Enhancing coral-reef monitoring programs, data analysis, and reporting in Guam and the Commonwealth of the Northern Mariana Islands

Progress Report 9/1/11 – 8/31/12

Applicant Organization: Pacific Marine Resources Institute, Inc. (PMRI)

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Relevant Program Priorities (in prioritized order):

(c) Land-based sources of pollution
(a) Fishing Impacts
(f) Emerging local management concerns
(d) Climate change

Geographic Location: Commonwealth of the Northern Mariana Islands and Guam

Federal Funds Requested: $49,990

Matching Funds Available: $50,090

Project Start: 09/01/2011

Project Completion: 08/31/2012

Project summary:

Despite a well-founded team of governmental agency staff that conduct annual coral-reef monitoring activities in Guam and the Commonwealth of the Northern Mariana Islands (CNMI), the desirable monitoring framework (*data collection – processing – reporting – applying to management*) remains limited due to financial, technical, and personnel capacity needs. Earmarked coral monitoring grants provided by NOAA have been essential for maintaining monitoring program staff that continue to develop datasets. However, building deeper insight and meaning behind the data being collected, and its practical translation for management, requires additional expertise and resources. Thus, collaboration is instrumental for monitoring program success. The Pacific Marine Resources Institute, a small non-profit organization dedicated to improving coral-reef monitoring and the application of science to management, has become established with these concepts in mind (www.pacmares.com). The present grant award focused on improving local monitoring programs in Guam and CNMI by facilitation their professional collaboration with Dr. Peter Houk, and providing digestible summaries of the lessons learned to a wider audience through both the peer-reviewed publication and outreach process. Specifically, partnerships have ensured consistency and accuracy in collecting monitoring datasets, assisted in designing localized database frameworks, provided assessments and a template for the assessment of newly developed monitoring protocols, and most notably, provided a professional analysis and reporting of monitoring trends. Major accomplishments included: 1) the development of datasets to assess differential coral-reef recovery from natural disturbance cycles in the CNMI over the past decade due to varying levels of water quality and herbivory, 2) translation of decadal trends to CNMI's resource managers, key stakeholders, and decision makers, 3) assisting with the development of Guam's coral monitoring program, including program design, initial data assessment for statistical power, and evaluation of year 1 datasets, and 4) preparing a peer-reviewed publication (*in press*) that summarizes key lessons learned for the benefit of a broader audience dealing with coral-reef monitoring.

Summary of progress:

Major action items complete are listed below, and described in further detail within the report.

- Assessed survey designs with Guam's monitoring program
- Evaluated monitoring datasets for both jurisdictions to ensure a desirable balance between sampling effort and statistical confidence exists for all protocols
- Collaboratively recommended adjustments that have been integrated into long-term monitoring designs
- Prepared a formal analysis of monitoring datasets from both programs and summarized collective lessons learned across both monitoring programs into a peer-review manuscript (*accepted pending final revisions, Bioscience, attached*);
- Combine datasets across Guam and CNMI's monitoring program to evaluate how coral reef condition changes across iconic *Porites rus* habitats that constitute Marine Protected Areas across all islands
- Improving the local taxonomic expertise of CNMI's coral reef monitoring staff;
- Assist in developing 2012 monitoring datasets (coral, benthic, fish and macroinvertebrate assemblages) across CNMI;
- Developing a data storage and sharing structure for CNMI's monitoring program in association with local partners;
- Lead group analyses of decadal trends with CNMI's program to interpret how putative stressors impact coral recovery patterns;
- Conducted numerous public presentations that summarize CNMI's reef status for key stakeholders and decision makers: Rotary Club, Fishing Association, Legislature, local community college, resource management agencies/directors, and local monitoring program personnel;
- Aided with the development of improved fishery legislation in CNMI that is currently being considered for introduction by the natural resources management legislative committee.

Narrative of project progress:

CNMI –

CNMI's coral-reef monitoring program was formally initiated 12 years ago as a partnership between the CNMI Coastal Resources Management Office (CRM, who manage the NOAA monitoring grant) and the Division of Environmental Quality (DEQ, who manage EPA non-point source pollution and water quality grants). Although some protocols have been updated as new insight and technology emerged over the past decade, the standardized approach taken provides unique insight into ecological trends through the past decade, rarely available. Despite a relatively long history of incorporation, the current program is facing the challenges of staff turnover, and thus is at a critical juncture with respect to long-term consistency. Collectively, the present project was focused upon ensuring program consistency and developing insight into decadal trends. Specific tasks completed are listed, while major tasks are described in detail below:

1) Assisting with the collection, development, and QA/QC of 2012 monitoring datasets
2) Build localized, Microsoft Excel based databases with restrictive features that maintain data quality into the future, and are appropriate for eventual transfer into MS Access-based databases once developed (i.e., the Micronesian Challenge database currently under development)
3) Assist the program with incorporating fish assemblage monitoring into their ‘ecosystem-based’ program, which was historically focused upon coral populations, benthic substrates, and macroinvertebrate abundances across 30 sites spanning Rota, Tinian, and Saipan
4) Assist the program with field surveys, namely coral population surveys and taxonomic insight needed to conduct them
5) Assist the program develop a simple and safe sharing process and policy
6) Undertake a collaborative analysis of long-term trends through time with respect to human and natural stressors
7) Provide digestible summaries of the state of coral-reef science through numerous vectors described within, inclusive of presentations to key stakeholders, assisting with preparing enhanced fisheries legislation, and publication of findings

Data and databases:

Individual databases for each survey protocol have undergone a collaborative quality control and assurance procedure, including: benthic substrate abundances, macroinvertebrate densities, coral assemblages, and newly collected fish abundance data. Initially, data entry inconsistencies and errors were identified and corrected for the entire 10-year dataset. Data validations were next established for the entry of new information, consisting of dropdown lists where only specified fields are allowed to populate the data tables. Next, a series of lookup tables were established to translate scientific names into informative grouping categories for analyses, such as fish functional groups or trophic levels. Finally, backups of all datasets reside in three independent offices, and a collaborative copy remains online for updating and sharing using the free cloud computing software “Dropbox”. These consistent formats were needed to facilitate the next steps of data interpretation and analyses, and provide a foundation for program consistency and efficient data analyses into the future.

Incorporation of fish assemblage data:

Since the inception of CNMI’s coral monitoring program, fish and fishery monitoring has never been a central focus due to a lack of available resources and personnel, and jurisdictional overlap with the local Division of Fish and Wildlife. However, as long-term coral assemblage and benthic substrate trends have developed, it is becoming clear that data pertaining to putative stressors (i.e., water quality and fisheries) are needed to aid our understanding of the emerging temporal dynamics. This situation formed the basis for using additional resources to incorporate fish assemblage surveys into monitoring protocols. PMRI’s (Dr. Peter Houk) role in this process has been to advise the program on the advantages and disadvantages of several common protocols that exist, help perform initial surveys to assess pilot data, and lead a collaborative assessment of the resultant data quality (*attached manuscript in press*). We currently have developed datasets for all sites using standard protocols that included 12 replicate stationary point counts at each site, within which all fish were recorded to the species level within a 5 m circular area for a 3-minute time period.

Decadal trends in CNMI's nearshore coral reef assemblages:

Beyond assisting with CNMI's program structure and design, a major aspect of this project has been to perform a collaborative analysis of decadal trends alongside MMT personnel. This approach has resulted in both the development of novel science for CNMI and beyond, as well as provided essential training for MMT staff in professional approaches towards data analysis. Our goals were to understanding the nature and extent of recovery following *Acanthaster planci* (Crown-of-Thorns Starfish, COTS) disturbances that were anomalously high between 2003 – 2006 (Figure 1a).

In accordance with high COTS abundances between 2004 - 2007 there was an overall decline in coral cover (Figure 1b) and colony size (Figure 2) at many long-term monitoring locations, with recovery trends differing strongly by island. Saipan, the capital and population center, had significantly diminished recovery as compared with Rota. Deeper insight into coral assemblage dynamics on Saipan revealed stark differences in recovery trajectories from disturbance years (Figure 3). Beyond just impacting coral assemblages, the COTS abundances seem to have directly impacted grazing urchin populations as well. Notable declines in grazing sea urchin were concomitant with high COTS abundances, which purports competition for limited refuge within the reef matrix, and potential displacement of urchins by COTS (Figure 1c). Given the influential role grazing urchins play in controlling algal abundance on coral reefs, as well as the suite of localized stressors that might contribute to differential recovery patterns, we next performed regression modeling to quantify the relationships between localized stressors and reef condition.

Reef condition was defined by benthic assemblage trends. First, we calculated a benthic substrate ratio as the percent cover of all calcifying corals and crustose corralling algae divide by less calcareous turf, fleshy coralline, and macroalgal growth. For each site we added the mean percent decline in benthic substrate ratio during disturbance years to the mean percent improvement in the years following disturbance. The resultant percentages indicated a rate of benthic substrate recovery. We subsequently asked how a suite of localized stressors and environmental regimes may have driven benthic substrate recovery. Independent variables included proxies to pollution (watershed size, development, and human population), grazing (grazing urchins, herbivorous fish, and sea cucumbers), and natural regimes (i.e., wave exposure).

Regression indicated that three significant, but weak models existed. In all three instances wave exposure was a primary predictor of recovery, whereby higher recovery was associated with greater exposure and flushing. Strong secondary interactions emerged when adding metrics of herbivory into the models (i.e., herbivore size, herbivore biomass, and grazing urchin density; $R^2>0.24$, $P<0.05$ for all, Figure 4). In all instances, recovery increased with grazing. However, deeper insight came from stratifying our examinations across reeftypes. Four distinct reeftypes exist across the monitoring stations in the CNMI (Houk and van Woesik, 2010). Two have notable coral presence (spur-and-groove and loose-framework reefs), and two have limited coral presence (incipient reefs and Rota reefs). Previous studies and monitoring reports describe this situation in detail, but the reason for failed coral growth in the latter two reeftypes are

Figure 1a-c. Mean COTS abundances at all monitoring locations across the CNMI (a-top). The influence of COTS abundances is highlighted by examining change in live coral cover at two islands that differed in human influence over the past decade (b-middle). Finally, secondary impacts of COTS on grazing urchin populations are noted (c-bottom). In all instances, letters indicate statistically differentiated groups.

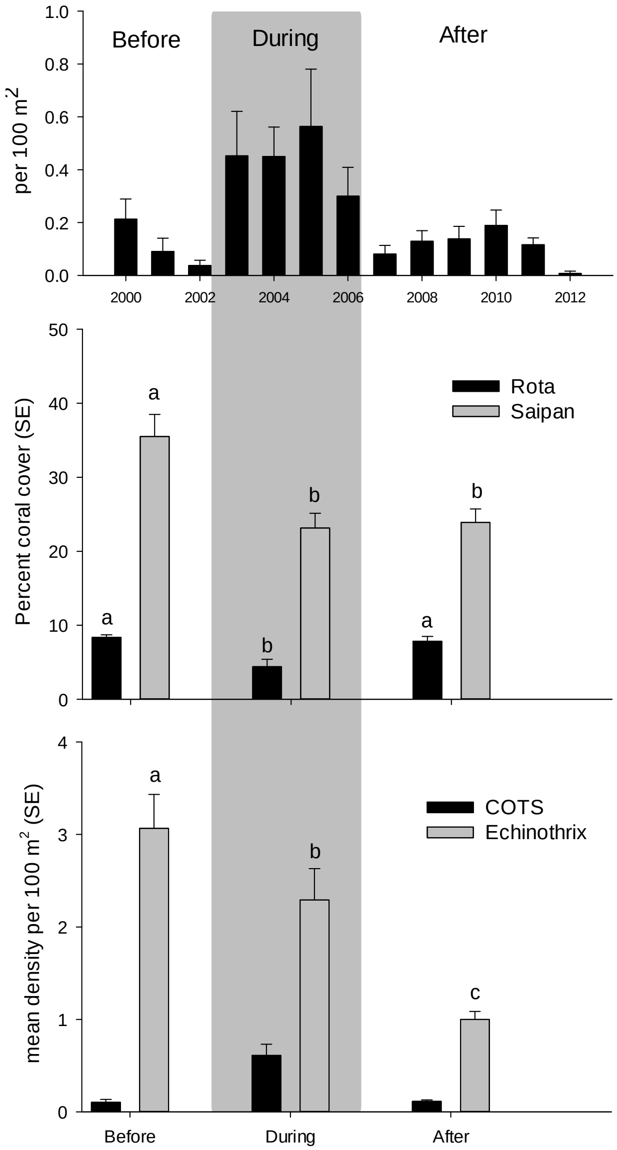


Figure 2. Declines in coral colony sizes in accordance with high COTS years, note the return of favorable coral colony sizes on Rota as compared with Saipan.

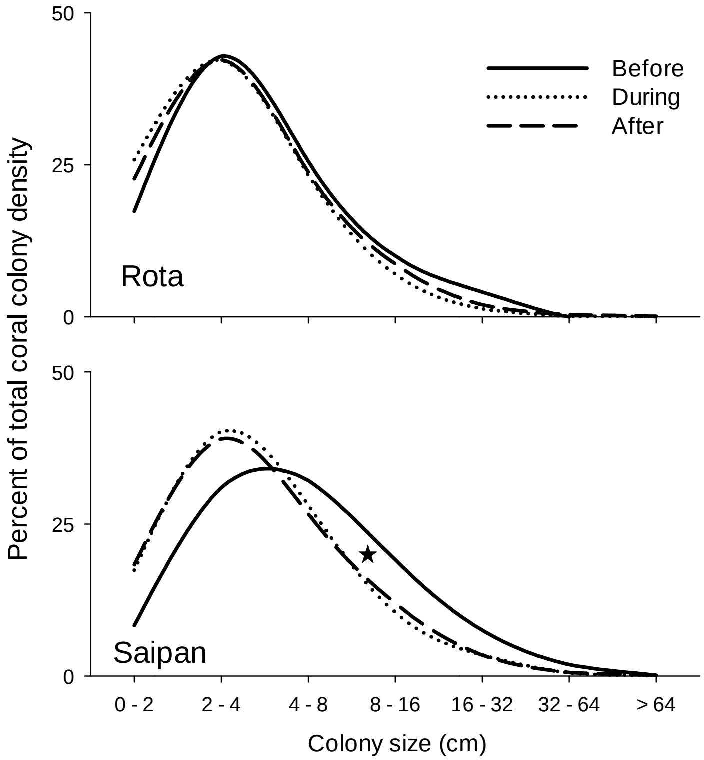
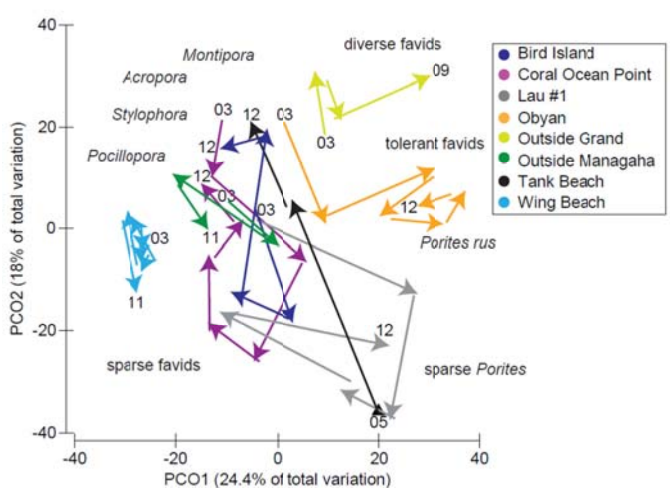


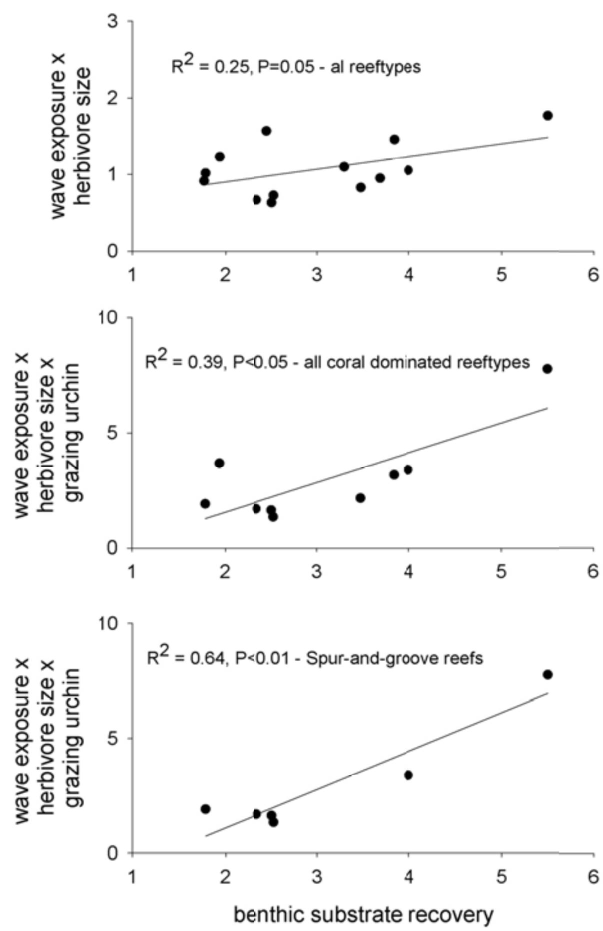
Figure 3. Principle components ordination plot highlighting differential recovery in coral assemblages following COTS disturbance years. Each color indicates a long-term monitoring site and vectors depict coral assemblage transitions across the years. Start and ending years are labeled on figure, intermediate years were left out for clarity. Coral names are provided for all genus (or functional groups) that were the strongest drivers of the noted trends. Note a general shift from Acropora, Montipora, and Pocillopora to favids and Porites during disturbance years, followed by differential rates of recovery.



consistently high wave exposure for incipent reefs and significant groundwater contribution to the nearshore reefs around Rota due to island geology. When we examine regression models for reeftypes where notable coral growth exists, the relationships between benthic substrate recovery, exposure, and herbivory grew significantly (Figure 4). Further, when we only consider the most optimal reef settings in the CNMI (i.e, the spur-and-groove reefs), relationships with benthic substrate recovery were maximal (Figure 4). This example highlights the strong influence of exposure regime and herbivore populations in dictating recovery dynamics in the CNMI. Notably, no significant regression models included proxies to land-based pollution, suggesting that when considering reefs across all of CNMI, land-based pollution may represent weaker driver of recovery dynamics.

We strive to continue our decadal recovery examinations and formalize our findings into both a scientific publication and digestible summaries for stakeholder consumption. Once developed, such insight offers ideal input into policy and management strategies.

Figure 4. Example regression modeling results depicting the how benthic substrate recovery following COTS disturbances was predicted by wave exposure and mean herbivore size. From top to bottom the models include: all reeftypes, only reeftypes with notable coral presence, and only the well-developed, spur-and-groove reeftype.



Guam –

With regards to Guam's monitoring program, individual tasks ranged from assessing question-driven protocols for their ability to answer pressing management questions, assisting with database development and query, quantitatively assessing decadal trends with respect to localized stressors, and summarizing our findings for wider audiences. These efforts have not only assisted the programs in evaluating the current status of their reefs and monitoring designs, but the collective results have been assimilated into a peer-reviewed manuscript that was developed to share common insight gained (*attached*).

The central theme of the lessons shared is that many monitoring programs determine questions that can be answered *after* monitoring programs are initiated, rather than clearly developing questions that need addressing *before* monitoring commences. The improved approach taken by Guam's monitoring program was to first gain a better understanding of the natural strata and population distributions of corals and fish prior to establishing protocols. Thus, the pilot study approach taken by Guam greatly improved their ability to decide upon long-term protocols.

Guam's pilot monitoring study took a stratified approach to assess the efficacy of a limited-take marine protected area (MPA) in Tumon Bay. Randomized transects were placed along the outer reef slope, at 7 - 15 m, within the MPA and also within a reference location (Figure 5a). Initial studies found that coral assemblages varied predictably along a gradient of wave exposure. Particularly variable was *Porites rus,* which is more common in sheltered bays than on shallow exposed slopes (Figure 5b). At the site-level, the wave-exposure gradient in Tumon Bay resulted in a high (statistical) variance in coral coverage estimates, and the pilot study found a low (statistical) power to detect change through time. One common resolution to the high variance problem seen in Tumon Bay, would be to increase the number of replicate transects surveyed to increase power. Alternatively, a second option would be to stratify the sampling regime based on predictable wave exposure. Subsequent surveys showed that food-fish abundances were not influenced by the same wave-exposure gradient as corals (Figure 5c), and because the goal of monitoring is to evaluate trends and relationships in both assemblages, further stratification has been undertaken. This example supports that sampling protocols strongly influenced the population variances, which in turn constrained the questions that could be answered.

We next addressed the common problem of addressing high population variances that are common to coral reef ecosystems (i.e., variable fish abundance estimates). In order to examine what happens if programs encounter influential natural regimes with their survey designs and protocols, an example was developed. Statistical power versus sampling effort for hypothetical coral and fish populations that were 'aggregated' (distributed evenly among the sampling area, such as site-attached, small-bodied, surgeonfish) and 'sparsely' (distributed irregularly across the sampling area, such as large-bodied parrotfish and larger predators) distributed was plotted (Figure 6, R-code for assessing statistical confidence versus effort provided as a reference for any interested monitoring program provide through numerous vectors). As sampling effort increased, the estimated means remained similar for both populations. However, a reduced standard deviation quickly became evident for the aggregated population, which led to improved statistical confidence in detecting a change. In order to improve our confidence in sparsely distributed population estimates, a hypothetical tripling of sampling effort was performed. This

Figure 5a-c. (a) Map of Tumon Bay, Guam, with a polygon showing the boundary initially used for coral-reef monitoring. Points indicate randomly generated sampling locations within the defined boundary at the 7 – 15 m depth. Principle component ordination (PCO) highlighted a clear gradient in benthic assemblage structure (b) that was driven by Porites rus coverage that was highest where exposure to northeast wind and swell was minimal. Circle size indicates the percent cover of P. rus, while the numbers indicate a measure of distance from the easternmost, protected portion of the bay. A similar PCO plot for fish assemblages (c) showed no clear trends along the same gradient of exposure. Here, circle size represents total fish biomass per stationary point count (SPC), and numbers again indicate wave exposure.

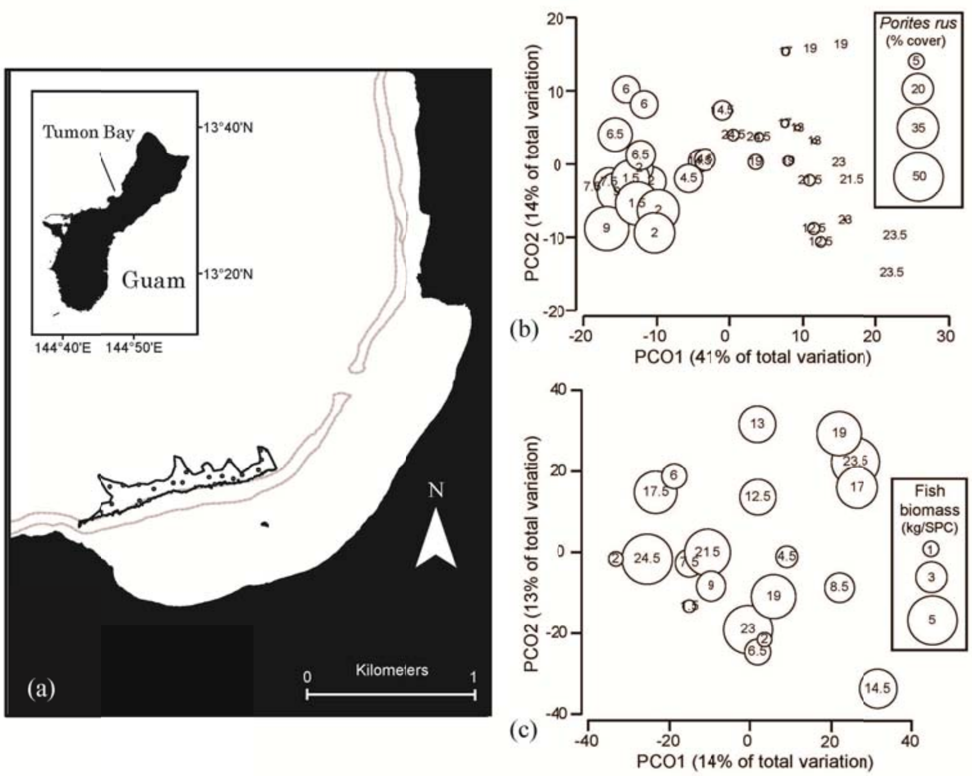
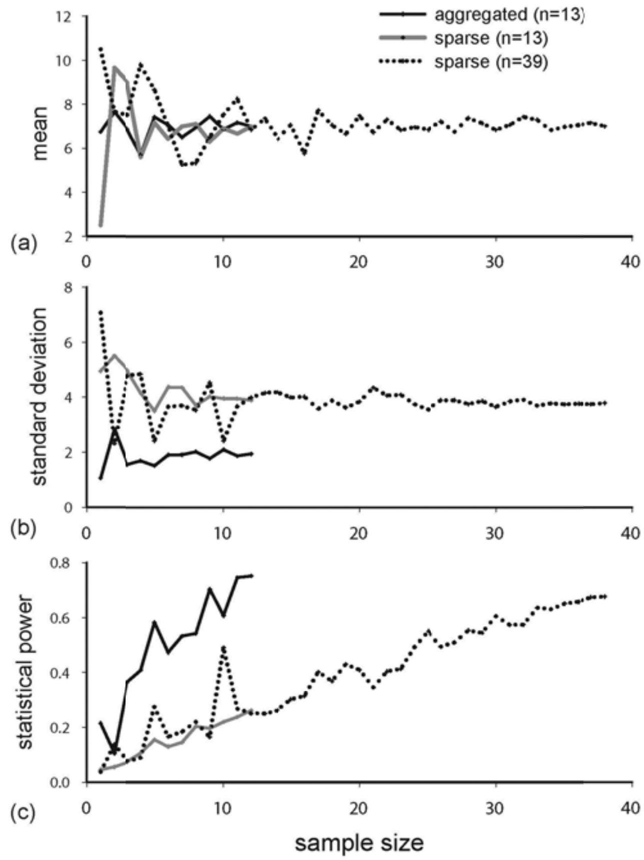


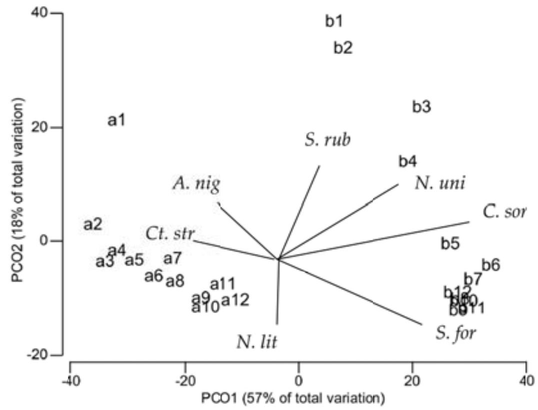
Figure 6a-c. Estimates of (a) population means, (b) standard deviations, and (c) statistical power as a function of sample size for: (1) an aggregated population (n=13, mean of 7 ± 2 SD), (2) a sparsely distributed population (n=13, mean of 7 ± 3.9 SD), and (3) a sparsely distributed population sampled with tripled effort needed to attain high (>70%) statistical power (n=39, mean of 7 ± 3.8 SD), assuming α=0.05 and a change detection threshold (delta) of 30%.



approach was consistent with the Tumon Bay dataset. While tripling sampling effort resulted in obtaining the high statistical power desired, the standard deviation reached an asymptote by the time only 13 samples were taken. Thus, the continuous rise in statistical power was simply an artifact of increasing the sample size (*n*, where power~1/(variance/*n*), and had nothing to do with an improved ability to account for the spatial variance in the population. So, the pertinent question that remained was, how can programs improve upon their statistical confidence while maintaining a realistic level of sampling effort?

Our approach to this dilemma was to assess trends using a novel metric of multivariate statistical confidence that decreased the assemblage-level population variance (Figure 7). Principle component ordinations were used to depict the relationship between sampling effort and saturation of the coefficient of variation (i.e., the point where additional effort did not improve multivariate confidence intervals). Using the sampling intensity at the saturation point, we found

Figure 7. Principle component ordination (PCO) plot of food-fish abundances from two exemplary long-term monitoring sites ("a" and "b"). Numbers refer to sampling effort (the number of replicate stationary point count surveys considered), and data points represent sample centroids (the mean location of assemblage estimates in multivariate space given varying sample sizes). Saturation is considered to be the point where additional replicates do not change the overall centroid location.

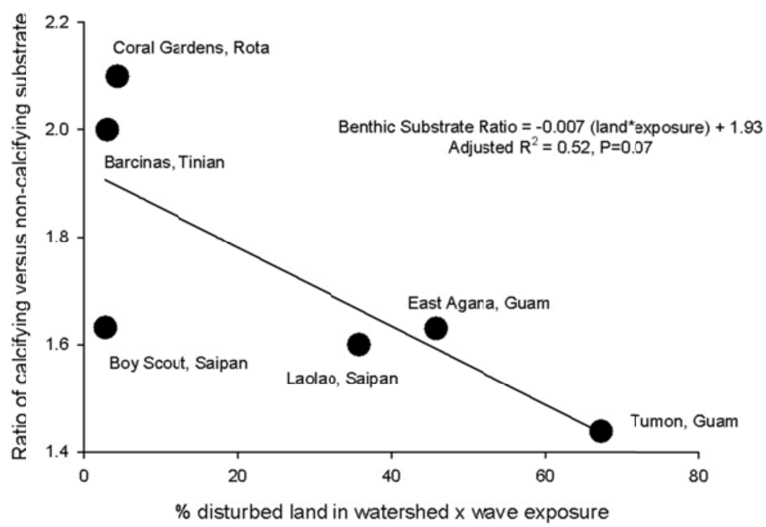


no significant difference in overall fish biomass based upon univariate comparisons between these two study sites that differed in management status (5.85 kg ±0.63 versus 4.17 kg ±0.58 per SPC, t-statistic = 2.02, P=0.065, t-test). There were, however, significant difference in fish composition based upon multivariate pairwise comparisons (Pseudo F-statistic = 2.38, P=0.006, PERMANOVA test) (Anderson et al., 2008). Multivariate patterns were subsequently interpreted using vector overlays that depicted species weights based on their correlation coefficients, highlighting the relative contribution of each species in determining the overall plot structure. Similar pairwise comparisons of all major fish families would suffer from non-independence and require extensive Bonferroni, or other P-value corrections. This example highlights how taking a complementary, multivariate approach that best matches species rich fish assemblages on coral reefs improved our ability to interpret emerging trends confidently. Thus, programs can benefit from bet-hedging and employing a variety of sampling and analytical techniques.

Analysis of *Porites rus* habitats

Across Guam and CNMI, a unique, *Porites rus* dominated habitat exists in several wave-protected embayments (Houk and van Woesik, 2010). It is speculated that this habitat has formed due to both low wave exposure and significant groundwater contribution through karst aquifers. Regardless of cause, *Porites rus* habitats are very influential for Guam and CNMI for their tourism industry and easy access for recreational fishers. Interestingly, these habitats represent marine protected Areas on Saipan (Laolao Bay), Tinian (Barcinas Cove), Rota (Coral Gardens), and Guam (Tumon Bay). Given their disproportional contribution to society and tourism, it is critical to improve our understanding of what drives reef condition in these habitats. Similar to the CNMI example, regression analyses were undertaken to examine how wave expsure, herbivory, and water quality might be driving habitat condition. In this example we used benthic data from both CNMI and Guam monitoring programs to calculate a ratio of calcifying versus non-calcifying substrate on the *Porites rus* reefs. Our initial analyses found that wave exposure and proxies to pollution were the strongest drivers of reef condition (Figure 8). Interesting, these results are contrary to the CNMI example (*above*) where herbivory was the strongest driver of recovery, yet these results were expected as known connections between the watershed aquifer and *Porites rus* habitats exist. Thus, while herbivory appears to be the dominant driver of reefs at the island scale, *Porites rus* habitats, which constitute <10% of the entire reef area, are uniquely sensitive to watershed pollution. Similar to the example above, these initial results are slated for future investigation, and the results are essential for key stakeholders who can influence management and policy.

Figure 8. Regression model highlighting significant relationships between reef condition (i.e., benthic substrate ratio, see text), wave exposure, and a proxy of land-based pollution. Note all sites represent Porites rus dominated habitats, representing reefs where known connections between the watershed aquifer and salinity levels exist.



Other outreach activities completed:

Beyond the training of staff and personnel, this project resulted in the production of a peer-reviewed manuscript that aims to provide outreach to a broader, regional audience and foster discussions central to coral-reef monitoring. In addition, specific outreach was conducted with three target audiences: 1) Northern Marianas College natural resources management program, 2) natural resource management agencies and directors, and 3) policy and decision makers. Presentations were geared towards injecting the latest insight regarding the current status of CNMI's coral reef assemblages into education and policy making platforms. For instance, PMRI conducted presentations to key stakeholders that influence decision making, such as the CNMI Legislature, Chamber of Commerce, and the Rotary Club of Saipan. The presentations have had immediate impacts, and resulted in PMRI assisting with the creation of improved fishery legislation to regulate the size at capture for common fish that make up the greatest contribution to CNMI's inshore landings (*see progress report for details*). Also of notable importance were results that suggested declining efficacy of CNMI's marine protected areas. FY 2012 monitoring results indicated that, unfortunately, fish biomass had significantly declined inside of two of the largest marine protected areas over the past two years, in comparison with reference sites (*see progress report for details*). While alarming, these trends had apparently emerged without the knowledge of any of CNMI's natural resource management agencies, and highlight a continued need to translate monitoring data that is being generated.

References:

Anderson, M., Gorley, R., Clarke, K., 2008. PERMANOVA+ for PRIMER: Guide to Software and Statistical Methods. Plymouth, UK, 214pp. PRIMER-E, Plymouth, UK, 214pp.

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