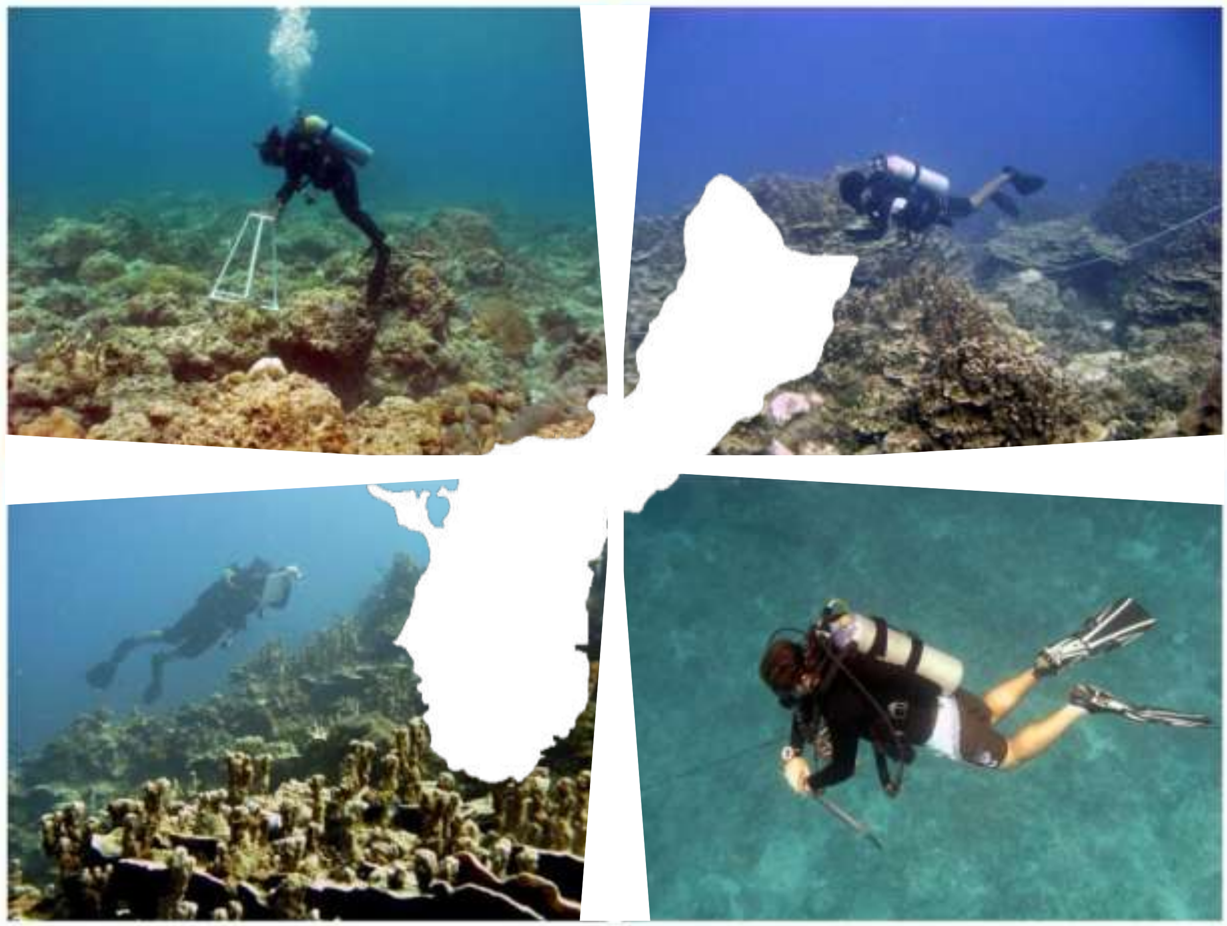

Comprehensive Long-Term Monitoring at Permanent Sites in Guam

Report of program status and presentation of preliminary baseline data and power analyses results for Tumon Bay, East Agana Bay, and Western Shoals sites

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Applicant Organization: Bureau of Statistics and Plans - Guam Coastal Management Program
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Photo: Two monitoring assistants and a research assistant from the University of Guam Marine Lab rescue an entangled green sea turtle encountered at a monitoring site in Tumon Bay. Photo by D. Burdick.

Introduction

Until recently, continuous, comprehensive long-term monitoring of coral reef health had not been conducted at any reef sites around Guam. Several existing monitoring efforts, as well as disparate assessments and studies, have provided important pieces of information to the island's coral reef managers, researchers, policy-makers, resource users, and the general public; however, the lack of a long-term monitoring program that addresses multiple aspects of reef health significantly limited our understanding of how Guam's reefs have changed in recent decades. In order to fill this major gap, a coral reef monitoring strategy was developed in 2006 by the Guam Coral Reef Monitoring Group (GCRMG)[1]. The strategy, which has been updated since 2006, provides a framework for collecting high quality, statistically-robust data for a number of coral reef ecosystem health parameters at reef sites around the island. The monitoring of these parameters, which include water quality, benthic habitat, and associated biological community parameters, provides an early warning system for changes in reef health and furthers our understanding of the processes underlying these changes. The monitoring program will yield information that will allow managers to respond to changes in reef health in a timely manner, evaluate the effectiveness of specific management strategies, and improve our understanding of reef resilience in the face of climate change impacts and other stressors.

Through the implementation of the updated island-wide monitoring strategy, monitoring coverage continues to expand over existing monitoring efforts, statistically-robust data is being collected at high priority reef sites, coordination among partners continues to improve, and local capacity continues to increase. The long-term monitoring program is still in the process of development, and while consistent data collection was delayed until August 2010 due to boat availability issues, a contract with a private charter has been established and regular data collection has since occurred. High quality, comprehensive reef ecosystem data has thusfar been collected at 20 sampling stations along a portion of the outer reef slope in Tumon Bay (2010), at 20 stations along the outer reef slope in East Agana Bay (2010), and at 23 stations across three strata at Western Shoals in Apra Harbor (2011). A sampling design has been developed for a portion of the outer reef slope in Piti Bay after a series of exploratory dives, and data collection will commence shortly.

This report includes detailed background information of the comprehensive long-term monitoring at permanent sites project; detailed descriptions of each of the monitoring sites; and the results of the initial analyses of baseline data collected at the Tumon Bay, East Agana Bay, and Western Shoals sites. The results of an analysis of data collected through the related, but separate, reef flat monitoring effort carried out by Dr. Laurie Raymundo of the University of Guam Marine Lab will be provided in a subsequent report.

[1] The agencies and organizations currently involved in the Guam Coral Reef Monitoring Group include: Guam Department of Agriculture's Division of Aquatic and Wildlife Resources (DAWR), Guam Environmental Protection Agency (Guam EPA), Bureau of Statistics and Plans, Guam Coastal Management Program (GCMP), University of Guam Marine Laboratory (UOGML), National Park Service (NPS) – War in the Pacific National Historical Park, and NMFS PIRO Habitat Conservation Division.

Project Background

Guam is the southernmost island in the Mariana Archipelago, located at 13° 28' N, 144° 45' E. It is the largest and most heavily populated island in Micronesia. The island possesses a variety of reef types including fringing, patch, submerged, and barrier reefs. Over 5000 species of major coral reef organisms are currently documented on Guam, including over 1000 species of reef fish and over 400 species of corals.[2] For thousands of years, coral reefs have sustained and protected the people of Guam. Today, coral reef resources are both economically and culturally important. Reef fish, invertebrates, and algae are eaten locally and family and group fishing are still commonly practiced. Guam's coral reefs are an important part of the tourism industry and protect the island from large waves associated with frequent typhoons. The health of Guam's coral reefs varies considerably, depending on a variety of factors including geology, level of coastal development, and the level and types of uses of marine resources[3]. Resource managers are expected to balance the costs and benefits of human uses of Guam's coral reef ecosystems, and they need data provided by comprehensive long term monitoring to inform their decisions.

While Guam's reefs have been the subject of numerous studies, until recently there had not been a continuous monitoring program that comprehensively addressed the status of water quality, the benthos, and associated biological communities for specific reef areas. This lack of quantitative reef health data has limited the ability of managers to evaluate natural and anthropogenic impacts to Guam's reefs over the last several decades. In 2004, Guam resource managers assessed the island's past and present coral reef monitoring and assessment projects for the National Oceanic and Atmospheric Administration's (NOAA) *State of the Coral Reef Ecosystems of the U.S. and Pacific Freely Associated States: 2005* report. While the report presented data for numerous biotic and abiotic variables, most were the result of discrete studies, and the need for a comprehensive, continuous monitoring program was evident. In response, the resource agencies, with the assistance of the University of Guam Marine Laboratory (UOGML) and NOAA, developed a long-term monitoring strategy aimed at addressing the management needs of local resource agencies and achieving the objectives set by the National Coral Reef Ecosystem Monitoring Program (NCREMP).

A Monitoring Coordinator was hired in 2007 to coordinate the updating of the monitoring strategy; coordinate the monitoring efforts carried out by local and federal agencies/institutions; as well as to supervise and participate in the design, data collection, data analysis, and reporting efforts associated with the long monitoring of several permanent sites around the island. This individual facilitates communication between monitoring entities, coordinates training and calibration sessions prior to each field season, schedules and participates in core monitoring activities, oversees data analysis, compiles annual reports, and produces outreach materials. The coordinator also assists local resource agencies with resource assessments through participation in field surveys and in assembling the field teams.

Once the Monitoring Coordinator was hired, an updated monitoring strategy was then developed based on meetings with members of the GCRMG. This updated strategy, which called for a modified approach to the long-term monitoring of multiple coral reef ecosystem health parameters at permanent sites, was a response to managers' concerns that existing and proposed monitoring efforts were not able to provide the high-quality,

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[2] Porter, V., Leberer, T., Gawel, M., Burdick, D., Gutierrez, J., Torres, V., and Lujan, E. 2005. "The State of the Coral Reef Ecosystems of Guam" in The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2005. NOAA Technical Memorandum NOS NCCOS 11. NOAA/NCCOS Center for Coastal Monitoring and Assessment's Biogeography Team. Silver Spring, MD. 522pp.

[3] Burdick, D., V. Brown, J. Asher, M. Gawel, L. Goldman, A. Hall, J. Kenyon, T. Leberer, E. Lundblad, J. McIlwain, J. Miller, D. Minton, M. Nadon, N. Pioppi, L. Raymundo, B. Richards, R. Schroeder, P. Schupp, E. Smith, and B. Zgliczynski. 2008. The State of the Coral Reef Ecosystems of Guam. pp. 465-509. In: J.E. Waddell and A.M. Clarke (eds.), /The State of the Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2008/. NOAA Technical Memorandum NOS NCCOS 73. NOAA/NCCOS Center for Coastal Monitoring and Asessment's Biogeography Branch. Silver Spring, MD. 569 pp.

statistically robust data required to detect and understand ecosystem trends at key reef areas. Existing monitoring programs, such as the Guam Environmental Protection Agency's (GEPA) Environmental Monitoring and Assessment Program (EMAP) or NOAA's Marianas Archipelago Reef Assessment and Monitoring Program (MARAMP), utilize a limited number of transects at sampling stations located around the entire island. While these programs have the potential to detect large changes at sites across the island, and have some limited ability for comparison among sites, they could not provide the statistical power necessary to detect smaller changes at specific reef sites; the ability of these programs to provide indications of possible causes of detected trends was also limited. The managers' concerns were reflective of the move towards more comprehensive, site-based management – a move made in response to recent concerns about project-specific impacts to certain coral reef sites (e.g. dredging in Apra Harbor), with the adoption of the Conservation Action Planning (CAP) approach for comprehensive, site-based watershed management, as well as increased focus on Guam's marine preserves.

Initially, the GCRMG aimed to establish up to twenty core monitoring sites around the island to supplement existing island-wide monitoring efforts, but it soon became clear that the managers' interest in more intensive site-based monitoring would necessitate the establishment of fewer sites and the adoption of a sampling design that would produce more statistically robust data for key ecosystem parameters. Instead of considering the entire island as the area of interest, with sampling stations scattered around Guam, it was determined that high priority reef sites would be considered separate areas of interest, with numerous sampling stations randomly distributed within targeted strata for each area of interest. The monitoring sites would be established by consensus, with the sites of highest management priority targeted first. Programs such as Guam EPA's EMAP and NOAA CRED's MARAMP would provide adequate island-wide coverage to examine island-scale trends, with the MARAMP also providing archipelagic- and Pacific basin-wide coverage.

In addition to updating the monitoring strategy, the monitoring coordinator also facilitated the hiring of three monitoring assistants. The original strategy called for the hiring of six monitoring assistants that would work for only six months, but it soon became clear that it would be more beneficial to hire three monitoring assistants to work part-time for the entire year. This change better conformed to the needs of UOGML graduate students, who are the primary pool of potential monitoring assistants. It also provided year-round assistance to the monitoring coordinator, which was especially useful in the initial development of the program when survey protocols were researched and developed and a large amount of equipment and supplies were researched and procured. The use of three year-round monitoring assistants continues to be important, as data collection, compilation, and analysis occurs beyond the time period originally anticipated. Thus far, the program has provided part-time employment for a total of six graduate students from the University of Guam Marine Laboratory. While all students have had significant previous monitoring experience, participation in this program has provided a wider range of experiences and a level and quality of participation in sampling design, protocol development, procurement, data collection, and data analysis that most have not previously experienced. Capacity building continues to be a top priority for the GCRMG. In order to collect quality data, all monitoring personnel are trained in the appropriate survey methods and calibrated in order to minimize observer bias. Standard Operating Procedures (SOPs) have been developed for each of the survey techniques and are updated as necessary. These SOPs are provided to all of the personnel working on the monitoring program or using the data, and serve to improve continuity and consistency between current and future observers.

The initial stages of the monitoring program development also involved the procurement of equipment, supplies, and services. Scuba gear, a digital SLR camera and housing, a digital video camera and housing, four digital point and shoot cameras and housings, two DAN emergency oxygen kits, a GPS receiver, two handheld depth finders, video editing software, transect reels, and additional supplies were procured within the first two years. The procurement of additional key items occurred in subsequent years; these items included three additional sets of scuba gear, a dome port for the dSLR housing, three additional point-and-shoot cameras and housings, statistical software, field guides, GPS-Photo Link software, Adobe software suite, temperature loggers, two YSI multiparameter data loggers, and consumable supplies.

As with the original monitoring strategy, the updated strategy was developed with several local and federal monitoring programs in mind and thus coordination with staff involved in these programs is required. Data collected from these programs will be used to complement data collected at the core long-term monitoring sites and vice-versa. These programs include Guam EPA's Status and Trends Monitoring Program (STMP) and Environmental Monitoring and Assessment Program (EMAP), DAWR's Marine Preserve Monitoring, NPS monitoring activities, and the NOAA Coral Reef Ecosystem Division's Marianas Archipelago Rapid Assessment and Monitoring Program (MARAMP). Data collected as part of environmental impact assessments and other one-time assessments will also be used to supplement the long-term monitoring data.

Project Description

The Comprehensive Long-term Monitoring at Permanent Sites in Guam project involves the collection of data for a suite of coral reef ecosystem health parameters at several high priority reef sites around the island. Data are collected annually by a team of highly-trained field biologists from the Guam Coastal Management Program, the NOAA Pacific Islands Regional Office, the University of Guam Marine Lab, and with occasional assistance from other agencies.

The primary goals of the updated monitoring strategy are to:

- Determine the status and trends in selected coral reef ecosystem indicators to better inform the resource managers' decision making process and increase the effectiveness of natural resource management on Guam.
- Provide managers with early notice of abnormal conditions of selected resources to encourage effective mitigation measures and reduce the costs of management.
- Provide data to better understand the dynamic nature and condition of the island's coastal ecosystems.
- Allow natural resource agencies to meet certain legal and Congressional mandates related to coastal resource protection.
- Measure progress towards performance goals.

Specific questions raised by managers that will be addressed by the long-term monitoring program to the fullest extent possible include (in no particular order):

1. What are/will be the impacts of existing/future coastal development on nearby coral reef resources?
2. What are the impacts of specific construction projects related to the military buildup on nearby coral reef resources (e.g., nuclear aircraft carrier deep-draft wharf and turning basin)?
3. What are the impacts of specific management actions on coral reef resources (e.g., Cetti Bay watershed restoration, Conservation Action Plan (CAP) projects in Piti-Asan and Mannel-Geus watersheds)?
4. Do the marine preserves support a greater abundance/biomass and diversity of fishes than similar non-protected areas?
5. Do the marine preserves support "healthier" benthic communities than similar non-protected areas?
6. Are coral reef resources within the preserves more resistant to/recover more rapidly from acute disturbances? If so, what factors contribute to their enhanced resiliency?
7. What is the status of target fish groups and species of interest at sites located around the island?
8. What is the distribution and abundance of ecologically and commercially important macroinvertebrates at sites located around the island?
9. What are the impacts of acute disturbances on Guam's reef resources (e.g., typhoons, *Acanthaster* outbreaks, coral bleaching events, etc.)
10. What is the distribution of coral recruitment rates at sites located around the island? Are the results of previous artificial substrate settlement studies at Asan, Luminao, and Tanguisson representative of the rest of the island?
11. What is the distribution and intensity of coral predation (*Acanthaster*, *Drupella*, etc.)?
12. What are the coral disease prevalence rates at sites around the island? Are these rates changing over time? If so, what factors contribute to these changes? What impacts are coral diseases having on Guam's coral reef ecosystem?
13. What is the impact of terrigenous discharge on nearby coral reef resources?
14. How effective are mitigation projects at compensating for the loss of ecosystem function as a result of injuries associated with military buildup-associated projects and other projects that impact Guam's reef resources?

15. What is the distribution and impact of invasive/nuisance species (e.g., *Terpios*, *Chrysocystis*) on Guam's coral reef resources?
16. What coral species are more susceptible/resistant to temperature/UV stress (bleaching/paling)?
17. What coral reef areas are particularly susceptible/resistant to temperature/UV stress?
18. At what rate is ocean acidification occurring around Guam and what are the impacts of ocean acidification on Guam's reef resources?

The monitoring program collects data about a number of important parameters related to ecosystem health. These parameters are grouped into three categories: water quality, benthic habitat, and associated biological communities. Many of these parameters are indicators of specific stressors and likely to be of concern if levels change significantly. They also provide important information about reef resilience. Monitoring these parameters will allow resource managers to evaluate the effectiveness of specific management strategies and serve as an early warning system for identifying changes in reef health. The parameters identified for Guam are provided below, with parameters currently being monitored in bold:

Water Quality:
- Turbidity
- Dissolved Oxygen
- pH
- Conductivity
- Chlorophyll
- Nutrients (P, N)
- Bacteria

Benthic Habitat
- **Benthic % Cover**
- **Coral Recruitment**
- **Coral Colony Size**
- **Coral Colony Density**
- **Coral Condition**
- Macroalgae Diversity
- Coral Colony Growth Rates
- Macroalgae Biomass
- Rugosity

Assoc. Biological Communities
- **Reef Fish Abundance and Biomass**
- **Reef Fish Diversity**
- **Protected Species**
- **Abundance of Ecologically and Commercially Important Macroinvertebrates**
- Macroinvertebrate diversity

The parameters targeted for monitoring are essentially the same between the original and updated strategies, although water quality parameters and a few others have not yet been incorporated into field surveys. Water quality parameters are especially important to the program and will commence upon the procurement and deployment of multi-parameter datasondes, which will occur during the 2012 field season. In recognition of the limited analytical potential of annual water samples taken at each sampling station, the installation of *in situ* instrumentation to provide continuous water quality data for one or two key sites is planned. It is also important to note that while reef fish abundance and biomass data will not be collected for all taxa (e.g., gobies, blennies), a focus on commercially and culturally important species, as well as on herbivore functional groups, will provide insight into the impacts of harvesting on important ecological processes, and will contribute to our understanding of the resilience of Guam's reef ecosystems.

The development and implementation of the comprehensive monitoring strategy has strengthened partnerships between participating agencies and has resulted in a more coordinated, efficient approach to monitoring the health of Guam's coral reef resources. This project will result in a comprehensive set of long term data for at least five permanent monitoring sites around the island of Guam. The data will eventually be georeferenced and entered into a geodatabase specifically designed for this project to provide an easily accessible data source for managers. Data will be summarized annually, provided to NOAA's Coral Reef Information System (CoRIS), and included in the periodic *State of the Coral Reef Ecosystems of the U.S. and Freely Associated States* report. Data will also be used to improve the accuracy of benthic habitat data for Guam. Most importantly, this data will provide valuable information for local managers and decision makers, particularly in the coming years of military expansion on Guam.

Methods

The original and updated strategies were developed by a team of knowledgeable, experienced resource agency staff and UOGML faculty. The methods are not novel and have proven economical, efficient, and successful on Guam and in other jurisdictions. Standard operating procedures are provided to all personnel participating in the field surveys to facilitate consistency across observers. Calibration surveys are conducted at the beginning of each field season to further ensure consistency across observers, thus minimizing inter- and intra-observer bias. Training of field personnel is conducted by agency and university staff prior to each field season, and participation by the field personnel in related monitoring and assessment efforts conducted by UOGML faculty is encouraged in the off-season to facilitate the maintenance of survey skills. Care has been taken in the creation of this plan to ensure that the methods are reasonable and reliable and can be completed with the resources available on Guam. Detailed descriptions of the methods employed are provided below.

Site Selection

As mentioned in the previous proposal, the GCRMG is currently aiming to conduct more intense monitoring at fewer reef sites instead of the original plan to conduct less robust monitoring at twenty sites. Initially, a total of five reef areas were targeted for long-term monitoring; this number could change, depending on the amount of effort required to conduct adequate monitoring at the first five sites.

Tumon Bay was selected as the first area targeted for long-term monitoring, with partial monitoring within the bay having occurred in June 2009 and a full data collection having occurred in 2010. Tumon Bay (Figure 1) hosts the Tumon Bay Marine Preserve and is a hub for tourism, recreational, and cultural activities on Guam. While the numerous potential impacts (e.g., from coastal development, recreational and commercial use) to the bay's reef ecosystem make discerning individual impacts difficult, the intensive, comprehensive monitoring of carefully selected reef zones and depth strata will increase the likelihood that even relatively small changes in key ecosystem health parameters can be detected, and that reasonable indications of probable causes will be provided. Data collected by other programs, such as in situ instrumentation installed and maintained by NOAA CRED, a comprehensive resource inventory and subsequent monitoring occurring as part of DAWR's eco-permit program, Rapid Ecological Assessment data collected as part of the NOAA MARAMP, Guam EPA EMAP and STMP data, and other monitoring and assessment activities will all contribute to the improved understanding of coral reef ecosystems in the bay, how they are changing over time, and how they are affected by human activities.

East Agana Bay (Figure 2) was the next site to be established for long-term monitoring, with the completion of baseline data collection in 2010. East Agana Bay was chosen as a comparison site to Tumon Bay, thus monitoring in East Agana occurs along the reef slope terrace within the same depth range as that used in Tumon Bay. The reef structure in the bays appears to be similar and the bays are both impacted by non-point source pollution and recreational misuse/overuse, so the pairing of the bays will allow an examination of the relative effects of protection status on the reef communities in the bays. As no two reef sites are exactly the same, a detailed analysis of the baseline data collected at each site will be carried out in order to determine if comparison between the sites is appropriate for a given data set.

Western Shoals, in Apra Harbor, was selected as the third site for long-term monitoring, with the first year of data collected in 2011. Western Shoals was selected due to its high economic and cultural value, and the vulnerability of this important reef to impacts by the large number of recreational users, the potentially high fishing pressure, and the potential for indirect impacts associated with dredging required for the proposed nuclear aircraft carrier wharf and turning basin (Figure 3). The sampling plan for Western Shoals was designed to detect changes in several strata located across the shoals, with particular focus on changes that may be caused by reduced water quality associated with dredging or land-based activities, heavy fishing pressure, recreational misuse/overuse, or thermal stress.

Figure 1. The Tumon Bay Marine Preserve is the most popular tourism location on Guam, but intense coastal development, heavy recreational use, the anticipated increase in sea level and temperature associated with climate change, and other stressors threaten the bay's most important assets – its white sand beaches and spectacular coral reef ecosystem. Photo by Mitch Warner, Guam Department of Agriculture - Division of Aquatic and Wildlife Resources

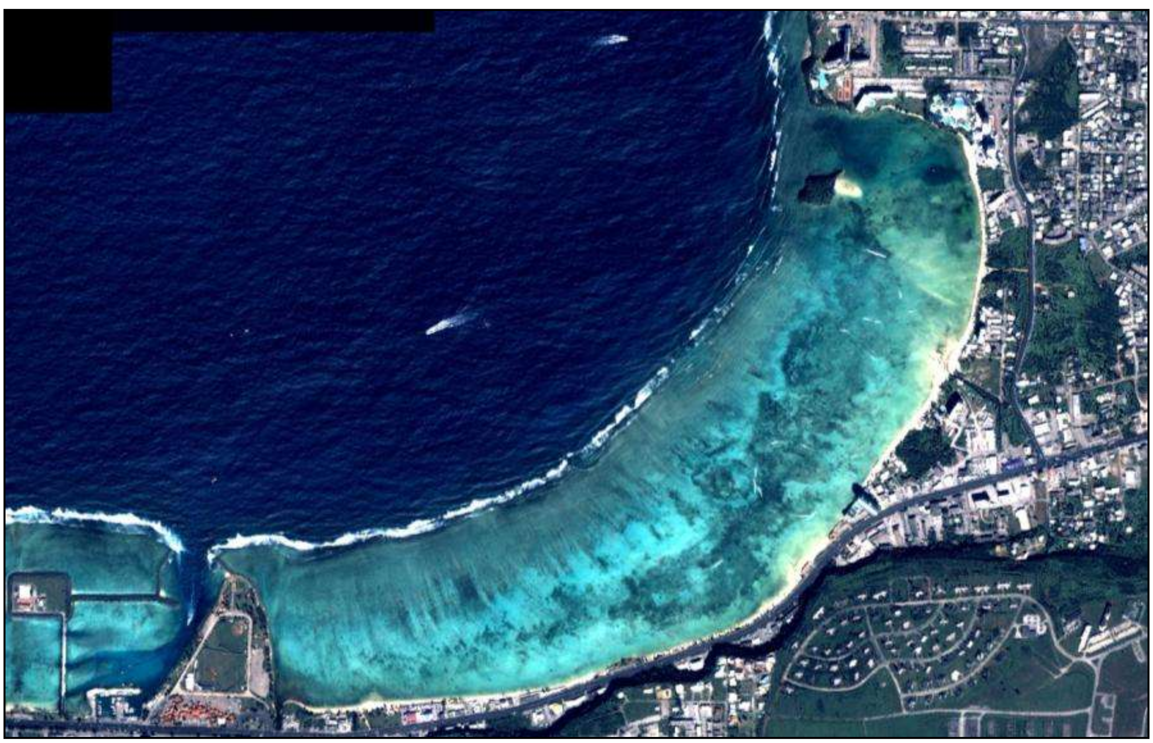


Figure 2. East Agana Bay is also a popular tourism location on Guam, with several hotels along its northeastern shore and several motorized personal watercraft operators utilizing the bay. The impact of stormwater runoff, heavy recreational and harvesting pressure, the anticipated increase in sea level and temperature associated with climate change, and other stressors threaten the bay's coral reef ecosystem. 2004 IKONOS satellite imagery provided by Space Imaging.

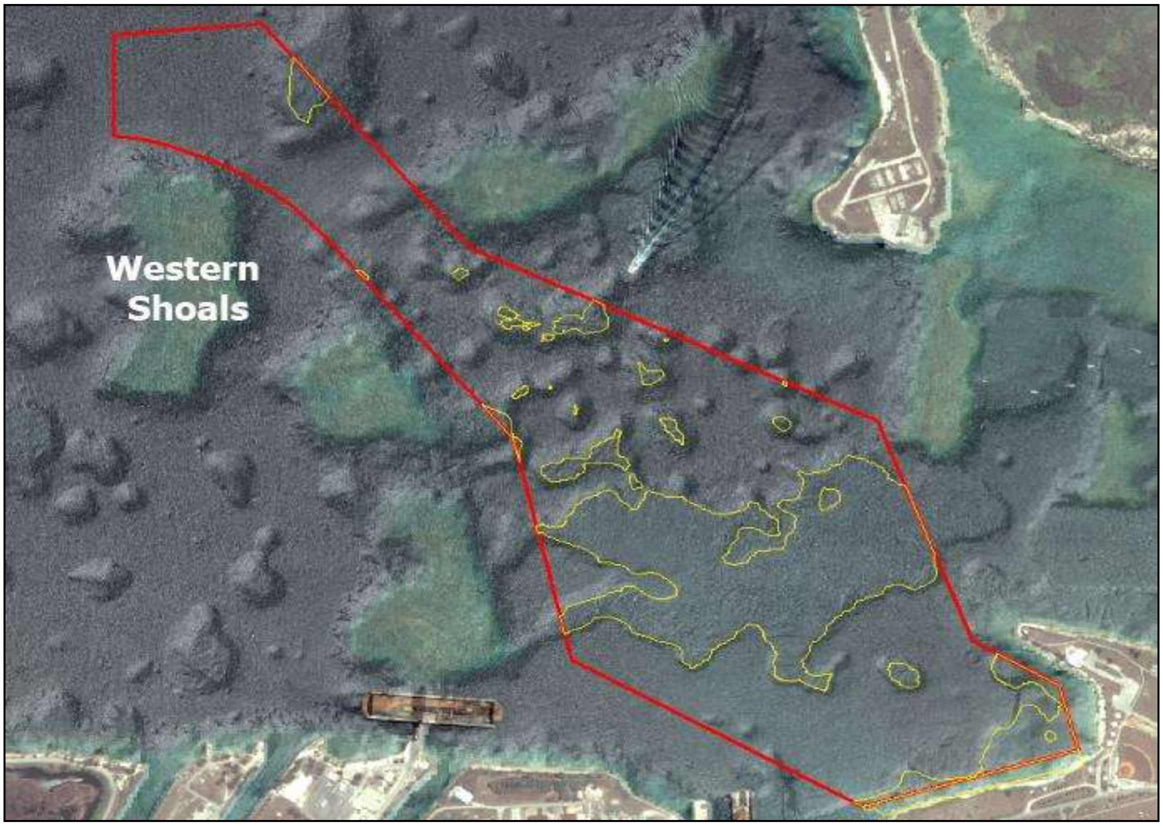


Figure 3. Western Shoals is an economically and culturally important reef system that is heavily used by tourism operators. In addition to the other stressors, the integrity of the reef system may also be impacted by dredging operations required for a proposed nuclear aircraft carrier wharf and turning basin. The figure depicts the proximity of this valuable reef system to the project boundary (red line) and dredging footprint (yellow line) for the Navy's preferred wharf/turning basin location. 2005 Quickbird satellite imagery provided by DigitalGlobe.

Figure 4. The Piti Bomb Holes Marine Preserve, in Piti Bay, hosts yet another culturally and economically important reef area on Guam. While a small portion of the Preserve is impacted by heavy recreational use, the biological communities across the bay are regularly subjected to severely degraded riverine discharge and stormwater runoff. Photo by Mitch Warner, Guam Department of Agriculture – Division of Aquatic and Wildlife Resources.

Upon completion of baseline monitoring at Western Shoals, Piti Bay was selected for monitoring. Piti Bay (Figure 4) is of high priority because it hosts a marine preserve, is downstream from watershed restoration activities, and is the site of at least two other, shorter-term assessment/monitoring projects that would serve as a strong supplement to a dedicated long-term monitoring program. In order to maintain consistency with the East Agana and Tumon Bay monitoring sites, monitoring in Piti Bay will occur within the same reef zone and depth range. However, in order to contribute to our understanding of the impacts of land-based sources of pollution on coral reef ecosystems within Piti Bay, and to assist in the evaluation of the effectiveness of watershed restoration activities in improving water quality and coral reef health, the Piti site includes two separate sections of reef slope: one extending to the west of Tepungan Channel and one extending to the east of the channel.

The locations of subsequent monitoring areas have not yet been finalized. Several additional candidate sites were chosen by members of the monitoring group at a meeting held in May 2008, but the list of target areas will need to be revisited as the management priorities continue to evolve, and as more information about the military buildup becomes available. Considering the massive scale of compensatory mitigation projects expected as a result of proposed military buildup actions on Guam's reef resources, it is also crucial that reef sites occurring in close proximity to one or more of these mitigation projects also be independently monitored. Also under consideration for long-term monitoring is another site in Apra Harbor, perhaps a reference site for Western Shoals, as well as another marine preserve/non-preserve pairing, such as a portion of the Achang Reef Flat Marine Preserve and a nearby, non-preserve area. The Achang Reef Flat Preserve and adjacent reef areas are also of interest because of their occurrence within the Mannel-Geus watershed unit, which has recently been designated as a high priority watershed management area.

Sampling design

The updated strategy calls for a stratified random sampling design in order to minimize variability for key ecosystem parameters, and thus reduce the total number of samples required to achieve the desired level of detection (10-20% change) and confidence (80-90%). This approach would be used for each site, but the sampling design may differ between sites. In contrast to a more uniform approach required for island-wide monitoring, such as that utilized by Guam EPA's EMAP or NOAA's MARAMP, a site-based approach may result in the use of different sampling designs for each site, depending on the management questions specific to each site and the types of data required to answer these questions. Differences between sampling design may include utilizing different strata or targeting a slightly different set of parameters. For example, continuous in situ monitoring of turbidity or total suspended solids would be relevant at Cetti Bay, while it may not be of high priority along the forereef of Tumon Bay or other sites in northern Guam; impacts on the forereef slope (e.g., from *Acanthaster* predation) at one site may be of greater concern, while impacts to the reef flat may be greater concern at another site – or a site may not even possess a reef flat. However, sampling strategies and survey methods will be consistent across sites to the fullest extent possible to maximize the ability to make between-site comparisons. This will be especially crucial for marine preserve and non-marine preserve site comparisons.

Another key component to the updated strategy was the adoption of a sampling design that involves both fixed and non-fixed transects and quadrats. This approach, known as a split-panel approach, has been used by the National Park Service in the Caribbean for years, but only recently has been brought to Guam by the National Park Service for use in their monitoring program. With this type of design, the statistical power afforded by the repeated measure of permanently-marked transects and quadrats would be complimented by the spatial inference provided by additional, non-fixed sites that are re-randomized across the study area each year.

Monitoring is currently only focused on the reef slope terrace within Tumon, East Agana, and Piti Bays, although sampling stations may eventually be established in other reef zones. The reef slope terrace was chosen because of the relative homogeneity of the benthic community within this zone, because of the concern about the susceptibility of coral communities within this zone to predation by *Acanthaster*, because access to the reef front and reef margin is very limited due to ocean conditions, and field surveys at depths beyond the reaches of the terrace are often impractical and unsafe. The monitoring of fish communities on the reef slope terrace is also

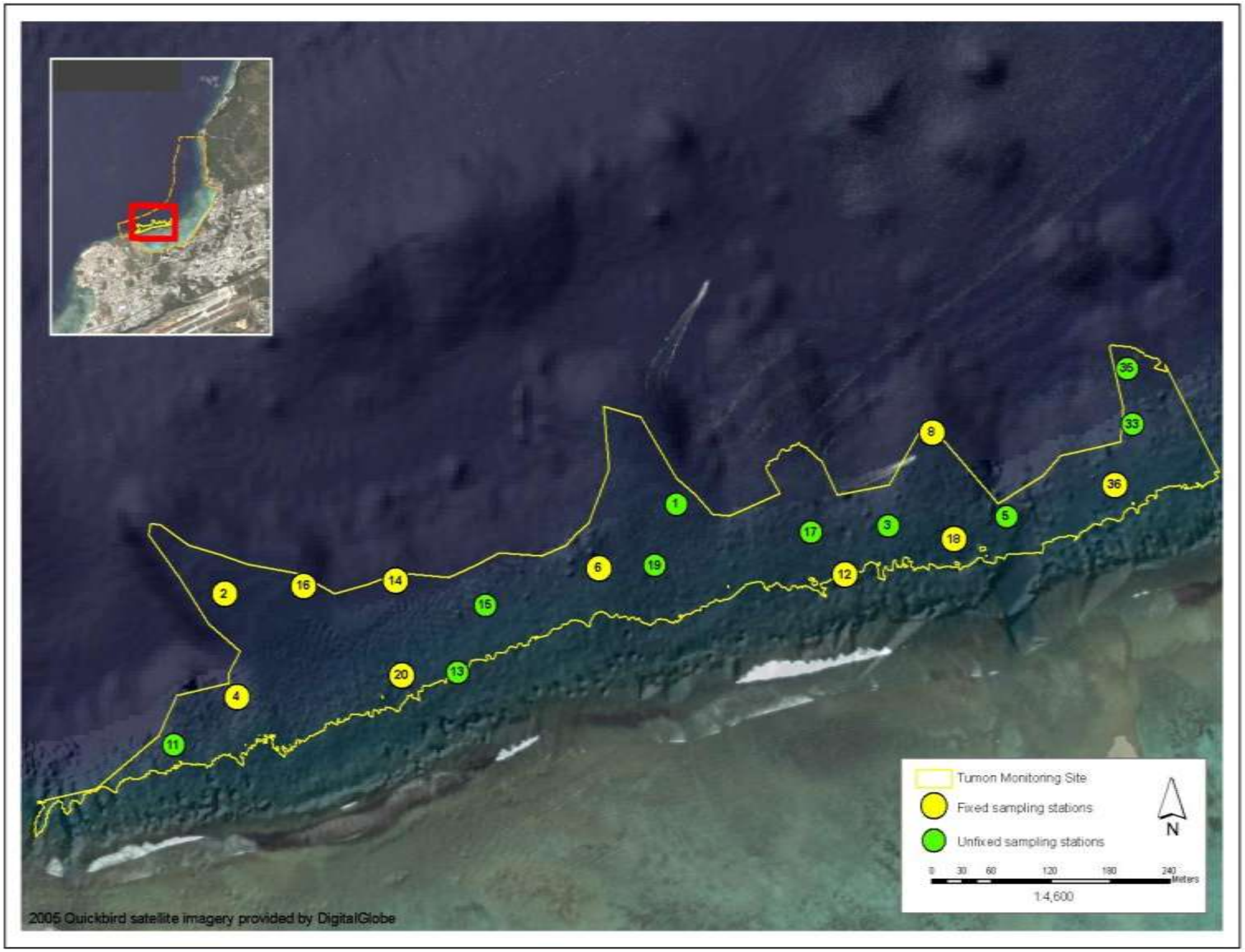


Figure 5. Original (2010) site boundaries and sampling station locations for the Tumon Bay monitoring site. The site boundaries may be modified based on the results of the analysis of the baseline data.

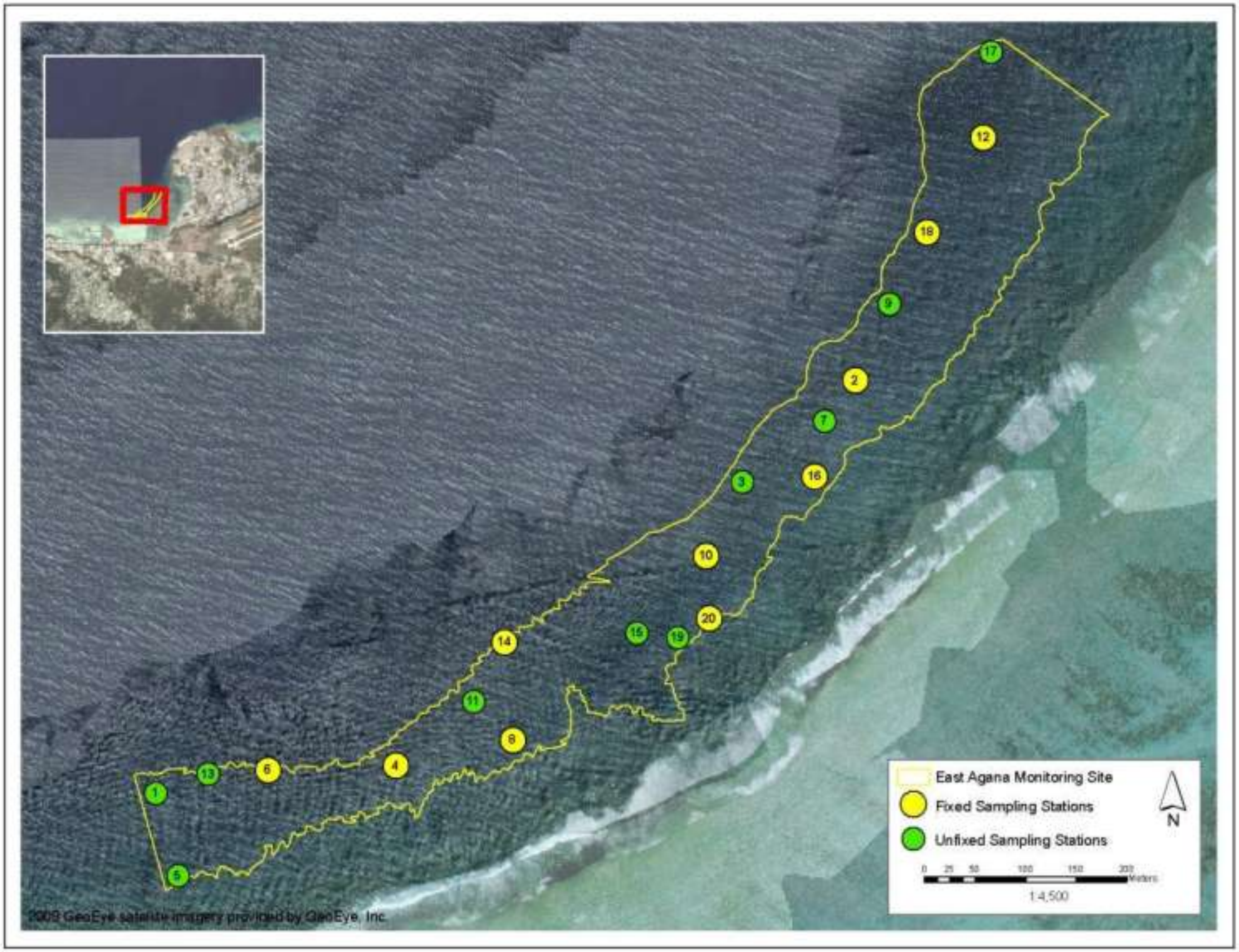


Figure 6. Original (2010) site boundaries and sampling station locations for the East Agana Bay monitoring site. The site boundaries may be modified based on the results of the analysis of the baseline data.

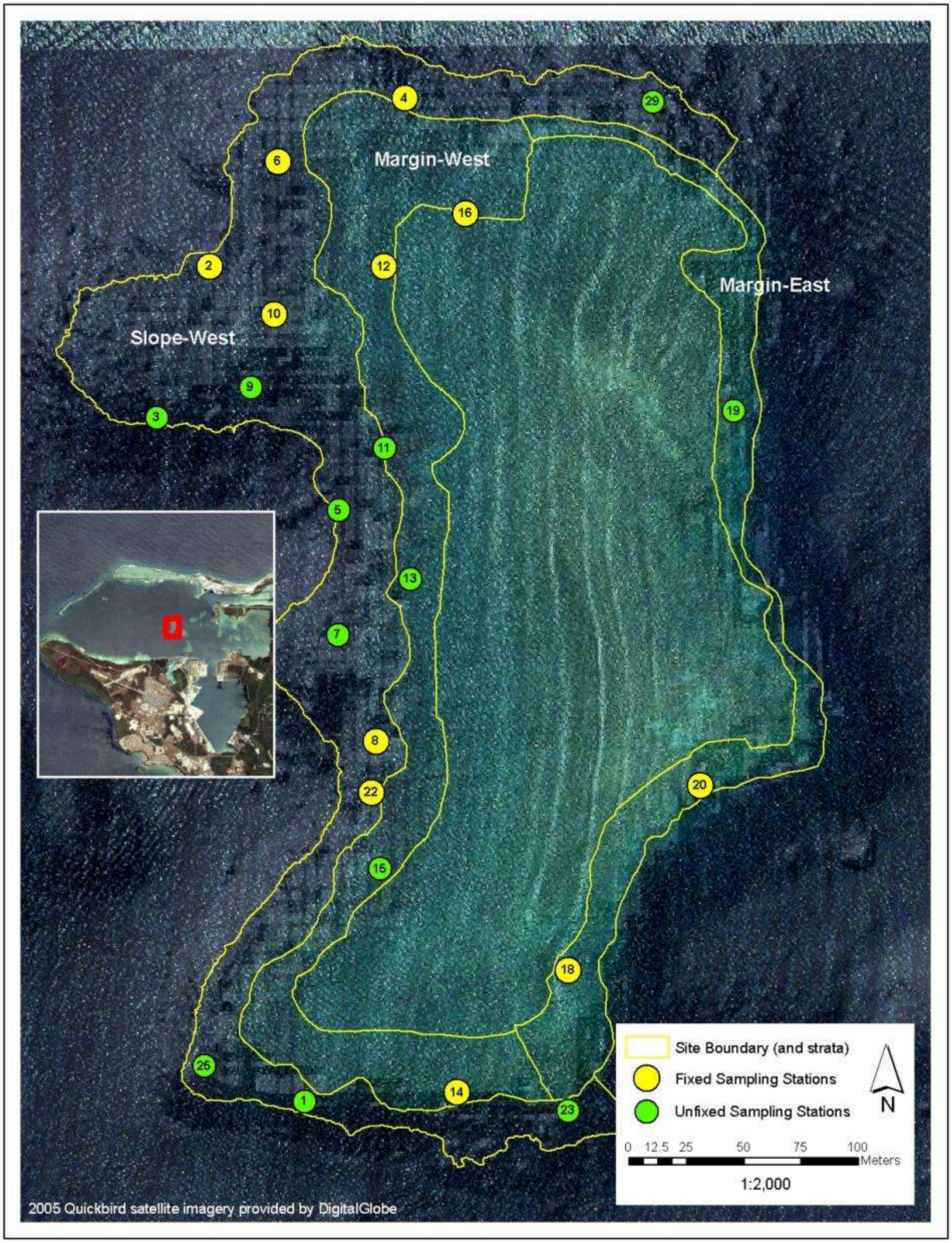


Figure 7. Original (2011) site/strata boundaries and sampling station locations for the Western Shoals monitoring site. The site boundaries may be modified based on the results of the analysis of the baseline data.

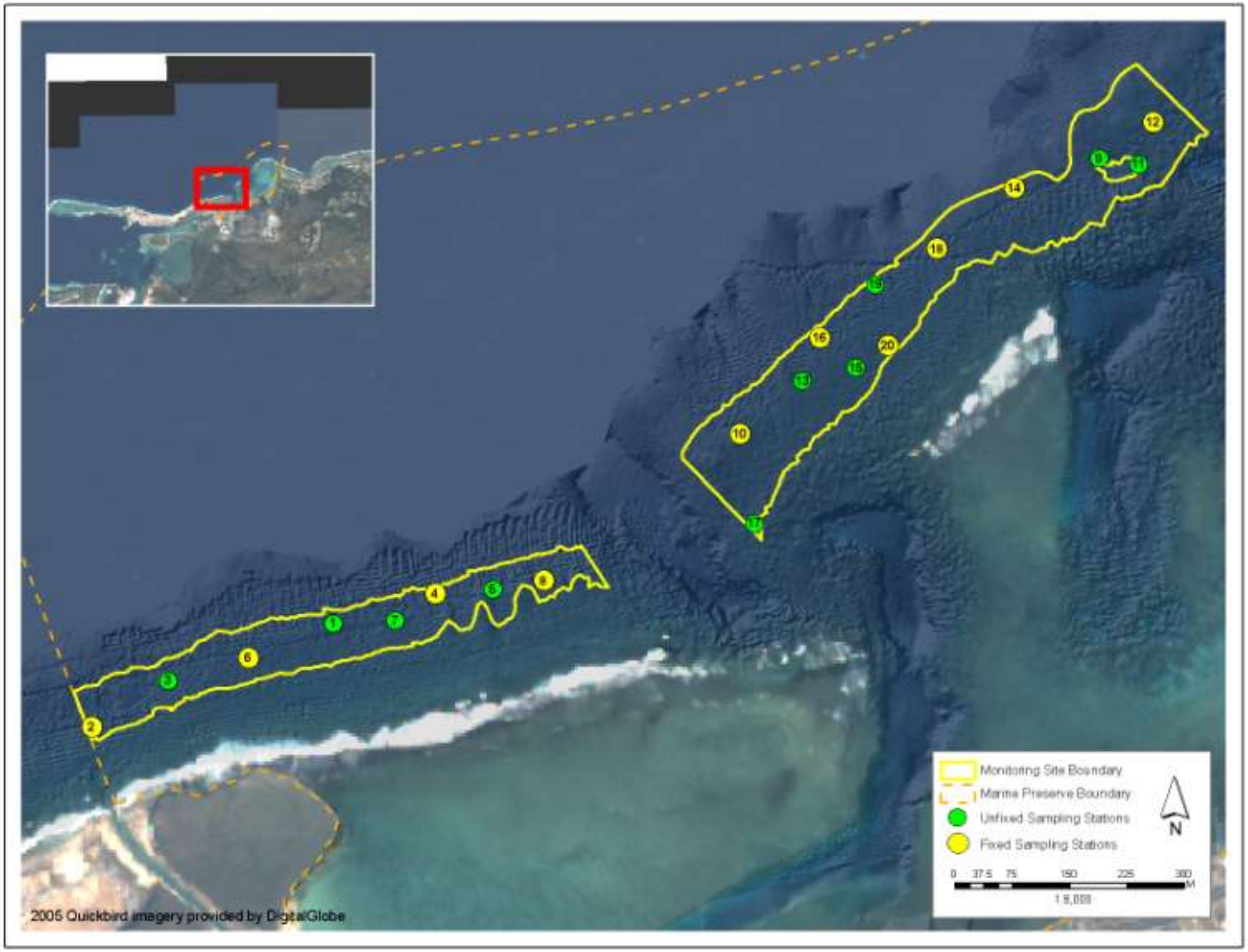


Figure 8. Proposed site boundary and sampling station locations for the Piti Bay monitoring site. Data collection at the Piti Bay site is expected to begin in May 2012.

preferred to monitoring on the reef flat or other shallow reef zones due to the comparatively limited influence of recreational users on fish communities (e.g., through fish feeding) on the reef slope terrace and the presence of larger, vulnerable fish species that are generally found in deeper waters. The reef flat monitoring effort carried out by Dr. Raymundo will supplement the long-term monitoring data along the outer reef slope to provide a more holistic picture of the status and trends of key ecosystem health parameters across the sites' various reef zones and habitats.

Monitoring at the Western Shoals site is currently focused within three strata, including the reef slope on the western half of the shoals, the reef flat margin on the western half of the shoals, and the reef flat margin on the eastern half of the shoals. These strata, each of which were expected to be comprised of relatively homogeneous benthic communities, were chosen because of the high coral cover found in these strata, the frequent use of the western-facing strata by recreational users, and the perceived vulnerability of reef communities within these strata to existing or anticipated impacts, such as recreational user impacts and degraded water quality associated with dredging or land-based activities. Preliminary assessments of the shoals have shown that the area of shallow reef flat found towards the center of the shoals (and away from the margins) possesses relatively little coral and very high cover of the ephemeral algae, *Padina* spp., while the reef slope on the eastern half of the shoals is primarily comprised of unconsolidated substrate. Coral, sponges, fishes, macroinvertebrates and other important reef flora and fauna can be found in these strata, however, so sampling stations may be strategically located within the reef flat and eastern reef slope areas if logistically feasible and if new information suggests that these areas may be of greater concern than originally thought.

The locations of sampling stations along equivalent areas of the reef slope terrace in Tumon (Figure 5), East Agana (Figure 6), and Piti Bays (Figure 8), as well as for sampling stations within the three Western Shoals strata (Figure 7), were generated randomly using Geographic Information System (GIS) software. Even-numbered stations are fixed, while odd-numbered stations are unfixed; a new set of re-randomized, unfixed stations will be generated each subsequent year. Data collection may not occur at all stations in subsequent years if is determined that the desired level of detection can be achieved with fewer stations. Conversely, if it is determined that the number of established sampling stations does not allow the desired level of detection and confidence, a larger number of stations will be monitored or the total sampling area will have to be reduced.

In order to further minimize variation for key parameters, the generation of random sampling stations for the Tumon, East Agana, and Piti Bay sites was limited to areas of hardbottom along the reef slope terrace between 7 and 15 meters depth. A benthic habitat data GIS layer and SHOALS lidar bathymetry data were used in this analysis. This depth range was chosen because of diver safety and logistical issues at shallower and greater depths, but also because it was generally held that the coral communities along the gentle slope of the reef shelf/terrace occurring between these depths across much of the bay are relatively homogenous.

Site Monitoring

Site monitoring currently involves the collection of data for benthic habitat and associated biological communities parameters listed above. Water quality monitoring will begin with the 2012 field season. Sites are visited once a year, but some sites will eventually be chosen for year round water quality monitoring using in situ sensors. Also, due to the greater time required for the initial establishment of the sites and the implementation of sampling design changes resulting from the initial power analyses for key parameters, the second round of data collection may not occur for two years for some sites.

The following field survey methods were developed by monitoring personnel from the local resource agencies, UOGML, and the NMFS/PIRO Habitat Conservation Division, Guam Field Office, and are based on established coral reef survey protocols used by various U.S. and international agencies/organizations.

Survey logistics and permanent site establishment

Each sampling station is located using a GPS receiver. Upon reaching a given station, a small weight and line tied to a buoy is carefully lowered to the ocean floor. In optimal situations where four divers are available, two divers enter the water first to carry out the fish surveys. Starting at the weight tied to the buoy, a 30-meter transect is laid out (Figure 9). The transect is laid out in a northerly direction, following the depth contour if it is readily determined; if the area is relatively flat and a depth contour is not readily discernable the transect is laid at an angle parallel to the reef margin (which is determined prior to entering the water). The two divers conducting the benthic surveys enter the water approximately 20-30 minutes after the divers conducting the fish surveys in order to avoid disruption of the fish surveys. In situations where only three divers are available, all three divers enter the water at the same time and remain as a three-person buddy team to ensure diver safety throughout the survey. Compact digital point and shoot cameras and housings are used by individual observers to document unknown organisms, incidences of coral disease, and species/behaviors of special interest. At the fixed sampling stations, 24” rebar is installed at the beginning of the transect and 12” rebar is installed at the center and end of the transect; four-inch concrete nails are installed at two of the corners of each quadrat. For the Western Shoals site, rebar and concrete nails were not used and instead a small PVC float was tied to dead coral with a line at the beginning of the transect and large zip ties were placed at the beginning, middle, and end of the transect. Two small zip ties were used to mark two corners of each permanent quadrat location.

Qualitative surveys

Short qualitative surveys are conducted at each station when possible to establish species lists for key taxa and to characterize the site. These surveys are usually conducted immediately before or after the quantitative surveys, when time is available. This effort will provide a master species list and general site description for each site that can be referenced by monitoring personnel and local agencies. More comprehensive biodiversity surveys will be carried out in the near future. The surveys will be conducted by taxonomic experts, but when field technicians do not possess the requisite taxonomic expertise, photos of specimens that cannot be identified by field personnel will be provided to taxonomic experts for identification. In instances where organisms cannot be identified from photos, samples will be collected and provided to the taxonomic experts. Efforts to more exhaustively inventory the biodiversity of each site may be carried out in the near future.

Water Quality

While water quality sampling has not yet been carried out, it will be carried out beginning in 2012, with annual sampling at each station following Guam EPA’s EMAP QAPP2003[4] procedures. Water column profiles will be performed at each sampling station using an electronic multiparameter water quality monitoring system/datasonde equipped for conductivity/salinity, depth, dissolved oxygen, pH, temperature and turbidity. Once the vessel is stationary, the probe will be deployed. Probe measurements as viewed from the on-deck display will be recorded on the station occupation data form at specific descending levels depending on depth of the water at the site as follows:

- Water depth >10m<20m – 0.5m (near surface) and every 1m interval to 10m, then at 5m intervals, thereafter, to near-bottom (0.5m off bottom)
- Water depth >2m<10m –0.5m (near surface) and every 1m interval to near-bottom (0.5m off bottom)
- Water depth <2m – every 0.5m interval.

[4] Guam Environmental Protection Agency. 2003. Environmental Monitoring and Assessment Program (EMAP) Coastal Sampling for Guam and Micronesia Region: Quality Assurance Project Plan (QAPP). Guam EPA, Tiyan Guam. 82pp.

Figure 9. Transect tape laid across the reef at a sampling station in East Agana Bay. Diver in the background is taking contiguous, non-overlapping photos of the benthos along the transect.

The probe will be held at each of these levels until the data readings have stabilized. If the probe hits bottom, disturbed conditions will be allowed to settle for 2-3 minutes before taking near-bottom readings. Reading will also occur on the up trip of the probe for data verification. But only data from the down trip will be reported in the final data.

Temperature loggers will be deployed at all sites in 2012; data will be downloaded from each instrument periodically. Datasondes equipped for conductivity/salinity, depth, dissolved oxygen, pH, temperature and turbidity will be deployed at select sites for long term in situ monitoring. These devices will be attached to the bottom and will read measurements at selected time periods (e.g. hourly) for all of the parameters. This data will be stored in an integrated data logger and recovered at appropriate intervals (dependent upon the model and sample frequency).

Water quality data collected at the core long-term monitoring sites will be supplemented by data collected from Guam EPA's EMAP, STMP, and Marine Preserve water quality monitoring, as well as water quality and oceanographic data collected by NOAA CRED and UOGML. In combination, these projects include data for nutrients, bacteria, chlorophyll-a, pollutants, as well as for current patterns and additional ocean temperature data. Grab samples are not currently included in this plan as they are expensive to collect and analyze and have limited usefulness at such a low sampling frequency,. Local agencies and university researchers are exploring new techniques for assessing nutrient levels in coastal areas such as stable isotope analysis for nitrogen. Should these methods prove viable they will be adopted into the plan.

Benthic Habitat

Benthic Cover

Benthic cover and coral and algal generic diversity are currently being assessed using digital photo transects. The still images provide a permanent record of the transects and are analyzed using point sampling software. A video camera is occasionally used to provide additional documentation at a subset of sampling stations for each site, and will be used to provide video clips for use in outreach and education activities.

A video camera was used to document transects at the seven Tumon Bay stations surveyed in 2009, but upon commencement of the 2010 monitoring season, non-overlapping digital photos were taken every 0.5 meters along each transect with an 8 megapixel digital point and shoot camera mounted on a PVC frame (Figure 10). Percent cover is estimated from the still images using CPCe, a software application developed by Nova Southeastern University's National Coral Reef Institute. Initially, every frame was analyzed using 25 random points, but the number of frames and points may change after conducting a series of tests using various combinations of images and points in an effort to maximize accuracy while minimizing effort.

Figure 10. A monitoring assistant taking photos of the benthos along a transect using a camera mounted on a PVC frame.

Living, recently dead, and dead corals will be identified to the lowest taxonomic level possible, as will macroalgae, sponges, soft corals, cyanobacteria, and other living organisms. Living coral fragments will be counted as living coral, but will be distinguished from attached colonies when possible. Within the database, growth form for each coral species and functional group for each algae species will be identified in order to facilitate higher order analysis. The database will automatically attribute this information to each species or genera entered.

Coral Community

Shortly after the first diver begins the photo transect, another diver then identifies and measures all coral colonies within quadrats placed at 0 m, 5 m, 10 m, 15 m, and 20 m along the right side of the transect (Figure 11). A 0.5 x 0.5 m quadrat was used for the East Agana and Tumon Bay sites (see photo below), but a 1 x 0.75 m quadrat was used at Western Shoals because of the dominance of large *Porites rus* and massive *Porites* colonies. Percent dead, percent recent dead, and coral condition (e.g., disease, disease severity) observations are recorded for each colony (Figure 12). The cause of death will also be noted if it can be determined with a reasonable degree of confidence. Measurements of the longest dimension and the width of the colony perpendicular to the longest dimension are made. An effort is made to carefully count all coral recruits/juvenile corals in order to assess the rates of coral recruitment to natural substrate. Care is taken to prevent the count of remnants of larger colonies as coral recruits/juvenile corals. Any tissue isolate suspected of being a remnant of a larger colony will be noted as such, in order to prevent the calculation of erroneous coral recruitment rates. At least two photos are taken of each quadrat in order to maintain a photographic record of all quadrats.

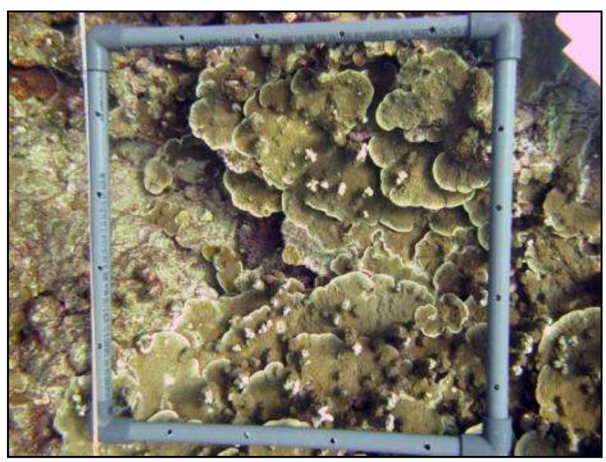


Figure 11. The size and condition is recorded for all coral colonies occurring within a PCV quadrat such as the one pictured here.

Figure 12. The type and severity of coral disease affecting colonies within the survey quadrats are recorded; observations of coral disease and other sources of coral mortality are also noted during qualitative surveys.

Drupella, Acanthaster planci (COTS) and *Corallophyllia* will also be counted and their density on host colonies determined in order that mortality rates attributed to these coral predators can be separated from disease and bleaching mortality. At a future date, a subset of diseased or bleached colonies may be tagged and photographed during sampling in order to supplement the continued coral health work conducted by Dr. Laurie Raymundo at several reef flat sites (for which funding is requested in this proposal).

Upon completion of the quadrat surveys, and if time is available, the benthic specialist conducts a 10-minute timed swim within the vicinity of the transect in order to better understand the coral species diversity of the site. After the appropriate permits are obtained, a sparing number of specimens of those corals for which identification is uncertain may be collected.

Rugosity

Beginning in 2012, rugosity will be measured using the chain-and-tape method at two 10 m sections along the 25 m transect at each sampling station. A diver will drape a light chain over the substrate next to a taut transect tape, paying out as much chain as is necessary to conform to the substrate profile along the length of the tape. The diver will measure the length of chain needed to cover a 10 m distance and record it on the data sheet.

Associated Biological Communities

Reef Fish

Fish surveys are one of the key components of the Guam Comprehensive Long Term Monitoring Program. Fish are a culturally and economically valuable resource for the island (van Buekering et al., 2007). Coral reef fish communities play an important role in Guam's coral reef ecosystems and may be an indicator of reef resiliency (Green and Bellwood 2009). The monitoring data collected by the Guam Comprehensive Long Term Monitoring Program are expected to provide results on fish density, biomass, and diversity as well as allow exploration of community structure by functional group and size structure. The surveys will also be used to detect changes in fish communities over time.

The fish team uses a Stationary Point Count Method (SPC) adapted from Ault et al. (2006) and NOAA Fisheries Coral Reef Ecosystem Division (Williams et al., 2011) at all sites. To conduct the surveys a pair of fish divers descend and deploy a 30 m transect across the substratum. Divers are positioned at 7.5m and 22.5m and count fish within a 7.5m radius cylinder extending from the substrate to the limits of vertical visibility. The simultaneous surveys start once the divers deploy the transect and both divers are ready to proceed.

The SPC surveys are conducted in two parts. During the first five minutes, divers record all species observed within the cylinder, but do not count or size fish. All fish are identified to species level or the next lowest taxonomic level possible (genus or family). If a rare fish (shark, species of concern, large mobile predators, etc.) is observed during the first 5 minutes, it is counted and sized, but the diver notes that it was not an instantaneous count[5]. After the first five minutes divers enumerate fish, one species grouping at a time, using rapid visual sweeps of the plot. The counts are designed to be "instantaneous" to avoid double counting. All fish of the target species within the SPC boundaries are counted and sized to the nearest centimeter; however, divers use size

[5] This survey method for rare fish was not in place during the Tumon Bay and East Agana Bay surveys. Rare fish were counted and sized but it was not clear if it was an instantaneous count or not.

classes for large schools or high densities. This process is continued until all of the listed species are counted. If a species is no longer present in the cylinder during the second phase, divers record their best estimate of size and number. During the Western Shoals surveys, this type of count was marked as "noninstantaneous" and excluded from the biomass and density calculations. At the end of the survey, divers swim throughout the 7.5m radius plot to enumerate small and cryptic species that were not captured from the stationary central position. If a rare fish is still present during the counts, it is counted and sized and the original measures are crossed off. Species that enter the SPC after the first five minutes are noted on the species list for the site, but are not counted unless they are a rare fish recorded with a noninstaneous designation. Surveys are not completed if the visibility is less than 7.5 m. To document species richness at the sites, the fish team conduct roving diver swims throughout the survey station after the SPCs.

To minimize diver disruptions, the benthic team does not descend until the fish team finishes enumerating fish. A fish diver partners with a benthic diver when two fish divers are not available. In this situation, the fish diver would lay the transect and conduct the first SPC at 22.5m while the benthic diver would work from 0-15 m; they would then switch positions along the transect.

For the first two monitoring sites, Tumon Bay and East Agana Bay, fish divers also conducted belt transects along the transect lines prior to conducting SPCs. As the fish divers deployed the transect line they recorded the species, number, and size of all fish >20 cm in length within 5m of the transect (25 m x 10 m). They then returned along the transect counting and sizing all fish <20 cm within 1m of the transect (25 m x 2 m). Fish were identified to species or next lowest taxonomic level and sized to centimeter. Once the belt transects were complete, the divers conducted the modified SPC method as described above.

Macroinvertebrates

Counts of target macroinvertebrate species (*Acanthaster*, echinoids, holothurians, *Tridacna*, etc.) are made within a 4 m belt (2 meters on either side of the transect)(Figure 13). The size of *Tridacna* spp. are measured to the nearest cm.

Rare Species

Protected or rare species utilizing the general area around the site will be recorded and photographed. These species include marine mammals, sea turtles, *Bolbometopon muricatum*, and *Cheilinus undulatus*. Data will include species, number, activity, and size when possible.

Figure 13. The Crown of Thorns sea star (*Acanthaster planci*), which is a major source of coral mortality on Guam's reefs, is one of the several macroinvertebrate species targeted by the long-term monitoring program.

Other Data

At each site general site conditions are recorded. These include: location, time, depth, tidal stage, wave height (est), habitat description, and meteorological conditions (precipitation, air temp, wind speed). Researchers will also be trained to look for invasive species, marine debris, and physical damage consistent with storms, recreational use, or groundings.

Data Analysis

The initial analyses of the baseline data for the Tumon Bay, East Agana Bay, and Western Shoals monitoring sites involved the exploration of the various datasets in multivariate space, several types of power analyses, and the generation of descriptive statistics. These initial analyses were completed only for the benthic cover and reef fish community datasets, and thus a thorough description of the results for these two datasets will be presented in this report. The analysis of the coral size/condition dataset and the macroinvertebrate dataset is only partially complete, so only basic descriptive statistics are presented for these datasets within this report. It should be noted that Dr. Peter Houk, from the Pacific Marine Resources Institute based in the CNMI, provided invaluable guidance for the appropriate and efficient use of the PRIMER statistical software package and PERMANOVA add-on over a three day coaching session funded by a NOAA Domestic Grant.

Benthic Habitat

Benthic Cover

Prior to generating description statistics and carrying out power analyses on the benthic cover data derived from photo transects, the data for each site were explored in multivariate space using the statistical software package PRIMER and the PERMANOVA add-on. The exploration of the benthic cover data in multivariate space allowed for the visualization of the spatial structure of the data and the exploration of the possible influence of environmental factors on this spatial structure. This preliminary data exploration also assisted in determining if the benthic community remained relatively homogeneous across the monitoring sites or strata as original delineated, and whether or not the site boundaries should be adjusted, subdivided into two or more strata, or if certain sampling stations should be abandoned.

Benthic cover values generated by the CPCe application were re-formatted in Microsoft Excel to conform with PRIMER, such as including the addition of separate fields for environmental factors (e.g., depth, exposure) that may be expected to have some influence on the benthic community structure. Benthic cover classes were selected at the lowest taxonomic level, log-transformed, and then used to generate a Bray-Curtis Similarity Matrix (on which many PERMANOVA functions are based). A series of Principle Coordinates Analyses (PCO) were carried out on the benthic cover data, with a resulting series of scatter plot displays. These scatter plots depicted the clustering (or the lack thereof) among sampling stations within a given site/stratum, as well as indications of the environmental and biological factors that may be contributing to the differences in benthic community structure across the sampling stations. Distance-based Linear Models (DistLM) were then created using the Bray-Curtis Similarity Matrices created using the log-transformed benthic cover values in order to quantify the influence of environmental factors on the benthic communities. A SIMPER analysis was used to quantify the contribution of the dominant benthic cover taxa to the average Bray-Curtis dissimilarity and similarity between the benthic communities of different strata or other sampling station groupings (e.g., Tumon-East and Tumon-West). 2D Bubble Plots were then created to visualize the relative differences in average abundances for each of the benthic community components that contribute most strongly to the differences between stations from different strata or other sampling station groupings.

Univariate power analyses were carried out separately on total coral cover for sampling stations from different strata or other sampling station groupings in order to determine the probability that a t-test for a normal distribution would reject the null hypothesis when the null hypothesis is actually false (i.e., as power increases the chances of a Type II – or false negative – error decreases). The power.t.test function of the freely available program R was used to carry out the univariate power analysis for total coral cover and a graphical exploration of statistical power for total coral cover was carried out using a custom R function developed by Dr. Houk. Power analyses using R's power.t.test function and the custom R function will be carried out for additional benthic cover taxa/values (e.g., benthic cover ratio, macroalgae, crustose coralline algae, etc.) at a later date. Multivariate power analyses were carried out in order to examine the ability of the sampling regime to adequately capture the overall "character" of the benthic communities. Dominance plots and PCOs of cumulative means for benthic cover components (at the lowest taxonomic level) were generated within PRIMER/PERMANOVA to examine the shape of the cumulative dominance curve. Additionally, PCOs were created based on Bray-Curtis Similarity Matrices generated using the log-transformed cumulative mean abundances of benthic taxa for each site, strata, or other sampling station grouping. Power analyses will also be carried out on benthic cover data in order to determine the optimal number of frames and points should be utilized in CPCe. The results of a preliminary analysis on frames and points carried out by Dr. Houk indicates that the number of images taken along each transect could be halved (from 50 to 25) and the number of points used in the analysis of images within CPCe could be lowered from 25 to

5-10 without sacrificing statistical power for the dominant benthic taxa. However, further analysis must be conducted prior to proceeding with a change in the methodology.

Based on the results of the exploration of the data in multivariate space and the power analyses, site and strata boundaries were then modified, and some sampling stations eliminated. These modifications should only be considered tentative until further analysis can be conducted on the benthic cover data, as well as on the coral size/condition, reef fish, and macroinvertebrate data. Mean percent cover and standard deviation were then generated for key benthic cover categories and presented by site, strata, or other sampling station grouping when appropriate.

Coral Community

While the analysis of the coral colony size/condition data has not yet been completed, this analysis will involve the comprehensive exploration of the coral community across strata and across monitoring sites. The diversity of coral taxa (species level when possible), relative abundance, evenness, and other coral community measures will be generated and explored in multivariate space. Coral community size structure will also be examined across strata and across entire monitoring sites. Aspects of coral condition, such as partial mortality (old and recent), sources of mortality, and coral disease prevalence will be calculated for each sampling station and for each monitoring site/strata.

Associated Biological Communities

Reef Fish

The initial analyses of the baseline reef fish community data involved the generation of basic descriptive statistics and power analyses for the determination of adequate sample size. As this is the first set of reef fish data for the program, the goal of this report is to summarize the first round of monitoring data for the Tumon Bay, East Agana Bay, and Western Shoals sites, and make recommendations to improve data collection and analysis in the future. This report examines only the SPC data, as SPCs were used across all of the sites.

Reef fish density was calculated by combining the number of fish observed at each station and dividing it by the number of SPCs conducted. This was then converted into an area based measure (# of fish/ 100 m^2).

$$Density = \frac{\#\ of\ fish\ at\ station}{\#\ of\ SPC * (\pi * 7.5^2)} \times 100$$

Biomass, the estimated mass of the fish, was computed from length-weight regression factors and the observed length of the fish multiplied by the number of fish of that length observed and converted to kilograms. Length-weight regression values were obtained from a number of sources, including DAWR, Fishbase, and NOAA NMFS CRED. All fish were aggregated to species or family by station. Measures were then converted to an area based measure.

$$W = a \times l^b$$

$$Biomass = \frac{\sum \left(Wn \times \frac{1\ kg}{1000\ g}\right)}{\#\ of\ SPC * (\pi * 7.5^2)} \times 100$$

Where W is weight per record, a and b are species specific length-weight coefficients, l is length of fish observed, n is the number of fish of size l observed at the station.

Species richness was calculated by using a pivot table in Excel to create a table of the stations at which each species was observed. The number of stations at which a species was observed was counted and converted to a percentage of occurrences.

In order to explore the reef fish community data in multivariate space, the data were imported into PRIMER, log transformed, and Bray-Curtis Resemblance matrices were calculated for each data set. The data were then explored using the Multidimensional Scaling (MDS) function; factors such as depth and "exposure" were examined for total density and total biomass, as well as density and biomass by family and species. When potential relationships were observed in the MDS plot, the ANOSIM function was used to determine if the relationship was statistically significant. The data were also explored for the contribution of specific species and families using the SIMPER function.

PRIMER was also used to determine the optimum number of transects for the sampling of the reef fish community. This analysis was carried out for both biomass and density, both by family and at the species level. Cumulative averages across the transects surveyed were calculated, log transformed, and then plotted using the Dominance Plot function in PRIMER. R was used to generate the mean, standard deviation, and power for reef fish biomass, density, and species richness. A custom R script developed by Dr. Houk was used to visualize changes in the cumulative mean, standard deviation, and power as the sample size increased.

Macroinvertebrates

While the analysis of the macroinvertebrate data has not yet been completed, this analysis will involve the comprehensive exploration of the data across strata and monitoring sites. Macroinvertebrate diversity, density, and relative abundance will be generated for species and species groups.

Comparison Analyses

Comparisons of data between monitoring sites are not presented in the present report; such comparisons may be made at a later date once an adequate understanding of factors influencing the biological communities at each site is achieved and comparisons of one or more datasets is determined to be appropriate. When appropriate, comparisons of various parameters between reefs and between sampling periods will make use of a One-Way Analysis of Variance (ANOVA) or Repeated Measures ANOVA, or other appropriate statistical tests, to determine if any differences are statistically significant. Regression analyses will be used to examine relationships between biological parameters and environmental variables. Multidimensional scaling and other multidimensional statistical tools will be used to visualize similarities and dissimilarities between reef communities. Modifications to statistical analyses carried out on data between sampling periods will have to be made to account for the combined use of fixed and non-fixed transects and quadrats. Support will be sought by the National Park Service and others utilizing this sampling approach. Assistance by Dr. Houk will also be sought in the further analysis of the baseline data and data collected at subsequent sampling periods. The results of further analyses will be presented in subsequent reports.

Data Storage and Management

A database server and associated applications will be developed to facilitate data entry, quality control, management, analysis and reporting. Funding has already been secured for the database server and efforts are currently underway to procure the appropriate hardware and software and to hire a contractor to assist the monitoring coordinator in preparing the data for migration to the database. The database solution will eventually include one or more web-based applications to facilitate remote data entry by field personnel, data quality analysis/quality control, and the dissemination of data through tabular and spatial queries. The design of the data models, the migration of the data to the database server, and the development and testing of the web applications will be carried out by the NOAA Pacific Islands Fisheries Science Center's Coral Reef Ecosystem Division (CRED). Future web application development will likely provide for the automatic generation of descriptive statistics and summary reports, as well as additional functionality for the display and query of spatial data.

Reporting

The database server and associated web-based applications will facilitate faster reporting and better informed management decisions by the local resource agencies. The use of GIS will help managers view the data in more meaningful ways and answer site specific queries with a few clicks of the mouse button. The monitoring coordinator will coordinate and compile annual reports summarizing the data for resource managers. This information will be included in Guam's chapter of future NOAA *Status of the Coral Reef Ecosystems of the U.S. and Freely Associated* States reports and will be submitted to CoRIS. Information obtained through the monitoring program will be incorporated into a variety of outreach and education activities carried out by various local and federal agencies in an effort to raise awareness of the status of Guam's coral reef resources among Guam's community.

The program will be reviewed each year to determine its effectiveness and to decide if any modifications need to be made to the monitoring strategy. Any updates or changes will be incorporated into the following year's training and will be documented for future reference.

Field Work Completed To-Date

Field surveys began in June 2009, with initial surveys targeting the Tumon Bay Marine Preserve. Due to a number of limitations, only benthic cover, coral colony size/condition, and fish data were collected at seven sampling stations along the reef slope terrace in Tumon Bay in 2009. Because the field survey trips were less frequent than expected – mainly because of limited boat availability – the monitoring assistants were temporarily assigned to assess the extent and document the health of many of the large staghorn *Acropora* thickets around Guam. Most of these thickets occur on the reef flat and are accessible from shore, so the monitoring assistants were able to carry out this monitoring task without the need for a boat and could do so when conditions outside the reef prohibited access to outer reef monitoring sites. This effort will help improve the accuracy of the benthic habitat data, which will in turn enhance our ability to define strata for use in the long-term monitoring program. The *Acropora* mapping/monitoring project will also provide valuable baseline data for future analysis of the impacts of climate change on coral species that are among the most sensitive to thermal stress. University of Guam Marine Lab researchers have already utilized information collected through the *Acropora* mapping/monitoring project in the development of projects aimed at tracking the health of these vulnerable coral communities, elucidating the connectivity between them, and furthering our understanding about their resilience in the face of climate change and other stressors.

Field surveys were conducted along a portion of the Tumon Bay lower reef slope during the 2010 field season beginning on August 4 and ending September 2. A total of 10 fixed and 10 unfixed sampling stations were surveyed during this time. Upon completion of surveys of the Tumon Bay study area, surveys of an equivalent area along the lower reef slope in East Agana Bay began, with 10 fixed and 10 unfixed sampling stations surveyed by November 26, 2010. Upon receiving the appropriate permits, rebar and concrete nails were installed at half of the sampling stations at each site to permanently establish transect and quadrat locations. A photo transect, five coral quadrats, one fish belt transect, and 3-4 fish stationary point counts were carried out at each sampling station in the Tumon and East Agana study areas.

Prior to conducting surveys at the Western Shoals site, a preliminary assessment was carried out on July 5, 2011, in order to gain familiarity with the site and to gather information for use in the delineation of appropriate strata (Figure 14). A GPS receiver attached to a float was towed twice around the perimeter of the shoals – once while at the surface using snorkeling equipment and another while scuba diving at a depth of approximately 10 meters. Photographs taken at regular intervals during the snorkeling and diving were then matched to the nearest GPS point using the GPS-Photo Link software. The geographically-referenced photos were then brought into GIS software and used, along with satellite imagery and lidar bathymetry data, to delineate the survey strata (Figure 14). Field surveys were then conducted at Western Shoals, in Apra Harbor, between July 11 and August 19, 2011. Data for multiple benthic and reef fish community parameters were collected at 10 fixed and 12 unfixed sampling stations spread across three strata (west-slope, west-margin, and east-margin).

Upon completion of surveys at Western Shoals, a preliminary site assessment was carried out along the reef slope spanning Piti Bay (Figures 15 and 16). Three drift dives were carried out along the reef slope, during which GPS receivers attached to floats were towed by two of the divers and photos were taken at regular intervals as well as for features/organisms of particular interest. The photos were then linked to the GPS waypoints using GPS-Photo link software. The GPS-linked photos assisted in the delineation of the study site and to further refine the benthic habitat data for the Piti Bay reef slope. The next site to be established will be a site in southern Guam (e.g, Achang, Cetti Bay, etc.), but the site has not yet been selected.

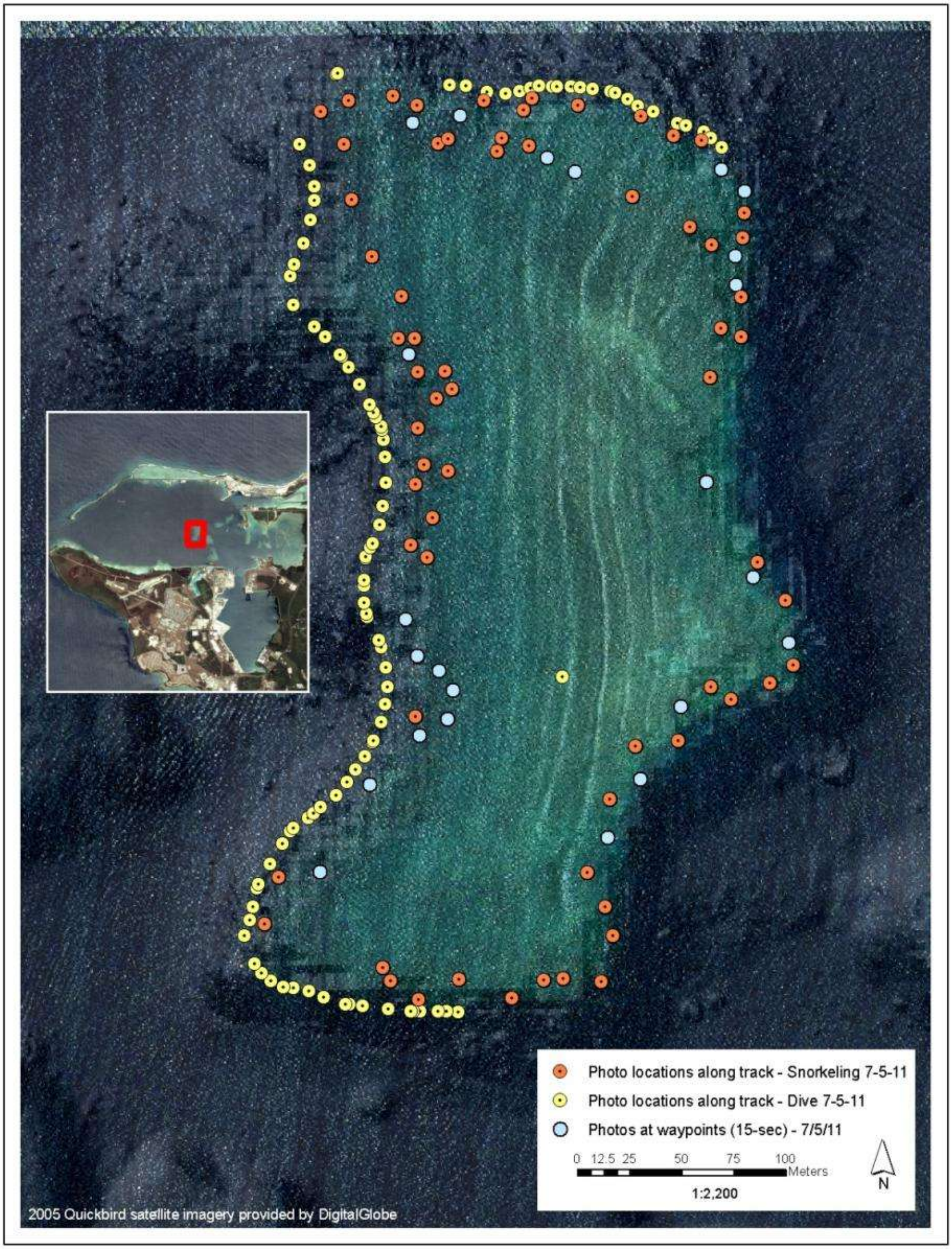


Figure 14. The locations of photographs taken of the reef community during the preliminary assessment of the Western Shoals monitoring site. The photos, along with observations recorded in the field, and analysis of the satellite imagery and lidar data in ArcGIS, were used to established the original strata boundaries. The strata boundaries may change depending on the results of the analyses of baseline data sets collected during 2011.

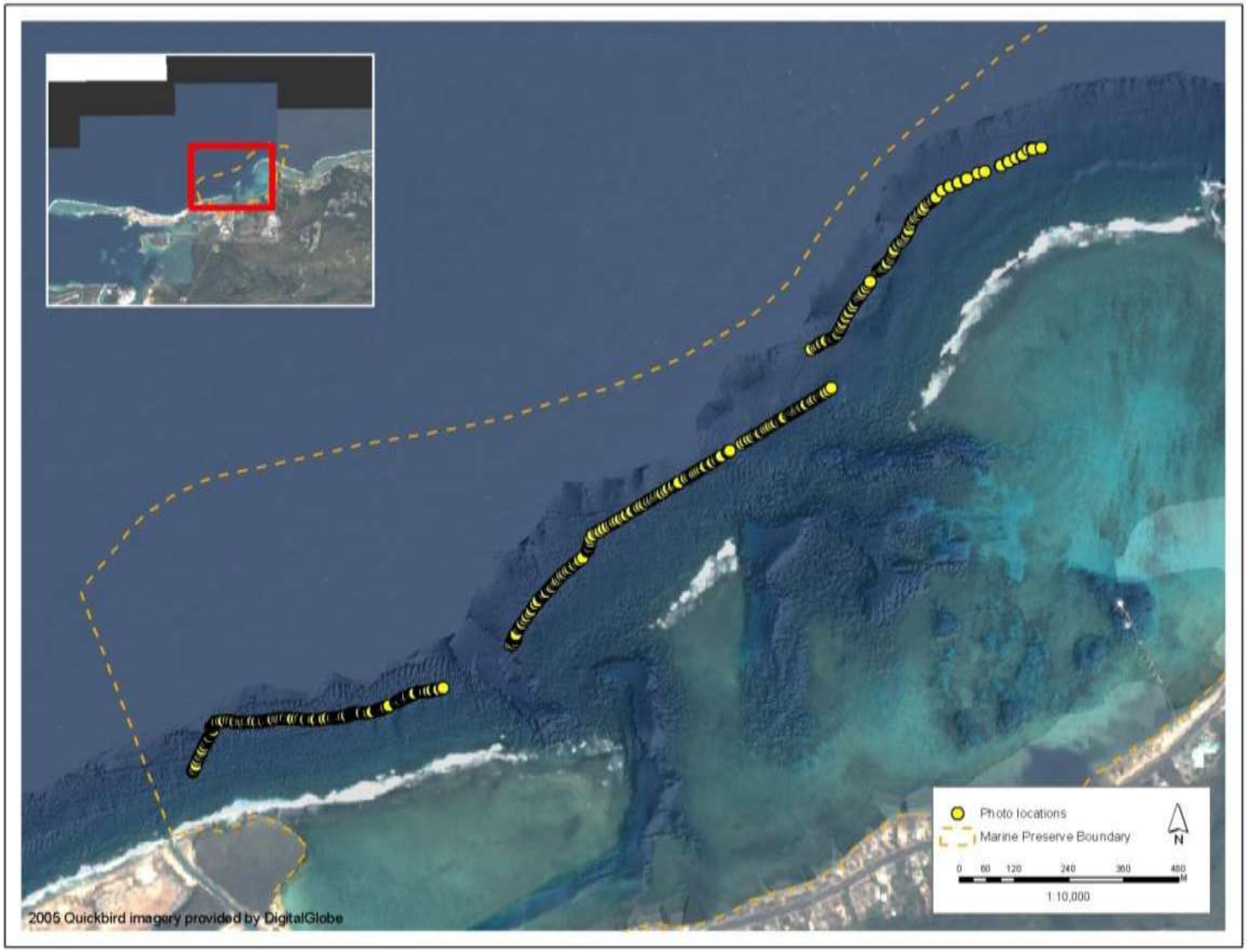


Figure 15. The locations of photographs taken of the reef community during the preliminary assessment of the Piti Bay monitoring site.

Figure 16. Divers conducting a preliminary site assessment along the outer reef slope in Piti Bay.

Results and Discussion

The following results and associated discussion are presented by site. A detailed between-site comparison for relevant parameters will not be presented at this time, as further analysis and methods revision must be conducted to ensure that such comparisons are justifiable. However, even if it is later determined that direct comparisons of baseline data for certain parameters between two or more sites is not appropriate, other comparisons, such as changes in cumulative dominance curves, rates of change, etc., may be made at a later date once additional data is collected.

Tumon Bay

Tumon: Benthic Cover

Exploration of benthic cover data in multivariate space

Prior to generating description statistics and carrying out power analyses on the benthic cover data derived from photo transects in the Tumon Bay monitoring site in 2010, the data were explored in multivariate space using the statistical software package PRIMER and the PERMANOVA add-on. The exploration of the benthic cover data in multivariate space allows the visualization of the spatial structure of the data, and the exploration of the possible influence of environmental factors on this spatial structure. This preliminary data exploration can also assist in determining if the benthic community remains relatively homogeneous across the monitoring site as originally delineated, and whether or not the site boundaries should be adjusted, subdivided into two or more strata, or if certain sampling stations should be abandoned.

Benthic cover values generated by the CPCe application were re-formatted in Microsoft Excel to conform with PRIMER, such as including the addition of separate fields for environmental factors (e.g., depth, exposure) that may be expected to have some influence on the benthic community structure. Benthic cover classes were selected at the lowest taxonomic level, log-transformed, and then used to generate a Bray-Curtis Similarity Matrix (on which many PERMANOVA functions are based). For the Tumon data, only those data for frames from the left side of the transect were used because of a complication in combining the frames from both the left and right sides using CPCe. A Principle Coordinates Analysis (PCO) was carried out on the benthic cover values from transects at all sampling stations in Tumon Bay, with a result being a two-axis scatter plot display (Figure 17).

While the sampling stations did not cluster tightly, a small number of outliers were evident (e.g, sampling stations 12, 13, and possibly 20). In order to better understand what environmental factors may be influencing the apparently different benthic communities at these sampling stations, depth and exposure at each sampling station were visualized (Figures 18 and 19, respectively). In general it appeared as though depth was having an influence on the benthic communities observed at the Tumon sampling stations, with stations with similar depths clustering together. But, more strikingly, the shallow depths (5-6 meters) of stations 12, 13, and 20 likely explain their distance from the rest of the sampling stations; this is as expected, as these sites straddle the transition between the reef front and the lower reef slope terrace and possess benthic communities better adapted to higher wave energy.

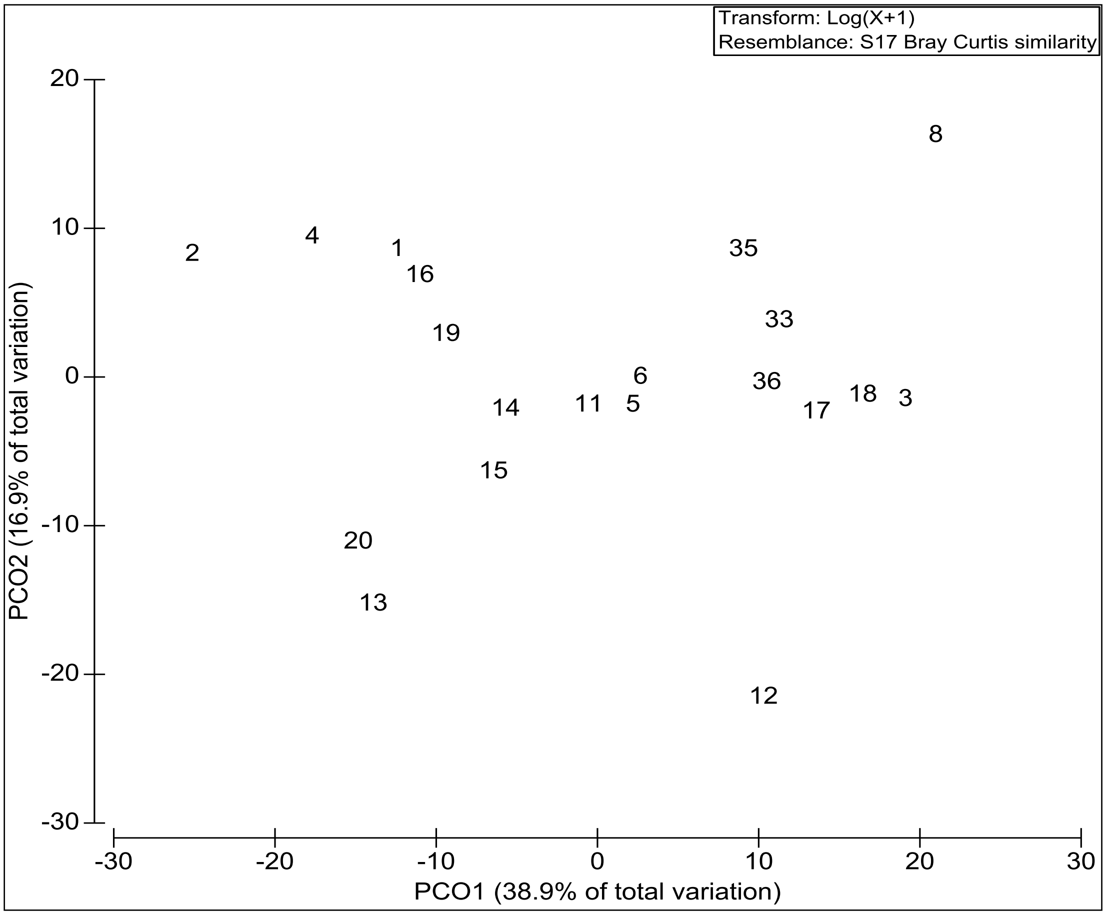


Figure 17. A Principle Coordinates Analysis (PCO) scatter plot displaying the sampling stations from the Tumon Bay monitoring site. The PCO was based on a Bray-Curtis Similarity Matrix created using log-transformed benthic cover values for benthic classes selected at the lowest taxonomic level. While tight clusters of sampling stations were not evident, sites 12, 13, and 20 appeared to be outliers, indicating that they hosted somewhat different benthic communities than those found at other stations.

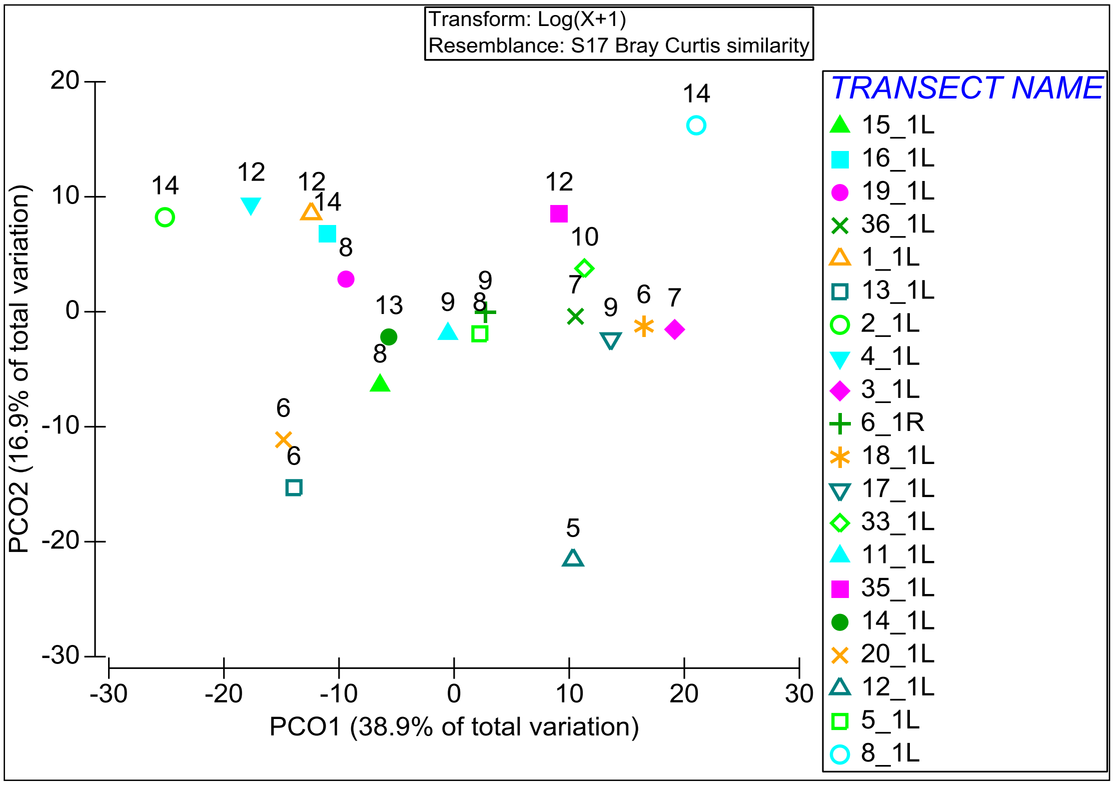


Figure 18. A Principle Coordinates Analysis (PCO) scatter plot of sampling stations from the Tumon Bay monitoring site with the labels indicating the depth in meters of each sampling station. The PCO was based on a Bray-Curtis Similarity Matrix created using log-transformed benthic cover values for benthic classes selected at the lowest taxonomic level.

While a direct measure of exposure was not immediately available, a proxy – East-West Gradient – was developed based on the distance of each sampling station from the eastern-most boundary of the study area. For the Tumon Bay area it is generally held that reef areas in the southwestern portion of the bay are less protected from wave action than reef areas further north, due to the shape of the bay, its position along the coast, and the prevailing direction of wind and waves. But It must be clear that this proxy was used only on a tentative basis, as the relationship between the proxy and exposure has not been tested. Additionally, submarine aquifer discharge could also influence benthic communities such that a relationship with an East-West Gradient would be evident. Horizontal water quality profiles can be generated in the near future using a datasonde for moderately large stretches of reef in order to examine the relationship between water quality (likely associated with localized submarine discharge) and biological communities in the Tumon Bay monitoring site.

Once the East-West Gradient values were visualized on the scatter plot it was clear that this factor had a significant influence on the benthic communities of the Tumon sampling stations, with those sampling stations with similar East-West Gradient values clustering closer together (Figure 19).

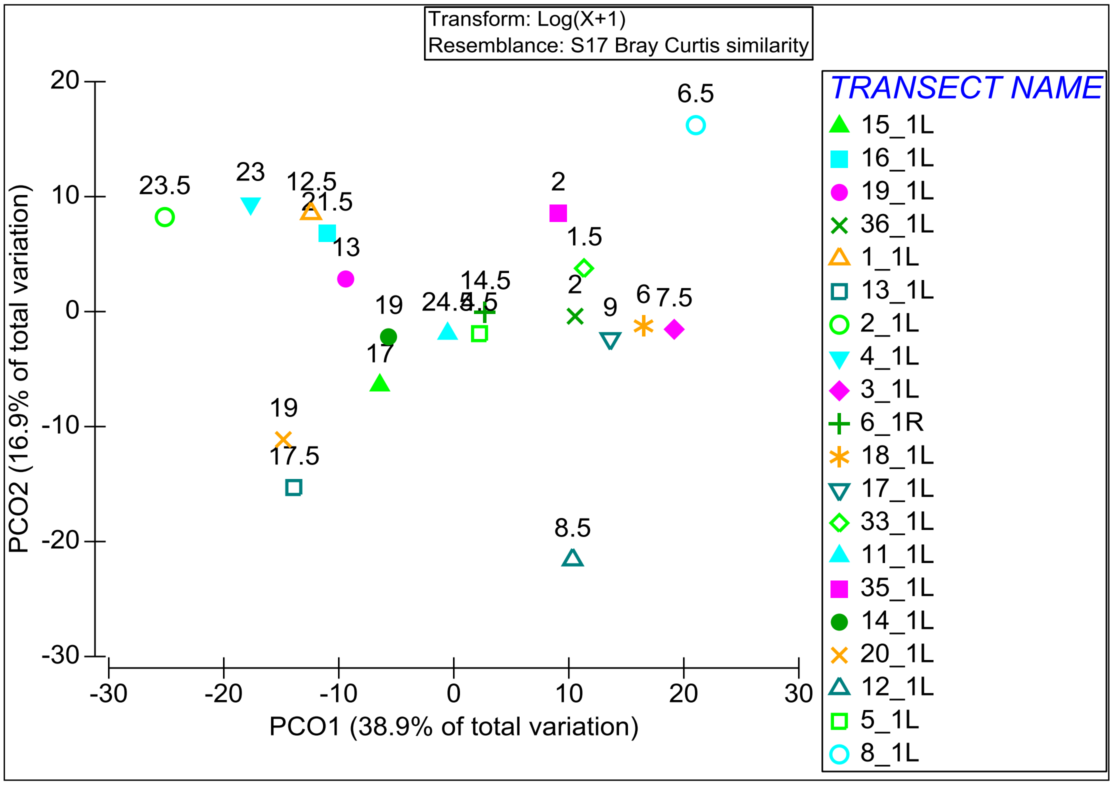


Figure 19. A Principle Coordinates Analysis (PCO) scatter plot of sampling stations from the Tumon Bay monitoring site with the labels indicating the East-West gradient value (distance from eastern boundary of Tumon site) for each sampling station. The PCO was based on a Bray-Curtis Similarity Matrix created using log-transformed benthic cover values for benthic classes selected at the lowest taxonomic level.

Based on the results of the PCO, the Tumon sampling stations were experimentally divided into Tumon-East and Tumon-West; this delineation, depicted in Figure 20, was used as a working model for the remainder of the multivariate analysis and, with further refinements, was used to carry out separate power analyses for Tumon-East and Tumon-West and was used in the generation of descriptive statistics for the two areas. The data were re-visualized on the PCO scatter plot using this new delineation, with each sampling station assigned to either Tumon-East or Tumon-West (Figure 21). The resulting scatter plot depicted two nearly non-overlapping clusters corresponding to the East-West delineation, indicating that the sampling stations at a given Tumon sub-site are more similar to each other than with sampling stations in the other sub-site.

The PCO scatter plots provided a strong indication that both depth and the East-West gradient explained at least some of the differences observed between the benthic communities at the sampling stations, but in order to quantify the influence of these environmental factors a Distance-based Linear Model (DistLM) was performed on the Bray-Curtis Similarity Matrix created using log-transformed benthic percent cover values. The results of the DistLM indicated that depth and the exposure proxy explained 15% and 25% of the difference between the benthic communities at the Tumon sampling station, respectively ($p = 0.006$ and 0.001, respectively).

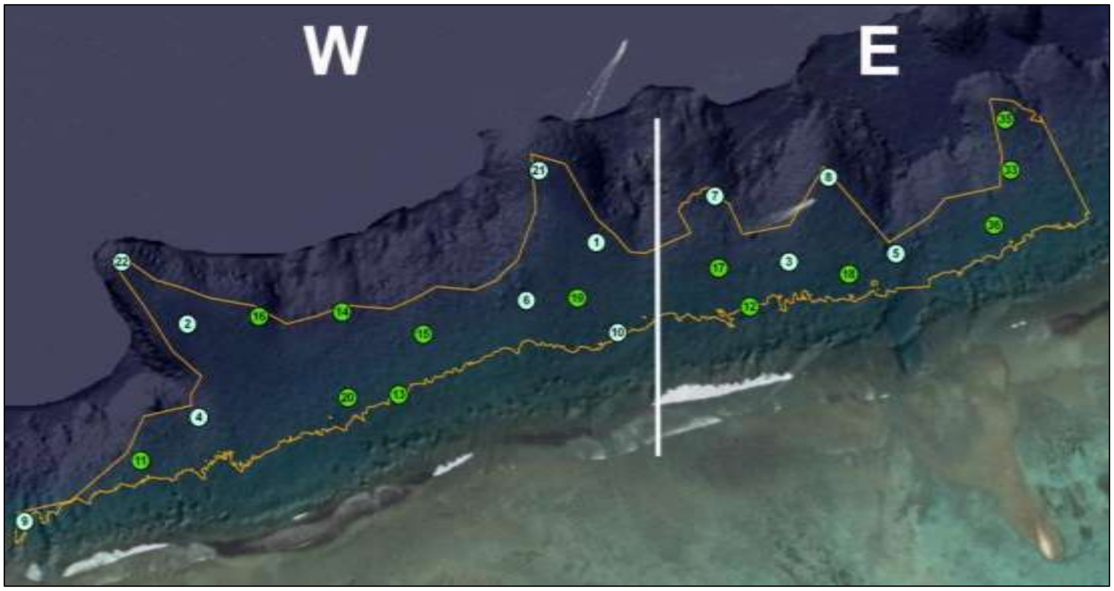


Figure 20. Depiction of the East-West delineation for the Tumon Bay sampling stations, based on the similarity/dissimilarity of the benthic communities at the sampling stations.

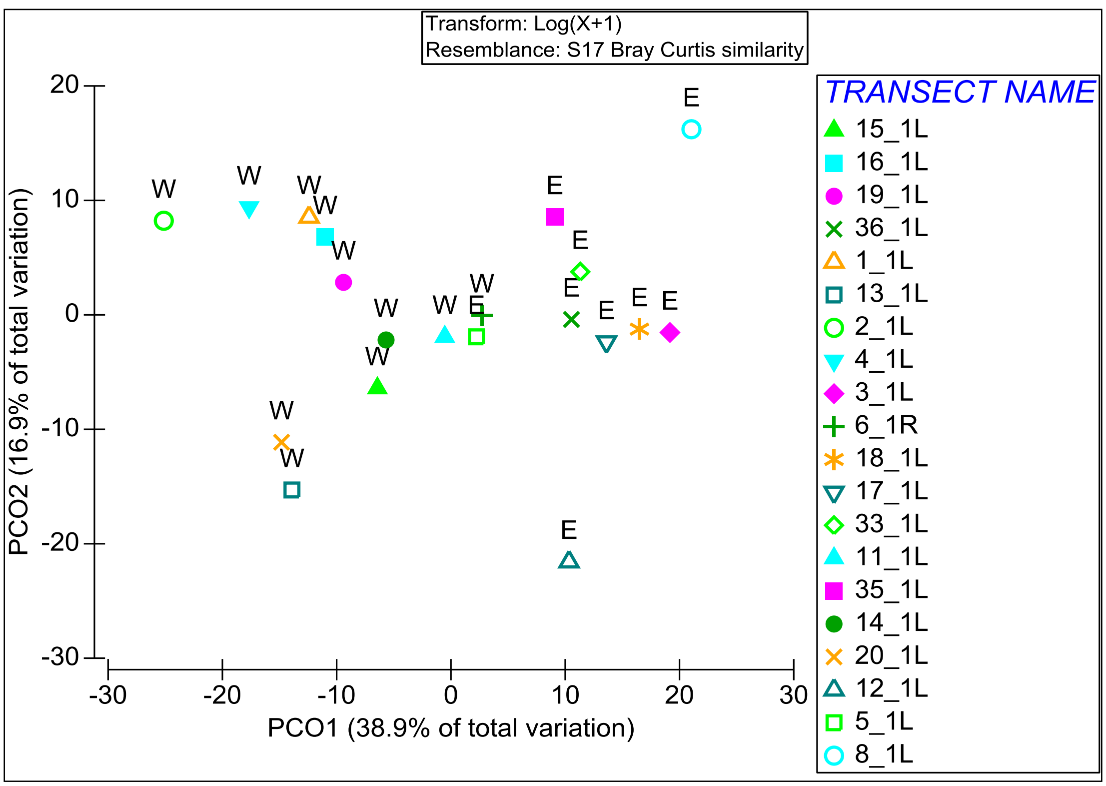


Figure 21. A Principle Coordinates Analysis (PCO) scatter plot of sampling stations from the Tumon Bay monitoring site with labels indicating the classification of the sampling station as belonging to the Tumon-East ("E") or Tumon-West ("W") portion of the overall study site. The PCO was based on a Bray-Curtis Similarity Matrix created using log-transformed benthic cover values for benthic classes selected at the lowest taxonomic level.

To further explore how the aspects of the benthic communities themselves – as opposed to environmental factors – drive the differences between sampling stations, the dominant benthic community factors (Spearman Correlation >0.6) were displayed on the PCO scatter plot (Figure 22). The resulting display indicated that the factors contributing the most to the differences between the benthic communities at the Tumon-East and Tumon-West sampling stations included the greater cover of the corals, *Porites rus* and massive *Porites* spp., and the calcareous algae, *Halimeda* spp. and *Galaxaura* spp. (which are often associated with *Porites rus*) at Tumon-East stations compared to the Tumon-West stations and the greater cover of turf algae, the encrusting coral, *Montipora verrucosa*, the sponge *Dysidea* spp., and cyanobacteria at the Tumon-West stations compared to the Tumon-East stations. Also evident were the factors most heavily influencing the differences between the benthic communities at the shallower stations (12, 13 and 20 – the three stations at the bottom of the plot) and those at deeper stations. In particular, the submassive coral *Leptoria phrygia*, fire coral, *Millepora* spp., and crustose coralline algae appear to be driving the difference between stations 12, 13, and 20 and the rest of the sampling stations; these benthic taxa are generally found in greater abundance in the high energy environment of the reef front, as opposed to the lower energy environment of the lower reef slope terrace. Thus, it appears as though the original Tumon monitoring site boundary extended too shallow and included sampling stations that straddled the transition between the reef front and the lower reef slope terrace, instead of occurring firmly within the terrace zone nominally targeted for monitoring.

A SIMPER analysis was then carried out in order to quantify the contribution of each variable to the average Bray-Curtis dissimilarity and similarity between the benthic communities of the Tumon-East and Tumon-West stations. The results of the SIMPER analysis indicate that the variables that contribute the most to the similarity between Tumon-West sampling stations include turf algae, crustose coralline algae, cyanobacteria, *Porites rus*, and massive *Porites* spp., with turf algae and crustose coralline algae comprising a total of more than 55% of the similarity, and all five variables contributing a total of more than 90% of the similarity between the benthic communities at the Tumon-West sampling stations (Table A). Similarly, both turf algae and crustose coralline algae were the primary contributors to the similarity between benthic communities at the Tumon-East stations, with a combined contribution of over 40%. Also similar to the Tumon-East stations, *Porites rus*, massive *Porites* spp., and cyanobacteria were significant variables, although cyanobacteria played a less significant role than *Porites rus* and massive *Porites* spp. in the Tumon-West stations.

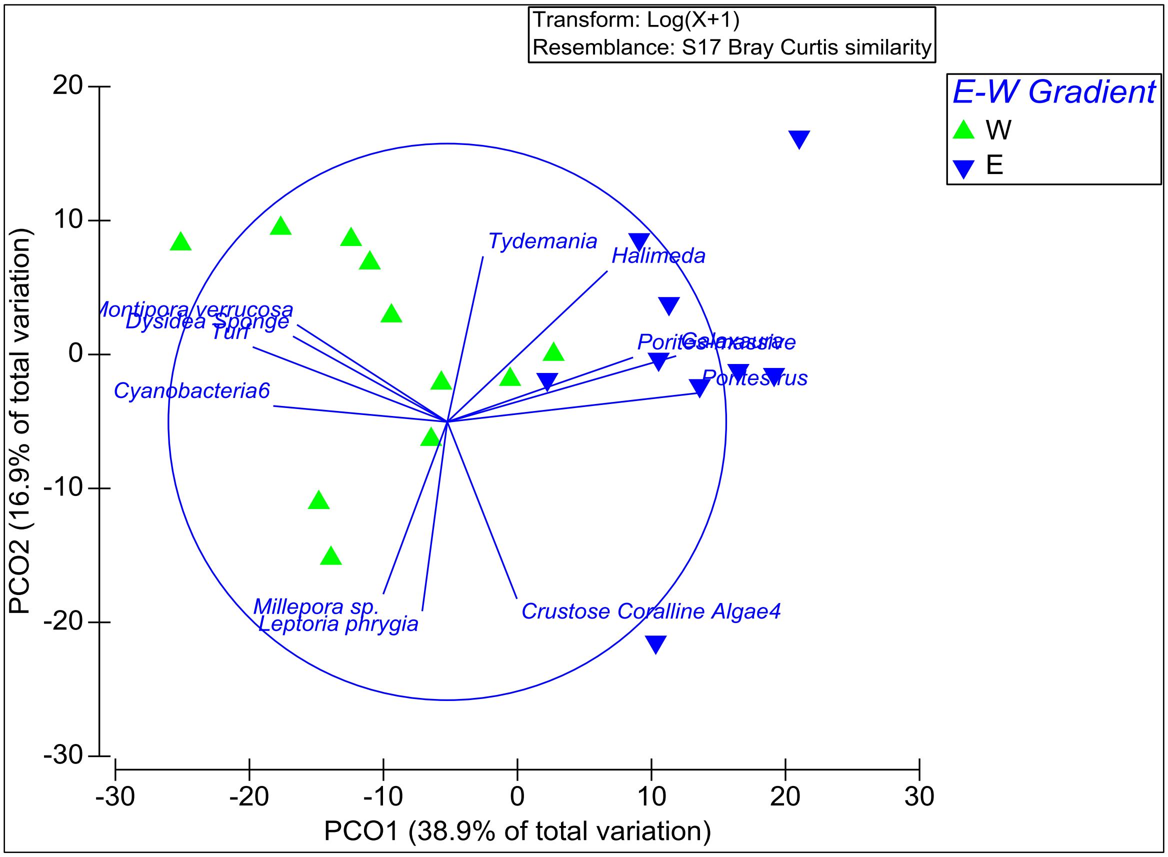


Figure 22. A Principle Coordinates Analysis (PCO) scatter plot of sampling stations from the Tumon Bay monitoring site with stations symbolized as belonging to the Tumon-East or Tumon-West areas and with vectors defining correlations between variables plotted over the scatter plot (blue lines and blue labels). The PCO was based on a Bray-Curtis Similarity Matrix created using log-transformed benthic cover values for benthic classes selected at the lowest possible taxonomic level.

2D Bubble Plots were then created to visualize the relative differences in average abundances for each of the benthic community components that contribute most strongly to the differences between stations from Tumon-East and Tumon-West (Figures 25 and 26). The bubble plots reveal a striking pattern in the distribution of the average abundance (log-transformed values) of *Porites rus*, with noticeably greater average *P. rus* abundances at the Tumon-East stations than the Tumon-West stations; similarly, the average abundances of the often *Porites rus*-associated calcareous algae, *Halimeda* spp. and *Galaxaura* spp., are also greater at the Tumon-East stations, with *Galaxaura* being entirely absent from all Tumon-West stations (Figure 23, 24, and 25). The pattern for the average abundance of massive *Porites* spp. is less distinct, as sampling stations from both sub-sites possess somewhat similar average abundances of massive *Porites* spp.; however, the Tumon-East stations appear to possess, on average, greater abundances of massive *Porites* spp.

Table A. Results of a SIMPER analysis of log-transformed benthic cover data for Tumon-East and Tumon-West sampling stations.

Group W
Average similarity: 73.40

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Turf Algae	3.93	25.71	8.69	35.02	35.02
Crustose Coralline Algae	2.73	15.38	3.74	20.96	55.98
Cyanobacteria	2.47	14.51	4.53	19.78	75.76
Porites-massive	1.71	9.66	2.85	13.16	88.91
Porites rus	0.90	3.09	0.92	4.20	93.12

Group E
Average similarity: 75.59

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
Turf	3.41	17.58	15.42	23.26	23.26
Crustose Coralline Algae	2.98	15.04	8.18	19.89	43.15
Porites rus	3.02	14.76	6.09	19.53	62.68
Porites-massive	2.40	11.66	8.26	15.43	78.11
Cyanobacteria	1.76	7.49	2.67	9.91	88.02
Chrysophyte	0.96	2.38	0.78	3.15	91.17

Groups W & E
Average dissimilarity = 33.43

Species	Group W Av.Abund	Group E Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Porites rus	0.90	3.02	6.47	2.39	19.34	19.34
Cyanobacteria	2.47	1.76	2.71	1.50	8.12	27.46
Chrysophyte	0.26	0.96	2.64	1.22	7.89	35.34
Porites-massive	1.71	2.40	2.31	1.25	6.91	42.26
Crustose Coralline Algae	2.73	2.98	2.13	1.36	6.37	48.62
Turf Algae	3.93	3.41	1.76	1.70	5.25	53.88
Galaxaura spp.	0.00	0.45	1.36	1.66	4.07	57.94
Halimeda spp.	0.17	0.54	1.35	1.24	4.03	61.97
Porites annae	0.22	0.45	1.33	1.26	3.97	65.95
Branching Coralline Algae	0.29	0.46	1.25	1.03	3.73	69.68
Galaxea fascicularis	0.06	0.35	1.05	0.73	3.15	72.83
Sponges	0.18	0.12	0.69	0.74	2.07	74.90
Millepora spp.	0.14	0.12	0.68	0.59	2.02	76.92
Asparagopsis spp.	0.08	0.15	0.60	0.54	1.79	78.71
Leptoria phrygia	0.06	0.15	0.55	0.55	1.66	80.36
Leptastrea purpurea	0.18	0.02	0.52	0.94	1.57	81.93
Dysidea Sponge	0.16	0.05	0.47	1.07	1.40	83.33
Favites spp.	0.09	0.11	0.41	0.79	1.23	84.56
Montipora spp.	0.09	0.13	0.41	1.14	1.23	85.79
Porites spp.	0.03	0.12	0.38	0.62	1.15	86.94
Tridacna spp.	0.12	0.08	0.38	1.06	1.13	88.06
Holothurian	0.12	0.07	0.35	1.10	1.04	89.11
Favia spp.	0.08	0.06	0.34	0.96	1.02	90.13

Figure 23. A coral community with a moderate degree of topographical structure dominated by *Porites rus* at sampling station 33, in the tentatively-established Tumon-East sub-site.

Figure 24. A coral reef community with a relatively low degree of topographical structure at sampling station 15, in the tentatively-established Tumon-West sub-site. The lower abundance of *Porites rus* and massive *Porites* species at this and other Tumon-West sampling stations may be a result of greater exposure at these stations in comparison to those in the Tumon-East sub-site.

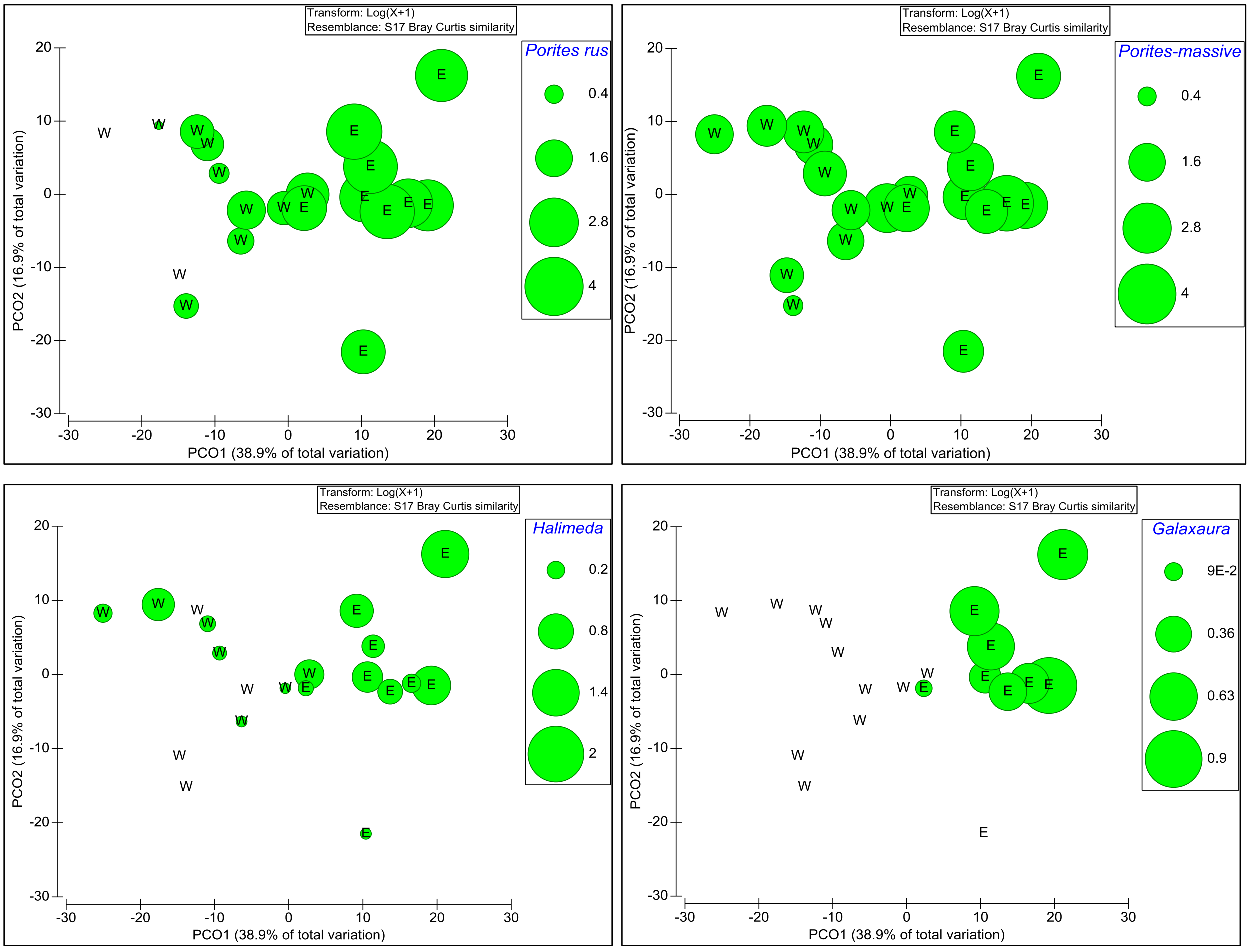


Figure 25. Principle Coordinates Analysis (PCO) 2D Bubble Plots of the relative abundance of the corals, *Porites rus* (upper left) and massive *Porites* spp. (upper right), and the calcareous aglae, *Halimeda* spp. (lower left), and *Galaxaura* spp. (lower right) at sampling stations from the Tumon Bay monitoring site. Labels indicate the classification of the sampling station as belonging to the Tumon-East ("E") or Tumon-West ("W") portion of the overall study site. The PCO was based on a Bray-Curtis Similarity Matrix created using log-transformed benthic cover values for benthic classes selected at the lowest possible taxonomic level.

The bubble plots also allowed for the visualization of the lop-sided distribution of the average abundance (log-transformed values) of *cyanobacteria,* the sponge, *Dysidea* spp.*,* the encrusting coral, *Montipora verrucosa* , and chrysophytes, with noticeably greater average abundances of these benthic features at the Tumon-West stations than the Tumon-East stations, with the exception of chrysophytes, which appear to be more abundant at Tumon-East stations (Figure 26). Also quite evident from the bubble plots were the abundances of *Millepora* spp. and *Leptoria phrygia*, which were present at the relatively shallow stations (12, 13, and 20) but were absent or nearly-absent in all other stations (Figure 27).

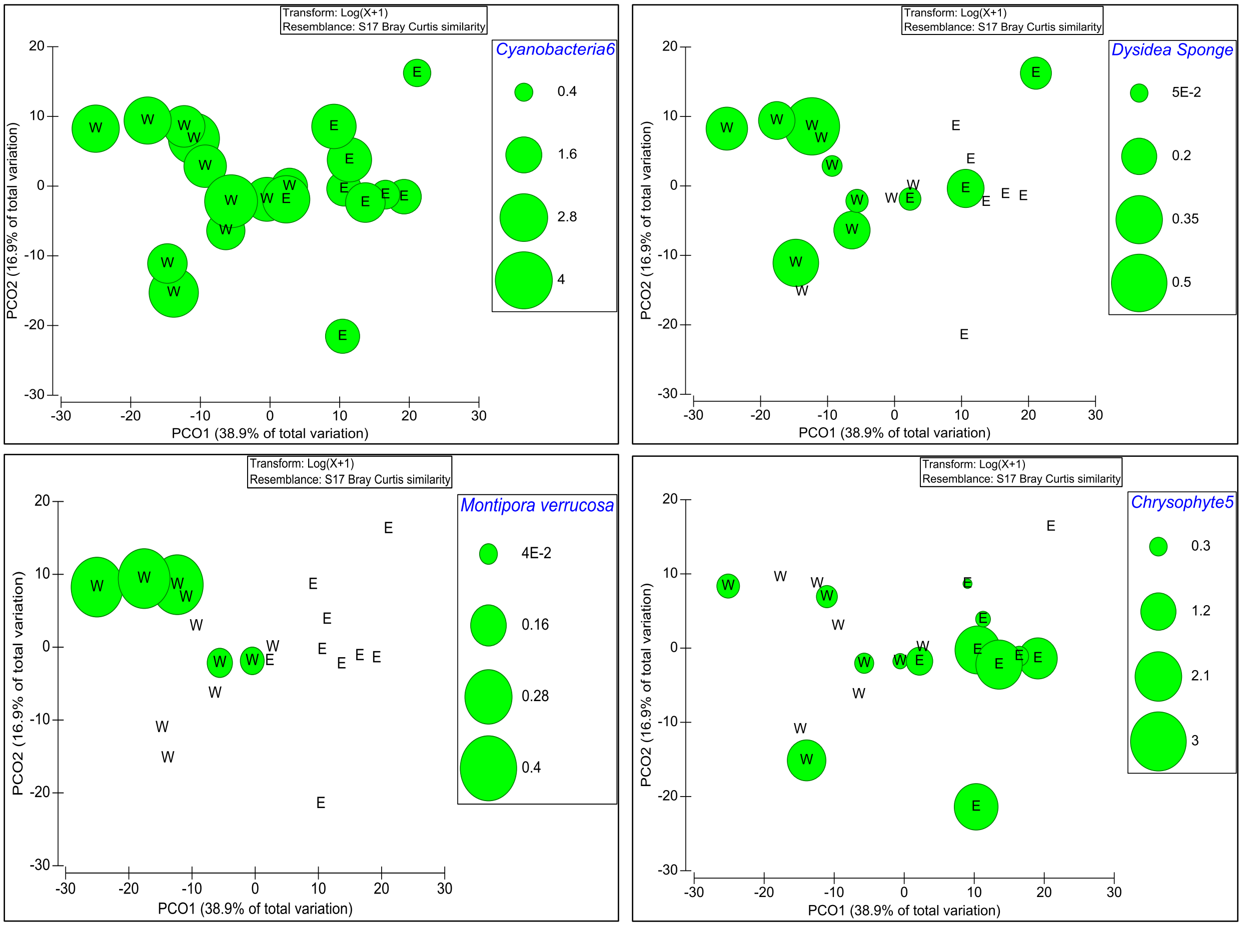


Figure 26. Principle Coordinates Analysis (PCO) 2D Bubble Plots of the relative abundance of cyanobacteria (upper left), the sponge, *Dysidea* spp. (upper right), the encrusting coral, *Montipora verrucosa* (lower left), and chrysophytes (lower right) at sampling stations from the Tumon Bay monitoring site. Labels indicate the classification of the sampling station as belonging to the Tumon-East ("E") or Tumon-West ("W") portion of the overall study site. The PCO was based on a Bray-Curtis Similarity Matrix created using log-transformed benthic cover values for benthic classes selected at the lowest possible taxonomic level.

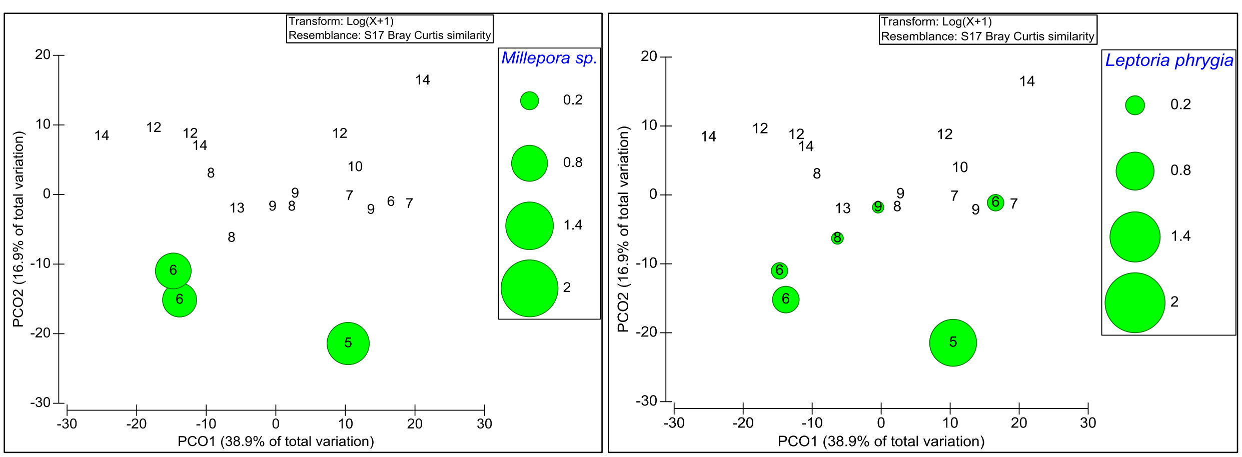


Figure 27. Principle Coordinates Analysis (PCO) 2D Bubble Plots of the relative abundance of *Millepora* spp. (left) and *Leptoria Phrygia* (right) at sampling stations from the Tumon Bay monitoring site. Labels indicate the depth at each sampling station. The PCO was based on a Bray-Curtis Similarity Matrix created using log-transformed benthic cover values for benthic classes selected at the lowest possible taxonomic level.

Power analyses for Tumon benthic cover data

Univariate power analyses were carried out separately on total coral cover for sampling stations in the Tumon-East and Tumon-West areas. Additional univariate power analyses for coral cover were carried out with station 12 excluded from the analysis of Tumon-East stations and with stations 13 and 20 excluded from the analysis of Tumon-West stations due to the significantly different benthic communities at these shallow locations. These stations may not be re-surveyed in 2012 and instead new permanent transects may be established in their place. Similarly, multivariate power analyses using Dominance Plots and PCOs were carried out separately for each sub-site, as well as for the modified sub-sites.

Power (of a two-sided t-test, $\alpha=0.05$) for mean coral cover values at all nine Tumon-East stations (left side of transect) was 0.65 and remained the same when station 12 was removed from the analysis (Table B). Power for mean coral cover values at all 11 Tumon-West stations (left side of transect) was considerably lower, at 0.38, but increased slightly (to 0.45) once stations 13 and 20 were removed. The relatively low power for the Tumon-West stations appeared to be influenced, at least in part, by an anonymously high coral cover value (17%) for one of the stations and the resulting increase in the standard deviation for mean coral cover across all Tumon-West stations. The power analysis was then run using coral cover values from the right side of the transect at Tumon-West stations. The results of the analysis indicated that power for mean coral cover values at all 11 Tumon-West stations (right side of transect) was the same as the power achieved by the Tumon-East stations. However, when stations 13 and 20 were excluded the power dropped to 0.49. The power analysis for both the Tumon-West and Tumon-East sampling stations will be re-run after data from the left and right sides of the transects are combined, but the results are expected to be similar.

A power of 0.65 for the detection of changes in coral cover of 30% relative to the mean is lower than originally desired for the program, so the power.t.test function was used to determine the number of samples (n) required to achieve a power of 0.7 and 0.8. The results indicated that for the Tumon-East stations about 10 samples would be required to achieve a power of 0.7 and about 12 stations would be required to achieve a power of 0.8 (Table B). Due to the greater amount of variability (i.e., higher standard deviation) in coral cover for the Tumon-West stations, a larger number of samples would be required to achieve a power of 0.7 or 0.8. When looking at data from the left side of the transect (and including the anomalously high coral cover value), 16-24 samples would be required in order to achieve a power of 0.7, with fewer samples required after excluding stations 13 and 20. However, when looking at data from the right side of the transect, the results of the power analysis indicated that between 12 and 14 samples would be required. Using data from the left side of the transect, between 20 and 30 stations would be required in order to achieve a power of 0.8 for the Tumon-West stations, while only 15-18 samples were required when using data from the right side of the transect.

Table B. Results of t-test power analysis for Tumon-East and Tumon-West sampling stations.

Group	Mean	SD	n	delta (mean*0.3)	power	n required for power = 0.7	n required for power = 0.8
East - Left side	35.5	9.0	9	10.6	0.65	10	12
East - Left side, excl. 12	36.7	8.8	8	11.0	0.65	9	11
East - Right side	36.7	9.5	9	11.0	0.64	10	13
East - Right side, excl. 12	37.7	9.6	8	11.3	0.6	10	12
West - Left side	9.1	3.7	11	2.7	0.38	24	30
West - Left side, excl. 13	9.6	3.5	10	2.9	0.42	19	24
West - Left side, excl. 13, 20	10.1	3.3	9	3.0	0.45	16	20
West - Right side	8.9	2.5	11	2.7	0.65	12	15
West - Right side, excl. 13	9.1	2.6	10	2.7	0.59	13	16
West - Right side, excl. 13, 20	9.0	2.8	9	2.7	0.49	14	18

An R code developed by Dr. Peter Houk of the Pacific Marine Resources Institute was then used to view how the mean, standard deviation, and power of a group of samples changed with an increasing number of randomly selected samples. In an ideal situation the mean and standard deviation would reach an asymptote and a fairly high level of power would be achieved with relatively few samples. The test can reveal, for instance, if the standard deviation reaches an asymptote for a given number of samples one can reasonably conclude that the standard deviation value at that asymptote is likely representative of the inherent variability between the sampled benthic communities, and that it will not decrease unless sources of variation are identified and removed (e.g., by eliminating one or more stations and established new ones if necessary). Power will continue to increase with an increasing number of samples, but because increasing the number of samples may not be a logistically or financially viable option, another approach is to reduce the variances of key parameters by re-defining the boundaries of the study area to include more homogeneous benthic communities or stratifying the original study area into two or more strata, or a combination of both. The results of the custom R analysis for mean coral cover at the Tumon-East stations (excluding station 12) indicated that mean and standard deviation appears to level off at around 8-9 samples, while the power gradually increases to around 0.7 by the 8th sample (Figure 28). The results for the Tumon-West stations (excluding stations 13 and 20) were similar, with the mean and standard deviation leveling out around 7 or 8 samples; power for the Tumon-West stations gradually increases to around 0.5 at the 9th sample (Figure 29).

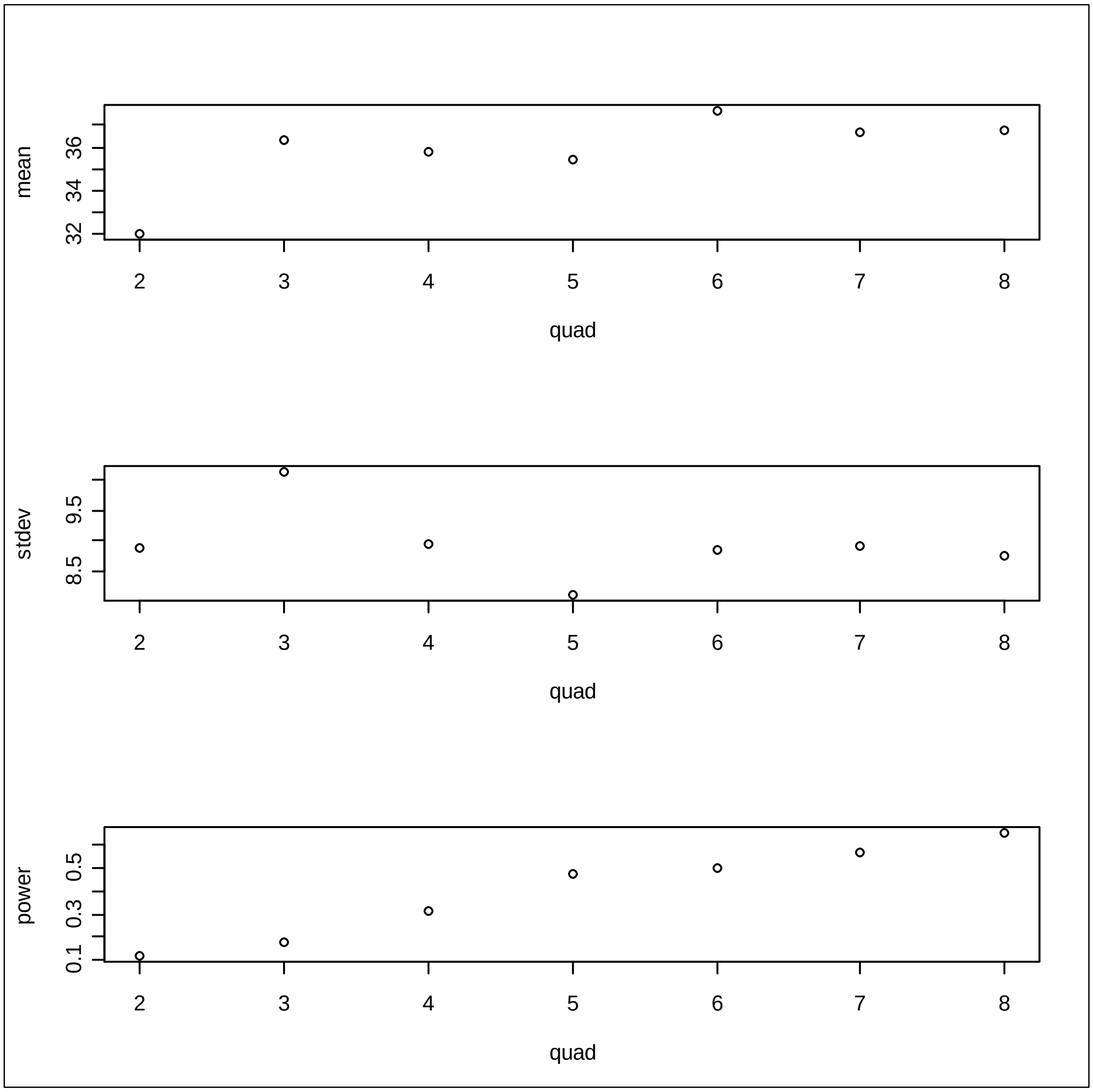


Figure 28. Results of a power analysis carried out on mean coral cover values for Tumon-East sampling stations (excluding station 12) using an R code developed by Dr. Peter Houk of the Pacific Marine Resources Institute.

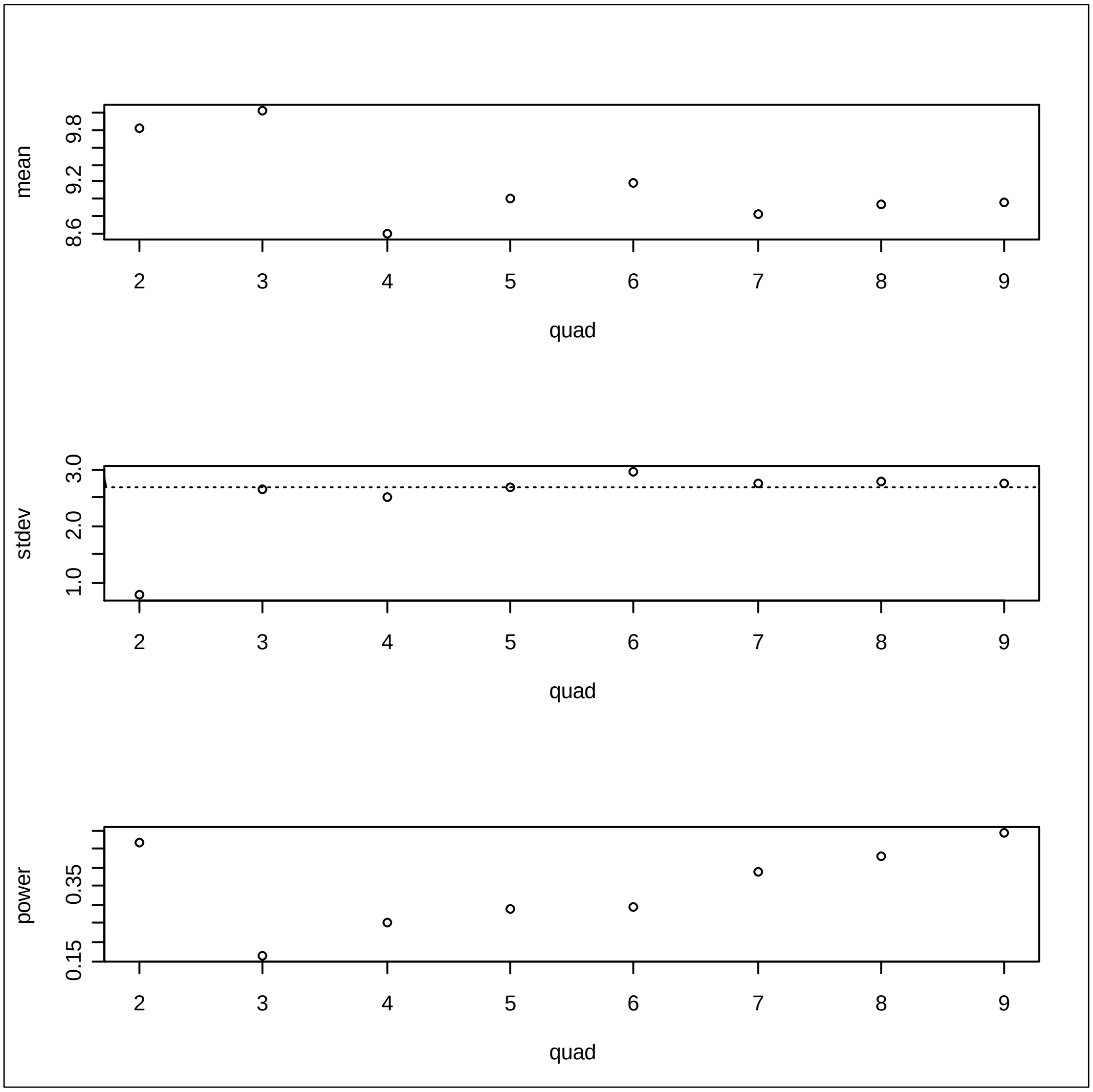


Figure 29. Results of a power analysis carried out on mean coral cover values for Tumon-West sampling stations (excluding stations 13 and 20) using an R code developed by Dr. Peter Houk of the Pacific Marine Resources Institute. The dotted line indicates the delta value (mean of all samples*0.3).

In order to visualize in multivariate space the ability of the present sample size to adequately capture the abundances of the dominant benthic taxa, the cumulative means of benthic classes (at the lowest taxonomic level) were calculated in Excel and brought into PRIMER/PERMANOVA. After a Bray-Curtis Similarity Matrix was created using the log-transformed cumulative means, a Dominance Plot was created using the cumulative means for the benthic cover values from the Tumon-East (excluding station 12) and Tumon-West (excluding stations 13 and 20) stations. The Dominance plots for both the Tumon-East and Tumon-West sampling stations depicted unusually tight clustering of cumulative dominance curves, indicating that the mean abundance values didn't change much with an increasing number of samples, and thus it is likely that the current sample sizes adequately capture the abundances of dominant benthic taxa within the study site (Figure 30).

The overall shape of the dominance curve, or cluster of dominance curves – particularly how quickly (or slowly) the curve slopes upwards – can provide one measure of the status of a benthic community; a cumulative dominance curve that rises rapidly, and reaches a cumulative dominance value of 50% at, say, a species rank of 3 or 4, indicates that only a very few number of species (or, more accurately in this case, benthic taxa or cover types) comprise a significant proportion of the total bottom cover within the monitoring site. This dominance by relatively few species/taxa/cover types may be indicative of low taxonomic and possibly low functional diversity, and may suggest a low level of resilience. In contrast, a cumulative dominance curve that rises slowly, and, for example, doesn't reach a cumulative dominance value of 50% until a species rank of 6 or 7, may indicate a higher level of taxonomic and functional diversity, and may suggest a greater degree of resilience. The cumulative dominance curves for the Tumon-East sub-site rise relatively rapidly, achieving a 50% cumulative dominance value at a species rank of between 3 and 4, while the dominance curve for the Tumon-West sub-site is even steeper, achieving a 50% cumulative dominance value at a species rank of between 2 and 3. The steep cumulative dominance curves for both the Tumon-East and Tumon-West sub-sites suggest that taxonomic/functional diversity within the benthic communities in these areas is relatively low, and that the resilience of these reef systems may be low. Care should be taken in interpreting the meaning of the shape of dominance curves generated from a single sampling period, however, and instead it may be more useful to utilize these curves as baselines against which curves generated from future data collection efforts can be compared. A change in the shape of cumulative dominance curves over time may indicate a change towards more or less taxonomic/functional diversity and a greater or lesser degree of resilience. In situations where a direct comparison of the absolute cover of hard coral or some other benthic cover type between monitoring sites may not be appropriate, comparison of the relative rate and direction of change in the shape of dominance curves for each site could provide an insight into the relative level of taxonomic/functional diversity and ecosystem resilience.

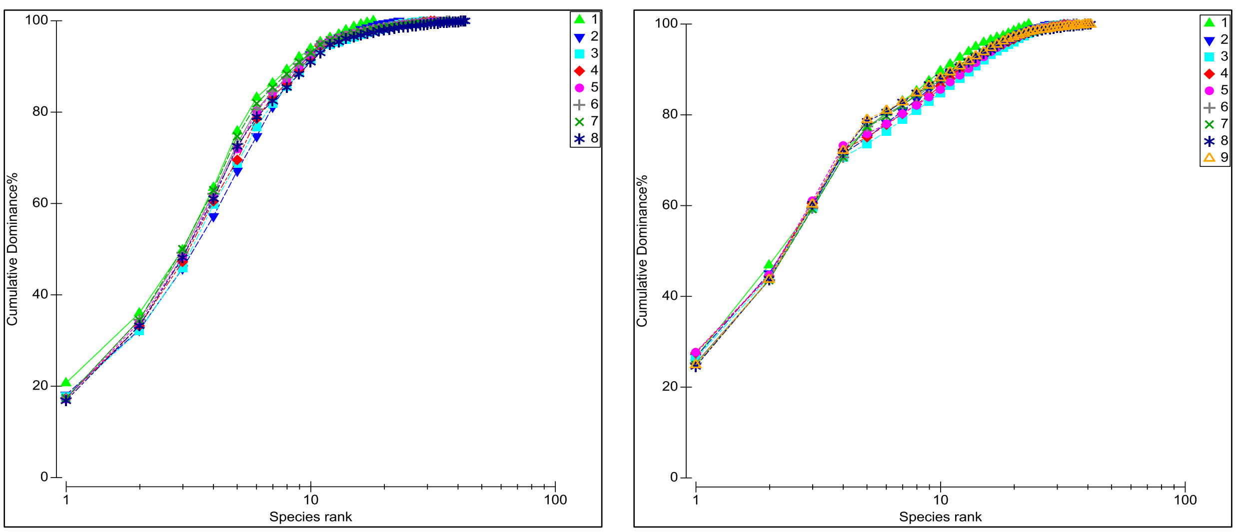


Figure 30. Dominance plots depicting the cumulative dominance curves for log-transformed benthic cover values from Tumon-East (excluding station 12)(left) and Tumon-West stations (excluding stations 13 and 20)(right).

In order to explore the ability of the sampling regime to adequately capture the overall "character" (for lack of a better word) of the Tumon-East and Tumon-West benthic communities, PCOs were created based on Bray-Curtis Similarity Matrices generated using the log-transformed cumulative mean abundances of benthic taxa for the Tumon-East and Tumon-West sampling stations. The resulting scatter plots depict a series of points, with point 1 representing the overall "character" of the benthic community based on the mean abundances from a single station, with point 2 based on the cumulative mean abundance data from two stations, and so on. The Tumon-East stations did not appear to cluster tightly even after incorporating all eight sampling stations, indicating that additional samples are likely required in order to adequately capture the character of the benthic communities occurring within the Tumon-East monitoring sub-site. The plot for the Tumon-West stations, on the other hand, depicts relatively tight clustering after about the seventh cumulative sample, suggesting that the current number of samples is likely adequate for capturing the character of benthic communities within this sub-site (Figure 31).

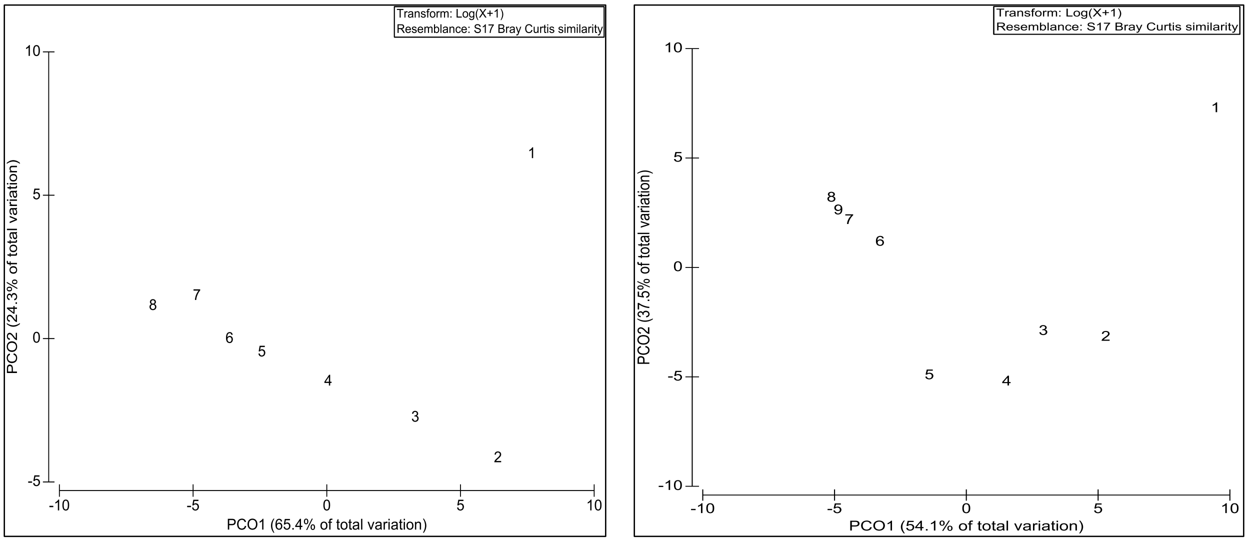


Figure 31. Principle Coordinates Analysis (PCO) based on Bray-Curtis matrices generated using the log-transformed cumulative average abundances of benthic taxa for Tumon-East (excluding station 12)(left) and Tumon-West stations (excluding stations 13 and 20)(right).

Descriptive statistics for Tumon benthic cover data

Mean percent cover (± SD) values of major benthic cover categories for the Tumon-East and Tumon-West sub-sites are presented in Figure 32.

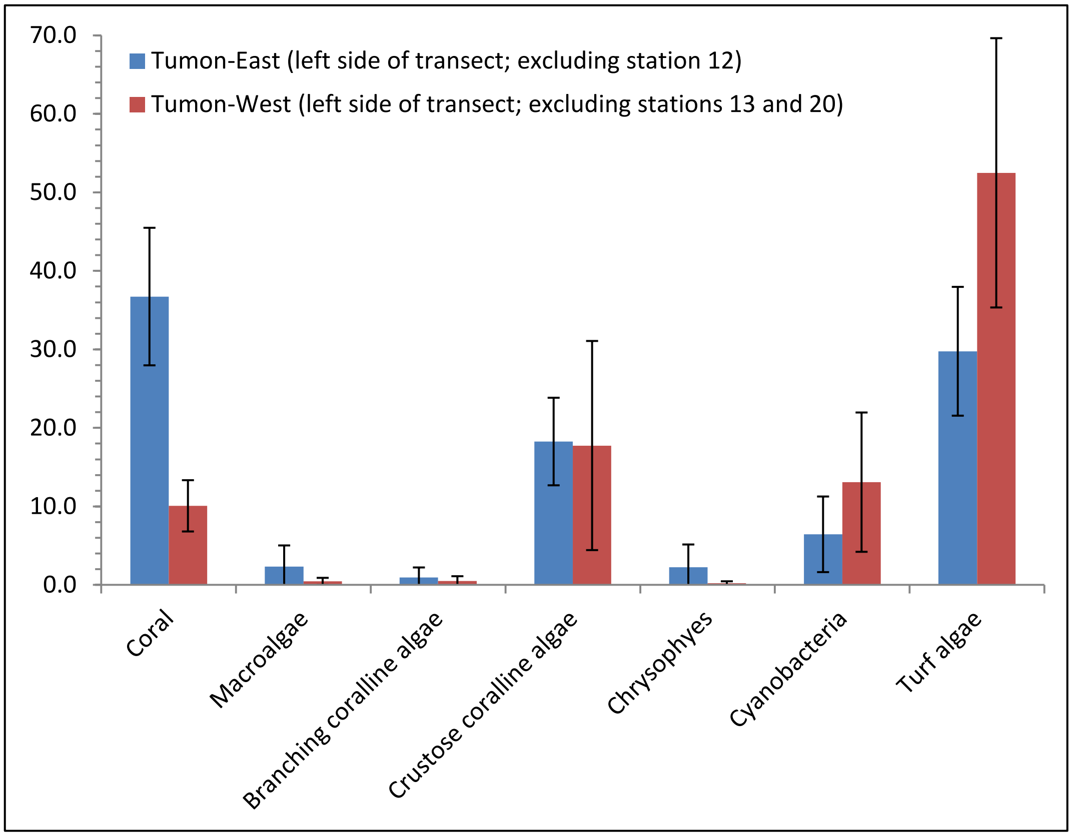


Figure 32. Mean percent cover (± SD) for major benthic categories within the Tumon-East and Tumon-West sub-sites.

Tumon: Associated Biological Communities – Reef Fishes

Twenty stations within the Tumon Bay Site were surveyed by the Fish Team. Two SPCs and one belt transect were conducted at 14 of these stations, while one SPC and one belt transect were conducted at the remaining 6 stations. This report will only examine the SPC data.

Descriptive statistics for Tumon reef fish community data

Density

Reef fish density at the Tumon Bay site ranged from 97 fish/ $100m^2$ at station 13 to 252 fish / $100m^2$ at station 36 (Figure 33). The average fish density was 144 fish /100 m^2 (SE = ± 9) and the median was 130 fish /100 m^2. Relative density by family is presented in Figure 33. The Pomacentrids were a major contributor to density, accounting for approximately 39% of fish counted, followed by Acanthurids (16%) and Labrids (12%). Other contributors to density included the Scarids (9%), and Chaetodontids (5%).

Biomass

The minimum biomass recorded was 5.60 kg/100 m^2, the maximum biomass was to 53.18 kg/100 m^2, the average biomass across the site was 11.13 kg/$100m^2$ (SE = ± 2.5), and the median was 7.7 kg/100 m^2 (Figure 33). Relative density by family is presented in Figure 33. Acanthurids were the primary contributor to biomass (25%), followed by Scarids (16%). Other contributors included Lethrinids (9%), Carangids(9%), Labrids(7%), and Hemigaleids (7%). The maximum biomass was observed at Station 6 and included a *Trianodon obesus* and a school of large Carangids. Station 36 also had an unusually high biomass value due to the presence of a school of large Lethrinids. If these two sites are excluded from the calculations, the maximum biomass in Tumon Bay was 10.36 kg/ 100 m^2 and the average biomass was 7.7kg / 100 m^2 (SE = ± 2.5).

Species Richness

The Fish Team documented a total of 150 species across the Tumon Bay monitoring site (Appendix A). The species richness varied from 26 species at station 19 to 65 species at station 36 (Figure 34). The average number of species observed was 44, the median was 44, and the standard error was 0.77. Of the species recorded, only 5 species were found at all twenty sites and 43 were recorded at only one of the stations. The majority of species (117) were found at less than half of the stations.

Sea Turtles

No Sea Turtles were documented within the SPC cylinders, however, turtles were observed in the site.

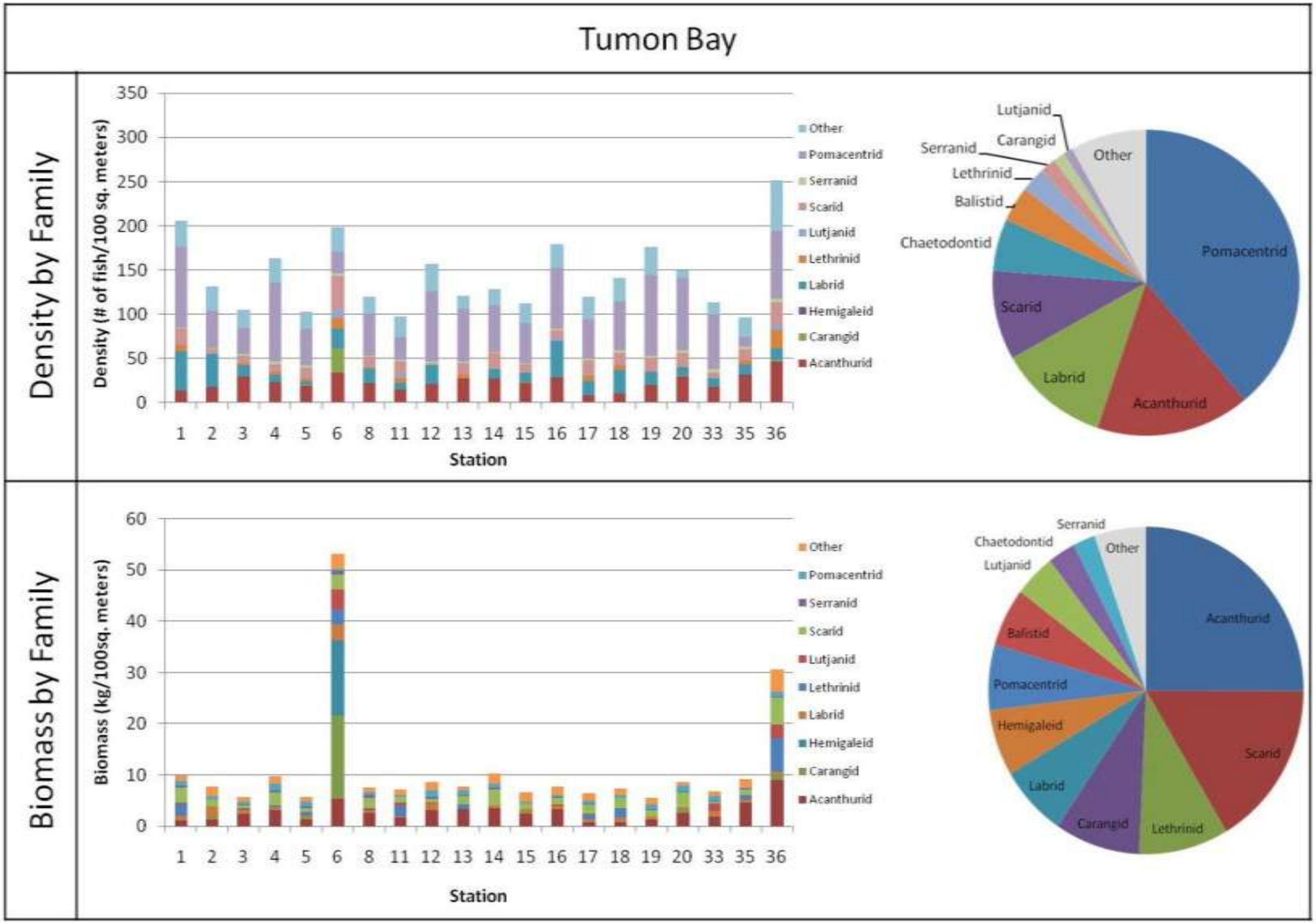


Figure 33. Reef fish density (# of fish/100m^2) by family and relative density by family (top); reef fish biomass (kg/ 100m^2) by family and relative biomass (bottom).

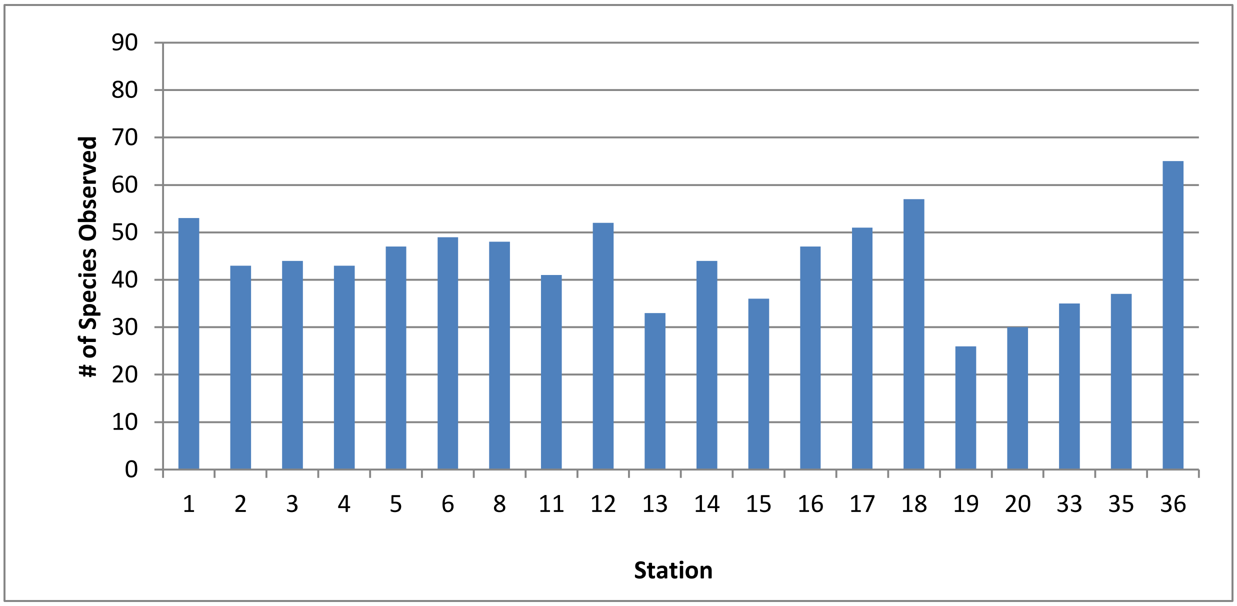


Figure 34. Reef fish species richness for sampling stations within the Tumon Bay monitoring site

Exploration of Tumon reef fish community data in multivariate space

For the Tumon Site, PRIMER was used to examine the effect of depth and the East-West gradient (a tentative proxy of exposure). While benthic cover data were clearly influenced by the East-West gradient, and served as the basis for tentatively divided the monitoring site into the Tumon-East and Tumon-West sub-sites, the fish data remained fairly heterogeneous across the site and no clear trends were observed. Stations 6 and 36 stood out due to relatively high biomass and density, but there did not seem to be a correlation with depth or gradient. The various MDS plots used to examine the data are presented in Figures 35 and 36.

Power analysis and optimum sample size determination for Tumon reef fish community data

Total density, total biomass, and species richness were examined using R (Figure 37). The results of the analyses of all three measures suggested that the standard deviation and power appeared to level off at approximately 15 stations. The SPCs have the highest power for species richness and density. The biomass power improves significantly if the two outliers, stations 6 and 36, are removed. The results of the PRIMER analysis also support the use of approximately 15 stations for family level data regarding biomass and density (Figure 38). The analysis also suggests that a large number of transects would be required for increased power for species level comparisons. Dominance plots for species level analysis became more disperse as the number of transects increased (Figure 39).

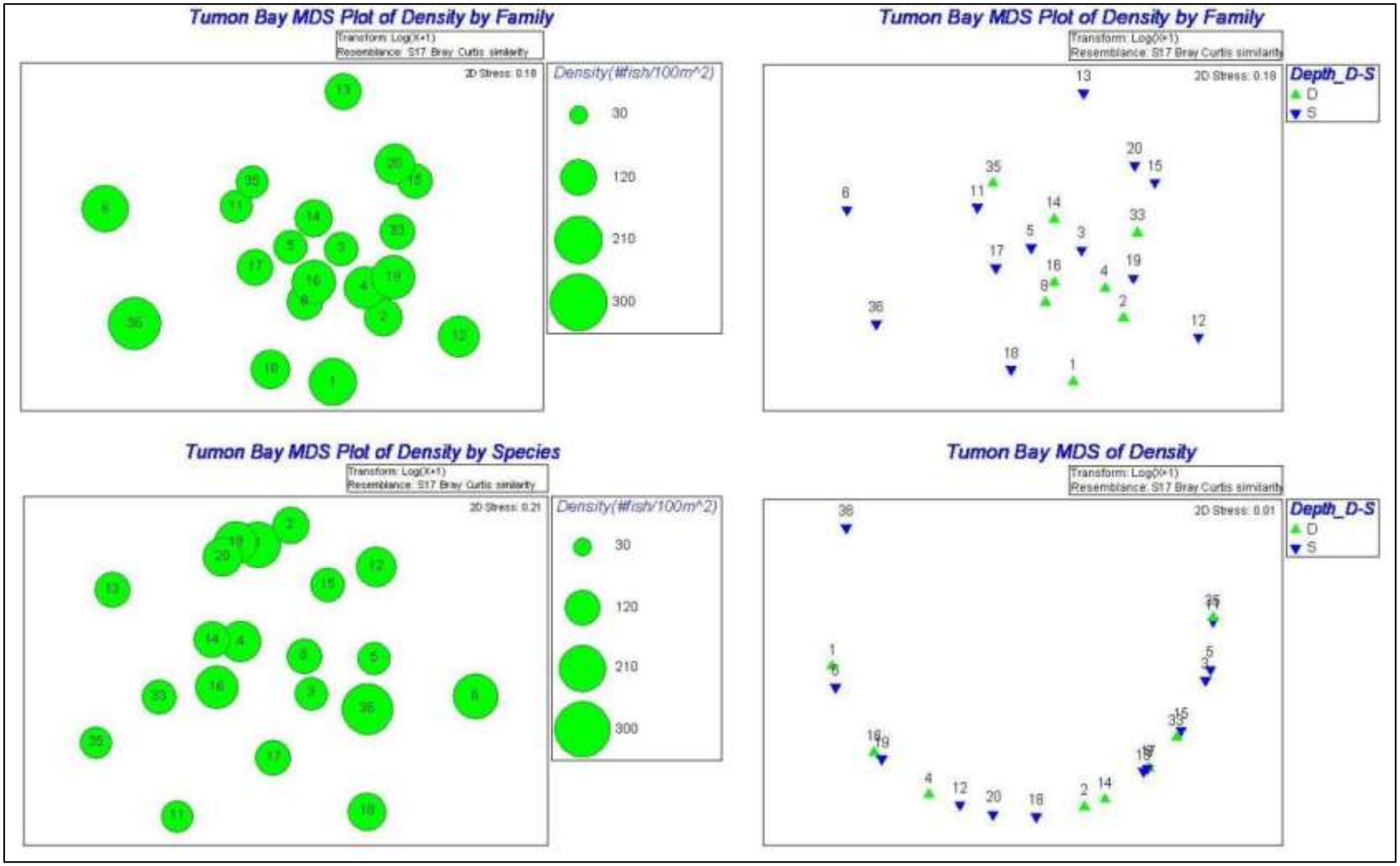


Figure 35. PRIMER MDS plots of reef fish density at Tumon Bay sampling stations. Plots do not reveal any distinct clustering among in the stations and there was no clear influence of depth on reef fish communities.

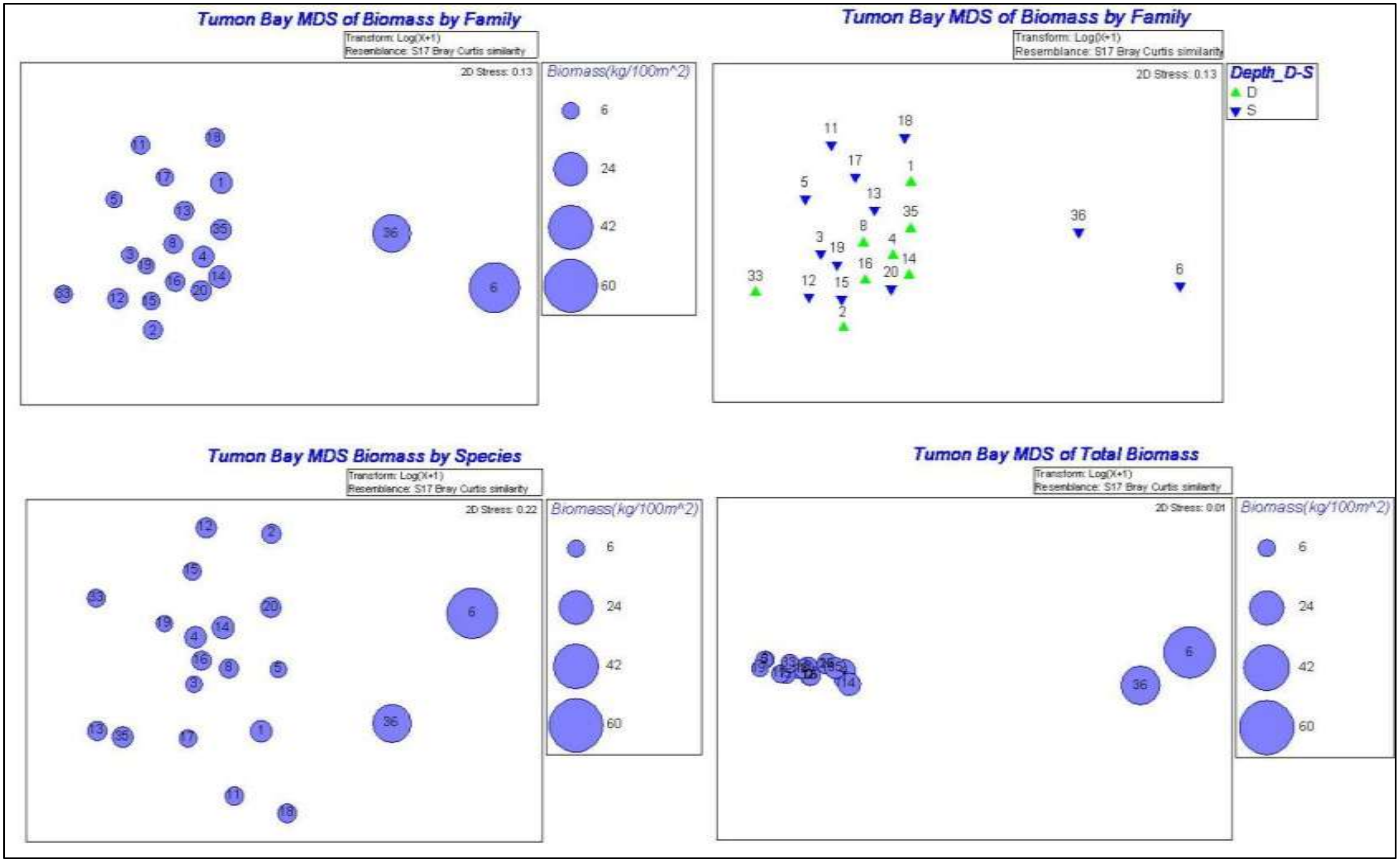


Figure 36. PRIMER MDS plots of reef fish biomass at Tumon Bay sampling stations. Stations 6 and 36 had unusual biomass due to the presence of large mobile predators. There was no clear distinction between depth ranges.

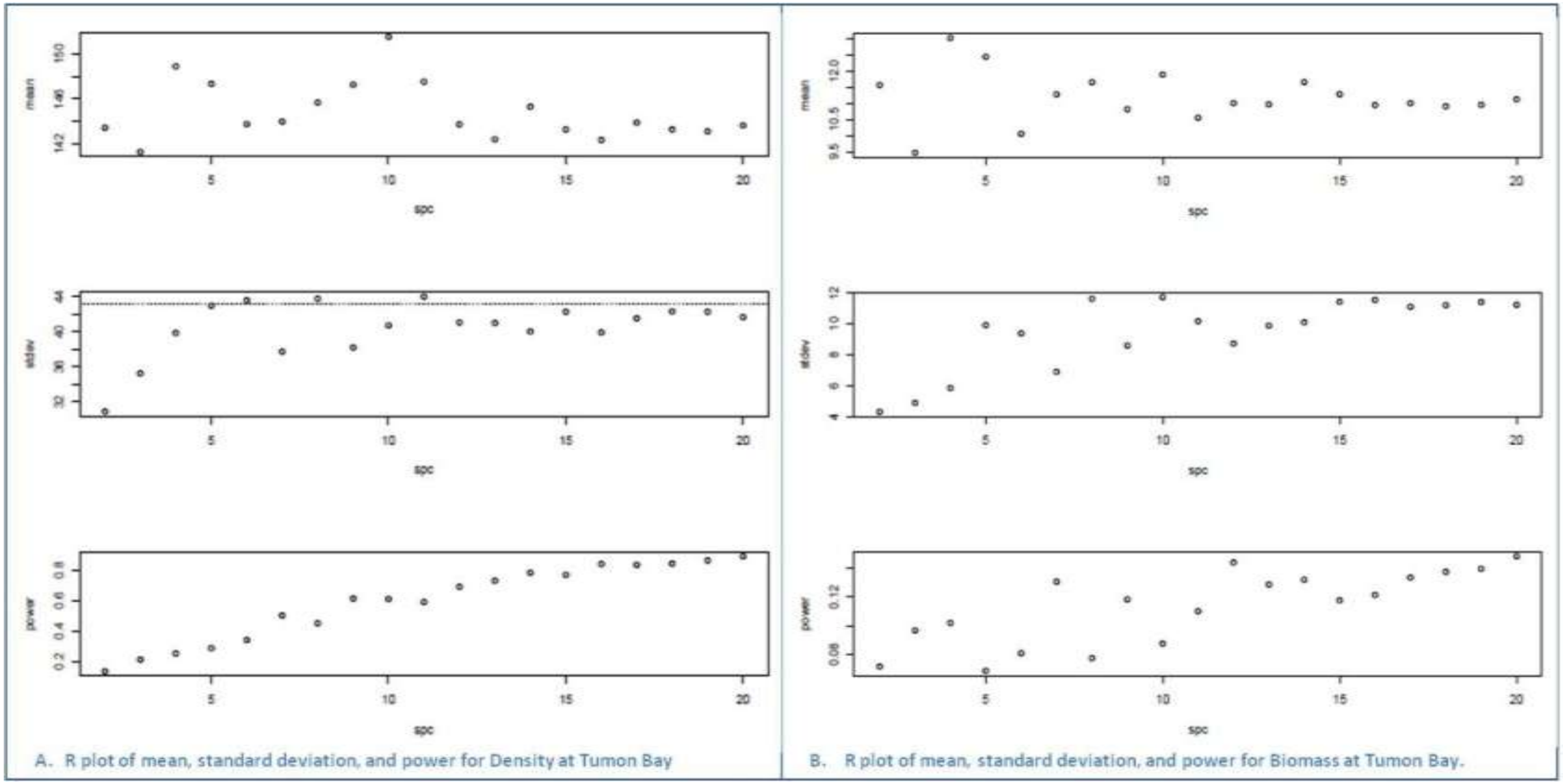


Figure 37. R power analysis plots for reef fish density (Plot A) and Biomass (Plot B) in the Tumon Bay monitoring site; the plots were created using a custom code developed by Dr. Peter Houk of the Pacific Marine Resources Institute. Results of the analysis indicate that 15 to 20 stations should be sampled in order to achieve 80% power for reef fish density, but power remained low for biomass if data from all stations was included in the analysis.

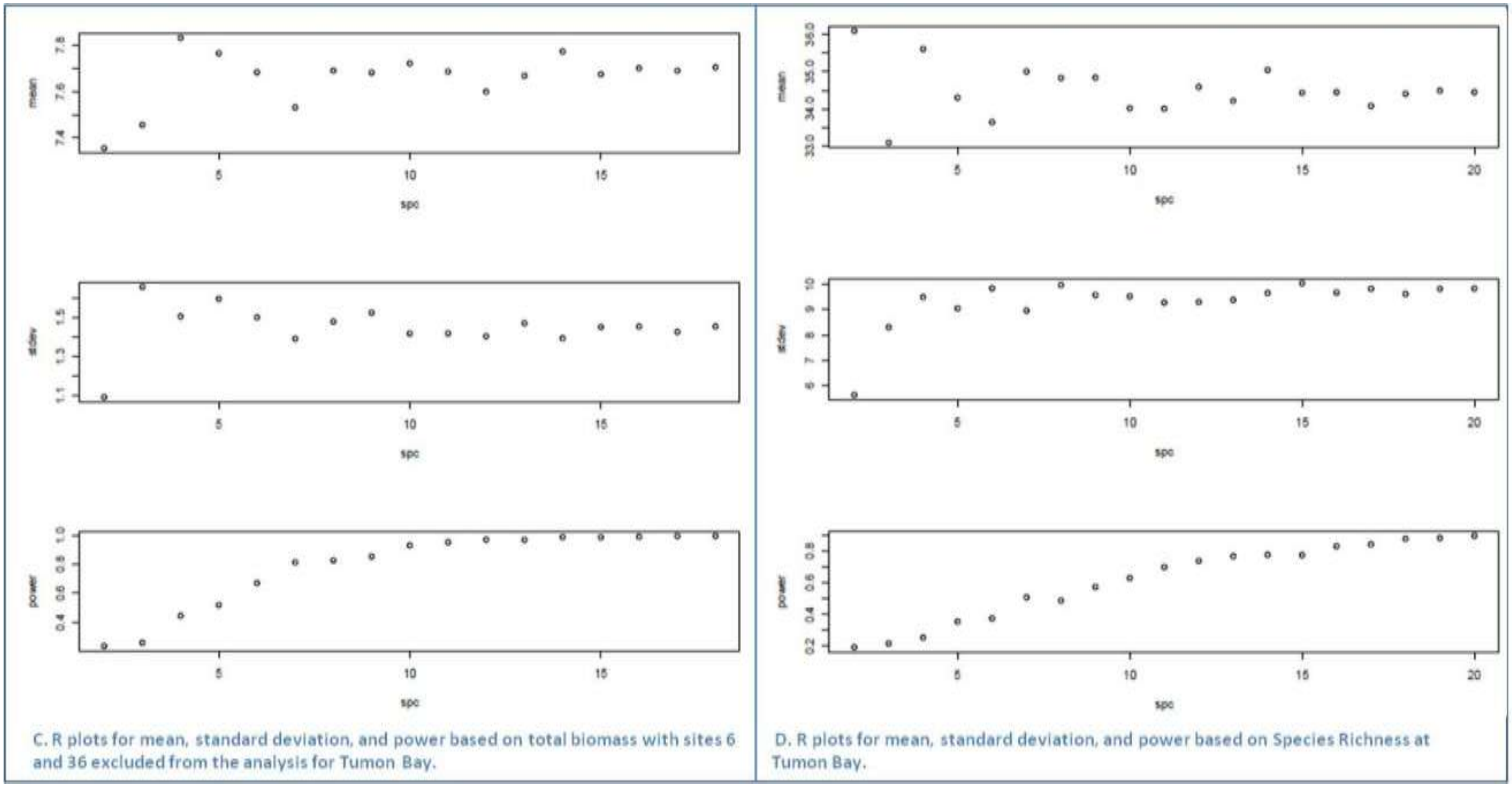


Figure 38. R power analysis plots for reef fish biomass (Plot C) and species richness (Plot D) in the Tumon Bay monitoring site after stations 6 and 36 were excluded from the analysis and for species richness. Sufficient power for biomass measures was obtained after outliers (stations 6 and 36) were excluded from the analysis.

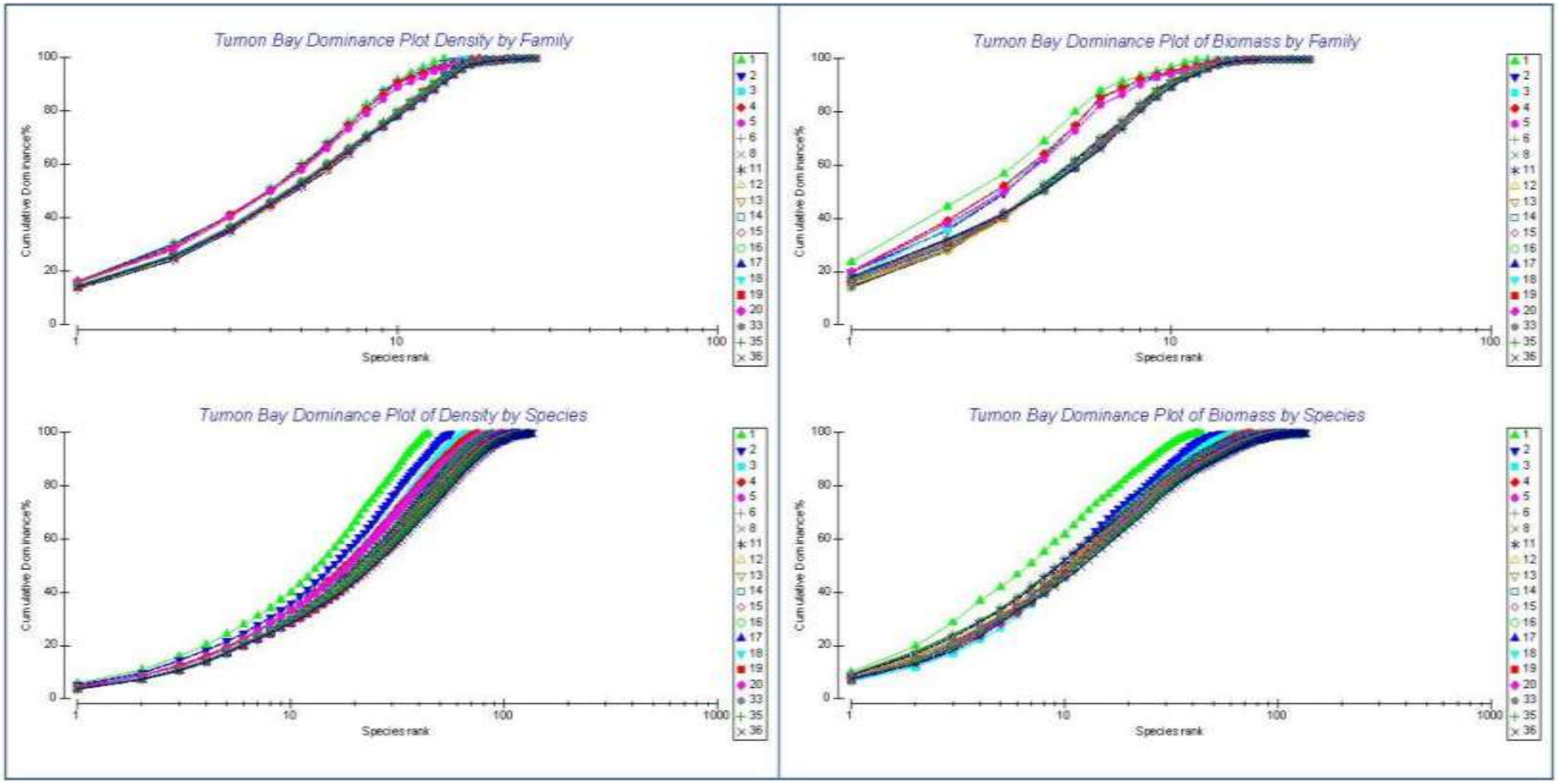


Figure 39. PRIMER Dominance Plots of Cumulative Averages for reef fish density and biomass in the Tumon Bay monitoring site. Results suggest that 15 stations are sufficient for family level analysis, but not for species level analysis.

East Agana Bay

East Agana: Benthic Cover

Exploration of benthic cover data in multivariate space

As with the benthic cover data for the Tumon Bay sampling stations, benthic cover data for East Agana Bay sampling stations were explored in multivariate space using the statistical software package PRIMER and the PERMANOVA add-on prior to carrying out power analyses and generating descriptive statistics.

The East Agana Bay benthic cover values generated by the CPCe application were re-formatted in Microsoft Excel to conform to PRIMER. Once in PRIMER the data were selected at the lowest taxonomic level, log-transformed, and then used to generate a Bray-Curtis Similarity Matrix. As with the Tumon benthic cover data, only those data for frames from the left side of the transect were used for this analysis. A Principle Coordinates Analysis (PCO) was carried out on the benthic cover values from transects at all East Agana Bay sampling stations and a two-axis scatter plot was generated (Figure 40).

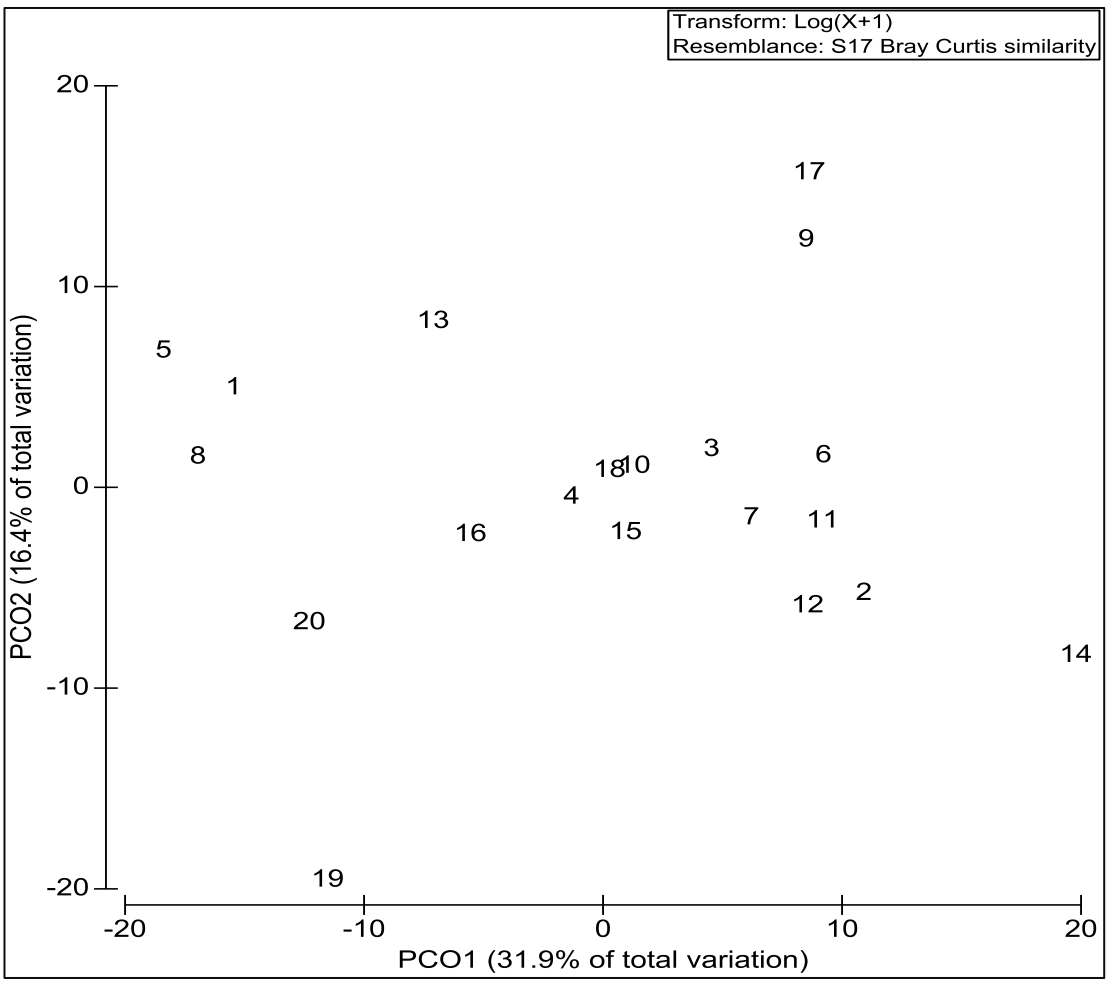


Figure 40. A Principle Coordinates Analysis (PCO) scatter plot displaying the sampling stations from the East Agana Bay monitoring site. The PCO was based on a Bray-Curtis Similarity Matrix created using log-transformed benthic cover values for benthic classes selected at the lowest taxonomic level.

The sampling stations did not cluster tightly, but sampling stations 14 and 19 appeared to be outliers, and while less distinct, stations 9 and 17 and the small cluster of stations 1, 5, and 8 also appeared to be outliers. As with the Tumon benthic cover data, the potential influence of depth and exposure (using the East-West Gradient as a proxy) on the benthic communities at the East Agana sampling stations were visualized in multivariate space using a PCO scatter plot (Figures 41 and 42, respectively). In general it appeared as though depth had at least some influence on the benthic communities observed at the East Agana sampling stations, with a core group of stations within a depth range between about 8 to 13 meters clustering together and with the shallowest station (Station 19 at 6 m) and the two deepest stations (Stations 13 and 14, both at 15 m) separated from the core group of stations. But the influence of depth didn't explain the pair of stations 9 and 17 and the trio of stations 1, 5, and 8, and it was clear that other factors may have a greater influence in the differences between these stations and the loosely clustered "core" sampling stations.

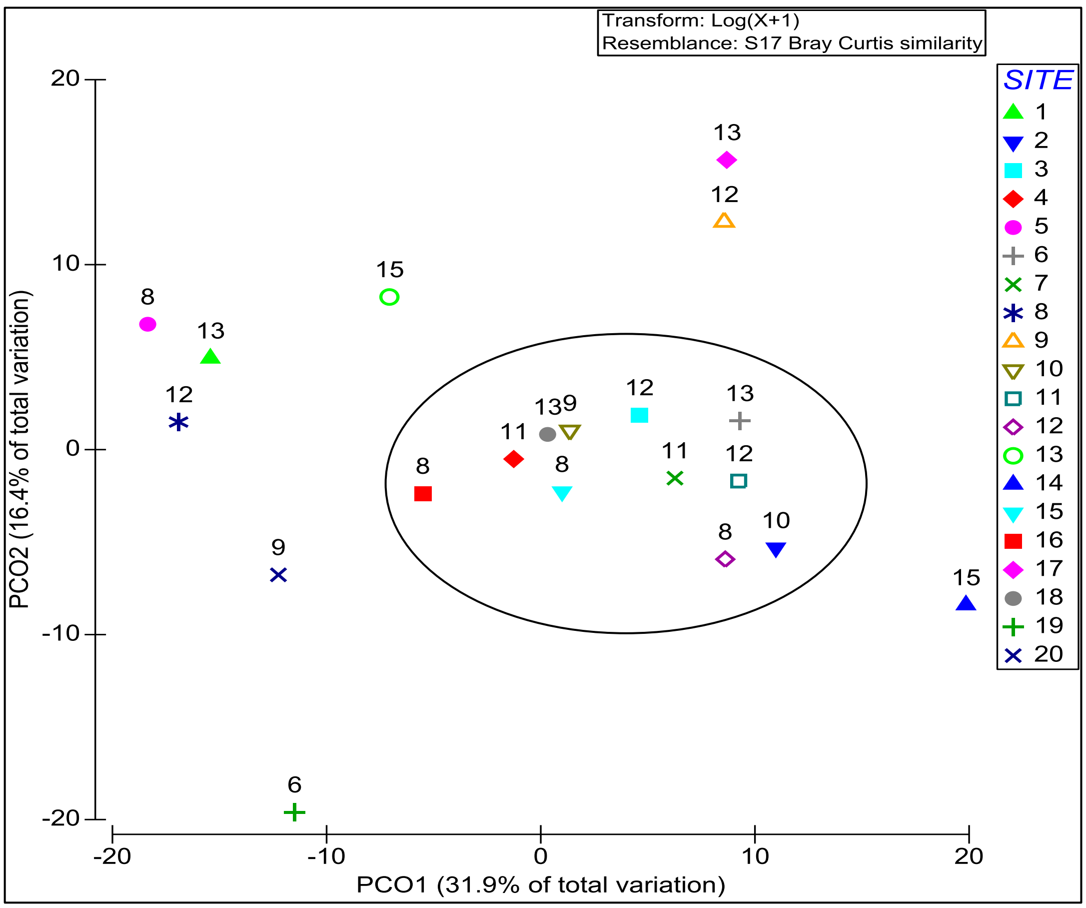


Figure 41. A Principle Coordinates Analysis (PCO) scatter plot of sampling stations from the East Agana Bay monitoring site with the labels indicating the depth in meters of each sampling station. The oval was drawn around the approximated "core" cluster of sampling stations. The PCO was based on a Bray-Curtis Similarity Matrix created using log-transformed benthic cover values for benthic classes selected at the lowest taxonomic level.

As with the Tumon Bay area it is generally held that reef areas in the southwestern portion of East Agana bay are less protected from wave action than reef areas further north, due to the shape of the bay, its position along the coast, and the prevailing direction of wind and waves. Once the East-West Gradient values were visualized on the scatter plot it was clear that while this factor didn't have a significant influence on the benthic communities of the Tumon sampling stations as was evident with the Tumon stations, it did help at least partially explain the outliers that did not appear to be influenced by depth (Figure 41). Stations 1, 5, and 13, for example, are located along the southwestern-most boundary of the monitoring site, and are presumably the most exposed, while station 17 is located the the northeastern most boundary, which is believed to be a more protected environment. The overlap between some stations with more moderate East-West Gradient values and those at the margins, however, suggest that the influence of the East-West Gradient is perhaps not particularly strong.

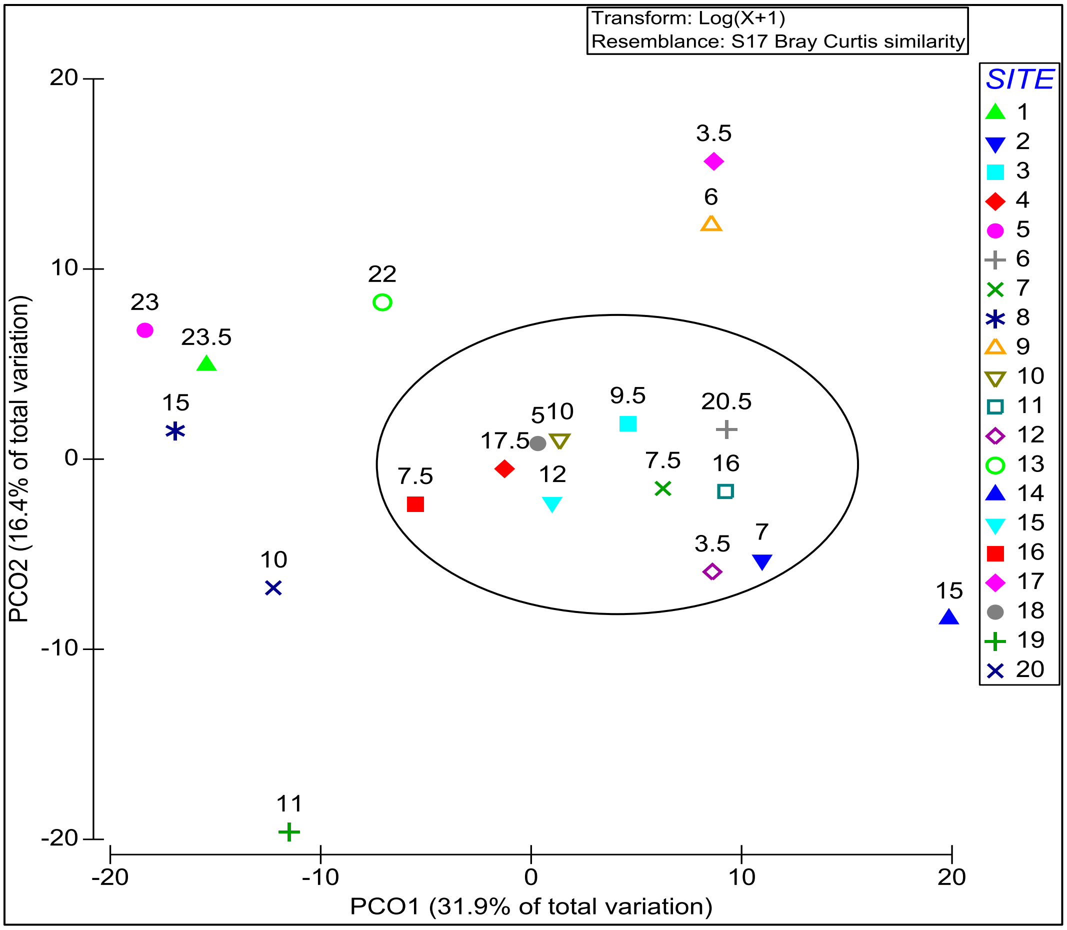


Figure 42. A Principle Coordinates Analysis (PCO) scatter plot of sampling stations from the East Agana Bay monitoring site with the labels indicating the East-West gradient value (distance from eastern boundary of Tumon site) for each sampling station. The oval was drawn around the approximated “core” cluster of sampling stations. The PCO was based on a Bray-Curtis Similarity Matrix created using log-transformed benthic cover values for benthic classes selected at the lowest taxonomic level.

While the PCO scatter plots suggested that depth and East-West Gradient may explain some of the differences observed between the benthic communities at some of the outlying sampling stations and those of the loose, central cluster of stations, the influences of these environmental factors did not appear to be consistent and strong. In order to quantify the influence of these environmental factors a Distance-based Linear Model (DistLM) was performed on the Bray-Curtis Similarity Matrix created using log-transformed benthic percent cover values. The results of the DistLM indicated that depth and the exposure proxy explained about 10% and 9% of the difference between the benthic communities at the East Agana sampling station, respectively , although in neither case was the difference statistically significant (p = 0.06 and 0.09, respectively). The results of the initial PCO analyses suggest that the exclusion of sampling stations with marginal depth and East-West Gradient values may improve stations power by reducing the variability between East Agana stations, and that these marginal areas be excluded for future monitoring, but the relatively weak influence of these environmental factors suggests that there are other sources of variability among the benthic communities at the East Agana stations.

To further explore how biological factors drive the differences between sampling stations, the dominant benthic community factors were displayed on PCO scatter plots (Spearman Correlation 0.6 and 0.4), along with the East-West Gradient values (Figures 43 and 44). The resulting display indicated that the factors contributing the most to the differences between the benthic communities at the East Agana stations are the corals, *Porites rus* and massive *Porites* spp., as well as turf algae, crustose coralline algae, and branching coralline algae. The relatively large plot distance between several of the stations with the greatest East-West Gradient (e.g., stations 1, 5, and 13) and the stations within the central cluster appears to be at least partially influenced by the greater cover of massive *Porites* spp., along with the greater cover of the corals *Favia* spp., *Leptastrea purpurea*, and *Astreopora* spp., and the lower cover of *Porites rus*, at the stations with high East-West Gradient values.

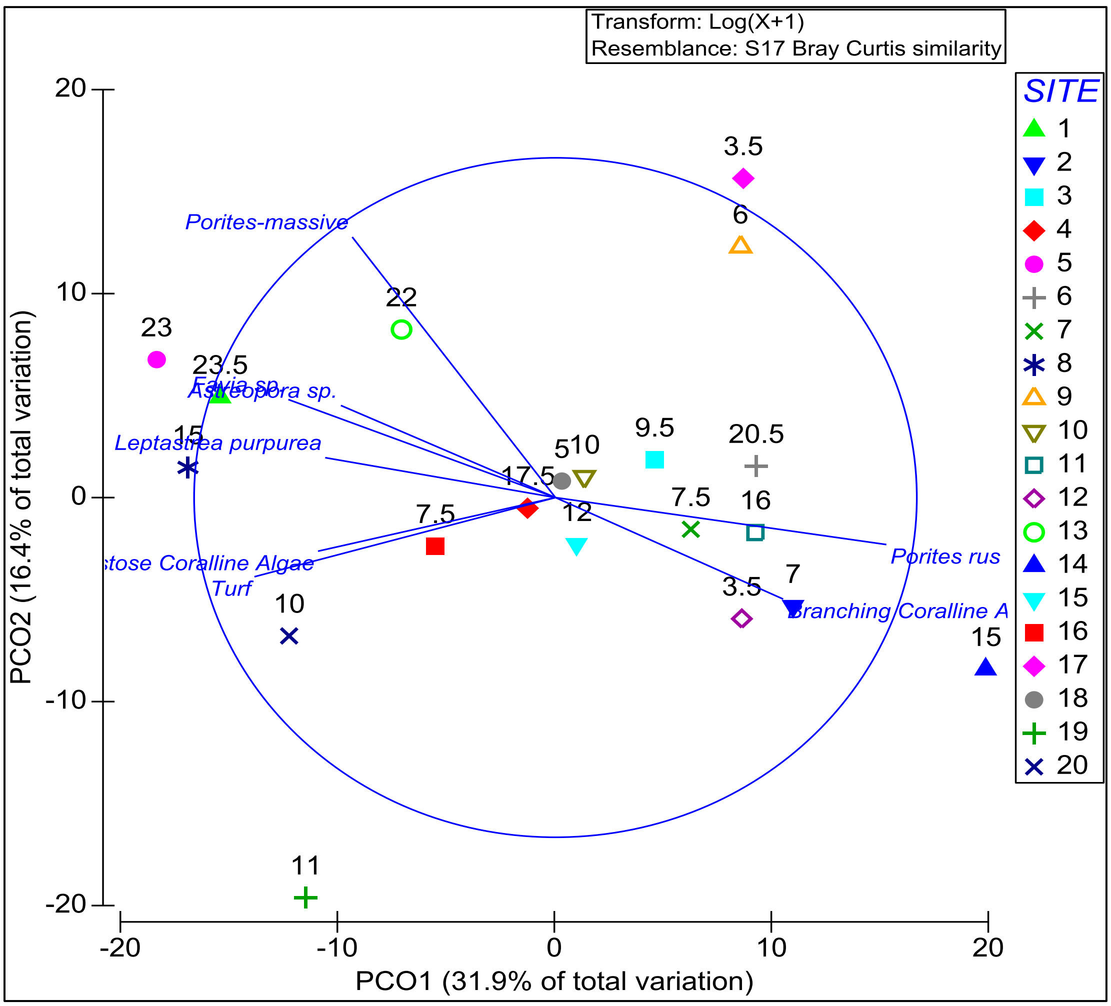


Figure 43. A Principle Coordinates Analysis (PCO) scatter plot of sampling stations from the East Agana Bay monitoring site, with each station given a unique symbol and labeled with its East-West Gradient value, and with vectors defining correlations between variables plotted over the scatter plot (blue lines and blue labels). The PCO was based on a Bray-Curtis Similarity Matrix created using log-transformed benthic cover values for benthic classes selected at the lowest possible taxonomic level.

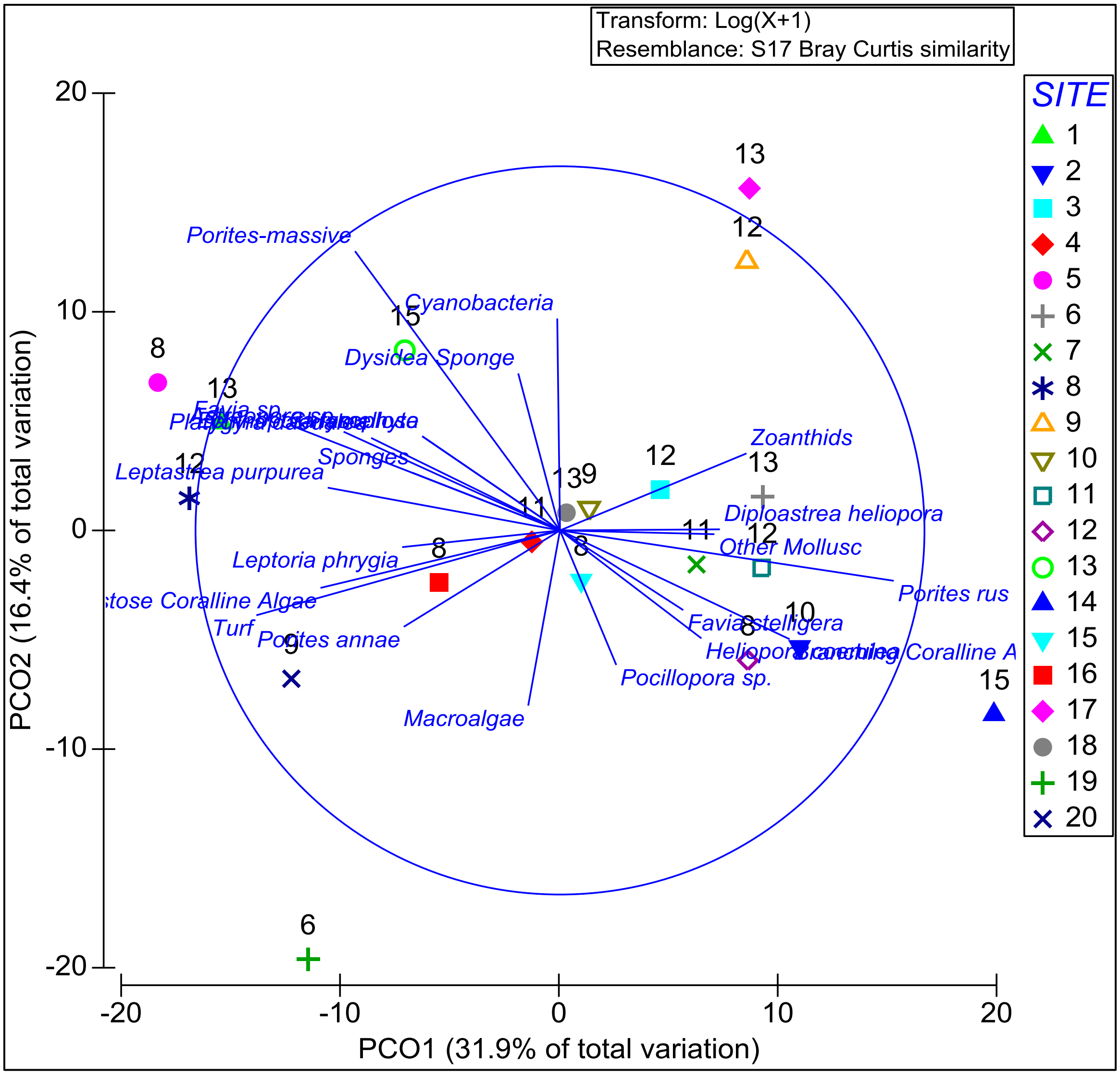


Figure 44. A Principle Coordinates Analysis (PCO) scatter plot of sampling stations from the East Agana Bay monitoring site, with each station given a unique symbol and labeled with its depth value, and with vectors defining correlations between variables plotted over the scatter plot (blue lines and blue labels). The PCO was based on a Bray-Curtis Similarity Matrix created using log-transformed benthic cover values for benthic classes selected at the lowest possible taxonomic level.

2D Bubble Plots were then created to visualize the relative differences in average abundances for each of the benthic community components that contribute most strongly to the differences between the East Agana sampling stations (Figures 45 and 46). While certainly not striking, the bubble plots reveal a discernible pattern in the distribution of the average abundance (log-transformed values) of *Porites rus*, with somewhat greater average *P. rus* abundances clustering towards the right of the scatter plot, and lower *P. rus* abundances for those stations towards the left of the plot. As mentioned above, while the influences of depth and the East-West Gradient was not strong, it did appear to at least partially explain the plot distances of some of the stations with marginal depth and East-West Gradient values. With regard to the abundance of *Porites rus* and massive *Porites* spp., in this case it appears as though the shallowest and eastern-most stations tend have lower *P. rus* abundances and greater massive *Porites* spp. abundances, than deeper, more western stations, although a couple of the stations buck this relatively weak trend. The average abundances of the corals, *Favia* spp., and *Leptastrea purpurea*, while relatively low across all stations, appear to be slightly higher in these same stations.

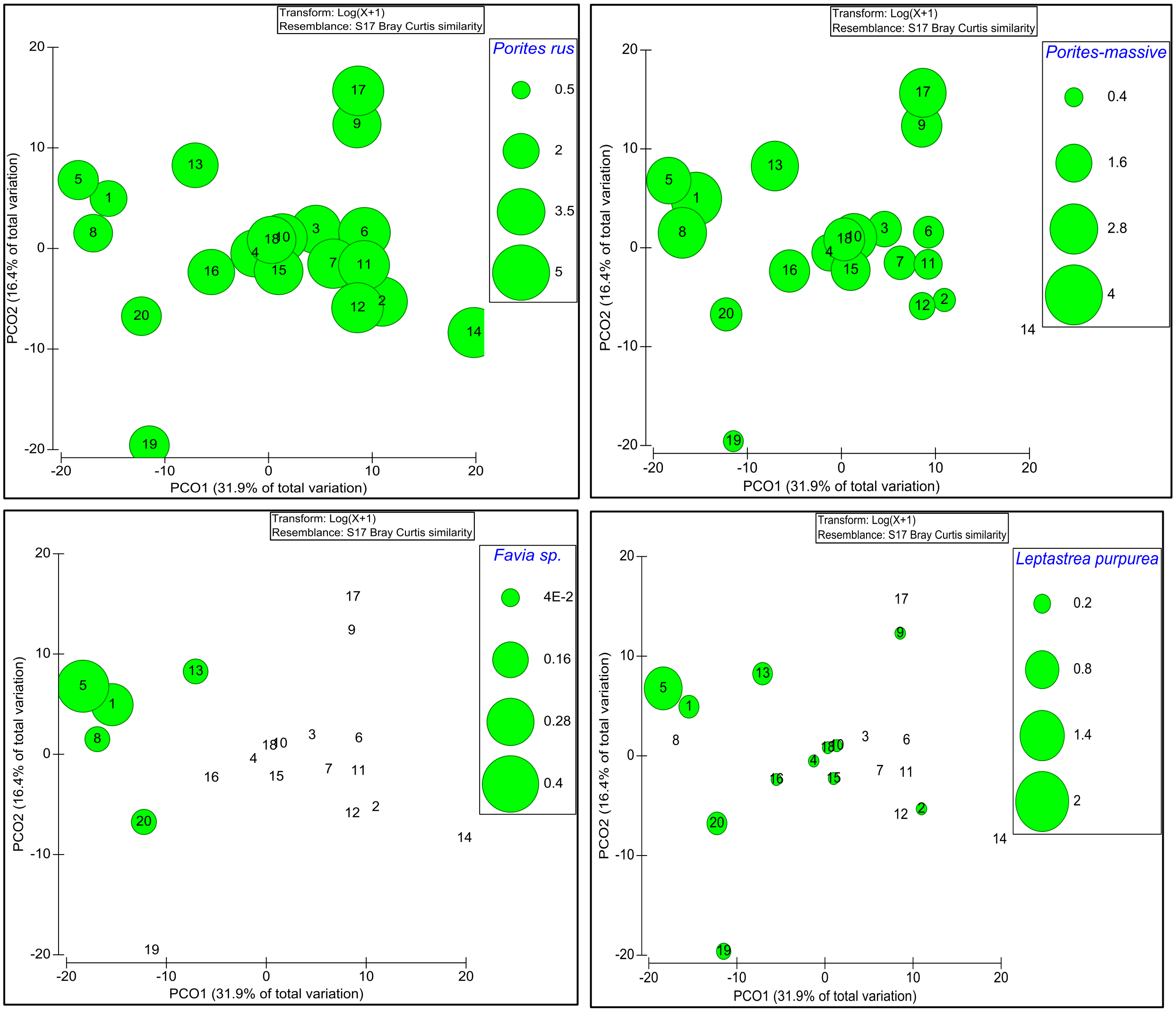


Figure 45. Principle Coordinates Analysis (PCO) 2D Bubble Plots of the relative abundance of the corals, *Porites rus* (upper left), massive *Porites* spp. (upper right), *Favia* spp. (lower left), and *Leptastrea purpurea* (lower right) at sampling stations from the East Agana Bay monitoring site. Labels indicate the sampling station number. The PCO was based on a Bray-Curtis Similarity Matrix created using log-transformed benthic cover values for benthic classes selected at the lowest possible taxonomic level.

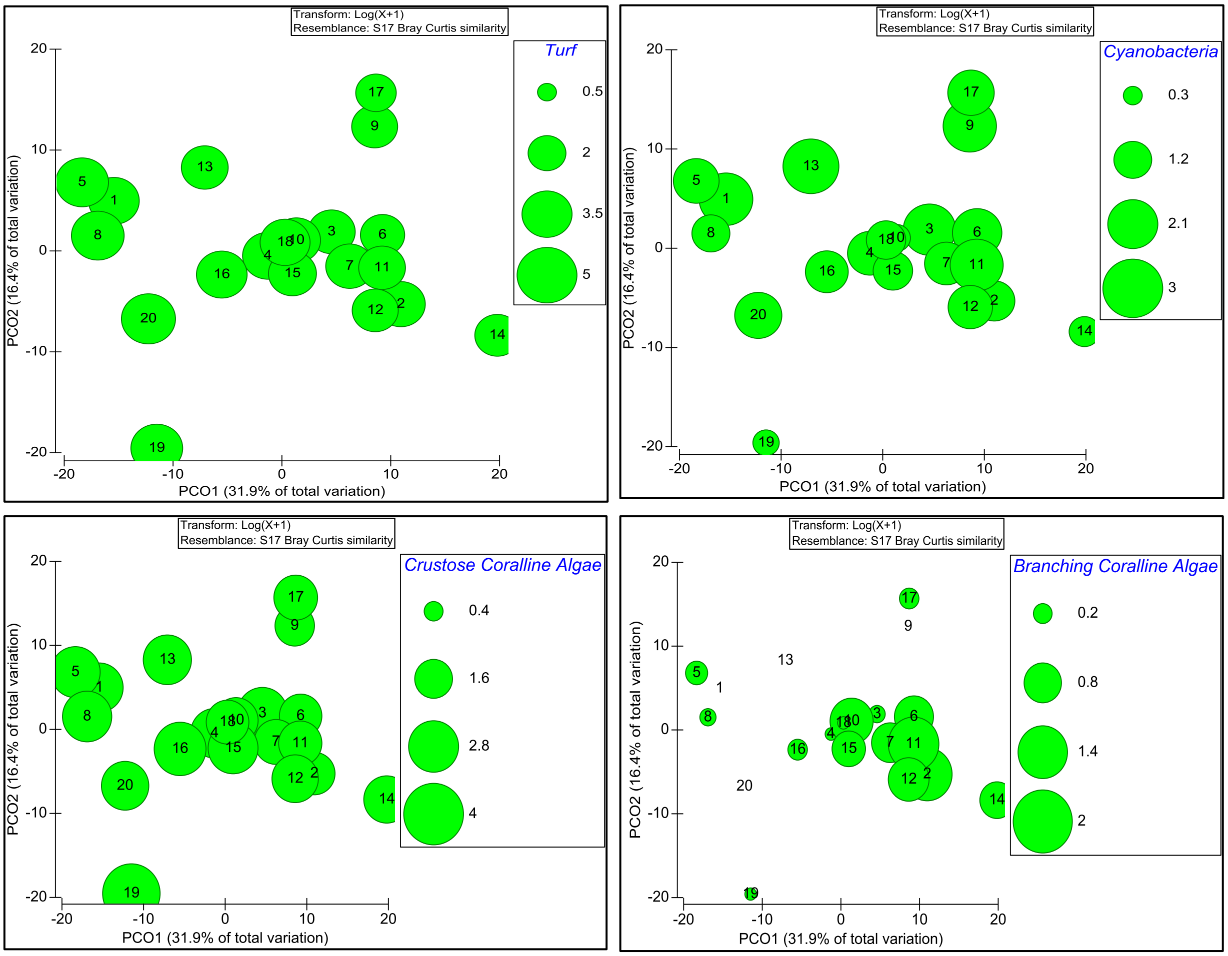


Figure 46. Principle Coordinates Analysis (PCO) 2D Bubble Plots of the relative abundance of turf algae (upper left), cyanobacteria (upper right), crustose corralling algae (lower left), and branching coralline algae (lower right) at sampling stations from the East Agana Bay monitoring site. Labels indicate the sampling station number. The PCO was based on a Bray-Curtis Similarity Matrix created using log-transformed benthic cover values for benthic classes selected at the lowest possible taxonomic level.

While the abundance of turf algae, cyanobacteria, and crustose coralline algae were noted as among the more influential driving biological factors behind the differences in benthic communities at the East Agana sampling stations, no major patterns were discernible in the bubble plots for these factors (Figure 46). The presence of colonial zooanthids at some stations, however, was in contrast with their absence at most other stations (Figure 47). A cursory examination of this pattern suggests that some of the deeper, more easterly stations tended to possess these zooanthids.

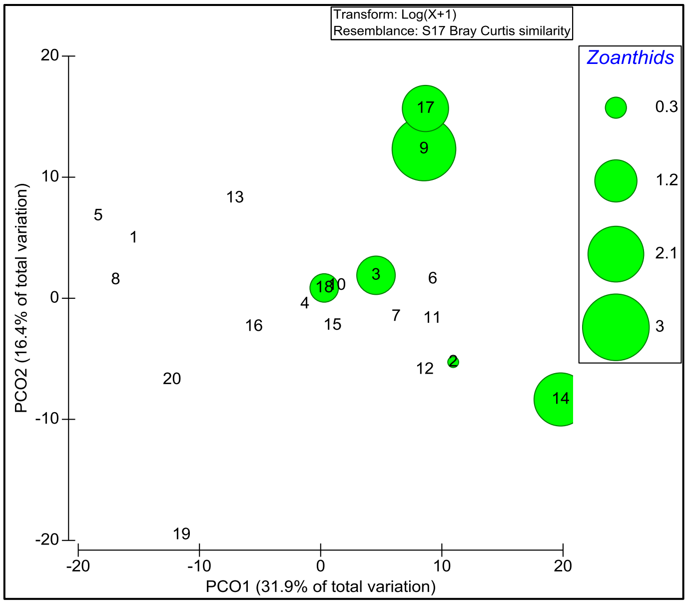


Figure 47. Principle Coordinates Analysis (PCO) 2D Bubble Plot of the relative abundance of zoanthids (mainly *Protopalythoa* sp.) at sampling stations from the East Agana Bay monitoring site. Labels indicate the sampling station number. The PCO was based on a Bray-Curtis Similarity Matrix created using log-transformed benthic cover values for benthic classes selected at the lowest possible taxonomic level.

Power analyses for East Agana benthic cover data

A univariate power analysis was carried out on total coral cover for all East Agana sampling stations, with a separate analysis carried out for a subset of stations; the subset, which is comprised of stations believed to possess relatively similar benthic communities, was created by excluding stations 1, 5, 14, 17, 19, and 20, based on their outlier status, as revealed in the previous PCO analyses. As with stations excluded from the analysis of the Tumon benthic cover data, these excluded East Agana stations may not be re-surveyed in 2012 and instead new permanent transects may be established in their place and the boundaries of the monitoring site be restricted to minimize the influence of depth and the East-West Gradient, reduce the level of heterogeneity of benthic communities across the sampling stations, and ultimately achieve a desirable level of statistical power with the optimum amount of efficiency. Multivariate power analyses involving Dominance plots and PCOs were also carried out for all sampling stations as well as for the subset of stations described above.

Power (of a two-sided t-test, delta = 0.3, α=0.05) for mean coral cover values for all 20 East Agana stations (images on left side of transect only) was 0.73; a power of 0.7 could be achieved with one fewer sample, while an additional 3 samples would be required to achieve a power of 0.8 (Table C). Power for mean coral cover for the subset of sampling stations (excluding stations 1, 5, 14, 17, 19, and 20) was quite high, at 0.95; a power of 0.7 could be achieved with only 7 samples while a power of 0.8 could be achieved with only 9 samples. The very high level of statistical power achieved in for the detection of a 30% change in coral cover at the subset of East Agana stations suggested that even the reduced number of sampling stations may achieve a greater level of change detection while still retaining an acceptable level of power. The power analysis for the East Agana sampling stations will be re-run after data from the left and right sides of the transects are combined, but the results are expected to be similar.

Table C. Results of t-test power analysis for East Agana sampling stations.

Group	Mean	SD	n	delta (mean*0.3)	power	n required for power = 0.7	n required for power = 0.8
All Stations - Left Side	44.8	16.0	20	13.4	0.73	18.6	23.4
Subset, Excluding 1, 5, 14, 17, 19, 20 - Left Side	48.3	10.2	14	14.5	0.95	7	9
				delta (mean*0.2)			
Subset, Excluding 1, 5, 14, 17, 19, 20 - Left Side	48.3	10.2	14	9.7	0.68	15	18

The custom R code developed by Dr. Houk was then used to view how the mean, standard deviation, and power changed with an increasing number of randomly selected samples. The results of the custom R analysis for mean coral cover at all East Agana stations indicated that mean and standard deviation appears to level off at approximately 14 or 15 samples, while the power gradually increases to around 0.7 by the 20th sample (Figure 48). The results for the subset of East Agana stations (excluding stations 1, 5, 14, 17, 19, and 20) indicated that the mean leveled out at around 12 samples, while the standard deviation leveled out at around 10 samples (Figure 49). Power for the subset of East Agana stations gradually increases to more than 0.9 by the 14th sample.

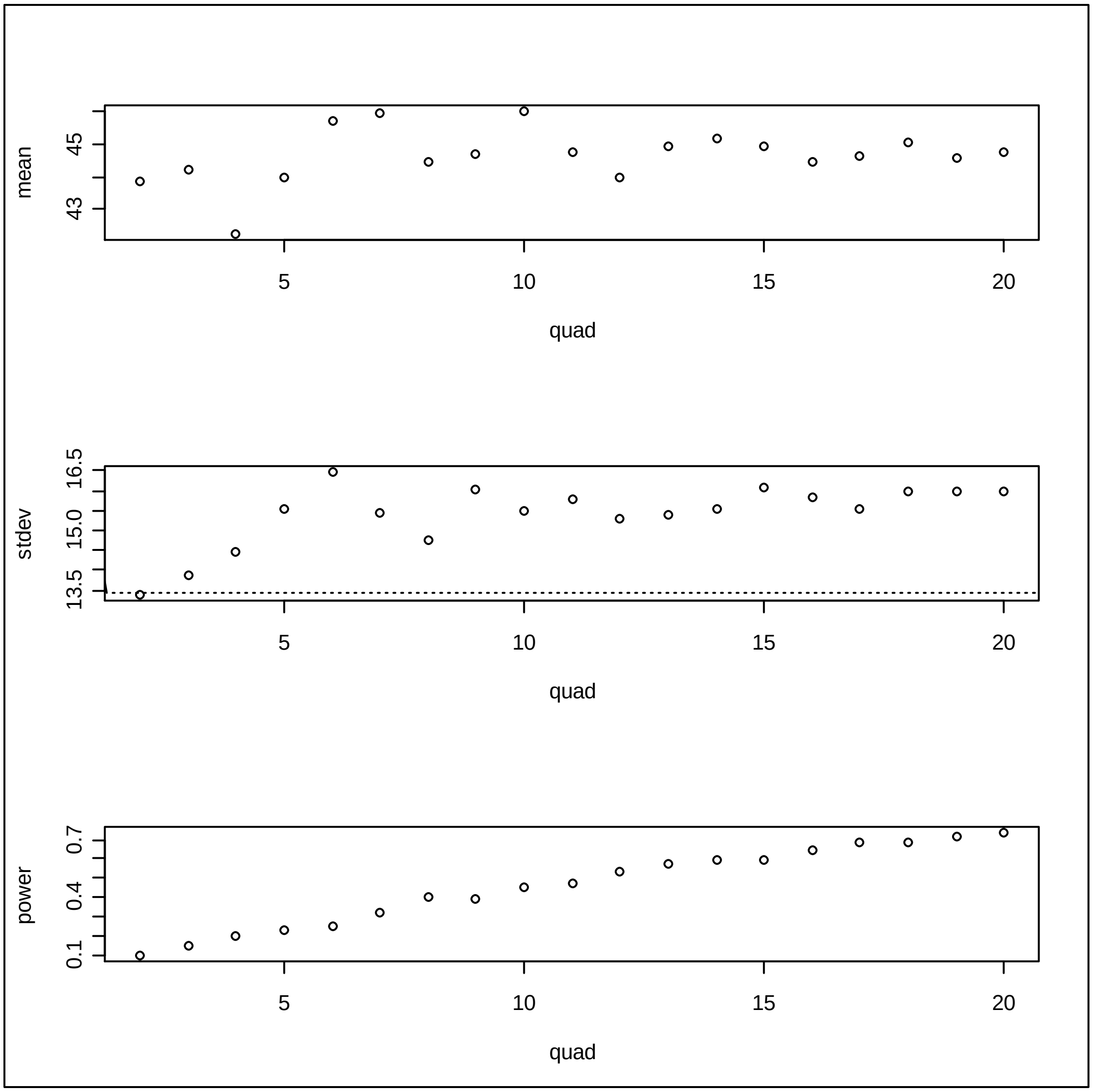


Figure 48. Results of a power analysis carried out on mean coral cover values for all East Agana sampling stations using an R code developed by Dr. Peter Houk of the Pacific Marine Resources Institute.

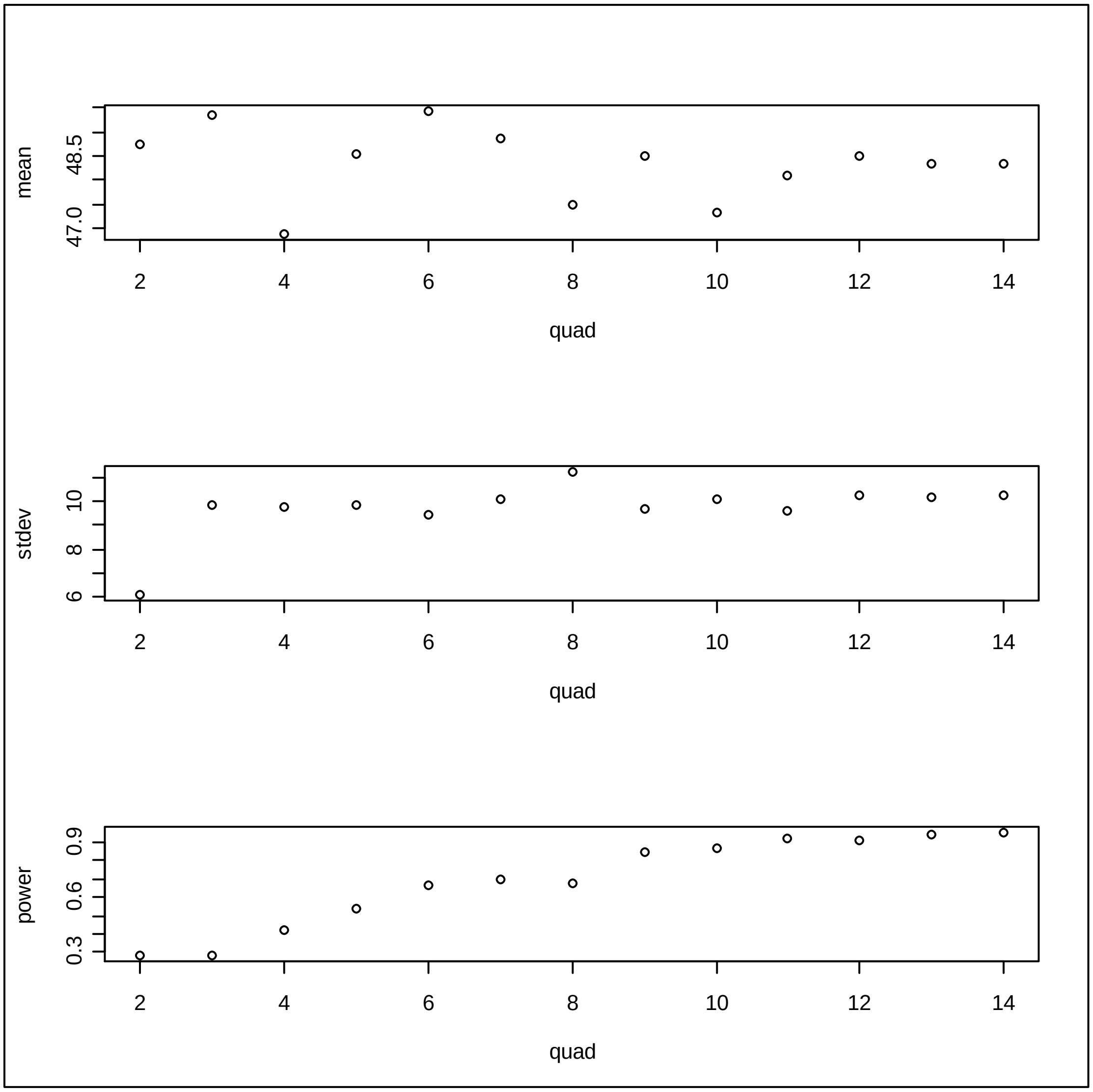


Figure 49. Results of a power analysis carried out on mean coral cover values for a subset of East Agana sampling stations (excluding stations 1, 5, 14, 17, 19, and 20) using an R code developed by Dr. Peter Houk of the Pacific Marine Resources Institute. The dotted line indicates the delta value (mean of all samples*0.3).

In order to visualize in multivariate space the ability of the present sample size to adequately capture the abundances of the dominant benthic taxa, the cumulative means of benthic classes (at the lowest taxonomic level) were calculated in Excel and brought into PRIMER/PERMANOVA. After a Bray-Curtis Similarity Matrix was created using the log-transformed cumulative means, a Dominance Plot was created using the cumulative means for the benthic cover values from all East Agana sampling stations and a subset of stations (excluding stations 1, 5, 14, 17, 19, and 20). Overall, both Dominance Plots depicted relatively tight clustering of cumulative dominance curves, although the cumulative dominance curves for all stations appeared to be more tightly clustered than those for the subset of stations. The clustering remains somewhat loose with the cumulative means of the first several samples of the subset of stations, but then tightens with additional samples. The relatively tight clustering of the dominance curves indicates that the mean abundance values didn't change much with an increasing number of samples; thus, it is likely that the abundances of dominant benthic taxa within the study site are adequately captured with the original sample size of 20 stations, and that after eliminating outlier stations – even with a smaller number of samples – the abundances of dominant benthic taxa still appear to be adequately captured (Figure 50).

As with the cumulative dominance curves for the Tumon-East and Tumon-West sub-sites, the curves for all East Agana stations and for the subset of stations rise relatively rapidly, with both sets of curves achieving a 50% cumulative dominance value at a species rank of between 3 and 4. While the relatively steep curves do suggest that taxonomic/functional diversity may be low at the East Agana monitoring site and may indicate a low level of resilience, caution should again be made in placing too much emphasis on the meaning of curves generated from a single sampling period, and attention should be focused on the change in the shape of the curves as additional data is collected over time.

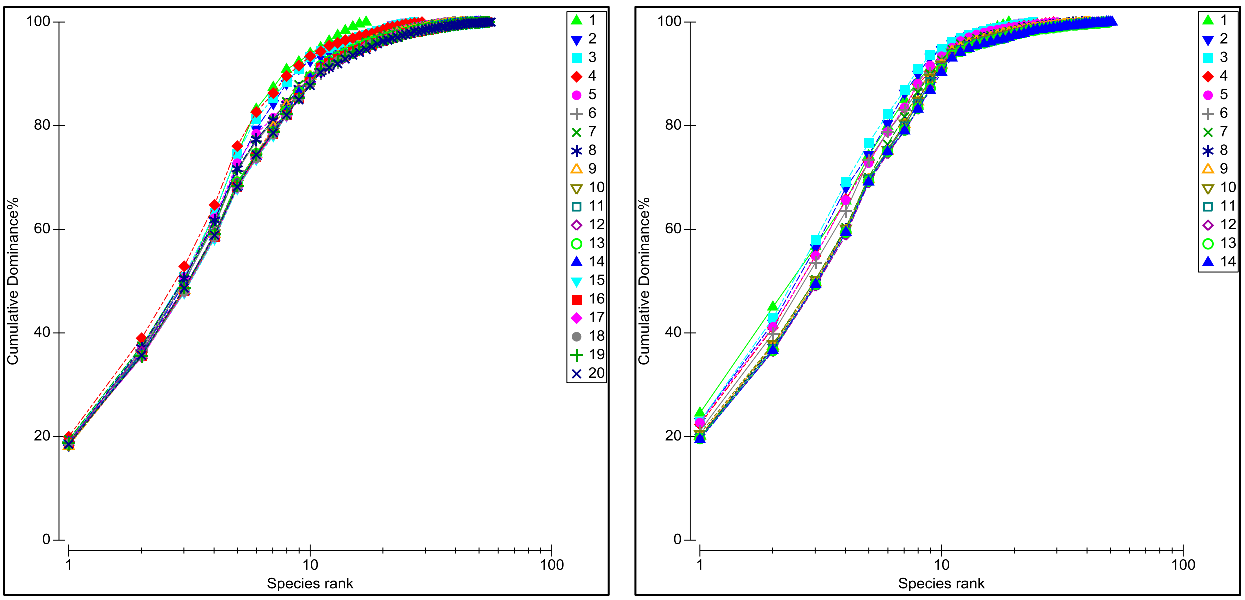


Figure 50. Dominance plots depicting the cumulative dominance curves for log-transformed benthic cover values from all East Agana stations (left) and a subset of East Agana stations (excluding stations 1, 5, 14, 17, 19, and 20)(right).

In order to explore the ability of the sampling regime to adequately capture the "character" of benthic communities at the East Agana stations, PCOs were created based on Bray-Curtis Similarity Matrices generated using the log-transformed cumulative mean abundances of benthic taxa for all East Agana stations as well as for the subset of stations (excluding stations 1, 5, 14, 17, 19, and 20)(Figure 51). The resulting scatter plots depict a series of points, with point 1 representing the overall "character" of the benthic community based on the mean abundances from a single station, with point 2 based on the cumulative mean abundance data from two stations, and so on. In both PCO plots, the stations begin to cluster after about the 10th or 11th station, although clustering grows even tighter after about 14 or 15 stations in the plot for all sampling stations and at about 12 stations for the plot for the subset of stations. These results suggest that the a holistic measure of the general "character" of the benthic community within the East Agana monitoring site is adequately sampled with somewhere between 10 and 15 stations (=10 or 15 transects).

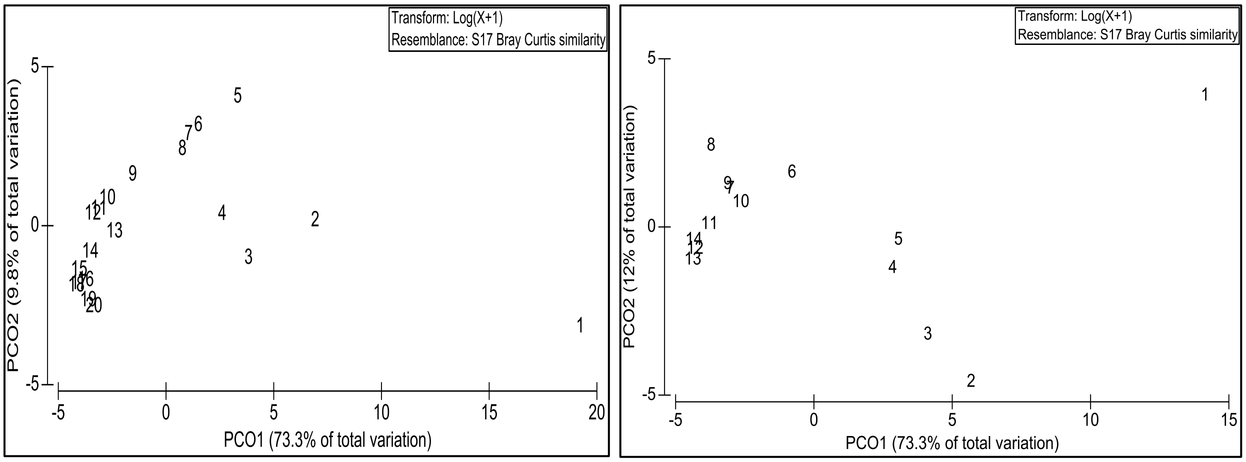


Figure 51. Principle Coordinates Analysis (PCO) based on Bray-Curtis matrices generated using the log-transformed cumulative average abundances of benthic taxa for all East Agana stations (left) and a subset of East Agana stations (excluding stations 1, 5, 14, 17, 19, and 20).

Descriptive statistics for East Agana benthic cover data

Mean percent cover (± SD) values of major benthic cover categories for the Tumon-East and Tumon-West sub-sites are presented in Figure 52.

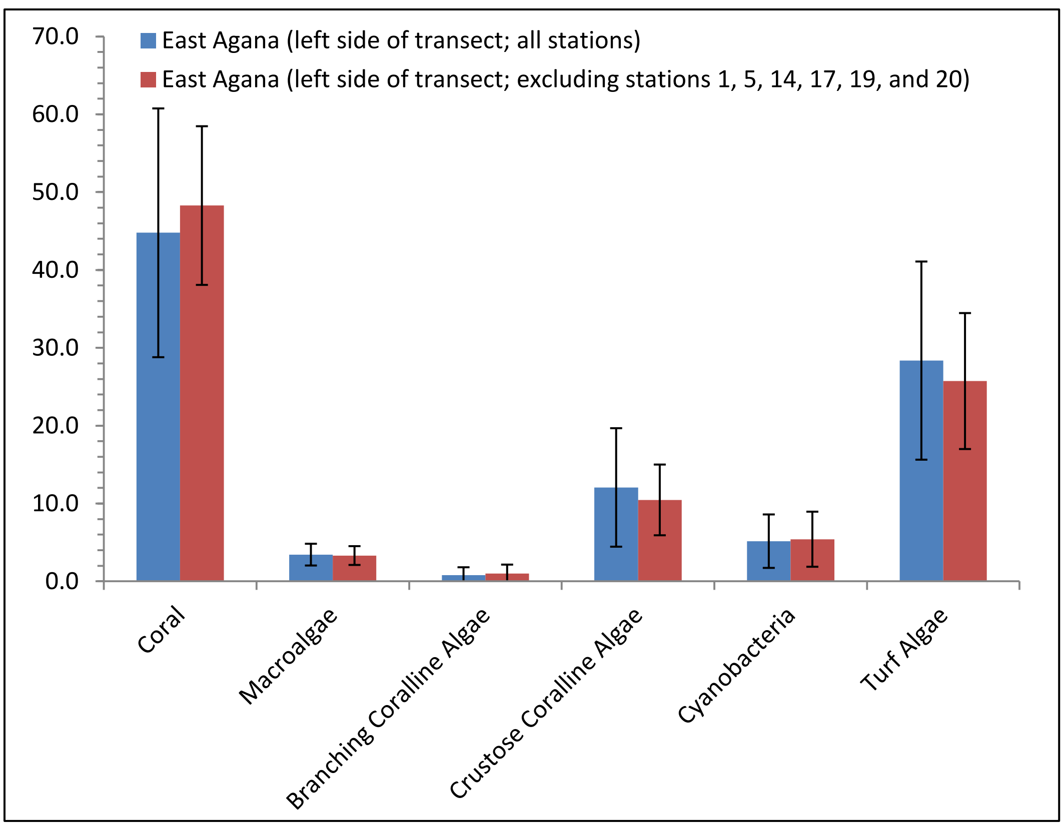


Figure 52. Mean percent cover (± SD) for major benthic categories within the East Agana monitoring site; sampling stations 1, 5, 14, 17, 19, and 20 were excluded from the calculations.

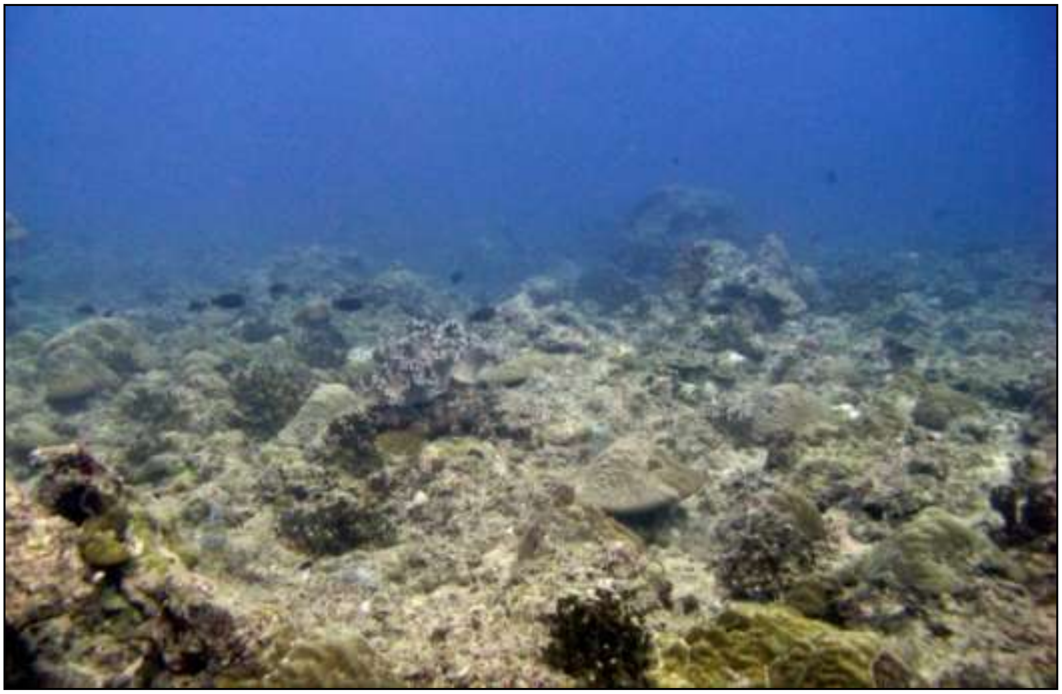


Figure 53. While the apparently exposure-related differences in benthic communities observed at the Tumon-East and Tumon-West stations were not as pronounced in the East Agana stations, stations at the southwestern margin of the East Agana site, did appear to exhibit the lower reef complexity and lower *Porites rus*-abundance observed at the more exposed Tumon-West stations.

Figure 54. Dense *Porites rus* growth and large massive *Porites* colonies can be found at many of the East Agana sampling stations, such as station 11 (pictured here), which is located towards the center of the monitoring site.

East Agana: Associated Biological Communities – Reef Fishes

Twenty stations within the East Agana Bay Site were surveyed by the Fish Team. At each of these stations one belt and at least two SPCs were conducted. This report will only examine the SPC data.

Descriptive statistics for East Agana reef fish community data

Density

The total density of reef fish at the East Agana stations ranged from 55 fish/ $100m^2$ at station 1 to 325 fish/ $100m^2$ at station 8 (Figure 55). The average reef fish density was 171 fish/$100m^2$, median density was 159 fish/$100m^2$, and the standard error was 20. Relative density by family is presented in Figure 55. The Pomacentrids were the primary contributor to density, accounting for approximately 52% of fish counted, followed by Acanthurids (15%). Other significant contributors to density were the Labrids (8%), Scarids (7%), and Chaetodontids (5%).

Biomass

The average total biomass at East Agana was 7.68kg /$100m^2$, with a median value of 7.01 kg/$100m^2$ and standard error of 0.78 (Figure 55). The minimum total biomass was observed at station 1 (3.22kg/$100m^2$) and the maximum total biomass was observed at station 19 (17.33kg/$100m^2$). Acanthurids were the primary contributor to biomass (23%), followed by Pomacentrids (18%), Scarids (15%), and Lethrinids (14%).

Species Richness

A total of 161 species were observed at stations across the East Agana Bay monitoring Site (Appendix B). Reef fish species presence/absence for all East Agana sampling stations is presented in Figure 56. The lowest number of species was observed at station 12 (35 species), while station 16 had the highest species richness with 80 species. The average number of species per station was 48, the median was 46 species, and the standard error was 3. Of the species recorded, only 13 species were found at all twenty stations and 37 occurred at only one of the stations. The majority of species (123) were found at less than half of the stations.

Sea Turtles

No Sea Turtles were documented within the SPC cylinders, however, a green sea turtle, *Chelonia mydas,* was observed at station 10. Others were observed from the surface but not documented during fish counts.

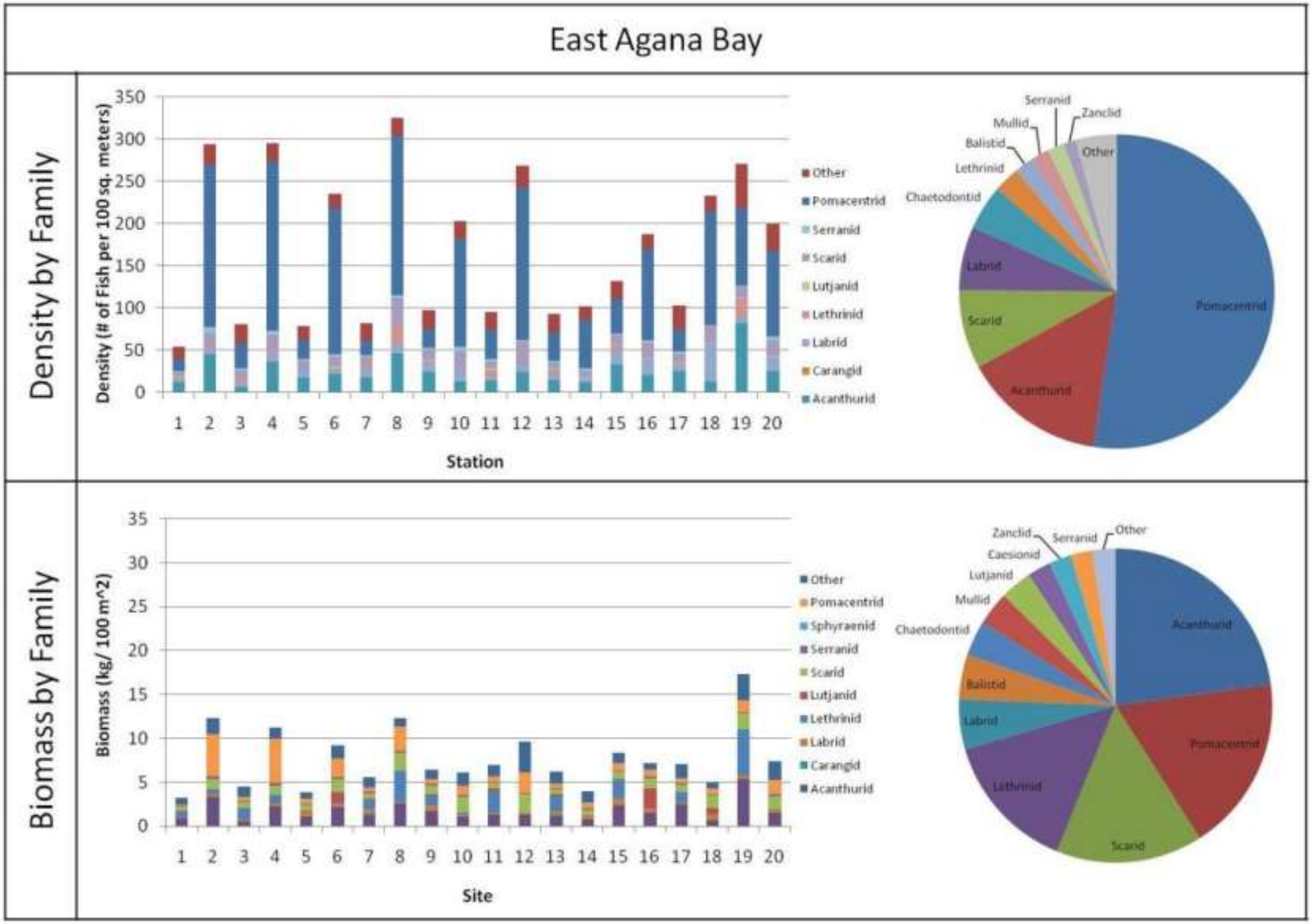


Figure 55. Reef fish density (# of fish/100m^2) by family and relative density by family (top); reef fish biomass (kg/ 100m^2) by family and relative biomass (bottom).

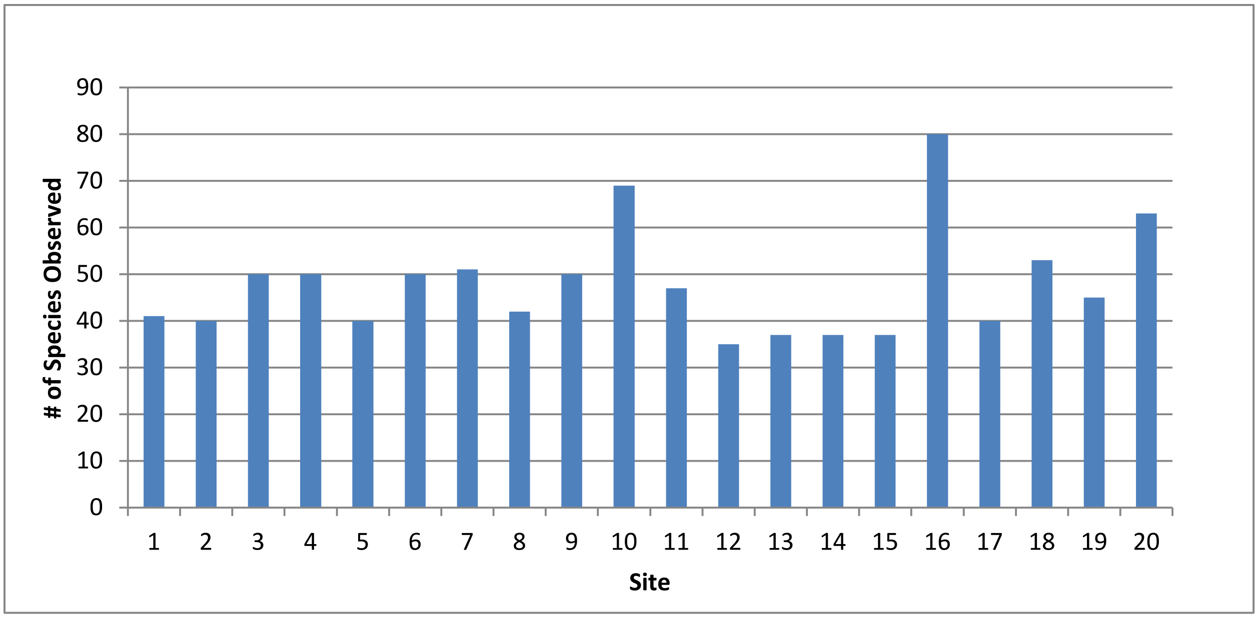


Figure 56. Reef fish species richness for sampling stations within the East Agana Bay monitoring site

Exploration of East Agana reef fish community data in multivariate space

PRIMER was used to examine the effect of depth and exposure on the reef fish communities at the East Agana sampling stations. While the benthic data showed a signal from exposure, the fish data remained fairly heterogeneous across the site. No clear trends were observed. Stations 20 stood out on the MDS plot of Density grouped by species, but there did not seem to be a correlation with depth or the East-West gradient. The MDS plots used to examine the data are presented in Figures 57 and 58.

Power analysis and determination of optimum sample size for East Agana reef fish community data

The number of stations necessary to adequately measure total density, total biomass, and species richness was examined using R (Figures 59 and 60). The results of the analysis suggest that the standard deviations appear to level off at approximately 15 stations; however, the power for density and biomass remains less than the desired 0.7, even at 20 stations. The analysis does suggest that 15 SPCs would provide an approximate power of 0.8 for species richness. The results of the PRIMER analysis support the use of approximately 15-20 stations for adequately estimating biomass and density at the family level. The analysis also suggests that a large number of transects would be required for increased power for species level comparisons. Dominance curves for multivariate power analysis at the species level appeared to become more disperse as the number of transects increased (Figure 61), suggesting that a large number of additional samples may be required before the curves begin to cluster.

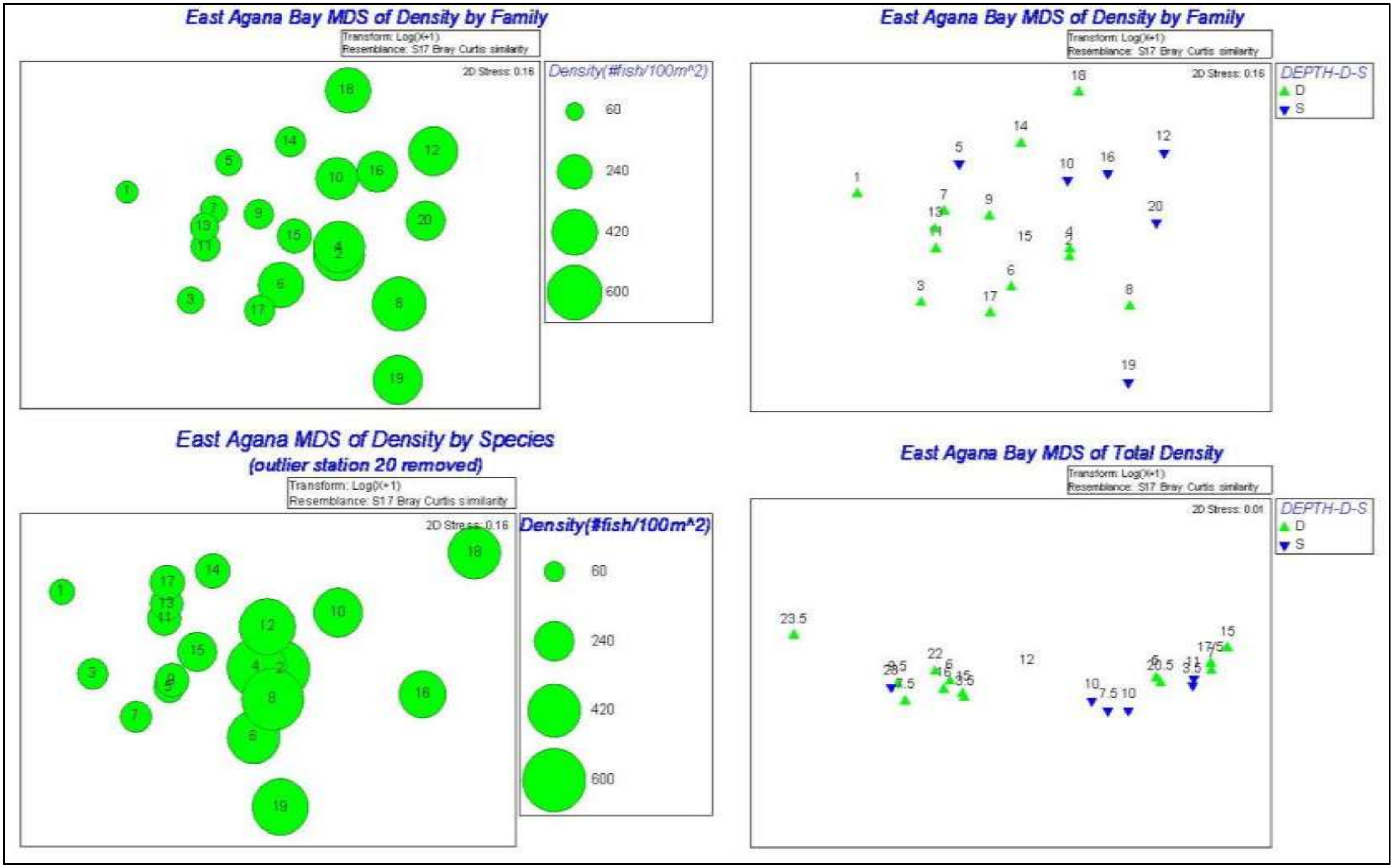


Figure 57. PRIMER MDS plots of reef fish density at East Agana sampling stations. Plots do not reveal any distinct clustering among the stations and there was no clear influence of depth on reef fish communities.

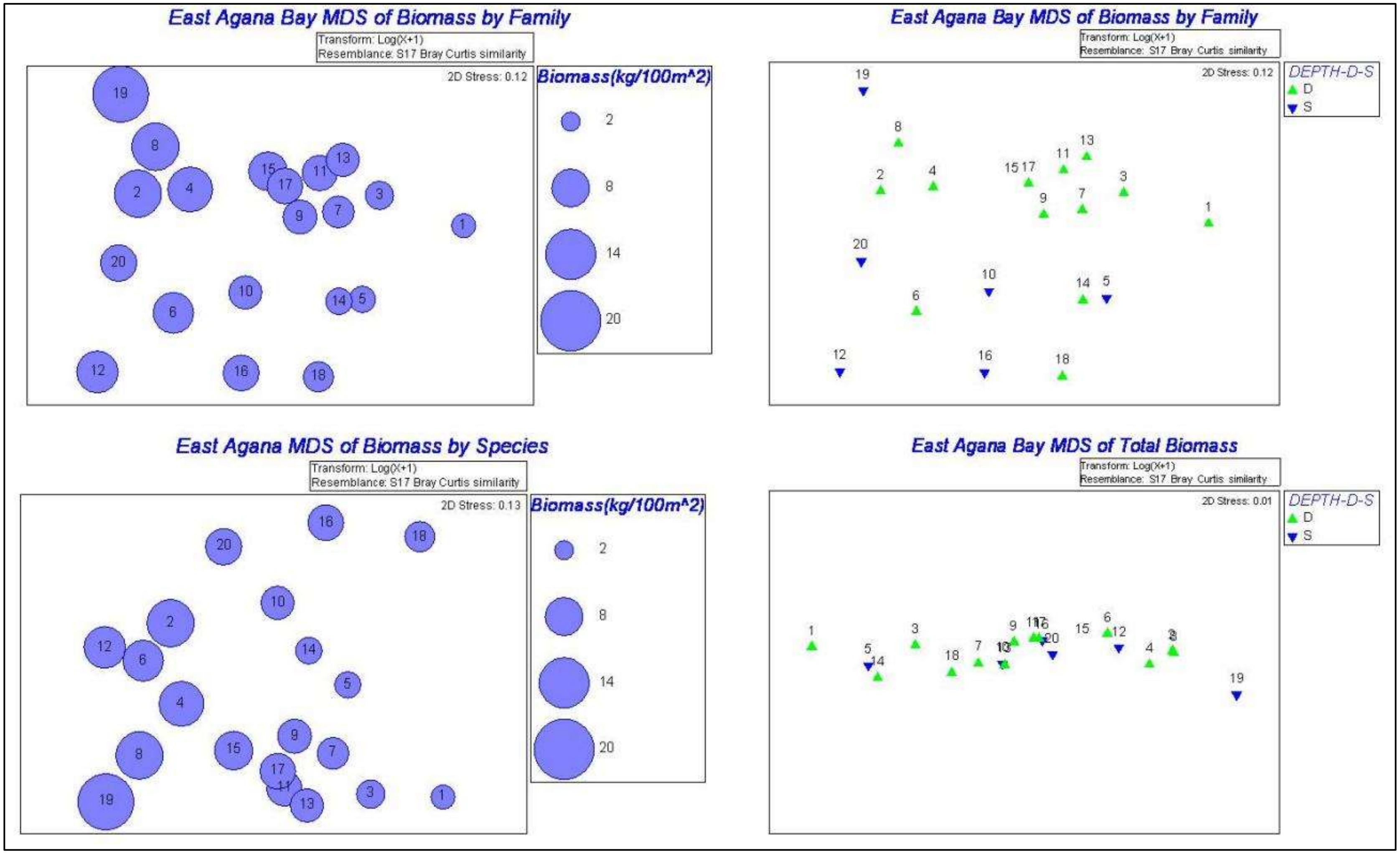


Figure 58. PRIMER MDS plots of reef fish biomass at East Agana sampling stations. There was no clear distinction between depth ranges.

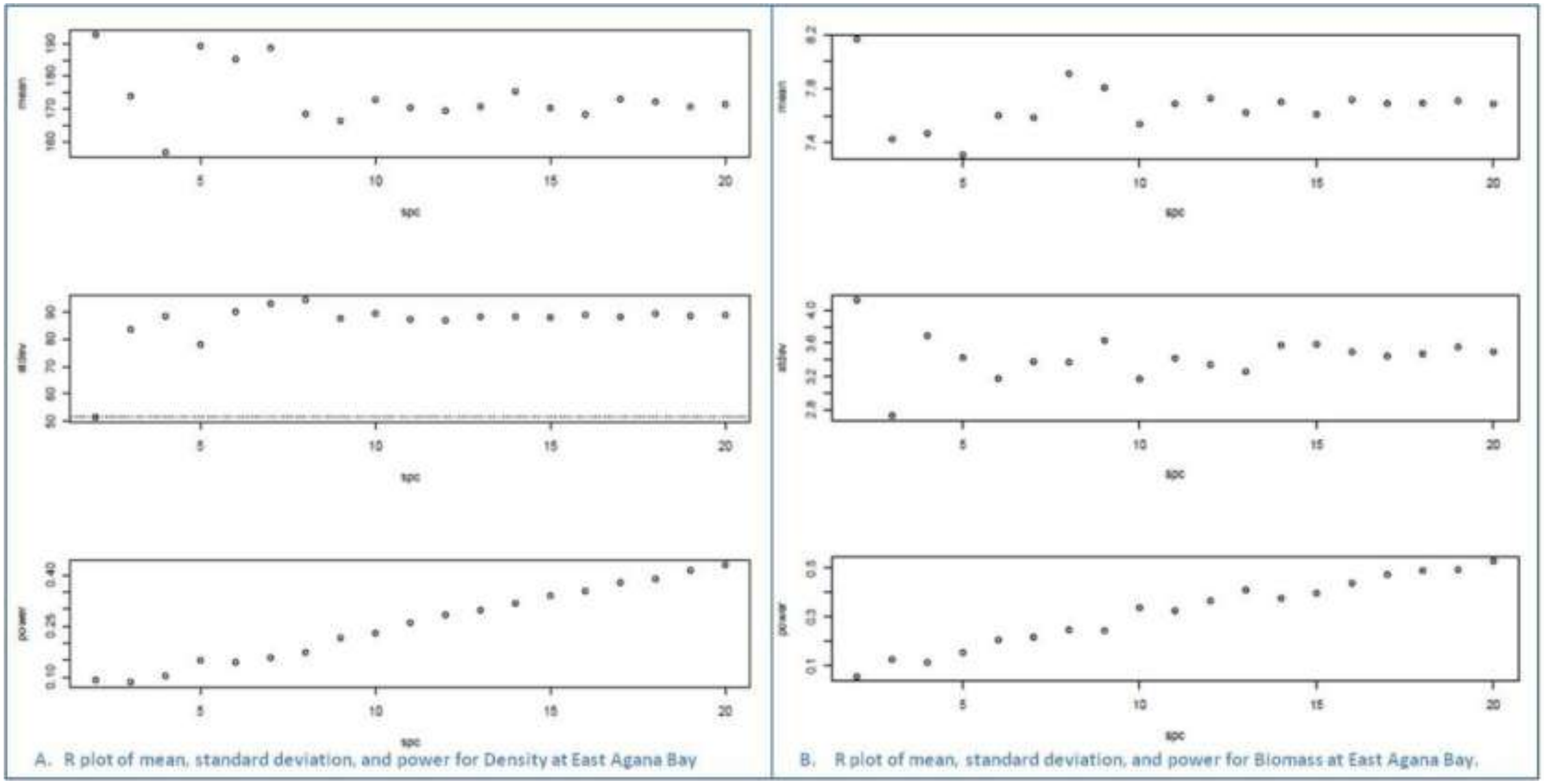


Figure 59. R power analysis plots for reef fish density (Plot A) and Biomass (Plot B) in the East Agana monitoring site; the plots were created using a custom code developed by Dr. Peter Houk of the Pacific Marine Resources Institute. Results of the analysis indicate that more than 20 stations should be sampled in order to achieve desired power levels for reef fish density and biomass.

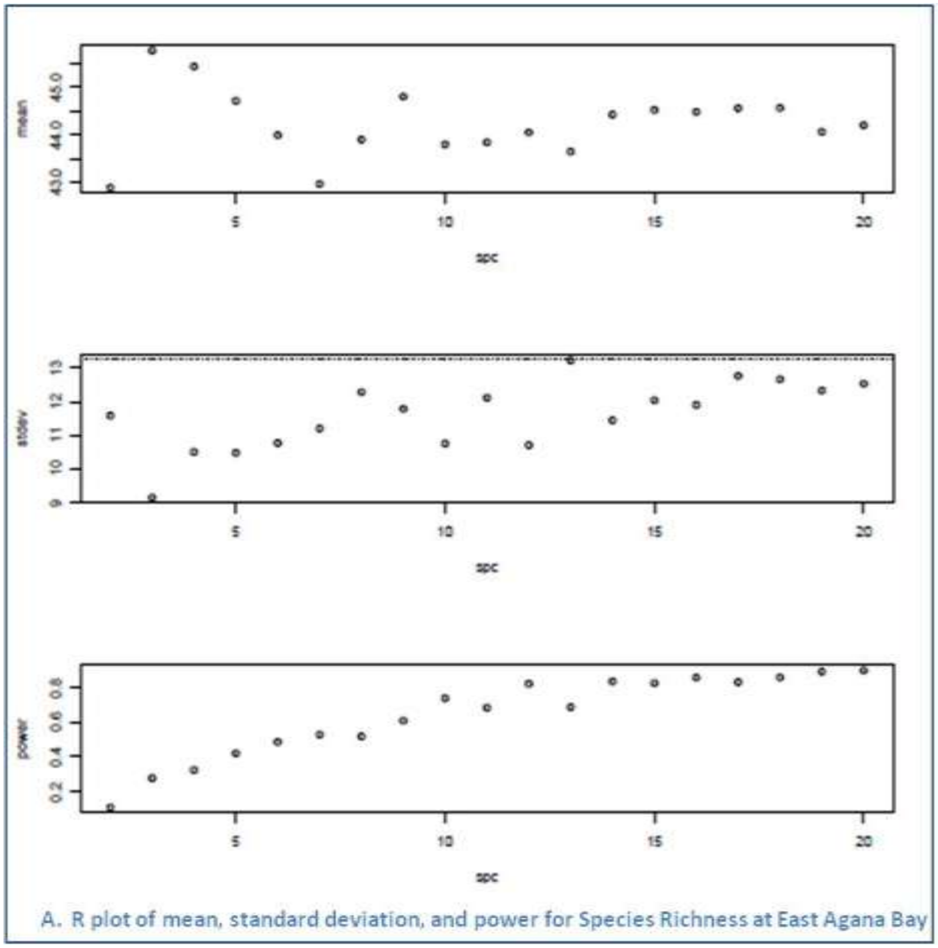


Figure 60. R power analysis plots for reef fish species richness in the East Agana monitoring site; Results of the analysis indicate that 20 stations is sufficient to achieve an adequate level of power (0.8) for species richness.

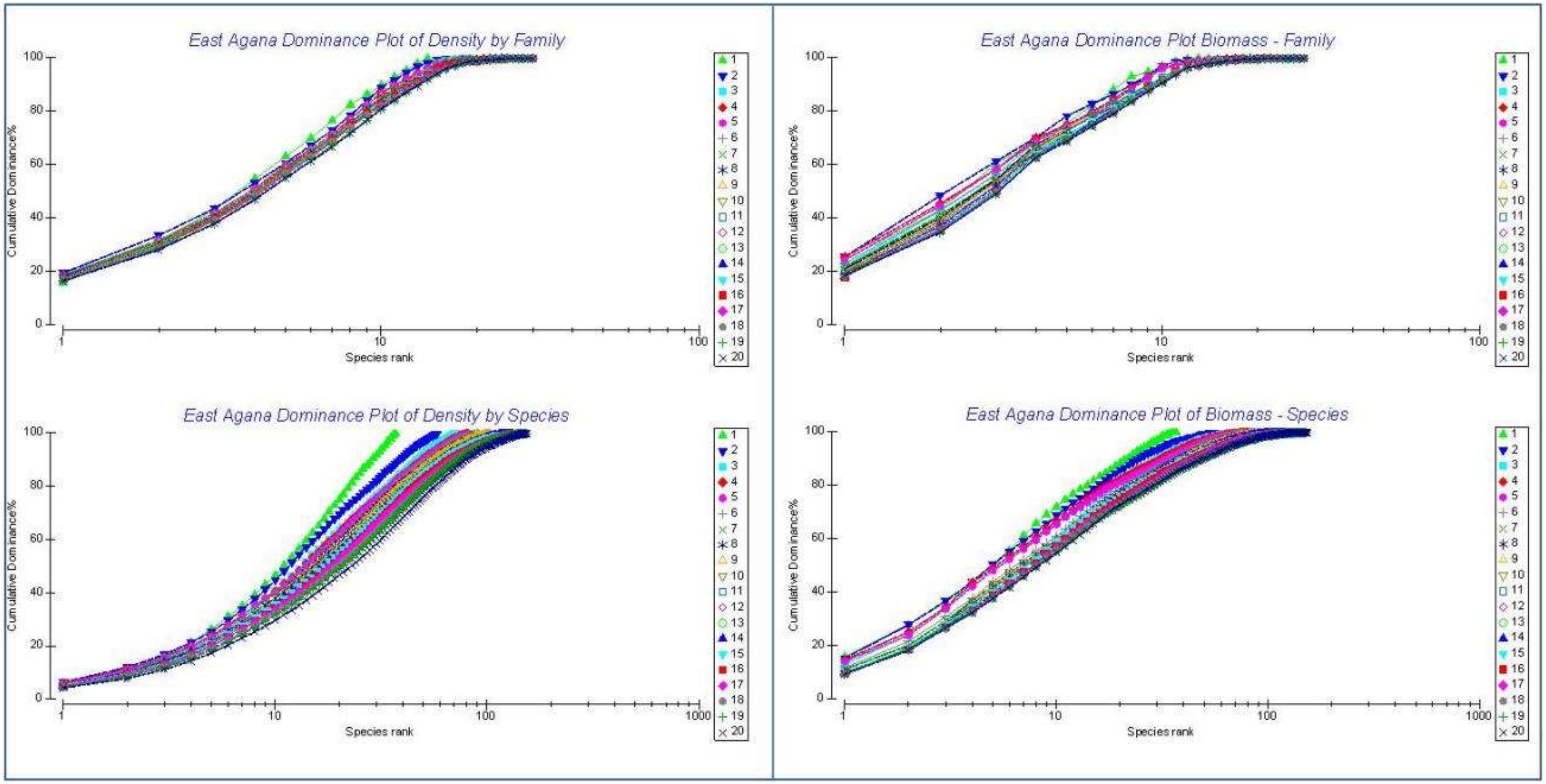


Figure 61. PRIMER Dominance Plots of Cumulative Averages for reef fish density and biomass in the East Agana monitoring site. Results suggest that 15 stations are sufficient for family level analysis, but not for species level analysis.

Western Shoals

<u>Western Shoals: Benthic Cover</u>

Exploration of benthic cover data in multivariate space

As with the benthic cover data for the Tumon Bay and East Agana Bay sampling stations, benthic cover data for Western Shoals sampling stations were explored in multivariate space using the statistical software package PRIMER and the PERMANOVA add-on prior to carrying out power analyses and generating descriptive statistics.

The Western Shoals benthic cover values generated by the CPCe application were re-formatted in Microsoft Excel to conform with PRIMER. Once in PRIMER the data were selected at the lowest taxonomic level, log-transformed, and then used to generate a Bray-Curtis Similarity Matrix. As with the Tumon benthic cover data, only those data for frames from the left side of the transect were used for this analysis. A Principle Coordinates Analysis (PCO) was carried out on the benthic cover values from transects at all Western Shoals sampling stations and a two-axis scatter plot was generated (Figure 62).

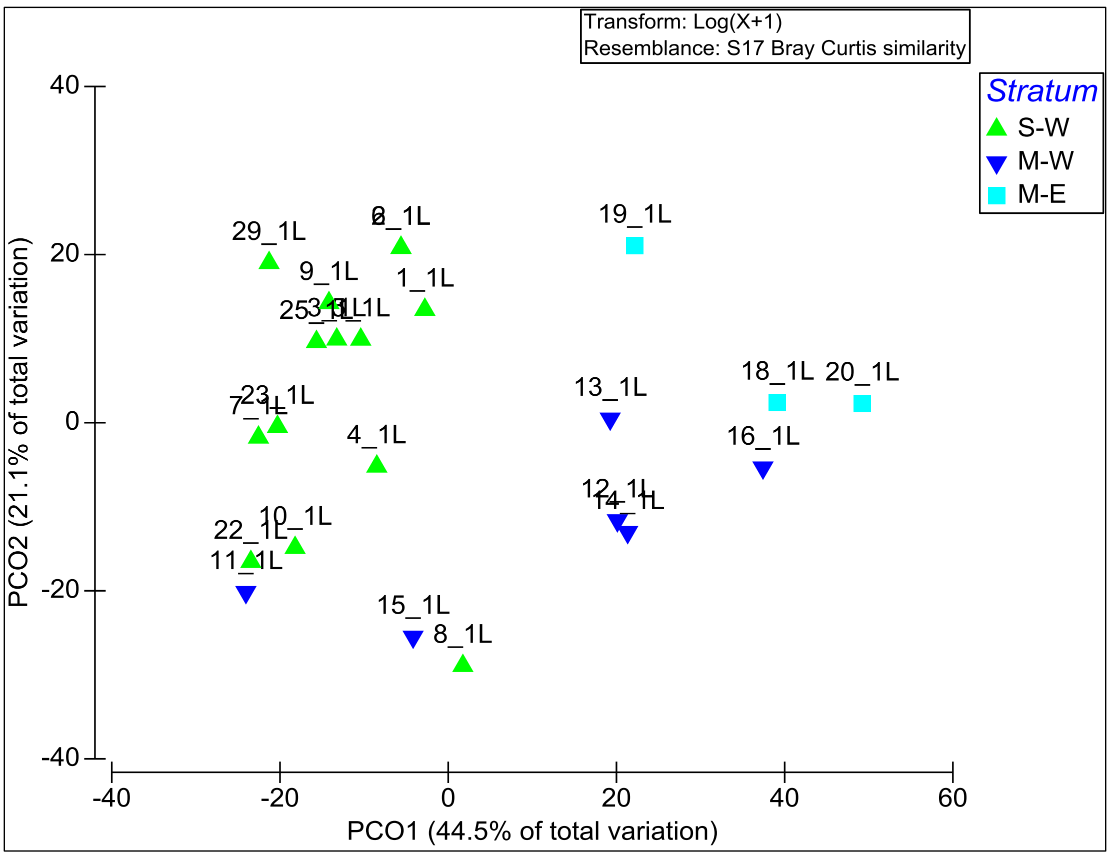


Figure 62. A Principle Coordinates Analysis (PCO) scatter plot displaying the sampling stations from the Western Shoals monitoring site. Stations are symbolized by strata (S-W = Slope-West; M-W = Margin-West; M-E = Margin-East) and labeled by transect name. The PCO was based on a Bray-Curtis Similarity Matrix created using log-transformed benthic cover values for benthic classes selected at the lowest taxonomic level.

As described above, the Western Shoals monitoring site was divided into three strata prior to data collection; this division was based upon qualitative observations and information from spatially referenced underwater photographs gathered during an exploratory dive and snorkel around the shoals; these strata were utilized in the initial exploration of the benthic cover data, with the understanding that the strata may eventually be redefined to minimize the variances and thus increase statistical power for key parameters within each strata. In general, the scatter plot revealed that sampling stations clustered with other stations from the same stratum. Some overlap was evident, however, indicating that some stations may be better placed with a different stratum.

As with the Tumon and East Agana benthic cover data, the potential influence of depth on the benthic communities at the Western Shoals sampling stations were visualized in multivariate space using a PCO scatter plot (Figures 63 and 64, respectively). In general it appeared as though depth influenced the benthic communities observed at the Western Shoals sampling stations, with stations with similar depths clustering together; deeper (> 10 m) sampling stations clustered more tightly, indicating a greater degree of similarity among the benthic communities at these stations.

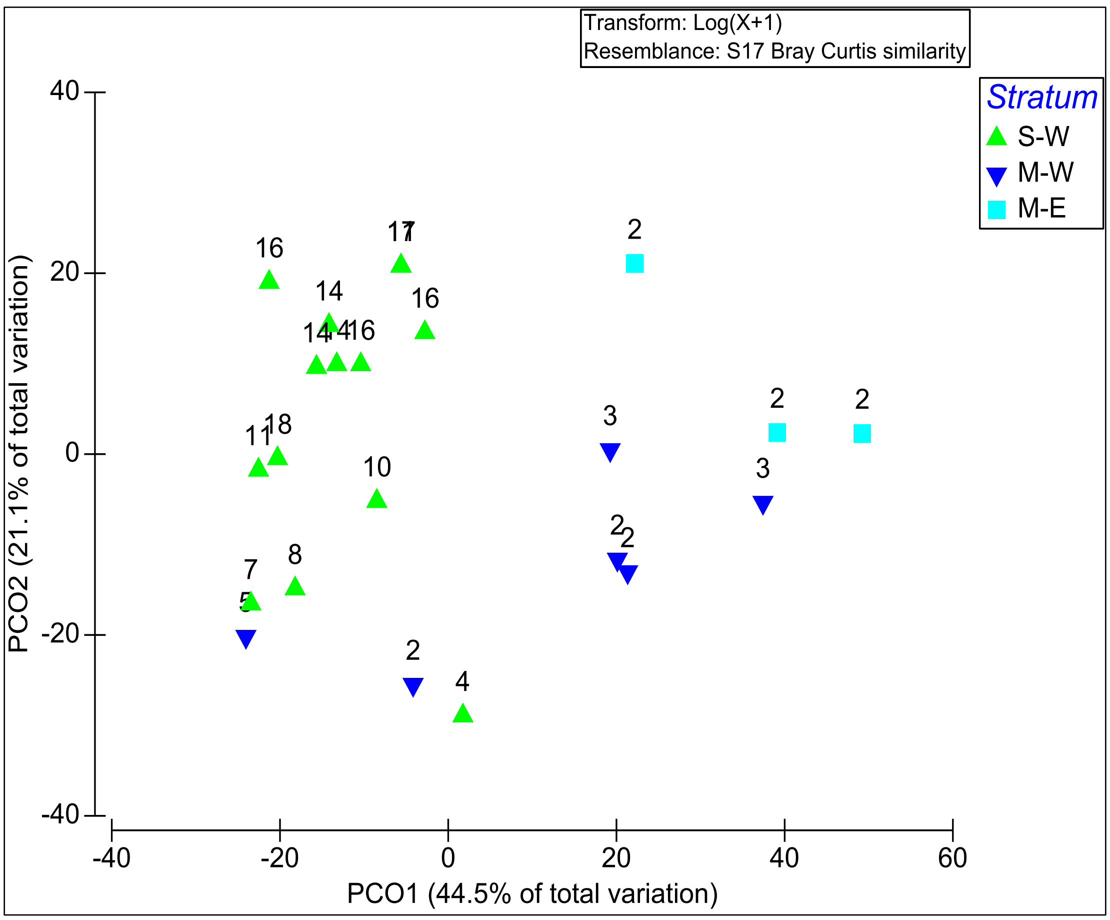


Figure 63. A Principle Coordinates Analysis (PCO) scatter plot of sampling stations from the Western Shoals monitoring site. Stations are symbolized by strata; labels indicate the depth in meters. The PCO was based on a Bray-Curtis Similarity Matrix created using log-transformed benthic cover values for benthic classes selected at the lowest taxonomic level.

The benthic cover data for the Western Shoals sampling stations were also examined based on their occurrence on the East or West sides of the shoals. When the sampling stations were visualized on the scatter plot and labeled according to their occurrence on either the East or West side of the shoals, the three stations on the East side appeared to be somewhat separate from the West stations; very clear clustering was not evident, however, and a few of the shallower West stations appeared to share somewhat similar benthic communities with the East stations, all of which occurred at a depth of 2 meters (Figure 64). The small number of stations from the east side of the shoals prevented a more robust analysis of the effect of shoals side. Anecdotal observations indicate that the substantial *Porites rus*-dominated coral growth occurs predominantly on the West side of the shoals facing the mouth of the harbor; the reef community on the West side of the shoals likely experiences more water movement and may be less affected by turbid water generated from Sasa Bay and the Inner Harbor. The reef community on the West side is also exposed to storm swell that enters the mouth of the harbor. Coral growth on the East side of the shoals is generally much less prolific than on the West side, although a relatively thin band of dense, diverse coral growth can generally be found along the eastern margin of the shoals. The reef community on the East side is more protected from storm swell but may be somewhat more exposed to the relatively small waves generated by the prevailing winds and may be more heavily impacted by turbid water from Sasa Bay and the Inner Harbor.

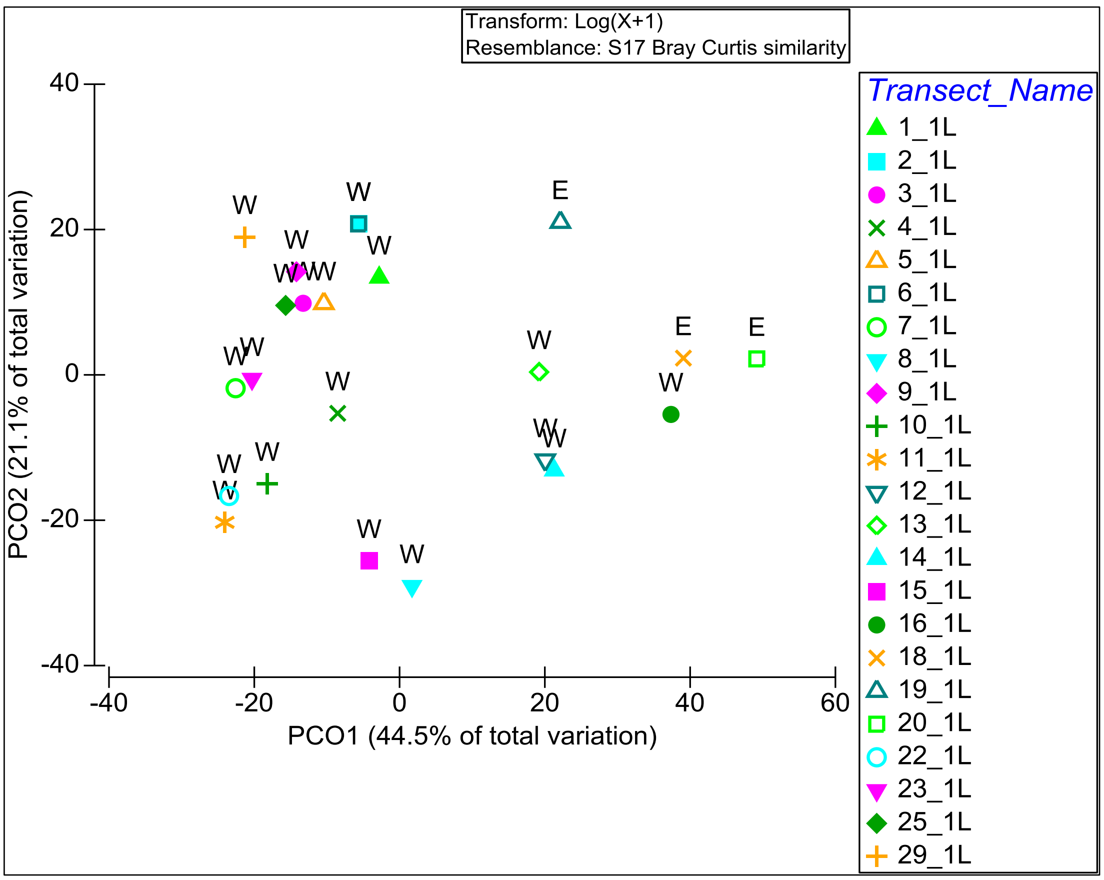


Figure 64. A Principle Coordinates Analysis (PCO) scatter plot of sampling stations from the Western Shoals monitoring site with the labels indicating the side of the shoals (East or West) on which the stations occurred. The PCO was based on a Bray-Curtis Similarity Matrix created using log-transformed benthic cover values for benthic classes selected at the lowest taxonomic level.

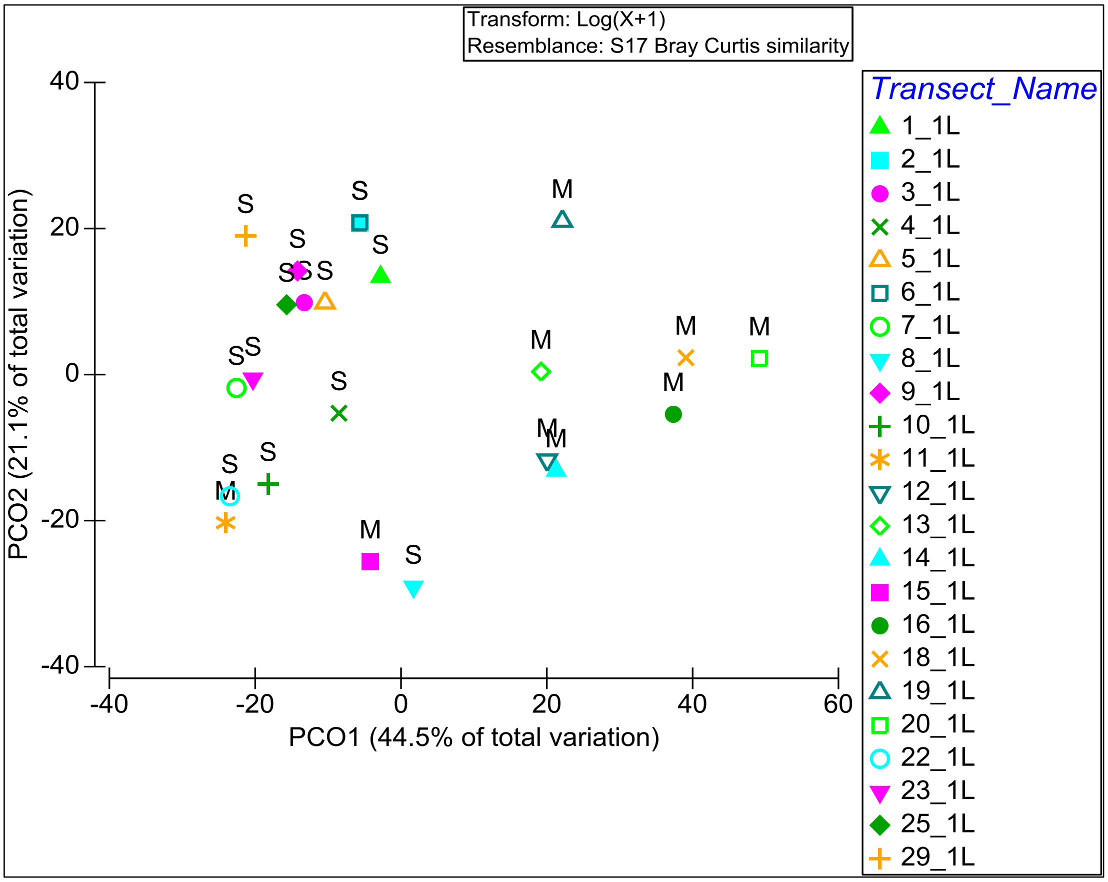


Figure 65. A Principle Coordinates Analysis (PCO) scatter plot of sampling stations from the Western Shoals monitoring site with the labels indicating the reef zone (Slope or Margin) within which the stations occured. The PCO was based on a Bray-Curtis Similarity Matrix created using log-transformed benthic cover values for benthic classes selected at the lowest taxonomic level.

The PCO scatter plots provided an indication that both depth, shoals side, and reef zone (Figure 65) explained at least some of the differences observed between the benthic communities at the sampling stations, but in order to quantify the influence of these environmental factors a Distance-based Linear Model (DistLM) was performed on the Bray-Curtis Similarity Matrix created using log-transformed benthic percent cover values. The results of the DistLM indicated that depth, shoals side, and reef zone explained 27%, 23%, and 26% of the difference between the benthic communities at the Western Shoals sampling stations, respectively (p = 0.001, 0.002, and 0,001 respectively). The stratum within which the sampling stations occurred, which is a combination of shoals side and reef zone (e.g., Slope-West, Margin-West, and Margin-East) provided a slightly stronger influence than a single environmental factor, explaining 30% of the difference in the benthic communities at the stations.

In order to explore how the aspects of the benthic communities drive the differences between sampling stations, the dominant benthic community factors (Spearman Correlation >0.6) were displayed on the PCO scatter plot (Figure 66). The resulting display indicated that the factors that contributed the most to the differences between the benthic communities at stations within the three sampling strata were the greater cover (graph) of *Porites rus* at the Slope-West stations the deeper of the Margin-West stations, the greater cover of the coral, *Pavona cactus*, and living and dead *Halimeda* spp. at the Slope-West stations, and the greater cover of macroalgae, such as *Padina* spp., *Dictyota* spp., and *Turbinaria* spp., and the corals, *Porites annae*, *Porites monticulosa*, *Pavona decussata*, and *Pocillopora damicornis*.

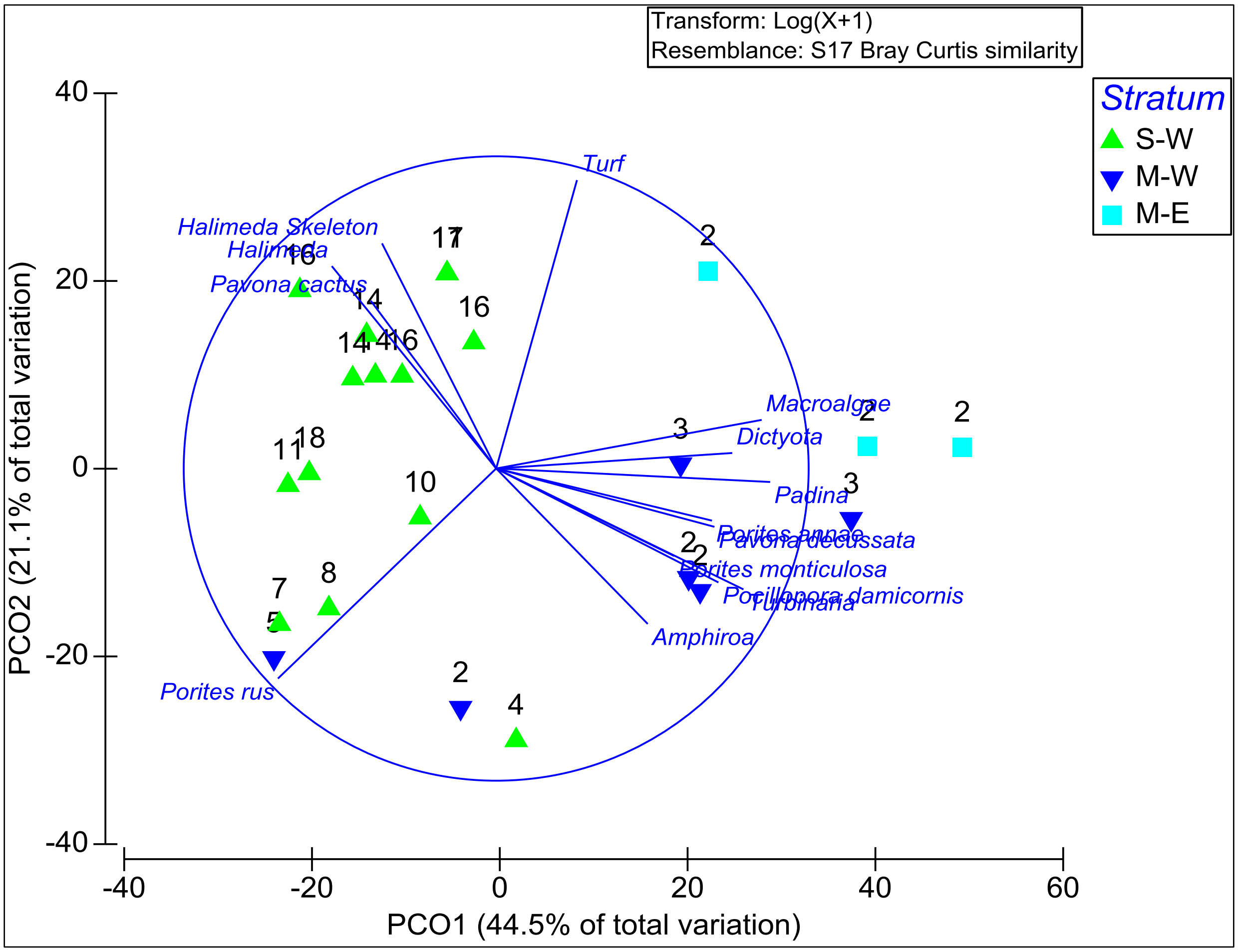


Figure 66. A Principle Coordinates Analysis (PCO) scatter plot of sampling stations from the Western Shoals monitoring site with stations symbolized by stratum (S-W = Slope-West; M-W = Margin-West; M-E = Margin-East) and with vectors defining correlations between variables plotted over the scatter plot (blue lines and blue labels). The PCO was based on a Bray-Curtis Similarity Matrix created using log-transformed benthic cover values for benthic classes selected at the lowest possible taxonomic level.

A SIMPER analysis was then carried out in order to quantify the contribution of each variable to the average Bray-Curtis similarity of the benthic communities within each stratum (Table D) as well as the contributions to the average dissimilarity of stations across strata (Table E). The results of the SIMPER analysis indicate that *Porites rus* and turf algae, in combination, contribute more than 50% to the similarity between sampling stations within the Slope-West stratum, with the macroalgae, *Halimeda* spp. and *Lobophora* spp., contributing an additional 24%. Similar benthic taxa are responsible for the majority of the similarity among stations within the Margin-West stratum, with *Porites rus*, turf algae, and *Lobophora* spp. contributing about 55% to the similarity between sampling stations. *Halimeda* spp. are conspicuously absent from this zone, however, likely limited by the greater wave energy of the reef flat margin. The SIMPER analysis indicated that the benthic communities at the three Margin-East sampling stations were similarly dominated by turf and macroalgae, including *Padina* spp. and *Dictyota* spp., and shared similar abundances of the coral, *Pocillopora damicornis*.

Table D. Within group similarity values from a SIMPER analysis of log-transformed benthic cover data for Western Shoals sampling stations.

Group S-W
Average similarity: 65.61

Species	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
Porites rus	3.98	23.87	4.39	36.38	36.38
Turf	2.65	12.86	3.06	19.60	55.98
Halimeda	1.88	8.95	2.29	13.65	69.62
Lobophora	1.53	6.44	1.68	9.82	79.45
Sponges	0.80	3.86	1.98	5.88	85.32
Halimeda Skeleton	0.85	2.36	0.93	3.60	88.92
Crustose Coralline Algae	0.70	2.11	0.95	3.22	92.14

Group M-W
Average similarity: 56.86

Species	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
Porites rus	3.69	17.14	2.12	30.13	30.13
Turf	2.15	7.94	4.58	13.96	44.10
Lobophora	1.67	6.26	3.41	11.01	55.10
Macroalgae	1.32	4.42	2.65	7.78	62.88
Sponges	0.96	3.64	2.67	6.40	69.28
Padina	1.26	2.57	0.92	4.51	73.80
Porites-massive	1.09	2.37	1.04	4.17	77.97
Crustose Coralline Algae	0.63	1.84	1.29	3.24	81.21
Pocillopora damicornis	0.60	1.83	1.51	3.22	84.42
Turbinaria	0.62	1.65	1.16	2.91	87.33
Porites cylindrica	1.06	1.59	0.48	2.79	90.11

Group M-E
Average similarity: 62.61

Species	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
Turf	3.39	14.46	10.17	23.09	23.09
Padina	3.09	11.96	6.07	19.10	42.19
Macroalgae	2.29	8.41	2.61	13.43	55.62
Pocillopora damicornis	1.16	4.75	8.03	7.58	63.20
Dictyota	1.36	4.68	5.94	7.47	70.67
Porites rus	1.52	4.21	4.14	6.72	77.39
Sponges	1.19	3.21	0.84	5.13	82.52
Acropora sp.-corymbose	1.64	3.02	0.58	4.82	87.34
Crustose Coralline Algae	1.01	2.56	2.48	4.10	91.44

Table E. Between group dissimilarity values from a SIMPER analysis of log-transformed benthic cover data for Western Shoals sampling stations.

Groups S-W & M-W
Average dissimilarity = 47.41

Species	Group S-W Av.Abund	Group M-W Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Halimeda	1.88	0.19	4.68	2.95	9.87	9.87
Turf	2.65	2.15	3.18	1.22	6.71	16.58
Padina	0.23	1.26	3.03	1.35	6.39	22.97
Porites cylindrica	0.03	1.06	2.67	1.01	5.63	28.60
Macroalgae	0.67	1.32	2.57	1.49	5.43	34.02
Porites-massive	0.30	1.09	2.52	1.40	5.32	39.34
Lobophora	1.53	1.67	2.43	1.35	5.13	44.47
Halimeda Skeleton	0.85	0.04	2.23	1.11	4.71	49.18
Dictyota	0.19	0.93	2.14	1.11	4.52	53.70
Porites monticulosa	0.08	0.80	2.00	0.96	4.21	57.91
Porites rus	3.98	3.69	1.95	1.28	4.11	62.02
Crustose Coralline Algae	0.70	0.63	1.64	1.47	3.46	65.48
Turbinaria	0.07	0.62	1.61	1.58	3.39	68.87
Pocillopora damicornis	0.26	0.60	1.48	1.53	3.13	72.00
Acropora sp.-corymbose	0.00	0.55	1.29	0.44	2.73	74.73
Cyanobacteria	0.40	0.37	1.21	1.03	2.55	77.28
Pavona decussata	0.00	0.49	1.20	0.98	2.53	79.81
Sponges	0.80	0.96	1.17	1.39	2.47	82.28
Amphiroa	0.08	0.36	1.01	1.11	2.14	84.42
Porites horizontalata	0.35	0.00	0.97	0.70	2.04	86.46
Porites annae	0.00	0.37	0.88	0.65	1.86	88.32
Pavona cactus	0.31	0.00	0.87	0.52	1.84	90.16

Groups S-W & M-E
Average dissimilarity = 60.64

Species	Group S-W Av.Abund	Group M-E Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Padina	0.23	3.09	7.51	3.19	12.38	12.38
Porites rus	3.98	1.52	6.57	2.36	10.83	23.20
Macroalgae	0.67	2.29	4.38	1.89	7.23	30.44
Acropora sp.-corymbose	0.00	1.64	3.94	1.38	6.50	36.94
Lobophora	1.53	0.04	3.81	1.84	6.28	43.22
Halimeda	1.88	0.62	3.39	1.73	5.60	48.81
Dictyota	0.19	1.36	3.03	2.52	5.00	53.81
Porites monticulosa	0.08	1.02	2.45	0.96	4.04	57.85
Pocillopora damicornis	0.26	1.16	2.37	2.45	3.92	61.77
Turf	2.65	3.39	2.35	1.00	3.87	65.64
Porites annae	0.00	0.96	2.33	1.32	3.84	69.49
Sponges	0.80	1.19	1.97	2.01	3.25	72.73
Halimeda Skeleton	0.85	0.24	1.89	1.21	3.12	75.85
Crustose Coralline Algae	0.70	1.01	1.74	1.49	2.86	78.71
Porites-massive	0.30	0.71	1.60	1.44	2.64	81.36
Psammocora sp.	0.00	0.65	1.55	0.70	2.55	83.91
Turbinaria	0.07	0.55	1.35	1.76	2.22	86.13
Cyanobacteria	0.40	0.22	1.13	1.06	1.86	87.99
Porites horizontalata	0.35	0.00	0.87	0.72	1.44	89.43
Pavona cactus	0.31	0.00	0.78	0.53	1.29	90.72

Table E (cont.).

Groups M-W & M-E
Average dissimilarity = 50.98

Species	Group M-W Av.Abund	Group M-E Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Porites rus	3.69	1.52	5.56	1.58	10.91	10.91
Padina	1.26	3.09	4.80	1.32	9.41	20.32
Lobophora	1.67	0.04	3.74	2.72	7.34	27.66
Acropora sp.-corymbose	0.55	1.64	3.72	1.31	7.29	34.95
Turf	2.15	3.39	3.25	1.21	6.38	41.33
Macroalgae	1.32	2.29	2.73	1.26	5.35	46.68
Porites monticulosa	0.80	1.02	2.55	1.17	4.99	51.67
Dictyota	0.93	1.36	2.29	1.51	4.48	56.15
Porites cylindrica	1.06	0.04	2.27	0.99	4.44	60.60
Porites annae	0.37	0.96	2.04	1.25	4.00	64.60
Porites-massive	1.09	0.71	1.90	1.27	3.72	68.32
Sponges	0.96	1.19	1.71	1.72	3.36	71.68
Halimeda	0.19	0.62	1.66	0.94	3.26	74.94
Psammocora sp.	0.02	0.65	1.45	0.69	2.85	77.79
Pocillopora damicornis	0.60	1.16	1.41	1.36	2.77	80.57
Crustose Coralline Algae	0.63	1.01	1.38	1.19	2.71	83.28
Pavona decussata	0.49	0.29	0.99	1.15	1.94	85.21
Turbinaria	0.62	0.55	0.97	1.26	1.91	87.12
Cyanobacteria	0.37	0.22	0.80	1.06	1.57	88.69
Amphiroa	0.36	0.17	0.79	1.11	1.54	90.23

As with the analysis of the Tumon benthic cover data, 2D Bubble Plots were created to visualize the relative differences in average abundances for each of the benthic community components that contribute most strongly to the differences between stations from the three Western Shoals strata (Figures 67 and 68). The bubble plots reveal a strong pattern in the distribution of the average abundance (log-transformed values) of *Porites rus*, with noticeably greater average *P. rus* abundances at the Slope-West and Margin-West stations compared to the Margin-East stations. *P. rus* abundance appeared to be greatest at some of the Margin-West stations and the shallower of the Slope-West stations.

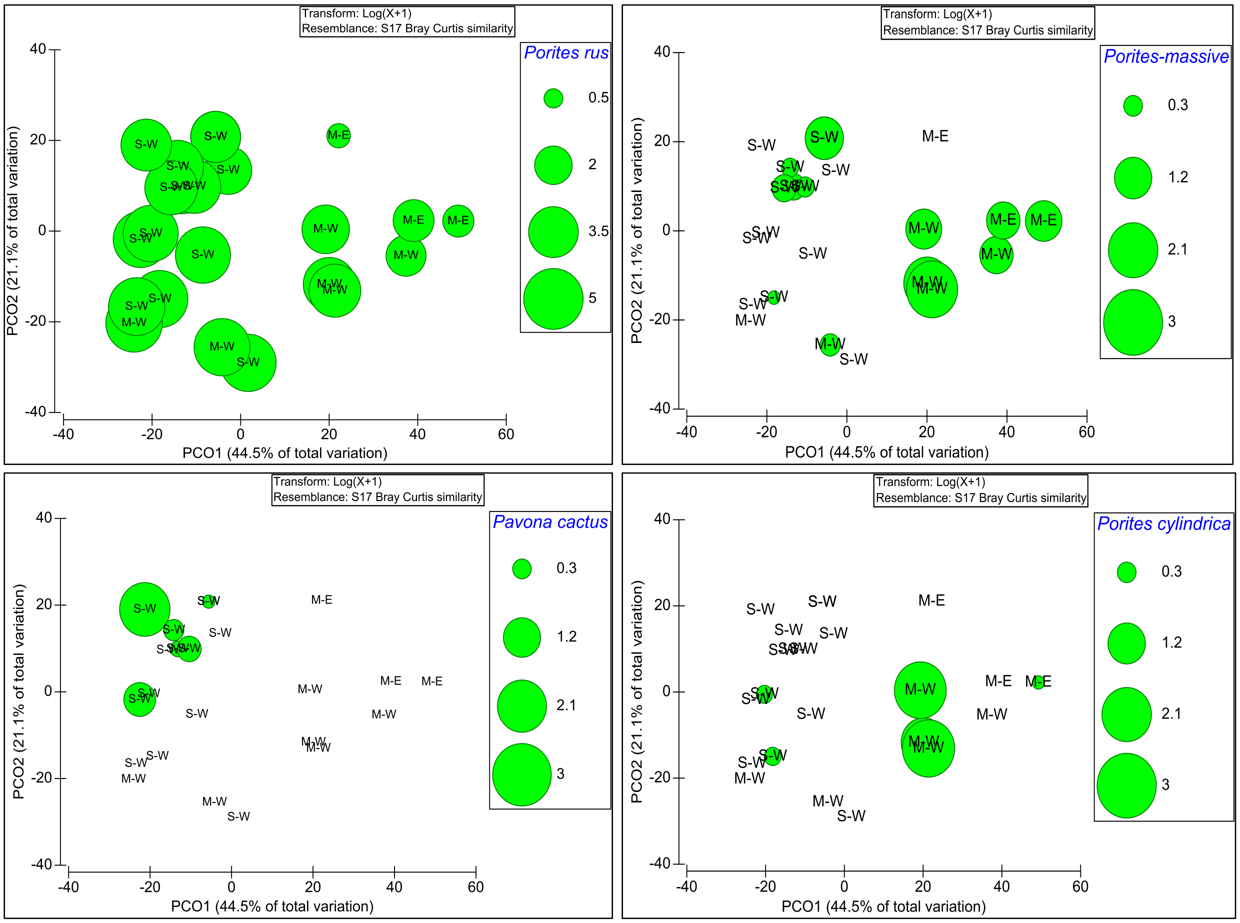


Figure 67. Principle Coordinates Analysis (PCO) 2D Bubble Plots of the relative abundance of the corals, *Porites rus* (upper left), massive *Porites* spp. (upper right), *Pavona cactus* (lower left), and *Porites cylindrica* (lower right) at sampling stations from the Western Shoals monitoring site. Stations are labeled by strata. The PCO was based on a Bray-Curtis Similarity Matrix created using log-transformed benthic cover values for benthic classes selected at the lowest possible taxonomic level.

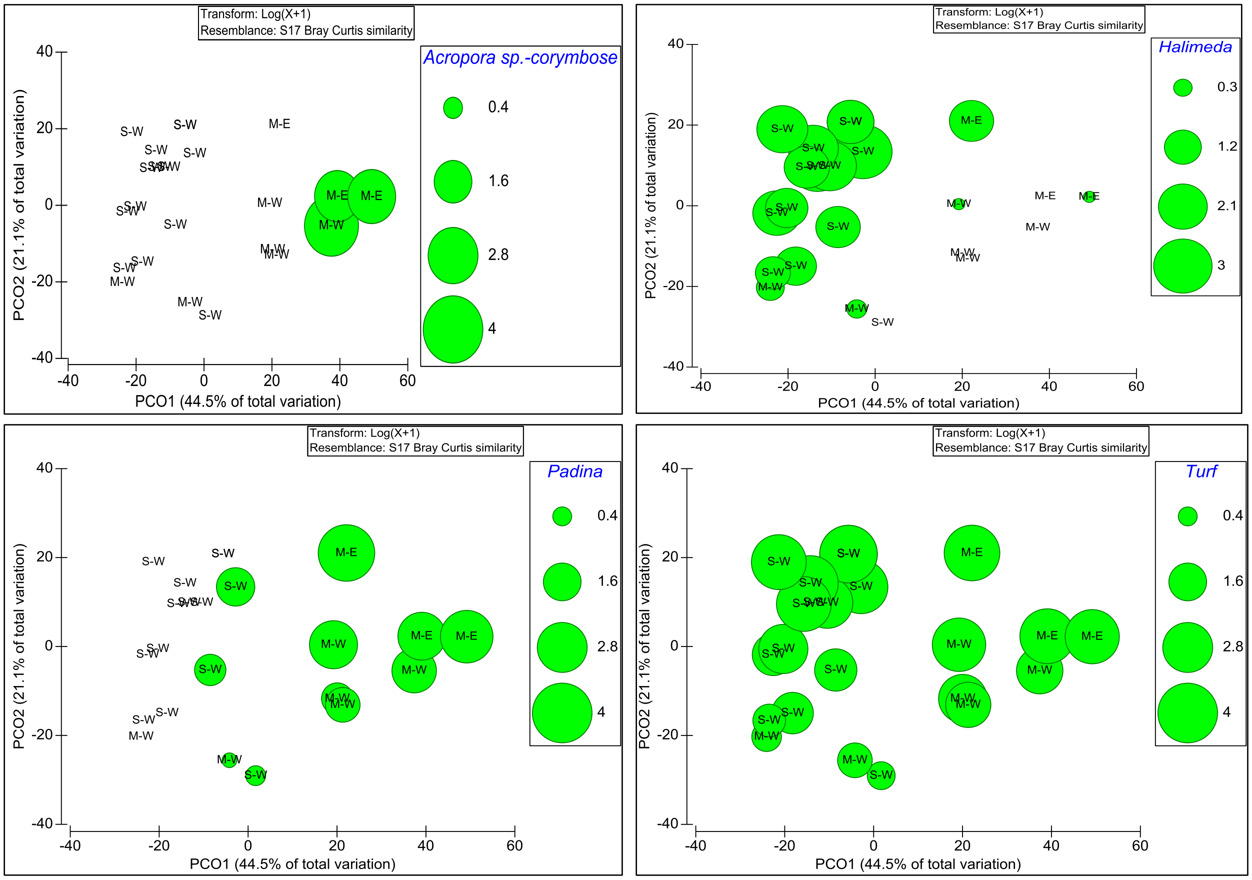


Figure 68. Principle Coordinates Analysis (PCO) 2D Bubble Plots of the relative abundance of the coral, *Acropora*-corymbose spp. (upper left), the macroalgae, *Halimeda* spp. (upper right) and *Padina* spp. (lower left) and turf algae (lower right) at sampling stations from the Western Shoals monitoring site. Stations are labeled by strata. The PCO was based on a Bray-Curtis Similarity Matrix created using log-transformed benthic cover values for benthic classes selected at the lowest possible taxonomic level.

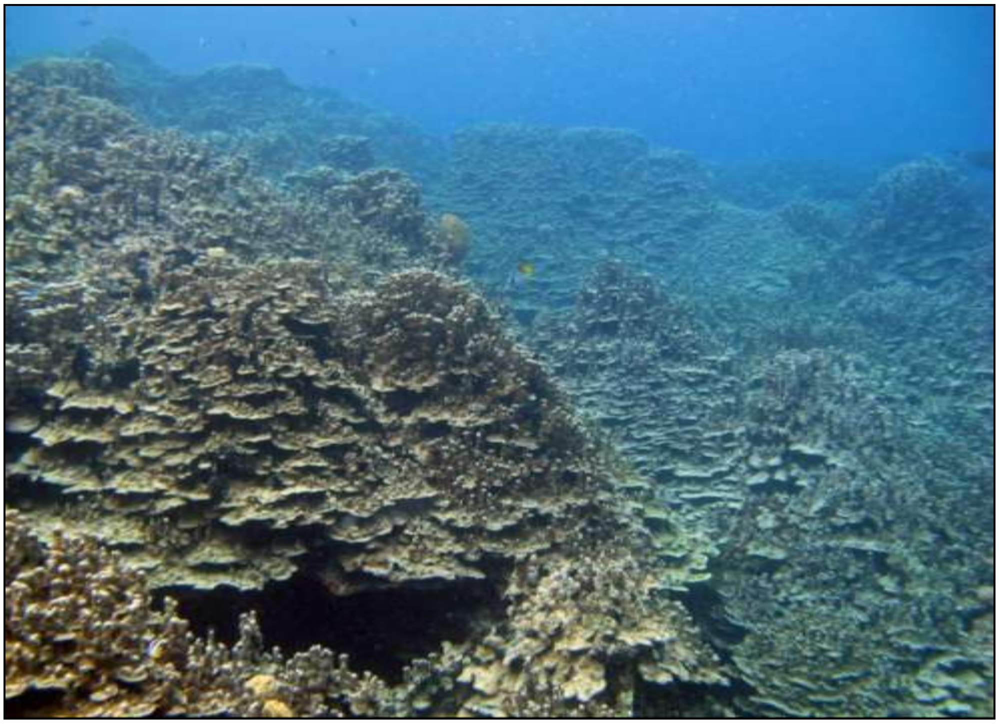


Figure 69. A highly complex, *Porites rus*-dominated benthic community near sampling station 10, within the Slope-West strata of the Western Shoals monitoring site.

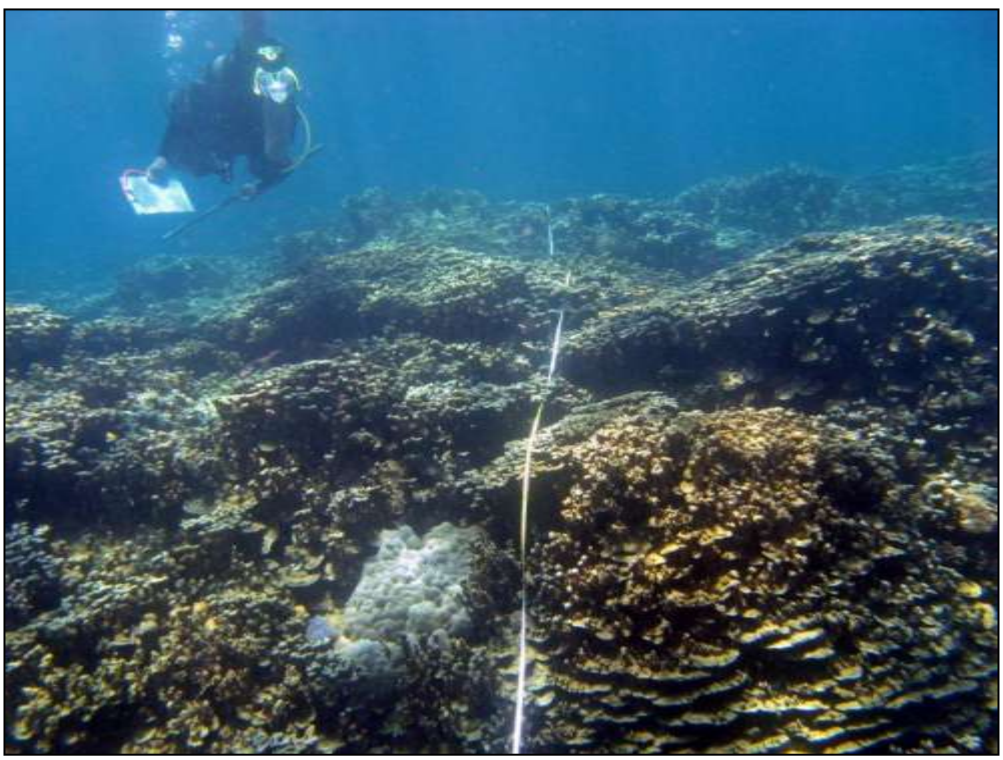


Figure 70. Complex *Porites rus*-dominated benthic communities can also be found at several of the Margin-West sampling stations, such as station 15 (pictured above).

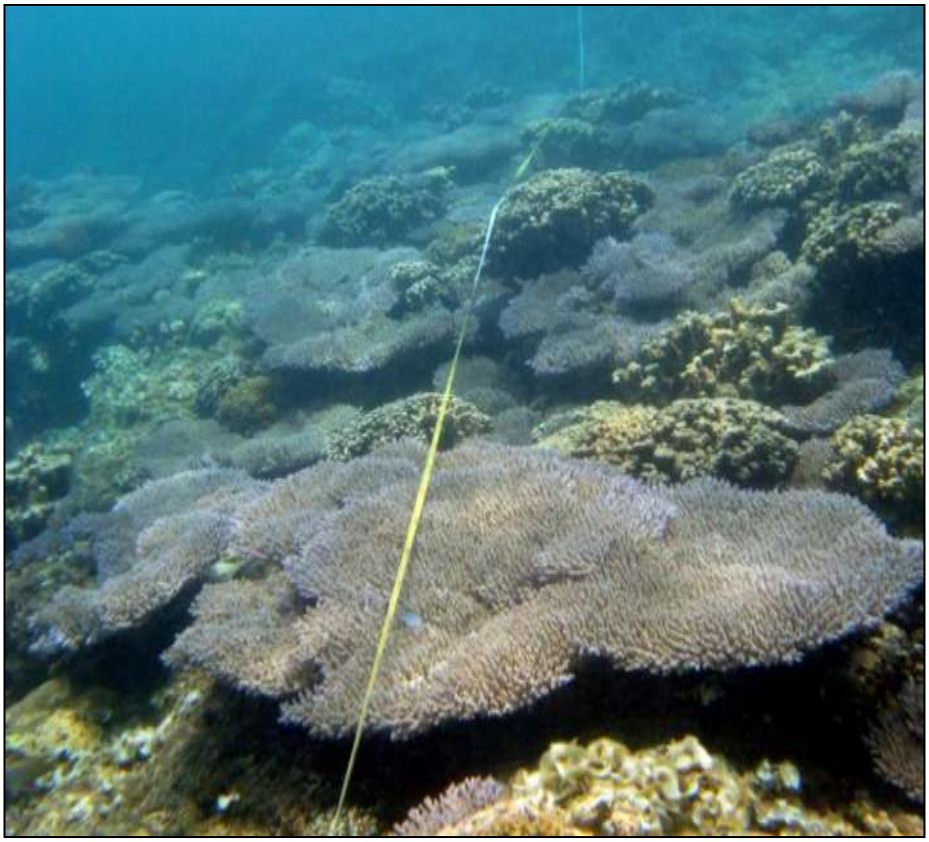


Figure 71. One notable portion of the Margin-West stratum hosts a benthic community with sometimes dense growth of the corymbose Acropora species, *Acropora* cf. *latistella*, pictured here at sampling station 16.

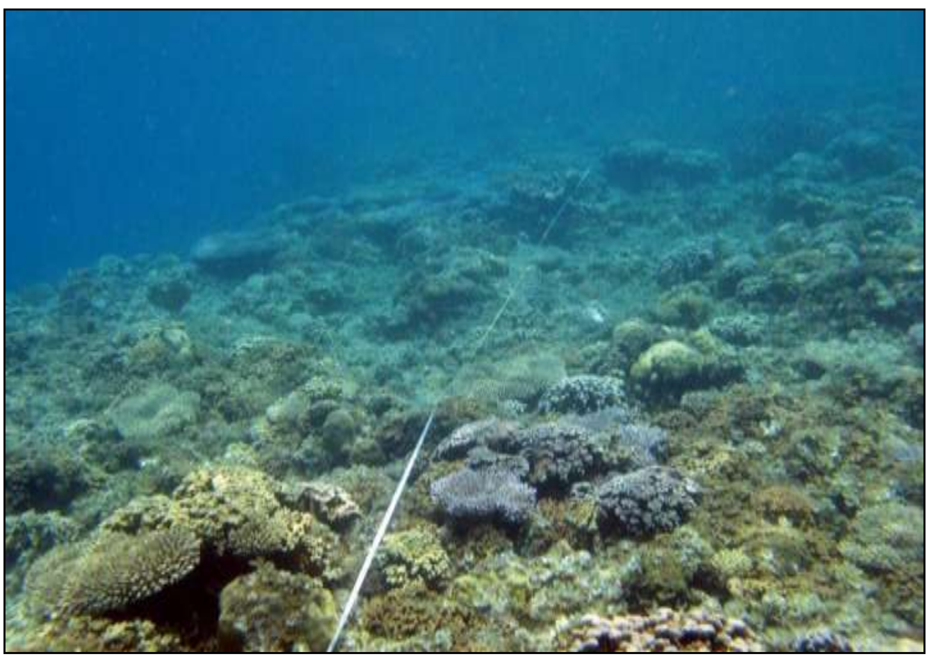


Figure 72. A relatively rich coral community can be found in the narrow Margin-East stratum. The transect visible in the photo belongs to sampling station 20.

Power analyses for Western Shoals benthic cover data

Univariate power analyses were carried out separately on total coral cover for sampling stations in each of the Western Shoals strata; because of technical issues the power analyses could not be carried out on the combination of frames from the left and right sides of the transects and were instead carried out separately for both the left and right side of the transects. Univariate power analyses were also carried out for stations occurring within strata modified based on the results of the preliminary evaluation of the benthic cover data in multivariate space. Multivariate power analyses were carried out for each stratum/modified stratum using Dominance Plots and PCOs of cumulative means of all benthic taxa (at the lowest taxonomic levels).

Power (of a two-sided t-test, α=0.05) for mean coral cover values at all of the original 14 Slope-West stations was 0.61 for the left side of the transects and 0.78 for the right side of the transects (Table F). Power didn't change significantly when stations were excluded from the analysis of data from the left side of the transects, but it dropped to 0.68 when stations were excluded from the analysis of data from the right side of the transects. It is not clear why mean coral cover and standard deviation values differed enough for power to be significantly different for the left and right sides of the transects, but because the analysis was carried out by the same individual it is likely due to what appears to a surprising amount of heterogeneity in the benthic communities – even at the scale of individual sampling stations. Further exploration of the data may reveal more information about this discrepancy. Additionally, power analyses will be carried out after data from the left and right sides of the transects are combined. Power was quite low for the various station groupings for the Margin-West and Margin-East strata, ranging from 0.27 to 0.35 for the Margin-West stations and from 0.06 to 0.16 for the Margin-East stations.

Most of the power values for the detection of changes in coral cover of 30% relative to the mean were lower than originally desired for the program, so the power.t.test function was used to determine the number of samples (n) required to achieve a power of 0.7 and 0.8. The results indicated that for the Slope-West stations (excluding stations 8, 10, and 22) about 11-14 samples (depending on which side of the transect was used) would be required to achieve a power of 0.7 and about 14-18 stations would be required to achieve a power of 0.8 (Table F). Similarly – and despite the smaller area comprised by the Margin-West stratum – the results indicated that for the Margin-West stations (excluding station 11, including station 8) about 13-17 stations would be required to achieve a power of 0.7 and about 17-20 stations would be required to achieve a power of 0.8. Due to the high degree of variability (indicated by higher standard deviation values) in coral cover for the few Margin-East stations, a very larger number of samples (>75) would be required to achieve a power of 0.7 or 0.8. When station 19, which had very low coral cover, was excluded the number of samples required to achieve a power of 0.7 or 0.8 declines significantly (to about 6-10 and 7-13, respectively); however, the results of a power analysis for data from only two stations have very limited value and should not be solely relied upon in re-designing the sampling plan for that stratum.

Table F. Results of t-test power analysis for Western Shoals sampling stations.

Group	Mean	SD	n	delta (mean*0.3)	power	n required for power = 0.7	n required for power = 0.8
Slope-West - Left side	60.0	20.5	14	18.0	0.61	17	21
Slope-West - Left side, excl. 8, 10, 22	52.6	16.3	11	15.8	0.58	14	18
Slope-West - Right side	64.8	18.0	14	19.4	0.78	12	15
Slope-West - Right side, excl. 8, 10, 22	59.3	16.3	11	17.8	0.68	11	14
Margin-West - Left side	67.2	21.6	6	20.2	0.31	15	19
Margin-West - Left side, excl 11, incl 8	66.0	19.8	5	19.8	0.35	13	17
Margin-West - Right side	61.2	21.6	6	18.4	0.27	18	23
Margin-West - Right side, excl 11, incl 8	60.3	20.4	5	18.1	0.28	17	21
Margin-East - Left Side	25.3	20.2	3	7.6	0.06	88	112
Margin-East - Left Side, excl 19	36.3	9.5	2	10.9	0.1	10	13
Margin-East - Right Side	22.9	17.4	3	6.9	0.06	79	101
Margin-East - Right Side, excl 19	32.7	6.1	2	9.8	0.16	6	7

The R code developed by Dr. Peter Houk of the Pacific Marine Resources Institute was then used to view how the mean, standard deviation, and power of a group of samples changed with an increasing number of randomly selected samples. The results of the custom R analysis for mean coral cover within the Slope-West stratum (left side of transects only) of the Western Shoals site indicated that mean and standard deviation appears to level off at around 8-9 samples, while the power gradually increases to around 0.6 (Figure 73). The results were similar for the Slope-West stratum when station 11 was excluded and station 8 was included (Figure 74). The mean and standard deviation for the Margin-West stratum (left side of transects only) do not convincingly approach an asymptote (Figure 75), even after excluding station 11 and including station 8 (Figure 76), while power reaches only around 0.3 with the final sample.

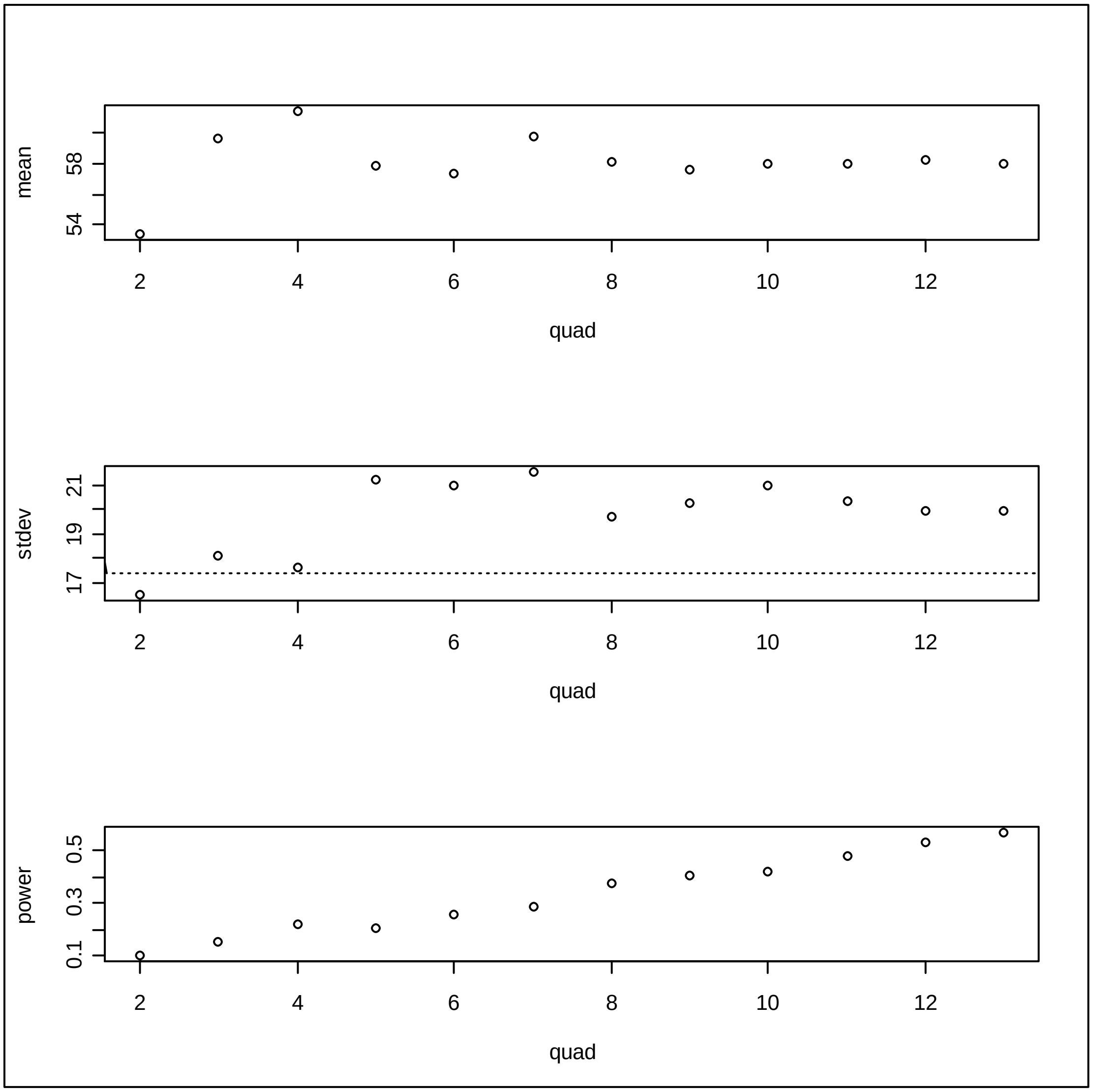


Figure 73. Results of a power analysis carried out on mean coral cover values for sampling stations within the Slope-West stratum (left side of transect only) of the Western Shoals monitoring site using an R code developed by Dr. Peter Houk of the Pacific Marine Resources Institute. The dotted line indicates the delta value (mean of all samples*0.3).

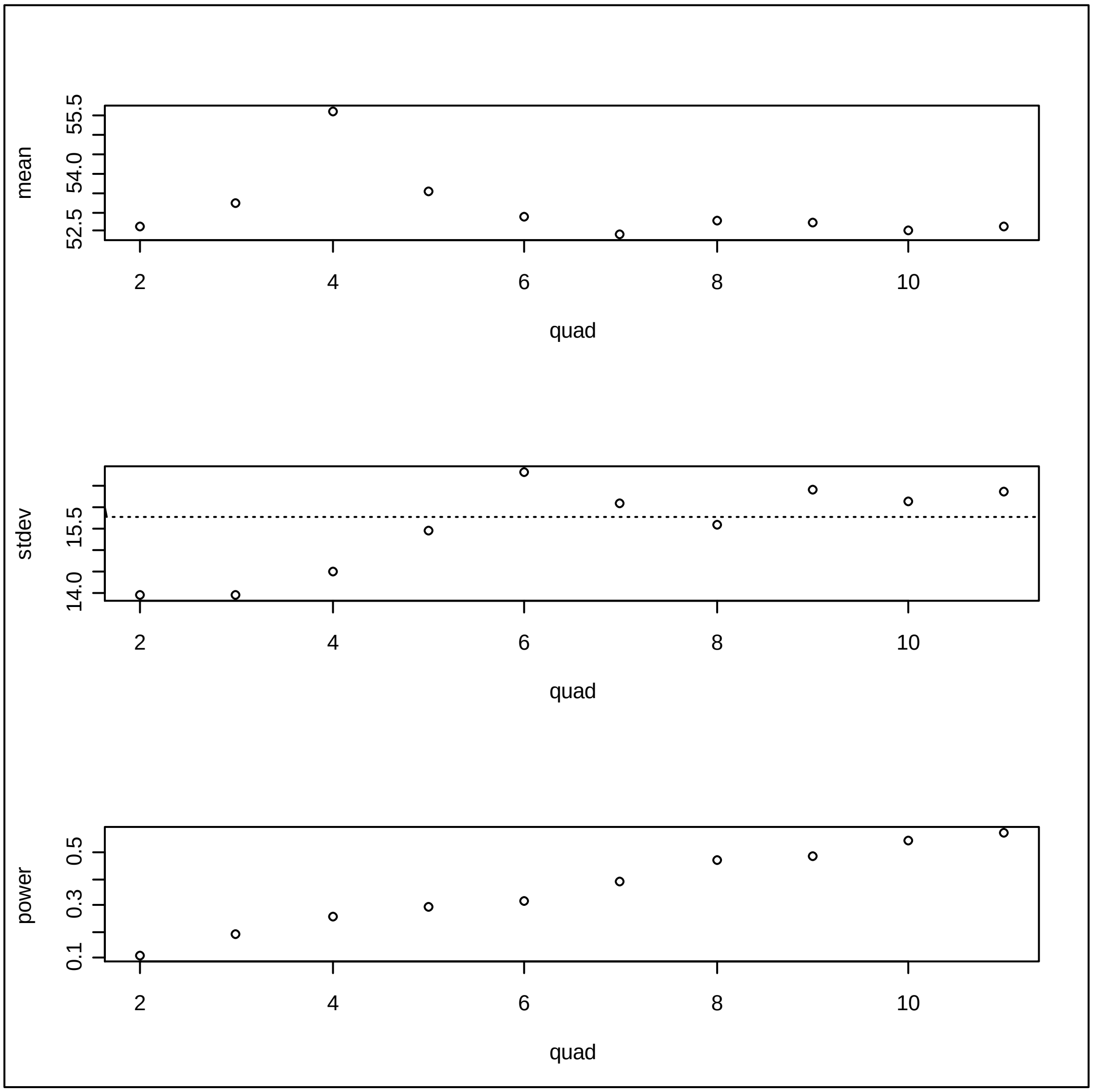


Figure 74. Results of a power analysis carried out on mean coral cover values for sampling stations within the Slope-West stratum (left side of transect only; excluding stations 8, 10, and 22) of the Western Shoals monitoring site using an R code developed by Dr. Peter Houk of the Pacific Marine Resources Institute. The dotted line indicates the delta value (mean of all samples*0.3).

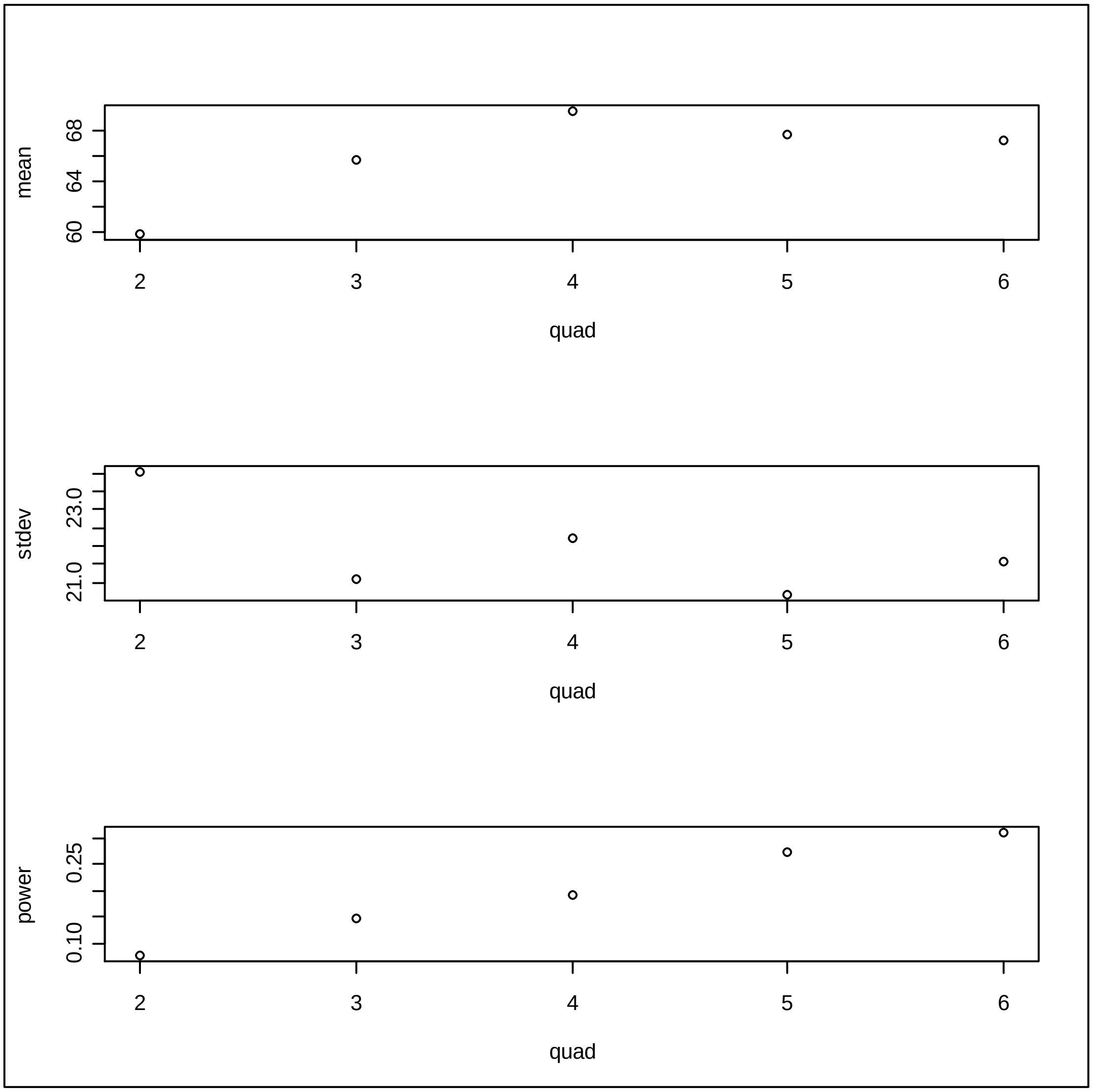


Figure 75. Results of a power analysis carried out on mean coral cover values for sampling stations within the Margin-West stratum (left side of transect only) of the Western Shoals monitoring site using an R code developed by Dr. Peter Houk of the Pacific Marine Resources Institute.

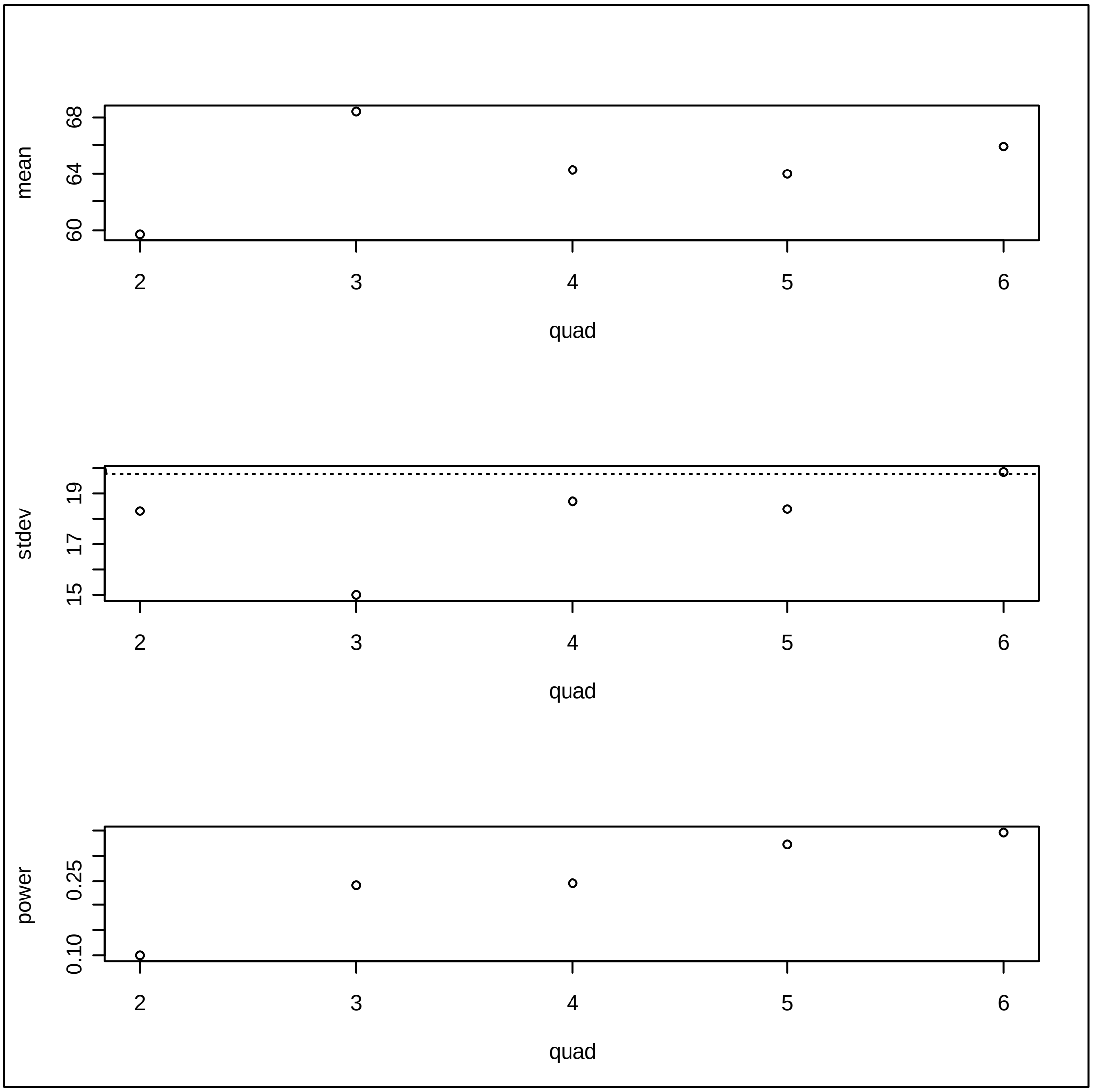


Figure 76. Results of a power analysis carried out on mean coral cover values for sampling stations within the Margin-West stratum (left side of transect only; excluding station 11 and including station 8) of the Western Shoals monitoring site using an R code developed by Dr. Peter Houk of the Pacific Marine Resources Institute.

In order to visualize in multivariate space the ability of the present sample size to adequately capture the abundances of the dominant benthic taxa, the cumulative means of benthic classes (at the lowest taxonomic level) were calculated in Excel and brought into PRIMER/PERMANOVA. After a Bray-Curtis Similarity Matrix was created using the log-transformed cumulative means, Dominance Plots were created using the cumulative means for the benthic cover values (left side of transect only) from the Slope-West (excluding stations 8, 10, and 22) and Margin-West (excluding station 11, including station 8) sampling stations. A Dominance Plot was not generated for the Margin-East strata, as its clear that the strata will have to be redefined and additional sampling must occur to adequately capture the benthic communities found in this portion of the shoals. The Dominance Plot for the Slope-West stations depicted relatively tight clustering of cumulative dominance curves, while the curves in the Dominance Plot for the Margin-West stations do not appear to cluster, except possibly a loose clustering between the 4th and 9th stations (Figure 77). The tight clustering of the Slope-West dominance curves indicates that mean abundance values didn't change much with an increasing number of samples; thus, it is likely that the abundances of dominant benthic taxa within the Slope-West stratum are adequately captured with the modified sample size of 11 stations. The loose distribution of the Margin-West curves, however, indicates that the mean abundance values continued to changed significantly with an increasing number of samples – a result of the apparently high level of heterogeneity of benthic communities within the Margin-West stratum as currently delineated; this suggests that the Margin-West stratum will likely have to be re-delineated and additional stations established.

As with the cumulative dominance curves for the Tumon and East Agana sites, the curves for Slope-West stratum of the Western Shoals site rise relatively rapidly, with the curves achieving a 50% cumulative dominance value at a species rank of between 3 and 4. The loose distribution of curves within the Dominance Plot for the Margin-West stratum prevents an accurate approximation of the curves, with curves on one end of the spectrum reaching a cumulative dominance value of 50% at a species rank of between 2 and 3 and curves on the other end of the spectrum reaching a 50% cumulative dominance value at a species rank of about 6. While the relatively steep curves generated for the Slope-West stations suggest that taxonomic/functional diversity may be low within this stratum and may indicate a low level of resilience, caution should again be made in placing too much emphasis on the meaning of curves generated from a single sampling period, and attention should be focused on the change in the shape of the curves as additional data is collected over time.

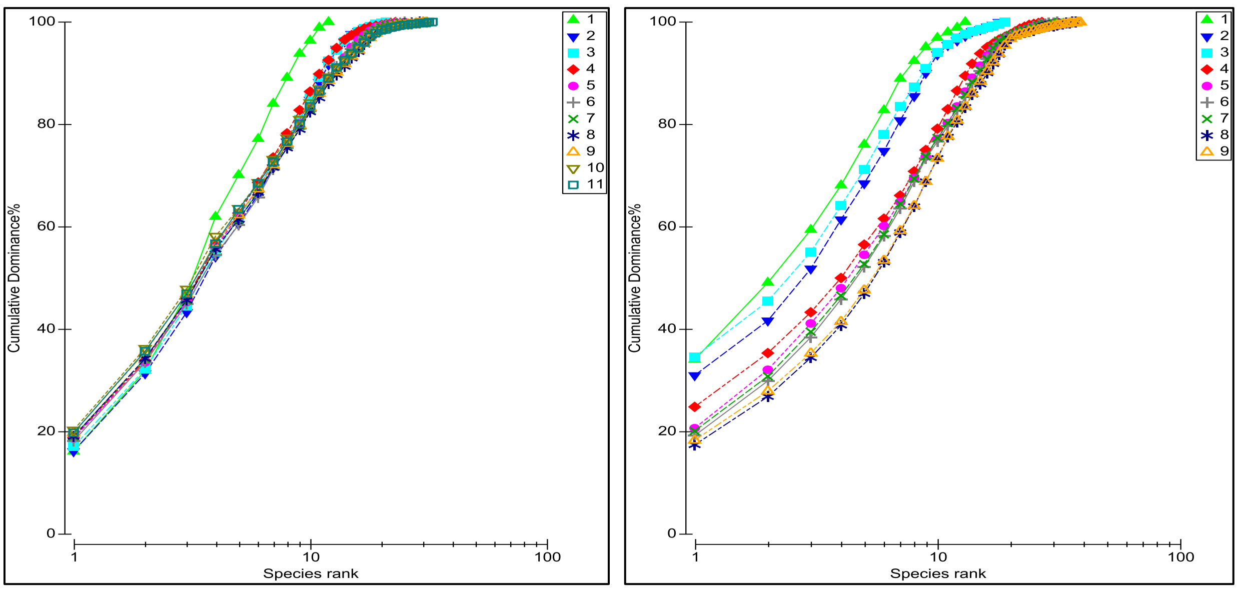


Figure 77. Dominance plots depicting the cumulative dominance curves for log-transformed benthic cover values from Slope-West (left side of transect only; excluding stations 8, 10, and 22)(left) and Margin-West stations (left side of transect only; excluding station 11 and including station 8)(right).

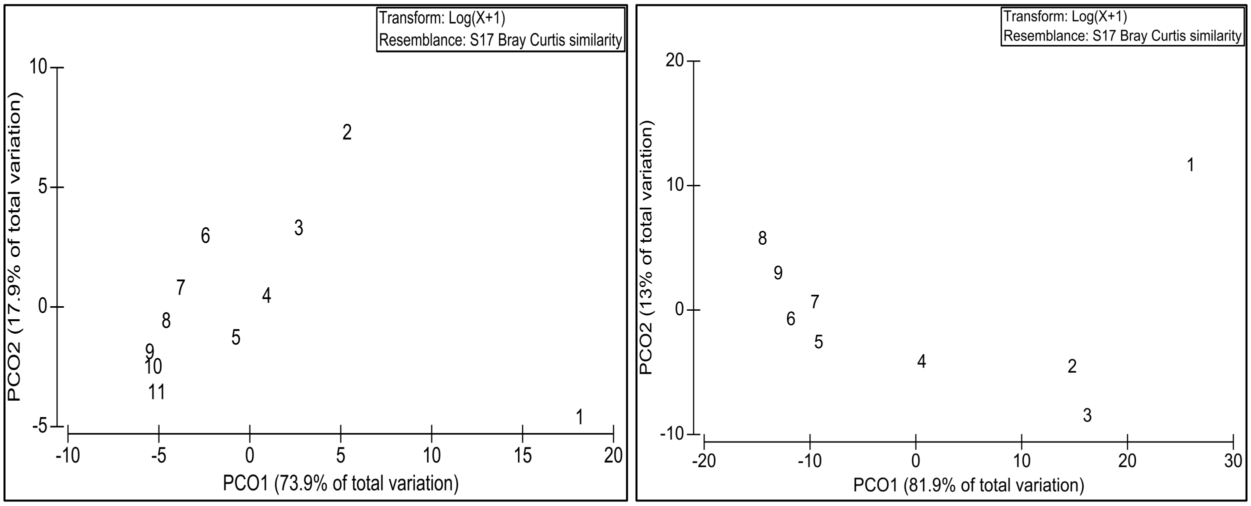


Figure 78. Principle Coordinates Analysis (PCO) based on Bray-Curtis matrices generated using the log-transformed cumulative average abundances of benthic taxa for Slope-West (left side of transect only; excluding stations 8, 10, and 22)(left plot) and Margin-West stations (left side of transect only; excluding station 11 and including station 8)(right plot).

In order to explore the ability of the sampling regime to adequately capture the "character" of benthic communities within the Western Shoals strata, PCOs were created based on Bray-Curtis Similarity Matrices generated using the log-transformed cumulative mean abundances of benthic taxa (left side of transect only) from the Slope-West (excluding stations 8, 10, and 22) and Margin-West (excluding station 11, including station 8) sampling stations. In the PCO plot for the Slope-West stations, the points appear to begin to cluster after about the 9th station, although the clustering is still somewhat loose even after the 11th station is included (Figure 78). The points in the PCO plot for the Margin-West stations do not appear to cluster tightly, even after the 9th station. These results suggest that a holistic measure of the general "character" of the benthic community within the Slope-West stratum may be adequately sampled with somewhere between 9 and 11 stations, while additional stations will likely be required for the Margin-West stratum.

Descriptive statistics for Western Shoals benthic cover data

Mean percent cover (± SD) values of major benthic cover categories for the Slope-West, Margin-West, and Margin-East strata are presented in Figure 79. Mean percent cover values (± SD) are also presented for modified versions of the strata (Figure 80).

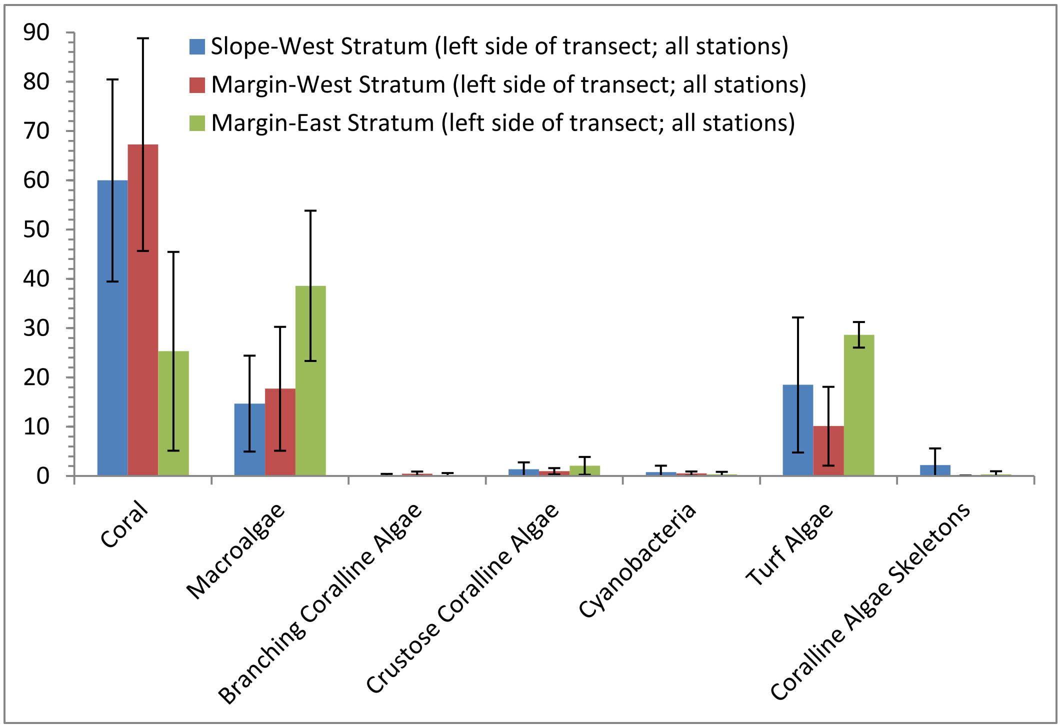


Figure 79. Mean percent cover (± SD) for major benthic categories within the Western Shoals strata (all stations).

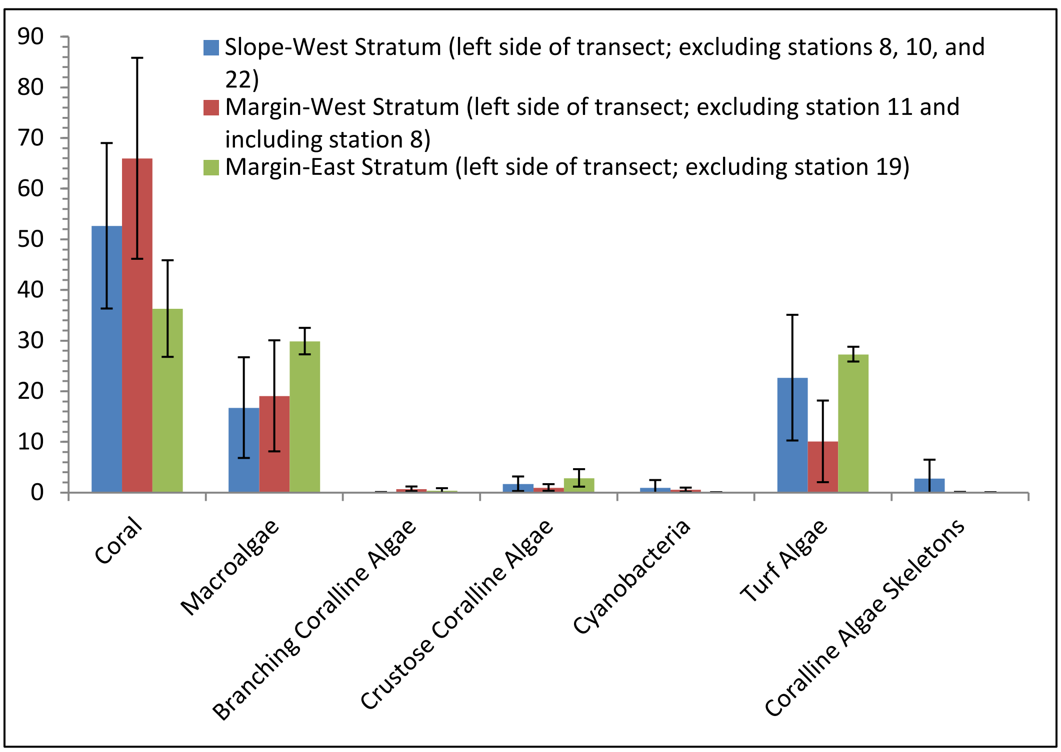


Figure 80. Mean percent cover (± SD) for major benthic categories within modified Western Shoals strata (all stations).

Western Shoals: Associated Biological Communities – Reef Fishes

Twenty-four stations within the Western Shoals monitoring site were surveyed by the Fish Team. Two SPCs were conducted at 23 of the stations, while only a qualitative species list was collected at one station due to poor visibility.

Descriptive statistics for Western Shoals reef fish community data

Density

The total density of reef fish observed at the Western Shoals monitoring site ranged from 91 fish/100m^2 at station 25 to 390 fish/100m^2 at station 36 (Figure 81). The average reef fish density was 230 fish/100m^2 (SE = ± 20) and median density was 209 fish/100m^2 fish per 100 square meters; these calculations do not include the school of Atherinids observed at site 17. The primary contributor to density were the Pomacentrids (65%); other contributors included the Scarids (9%), Acanthurids (7%),and Labrids (6%).

Biomass

The average total reef fish biomass for the Western Shoals site was 5.16 kg/100 m^2 (SE = ± 0.50) with a median value of 4.70 kg/100 m^2 (Figure 81). The minimum biomass observed was 1.71 kg/100 m^2 at station 1, while the maximum was 11.04 kg/100 m^2 at station 22; these calculations exclude the large school of carangids observed at station 10 (603 kg/100 m^2). The total reef fish biomass by station and the relative biomass by family is presented in Figure 81. The Pomacentrids were the primary contributor to biomass (24%), followed by Acanthurids (21%), Scarids (19%), Labrids(11%), and Chaetodontids (6%).

Species Richness

The fish team identified 196 species at the Western Shoals monitoring site (Figure 82). Reef fish species presence/absence data for the Western Shoals stations are presented in Appendix C. Station 25 had the fewest species (15), while station 13 had the most (69). The average number of species observed at each station was 49 species ((SE = ± 3) and the median was 52 species. Species lists for stations 5, 14, 23, 25, and 29 were generated only from quantitative data. Of the species documented, only 4 species were found at all stations and 52 were observed at only one station. The majority of species (165) were found at fewer than half of the stations.

Sea Turtles

No Sea Turtles were documented during the SPC counts; however, a foraging Hawksbill Sea Turtle, *Eretmochelys imbricata,* was observed at station 9 within the SPC cylinder boundary, but only after the counts were complete. Other sea turtles, primarily Green Sea Turtles (*Chelonia mydas*), were observed from the surface but were not documented during fish counts.

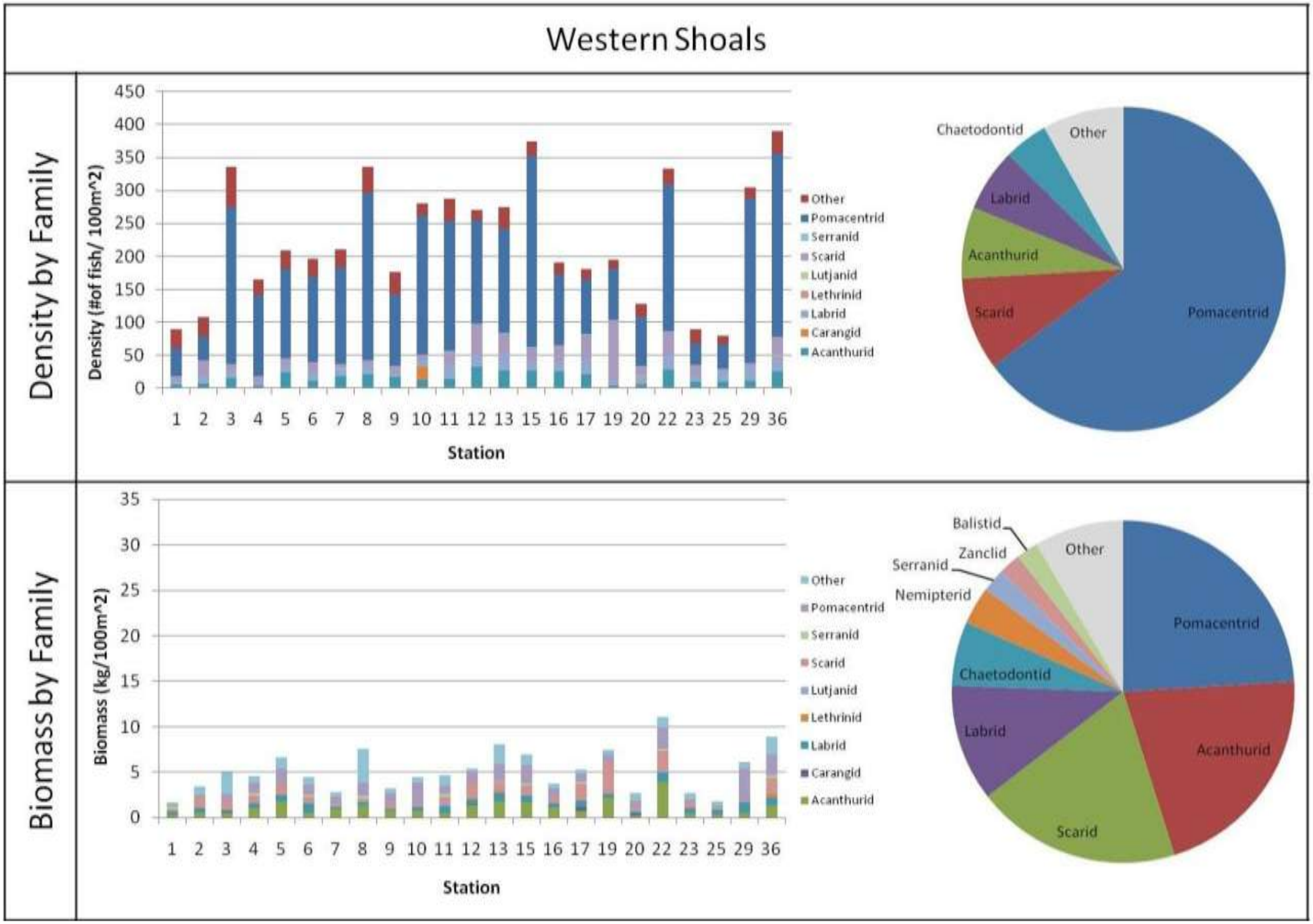


Figure 81. Reef fish density (# of fish/100m^2) by family and relative density by family (top), as well as reef fish biomass (kg/ 100m^2) by family and relative biomass (bottom).

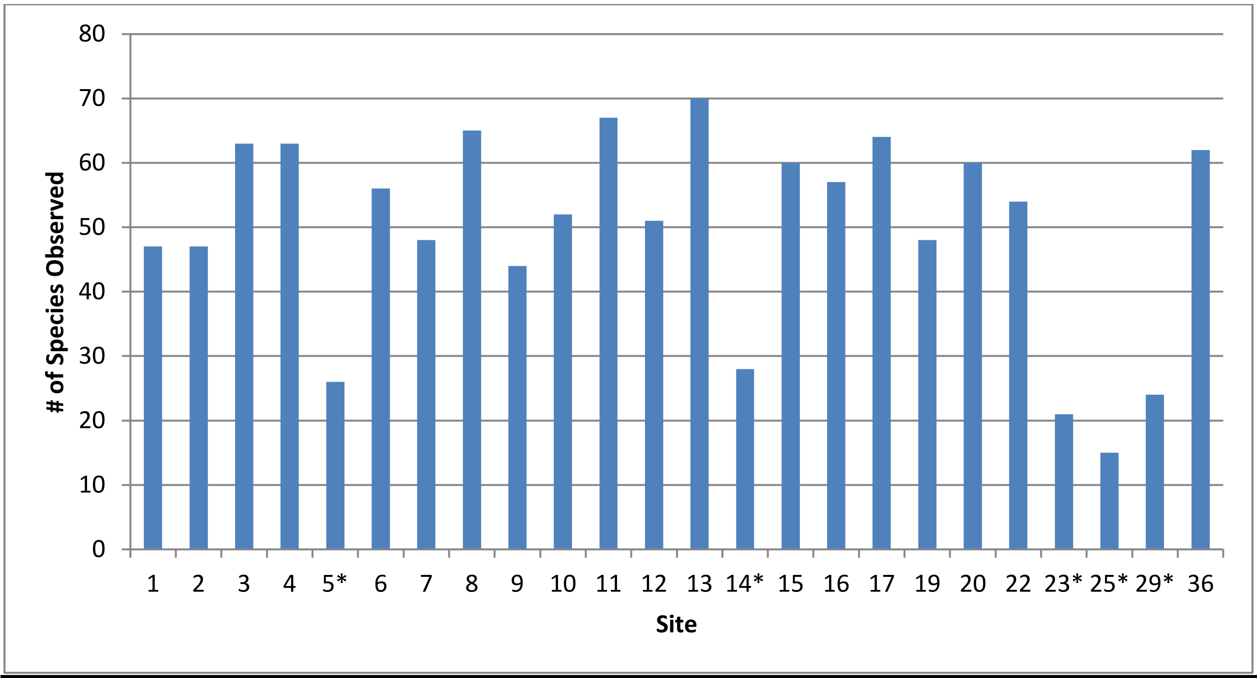


Figure 82. Reef fish species richness for sampling stations within the Western Shoals monitoring site

Exploration of Western Shoals reef fish community data in multivariate space

PRIMER was used to examine the effect of depth and exposure on the reef fish communities at Wester Shoals sampling stations. Unlike the other sites, the fish data appeared to show some subtle grouping based on depth. However, the effect was not significant when evaluated using ANOSIM. The exposure comparisons also did not have any significant findings; however, this was likely due to the low number of samples on the eastern side of Western Shoals (n=4). The MDS plots used to examine the reef fish community data are presented in Figures 83 and 84.

Power analysis and determination of optimum sample size for Western Shoals reef fish community data

The optimum number of stations necessary to adequately measure total density, total biomass, and species richness were determined using R (Figures 85 and 86). The analyses suggest that the standard deviations appear to level off at approximately 15-20 stations, however, the power for density and biomass remains less than the desired 0.7-0.8, even at 20 stations. The power for total density approaches 0.7 at 23 samples, but biomass only approaches 0.6 at 23 samples. The analysis suggests that 15-20 SPCs would provide an approximate power of 0.8 for species richness. The results of the PRIMER analysis support the use of at least 20 stations for biomass and density at the family level. The analysis also suggests that a large number of transects would be required for increased power for species level comparisons. Dominance plots for species level analysis became more disperse as the number of transects increased (Figure 87).

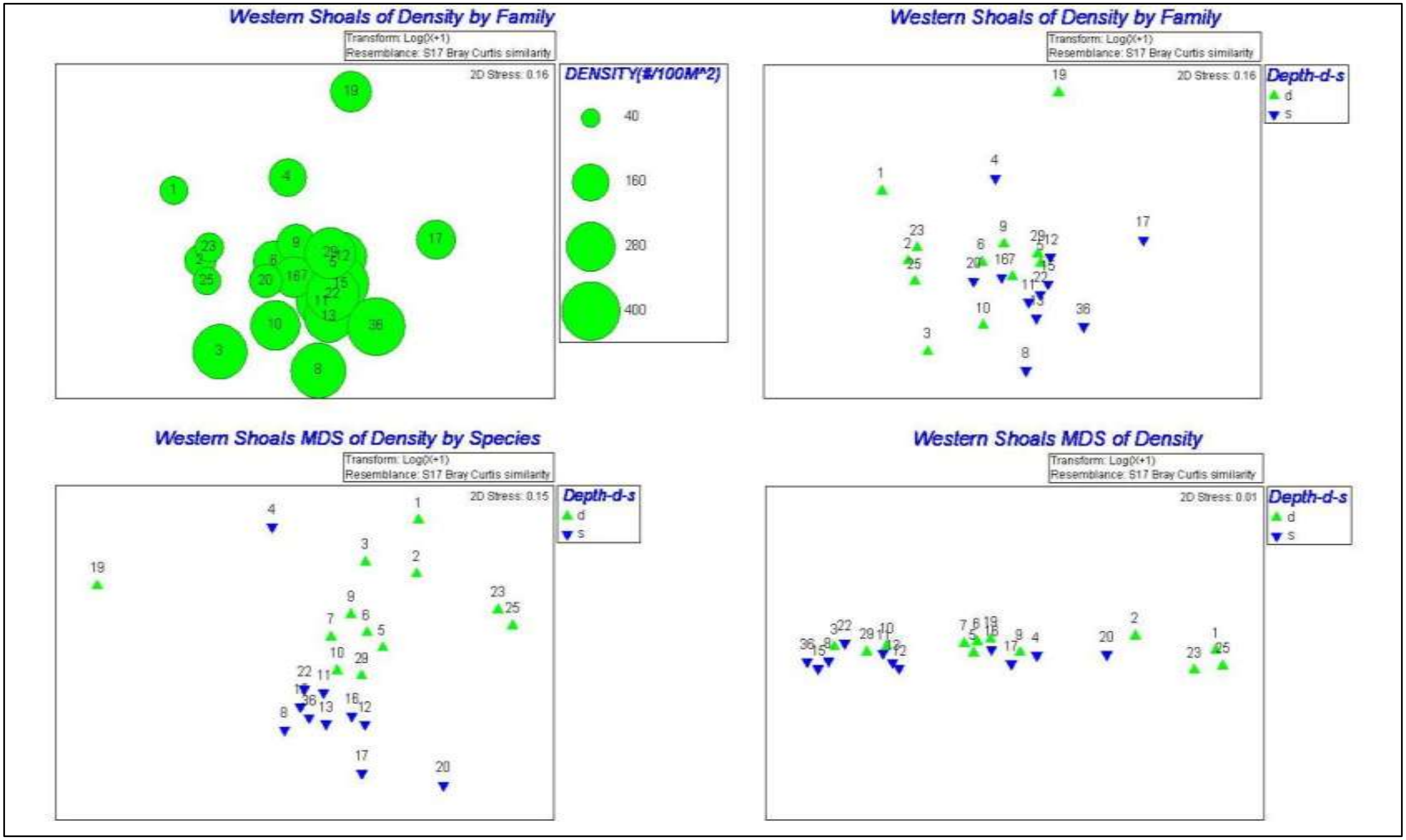


Figure 83. PRIMER MDS plots of reef fish density at Western Shoals sampling stations. Plots do not reveal any significant differences among the stations; however, there was a slight distinction between depths.

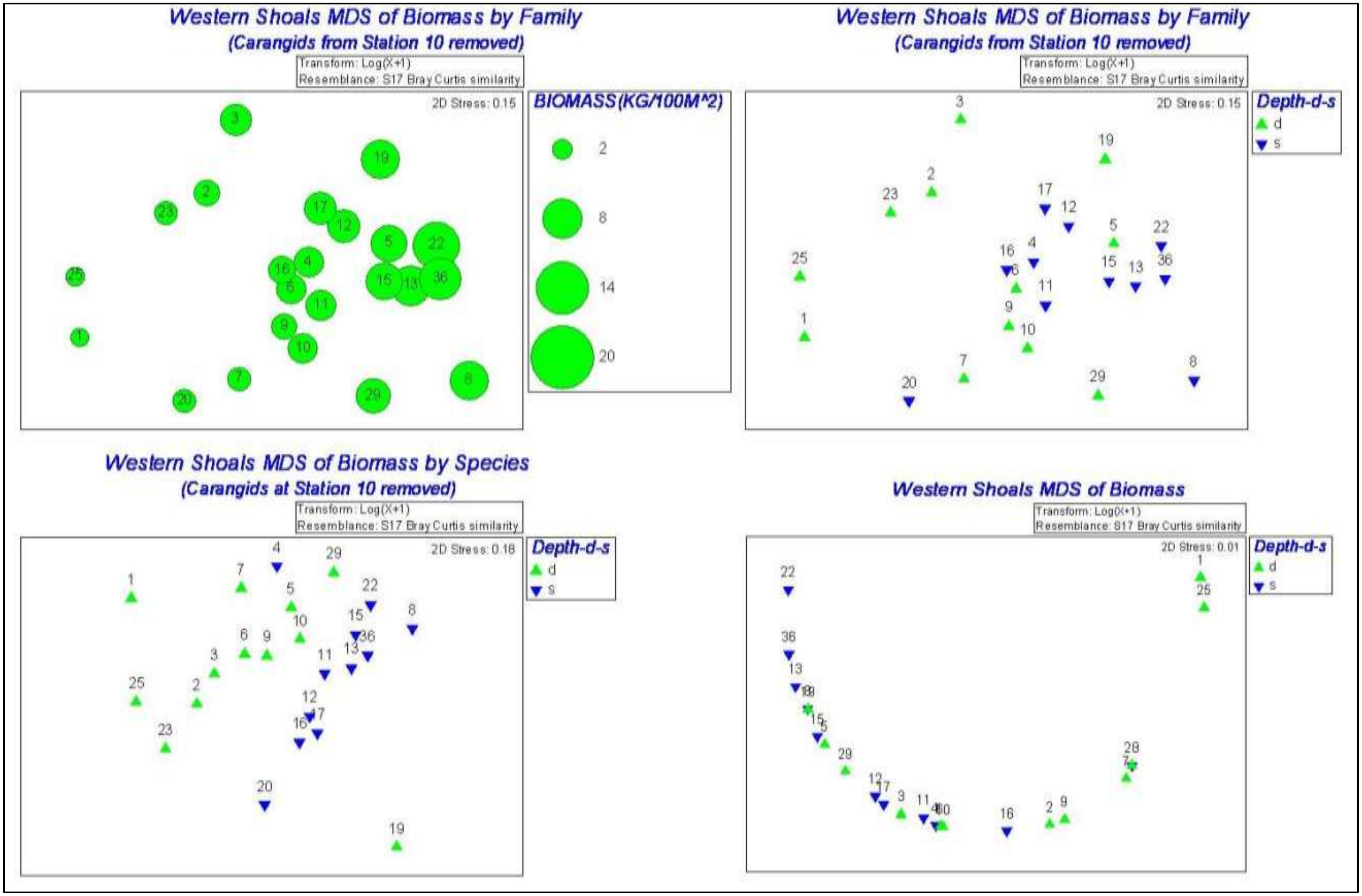


Figure 84. PRIMER MDS plots of reef fish biomass at Western Shoals sampling stations; carangids from station 10 were excluded from the analysis. Plots do not reveal any significant differences in the stations, however, there was a slight distinction between depths.

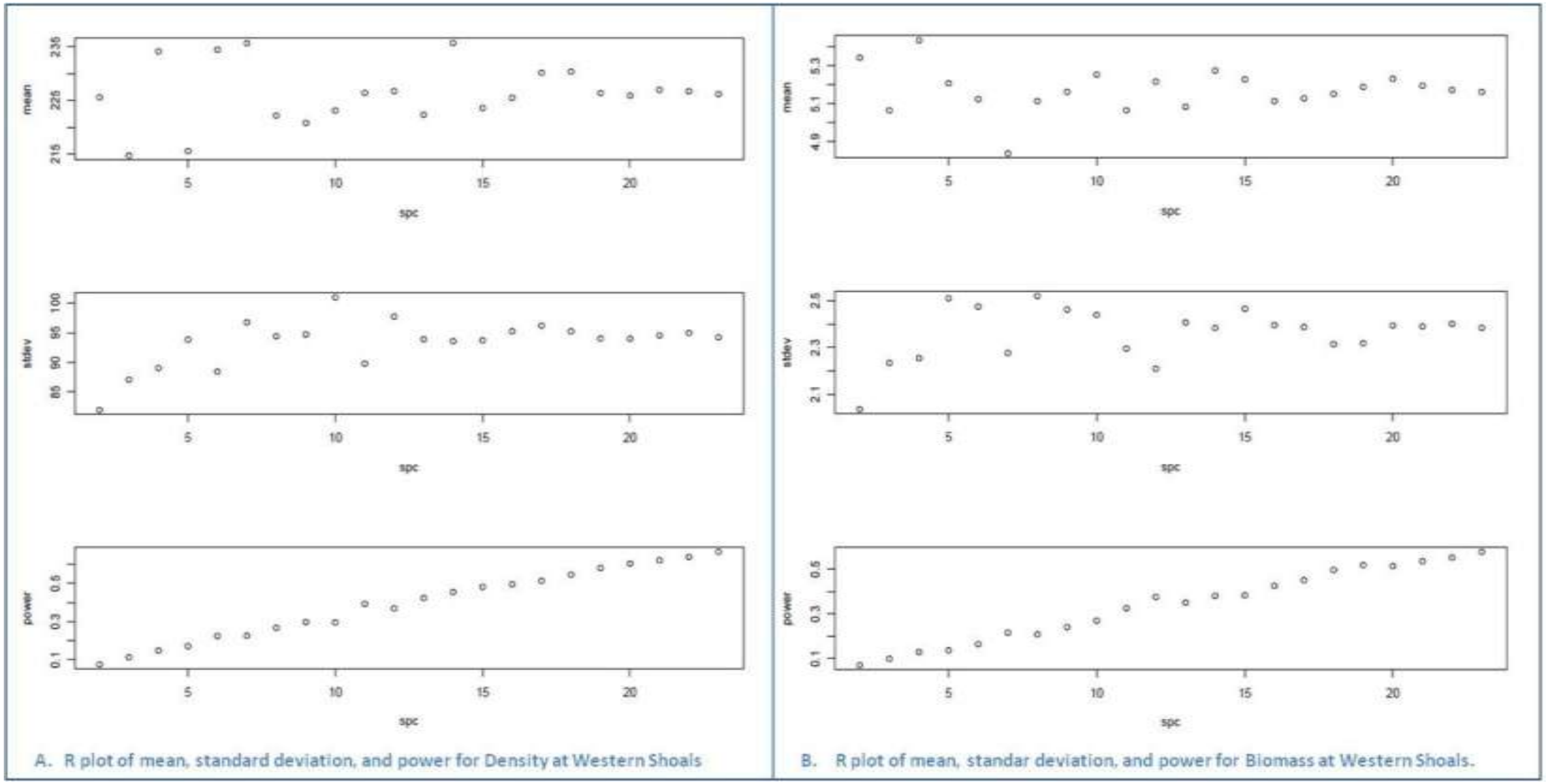
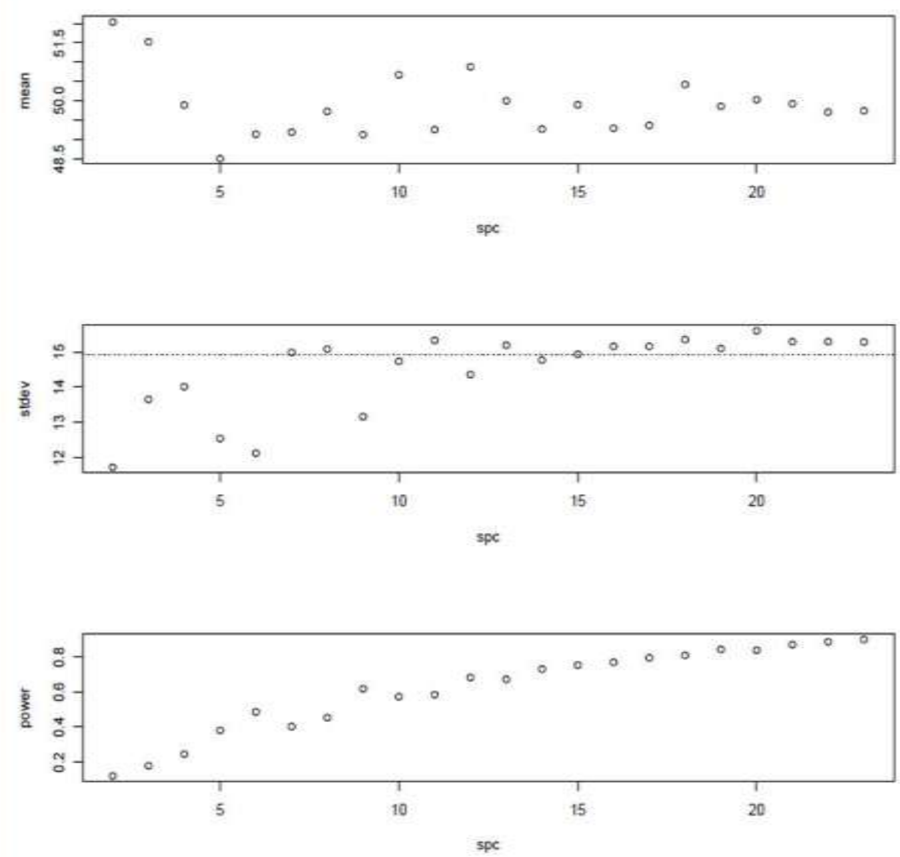


Figure 85. R power analysis plots for reef fish density (Plot A) and Biomass (Plot B) in the Western Shoals monitoring site; the plots were created using a custom code developed by Dr. Peter Houk of the Pacific Marine Resources Institute. Results of the analysis indicate that more than 20 stations should be sampled in order to achieve desired power levels for reef fish density and biomass.



C. R plot of mean, standard deviation, and power for Species Richness at Western Shoals

Figure 86. R power analysis plots for reef fish species richness in the Western Shoals monitoring site. Results of the analysis indicate that 20 stations is sufficient to achieve an adequate level of power (0.8) for species richness.

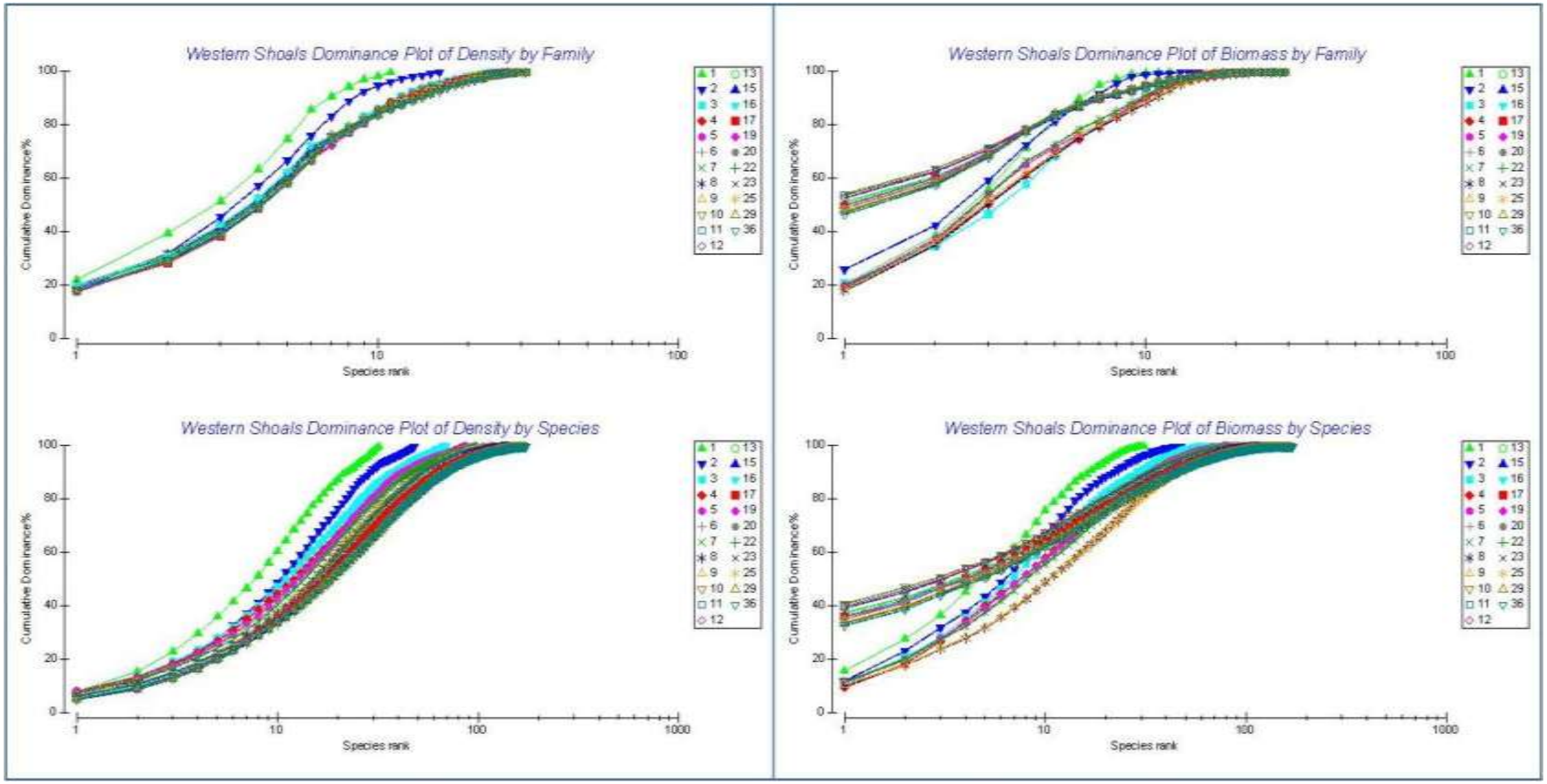


Figure 87. PRIMER Dominance Plots of cumulative averages for reef fish density and biomass in the Western Shoals monitoring site. Results suggest that additional stations or distinct depth strata may be necessary to achieve the desired power for biomass and density.

Discussion of Reef Fish Survey Methods

Both belt and SPC surveys were conducted at the first two monitoring sites (Tumon and East Agana bays) in order to compare the methods and determine which would work best for the monitoring team. Previous survey efforts on Guam primarily used belts, complemented by small SPCs for large fish (>20cm). The data could not be easily integrated into single biomass and density figures and therefore provided an incomplete picture of the fish communities. After working with NMFS-CRED on the Marianas Archipelago Reef Assessment and Monitoring Program cruise in 2009, the fish team lead decided to use the modified SPCs as well as belts to compare and decide on a single method for the program.

The SPC method has a number of advantages. First, the divers are stationary, so there is less impact on fish behaviors, allowing for more accurate counts (Colvocoresses and Accosta 2007). Belt transects tend to herd larger fish out of the survey site and the diver's movements can disturb fish behavior. In addition, Samoilys and Carlos (2000) found that less experienced divers had better accuracy in SPCs than belts. The SPC also utilizes a larger radius, which allows us to count larger, more wary fish that normally would not come close enough to a transect to be counted. In addition, the SPC method allows divers to make instantaneous counts. As divers count only one species at a time in one moment, they are less likely to double count, or miss a fish, while counting other species. This removes a great deal of observer bias encountered in belt transects.

The SPC is more accurate for larger fish, but is not as accurate for small fish such as damsels, cardinalfish, blennies, gobies, and small wrasses. Belts are more accurate for counting the number of small fish, however, these species have a limited contribution to overall biomass and estimates by order of magnitude seem to be sufficient(1, 10, 100). The SPC method is designed to minimize observer bias; however, this does make it difficult to capture large mobile predators that are present during the survey. Many species may not remain in the area after the five minutes species list. Due to this factor, we have adopted a non-instantaneous count designation to allow us to record the animal, but also provides the ability to include or not include it in the overall biomass estimates. Non-instantaneous counts were not used in the analysis of the Western Shoals data.

After one field season using both SPC and belt transect methods, the fish team lead decided to use only the modified SPC. It did a better job of characterizing the fish community and was more accurate. Minor concerns have been remedied through coding (note non-instant counts) and survey rules. This method also allows us to move faster and increase our sample effort. The modified SPC is a relatively new method in this region and is not directly comparable to previous surveys. However, most of the existing surveys are also not comparable as they used different types/sizes of belt transects. If future sites have extensive belt transect data, there may be cause to use belt transects to build on existing data sets, but this is not expected.

While the SPC methodology does require some further refinement, the results have provided sufficient power to answer a number of the questions proposed by the program. The following recommendations were developed based on the findings presented in this report; these recommendations will be incorporated into future data collection efforts.

- The fish team should try to increase the number of stations and continue to evaluate power for the different reef habitats encountered.
- The modified SPC method should be further refined to better account for large mobile predators such as sharks and trevallies.
- The team should evaluate other ways to collect and analyze data for large mobile predators or large schools.
- The team should also strive to obtain a more equal distribution across exposures and depths, if more than one exposure or depth strata will be surveyed.

Conclusions/Next Steps

From the commencement of funding until the present, significant progress has made in the development of the first comprehensive long-term monitoring program for Guam. Following the development of a monitoring strategy, the hiring of the monitoring coordinator, the hiring of monitoring assistants, and the procurement of equipment, supplies, and services, a substantial amount of baseline data has been collected for three important reef areas on Guam: Tumon Bay, East Agana Bay, and Western Shoals. A fourth site (Piti Bay) has been assessed and the sampling design completed; data collection in Piti Bay will begin in May 2012. Two or three additional sites will be established in 2012, with all sites occurring in the southern half of Guam.

The initial analyses of two key datasets – benthic cover and reef fish community data – provided important information regarding the effectiveness of the survey methods, the appropriateness of site and strata boundaries, and statistical power for key parameters. While tentative, the results also include descriptive statistics for several key parameters. The analysis and results presented in this report are only the first step in the analysis and interpretation of the benthic cover and fish community data. A substantial amount of data is also available for the coral and macroinvertebrate communities, but analysis of this data is not yet complete. Existing datasets will be further analyzed prior to the 2012 field season and the appropriate modifications to the sampling design may be made for each monitoring site. Beginning with the 2012 field season, water quality and temperature data will be collected at select locations.

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	STATION																				Total	%
SCIENTIFIC NAME	**1**	**2**	**3**	**4**	**5**	**6**	**8**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**33**	**35**	**36**	**Stations**	**Occurrence**
Abudefduf sexfasciatus									X						X						2	10
Abudefduf vaigiensis									X												1	5
Acanthurus lineatus			X						X	X					X						4	20
Acanthurus nigricauda												X									1	5
Acanthurus nigrofuscus	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	20	100
Acanthurus pyroferus	X							X			X		X				X				5	25
Acanthurus xanthopterus						X											X			X	3	15
Amphiprion chrysopterus															X						1	5
Amphiprion melanopus					X																1	5
Anampses caeruleopunctatus															X						1	5
Anampses twistii			X	X				X			X		X	X							6	30
Arothron hispidus														X							1	5
Arothron nigropunctatus														X							1	5
Aulostomus chinensis						X	X					X								X	4	20
Balistapus undulatus	X	X	X		X	X	X	X	X		X	X	X			X	X			X	14	70
Balistapus undulatus		X	X											X					X		4	20
Balistoides viridescens	X					X					X										3	15
Bodianus axillaris														X	X					X	3	15
Calotomus carolinus															X						1	5
Canthigaster solandri				X			X		X					X	X			X			6	30
Carangoides orthogrammus															X						1	5
Caranx melampygus		X			X	X			X			X					X			X	7	35
Caranx sexfasciatus					X	X														X	3	15
Centropyge flavissima			X	X	X	X	X	X			X		X	X	X			X	X	X	13	65
Centropyge heraldi													X								1	5
Cephalopholis argus				X	X	X	X		X		X			X	X				X		9	45

	STATION																					
SCIENTIFIC NAME	**1**	**2**	**3**	**4**	**5**	**6**	**8**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**33**	**35**	**36**	**Total Stations**	**% Occurrence**
Cephalopholis urodeta	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	20	100
Cetoscarus bicolor			X			X	X				X	X		X						X	7	35
Chaetodon auriga		X			X				X							X					4	20
Chaetodon citrinellus	X	X	X	X		X			X			X			X	X				X	10	50
Chaetodon ephippium			X			X			X			X					X			X	6	30
Chaetodon lineolatus															X						1	5
Chaetodon lunula					X			X	X	X					X					X	6	30
Chaetodon lunulatus								X	X			X		X	X			X		X	7	35
Chaetodon mertensii								X										X			2	10
Chaetodon ornatissimus	X				X		X		X	X					X					X	7	35
Chaetodon punctatofasciatus			X				X				X		X	X				X			6	30
Chaetodon reticulatus			X	X	X		X	X	X	X			X	X	X				X	X	12	60
Chaetodon trifascialis													X		X						2	10
Chaetodon ulietensis					X			X	X												3	15
Chaetodon unimaculatus																		X			1	5
Cheilinus fasciatus	X										X	X					X		X		5	25
Cheilinus trilobatus	X	X	X		X		X		X						X		X			X	9	45
Cheilio inermis													X								1	5
Cheilodipterus quinquelineatus	X	X							X												3	15
Chlorurus frontalis				X																	1	5
Chlorurus microrhinos	X					X			X			X		X							5	25
Chlorurus sordidus	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	20	100
Chromis atripectoralis																				X	1	5
Chromis viridis																				X	1	5
Chromis xanthura													X								1	5
Chrysiptera traceyi	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X		X	18	90
Cirrhilabrus katherinae	X	X		X		X	X			X			X								7	35
Cirrhitichthys falco	X	X		X			X	X			X		X		X	X	X			X	11	55

	STATION																				Total	%
SCIENTIFIC NAME	**1**	**2**	**3**	**4**	**5**	**6**	**8**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**33**	**35**	**36**	**Stations**	**Occurrence**
Cirripectes vanderbilti															X						1	5
Coris aygula	X			X	X	X			X					X	X					X	8	40
Coris gaimard	X	X	X	X							X		X				X				7	35
Ctenochaetus binotatus	X	X	X		X					X	X		X				X			X	9	45
Ctenochaetus hawaiiensis													X		X						2	10
Ctenochaetus striatus	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	20	100
Ctenochaetus strigosus															X						1	5
Dascyllus trimaculatus	X																				1	5
Diploprion bifasciatum		X																			1	5
Epibulus insidiator	X	X		X					X		X	X		X	X	X		X			10	50
Epinephelus fasciatus																		X	X		2	10
Epinephelus merra			X		X														X		3	15
Fistularia commersonii							X													X	2	10
Forcipiger flavissimus	X		X	X	X	X	X	X	X		X	X	X	X	X			X	X	X	16	80
Forcipiger longirostris													X								1	5
Gnathodentex aurolineatus						X								X						X	3	15
Gomphosus varius	X		X		X	X			X		X				X				X		8	40
Gymnothorax javanicus													X							X	2	10
Halichoeres hortulanus	X		X	X	X	X	X	X	X		X		X	X	X		X	X	X	X	16	80
Halichoeres margaritaceus															X						1	5
Halichoeres ornatissimus													X								1	5
Halichoeres trimaculatus																X					1	5
Hemigymnus fasciatus			X			X	X			X	X							X	X		7	35
Hemigymnus melapterus	X	X	X	X		X	X		X	X		X		X				X	X		12	60
Hemitaurichthys polylepis																				X	1	5
Heniochus chrysostomus					X															X	2	10
Heniochus chrysostomus														X				X			2	10
Heniochus monoceros								X			X	X									3	15

	STATION																				Total	%
SCIENTIFIC NAME	**1**	**2**	**3**	**4**	**5**	**6**	**8**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**33**	**35**	**36**	**Stations**	**Occurrence**
Heniochus varius					X									X							2	10
Hipposcarus longiceps				X			X														2	10
Labrichthys unilineatus															X						1	5
Labroides bicolor														X				X	X		3	15
Labroides dimidiatus	X	X		X	X		X	X	X	X	X	X	X	X	X		X	X	X	X	17	85
Labroides pectoralis									X												1	5
Lethrinus xanthochilus	X				X			X							X					X	5	25
Lutjanus argentimaculatus																				X	1	5
Lutjanus bohar																		X			1	5
Lutjanus fulvus						X		X												X	3	15
Lutjanus monostigmus					X	X															2	10
Macolor macularis	X		X		X	X	X	X	X				X	X						X	10	50
Malacanthus lattovittatus								X													1	5
Melichthys vidua	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	19	95
Monotaxis grandoculis	X		X	X	X	X	X			X				X					X	X	10	50
Myripristis adusta																				X	1	5
Myripristis amaena														X							1	5
Myripristis kuntee											X			X						X	3	15
Naso annulatus		X	X					X											X		4	20
Naso hexacanthus																				X	1	5
Naso lituratus	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	18	90
Naso unicornis						X			X	X									X		4	20
Naso vlamingii				X					X		X		X			X				X	6	30
Nemateleotris magnifica	X	X	X	X	X			X					X	X		X		X			10	50
Novaculichthys taeniourus		X												X	X	X	X				5	25
Odonus niger		X				X				X		X									4	20
Oxycheilinus unifasciatus	X	X	X	X		X	X	X	X		X	X	X	X		X	X	X			15	75
Oxymonacanthus longirostris	X																				1	5

	STATION																				Total	%
SCIENTIFIC NAME	**1**	**2**	**3**	**4**	**5**	**6**	**8**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**33**	**35**	**36**	**Stations**	**Occurrence**
Paracirrhites arcatus	X	X	X				X		X	X				X	X	X		X	X	X	12	60
Parapercis clathrata	X			X								X					X				4	20
Parupeneus barberinus	X	X					X		X	X	X			X	X		X		X		10	50
Parupeneus cyclostomus					X	X								X	X					X	5	25
Parupeneus insularis															X						1	5
Parupeneus multifasciatus				X				X		X			X								4	20
Plectroglyphidodon dickii			X		X	X	X		X						X				X	X	8	40
Plectroglyphidodon johnstonianus			X		X	X	X		X						X					X	7	35
Plectroglyphidodon lacrymatus	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	20	100
Plectropomus laevis	X	X																			2	10
Pomacanthus imperator	X				X				X			X		X							5	25
Pomacanthus xanthometopon	X																				1	5
Pomacentrus amboinensis			X	X	X	X		X	X	X		X								X	9	45
Pomacentrus vaiuli	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	19	95
Pomachromis guamensis	X	X		X		X	X	X	X	X	X					X	X		X	X	13	65
Pseudocheilinus octotaenia													X								1	5
Ptereleotris evides	X	X		X	X		X	X			X		X	X	X		X	X	X	X	14	70
Ptereleotris zebra	X	X		X												X					4	20
Pygoplites diacanthus	X		X		X	X	X	X			X		X	X				X	X	X	12	60
Sargocentron caudimaculatum													X								1	5
Sargocentron spiniferum			X		X	X	X				X			X					X	X	8	40
Scarus globiceps		X		X		X	X	X			X	X								X	8	40
Scarus oviceps	X	X	X	X		X	X								X					X	8	40
Scarus psittacus				X				X	X		X		X							X	6	30
Scarus rubroviolaceus	X				X		X	X	X	X	X	X				X			X	X	11	55
Scarus schlegeli	X	X		X			X			X	X				X		X				8	40
Siganus argenteus			X		X		X													X	4	20
Stethojulis bandanensis	X					X		X	X	X	X				X	X	X	X	X		11	55

	STATION																				Total Stations	% Occurrence
SCIENTIFIC NAME	**1**	**2**	**3**	**4**	**5**	**6**	**8**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**33**	**35**	**36**		
Sufflamen bursa		X	X	X			X	X		X	X	X	X	X	X		X		X	X	14	70
Sufflamen chrysoptera	X	X		X	X	X				X											6	30
Thalassoma amblycephalum													X								1	5
Thalassoma hardwicke												X	X		X					X	4	20
Thalassoma lutescens	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	19	95
Thalassoma quinquevittatum		X								X		X		X	X			X			6	30
Triaenodon obesus						X															1	5
Valenciennea strigata													X								1	5
Zanclus cornutus	X	X	X		X	X	X	X	X		X	X	X	X	X	X		X	X		16	80
Zebrasoma flavescens							X						X	X				X	X	X	6	30
Zebrasoma scopas		X																			1	5
Zebrasoma veliferum									X											X	2	10
TOTAL	**53**	**43**	**44**	**43**	**47**	**49**	**48**	**41**	**52**	**33**	**44**	**36**	**47**	**51**	**56**	**26**	**30**	**35**	**37**	**65**		

	STATION																				Total Stations	% Occurrence
SCIENTIFIC NAME	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**		
Abudefduf septemfasciatus		X		X	X	X	X		X	X						X			X	X	10	50
Abudefduf sexfasciatus						X										X			X	X	4	20
Abudefduf vaigiensis								X								X					2	10
Acanthurus lineatus																			X		1	5
Acanthurus nigricans										X											1	5
Acanthurus nigrofuscus	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	20	100
Acanthurus triostegus		X														X			X		3	15
Acanthurus xanthopterus	X																X			X	3	15
Amblyeleotris fasciatus																				X	1	5
Amphiprion clarkii																X					1	5
Amphiprion melanopus			X				X		X										X		4	20
Anampses twistii	X				X	X	X			X			X	X			X		X	X	10	50
Aphareus furca				X	X				X	X	X		X		X	X				X	9	45
Aprion virescens																X		X			2	10
Arothron nigropunctatus								X													1	5
Aulostomus chinensis				X				X			X		X	X							5	25
Balistapus undulatus		X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	18	90
Balistoides viridescens				X			X														2	10
Bodianus axillaris				X		X					X			X							4	20
Caesio caerulaurea	X					X					X	X									4	20
Calotomus carolinus										X						X				X	3	15
Cantherhines pardalis										X						X		X		X	4	20
Canthigaster solandri	X						X		X	X						X				X	6	30
Canthigaster valentini				X				X		X										X	4	20
Caranx melampygus							X						X								2	10
Centropyge flavissima	X	X		X		X	X	X	X	X	X	X	X	X		X	X	X	X		16	80

	STATION																				Total	%
SCIENTIFIC NAME	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**Stations**	**Occurrence**
Centropyge shepardi													X								1	5
Centropyge vroliki		X									X										2	10
Cephalopholis urodeta	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	20	100
Cetoscarus bicolor											X										1	5
Chaetodon bennetti			X		X			X	X					X					X	X	7	35
Chaetodon citrinellus	X		X	X	X		X		X	X						X			X	X	10	50
Chaetodon ephippium			X		X	X	X		X	X	X	X							X	X	10	50
Chaetodon lunula		X		X		X	X	X		X	X		X		X		X			X	11	55
Chaetodon lunulatus	X		X	X	X		X	X	X	X	X		X	X	X	X	X		X	X	16	80
Chaetodon mertensii	X																X				2	10
Chaetodon ornatissimus		X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	18	90
Chaetodon punctatofasciatus	X		X	X	X	X	X		X	X	X	X	X	X		X	X	X			15	75
Chaetodon reticulatus	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	20	100
Chaetodon trifascialis										X											1	5
Chaetodon ulietensis														X	X						2	10
Chaetodon unimaculatus		X										X		X		X					4	20
Chanos chanos			X																		1	5
Cheilinus fasciatus						X										X				X	3	15
Cheilinus trilobatus			X		X		X	X	X		X	X	X		X	X					10	50
Cheilio inermis				X																X	2	10
Cheilodipterus quinquelineatus					X		X		X												3	15
Chelonia mydas										X											1	5
Chlorurus frontalis	X								X								X				3	15
Chlorurus sordidus	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	20	100
Chromis acares																X		X			2	10
Chromis agilis										X						X					2	10
Chromis amboinensis		X				X															2	10
Chromis atripectoralis										X											1	5

	STATION																				Total Stations	% Occurrence
SCIENTIFIC NAME	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**		
Chromis margaritifer		X								X						X		X			4	20
Chromis xanthura																		X			1	5
Chrysiptera brownriggii																X					1	5
Chrysiptera traceyi										X						X		X		X	4	20
Cirrhilabrus katherinae															X						1	5
Cirrhitichthys falco							X									X				X	3	15
Cirripectes sp.																				X	1	5
Coris aygula								X					X								2	10
Coris gaimard								X									X	X		X	4	20
Ctenochaetus binotatus	X									X						X		X	X	X	6	30
Ctenochaetus hawaiiensis										X											1	5
Ctenochaetus striatus	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	20	100
Dascyllus reticulatus			X																		1	5
Dascyllus trimaculatus			X				X									X		X			4	20
Epibulus insidiator		X	X			X				X				X		X		X			7	35
Epinephelus fasciatus			X						X												2	10
Epinephelus merra		X	X	X	X		X		X								X				7	35
Fistularia commersonii										X											1	5
Forcipiger flavissimus	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	20	100
Forcipiger longirostris										X						X					2	10
Gnathodentex aureolineatus						X										X					2	10
Gomphosus varius		X		X	X		X	X	X	X	X	X	X		X	X		X		X	14	70
Halichoeres hortulanus	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	20	100
Halichoeres margaritaceus																X		X			2	10
Halichoeres marginatus		X						X				X				X	X				5	25
Halichoeres ornatissimus										X								X		X	3	15
Hemigymnus fasciatus					X		X		X	X	X	X				X		X	X		9	45
Hemigymnus melapterus	X			X	X		X		X		X		X	X		X	X		X	X	12	60

	STATION																				Total	%
SCIENTIFIC NAME	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**Stations**	**Occurrence**
Hemitaurichthys polylepis			X																		1	5
Heniochus chrysostomus			X	X		X					X		X	X		X					7	35
Heniochus monoceros	X		X				X			X	X		X	X	X			X		X	10	50
Hologymnosus doliatus																X				X	2	10
Labroides bicolor						X				X											2	10
Labroides dimidiatus			X	X				X		X	X	X				X	X	X			9	45
Lethrinus harak								X											X	X	3	15
Lethrinus xanthochilus	X	X	X	X		X	X	X	X	X	X		X		X		X	X	X		15	75
Lutjanus fulvus				X		X												X			3	15
Lutjanus monostigmus											X										1	5
Macolor macularis	X				X	X	X	X	X		X		X	X			X		X	X	12	60
Macolor niger										X						X				X	3	15
Macropharyngodon meleagris										X						X		X			3	15
Malacanthus lattovittatus															X						1	5
Meiacanthus atrodorsalis																X		X		X	3	15
Melichthys niger										X											1	5
Melichthys vidua	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	19	95
Monotaxis grandoculis		X		X			X			X	X					X					6	30
Mulloidichthys flavolineatus		X						X												X	3	15
Mulloidichthys vanicolensis				X																	1	5
Myripristis adjusta		X				X															2	10
Myripristis kuntee			X	X		X											X				4	20
Myripristis murdjan				X																	1	5
Naso annulatus			X																		1	5
Naso hexacanthus	X																X				2	10
Naso lituratus	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	20	100
Naso vlamingii										X	X										2	10
Nemateleotris magnifica			X													X	X			X	4	20

	STATION																				Total	%
SCIENTIFIC NAME	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**Stations**	**Occurrence**
Neoniphon opercularis			X														X				2	10
Novaculichthys taeniourus	X								X						X	X				X	5	25
Oxycheilinus unifasciatus	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	20	100
Paracirrhites arcatus		X	X		X	X	X		X	X	X	X		X	X	X		X			13	65
Paracirrhites forsteri				X		X					X										3	15
Paracirrhites hemistictus																		X			1	5
Parapercis clathrata	X															X		X			3	15
Parupeneus barberinus	X			X													X		X	X	5	25
Parupeneus cyclostomus																X			X		2	10
Parupeneus multifasciatus		X		X		X		X		X		X		X	X	X		X		X	11	55
Plagiotremus laudandus														X							1	5
Plagiotremus tapeinosoma																X					1	5
Plectroglyphidodon dickii	X	X	X	X	X	X	X	X	X	X		X			X	X		X	X	X	16	80
Plectroglyphidodon johnstonianus	X	X	X	X	X	X	X		X	X	X	X	X	X	X						14	70
Plectroglyphidodon lacrymatus	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	20	100
Pomacanthus imperator				X	X		X														3	15
Pomacentrus amboinensis	X				X				X		X	X	X		X				X		8	40
Pomacentrus vaiuli	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	20	100
Pomachromis guamensis						X									X	X			X		4	20
Pseudocheilinus tetrataenia																X					1	5
Ptereleotris evides	X		X		X				X	X						X		X	X	X	9	45
Ptereleotris zebra																X					1	5
Pterocaesio tile																		X			1	5
Pygoplites diacanthus			X	X		X	X			X			X			X			X		8	40
Sargocentron caudimaculatum						X										X					2	10
Sargocentron spiniferum			X		X	X	X		X	X							X				7	35
Scarus forsteni						X															1	5
Scarus ghobban																		X			1	5

	STATION																				Total	%
SCIENTIFIC NAME	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**Stations**	**Occurrence**
Scarus globiceps	X		X		X				X	X			X			X		X			8	40
Scarus oviceps	X								X		X										3	15
Scarus psittacus							X		X	X						X		X		X	6	30
Scarus rubrioviolaceus		X		X		X		X			X	X		X						X	8	40
Scarus schlegeli	X	X	X				X		X		X						X				7	35
Scarus sp.										X								X		X	3	15
Scolopsis lineata								X									X		X	X	4	20
Scorpaenopsis diabolus										X											1	5
Sphyraena barracuda																X					1	5
Stegastes fasciolatus																		X			1	5
Stethojulis bandanensis		X		X				X		X		X			X	X		X	X	X	10	50
Stethojulis strigiventer										X						X				X	3	15
Sufflamen bursa	X		X	X		X		X		X				X		X			X	X	10	50
Sufflamen chrysoptera								X					X						X		3	15
Thalassoma hardwicke			X	X	X	X	X		X			X			X	X			X		10	50
Thalassoma lutescens	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	20	100
Thalassoma purpureum										X						X				X	3	15
Thalassoma quinquevittatum															X					X	2	10
Un-id fish sp.										X											1	5
Valenciennea strigata																X		X			2	10
Zanclus cornutus	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	20	100
Zebrasoma flavescens			X		X	X	X	X	X		X	X		X	X	X	X	X			13	65
Zebrasoma veliferum		X	X			X	X		X												5	25
TOTAL	**41**	**40**	**50**	**50**	**40**	**50**	**51**	**42**	**50**	**69**	**47**	**35**	**37**	**37**	**37**	**80**	**40**	**53**	**45**	**63**		

	STATION																							Total	%
SCIENTIFIC NAME	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**19**	**20**	**22**	**23**	**25**	**29**	**36**	**Stations**	**Occurrence**
Abudefduf vaigiensis	X	X		X			X			X	X				X	X	X		X					X	11	46
Acanthurus lineatus																X	X		X						3	13
Acanthurus nigricans													X	X	X										3	13
Acanthurus nigricauda		X						X	X	X	X		X		X	X	X	X	X	X					12	50
Acanthurus nigrofuscus	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			X	X	22	92
Acanthurus nigroris				X																					1	4
Acanthurus olivaceus																		X							1	4
Acanthurus pyroferus				X																					1	4
Acanthurus xanthopterus		X	X								X														3	13
Aluterus scriptus													X							X					2	8
Amblyglyphidodon curacao	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			X	X	22	92
Amphiprion clarkii				X				X					X		X			X		X					6	25
Amphiprion melanopus						X		X	X	X	X				X										6	25
Amphiprion perideraion									X																1	4
Anampses caeruleopunctatus												X		X		X									3	13
Anampses twistii		X		X																					2	8
Aphareus furca		X	X	X			X	X			X		X		X					X				X	10	42
Apogon angustatus						X			X		X					X		X							5	21
Apogon luteus				X																					1	4
Apogon sp.			X																						1	4
Arothron nigropunctatus			X				X				X		X				X								5	21
Aspidontus taeniatus						X									X										2	8
Atherinid sp.																	X								1	4
Aulostomus chinensis			X	X				X	X	X	X		X								X			X	9	38
Balistapus undulatus	X	X	X	X		X		X								X	X			X			X	X	11	46
Balistoides viridescens			X	X	X	X		X					X		X		X	X	X					X	11	46
Blenniella chrysospilos																			X						1	4
Blenniid sp.																		X							1	4

	STATIONS																								
SCIENTIFIC NAME	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**19**	**20**	**22**	**23**	**25**	**29**	**36**	**Total Stations**	**% Occurrence**
Caesio caerulaurea			X																						1	4
Calotomus carolinus				X			X	X		X			X			X	X	X		X				X	10	42
Cantherhines dumerilii													X							X					2	8
Cantherhines pardalis		X								X															2	8
Canthigaster solandri	X															X	X								3	13
Canthigaster valentini																								X	1	4
Caranx melampygus			X			X	X					X					X		X						6	25
Caranx sexfasciatus										X															1	4
Centropyge flavissima			X	X						X	X				X		X		X			X			8	33
Centropyge potteri						X																			1	4
Cephalopholis argus				X							X		X		X					X					5	21
Cephalopholis spiloparaea	X																								1	4
Cetoscarus bicolor	X	X				X	X																		4	17
Chaetodon auriga	X	X	X	X		X	X	X	X	X	X	X	X			X	X	X	X	X				X	18	75
Chaetodon bennetti		X									X	X	X			X	X	X	X					X	9	38
Chaetodon citrinellus								X				X	X	X	X		X		X					X	8	33
Chaetodon ephippium	X	X		X		X			X	X	X		X	X	X		X	X	X			X		X	15	63
Chaetodon lunula				X				X	X	X	X		X		X		X		X	X	X		X		12	50
Chaetodon lunulatus		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X				X	19	79
Chaetodon ornatissimus								X			X				X					X				X	5	21
Chaetodon quadrimaculatus						X																			1	4
Chaetodon reticulatus	X				X						X		X		X		X								6	25
Chaetodon semeion		X																							1	4
Chaetodon trifascialis																X			X						2	8
Chaetodon ulietensis	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	23	96
Cheilinus chlorourus				X								X												X	3	13
Cheilinus fasciatus	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	24	100
Cheilinus oxycephalus							X	X		X	X	X	X		X		X								8	33

	STATION																								Total	%
SCIENTIFIC NAME	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**19**	**20**	**22**	**23**	**25**	**29**	**36**	**Stations**	**Occurrence**
Cheilinus trilobatus		X	X	X		X	X	X		X	X	X	X	X	X	X	X	X		X				X	17	71
Cheilinus undulatus															X										1	4
Cheilio inermis						X										X								X	3	13
Cheilodipterus quinquelineatus			X	X								X						X							4	17
Chlorurus frontalis																	X	X							2	8
Chlorurus microrhinos				X		X			X				X		X					X				X	7	29
Chlorurus sordidus	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	24	100
Choerodon fasciatus?	X		X				X																		3	13
Chromis agilis																			X						1	4
Chromis alpha			X				X							X											3	13
Chromis atripectoralis							X	X		X	X	X	X		X	X	X			X			X	X	12	50
Chromis atripes	X								X																2	8
Chromis ternatensis										X															1	4
Chromis viridis												X					X		X						3	13
Chrysiptera brownriggii																	X								1	4
Chrysiptera traceyi	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	23	96
Coris gaimard									X								X								2	8
Ctenochaetus binotatus		X		X		X			X	X			X			X		X							8	33
Ctenochaetus cyanocheilus	X		X				X																		3	13
Ctenochaetus striatus	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	23	96
Dascyllus reticulatus																		X							1	4
Dascyllus trimaculatus																				X					1	4
Diodon hystrix			X												X										2	8
Epibulus insidiator	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	23	96
Epinephelus maculatus												X													1	4
Epinephelus merra													X												1	4
Epinephelus polyphekadion				X																					1	4
Eretmochelys imbricata									X																1	4

	STATION																							Total	%
SCIENTIFIC NAME	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**19**	**20**	**22**	**23**	**25**	**29**	**36**	**Stations** / **Occurrence**
Eviota sp.																		X							1	4
Exallias brevis																X									1	4
Fistularia commersonii			X	X	X		X	X		X	X		X						X					X	10	42
Forcipiger flavissimus			X			X					X														3	13
Forcipiger longirostris			X																X						2	8
Gobiid sp.	X																								1	4
Gomphosus varius				X		X		X	X	X	X	X	X	X	X	X	X	X	X	X			X	X	17	71
Halichoeres hortulanus																X			X						2	8
Halichoeres margaritaceus																		X	X						2	8
Halichoeres marginatus	X						X	X		X						X			X	X					7	29
Halichoeres trimaculatus																	X	X							2	8
Hemigymnus fasciatus												X						X		X					3	13
Hemigymnus melapterus	X	X	X		X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	22	92
Heniochus chrysostomus								X			X		X	X	X	X				X				X	8	33
Heniochus monoceros			X	X		X			X												X		X		6	25
Hipposcarus longiceps	X	X		X		X		X	X	X	X	X	X		X			X							12	50
Kyphosus sp.			X																						1	4
Labrid sp.								X																X	2	8
Labroides bicolor											X		X												2	8
Labroides dimidiatus			X			X		X		X	X	X	X	X	X		X			X				X	12	50
Lehtrinus erythycanthus?								X																	1	4
Lethrinus harak											X		X				X	X	X						5	21
Lethrinus obsoletus										X			X												2	8
Lethrinus olivaceus						X			X																2	8
Lethrinus xanthochilus		X																						X	2	8
Lutjanus fulvus								X			X					X								X	4	17
Lutjanus gibbus							X									X									2	8
Lutjanus kasmira																			X						1	4

	STATION																									
SCIENTIFIC NAME	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**19**	**20**	**22**	**23**	**25**	**29**	**36**	**Total Stations**	**% Occurrence**
Lutjanus monostigma			X																X						2	8
Meiacanthus atrodorsalis	X	X	X	X		X	X	X	X	X	X	X	X	X		X			X						15	63
Monotaxis grandoculis				X								X													2	8
Myripristis adusta								X					X		X					X					4	17
Myripristis berndti								X								X									2	8
Myripristis murdjan									X		X														2	8
Myripristis violacea								X			X														2	8
Naso annulatus											X	X	X												3	13
Naso brevirostris			X			X											X	X	X						5	21
Naso lituratus						X	X	X	X	X			X		X		X			X	X			X	11	46
Naso unicornis				X				X		X		X	X		X	X	X			X	X			X	11	46
Naso vlamingii	X	X	X	X	X	X	X	X	X	X	X	X	X		X		X			X	X				17	71
Neoniphon opercularis								X							X					X				X	4	17
Neoniphon sammara				X			X	X	X		X		X		X	X			X	X				X	11	46
Novaculichthys taeniourus													X			X	X	X							4	17
Ostracion meleagris	X	X	X			X											X								5	21
Oxycheilinus digrammus		X	X	X	X	X																			5	21
Oxycheilinus unifasciatus	X	X				X				X	X		X				X	X	X				X		10	42
Oxymonacanthus longirostris													X						X					X	3	13
Parupeneus barberinus			X									X													2	8
Parupeneus cyclostomus			X																						1	4
Parupeneus insularis																			X						1	4
Parupeneus multifasciatus		X	X	X	X		X				X	X	X			X		X			X	X		X	13	54
Pentapodus caninus	X	X	X	X		X	X		X	X										X	X	X			11	46
Plagiotremus laudandus	X	X	X		X	X	X	X	X	X	X	X	X		X	X	X		X	X	X	X	X	X	21	88
Plagiotremus tapeinosoma																								X	1	4
Plectroglyphidodon dickii														X					X						2	8
Plectroglyphidodon lacrymatus	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	24	100

	STATION																								Total	%
SCIENTIFIC NAME	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**19**	**20**	**22**	**23**	**25**	**29**	**36**	**Stations**	**Occurrence**
Plectropomus laevis	X			X		X		X			X				X		X			X				X	9	38
Pomacanthus imperator																					X				1	4
Pomacentrus amboinensis	X	X	X		X	X	X	X	X	X	X	X	X		X	X	X		X	X	X	X	X	X	21	88
Pomacentrus pavo																	X	X						X	3	13
Pomacentrus vaiuli	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	24	100
Pseudobalistes flavimarginatus	X					X		X					X					X							5	21
Pseudocheilinus octotaenia								X																	1	4
Pteregogous enneacanthus				X							X	X													3	13
Ptereleotris evides	X																X							X	3	13
Pterocaesio tile	X		X																						2	8
Pygoplites diacanthus			X	X																X					3	13
Rhinecanthus aculeatus																			X						1	4
Sargocentron caudimaculatum															X										1	4
Sargocentron diadema														X											1	4
Sargocentron microstoma								X																	1	4
Sargocentron sp.															X										1	4
Sargocentron spiniferum				X			X	X			X		X		X	X			X	X				X	10	42
Sargocentron tiere											X														1	4
Saurida gracilis		X	X								X					X								X	5	21
Scarus altipinnis	X					X	X	X		X	X				X		X		X	X					10	42
Scarus dimidiatus	X									X						X									3	13
Scarus forsteni																								X	1	4
Scarus frenatus	X	X			X		X										X								5	21
Scarus ghobban	X		X	X		X		X			X		X		X					X					9	38
Scarus globiceps			X				X										X								3	13
Scarus psittacus	X	X		X					X									X		X					6	25
Scarus rubroviolaceus	X		X	X	X			X			X		X		X					X				X	10	42
Scarus schlegeli	X	X	X	X	X	X	X		X	X	X	X	X		X	X	X	X	X	X	X		X	X	21	88

	STATION																								
SCIENTIFIC NAME	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**19**	**20**	**22**	**23**	**25**	**29**	**36**	**Total Stations**	**% Occurrence**
Scarus sp.				X														X							2	8
Scolopsis lineata						X	X	X		X	X	X	X			X			X					X	10	42
Scomberoides lysan																	X								1	4
Selar crumenophthalmus			X																						1	4
Siganus argenteus											X														1	4
Siganus punctatus			X	X		X			X	X	X						X	X						X	9	38
Siganus spinus																		X							1	4
Stegastes albifasciatus																			X						1	4
Stegastes fasciolatus						X	X	X	X				X		X	X	X		X						9	38
Stegastes lividus													X												1	4
Stegastes nigricans				X				X				X		X		X									5	21
Stethojulis bandanensis																X	X	X	X						4	17
Stethojulis strigiventer																		X	X						2	8
Sufflamen bursa		X							X			X	X			X		X						X	7	29
Sufflamen chrysopterum	X	X	X							X		X	X			X					X				8	33
Synodus variegatus			X																						1	4
Thalassoma hardwicke				X			X	X		X	X	X	X	X	X	X	X	X	X	X			X	X	16	67
Thalassoma lutescens				X								X													2	8
Thalassoma purpureum												X							X						2	8
Thalassoma quinquevittatum												X							X						2	8
Tylosurus crocodilus								X			X								X					X	4	17
Un-id fish sp.		X		X																					2	8
Valenciennea strigata																	X								1	4
Variola louti						X											X								2	8
Zanclus cornutus	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	23	96
Zebrasoma flavescens	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X				X			X	X	18	75
Zebrasoma scopas			X	X			X	X							X	X				X				X	8	33
Zebrasoma veliferum	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X			X	X	21	88
TOTAL	**46**	**46**	**62**	**62**	**25**	**55**	**47**	**64**	**43**	**51**	**66**	**50**	**69**	**27**	**59**	**56**	**63**	**48**	**59**	**53**	**21**	**15**	**23**	**61**		