynamics across gradients of localized stressors and reef types in the CNMI (Houk et al. 2014; see below). Data gathered and analyzed by the monitoring program are consistently utilized in the planning and implementation of management goals and projects, including the identification and development of conservation action plans (CAPs) for the three priority watersheds in the CNMI. The MMT continues to work closely with the non-point-source pollution and water quality programs to identify areas of concern and evaluate the efficacy of management actions.

The current objectives of the long-term monitoring program are to,

1. Continue to fill gaps in monitoring coverage, including implementing climate change associated sites and parameters.
2. Continue to monitor changes in biological communities through time with respect to natural and human influences, including climate change.
3. Where natural disturbances are noted, examine recovery trends with respect to localized stressors (fish abundances and watershed pollution).
4. Examine the efficacy of management measures such as watershed improvement projects and marine protected areas.
5. Use datasets to prioritize where new management actions will be most effective
6. Harness the quantitative relationships to develop a predictive future under varying scenarios of management and climate change.

Here, we report on the activities and progress of the marine monitoring team during the 2013-2015 award period. We briefly describe the methodology employed, including site selection, survey protocols, and database management. We then report on sites surveyed, general trends, recent and ongoing analyses of monitoring data, as well as other MMT activities and projects that occurred during the award period. We summarize the observed ecosystem trends at sites associated with the three priority watersheds and report on other related projects that have been conducted within the reporting period. All outcomes and products are reported, and lastly, obstacles and delays are discussed.

METHODS

Overview

Currently, over 50 long-term monitoring sites across Saipan, Tinian, Aguijan (Goat Island), and Rota are surveyed on a rotating biennial basis. Two broad habitat types are represented: fore reef and lagoon. Fore reef sites are stratified by exposure to wind and waves, as well as geomorphological reef type. While the Saipan lagoon contains 19 unique ecological habitats (Houk and van Woesik, 2008), monitoring is focused on staghorn *Acropora* thickets and *Halodule* seagrass beds. Most sites within habitat types have been selected based on their association with management concerns (e.g. runoff, sewage outfalls, urban development, etc.) and/or management actions (e.g. watershed restorations efforts, marine protected areas, etc.) and include impacted sites and relatively non-impacted reference sites where possible.

All surveys are conducted along 50 meter transect lines laid out along the depth contour (7-9 m depth) on the fore reef, and across homogeneous habitat in the lagoon. Three to five replicate transects are surveyed per site, depending on the availability of homogenous habitat. While benthic cover analysis provides the foundation of the CNMI monitoring program, the current protocol uses several survey types per site to provide ecological depth beyond percent cover. Surveys methods have not changed since the last award period, so they will only be briefly described here.

Fore reef methods

Photos are taken every meter along each transect line using a 0.25m^2 quadrat frame, for a total of 250 photos at each site. Back at the office, the computer program CPCe4.1 is used to place five random points on each photo and the biota or substrate type under each point is identified. Organisms are identified to the genus level, whenever possible. This analysis provides percent cover of major benthic categories and community diversity. Twelve stationary point counts (SPC) are conducted at each site to evaluate fish assemblages. Each SPC is systematically positioned throughout the length of the site (250 m). The species and size (fork length) of all food fishes within a 5-meter radius are recorded in a three-minute period. Sixteen 0.25m^2 quadrats are haphazardly tossed along the length of the site and every coral colony within the quadrats is identified to the species level and measured. This method provides relative diversity, abundances, and size class of the coral community. Within these same quadrats all algae species present are identified to the species level to provide a measure of algae community composition and species richness. Finally, non-coral macro-invertebrates including sea cucumbers, urchins, crown-of-thorns seastars (COTS), giant clams, among others, are identified and counted within 1 m of each side of the transect lines (i.e. 5, 2m x50m belt transects).

Saipan lagoon methods

At lagoon sites, benthic cover is quantified using a 0.25 m^2 string quadrat with six intersections, placed every meter along the transect line. The biota or substrate under each intersection is recorded to the genus level, *in situ*. Additionally, ten, 1 m^2 quads are haphazardly placed across the length of the site (250 m) and all seagrass, algae, coral, and macro-invertebrates are identified to the species level and recorded. This method captures the relative diversity and abundances of lagoon communities. Additionally, select non-coral macro-invertebrates within 2m x 50m belt transects are identified and counted as described above.

Data management

Data are entered into Microsoft Excel® spreadsheets by the individual observer that collected the data in the field. Separate workbooks exist for each survey protocol. Validation mechanisms, such as drop down menus that only allow appropriate names and values are in place within the Excel environment. Further quality assurance & quality control (QA/QC) checks are conducted by the observer prior to uploading data into the master database files. All data are stored on the BECQ server. Excel spreadsheets have provided the monitoring program with an intuitive, inexpensive, and efficient means to store, query, and subset data for use. However, as the monitoring program and associated datasets grow and become more complex, Excel may become limiting. DEQ technical biologist, Dr. Lyza Johnston, is currently working to migrate the monitoring data into an Access database. This migration will allow improvements in QA/QC procedures as well as querying and reporting capacity, while maintaining database integrity as it grows in size and complexity. Data are analyzed using a variety of uni- and multivariate software platforms, including Canoco, Primer/Permanova, R, and Sigmaplot.

Spatial and other metadata data are also available to the public through DCRM's newly launched ArcGIS data portal, which can be found at:

http://www.arcgis.com/home/item.html?id=0c6fa047b5264b408285aa2b11b0b0cd

ACTIVITIES AND PROGRESS

Sites surveyed

During the current award period, ranging from October 1, 2013, to September 30, 2015, MMT conducted 59 biological surveys at 52 long-term monitoring sites across Saipan, Tinian, Aguigan, and Rota (Table 1).

Table 1 Checklist of permanent fore reef and lagoon sites surveyed through time across Saipan, Tinian, Aguigan, and Rota. Sites surveyed during the current award period are highlighted in yellow.

Site	Habitat	Island	GPS X	GPS Y	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
13 Fish Deep Coral Zone	Lagoon	Saipan	361726	1680517							x											
13 Fish Halodule (near shore)	Lagoon	Saipan	361905	1680261										x		x			x	x	x	
13 Fish out Halodule	Lagoon	Saipan	361371	1680116							x					x					x	
Achugao Halodule	Lagoon	Saipan	367211	1685984													x		x			
Chalan Laolao Staghorn	Lagoon	Saipan	360700	1678457							x					x				x		
Gold Beach Staghorn/Reef Flat	Lagoon	Saipan	361121	1680014							x					x				x		
Iguel Ranch EN/Mix	Lagoon	Saipan	366790	1685775								x		x		x		x		x		
Iguel Ranch Halodule	Lagoon	Saipan	366867	1685918								x		x				x		x		
Kilili Holodule	Lagoon	Saipan	360767	1676786							x		x	x		x	x		x	x		
Marianas Resort Back Reef	Lagoon	Saipan	369348	1687856								x		x				x		x		
Oleai Staghorn Coral	Lagoon	Saipan	360313	1677514							x		x			x		x	x	x		
Pau Pau Halodule	Lagoon	Saipan	368872	1686929							x					x		x		x		
Pau Pau Staghorn	Lagoon	Saipan	368491	1687287		x					x		x			x		x		x		
Quartermaster Halodule	Lagoon	Saipan	361433	1678869										x				x		x		
Ranch Halodule	Lagoon	Saipan	366867	1685918							x							x				
San Antonio Back Reef	Lagoon	Saipan	359334	1672663								x			x			x		x		
San Antonio Halodule	Lagoon	Saipan	359616	1673610							x							x		x		
San Antonio Rock Halodule	Lagoon	Saipan	359508	1672713								x				x	x	x				
San Roque Halodule	Lagoon	Saipan	368173	1686511							x					x				x		
San Roque Isopora	Lagoon	Saipan	368523	1687119							x		x			x		x		x		
Sugar Dock Halodule	Lagoon	Saipan	360335	1675552			x						x				x		x	x		
Tanapag Halodule	Lagoon	Saipan	365793	1685714							x		x			x		x		x		
Tanapag Staghorn (outside patch)	Lagoon	Saipan	366113	1686010								x	x		x	x		x		x		
Wing Beach Reef flat	Lagoon	Saipan	370284	1688818							x							x				
Hafa Adai South	Lagoon	Saipan	361996	1681649													x		x	x		
Fiesta	Lagoon	Saipan															x		x			
San Roque Acropora beds	Lagoon/Sta	Saipan	366750	1686351	x	x																
Pau Pau Acropora beds	Lagoon/Sta	Saipan	368566	1687310	x	x																
Pump Station	Lagoon/Sta	Saipan	361000	1679671	x	x																
Moylans	Lagoon/Sta	Saipan	361089	1679861	x	x														x		
Quartermaster Staghorn	Lagoon/Sta	Saipan	360835	1678875	x	x												x	x	x		
Dump Line	Lagoon/Sta	Saipan	363464	1683308	x	x																
MVA	Lagoon/Sta	Saipan	360448	1677969	x	x																
Oleai Line	Lagoon/Sta	Saipan	360311	1677518	x	x																
Diamond Hotel Line	Lagoon/Sta	Saipan	360030	1676739	x	x												x				
Fishing Base Line	Lagoon/Sta	Saipan	361466	1681197	x	x										x		x		x		
Achu Dankulu	Outer Reef	Saipan	366598	1686526														x	x			
AGU-1	Outer Reef	Aguigan	346467	1642256				x														
AGU-2	Outer Reef	Aguigan	342807	1642480		x	x										x					
Coral Gardens	Outer Reef	Rota	302280	1561368	x	x		x				x	x		x		x	x		x	x	
Iota South	Outer Reef	Rota	303979	1567839		x		x				x	x					x				
ROT-6	Outer Reef	Rota	300480	1566155						x			x				x		x		x	
Sasanhaya	Outer Reef	Rota	299549	1563712	x	x		x				x	x		x		x		x	x		
Sunset Villa	Outer Reef	Rota	303044	1567386									x					x		x		
Talakhaya	Outer Reef	Rota	305210	1561109	x	x			x	x		x	x		x		x	x	x	x	x	
Rota Resort	Outer Reef	Rota	308740	1570072		x						x					x		x		x	
West Harbor	Outer Reef	Rota	298271	1563772	x		x	x				x					x		x		x	
Ogak	Outer Reef	Rota	304442	1561090									x		x			x		x	x	
Iota North	Outer Reef	Rota	304192	1567872	x	x		x													x	
ROT-1	Outer Reef	Rota	315173	1567076				x									x		x		x	
ROT-2	Outer Reef	Rota	312666	1567076				x														
Bird Island	Outer Reef	Saipan	372724	1687351	x							x			x		x		x		x	
Boy Scout	Outer Reef	Saipan	365076	1669701		x			x	x		x	x		x			x		x	x	
Coral Ocean point	Outer Reef	Saipan	360977	1670710	x	x				x	x	x		x	x		x				x	
Laolao #1	Outer Reef	Saipan	366655	1676452	x		x	x		x	x		x		x		x		x			
Tank Beach	Outer Reef	Saipan	369943	1678305					x						x		x	x				
Akino Reef	Outer Reef	Saipan	359996	1683274	x		x							x					x			
Laolao #2	Outer Reef	Saipan	367312	1676554	x		x		x		x		x	x				x		x		
Managaha MPA	Outer Reef	Saipan	361112	1685496						x		x		x	x			x	x			
Managaha Patch Reef	Outer Reef	Saipan	362045	1684756		x	x					x		x	x		x			x		
Obyan	Outer Reef	Saipan	364462	1670303		x			x	x				x		x	x	x		x		
Outside Garapan	Outer Reef	Saipan	360569	1682142		x		x		x	x			x						x		
Outside Grand	Outer Reef	Saipan	359597	1676410	x	x				x			x	x		x		x				x
Outside Managaha	Outer Reef	Saipan	361046	1685949		x		x			x			x					x			
Wing Beach	Outer Reef	Saipan	370155	1688934		x		x	x	x	x	x			x			x		x		
Barcinas Bay	Outer Reef	Tinian	350028	1657824		x	x		x		x				x		x		x			
South Point	Outer Reef	Tinian	352435	1652286	x		x			x			x		x		x					
Unai Babui	Outer Reef	Tinian	351351	1667541		x			x	x				x								
Dynasty	Outer Reef	Tinian	352490	1653831		x	x			x			x				x		x			
Long Beach	Outer Reef	Tinian	355222	1662018				x		x			x						x			

Status and General Trends

Ecological coral reef data have been collected in the CNMI since 2001 and provides managers a useful tool to visualize coral trends over time and between sites. Analysis of current coral recruit data indicate no significant difference in the density of recruits between Saipan, Tinian, and Rota (Fig. 1). However, between sites, variation in recruit density does exist (Fig.2). On an island scale, coral recruitment on Saipan was greatest for sheltered reefs on the windward side and reefs located within the Managaha marine protected area (Fig. 3). In terms of colony size class distribution Bird Island, had the largest colony sizes among represented sites while, the size distribution at Akino

Reef was the most evenly distributed. For Rota, the density of recruits was the greatest for reefs sheltered from the eastern exposure. In fact coral density was at its lowest at “Rot1”, a long-term monitoring site that is completely exposed to eastern trade-winds. Larger coral colonies likewise, appear to be associated with sheltered reefs on the western and southern exposure. Upon examining species distribution among all sites (Fig. 6), it appears that sites with larger colonies have higher densities of the Genera, *Porites.*

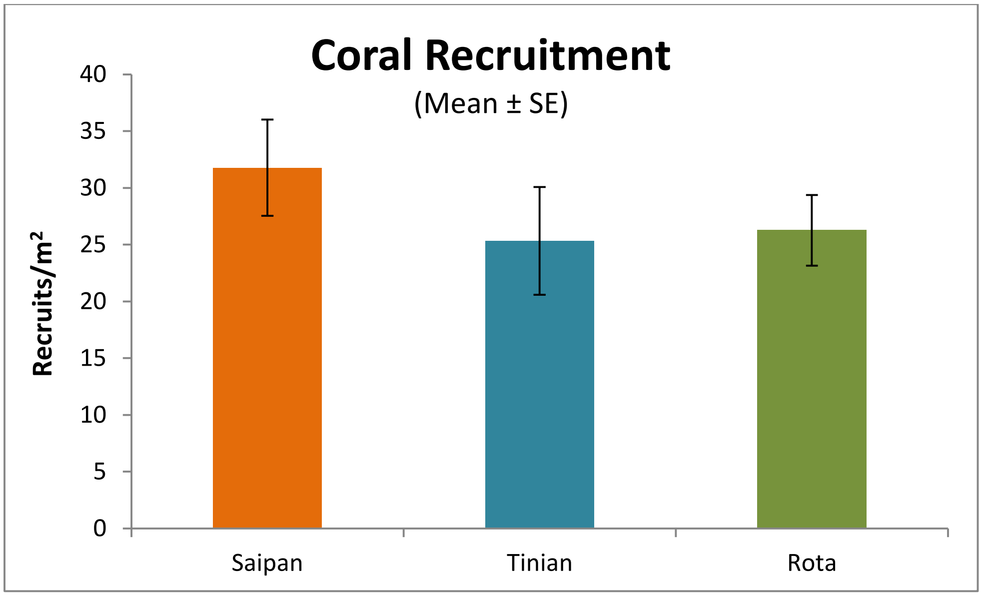

Figure 1 Density of coral recruits, averaged across sites for each island. There was no significant difference in the density of recruits among islands (One-way ANOVA: $F_{2,21} = 0.695$, $p = 0.51$).

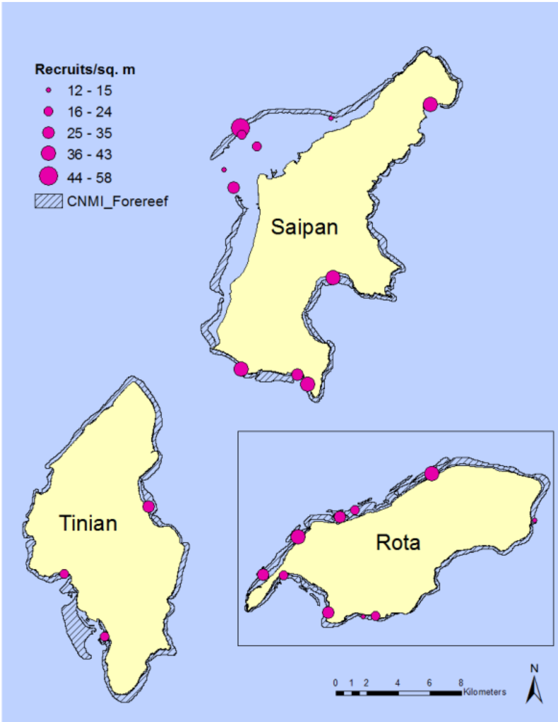

Figure 2 Density of coral recruits. Number of coral colonies < 5 cm maximum dimension per square meter, averaged across quadrats for each site.

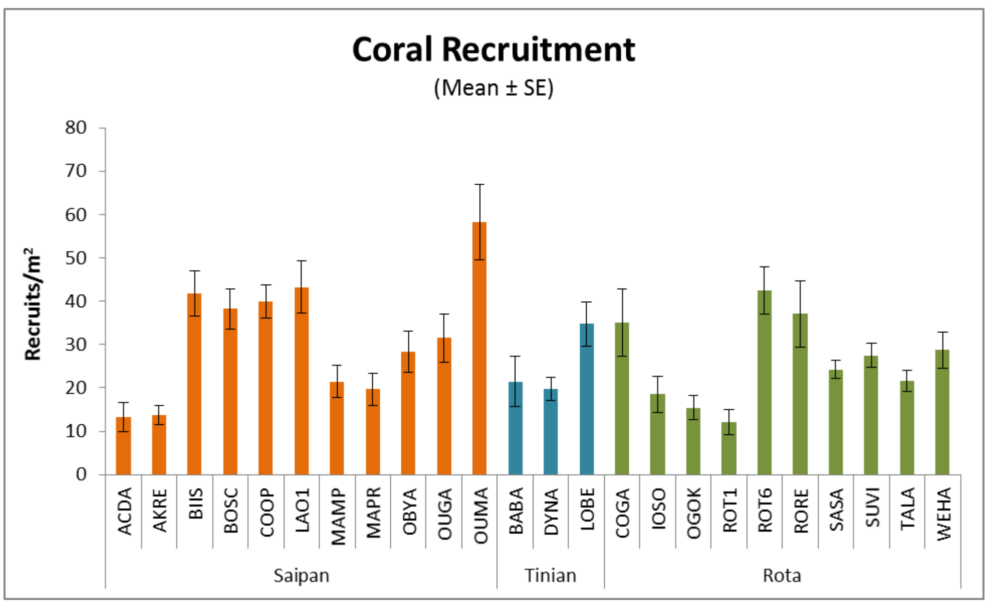

Figure 3 Density of coral recruits. Number of coral colonies < 5 cm maximum dimension per square meter, averaged across quadrats for each site.

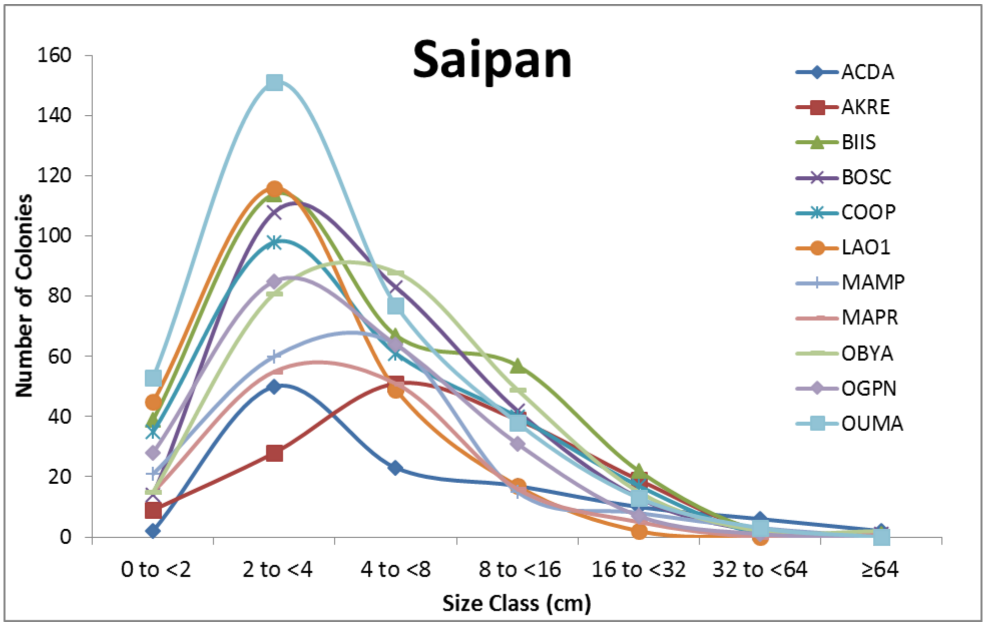

Figure 4 Coral size class distribution for each site on Saipan

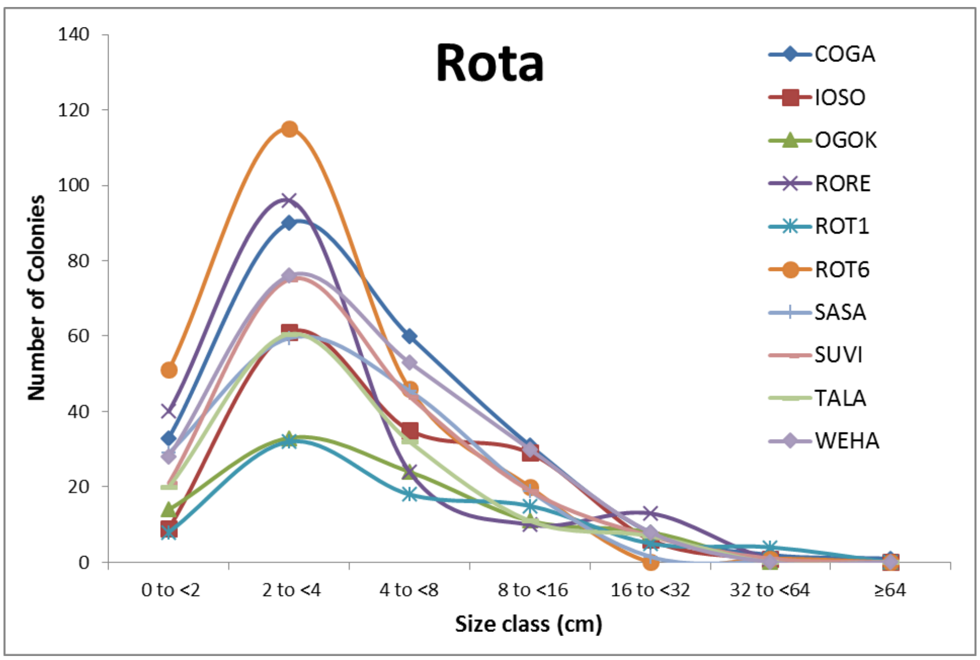

Figure 5 Coral size class distribution for each site and Rota

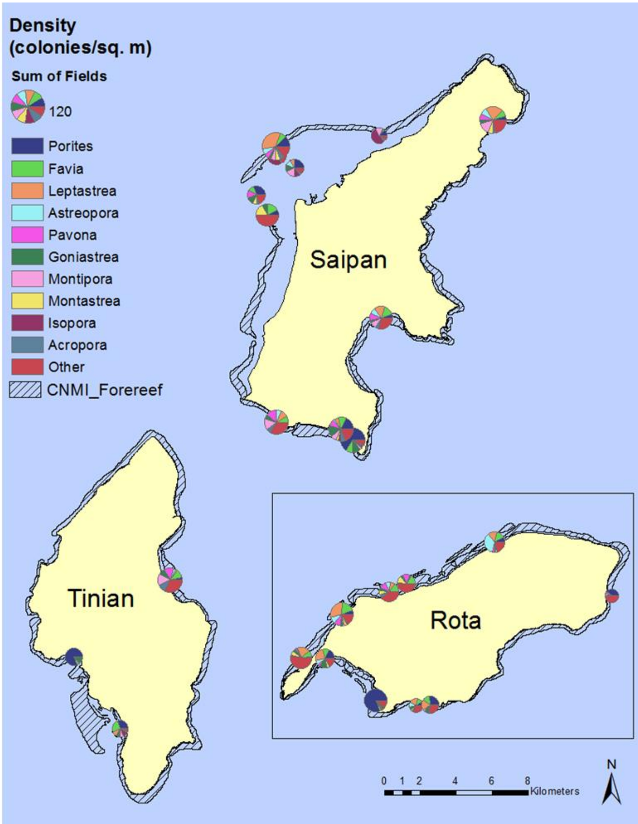

Figure 6 Coral colony density. Number of coral colonies averaged across quadrats for each site. The ten most dominant genera are indicated.

When compared with other ecological metrics captured by LTMMP surveys such as, algae, benthic composition, invertebrate and fish abundance; variation between sites and islands still exists. When analyzing the benthic composure The LTMMP uses the benthic substrate ratio or BSR as a metric to understand the ratio of reef accreting surfaces to macro-algal cover. For all islands there are sites that have relatively high ratio of coral to macroalgal cover and likewise sites with greater macroalgal to coral cover are present as well. The analyzed BSR's complement the findings of coral-size class and distribution and algal diversity data, in that generally sheltered reef habitats on Saipan and Rota have a BSR which favors reef accreting habitat (Fig. 7), while those with greater macroalgal cover also more likely to have great algal diversity (Fig. 8).

Generally, invertebrate abundance appears to be higher on reefs in Rota, especially for populations of grazing urchins (Fig. 9). Interestingly, the abundance of edible shell-fish such as clams and trochus seem to be relative for all three islands. Like due to steady harvesting pressure placed on these organisms. Sea cucumber abundance is relatively constant except for two site; Iota South in Rota and Outside Garapan in Saipan. Historically Iota South has had greater amounts of sedimentation due to ship salvage efforts that have occurred in the vicinity. For Outside Garapan, the increase in sea cucumber abundance has been more abrupt. Although further monitoring is required to verify these trends, it should be noted that the Outside Garapan site is located off-shore of the large-scale casino which is currently being constructed. Comparisons between ecologic and water-quality data should be made to look for associations between reduced water-quality affecting sea cucumber abundance at this particular site.

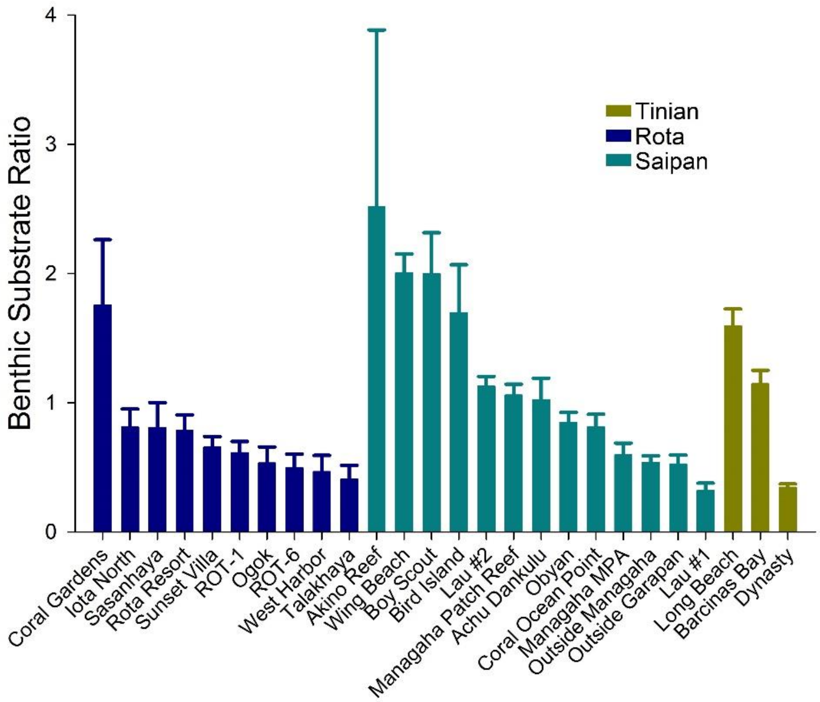

Figure 7 Benthic Substrate Ratio (BSR) for all sites surveyed during the current reporting period.

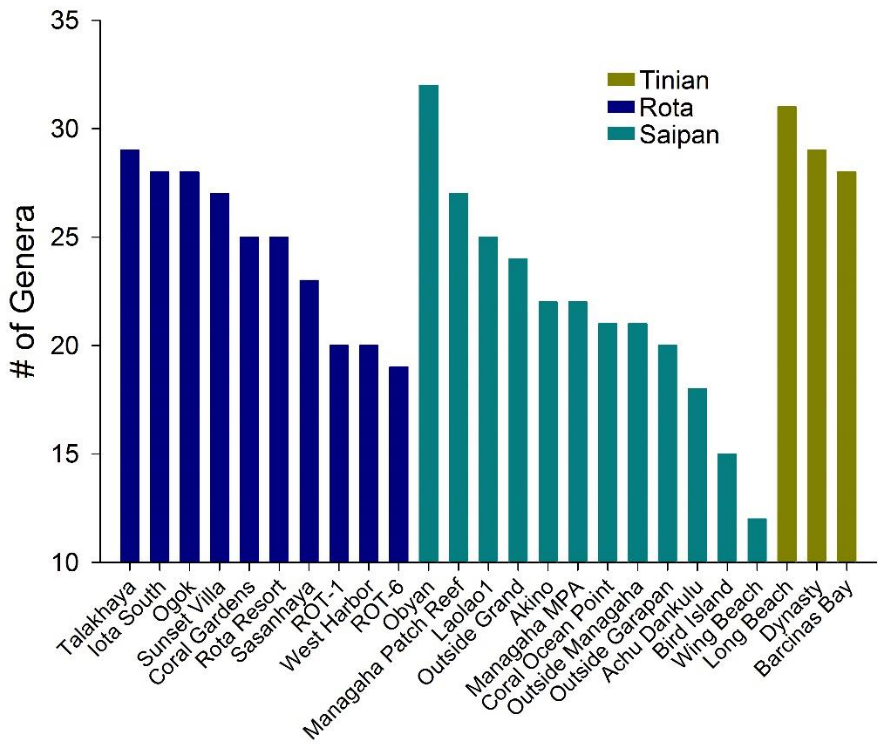

Figure 8 Differences in algal diversity among long-term monitoring sites in Saipan Tinian and Rota.

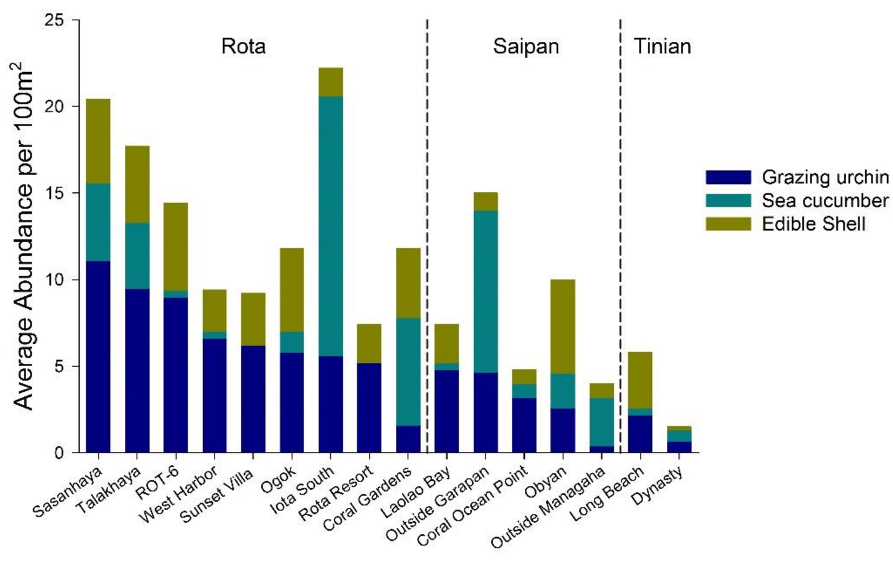

Figure 9 Average density of grazing urchins, sea cucumber, and edible shellfish among long-term monitoring sites.

Analysis of fishery-independent survey data for long-term monitoring sites have provided an interesting facet with which to look at holistic ecosystem characteristics. Because of their mobility fish surveys have a high degree of variability both across sites and through time. Analysis of fish trophic groups (Fig. 9) show the lack of apex predators across all sites and islands. Planktivorous fish biomass is generally low due to site selection which is focused on the shallow fore-reef habitat. Primary and secondary trophic level fish constitute majority of the fish biomass present at these sites. When analyzing data looking at fish groups, greater detail between fish populations can be appreciated (Fig. 11). The dominant herbivore groups among all sites are composed of small-bodied acanthuriids and small-bodied parrotfish. It appears that there are fewer larger bodied herbivores present on CNMI reefs. This trend is likely caused by the cumulative effects of water-quality and unmanaged harvest. However, these variables require more fishery dependent data and site based analysis of water-quality to tease out the causes for the current fish population dynamics seen at these sites.

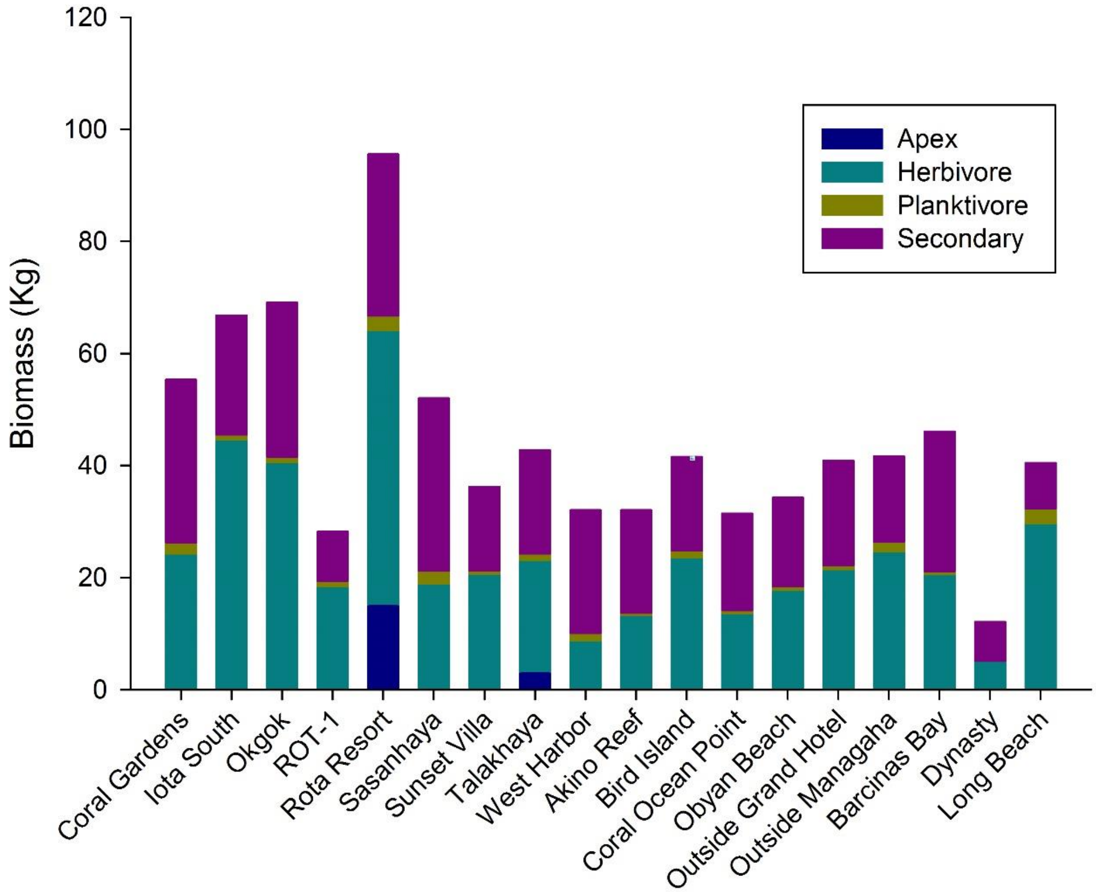

Figure 10 Biomass (Kg) for trophic fish groups among long-term monitoring sites on Saipan, Tinian and Rota

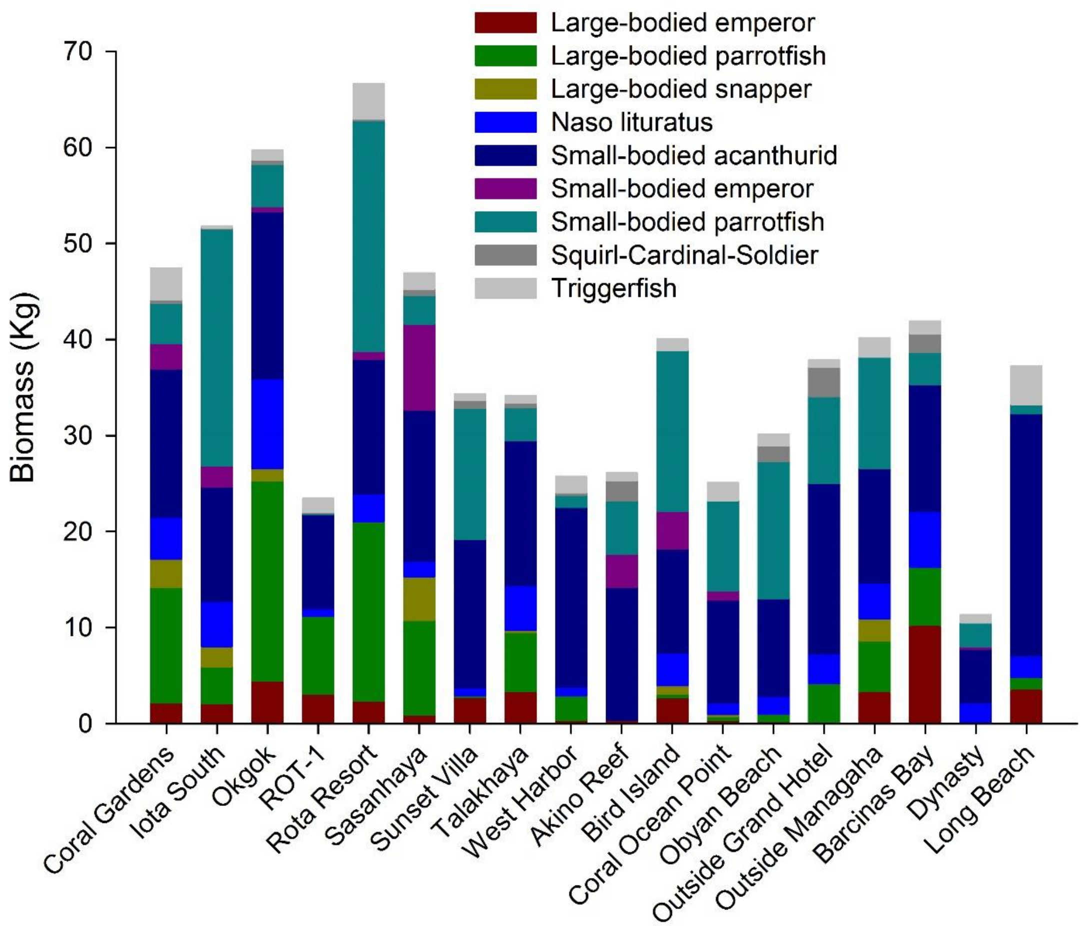

Figure 11 Biomass (Kg) for fish groups among long-term monitoring sites on Saipan, Tinian and Rota

Priority watersheds

As human population and development increase, nearshore aquatic ecosystems face growing threats from non-point sources of pollution (i.e. storm water runoff, agricultural waste, etc.), sedimentation, habitat destruction, and overfishing. In 2010, the coral reef managers of the CNMI produced a priority setting document that ranked land-based sources of pollution as the highest management priority to improve the condition of nearshore coral reefs and associated ecosystems (report can be found at www.cnmicoralreef.com). Because coral reef and seagrass assemblages show predictable shifts in response to nutrients, sediment loads, turbidity, and other proxies to pollution (Rogers 1990; Houk and van Woesik 2008), marine managers were able to evaluate existing data from the long-term monitoring program to identify priority watersheds that were likely to benefit from active management. During the current award period, CAPs for Garapan were updated. The MMT continues to monitor sites associated with these watersheds to evaluate the effectiveness of management actions and to alert managers of any new water quality issues. Below, we highlight trends observed in key ecosystem parameters for the Talakhaya and LaoLao priority watersheds. We also present preliminary data collected for sites established in response to the initiation of management actions for the Garapan CAP.

Talakhaya

The Talakhaya watershed on Rota primarily consists of public and protected lands that have historically been subject to uncontrolled burning from fires set by poachers. These fires have consumed soil-stabilizing vegetation on the steep hillside, resulting in severe erosion of the land and sedimentation of the nearshore coral reef habitats. In 2007, BECQ (formerly DEQ), in cooperation with Rota DLNR and the USDA-NRCS, began an annual revegetation program that utilizes volunteers to plant fire-resistant grasses and soil-producing trees to restore the integrity of the watershed and improve coral reef health. Additionally, outreach and educational campaigns have been conducted to inform the public about the importance of protecting the watershed. As a result of these efforts, over 200,000 grass and tree seedlings have been planted and only two major fires have occurred since 2007 (down from several each year).

The marine monitoring program currently has two permanent fore-reef sites associated with the Talakhaya watershed; 'Talakhaya' on the eastern boundary of the watershed and 'Ogok,' to the west (Fig. 12). Whereas biological data have been collected at the Talakhaya site since 2000, the Ogok site was established in 2008 and has only been surveyed four times to date. Majority of restoration efforts have been focused on the more impacted eastern side of the watershed, although more recently efforts towards revegetating the Ogok sub-watershed have been completed. Both sites serve as indicators of watershed health and may alert managers to unknown problems upstream. In addition to fore-reef monitoring, the MMT has assisted the NPS and water quality programs with reef flat surveys and water quality sampling within the watershed during the current reporting period.

Overall, the Talakhaya monitoring site is characterized by low coral cover and a predominance of turf and macro algae. The marine ecosystems have experienced a fair amount of change through time (Fig. 13). Prior to the 2003-2006 COTS outbreak benthic substrate was more closely associated with coral communities. During disturbance years community structure changed significantly, was dominated by turf and macroalgae, but recovered to pre-disturbance levels by 2013 (Fig.14). Although recovery has been observed, the occurrence of these disturbance and recovery events have left the benthic communities in an altered state. Around 2008, we began seeing significant inter-annual fluctuations in macroalgae and fleshy coralline algae (FCA), which previously had remained low and relatively stable. Since 2011 when we implemented our current fish survey protocols, we have collected baseline data on fish biomass, abundance, and species composition. Small bodied acanthurids and large bodied parrotfish have made up the majority of total fish biomass across years (Fig. 15). Increases in biomass of large-bodied parrotfish were also observed. Because watershed restoration activities and natural disturbance events happened within overlapping time frames, it remains difficult to tease apart the individual factors driving coral reef dynamics at this time. The ability of coral reefs to recover from disturbance, however, is often correlated with water quality (Houk and Wiles, 2010). Thus, the observed recovery of coral cover to pre-disturbance levels may be a positive indicator of watershed health.

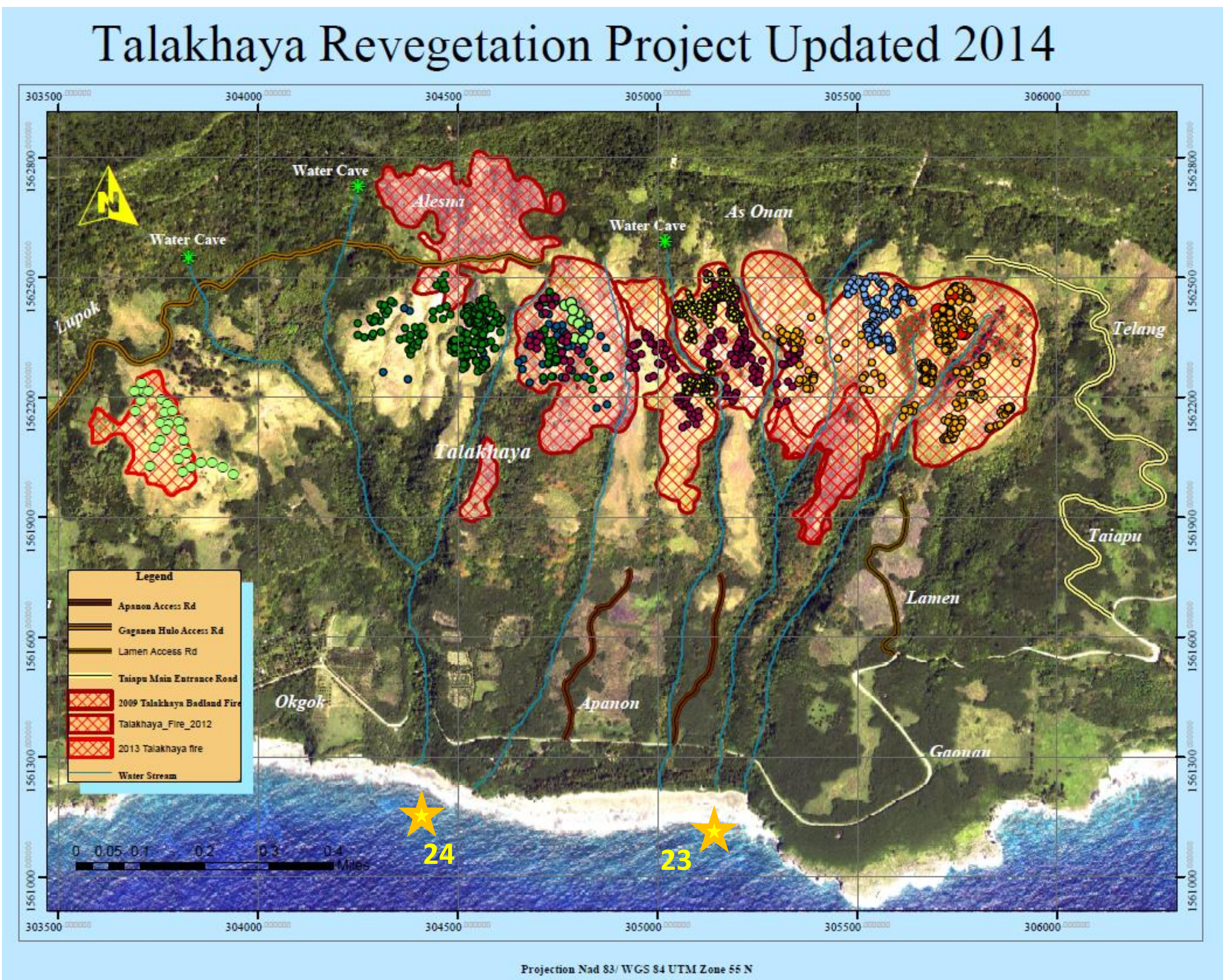

Figure 12 Long-term marine monitoring sites (Talakhaya, 23, and Ogkok, 24) associated with the Talakhaya watershed on Rota shown in in relation to recent fires and revegetation efforts. Colored circles represent grass and tree seedlings planted from 2007-2014.

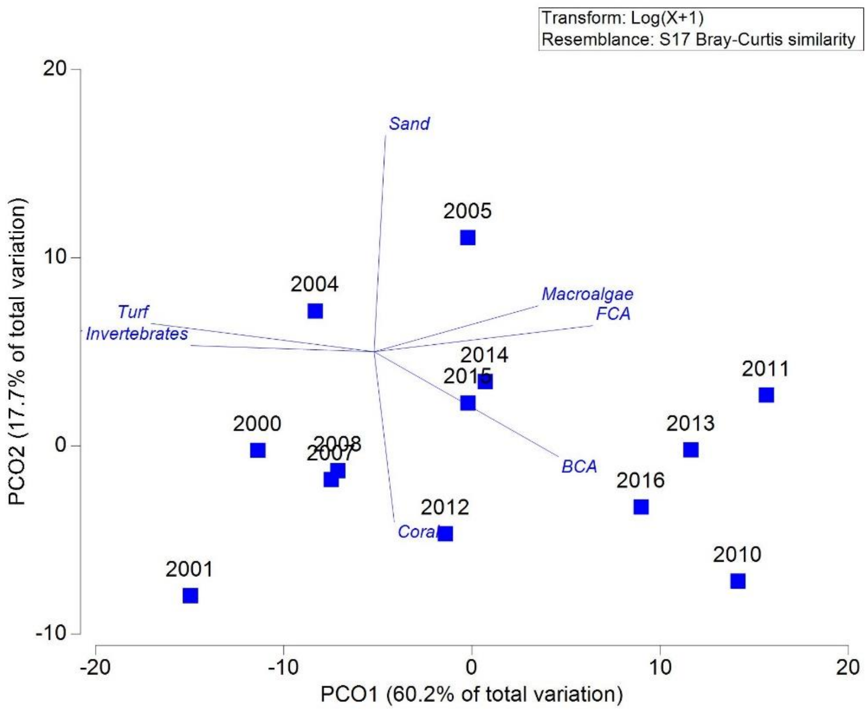

Figure 13 PRIMER PCO with vector overlays plot depicting trends in average percent cover of major benthic substrate categories as well reef accreting substrates for the Talakhaya long-term monitoring site. CCA= Crustose coralline algae; Branching coralline algae; FCA= Fleshy coralline algae.

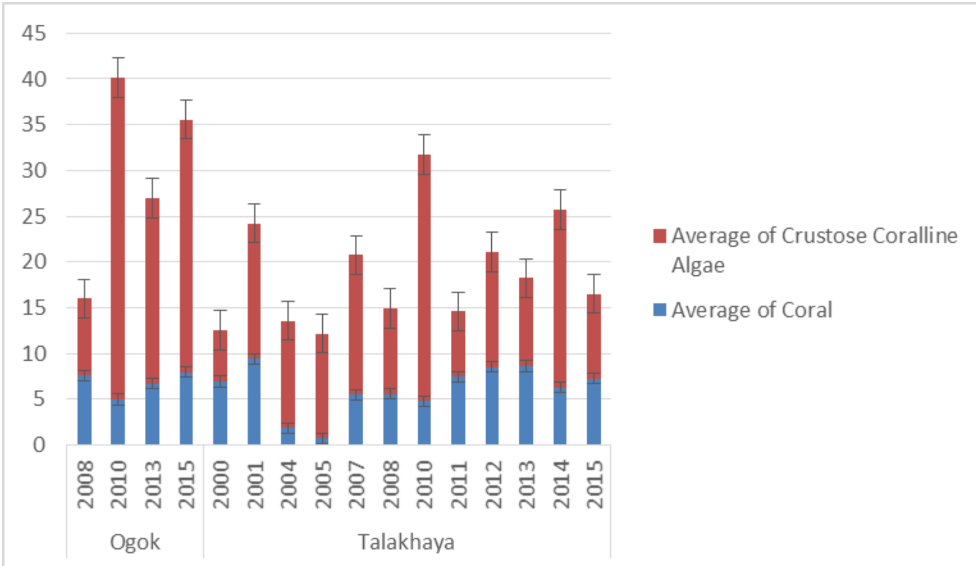

Figure 14 Trends in coral cover through time for the Talakhaya and Ogok monitoring sites. There has been significant variation in coral cover through time for the Talakhaya site. Coral cover declined as a result of the COTS outbreak from 2003-2006, but recovered by 2012. No change has been observed in coral cover at Ogok since monitoring began in 2008.

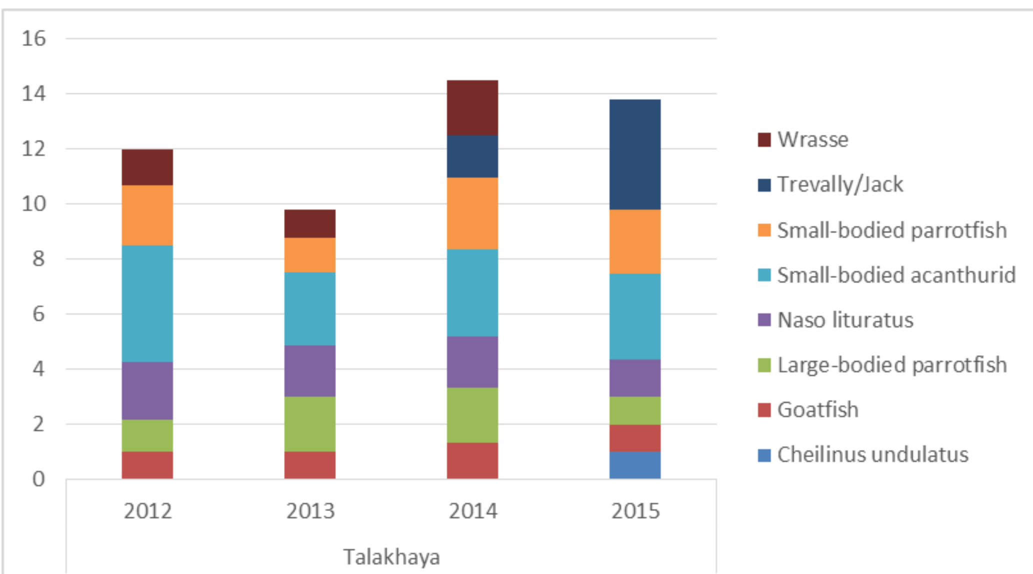

Figure 15 Total biomass of major food fish and functional groups across sampling years.

<u>LaoLao Bay</u>

LaoLao Bay was identified as a priority watershed because it is an area with high ecological, economic, and cultural value that was experiencing severe degradation due to coastal development and unsustainable use over the last two decades. The CAP for LaoLao was completed in 2009 and most of projects described in it were completed by 2012 when the cap was revisited and revised. Projects included revegetation of eroded upland areas, the paving and drainage improvements to Laolao Bay Drive, and installing stream crossing infrastructure to reduce sedimentation from the road. Erosion and stormwater control efforts are still ongoing, including upstream revegetation, and installing permeable parking and rain gardens. Two social marketing campaigns, OurLaolao and Laolao Bay Pride Campaign, have also been completed. A key component to our understanding of Laolao Bay's current state are attributable to three comprehensive studies comparing temporal changes in the ecological assemblages of Laolao Bay. In 2010 the MMT assisted Dr. Peter Houk, of the University of Guam, with the preparation of an ecological assessment to monitor management actions occurring within Laolao Bay. The study utilized the opportunity to mirror a previous ecological assessment conducted a decade before in 1991. The premise was to collect water-quality and biological data at the same sites for both study periods. The study purported a significant decline in coral-reef health throughout the bay, and identified water-quality and wave exposure of key drivers of change throughout Laolao Bay.

The marine monitoring program currently has two permanent fore reef sites associated with the Laolao Bay watershed; Laolao Bay #1 and Laolao Bay #2 (Fig. 16). Observed trends in key ecosystem parameters are illustrated below (Figs.17-19). Analysis of these data is ongoing in an effort to understand the efficacy of management efforts in relation to other natural and human disturbances and environmental regimes.

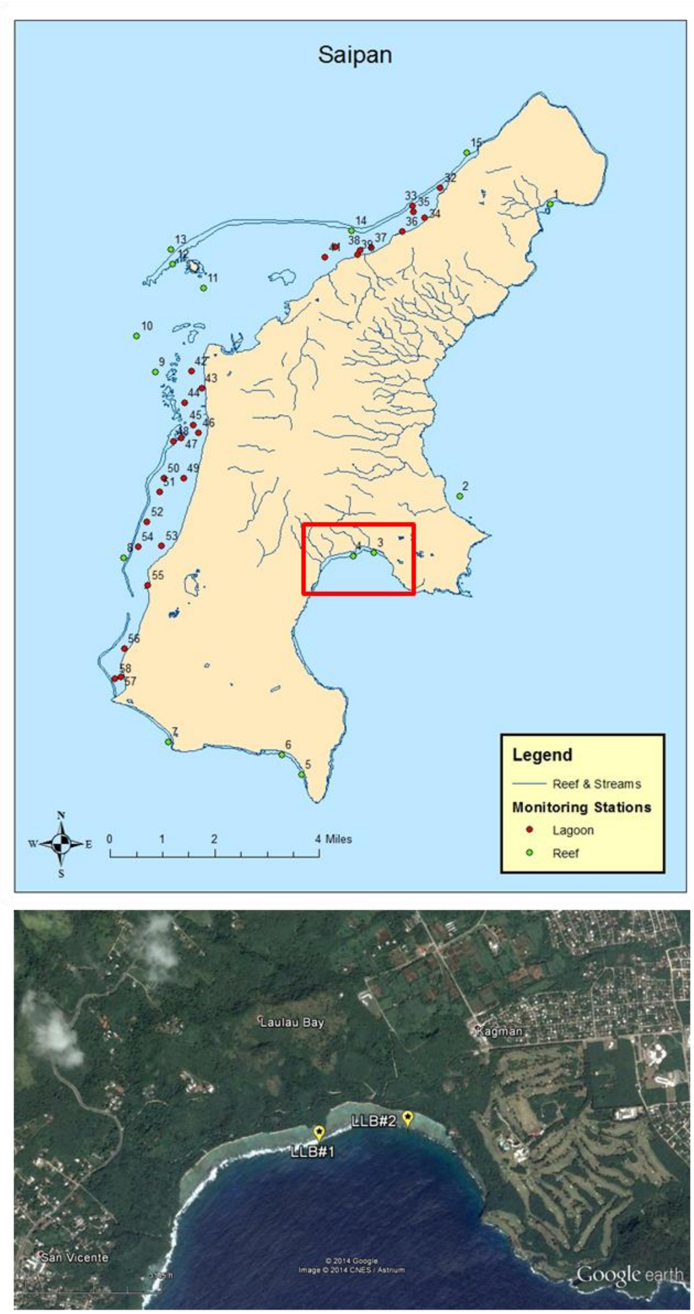

Figure 16 Coral reef monitoring sites associated with LaoLao Bay watershed.

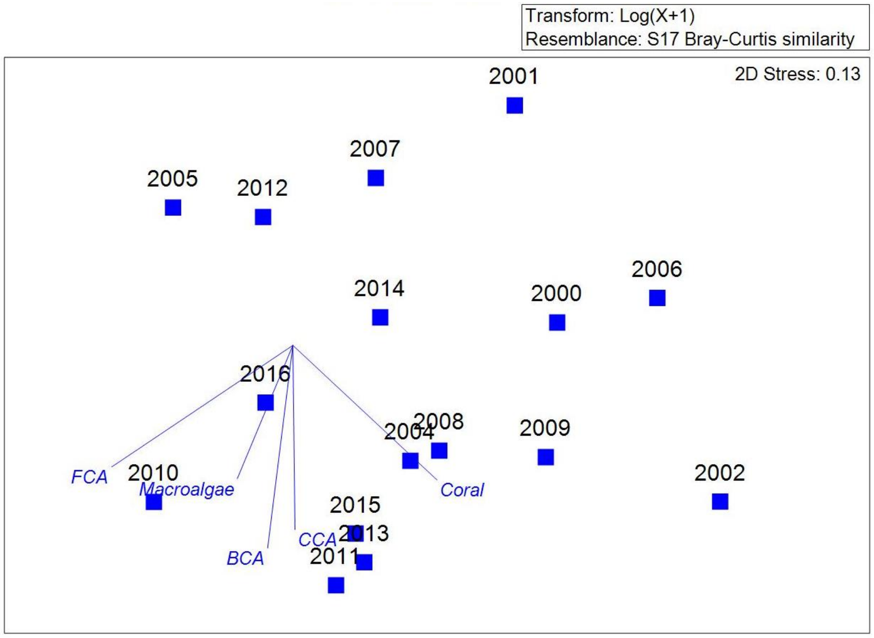

Figure 17 Non-parametric MDS plot with vector overlays illustrating changes in percent cover of major benthic substrate categories for the LaoLao Bay1 long-term monitoring site. CCA= Crustose coralline algae; FCA= Fleshy coralline algae; BCA= Branching coralline algae. Over time coral dominated habitats have shifted to benthic communities dominated by various coralline and macroalgae.

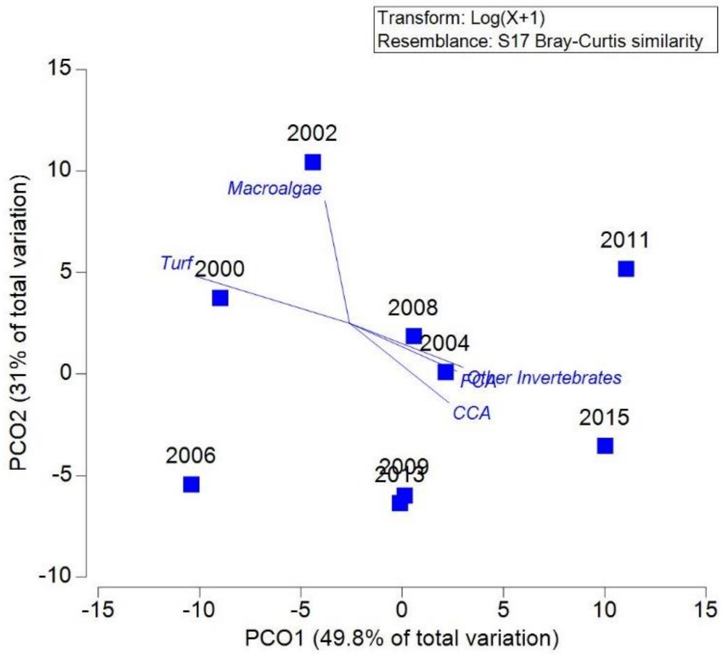

Figure 18 PCO plot with vector overlays that illustrate trends in percent cover of major benthic substrate categories as well as the sum of "good" reef-accreting substrates, and "bad" non-reef accreting substrates for the Laolao Bay 2 long-term monitoring site. CCA= Crustose coralline algae; FCA= Fleshy encrusting algae; BCA=Branching coralline algae.

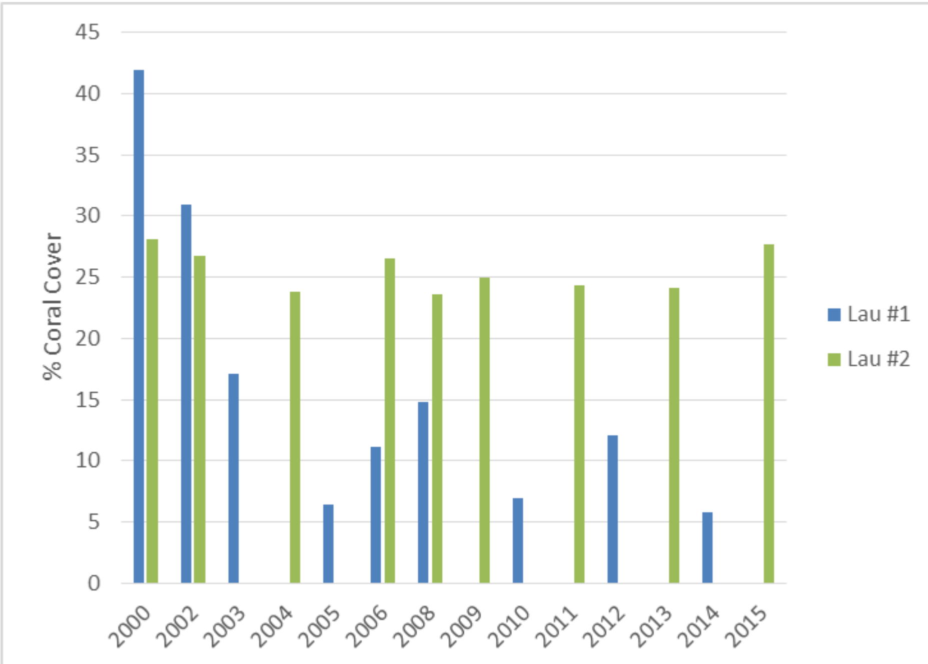

Figure 19Trends in coral cover through time for the Laolao Bay 1 (Lau #1) and Lao Lao Bay 2 (Lau #2) monitoring sites. For Lau #1, coral cover declined during 2003-2006, with no recovery to date. Conversely, there has been no change in coral cover from 2000-2013 for the Lau #2 site.

<u>Garapan Watershed</u>

Management actions to in response to the Garapan CAP have been forthcoming in recent years. The MMT has attempted to assist the CAP process by providing monitoring for adjacent marine habitats, in an effort to observe changes caused by management actions. Within the last reporting period the MMT established two new lagoon seagrass sites to provide ecological data to managers. Summaries of data collected are summarized in Figures' 20-22.

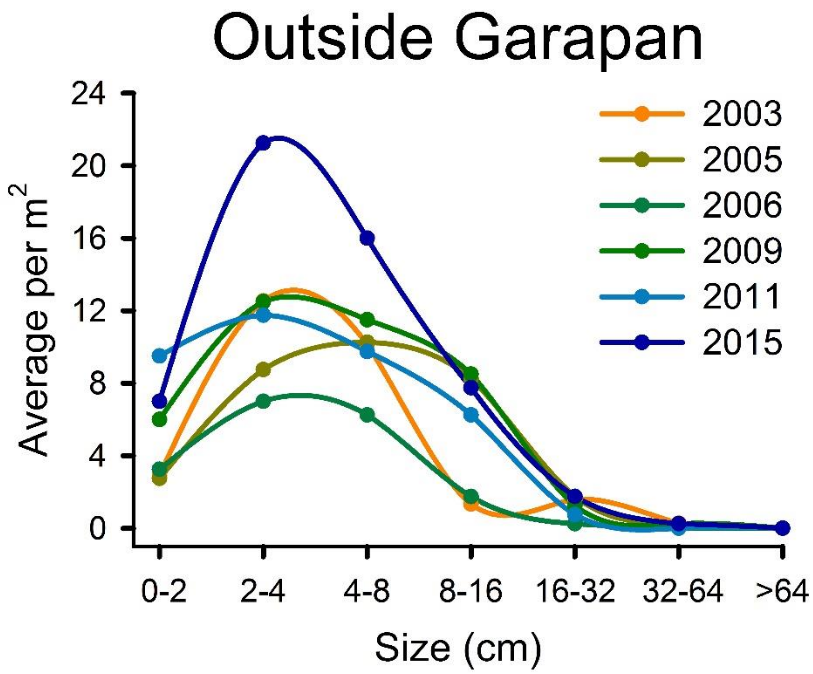

Figure 20 Observed distribution of coral colony size through time for MMT long-term monitoring site located at Outside Garapan. The figure shows an increase in recruits and a decrease in large coral colonies over time.

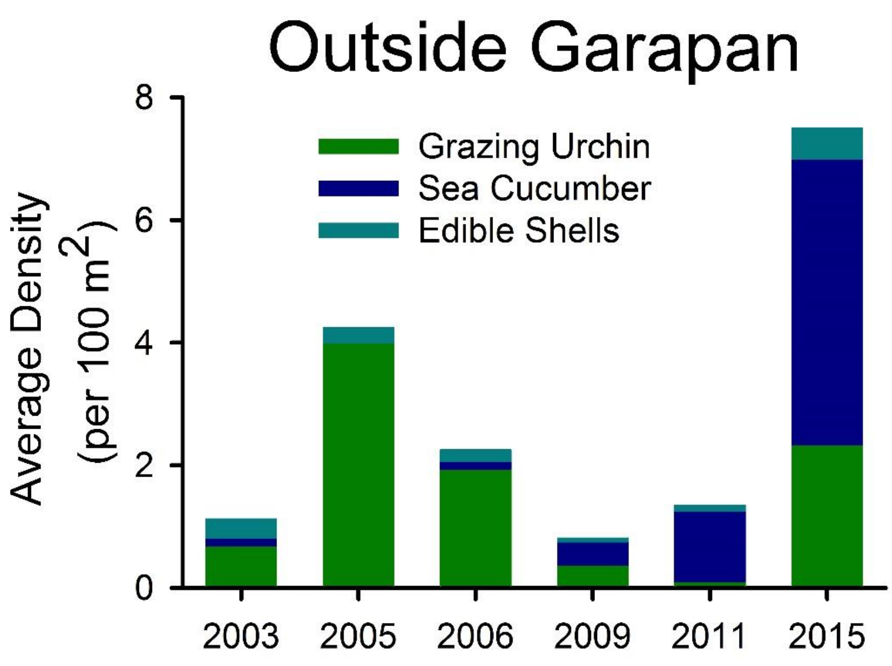

Figure 21 Temporal trends of invertebrate density at Outside Garapan site. Variation among survey years is evident, however, a stark increase in sea cucumber density is evident.

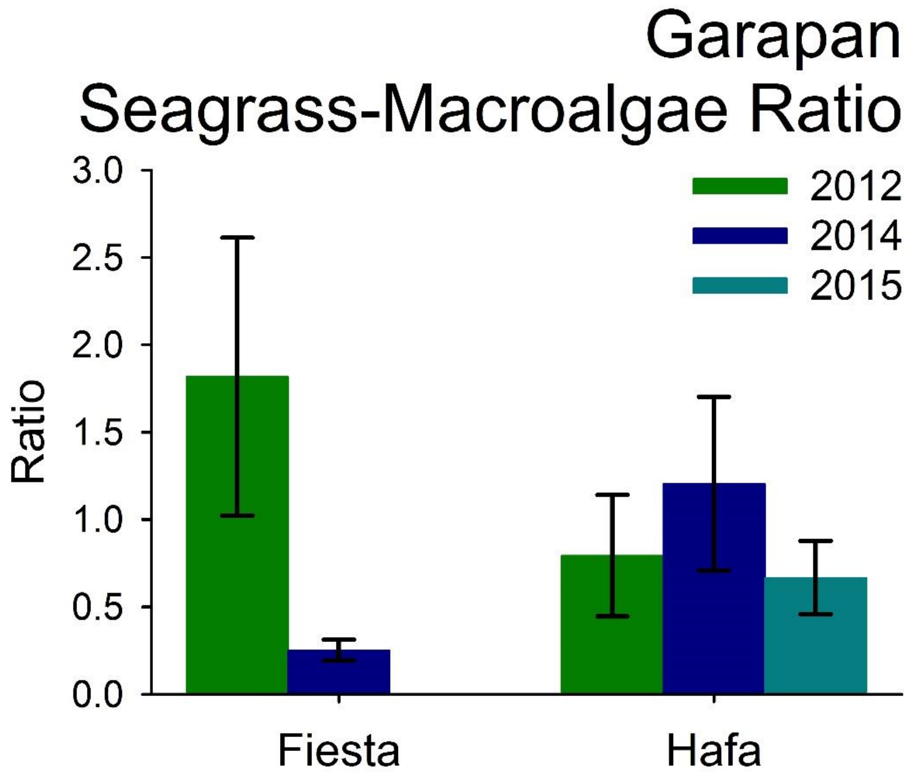

Figure 22 Sea grass-Macroalgae ratio for newly established lagoon monitoring sites. A ratio greater than 1.0 indicates the proliferation of macroalgae for that particular sampling period.

Although data collection for lagoon sites adjacent to the work established by the Garapan CAP, the MMT will continue to support monitoring efforts, as to provide reliable data for the use of managers in gauging the effectiveness of their management actions.

OTHER RELATED PROJECTS

Throughout the award period the MMT has had the opportunity to assist and participate in multiple inter-agency collaborations in support of other related projects such as, coral reef resilience studies, and an expedition to the remote northern islands. Because these projects have been covered extensively in past annual reports, they will only be briefly summarized here.

Seagrass resiliency study

DEQ technical biologist, Lyza Johnston has taken the lead on a seagrass resiliency study aimed at measuring a set of established resilience indicators at survey sites across the lagoon associated with multiple watersheds that vary in area and human population size and development. A pilot project was previously conducted with summer interns to help develop methodologies and sample strategy for this study. Currently Dr. Johnston is preparing to conduct in water surveys to gather resiliency metrics such as canopy cover and plant tissue biomass, nutrients, and carbohydrate reserves, as well seed bed sampling.

Benthic cover will be assessed by using a 0.25 m^2 string quadrat with 16 intersections placed every five meters along each transect. The biota under each intersection will be recorded to at least the genus level to give an estimate of percent canopy cover for each major organism or substrate. To quantify plant tissue characteristics and seed beddensity, twelve, 10cm (diameter) x 10cm (depth) cores will be collected at each siteAt the lab, sediments will berun through a 1mm mesh sieve to retain seagrass seeds. All seeds will be identified and counted. Mesograzers will be collected and stored in 95% ethanol until further processing. Seagrasses will be sorted from macroalgae and separated into above ground (shoots and leaves) and below ground (stems, roots, and rhizomes) tissue. Epiphytes and epifauna will be removed from leaves and shoots. All tissue, including macroalgae, epiphytes, epifauna, seagrass above ground tissue, and seagrass below ground tissue were dried separately to a constant weight at 60° C (~24hrs) and weighed to determine biomass.

The objectives of this project are; to assess ecological resilience of seagrass ecosystems in the Saipan lagoon based on a set of measurable resilience indicators and to develop recommendations in support of resilience based management of seagrass ecosystems in the CNMI.

Resilience surveys on Tinian and Rota

During this award period MMT assisted in coral reef resilience surveys on Saipan, Tinian, and Rota. The objectives were to measure key ecological indicators and proxies of anthropogenic stress at reef sites to predict their potential resilience to climate change in the future. Over 100 fringing reef sites around the three islands were surveyed. The results of the Saipan surveys were reported in Maynard et al (2012), while the analysis of the Tinian and Rota surveys were reported in Maynard et al (2015). The outcomes of the project will help CNMI resource managers protect and improve coral reef resilience to climate change.

Northern islands surveys

From June to July 2014, MMT participated in the *Insular Reef Fish & Bottomfish Bio-Sampling* cruise aboard the NOAA ship *Oscar Elton Sette* (NOAA project SE 14-04). The cruise was led by Robert Humphreys from the NOAA Fisheries Pacific Islands Fisheries Science Center and included participants from local CNMI natural resource management agencies (DFW and BECQ) as well as local fisherman.

Cruise operations occurred in the nearshore and coastal waters of the northern volcanic islands of the CNMI, including the islands within the Mariana Trench National Monument. The primary mission of the research cruise was to sample reef fish and bottomfish populations across the archipelago to learn more about the biology and life-history of important food fish species that support local fisheries. In addition to fish sampling, MMT conducted ecological surveys of the understudied nearshore shallow water habitats.

The MMT conducted a total of 62 surveys across seven islands (Uracas, Maug, Asuncion, Pagan, Guguan, Sarigan and Anatahan). Survey sites were selected using a stratified random sampling design. All surveys were conducted within 100m from shore, at depths of 1-6m. Surveys were conducted on snorkel. We collected data on benthic community composition; relative coral species richness and abundance; species richness for algae and non-coral macro-invertebrates; and food fish abundance, diversity, and biomass. In addition to ecological work, marine water quality parameters including temperature, salinity, conductivity and pH were measure at each site, and water samples were taken for nutrient (PO_2, NO_2, and NO3) and microbial analysis.

Mass coral mortality and bleaching

In 2013, coral reefs across the southern islands of Guam, Rota, and Saipan experienced widespread bleaching and mortality due to a prolonged period of abnormally high sea surface temperatures (SSTs) and low wind speeds. Although satellite data suggest that elevated SSTs extended farther north, the geographic extent of the bleaching event was unknown due to difficulties in accessing the remote and uninhabited northern volcanic islands. Thus the MMT was the first to document the impacts of recent thermal stress events on the shallow water coral communities of the northern islands. On an island scale, we estimate that >90% of *Pocillopora* and *Acropora* spp. corals died, with some sites experiencing near complete loss of one or both of these taxa. From August 10 - 13, 2014, we revisited the island of Maug (see below) and found widespread, extensive bleaching affecting most species down to depths of at least 20 m. High mortality of the less resilient genera, including *Pocillopora*, *Acropora*, and *Isopora* was already evident. These consecutive mass bleaching and mortality events across a region with relatively little anthropogenic influence highlight the importance of managing for coral reef resilience to climate change. The data collected by the MMT will provide a baseline for assessing the recovery of these shallow water ecosystems.

<u>Climate change research on Maug</u>

In May 2014, MMT members joined Dr. Enochs on an expedition to Maug aboard the NOAA ship *Hi'ialakai*. The cruise was led by scientists from NOAA's Pacific Island Fisheries Science Center Coral Reef Ecosystems Division and the Pacific Marine Environmental Lab's Earth-Ocean Interaction Group. The team mapped the carbonate chemistry around the vent; deployed various sensors to measure pH, temperature, and other parameters through time; set up coral growth experiments; deployed calcification accretion units/settlement tiles; and collected water and coral samples.

In August 2014, MMT members again traveled to Maug with Dr. Enochs aboard the CNMI vessel *Super Emerald*. The objectives of the expedition were to characterize the coral reef communities along the gradient in CO_2 created by the vent as well as retrieve instruments, sampling units, and experiments that were deployed in May. The MMT conducted benthic surveys and fish counts along 18, 15m transects across the CO_2 gradient. The usual ecological data was collected and will be used to assess the effects of increased CO_2 on the structure and function of coral reef ecosystems. In addition to the vent-associated surveys, MMT established three long-term monitoring sites using our standard methods. One site was on the western outside fore-reef and two were inside the caldera (one on the east side and one on the west side). These surveys will allow us to assess the impacts and recovery of the 2014 bleaching event on Maug, as the opportunity arises.

M/V Paul Russ Grounding

In September 2014, on its way into the Port of Saipan, the 530 ft. long cargo ship M/V *Paul Russ* ran aground on a coral reef located inshore of the channel. The CNMIs environmental response team for the incident consists of representatives from BECQ (MMT), DFW, and the local NOAA field office and was led by Dr. Johnston from the MMT. Over the weeks following the incident, the response team worked with third party representatives of the responsible party and the salvage company to measure, map, and photograph the disturbed area, upright and secure dislodged corals, and conduct biological surveys of the impact scar and the areas immediately surrounding it. Data collected was used in the formulation of the Habitat Equivalency Analysis (HEA). Currently, the CNMI government and the responsible party have agreed on the terms of compensatory mitigation for the grounding incident.

NPS reef flat surveys

Throughout the current reporting period members of the MMT travelled to Rota and Tinian to assist the BECQ Non-Point Source Pollution program in conducting biological reef flat surveys in conjunction with water quality sampling. Over 100 surveys were conducted to assess the benthic community composition of the reef flat. Surveys were conducted along a 50m transect that traversed the point designated for water quality sample collection. Benthic percent cover was assessed using the string quadrat method using a $0.25m^2$ quadrat with ten points, placed every meter along the transect. Non-coral macro-invertebrate abundances were also assessed by identifying and counting all organisms within one meter of the transect, on both sides (i.e. 2m x 50m belt).

CNMI Fish Kill Response

Beginning in Mid-August of 2014, the CNMI experienced a die-off of the blue-banded surgeonfish, locally known as Hiyok (*Acanthurs lineatus*). Thousands of dead fish washed up on beaches around Tinian and Saipan and "sick" fish were observed swimming erratically on the reef flats. The fish kill response was led by the CNMI Division of Fish and Wildlife (DFW), who have been working closely with the Department of Lands and Natural Resources and BECQ, as well as disease toxicology specialists from the US Geological Survey (USGS) National Wildlife Health Center (NWHC) in Honolulu. As needed, MMT has provided support to DFW with their assessment and monitoring of the fish kill events. Specifically, Dr. Okano has been assisting DFW in collecting water quality samples at affected areas.

<u>Education and Outreach</u>

During the current award period, members of MMT participated in numerous education and outreach events and initiatives, including, but not limited to, the following:

- *Annual Environmental Expo*. MMT mans an educational exhibit designed to educate students about coral reef and associated ecosystems. Hundreds of students and community members attended this event to learn about environmental programs and stewardship. All members of MMT participate in the expo.
- *CRI Summer Internship Program*, June-August. MMT consistently supports 1-2 summer interns.
- *CNMI Snorkels*. MMT member participate in the CNMI snorkels event as experts available to answer snorkeler's questions about the marine environment.
- *International Coastal Cleanup*, annually in September.
- Various beach cleanups
- Various community meetings and school events

OUTCOMES AND PRODUCTS

The fundamental product of this program is the long-term ecological database, which provides crucial information on the state of CNMI's marine communities through time and space. The database is managed by monitoring staff and housed on the BECQ server. This data is used to evaluate the potential environmental and anthropogenic causes of ecosystem decline, the factors contributing to resilience and recovery, and the effectiveness of management strategies. Marine monitoring data is consistently used by CNMI natural resource managers when developing and evaluating management activities such as re-vegetation efforts in LAS priority watersheds on Saipan and Rota, and changes inside and outside of local MPAs.

Data is made available to NOAA, natural resource managers, NGOs and the public through various outlets including peer-reviewed scientific journals (see below) and presentations at various symposia, workshops, lectures, and informational meetings. Graphics, photos, and metadata, will be made available no more than two years after collection via the CNMI's Coral Reef Initiative monitoring website (www.cnmicoralreef.com). To further broaden awareness of the program beyond the management and scientific community, a facebook© page has been created which is maintained and updated by monitoring personnel (www.facebook.com/cnmimmt). Finally, spatial and other metadata data will soon be available to the public through DCRM's newly launched ArcGIS data portal, which can be found at:

http://www.arcgis.com/home/item.html?id=0c6fa047b5264b408285aa2b11b0b0cd

The marine monitoring program has contributed to the following peer-reviewed scientific papers and agency reports over the award period:

- Houk P, Benavente D, Iguel J, Johnson S, Okano R (2014) Coral Reef Disturbance and Recovery Dynamics Differ across Gradients of Localized Stressors in the Mariana Islands. PLoS ONE 9(8): e105731 doi:10.1371/journal.pone.0105731.

- Enochs IC, Manzello DP, Donham E, Kolodziej G, Okano R, Johnston L, Young C, Iguel J, Edwards C, Fox M,Valentino L, Johnson S, BenaventeD, Clark SJ, Burton T, Eynaud Y, Price N (Submitted) *Ocean Acidification Causes Shift from Coral to Macroalgal Dominance on Reefs*

- Maynard J, McKagan S, Johnson S, Houk P, Ahmadia G, van Hooidonk R, Harriman L, Mcleod E (2012) Coral reef resilience to climate change in Saipan, CNMI; field based assessments and implications for vulnerability and future management. BECQ report. Saipan, MP

- Reynolds T, Burdick D, Houk P, Raymundo L, and Johnson S (2014) Unprecedented coral bleaching across the Marianas Archipelago. Coral Reefs DOI 10.1007/s00338-0141139-0

- Houk, P., Camacho, R., Johnson, S., McLean, M., Maxin, S., Anson, J., van Woesik, R. (2015). TheMicronesia Challenge: Assessing the Relative Contribution of Stressors on Coral Reefs to FacilitateScience-to- Management Feedback. PloS one, 10(6) DOI: 10.1371/journal.pone.0130823.

- Maynard J, McKagan S, Raymundo L, Johnson S, Ahmadia G, Johnston L, Houk P, Williams G, Kendall M, Heron S, van Hooidonk R, Mcleod E. (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 21. 150pp.

- Heron SF, Johnston L, Liu G, Geiger EF, Maynard JA, De La Cour JL, Johnson SJ, Okano R, Benavente D, Burgess TFR, Iguel J, Perez DI, Skirving WJ, Strong AE, Tirak K, Eakin CM (submitted). Monitoring Coral Bleaching using High-Resolution Thermal Stress Satellite Products. Remote Sensing

OBSTACLES AND DELAYS

The major obstacle during the 2013-2015 award period, was that the long-term marine monitoring program has experienced various changes in capacity; former DCRM Biologist I, Denise Perez vacated her position in 2014. DEQ biologist/water quality expert, Steven Johnson, resigned from his position shortly after in 2015. Later in 2015, Ryan Okano vacated his position as DEQ technical biologist. Although he continued to assist the MMT with field surveys, his ability to provide support has been limited. David Benavente who resigned in November of 2015 has returned to DCRM as the MMT's lead biologist, while Dr. Lyza Johnston has transferred to BECQ as its technical biologist (Sept. 2016). While the loss of capacity and various transfers have affected collection of long-term monitoring data, a regular field schedule has been implemented and priority has been given to those sites which have not been surveyed within the past two years.

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Houk P, Camacho R (2010) Dynamics of seagrass and macroalgal assemblages in Saipan Lagoon, Western Pacific Ocean: disturbances, pollution, and seasonal cycles. Botanica Marina 53:205-212

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