Long-Term Marine Monitoring Program
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SUMMARY

Despite being substantially understaffed during most of this award period, the marine monitoring team (MMT) managed to conduct 74 biological surveys at 52 long-term monitoring sites across Saipan, Tinian, Aguigan, and Rota (Table1). Standardized data was collected on coral, fish, algae, non-coral macroinvertebrate, and seagrass assemblages across the various marine habitats and management areas in the CNMI, including marine protected areas, species reserves, and priority watersheds. In addition to the standard long-term monitoring efforts, the MMT conducted over 100 additional surveys in support of related projects including a study on coral reef resilience, a rapid bleaching assessment, and an expedition to the remote northern islands, among others.

Here we report on these activities. We highlight general trends across sites and summarize a recently completed analysis of decadal trends in coral reef disturbance and recovery dynamics. We also present data collected to date at two of the priority watersheds. 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 specific management activities. This information then feeds back to support adaptive management strategies.

INTRODUCTION

Marine monitoring efforts in the Commonwealth of the Northern Mariana Islands (CNMI) began over a decade ago through a partnership among the Coastal Resource Management Office (CRMO), the Division of Environmental Quality (DEQ), and the Division of Fish and Wildlife (DFW). Over the years, the program has grown and adapted based on available resources and pressing management needs. In 2008, a formal long-term monitoring plan was developed, 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 2011-2014 award period. We briefly touch on the primary methods 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 highlight the results of a recently published report on differential disturbance and recovery dynamics of coral reefs across the CNMI as well as observed ecosystem trends at sites associated with the three priority watersheds. 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. It is thus a goal of the new lead biologist, Dr. Lyza Johnston, to migrate the monitoring data into an Access database over the next year. 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 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

ACTIVITIES AND PROGRESS

Sites surveyed

During the current award period, ranging from October 1, 2011, to September 30, 2014, MMT conducted 74 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 Name	Habitat	Island	GPS X	GPS Y	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
AGU-2	Fore Reef	Aguigan	342807	1642480		x	x										x		
Coral Gardens	Fore Reef	Rota	302280	1561368	x	x		x				x	x		x	x	x	x	
Iota South	Fore Reef	Rota	303979	1567839		x		x				x	x			x		x	
ROT-6	Fore Reef	Rota	300480	1566155						x			x			x	x		x
Sasanhaya	Fore Reef	Rota	299549	1563712	x	x		x				x	x		x	x	x		x
Sunset Villa	Fore Reef	Rota	303044	1567386									x					x	
Talakhaya	Fore Reef	Rota	305210	1561109	x	x			x	x		x	x		x	x	x	x	x
Rota Resort	Fore Reef	Rota	308740	1570072		x						x				x	x		x
West Harbor	Fore Reef	Rota	298271	1563772	x		x	x				x				x	x		x
Ogak	Fore Reef	Rota	304442	1561090									x		x			x	
ROT-1	Fore Reef	Rota	315173	1567076				x									x		x
Akino Reef	Fore Reef	Saipan	359996	1683274	x		x							x		x			x
Bird Island	Fore Reef	Saipan	372724	1687351	x							x			x		x		x
Boy Scout	Fore Reef	Saipan	365076	1669701		x			x	x		x	x		x	x		x	
Coral Ocean point	Fore Reef	Saipan	360977	1670710	x	x				x	x	x		x	x	x	x		
Laolao #1	Fore Reef	Saipan	366655	1676452	x		x	x		x	x		x		x		x		x
Laolao #2	Fore Reef	Saipan	367312	1676554	x		x		x		x		x	x		x		x	
Managaha MPA	Fore Reef	Saipan	361112	1685496						x		x		x	x	x		x	x
Managaha Patch	Fore Reef	Saipan	362045	1684756		x	x					x		x	x		x		
Obyan	Fore Reef	Saipan	364462	1670303		x			x	x				x		x	x	x	
Outside Garapan	Fore Reef	Saipan	360569	1682142		x		x		x	x			x		x			
Outside Grand	Fore Reef	Saipan	359597	1676410	x	x				x			x	x		x		x	
Out Managaha	Fore Reef	Saipan	361046	1685949		x		x			x			x		x			x
Tank Beach	Fore Reef	Saipan	369943	1678305					x						x		x	x	
Wing Beach	Fore Reef	Saipan	370155	1688934		x		x	x	x	x	x			x	x		x	
Barcinas Bay	Fore Reef	Tinian	350028	1657824		x	x		x		x				x		x		x
Dynasty	Fore Reef	Tinian	352490	1653831		x	x			x			x				x		x
Long Beach	Fore Reef	Tinian	355222	1662018				x		x			x			x			x
South Point	Fore Reef	Tinian	352435	1652286	x		x			x			x		x		x		
Unai Babui	Fore Reef	Tinian	351351	1667541		x			x	x				x		x			
Achu Dankulu	Fore Reef	Saipan	366598	1686526														x	x
13 Fish Deep Coral	Lagoon	Saipan	361726	1680517							x					x			
13 Fish Halodule near	Lagoon	Saipan	361905	1680261										x		x			x
13 Fish out Halodule	Lagoon	Saipan	361371	1680116							x					x			
Achugao Halodule	Lagoon	Saipan	367211	1685984							x						x		x
Chalan Laolao Stag	Lagoon	Saipan	360700	1678457							x					x			
Gold Beach Staghorn	Lagoon	Saipan	361121	1680014							x					x			
Iguel Ranch EN/Mix	Lagoon	Saipan	366790	1685775								x		x		x		x	
Iguel Ranch Halodule	Lagoon	Saipan	366867	1685918							x	x		x		x		x	
Kilili Holodule	Lagoon	Saipan	360767	1676786							x		x	x		x	x		x
Marianas Resort Back	Lagoon	Saipan	369348	1687856								x		x		x		x	
Oleai Staghorn Coral	Lagoon	Saipan	360313	1677514							x		x			x		x	x
Pau Pau Halodule	Lagoon	Saipan	368872	1686929							x					x		x	
Pau Pau Staghorn	Lagoon	Saipan	368491	1687287		x					x		x			x		x	
Quarter Halodule	Lagoon	Saipan	361433	1678869										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 Ant Rock Halodule	Lagoon	Saipan	359508	1672713								x				x	x	x	
San Roque Halodule	Lagoon	Saipan	368173	1686511							x					x			
San Roque Isopora	Lagoon	Saipan	368523	1687119							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	
Tanapag Staghorn	Lagoon	Saipan	366113	1686010								x	x		x	x		x	
Wing Beach Reef flat	Lagoon	Saipan	370284	1688818							x								
San Antonio Back Reef	Lagoon	Saipan	359334	1672663								x			x	x		x	
Diamond Hotel Line	Lagoon	Saipan	360030	1676739	x	x												x	
Fishing Base Line	Lagoon	Saipan	361466	1681197	x	x										x		x	
Quartermaster Stag	Lagoon	Saipan	360835	1678875	x	x										x		x	x
Hafa South	Lagoon	Saipan	361996	1681649													x		x
Fiesta	Lagoon	Saipan															x		x

General trends

Seagrasses

The predominant seagrass species in Saipan lagoon is *Halodule uninervis.* Although it is widely distributed throughout the lagoon, it is sensitive to variations in water quality associated with watershed size and population (Houk and van Woesik 2008). Houk and Camacho (2010) reported on the interactive effects of natural seasonal cycles, physical disturbances (i.e. wind and wave energy), and land-based sources of pollution on seagrass ecosystems within the lagoon over a three year period. They found that the lagoon typically experiences seasonal fluctuations in macroalgae abundances related to temperature and freshwater input (Houk and Camacho 2010). Where watershed size and human population were low, seasonal macroalgae blooms were short lived and seagrasses remained dominant. Conversely, where water quality was poor due to larger population sizes and development, macroalgae blooms persisted throughout the year and successfully outcompeted seagrasses for sunlight, nutrients, and space, resulting in less desirable macroalgae dominated systems. In areas with high disturbance regimes *and* pollutant loading, macroalgae would persist until wintertime swells increased lagoon surface currents beyond the threshold for macroalgae attachment, giving the rooted seagrasses a respite from competition. Thus, seagrass remained as the dominant canopy where disturbance regimes were high, even in the face of poor water quality. In accordance with these findings, the ratio of seagrass to macroalgae cover is often used as a measure of ecosystem health. Here we report on the current status of our seagrass sites in terms of the proportion seagrass relative to macroalgae and changes in this relationship between survey periods. Where adequate data exists, sites have been assigned a condition rank for every two year sampling period, as described below:

- "Good" – Natural seasonal changes are apparent, existing assemblage has statistically more *H. uninervis* than macroalgae, and seagrass abundance has remained stable or increased from the previous survey (where data is available).

- "Fair" – Natural seasonal changes are apparent, existing assemblage has statistically similar abundances of *H. uninervis* and macroalgae, or existing assemblage has statistically more *H. uninervis* than macroalgae but seagrass abundance has declined significantly since the previous survey.

- "Poor" – Seasonal cycles are masked by persistent macroalgae growth, or, persistent macroalgae growth dominates unless a disturbance event (i.e., large-swell and high surface currents) occurs.

Table 2 Current status and recent trends for Saipan Lagoon *Halodule uninervis* seagrass beds. Pairwise *t*-tests were used to test for significant ($p < 0.05$) differences in seagrass and macroalgae cover and changes between sampling periods. See text for condition definitions; NS= Not Surveyed.

SAIPAN LAGOON SEAGRASS						
Site No.	**Site Name**	**Current Status**	**Condition**			
			2008	**2010**	**2012**	**2014**
53	Kilili Halodule	Natural seasonal changes apparent, standing crop of seagrass significantly greater than macroalgae. Seagrass abundance has increased significantly from previous survey.	Poor	Fair	Good	Good
55	Sugardock Halodule	Seagrass abundance significantly greater than algae	Good	NS	Good	Good
56	San Antonio Halodule	Natural seasonal changes apparent, standing crop of seagrass is significantly greater than algae and stable while algal cover is sig. down.	NS	NS	Fair	Good
57	San Antonio Rock Halodule	Persistently high abundance of algae. Standing crop of algae and seagrass statistically similar. Seagrass trending up.	Poor	NS	Poor	Fair
42	Fiesta	Standing crop of algae and seagrass statistically similar	NS	NS	NS	Fair
43	Hafa South	Natural seasonal changes apparent, standing crop of algae and seagrass statistically similar, Seagrass significantly up.	NS	NS	Fair	Fair
46	13 fish Halodule (nearshore)	Natural seasonal changes apparent, standing crop of seagrass is significantly more than algae and sig. up from previous survey. Algae is also sig. down	NS	Fair	Poor	Good
49	Quartermaster Halodule	Seagrass abundance significantly less than algae and sig. down from previous survey	NS	Good	NS	Poor
36	San Roque Halodule	Natural seasonal changes apparent, standing crop of macro and seagrass statistically similar and stable	NS	NS	Fair	Fair
37	Achuago Halodule	Natural seasonal changes apparent, standing crop of algae and seagrass statistically similar, seagrass abundance trending up.	NS	NS	Fair	Fair
38	Iguel Ranch Halodule	Natural seasonal changes apparent, standing crop of algae and seagrass statistically similar, seagrass stable, algae sig. up	Poor	Fair	Good	Fair
39	Iguel Ranch EN/Mix	Natural seasonal changes apparent, standing crop of seagrass (*Enhalus* + *Halodule*) statistically greater than algae. Total seagrass abundance stable.	Fair	Good	Good	Good
41	Tanapag Halodule	Seagrass abundance significantly less than algae, seagrass trending down, macroalgae trending up	Good	NS	Fair	Poor
34	Pau Pau Halodule	Natural seasonal changes apparent, standing crop of algae and seagrass statistically similar, seagrass trending up, algae sig. up	NS	NS	Good	Fair

Coral reefs

The ratio of the sum of "good," reef accreting organism (coral, crustose coralline algae [CCA], & branching coralline algae) to the sum of "bad," competing, non-reef accreting organisms (turf, macroalgae, fleshy encrusting algae [FEA]) is often used as a metric for coral reef health and resilience (Rogers 1990; Houk and van Woesik 2010). Houk and van Woesik (2010) also reported that coral species richness was a good predictor of watershed health in the CNMI. From 2003-2006, high abundances of the crown-of-thorns seastar, *Acanthaster planci* (COTS), resulted in an overall decline in coral cover across sites in the CNMI (Houk et al 2014; see below). Benthic substrate ratio and coral richness also declined, but to a lesser extent. We thus evaluate the general status of our coral reef sites based on benthic substrate ratio, coral diversity, and recovery dynamics, as described below.

- "Good" – Minimal or significant impacts reported from disturbance events. If natural disturbances impacted coral assemblage metrics then statistically significant recovery is currently underway. If no significant impacts from natural disturbances were noted, metrics were evaluated relative to those from the previous survey period and found to be higher than the mean. If no previous data were available, metrics were compared to the global mean and found to be higher than average.

- "Fair" – Minimal or significant impacts reported from disturbance events. If natural disturbances impacted coral assemblage metrics then recovery trends are currently apparent, but they are not significant. If no significant impacts from natural disturbances then metrics were evaluated relatively to those expected from the previous survey period and found to be similar to the mean.

- "Poor" – Minimal or significant impacts reported from disturbance events. If natural disturbances impacted coral assemblage metrics then no recovery trends are currently apparent. If no significant impacts from natural disturbances then metrics were evaluated relatively to those from the previous survey period and found to be lower than the mean.

Table 3 Status and recent trends for coral reef monitoring sites across Saipan, Tinian, Aguigan, and Rota. See text for condition definitions; NS= Not Surveyed.

SAIPAN CORAL REEFS							
Site No.	Site Name	Benthic Substrate Ratio Trends	Coral Diversity Trends	Condition			
				2008	2010	2012	2014
1	Bird Island	Significant decline from previous reporting period	No significant change during this reporting period	Fair	Fair	Good	Fair
2	Tank Beach	No significant change during this reporting period	No significant change during this reporting period	NS	NS	NS	Good
3	Lau #2	No significant change	No significant change	Fair	Fair	Fair	Fair
4	Lau #1	Significant decline from disturbance years, no recovery	Significant decline from disturbance years, no recovery	Poor	Poor	Poor	Poor
7	Coral Ocean Point	No data available this reporting period	No data available this reporting period	Fair	Poor	Fair	NS
5	Boy Scout	No significant change during this reporting period	No significant change during this reporting period	Fair	Fair	Good	Good

6	Obyan	Significant decline during disturbance years, no recovery	No significant change during this reporting period	Fair	Poor	Poor	Poor
8	Outside Grand	No significant change during this reporting period	No significant change during this reporting period	NS	Good	Good	Good
9	Outside Garapan	No data available this reporting period	No data available this reporting period	NS	Poor	Fair	NS
11	Managaha Patch Reef	Significant recovery from disturbance year	No significant change during this reporting period	NS	Fair	Good	NS
15	Wing Beach	No significant change during this reporting period	Continuous significant recovery from disturbance year	NS	Good	Good	Good
12	Managaha MPA	No significant change during this reporting period	No significant change during this reporting period	Good	Good	Good	Good
13	Outside Managaha	No data available this reporting period	No data available this reporting period	NS	Good	Good	NS

TINIAN & AGUIGAN CORAL REEFS							
Site No.	Site Name	Benthic Substrate Ratio Trends	Coral Diversity Trends	Condition			
				2008	2010	2012	2014
16	Long Beach	No data available this reporting period	No data available this reporting period	Fair	Good	Good	NS
17	South Point	No significant change during this reporting period	No significant change during this reporting period	NS	Fair	Poor	Poor
18	Dynasty	No significant change during this reporting period	No significant change during this reporting period	Poor	Poor	NS	Poor
19	Barcinas Bay	No significant change during this reporting period	No significant change during this reporting period	Fair	Fair	NS	Fair
20	Unai Babui	No data available this reporting period	No data available this reporting period	Poor	Poor	Poor	NS
21	AGU-2	Significant decline from previous reporting period	No significant change	Good	Good	NS	Fair

ROTA CORAL REEFS							
Site No.	Site Name	Benthic Substrate Ratio Trends	Coral Diversity Trends	Condition			
				2008	2010	2012	2014
22	ROT-1	Non-sufficient data (NSD) to evaluate recovery dynamics, ratio increased from 2012	NSD to evaluate recovery dynamics	NS	NS	Poor	Fair
23	Talakhaya	Significant decline from disturbance years, no significant recovery	Significant decline from disturbance years, no significant recovery	Poor	Fair	Poor	Poor
24	Ogok	No significant change throughout	No significant change throughout	Poor	Fair	Fair	Fair
25	Coral Gardens	No significant change throughout	No significant change throughout	Good	Good	Good	Good
26	Sasanhaya	No significant change during this reporting period	No significant change during this reporting period	Fair	Fair	Good	Good
27	West Harbor	No significant change during this reporting period	No significant change during this reporting period	Poor	Poor	Fair	Fair

28	ROT-6	Significant recovery from disturbance year	No significant change throughout	NS	Fair	Fair	Good
29	Sunset Villa	Significant recovery from disturbance year	Significant recovery from disturbance year	Fair	NS	NS	Good
30	Iota South	No significant change during this reporting period	Significant decline from disturbance years	Fair	Fair	Fair	Fair
31	Rota Resort	No significant impact of disturbance, ratio sig. increased in 2014	No significant change during this reporting period	Poor	NS	Poor	Fair

Decadal trends: coral reef disturbance and recovery dynamics across the CNMI

During this award period, an analysis of decadal trends in coral reef assemblages across the CNMI with respect to disturbance events, environmental regimes, and localized stressors was published in the open access journal PLoS One (Houk et al 2014, DOI: 10.1371/journal.pone.0105731). This publication is a result of collaboration between the CNMI MMT and Dr. Peter Houk from the University of Guam. It is based on 12 years of CNMI marine monitoring data from 21 sites across Saipan, Tinian, and Rota (Fig. 1). The major findings and management implications are briefly discussed here.

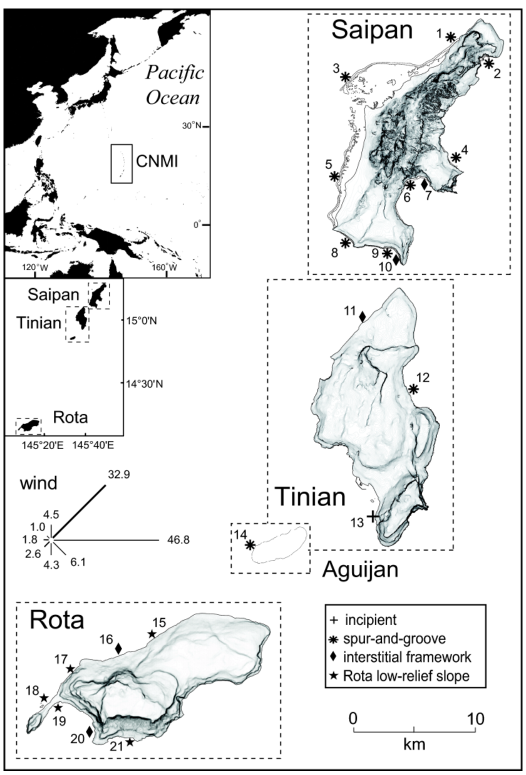

Figure 1(Houk et al. 2014, Figure 1). Map of the long-term monitoring sites across Saipan, Tinian, and Rota that were evaluated in this study. Reef types are indicated by symbols. DOI: 10.1371/journal.pone.0105731

From around 2003-2006, coral reefs in the CNMI experienced abnormally high abundances of the coral-eating crown-of-thorns seastar, *Acanthaster planci* (i.e. COTS; Fig. 2). High COTS densities led to an overall decline in coral cover but the magnitude, duration, and impacts of the outbreak varied significantly among islands and among sites within islands. On an island scale, Saipan was the most impacted by the COTS outbreak; predator densities were higher, coral loss was greater and recovery was incomplete and patchy. The results of these analyses indicate that relatively poor water quality, small fish (Fig. 3), and low abundances of grazing urchins may be partially responsible for these inter-island differences. On a site scale, reef type, wave exposure, and size of fish affected disturbance and recovery dynamics. These findings highlight the importance of improved water quality and fisheries management to support reef health and resilience.

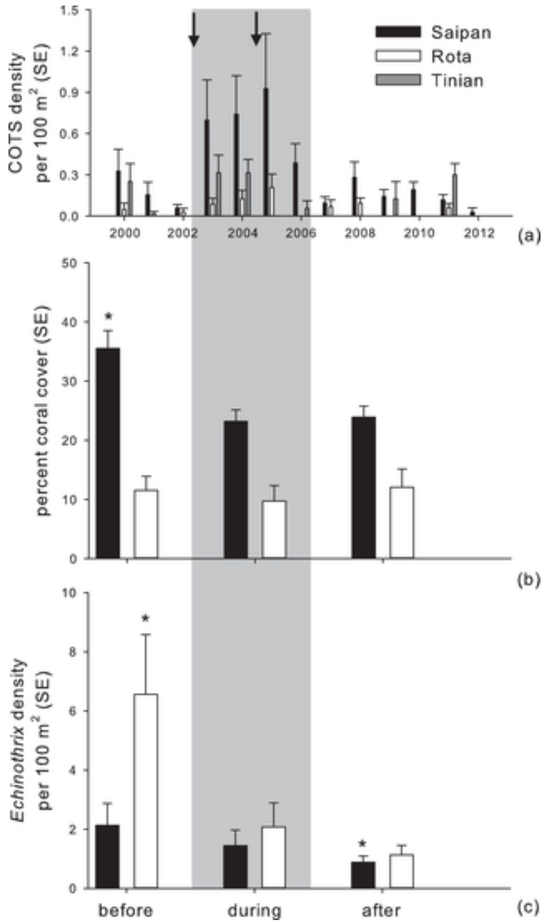

Figure 2 (Houk et al 2014, Figure 3) Density of Crown-of-Thorns Seastars (COTS) form 2000-2012 on Saipan, Tinian, and Rota (a) and percent coral cover (b) and Echinothrix density (c) before, during, and after the COTS outbreak on Rota and Saipan.

*(a). Densities represent island-based averages that diminish the highest and lowest observations in order to establish patterns across study years. Disturbance reduced coral cover on all islands, but recover trajectories, or the net rate of change, differed by island (b). Coral cover declined on Saipan with no significant recovery (*indicates P<0.05, repeat measures ANOVA and post-hoc tests), while a non-significant decline and recovery was noted on Rota. Echinothrix urchins also declined (c) in density during the disturbance period, with a further decline in the years after disturbance (*indicates P<0.05, zero-inflated hurdle models). Black arrows indicate tropical storms that passed by the study islands during the disturbance timeframe (grey rectangle box indicates the disturbance timeframe).*-Houk et al. 2014, DOI: 10.1371/journal.pone.0105731

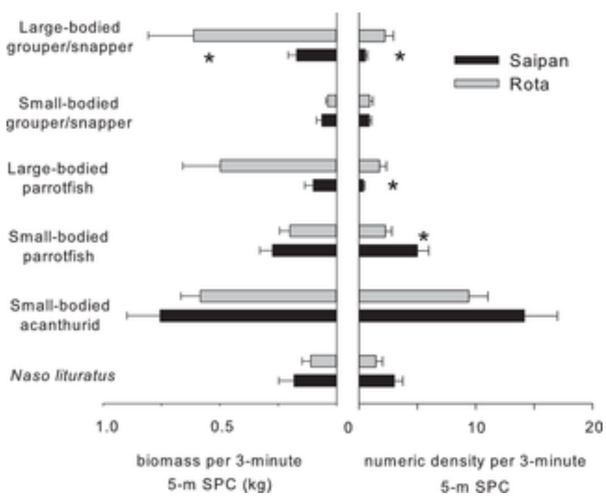

Figure 3 (Houk et al 2014, Figure 5) Fish Biomass and numeric density for major functional groups on Saipan and Rota. DOI: 10.1371/journal.pone.0105731

Priority watersheds

As the human population grows and coastal development increases, 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 identifying priority watersheds that were likely to benefit from active management. During the current award period, CAPs for the three identified priority watersheds (LoaLoa and Garapan on Saipan, and Talhakhaya on Rota) were completed or 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.

Talakhaya

The Talakhaya watershed on Rota primarily consists of public and protected lands that have historically been plagued by uncontrolled burning from fires presumably 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. 4). Whereas biological data have been collected at the Talakhaya site since 2000, the Ogok site was established in 2008 and has only been surveyed three times to date. Because restoration efforts have largely been focused on the more impacted eastern side of the watershed, the Ogok site may serve as a reference when evaluating the effectiveness of restoration efforts. 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 algae (Fig. 5). Coral cover declined significantly as a result of the 2003-2006 COTS outbreak, but recovered to pre-disturbance levels by 2013 (Fig. 6; Table 4). Around 2008, we also began seeing significant inter-annual fluctuations in macroalgae and fleshy encrusting algae (FEA), 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. 7). Because watershed restoration activities began in 2007, just as COTs densities returned to baseline levels, it is 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

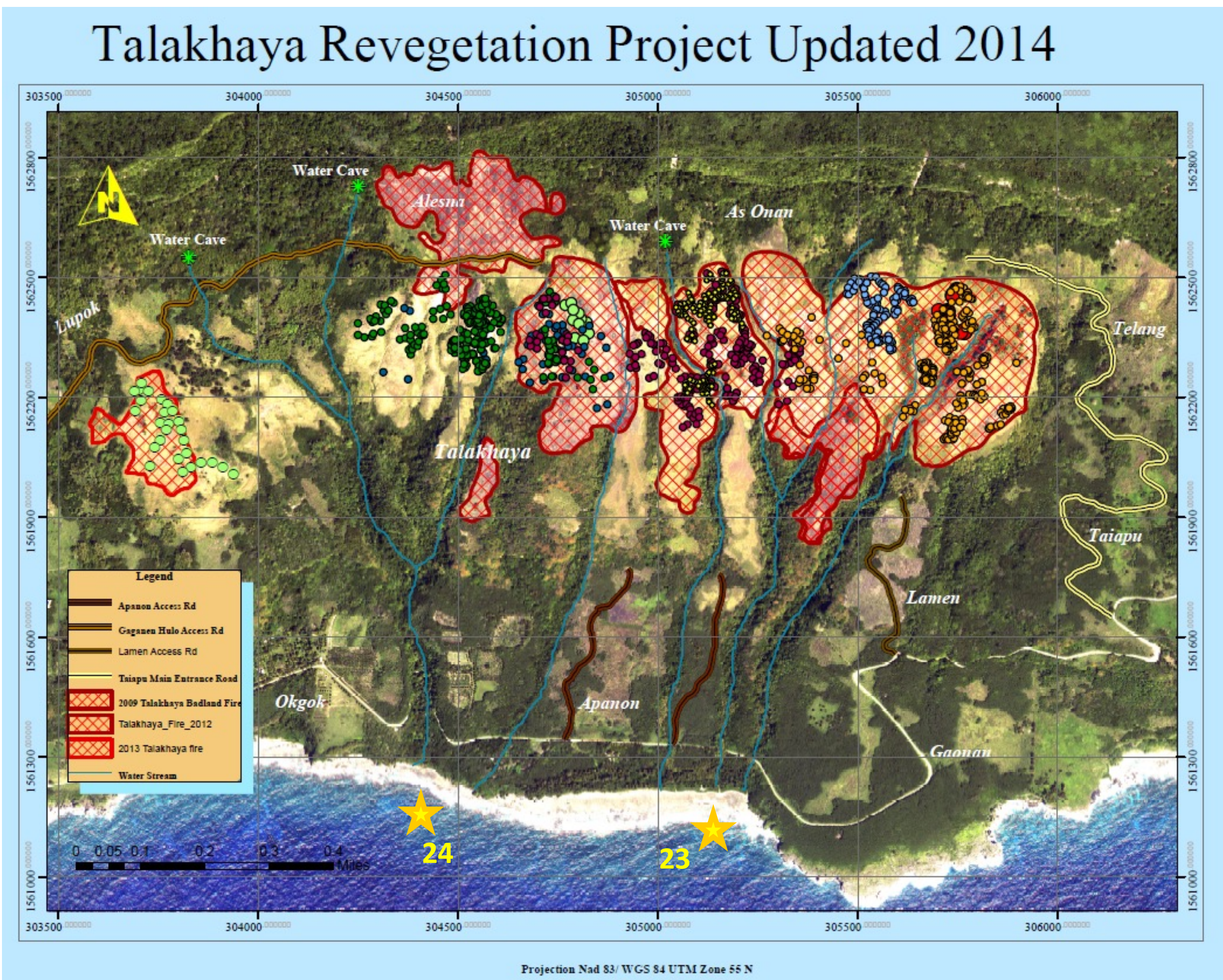

Figure 4 Long-term marine monitoring sites (Talakhaya, 23, and Ogkok, 24) associated with the Talakhaya watershed on Rota shown in in relation to recent fires and revegetation efforts. Colored circles represent grass and tree seedlings planted from 2007-2014.

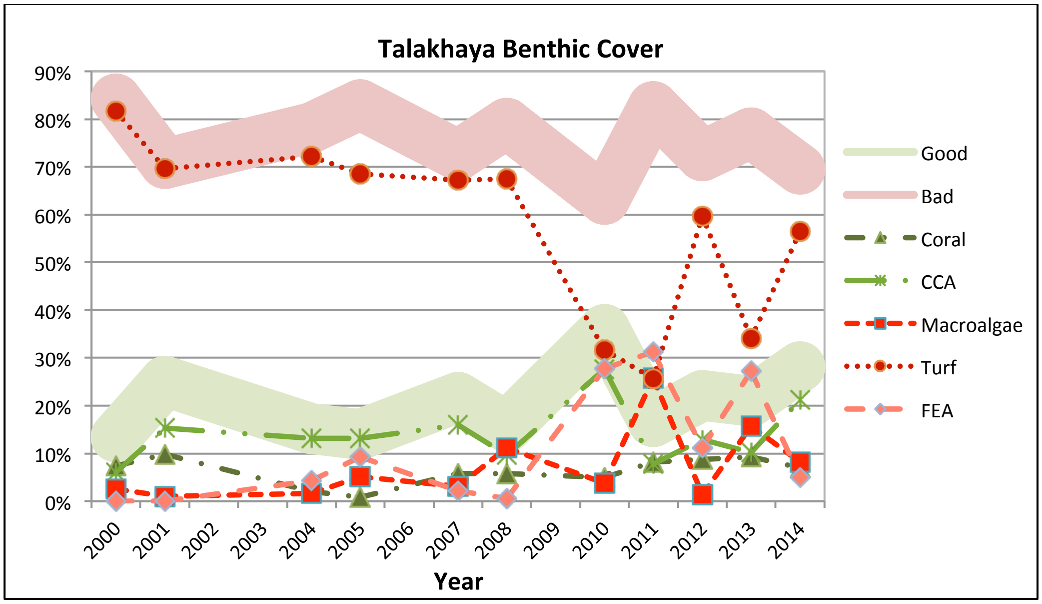

Figure 5 Trends in percent cover of major benthic substrate categories as well as the sum of "good" reef-accreting substrates, and "bad" non-reef accreting substrates for the Talakhaya long-term monitoring site. CCA= Crustose coralline algae; FEA= Fleshy encrusting algae.

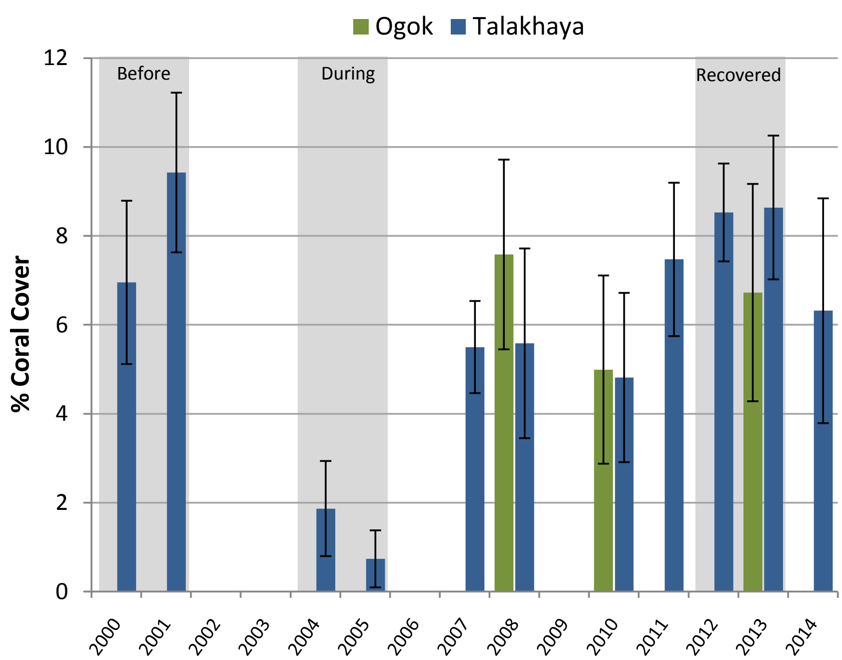

Figure 6 Trends in coral cover through time for the Talakhaya and Ogok monitoring sites. There has been significant variation in coral cover through time for the Talakhaya site (one-way repeated measures ANOVA, p <0.05); coral cover declined significantly as a result of the COTS outbreak from 2003-2006, but recovered significantly by 2012 (post-hoc pairwise comparisons; see table 4 for significance values). No change has been observed in coral cover at Ogok since monitoring began in 2008.

Table 4 P-values for post-hoc pairwise comparisons of coral cover between years for the Talakhay monitoring site: * $p < 0.05$; ** $p < 0.01$; ***$p < 0.001$.

	2000	2001	2004	2005	2007	2008	2010	2011	2012	2013	2014
2000	-		*	*							
2001		-	***	***	**	*	*				
2004			-		**	*		***	***	***	*
2005				-	***	*	*	***	***	***	**
2007					-				**	**	
2008						-					
2010							-		*	*	
2011								-			
2012									-		
2013										-	
2014											-

Figure 7 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, are also ongoing.

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. 8). Observed trends in key ecosystem parameters are illustrated below (Figs.9-11). 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 regime.

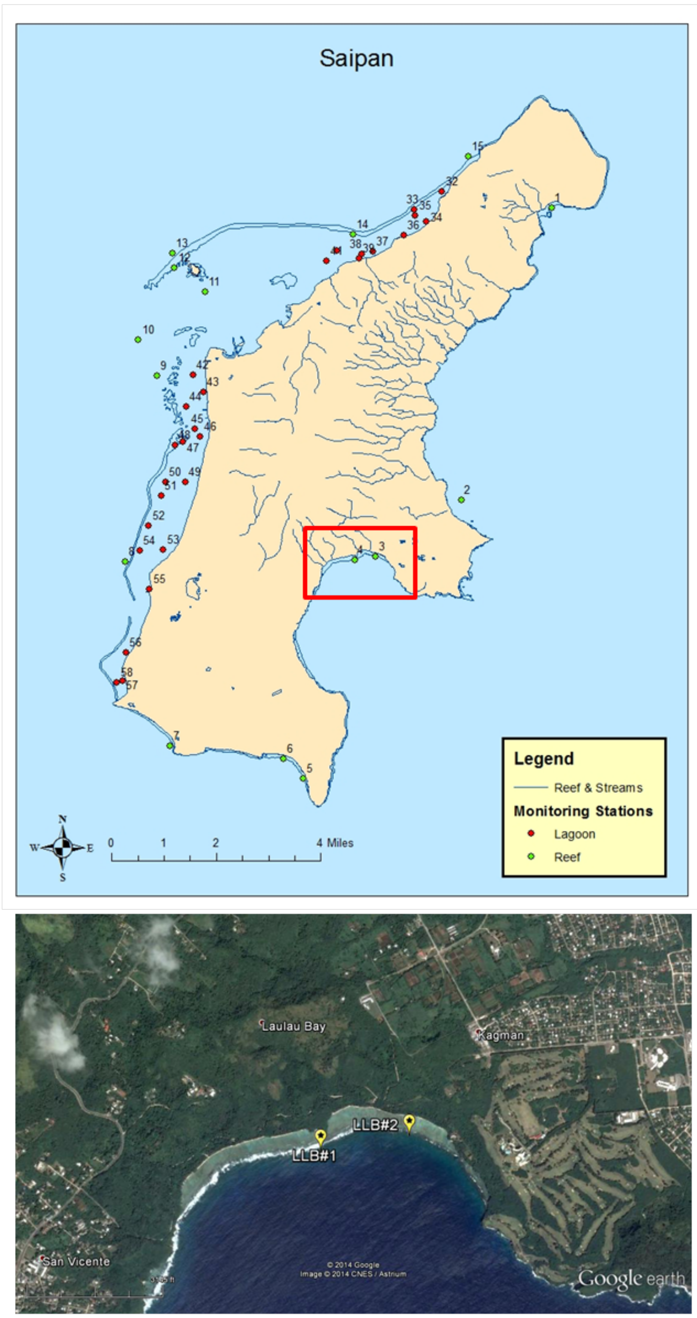

Figure 8 Coral reef monitoring sites associated with LaoLao Bay watershed.

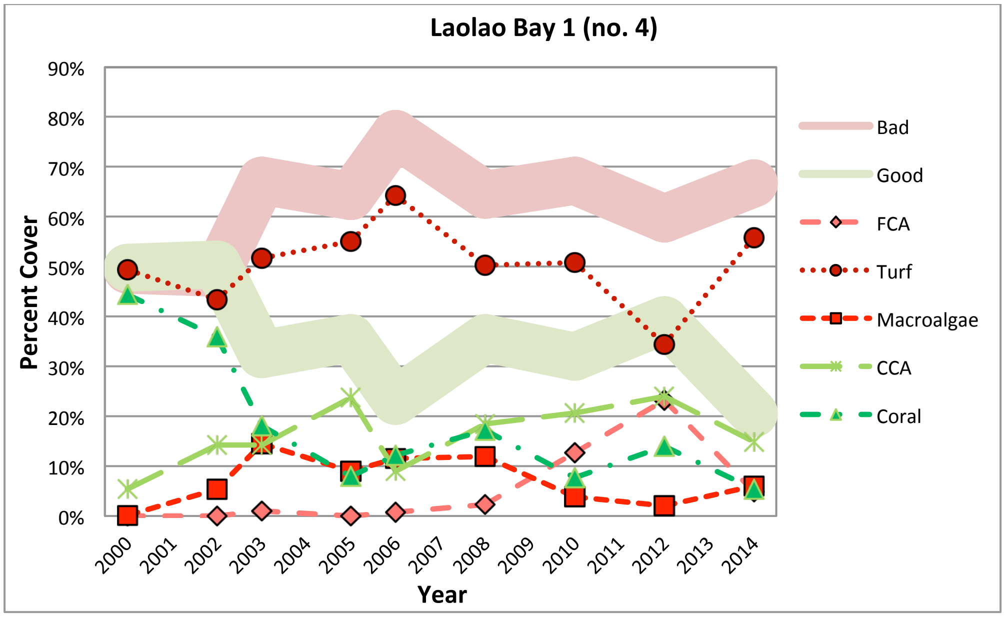

Figure 9 Trends in percent cover of major benthic substrate categories as well as the sum of "good" reef-accreting substrates, and "bad" non-reef accreting substrates for the LaoLao Bay1 long-term monitoring site. CCA= Crustose coralline algae; FCA= Fleshy encrusting algae.

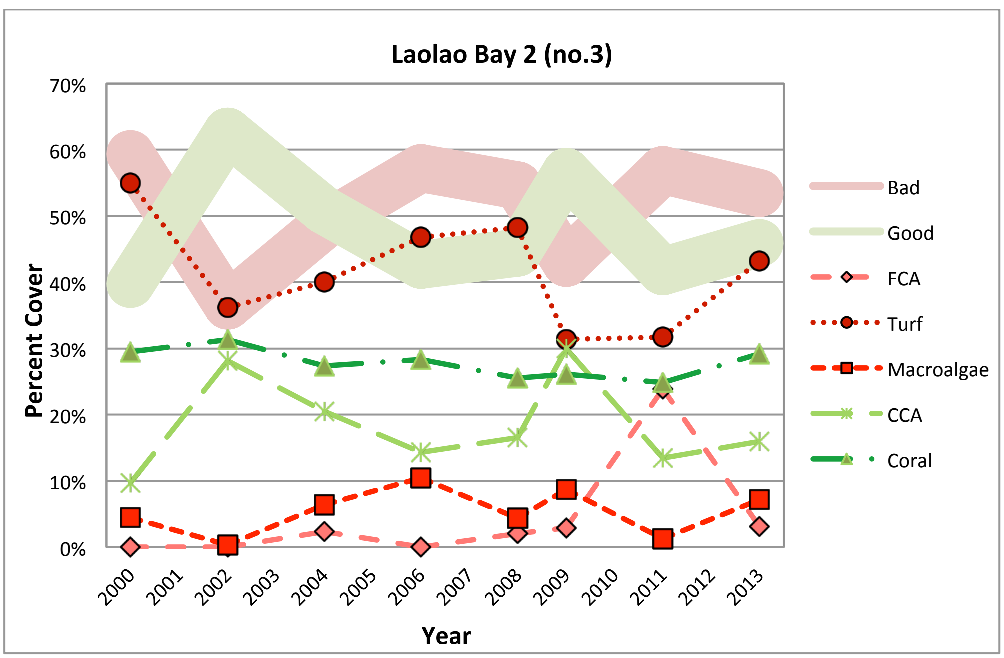

Figure 10 Trends in percent cover of major benthic substrate categories as well as the sum of "good" reef-accreting substrates, and "bad" non-reef accreting substrates for the Laolao Bay 2 long-term monitoring site. CCA= Crustose coralline algae; FCA= Fleshy encrusting algae.

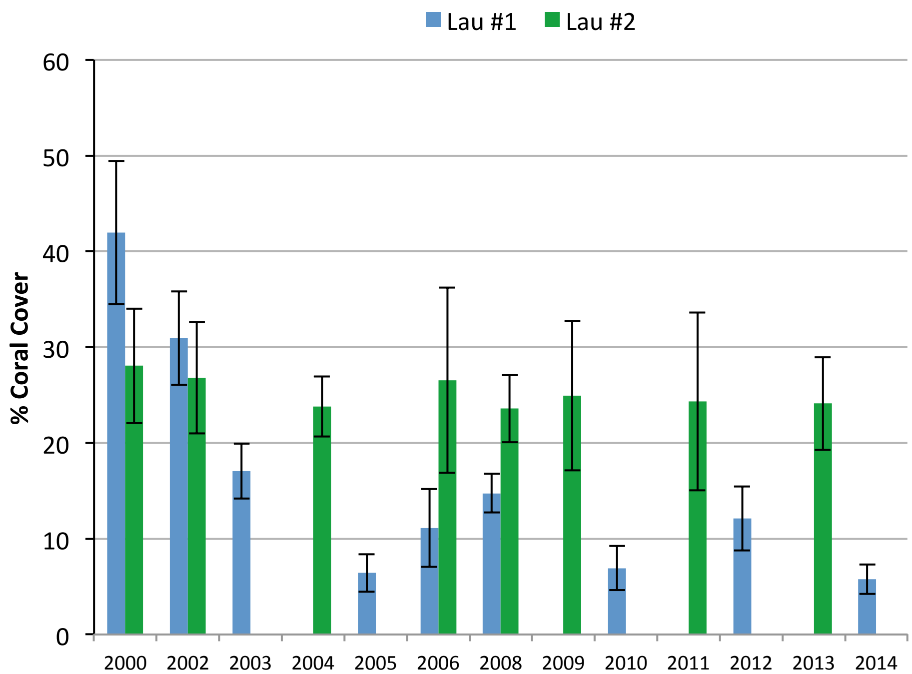

Figure 11 Trends in coral cover through time for the Laolao Bay 1 (Lau #1) and Lao Lao Bay 2 (Lau #2) monitoring sites. For Lau #1, coral cover declined significantly during the COTS outbreak from 2003-2006, with no recovery to date (p < 0.001; one-way repeated measures ANOVA, with post-hoc pairwise comparisons). Conversely, there has been no significant change in coral cover from 2000-2013 for the Lau #2 site.

OTHER RELATED PROJECTS

Bleaching response

Beginning in the summer of 2013, the Marianas islands experienced a mass coral bleaching event associated with higher than average sea surface temperatures and lower than average wind speeds (Reynolds et al. 2014). In response to this bleaching event, MMT collaborated with researchers from the University of Guam to survey reefs on Saipan and Rota. Surveys were designed to rapidly assess the magnitude (% of corals bleached) and patterns (species affected) of bleaching and bleaching related mortality across shallow (3-5m), spatially representative reefs. Other biological parameters associated with reef health such as fish and invertebrate assemblages were also characterized. The MMT conducted a total of 20 bleaching assessments across Saipan (n=7) and Rota (n=13). Data is being processed and analyzed by our collaborators at the University of Guam.

Resilience surveys on Tinian and Rota

During this award period, Dr. Johnston and Steven Johnson from MMT assisted in coral reef resilience surveys on Saipan, Tinian, and Rota. The objectives of the project 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 are ongoing. This project is collaborative effort among the University of Guam (UoG), The Marine Applied Research Center (MARC), NOAA Fisheries, and the CNMI BECQ office, with Dr. Jeff Maynard from MARC and Dr. Laurie Raymundo from UoG serving as the principal investigators. The outcomes of the project will help CNMI resource managers protect and improve coral reef resilience to climate change.

Northern islands surveys

From June 26 to July 20, 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.

We conducted a total of 62 surveys across seven islands (Uracas, Maug, Asuncion, Pagan, Guguan, Sarigan and Anatahan; Table 2). 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 as SCUBA diving was not supported on this cruise. 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. Due to environmental conditions (variable depth and surge) and snorkel restrictions, we had to modify our normal survey methods; surveys were conducted within an area approximately 250m x 20m, starting at the GPS location for each site. To assess benthic community composition and cover, a total of 75, 0.25m^2 photoquadrats were taken haphazardly across the distance of the survey area. To assess food fish assemblages, a snorkeler conduction 11 stationary point count surveys with a 5 meter radius along the length of the survey area. Algae and coral richness were determined by identifying and recording all species within 16 haphazardly located 0.25m^2 quadrats. The presence of all non-coral macroinvertebrate species within the study was recorded. 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. We were thus the first to document the impacts of recent thermal stress events on the shallow water coral communities of the northern islands. On Maug, Asuncion, and Pagan, we observed mild to moderate active bleaching of several of the more susceptible taxa but little evidence of high mortality from the 2013 thermal stress event. On Guguan, Sarigan, and Anatahan, however, we observed mass mortality of shallow water coral assemblages, likely due to the 2013 event. 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. While our surveys were conducted on shallow reefs (1 – 6 m), additional qualitative observations indicated that the mortality event extended to depths of at least 8 - 10 m. 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.

Table 2. Sites surveyed by the BECQ marine monitoring team during the *Insular Reef Fish & Bottomfish Bio-Sampling* cruise.

Site	Island	GPS X	GPS Y	Date	Site	Island	GPS X	GPS Y	Date
A-14	Uracas	144.902497	20.547791	6/21/2014	**D-18**	Pagan	145.756531	18.100817	7/9/2014
A-01	Uracas	144.901855	20.54407	6/21/2014	**D-05**	Pagan	145.713743	18.068599	7/10/2014
A-12	Uracas	144.889713	20.551993	6/22/2014	**D-03**	Pagan	145.740162	18.059719	7/10/2014
A-10	Uracas	144.886678	20.547666	6/22/2014	**D-06**	Pagan	145.710913	18.051839	7/10/2014
A-07	Uracas	144.886362	20.541824	6/22/2014	**D-09**	Pagan	145.794555	18.166461	7/11/2014
A-05	Uracas	144.889698	20.537087	6/23/2014	**D-14**	Pagan	145.760883	18.161277	7/11/2014
B-01	Maug	145.231654	20.013888	6/24/2014	**D-04**	Pagan	145.754723	18.147467	7/11/2014
B-02	Maug	145.236325	20.01734	6/24/2014	**E-01**	Guguan	145.8480062	17.30070093	7/12/2014
B-05	Maug	145.232617	20.028408	6/24/2014	**E-02**	Guguan	145.8411731	17.29774108	7/12/2014
B-15	Maug	145.220454	20.035966	6/25/2014	**E-08**	Guguan	145.8357738	17.30102873	7/12/2014
B-17	Maug	145.226109	20.032651	6/25/2014	**E-12**	Guguan	145.8492378	17.31514937	7/13/2014
B-20	Maug	145.214936	20.032531	6/25/2014	**E-10**	Guguan	145.8380427	17.32156717	7/13/2014
B-11	Maug	145.211779	20.018328	6/26/2014	**E-04**	Guguan	145.83502	17.31972958	7/13/2014
B-18	Maug	145.225515	20.030842	6/26/2014	**E-09**	Guguan	145.8315846	17.31077811	7/13/2014
B-04	Maug	145.229881	20.021952	6/26/2014	**F-03**	Sarigan	145.7877583	16.6999518	7/14/2014
B-21	Maug	145.227456	20.012359	6/26/2014	**F-05**	Sarigan	145.7879942	16.70605051	7/14/2014
B-14	Maug	145.207776	20.017002	6/27/2014	**F-10**	Sarigan	145.7829864	16.71456043	7/14/2014

B-13	Maug	145.218004	20.012057	6/27/2014	**F-09**	Sarigan	145.777658	16.71614736	7/15/2014
B-09	Maug	145.208611	20.027925	6/27/2014	**F-04**	Sarigan	145.774562	16.71365474	7/15/2014
C-02	Asuncion	145.407959	19.706158	6/28/2014	**F-15**	Sarigan	145.7661706	16.70590915	7/15/2014
C-20	Asuncion	145.398577	19.706254	6/28/2014	**F-06**	Sarigan	145.7836377	16.69175792	7/16/2014
C-16	Asuncion	145.391757	19.697591	6/28/2014	**F-07**	Sarigan	145.7732074	16.69706123	7/16/2014
C-01	Asuncion	145.407587	19.67679	6/29/2014	**F-02**	Sarigan	145.7870623	16.69329315	7/16/2014
C-08	Asuncion	145.400228	19.676747	6/29/2014	**G-12**	Anatahan	145.6615162	16.33178183	7/17/2014
C-21	Asuncion	145.390554	19.68332	6/30/2014	**G-04**	Anatahan	145.6461622	16.33209202	7/17/2014
C-14	Asuncion	145.390211	19.693802	6/30/2014	**G-14**	Anatahan	145.633026	16.35023986	7/17/2014
C-13	Asuncion	145.389478	19.688735	6/30/2014	**G-08**	Anatahan	145.6981677	16.36923607	7/18/2014
D-07	Pagan	145.773456	18.105659	7/8/2014	**G-06**	Anatahan	145.662585	16.37051672	7/18/2014
D-16	Pagan	145.793387	18.102631	7/8/2014	**G-02**	Anatahan	145.6506186	16.37005995	7/18/2014
D-08	Pagan	145.746854	18.092822	7/9/2014	**G-09**	Anatahan	145.6375215	16.36965165	7/19/2014
D-17	Pagan	145.733782	18.085993	7/9/2014	**G-13**	Anatahan	145.6334552	16.36212919	7/19/2014

Climate change research on Maug

Global climate change and ocean acidification (OA) associated with increased atmospheric carbon dioxide (CO_2) have been identified as major threats to coral reef ecosystems worldwide. Warming sea surface temperatures cause thermal stress to corals resulting in mass coral bleaching events and disease outbreaks. OA (declining seawater pH) resulting from increased absorption of atmospheric CO_2 impairs the growth and survival of corals and other calcifying organisms. Maug is an uninhabited volcanic island in the Northern Mariana Islands that serves as a natural laboratory for OA research. A submerged volcanic vent located within the caldera continuously releases CO_2, causing a decrease in the pH of the surrounding waters. The marine monitoring team has been collaborating with Dr. Ian Enochs from NOAA AOML to study the effects of lowered pH on the associated coral reef ecosystems.

From May 11-20, David Benavente and John Iguel of MMT 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.

From August 8-16, five members of MMT (Dr. Johnston, Dr. Okano, Steven Johnson, David Benavente, and John Iguel) 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

Figure 12 M/V *Paul Russ* hard aground on coral reef habitat near the entrance to the Port of Saipan on Sept. 9th, 2014.

On September 9, 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 (Fig. 12, 13). The CNMIs environmental response team for the incident consists of representatives from BECQ (MMT), DFW, and the local NOAA field office and is led by Dr. Johnston from 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. The analysis of the data is ongoing. Once the biological and economic impacts are determined, the next step will be to work with the responsible party to develop a comprehensive restoration and mitigation plan. All members of MMT have participated in the response effort.

Figure 13 Example of crushing damage to reef structure as a result of the Paul Russ grounding

NPS reef flat surveys

In September of 2013, members of the MMT (Lyza Johnston, Steven Johnson, and John Iguel) travel 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 30 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 six 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, the CNMI has been experiencing a die-off of the blue-banded surgeonfish, locally know as Hiyok (*Acanthurs lineatus*). Thousands of dead fish have washed up on beaches around Tinian and Saipan and "sick" fish have been observed swimming erratically on the reef flats. The fish kill response is being 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.

Education and Outreach

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.

- 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 Reynolds T, Burdick D, Houk P, Raymundo L, and Johnson S (2014) Unprecedented coral bleaching across the Marianas Archipelago. Coral Reefs DOI 10.1007/s00338-014- 1139-0

OBSTACLES AND DELAYS

The major obstacle during the 2011-2014 award period, was that the long-term marine monitoring program was largely understaffed; two of the three monitoring positions within the Division of Coastal Resources Management, including the lead biologist, were vacant until the last ten months of the no cost extension. The third position, filled by David Benavente was functionally vacant from January, 2013 to May, 2014 while Mr. Benavente was on educational leave finishing his Master's degree at the University of Guam. The majority of the marine monitoring duties during this time fell on staff from the Bureau of Environmental and Coastal Quality (BECQ; formerly the Division of Environmental Quality) not funded under this award. The lead biologist and marine technician positions were filled in November, 2013 and Mr. Benavente completed his Master's program and returned to work full-time at BECQ Division of Coastal Resources Management (DCRM) in May, 2014.

REFERENCES

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.

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

Houk P, Starmer, J (2008) Marine and Water Quality Monitoring Plan for the Commonwealth of the Northern Mariana Islands. Technical Report by the CNMI Division of Environmental Quality and Coastal Resource Management Office, Saipan, MP.

Houk P, van Woesik R (2008) Dynamics of shallow-water assemblages in the Saipan Lagoon. Marine Ecology Progress Series 356:39-50

Houk P, van Woesik R (2010) Coral assemblages and reef growth in the Commonwealth of the Northern Mariana Islands (Western Pacific Ocean). Marine Ecology 31:318-329

Houk, P. and Wiles P. 2010. Water quality and herbivory interactively drive coral-reef recovery in American Samoa. *PLoS ONE* 5(11): e13913.

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. Technical report created for the CNMI Bureau of Environmental and Coastal Quality, Saipan, MP.

Reynolds Reynolds T, Burdick D, Houk P, Raymundo L, and Johnson S (2014) Unprecedented coral bleaching across the Marianas Archipelago. Coral Reefs DOI 10.1007/s00338-014-1139-0

Rogers, C. S. (1990). Responses of coral reefs and reef organisms to sedimentation. *Marine ecology progress series. 62*(1), 185-202.