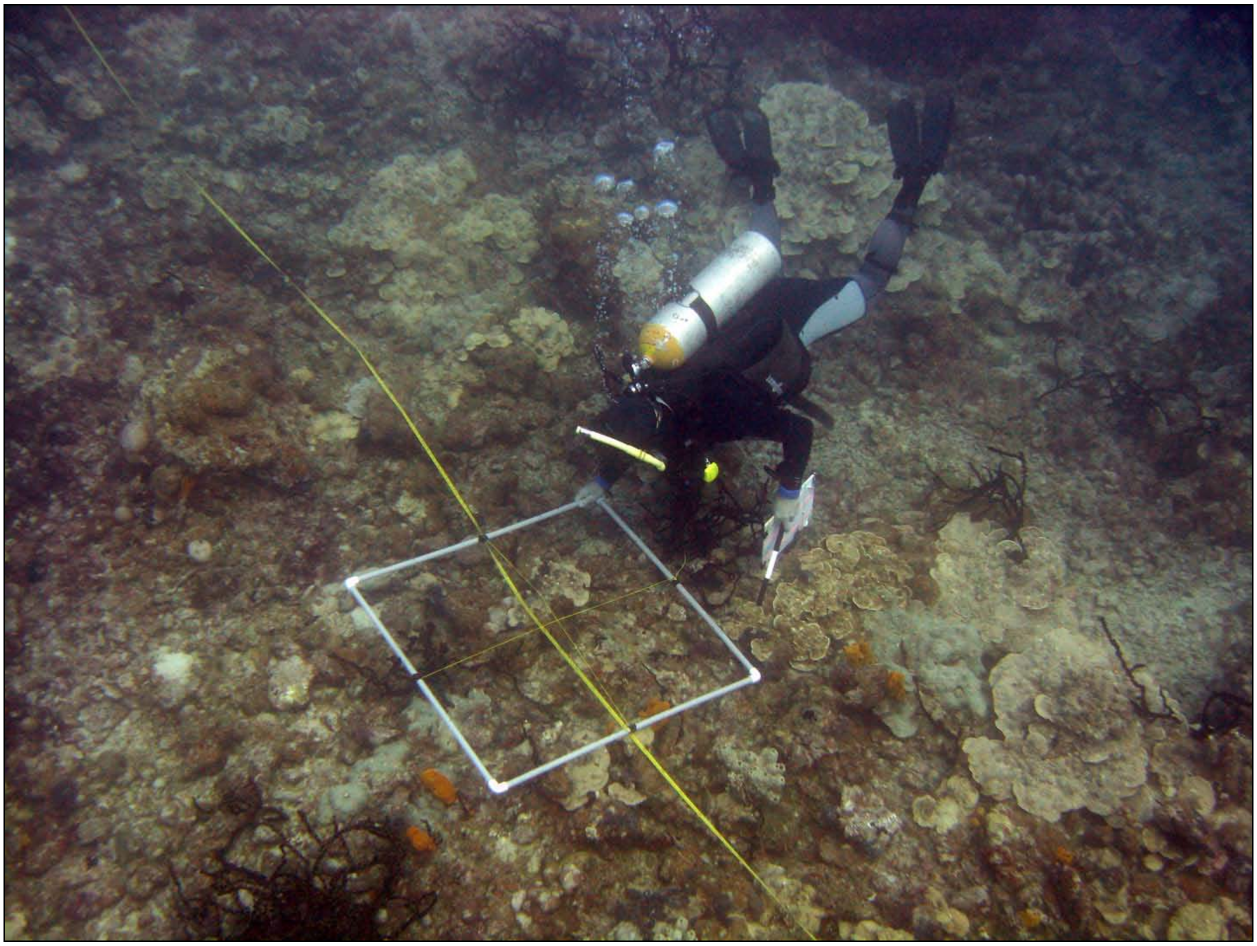

Photograph by Dave Burdick

DRAFT

Comparison of a Photographic and an *In Situ* Method to Assess the Coral Reef Benthic Community in Apra Harbor, Guam

July 10, 2009

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Comparison of a Photographic and an *In Situ* Method to Assess the Coral Reef Benthic Community in Apra Harbor, Guam

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Table of Contents

Cover Photo: A diver collects coral data *in situ* on a reef in Apra Harbor, Guam (photo by Dave Burdick).

List of Figures

List of Tables

Executive Summary

Many methods exist to assess coral reef benthic communities, all of which have specific advantages and limitations. Selecting an appropriate method is one of the most important decisions made by researchers and must consider the project-specific objectives; the type, resolution, and precision of the data to be collected; and the site-specific conditions of the study area. In this study, an *in situ* quadrat method (ISM) and a photographic quadrat method (PM) were compared using eight different data types collected on a heterogeneous coral reef in Apra Harbor, Guam. These data types included: 1) percent cover of all benthic taxa, 2) density of coral colonies, 3) size of coral colonies, 4) number of coral fragments, 5) percent of coral colonies undergoing complete fission, 6) percent mortality of colonies having undergone complete fission, 7) occurrence of gross growth or tissue loss anomalies on coral, and 8) taxonomic richness. Data collected using each method were compared to assess the direct comparability of the methods when describing the coral reef community within the same site and to assess the similarity of the communities described by each method across the study area.

Two survey teams collected data at a total of 30 randomly selected sites from four strata. The strata included slope (0-15 degree or >15 degrees) and type of project impact anticipated (Direct dredging or Indirect project-related risk). Each team collected data within the same 10 x 1 m belt transect. Methodological errors associated with the collection of density-based coral data for the PM resulted in Coral Colony Density and the number of Coral Fragments being overestimated. It may be possible to apply mathematical corrections to correct the problems observed with the PM density-based data, but this would require re-analysis of all photographs, introduce a different form of error into the estimates, and, in the case of this specific project, may not even be possible to use. No corrections were applied to the any of the PM data in time for inclusion in this report and all interpretation of the density-based results takes the known overestimation into consideration. Additionally, Coral Colony Size data collected by the PM was not a true measure of coral colony size and, therefore, no statistical analysis was conducted with the data set. Both methodological problems associated with the PM may be solvable by photographing areas of the bottom that lie outside of the photo-quadrat.

Analyses were conducted at different levels of taxonomic resolution: 1) “All Taxa,” where all taxa as identified by each method were used; 2) “Reduced Taxa,” where the taxa were lumped to create the same taxonomic groupings for each method (*e.g.*, all individual species of *Halimeda* were lumped into *Halimeda* spp. if one method did not distinguish between separate *Halimeda* species); and 3) “Grouped Taxa,” where all taxa were lumped into the broad categories of Algae, Coral, Cyanobacteria, Soft Coral, Sponge, Other and Unknown. For benthic percent cover data, two additional analyses were conducted using coral taxa only and general coral morphologies only.

Overall, the ISM and PM compared poorly. When comparing data collected at the same site, the two methods significantly differed for every variable examined except coral growth anomalies, for which none were observed by either method. The communities described by each method across the study area were also significantly different except at the coarsest levels of taxonomic resolution (*i.e.*, Grouped Taxa and Coral Morphologies). Both methods were able to distinguish differences among the strata when using the benthic cover data with both coral and non-coral

taxa included. However, the PM did not distinguish between strata when only coral cover was used in the analysis, whereas the ISM did.

Differences between the methods were associated primarily with the ability of the methods to identify Taxon Richness at the sites. The PM identified significantly fewer taxa (28 total taxa) compared to the ISM (184 total taxa) and found an average of 24.8 ± 1.8 fewer taxa per site than did the ISM.

On coral reefs, three-dimensional relief, or bottom rugosity, is often correlated with species richness and community structure. The ISM and PM responded differently to changes in rugosity. Data collected by the PM changed little or not at all with changes in rugosity. This is consistent with what would be expected when a three-dimensional structure is reduced into a flat, two-dimensional planar view. In contrast, data collection for the ISM was correlated in rugosity as would be expected because bottom rugosity is often correlated with Taxon Richness and community structure on coral reefs.

The coral *Porites rus* was a dominant component of the coral reef community at many sites. The similarity of the communities described by the PM and ISM improved when *P. rus* was a dominant component of the reef community. The PM could readily identify *P. rus* and the method may perform similarly to ISM in situations where the benthic community has low Taxon Richness and the common organisms can be easily identified in photographs. However, even when *P. rus* was dominant, the community described by the PM was still significantly different from the ISM. While *P. rus* may have dominated at a site, it did not exclude all other taxa, and this remaining Taxon Richness appears to have been captured by the ISM but not the PM.

Every method has its limitations in what types of data can be provided and under what field conditions it can adequately perform. It is important to understand these limitations and to select the most appropriate method to meet specific requirements of each individual project. The most likely preferred option will be some combination of *in situ* and photographic methods. While only *in situ* data collected by the ISM team and photographic data collected by the PM team were compared in this study, it is important note that both teams collected data with a mixture of photography and *in situ* methods. This highlights the importance combining methods as appropriate to take advantage of each method's individual strengths.

1.0 Introduction

Many different methods exist to assess coral reef benthic communities. This diversity of methods has generated considerable debate over which is the most appropriate to use and has resulted in multiple studies that have compared the data generated by two or more of these approaches (Chiappone and Sullivan 1991, Leonard and Clarke 1993, Brown et al. 2004, Beenaerts and Vanden Berghe 2005, Lam et al. 2006, Nadon and Stirling 2006, Alquezar and Wayne Boyd 2007, Bakus et al. 2007, Cabaitan et al. 2007, Leujak and Ormond 2007). The general consensus of these studies is that most methods have advantages and limitations, which must be considered in relation to the project-specific objectives, the environmental and/or ecological conditions of the study area (*e.g.*, depth, ocean condition, geomorphology, natural community variability etc.), and the resources (*e.g.*, time, expertise, cost etc.) available.

One drawback of these studies is that they have, almost exclusively, used percent cover and species richness as the primary data variables for comparison. However, other types of data (*e.g.*, size frequency, density, etc.) have become more common in studies of coral reef ecosystems and are desirable to collect (van Woesik and Done 1997, Bak and Meesters 1998, Oigman-Pszczol and Creed 2004, Smith et al 2005). No studies were located comparing methods using these types of data.

Additionally, comparison studies have tended to focus on only a single level of taxonomic resolution, often conducting analyses at a coarse taxonomic resolution (*e.g.*, live coral, algae etc.) or on a single component of the overall coral reef community (*e.g.*, hard corals only). All methods have limitations in the taxonomic resolution that can be achieved. Different levels of taxonomic resolution are needed to address different science, management and regulatory questions, so it is critical to know how methods compare at differing taxonomic scales so that the most appropriate method for answering project-specific questions can be selected.

Finally, previous comparison studies have focused on the direct comparability of two or more methods employed within relatively few sites. While valuable, this type of comparison overlooks the potential situation in which two or more methods could have low direct comparability within an individual site, but may produce estimates that are indistinguishable over larger spatial areas. This scenario could arise in habitats where the natural biological variability exceeds the error between the methods, and sufficient sampling cannot be conducted, perhaps for cost or time reasons. In this situation, a variety of methods may provide the same end result.

This comparison study resulted from the U.S. Navy's desire to use a less field-intensive method to collect benthic coral reef survey data to meet U.S. environmental regulatory requirements in support of dredging approximately 50 acres of submerged reef to construct a nuclear aircraft carrier (CVN) berthing facility and turning basin in Apra Harbor, Guam. In this study, we compare two commonly used methods to collect coral reef benthic data: an *in situ* quadrat method (ISM) and a photo-quadrat method (PM).

In situ quadrats have long a long history of use in the marine environment. This method is generally cost effective because it requires little expensive field equipment and it is capable of producing data with a high level of taxonomic resolution (Hill and Wilkinson 2004). The method is generally preferred for locating small or cryptic organisms (Lessios 1996) because observers are able to effectively search highly three-dimensional substratum. However, the method is potentially field intensive, which depending upon environmental conditions can lead to increased cost. In its purist form (*e.g.*, not combined with some photography), it produces no permanent record that can be consulted or used to cross-check the data collected.

With the technological advances in digital photography, photo-quadrats have become increasingly popular for collecting coral reef benthic data. A primary advantage of photographic methods is that data can be collected quickly in the field, reducing the field time and potentially allowing for increased sample sizes. A permanent record of what is photographed at the site can be made, which can be useful for cross-checking data for errors or, in some cases, to assist with identification. While the method may save time in the field, it can be time intensive during post-field photographic analysis. In general, taxonomic resolution may be low and small or cryptic organisms may be difficult to identify, but recent advances in digital photo resolution may be improving this limitation. Photographic methods reduce three-dimensional topographic relief into a two-dimensional planar projection resulting in the under-sampling of any organisms on vertical or over-hanging surfaces. Finally, expensive equipment is necessary to conduct the method (Hill and Wilkinson 1994, English et al. 1997).

This study addresses two questions: (1) do the data obtained by the *in situ* method and the photographic methods directly compare to each other, and (2) are the benthic communities described by these two methods the same over a larger spatial area? To answer these questions, we used multiple benthic coral reef data sets and conducted analyses at multiple levels of taxonomic resolution. The data sets included: 1) percent cover of all benthic taxa, 2) density of coral colonies, 3) size of coral colonies, 4) number of coral fragments, 5) percent of coral colonies undergoing complete fission, 6) percent mortality of colonies having undergone complete fission, 7) occurrence of gross growth or tissue loss anomalies on coral, and 8) taxonomic richness.

2.0 Methods

2.1 Survey Sites

Thirty survey sites (Figure 2.1) were selected from 60 random locations in Apra Harbor within the proposed project area of the CVN pier, turning basin, and entrance channel. Sites were restricted to depths ≤18 meters (m) because the direct project impacts are anticipated to occur no deeper. Additionally, this depth provided adequate time for the completion of the ISM data collection at a site in a single non-decompression dive. Some sites within the study area were known to contain no coral colonies. For the purpose of this comparison, sites that did not contain both algae and coral were excluded from selection. The physical attributes of all sites are included in Appendix A.

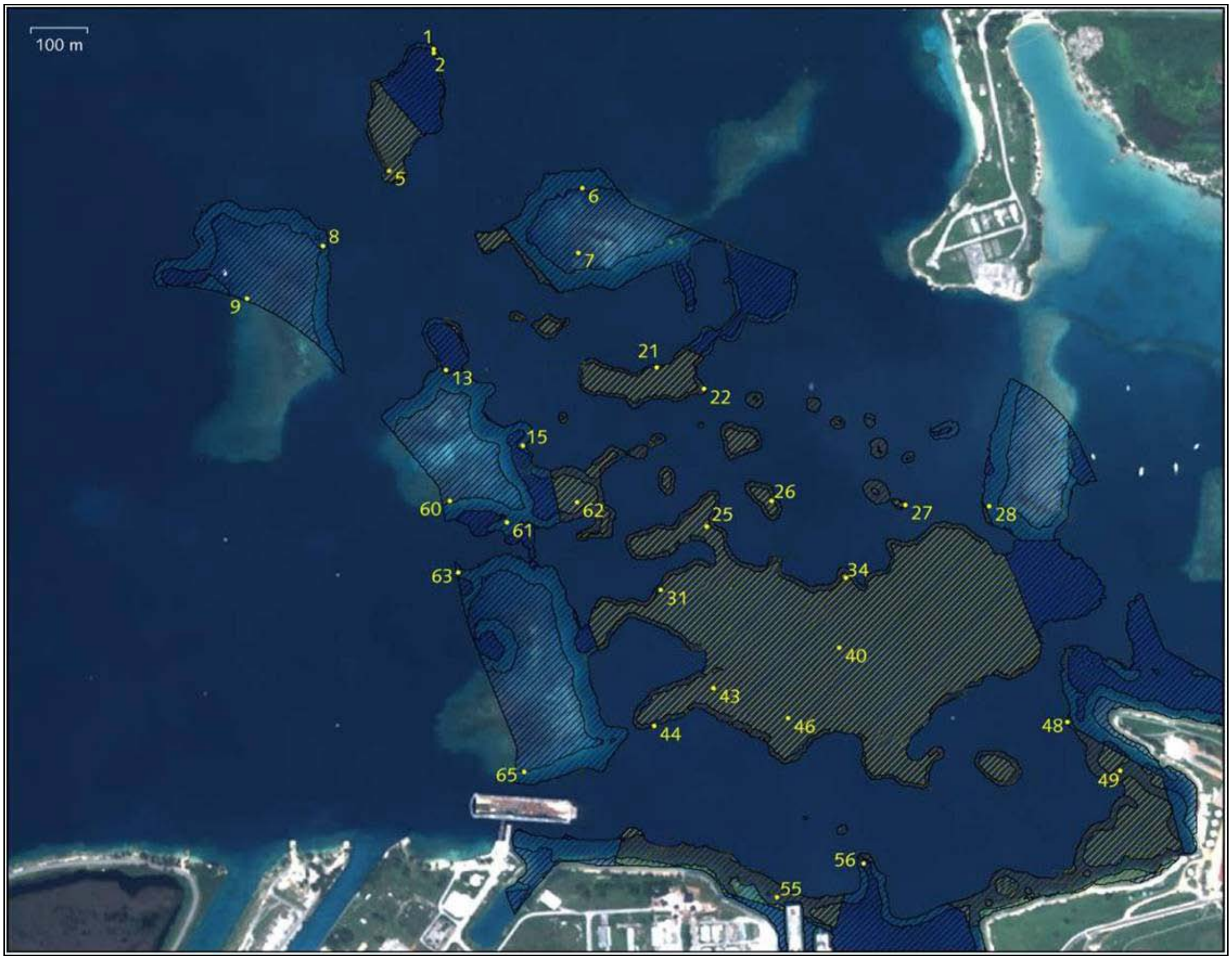


Figure 2.1. Map of the 30 survey sites analyzed in this study. Hatched areas are shallower than 18 m and comprised the survey area. Four strata were created: Indirect Impact-Slope, Indirect Impact-Flat, Direct Impact-Slope, and Direct Impact-Flat.

The survey sites were stratified by slope (0-15 degree or >15 degrees) and type of project impact anticipated (Direct dredging or Indirect project-related risk). A stratified sampling design is warranted when distinct community types are known to occur within the study area or if it is desirable to ensure adequate sampling within specific areas so that estimates within those areas can be made (Cochran 1977, Bakus 2007). In this study, the Direct-Indirect stratum was developed based upon dredge-fill footprints for the dredging alternatives considered as part of the proposed CVN project. This stratum was necessary to meet CVN project-specific goals. While this stratum was not specifically biologically based, the footprint for the proposed dredging alternative attempted to avoid sites with "significant" coral habitat. This provided an unexpected biological relevance to this seemingly non-biological stratum. Sites were distributed as evenly as possible among the four strata, but logistical constraints did not allow for a perfectly balanced design.

2.2 Variables Collected

Data for eight benthic community variables were collected (Table 2.1). These variables represent the data requested by the Federal environmental regulatory agencies to assess potential project-related impacts to coral reef communities.

Table 2.1. Variables and metrics selected for data collection as part of marine resource surveys conducted in Apra Harbor, Guam in support of the CVN project.

Variable	Metric
Benthic organism cover by species (or lowest possible taxonomic level)	Percent of bottom covered
Coral colony density by species (or lowest possible taxonomic level) and morphological form	# of colonies/m^2
Coral colony size	# of colonies/m^2 in each of nine size categories (<2cm, 2 to <5 cm, 5 to <10 cm, 10 to <20 cm, 20 to <40 cm, 40 to <80 cm, 80 to <160 cm, 160 to <320 cm, ≥320 cm)
Coral fragments	Number and size of fragments (see colony size above)
Coral colony fission[1]	Percent of colonies having undergone complete fission
Partial coral colony mortality	Percent mortality on colonies that have undergone complete fission
Occurrence of gross growth anomalies and/or anomalous patterns of tissue loss by coral species (or lowest possible taxonomic level)	% of colonies showing the described condition
Taxon Richness	Number of taxa

[1]Fission is partial mortality of a coral colony that results in separation of a colony into pieces that are genetically identical (*i.e.*, ramets) and remain attached to the substratum.

2.3 Deployment of Transect Lines

To avoid interfering with each other, only one team collected data at a site at a time. At almost all sites, the PM team conducted their data collection first. Using predetermined criteria, the first team on-site laid a calibrated 25-m transect line on the benthic substrate. Transect lines were left securely attached to the bottom until both teams had finished their data collection, usually within a few days of each other. All but one dive was conducted between 27 April 2009 and 12 May 2009. A single ISM dive (site 55) was conducted on 26 May 2009 to collect Benthic Cover data.

Survey teams used handheld GPS units to locate sites. A weighted surface float was deployed to mark the site and serve as the starting point for the transect line. The transect line was stretched across the benthic substrate starting at the float's weight. When a discernable slope was observed, the line was run along the depth contour. If no discernable slope was observed, the line was run north, provided it could fit entirely on the flat area. If the flat area began to slope, the line was turned to maintain a constant depth. At most sites, the entire 25-meter transect line was laid in a straight line.

2.4 Photographic Method

Procedures for conducting the PM were based on previously published protocols (Hill and Wilkinson 2004; English et al. 1997). Surveys were conducted by three divers. Digital photographs were collected by one diver using a digital SLR camera (14 mm lens with 114° diagonal field of view) mounted on a 4-legged PVC quadra-pod. The quadra-pod positioned the camera over the center of a 1 x 0.67 m rectangular frame. The digital SLR contained a full-frame display that provided for *in situ* verification of each image. Dual stereo strobes were used on some deeper transects (*e.g.*, >10 m) if the particulate load of the water column was not deemed sufficient to cause excessive backscatter. Fifteen photo-quadrats were collected contiguously along the 10-m length of transect, resulting in 10 m^2 photographed at each site. Upon completion of the photo-quadrats, a taxa list of all corals to the lowest possible taxonomic level was compiled within the general area of the transect (~5 m wide belt centered on the 25-m transect line), and descriptive notes on the overall biotic and geomorphological setting were recorded. All photographs and incidental observational data were collected by Dr. Steve Dollar.

A second diver laid the transect line as described above. A third diver collected *in-situ* topographical relief, or rugosity. Rugosity was measured on each transect as the actual length of chain laid over the reef surface divided by the transect length. For this index, a value of one represents a perfectly flat surface with no relief. Three different divers rotated through these two tasks. Prior to starting the fieldwork, all personnel were trained and calibrated to ensure consistency.

A total of 446 photo-quadrats (for Site 1, only 11 images were processed) were analyzed one at a time using the Coral Point Count with Excel Extensions (CPCe) software developed by the National Coral Reef Institute (Kohler and Gill 2006). Fifty randomly placed points laid over each quadrat (total of 22,150 points) were independently identified to the lowest possible taxonomic level by three different analysts. For all points where at least one analyst was in disagreement, all three analysts and the lead principle investigator for the photo-analysis (Dr. Eric Hochberg) examined the point and came to consensus on its final identification. The agreement rate between analysts (*i.e.*, number of points for which all three analyst agreed) was approximately 85 percent (~19,000 points).

For other data types, each analyst identified all discernible coral colonies, including coral fragments. Individual coral colonies were identified by tissue and or skeletal boundary separation on all sides. Corals were counted if any part of the colony was included in the frame. Corals were considered fragments if they were broken off the bottom, but still had living tissue. Recently broken fragments were not observed and were not counted. For each colony/fragment, analysts determined the length of the longest viewable dimension. The size of the quadrat frame limited the largest dimension that could be measured to 120 cm (the diagonal distance). For each analyst, the data were compiled by transect, and averaged to produce the final data. All photo-quadrats were analyzed in the lab by the individuals who conducted the field work.

Colonies undergoing complete fission were identified from digital images by Dr. Steve Dollar. Fission was defined as whole colonies that were completely split into at least two distinct sections by an area of non-living tissue. For each colony having undergone complete fission, the percent of dead tissue was visually estimated. Large colonies of *Porites rus* with multiple plates interspersed with living and dead tissue, and branching species, were ignored. Additionally, colonies with gross growth anomalies were noted in digital photographs when present. Other unusually conditions were also recorded, and the percent of the colony affected was visually estimated.

All data for the PM were collected by Dr. Steve Dollar of Marine Resources Consultants and Dr. Eric J. Hochberg, Mr. Mitchell B. Doctor, Ms. Harmony A. Hancock, and Mr. Christopher J. Lapointe, all of the National Coral Reef Institute, Oceanographic Center, Nova Southeastern University.

2.4.1 Methodological Errors

Two methodological problems were identified with all density data collected using the PM. In brief, criteria used for including boundary corals (*i.e.*, those only partially within a quadrat) can result in significantly biased density estimates (Zvuloni et al. 2008). By counting a boundary coral that has any piece of the colony in the quadrat, too many corals have been included in the density estimate for the PM, resulting in an overestimation (Zvuloni et al.'s Type II error). While Zvuloni et al. (2008) provide information on a possible correction factor, no adjustment was made to the PM data in time to be included in this report. Additionally, each image was processed independently and due to the contiguous arrangement of the quadrats (*i.e.*, fifteen photo-quadrats were laid end to end to make 10 x 1 m belt transect), corals along a shared quadrat edge were counted twice, further inflating all density estimates. Where relevant, interpretation of results will be done taking this known overestimation into consideration. The following PM data have this "Type II" error: Coral Colony Density, Coral Colony Size, and Coral Fragments.

An additional issue was identified with the Coral Colony Size data. Size measurements were not made of the entire coral colony, but only the longest visible dimension in the photo-quadrat. As a result, the PM measured the longest planar coral dimension occurring in the quadrat and not the planar size of a coral colony. The Coral Colony Size data are, therefore, skewed toward smaller sizes when compared to a true coral colony size frequency distribution. The nature of the skew cannot be predicted because, with a randomly placed quadrat, at least half of the boundary colonies are expected to have their longest dimension outside of the quadrat. These boundary corals will be forced randomly into any size class below its true size, and therefore the Coral Colony Size as measured by the PM does not reflect the true size of the corals within the project area. For example, a boundary coral sized as 5 cm by the PM could actually be 120 cm if only a small portion is viewable within the photo-quadrat boundary or 11 cm if almost half of it is within the photo-quadrat. No correction was made to the PM Coral Colony Size data in time to be included in this report. Therefore, no meaningful statistical comparison can be conducted.

2.5 *In situ* Method

Three ISM divers collected the data along the same pre-determined 10 x 1 m belt transect used for the PM. One diver located all coral colonies whose center lay within the belt transect and identified them to the lowest taxonomic level. Colonies were individually distinguished by a variety of factors including color, morphology, but most importantly tissue and or skeletal boundary separation. The vast majority of colonies were fairly simple to distinguish based on these four parameters; however, three species did provide greater challenge and required more time for distinguishing individuals. Delineation of individuals of *Porites rus* (a dominant coral constituent at many of the sites) often involved following and delineating the entire length of the tissue and skeletal boundary as intra-colony variation in color, morphology and incomplete fusion of overlapping or adjacent tissue areas occurred. Skeletal formation and direction often formed the major basis of colony delineation for *Porites cylindrica* (a minor coral constituent at the sites sampled) when tissue necrosis at branch bases and partial burial was found. Thick, extensive fields of *Pavona cactus* encountered at four of the sites could not reliably be distinguished on an individual colony basis. At one of these sites, *P. cactus* measures were not made. At three of these sites, measurements were made specific to recognizable clumps or aggregations and labeled as such. Such data were collected as a methodological means to allow compensatory mitigation equity to ultimately be achieved (a regulatory requirement), but were not included in the analysis of methods comparability. With consistent and careful application of this approach, the ISM team was confident that coral colonies were consistently delineated at all sites.

Coral fragments were defined as any unattached coral piece physically dissociated from a "parent" colony of skeletal and tissue material. All coral fragments were counted, identified to the lowest possible taxonomic level, and sized separately. At three sites where *P. cactus* fragments could not be easily counted, their presence was simply noted. Fragments that were obviously recently broken (*e.g.*, broken surface bone-white with rough intact skeletal porosity and no apparent overgrowth) were also not counted because it was assumed that these coral pieces were broken as a result of this study. The longest axis of each coral colony and fragment was measured using a meter stick with 10-cm gradations or, for smaller colonies, a flexible 1 cm delineated measuring tape. Based on their measured size, colonies were placed into one of nine size classes: <2 cm, 2 to <5 cm, 5 to <10 cm, 10 to <20 cm, 20 to <40 cm, 40 to <80 cm, 80 to <160 cm, 160 to <320 cm, and ≥320 cm.

If separate pieces of attached tissue appeared to be a part of a single individual colony (based on color, morphology and or skeletal connectivity), the separate pieces were considered an individual colony that had undergone complete fission and a visual estimate of percent tissue mortality was made. A fissioned colony was sized as a single measure across the longest diameter of the underlying skeleton (when readily discernable) or between the outermost boundaries of the furthest pieces of colony tissue.

All coral data were collected in 1-m intervals using a 1 m^2 quadrat frame. Care in identification of colony centers and boundary delineations helped ensure that colonies that crossed multiple quadrats were counted only once within each 10 m transect. For any colony that could not be positively identified in the field, multiple photographs were taken at different scales to assist with later identification. Photographs were taken perpendicular to and 0.5 m above the substratum every half-meter along the entire length of the 10-m belt transect. In addition, a series of images of the general habitat was collected along each 10 m belt transect. All photos were archived.

Two divers collected benthic composition data which included percent cover estimates for all algae, coral, and sessile invertebrate taxa. Ten 1 x 0.67 m quadrats were placed within the first 6 meters of the 10 x 1 m belt transect. Within each quadrat, the percent cover of *all* benthic taxa was visually estimated to the nearest 1 percent cover. To assist with visual estimates, each quadrat was strung to contain a grid in which each square represented 1.5 percent of the quadrat. When appropriate, overlying algae were gently waved aside so that estimates could be made down through the "canopy" layers. As a result, a total coverage estimate in excess of 100 percent could result if a community had well-developed canopy and/or understory layers. Taxa that were rare were assigned a cover of one percent. All taxa were identified to the lowest possible taxonomic level and, as necessary, specimens were collected to confirm field identifications in the laboratory. All quadrats were photographed to assist with data verification and for archiving.

The collection of Benthic Cover data in a 6 m^2 belt transect for the ISM (compared to a 10 m^2 belt for the PM) would not affect the statistical comparison of the two methods. Percent cover data is a relative measure and independent of area. It is, therefore, appropriate for this comparison to be conducted. Additionally, the objective of this study was to compare the data collected by each method, so as long the data collected by both methods are unbiased and represents the same thing (*e.g.*, percent cover of the bottom, density of coral colonies, size of coral colonies) then a comparison is appropriate.

The primary drawback of using a smaller belt transect to estimate Benthic Cover for the ISM compared to the PM is that the smaller belt transect may introduce additional variability across the larger spatial scale to the ISM's Benthic Cover estimates. This could potentially obscure real differences between the methods when comparing the communities described by each method (see study question 2 in section 1.0). The structure of the data allowed for a direct 6 m^2 to 6 m^2 comparison to be conducted between the two methods, but this would have require additional work to re-sort the PM data into a comparable form, for which the timeline of the study did not permit. More importantly, it would not be a fair assessment of the PM because it would artificially limit the full data set collected by the method.

Time permitting, upon completing the 10 x 1 meter belt transect, divers visually surveyed an approximately 5-meter wide belt to either side of the transect line and noted any benthic species not observed within the belt transect. In general, insufficient bottom time existed to spend more than a few minutes conducting visual surveys for Taxon Richness. For six survey sites, a second coral diver collected Taxon Richness data for approximate 30 minutes. This resulted in more than twice the number of taxa found at those sites (29.7 ± 2.4 coral taxa vs. 13.4 ± 1.2 coral taxa) and suggests that the Taxon Richness at the study sites is much higher than that estimated by the ISM. For the analysis of Taxon Richness in this report, only taxa observed within the belt transects were included.

2.6 Statistical Analysis

2.6.1 Overview

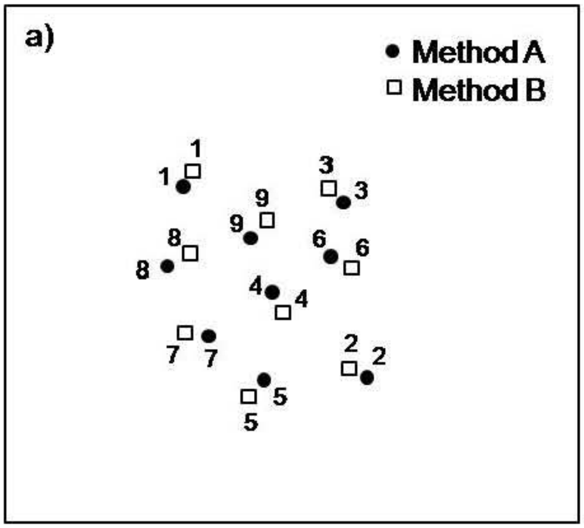
The statistical analysis was conducted to address two questions: (1) do the data obtained by the *in situ* method and the photographic methods directly compare to each other, and (2) are the benthic communities described by these two methods the same over a larger spatial area? Assuming each question is true or false, three potential outcomes are possible and would be illustrated by specific results and patterns within the data. These outcomes are:

1. A "best" case outcome would be the PM and ISM method would be directly comparable within sites, and the communities describe by the PM and ISM would not be significantly different (Figure 2.2a).

   The data collected by each method at the same site (hereafter, a method-site pair) would be identical. For a single variable (*e.g.*, total number of taxa), the value estimated by the two methods at the same site would be equal. For multiple variables (*e.g.*, percent cover of all benthic taxa), the similarity between the two sites could be calculated and would be equal to one. Additionally, a 60 x 60 matrix of all sites (30 PM sites and 30 ISM sites) could be created that includes the similarity between all method-sites. The similarity between the method-sites pairs would be the highest compared to the other 59 similarity values for each method-site (*i.e.*, Rank = 1). Cluster plots (see section 2.6.3) were used to visually display trends in the benthic community. In these plots, each point represents a description of the entire benthic community at a given site as described by one of the methods. The distance between any two points in the plot is directly related to the similarity of the community represented by those two points. Points that are close to each other in the figure are more similar to each other than points that are separated by a larger distance. In a cluster plot, the point representing the PM at a given site would lie closest to the point representing the ISM at the same site. The cluster of all points for the PM would be intermixed with the points for the ISM, signifying that the communities that have been described by the two methods are the same.

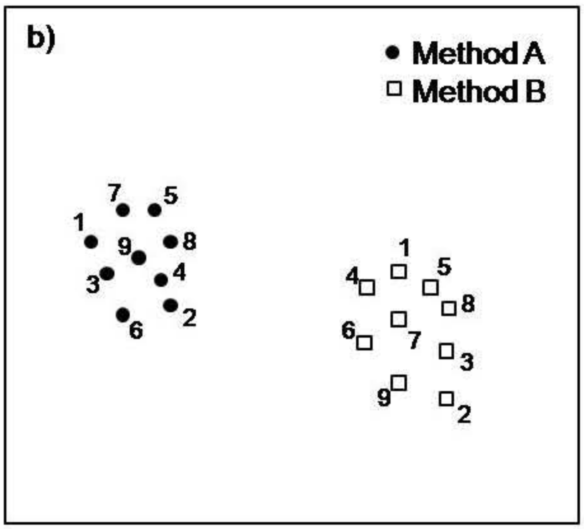
2. In contrast, a "worst" case outcome would occur if the methods were not directly comparable within sites and the communities described by the PM and ISM were significantly different from each other (Figure 2.2b).

   The data collected by each method within the same site would be significantly different. For a single variable, the values estimated by each method at the same site would be significantly different from each other. For multiple variables, the similarity between the method-site pair would be less than one and would not have the highest similarity value when compared to the other 59 similarity values (*i.e.*, Rank > 1). In a cluster plot, the two points representing the method-site pair would not lie closest to each other. The cluster of all points for the PM would be spatially distinct (*i.e.*, significantly different) from those for the ISM, signifying that the communities that have been described by the two methods are not the same.



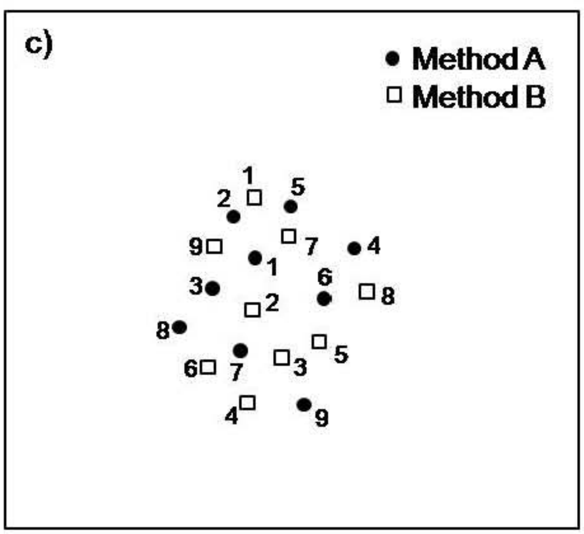
For the nine hypothetical sites surveyed, the method-site pairs (*e.g.*, A_1 and B_1) are aligned closest to each other in the cluster diagram, showing the two methods are directly comparable. In an idealized univariate model, A_1-B_1=0, and in the idealized multivariate model, the Similarity between A_1 and B_1 (S_{A_1,B_1}) = 1.

The cluster of points for the two methods overlap. The community described by Method A cannot be distinguished from that described by Method B.



The nine hypothetical survey sites cluster separately by method type. Method-site pairs (*e.g.*, A_1 and B_1) are not aligned together showing poor comparability between the two methods. In this case, the univariate model would result in A_1-$B_1 \neq 0$, and for the multivariate model, $S_{A_1,B_1} < 1$.

The clusters of points do not overlap. The community described by Method A is different from that described by Method B.



For the nine hypothetical sites surveyed, method-site pairs (*e.g.*, A_1 and B_1) do not align together showing poor comparability between the two methods.

However, the points for the two methods overlap. While the two methods are not directly comparable, the natural variability in the community is greater than the error between the two methods. With a sample size of nine, the community described by Method A cannot be distinguished from that described by Method B.

Figure 2.2. A hypothetical comparison study that sampled nine sites using two methods. Three potential outcomes for this study include: a) methods are directly comparable ("best" case); b) methods are not directly comparable and the communities described by each method are significantly different ("worst" case); and c) methods are not directly comparable, but the communities described by the two methods do not significantly differ ("inconclusive" case).

3. An “inconclusive” outcome would occur when the PM and ISM method are not directly comparable within sites, but the communities described by the PM and ISM across a larger spatial scale are not significantly different (Figure 2.2c). In this situation, the sample size was inadequate to show any difference in the community because the natural biological variability was larger than the error between the two methods. If a statistically adequate sample size was obtained, this inconclusive outcome would result in a “worst” case outcome.

   The data collected by the PM and ISM method within the same site would be significantly different and appear in the data as described above for the “worst” case outcome. In a cluster plot, the two points representing a method-site pair would not lie closest to each other, but the cluster of all points for the PM would be intermixed with the points for the ISM, signifying that the communities that have been described by the two methods are indistinguishable.

2.6.2 Data Reconciliation

Prior to conducting any comparison, data collected within each method and between each method was examined to ensure consistency in taxonomy. It is critical to any comparison analysis that the same organism receive the same name.

Data were visually investigated at the level of each site. If large differences in taxa were noted between different abundance measures (*e.g.*, between benthic cover and coral density) within the same method type they were investigated in more detail at the quadrat level. A similar cross-check was conducted between the two methods for data of the same type (e.g., within coral densities). Most differences were the result of observers placing different taxonomic names on the same organism. If this occurred, consensus was reached among the taxonomic experts involved in collecting the data in question and that name was assigned and used in the analysis. By crossing checking the data in this way, one mislabeled site within the PM data set was fortuitously identified and corrected prior to conducting any statistical analysis.

Each coral colony was assigned a morphology based on their taxa or direct observation in the field or from photographs (Appendix B). All density data was standardized to number of individuals per 10 m^2.

2.6.3 Comparison of Methods

The direct comparability of the ISM and PM were made using paired data at each of the sites. For univariate summary data (*e.g.*, total Coral Colony Density), either a paired t-test (Zar 1998) or a one sample Wilcoxon test (Hollander and Wolfe 1999) was used. Normality of the data was assessed using normal probability plots and the Anderson-Darlington test for normality (Stephens 1979). Where data were found to be non-normal, non-parametric tests were used. Follow-up tests were conducted using ANCOVA to examine the influence of strata and rugosity on the paired data, provided that the diagnostics (see below) used to assess the appropriateness of the ANCOVA analysis did not indicate serious assumption violations that would compromise the result.

For multivariate data, a Bray-Curtis similarity matrix (Bray and Curtis 1957) was generated using all sites and both methods (a 60 x 60 matrix). Similarity values range from 0-1, with a value of one meaning perfect agreement and value of zero meaning prefect disagreement. If the methods were directly comparable, the similarity of the described community for the method-site pair would be equal to one and would have rank of one. A one-sided Wilcoxon was used to test if the observed rank was greater than one.

Standard diagnostic procedures pertinent to the selected test were conducted on all analyses to assess the appropriateness of the statistical test for use with the data. Any violations of test assumptions were assessed for their potential impact on the results. If any violation was determined to compromise the test results, the analysis was discarded.

2.6.4 Comparison of Communities

Potential differences in the communities described by the two methods were examined using the suite of non-parametric multivariate procedures included in the PRIMER statistical software package (Plymouth Routines in Multivariate Ecological Research) (Clarke and Warwick 2001). These procedures have gained widespread use in the marine ecological community and have significant advantages compared to the standard parametric procedures (see Clarke 1993 for additional information).

The community data were generally analyzed at three different levels of taxonomic resolution. The levels of taxonomic resolution, going from finest resolution to coarsest, were: 1) “All Taxa,” where all taxa as identified by each method were used; 2) “Reduced Taxa,” where the taxa were lumped to create the same taxonomic groupings for each method (*e.g.*, all individual species of *Halimeda* were lumped into *Halimeda* spp. if one method did not distinguish between separate *Halimeda* species); and 3) “Grouped Taxa,” where all taxa were lumped into Algae, Coral, Cyanobacteria, Soft Coral, Sponge, Other and Unknown. For benthic percent cover data, two additional analyses were conducted using coral taxa only and general coral morphologies only.

Prior to analysis, data were square-root transformed and a Bray-Curtis similarity matrix was generated (Clarke and Warrick 2001, Clarke and Gorley 2006). An ANOSIM with 1000 permutations was used to test for significant differences between methods and among strata. Any observed differences were further investigated using a SIMPER analysis and by overlaying variables (*e.g.*, rugosity) and taxa on non-metric multidimensional scaling (nMDS) plots to explore patterns (Clarke and Gorley 2006). The SIMPER analysis identifies the contribution that taxa within the community make to any observed differences. Interactions between the factors were explored using second order methods (Clarke et al. 2006). Correlations between the community patterns and rugosity, depth, and Taxon Richness were tested using the BEST procedure in the PRIMER package (Clarke and Gorley 2006). To control the overall Type I error rate for each data set, an adjusted α_{crit}=0.01 was used when assessing significance. This adjustment to the critical value was applied only when test involved repeated analyses using the same data (*e.g.*, benthic percent cover data that is examined at multiple taxonomic resolutions). This adjusted α_{crit} would maintain an overall error rate of less than 0.05.

3.0 Results

3.1 Taxon Richness

3.1.1 Comparison of Methods

The ISM found an average of 24.8 ± 1.8 more taxa at a site than did the PM (Paired t-test, T=-13.64; df=29; p<0.001). The ISM found more taxa in every taxonomic group except soft corals, for which only one taxa was identified by both the ISM and PM (Table 3.1).

The two methods became more comparable with increasing rugosity (ANCOVA; F=11.72, df=1,25; p=0.002). The two methods responded differently to changes in rugosity. The number of taxa found by the PM did not change with rugosity (Figure 3.1). In contrast, the ISM had a significant negative correlation (Pearson; r=-.527; p=0.003); at higher rugosity, the ISM found fewer taxa. Total Taxon Richness did not vary by strata.

The number of taxa found often strongly correlated with area searched (Arrhenius 1920, Preston 1962). The larger an area searched, the more taxa that are generally identified. Only taxa found within the 10 x 1 m belt transect were included in this analysis. For the ISM, the Taxon Richness for all taxa other than coral were obtained from a 6 x 1 m belt transect. The ISM's belt transect was 40 percent smaller than that used by the PM, but still managed to identify 11.5 times more non-coral taxa (11 taxa for the PM versus 126 for the ISM).

The Shannon-Wiener Index (H') was calculated using the Benthic Cover data. The ISM had a significantly greater H' than the PM (Paired t-test, T=-7.38; df=29; p<0.001). A significant strata affect was also observed (ANCOVA; F=3.38, df=3,55;p=0.024) where Direct Flat and Indirect Slope were different. No relationship between H' and rugosity was found.

Table 3.1. The Taxon Richness found by the PM and ISM. The values represent the total number of taxa per taxonomic group found by the two methods over the course of this study.

	PM	ISM
Algae	8	62
Coral	16	58
Cyanobacteria	1	12
Other	0	2
Soft Coral	1	1
Sponge	1	49
	27	184

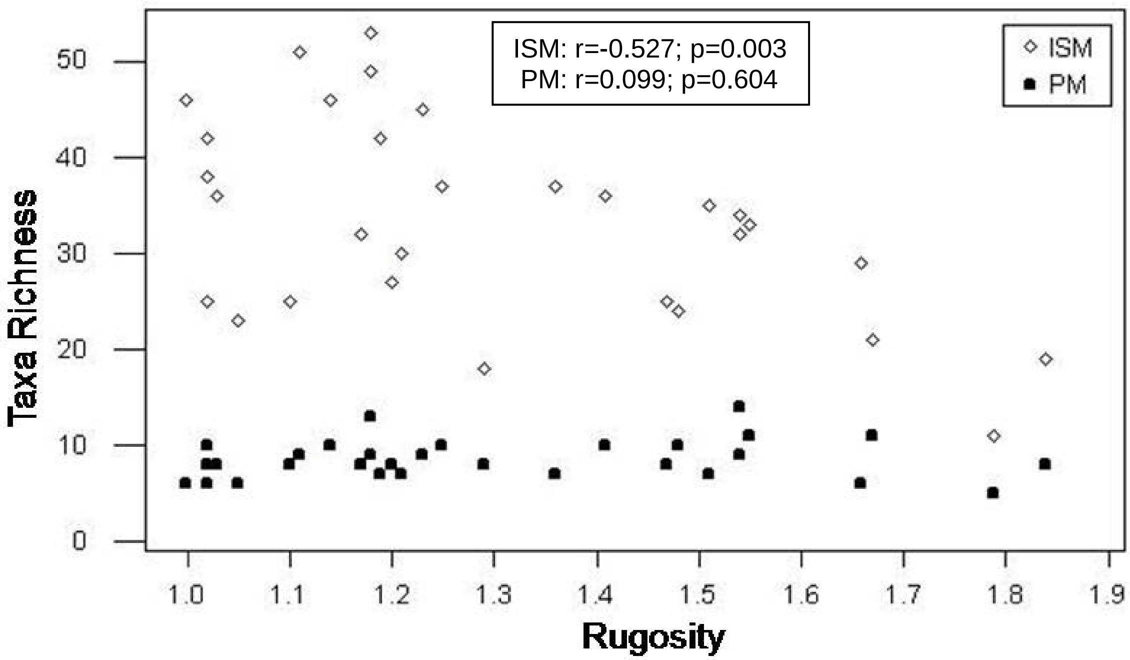


Figure 3.1. Taxon Richness found at a site using the ISM was negatively correlated with rugosity. No relationship was found between Taxon Richness and rugosity for the PM. This different relationship with rugosity resulted in greater comparability between the ISM and PM at higher rugosity, where Taxon Richness appeared reduced.

A 60x60 Bray-Curtis Similarity matrix was generated using square-root transformed data from all method-sites. If the methods were directly comparable, the similarity value between the community described by the ISM and PM at the same site (*i.e.*, method-site pair) would be equal to one and would have a rank of one for that method-site.

The method-site pairs had an average similarity of only 0.15 and, with a median rank of 32, ranked significantly lower than one (Table 3.2). This means that the community described at a site using the PM was more similar to 31 other communities described at other sites by either method than it was to the community at the same site described using the ISM. Comparability between the two methods improved when only coral Taxon Richness was considered. The similarity increased to 0.49, but the rank continued to be significantly lower than one.

Table **3.2.** The mean (±SE) similarity between the method-site pairs and its median (with interquartile range) rank when compared to the 59 other similarity values for the method site. If the methods are directly comparable, the method-site pairs would have a similarity value of one and a rank of one.

Taxa Resolution	Similarity	Rank	Wilcoxon Test
All	15 (0.7)	32 (30-36.8)	W=1830; p<0.001
Coral	48.8 (2.4)	10.5 (4-25)	W=1485; p<0.001

3.1.2 Comparison of Communities

3.1.2.1 All Taxa

When the presence and absence of taxa were examined, the ISM and PM described significantly different benthic communities (ANOSIM; R=0.989; p=0.001). A nMDS plot was generated. Each point in the plot represents a description of the entire benthic community based on the presence of All Taxa at a given site as described by either the PM or the ISM. The distance between any two points is directly related to the similarity of the community represented by those two points. Points that are close to each other in the figure are more similar to each other than points that are separated by a larger distance. The nMDS plots showed that the method-site pairs were not adjacent and that the points associated with each method were not intermixed (Figure 3.2). The nMDS plot showed two distinct clusters of points corresponding exclusively with the two methods.

A significant strata effect was found (ANOSIM; R=0.146; p=0.004), but the second-order analysis revealed a significant interaction term. Examining each method independently, the ISM

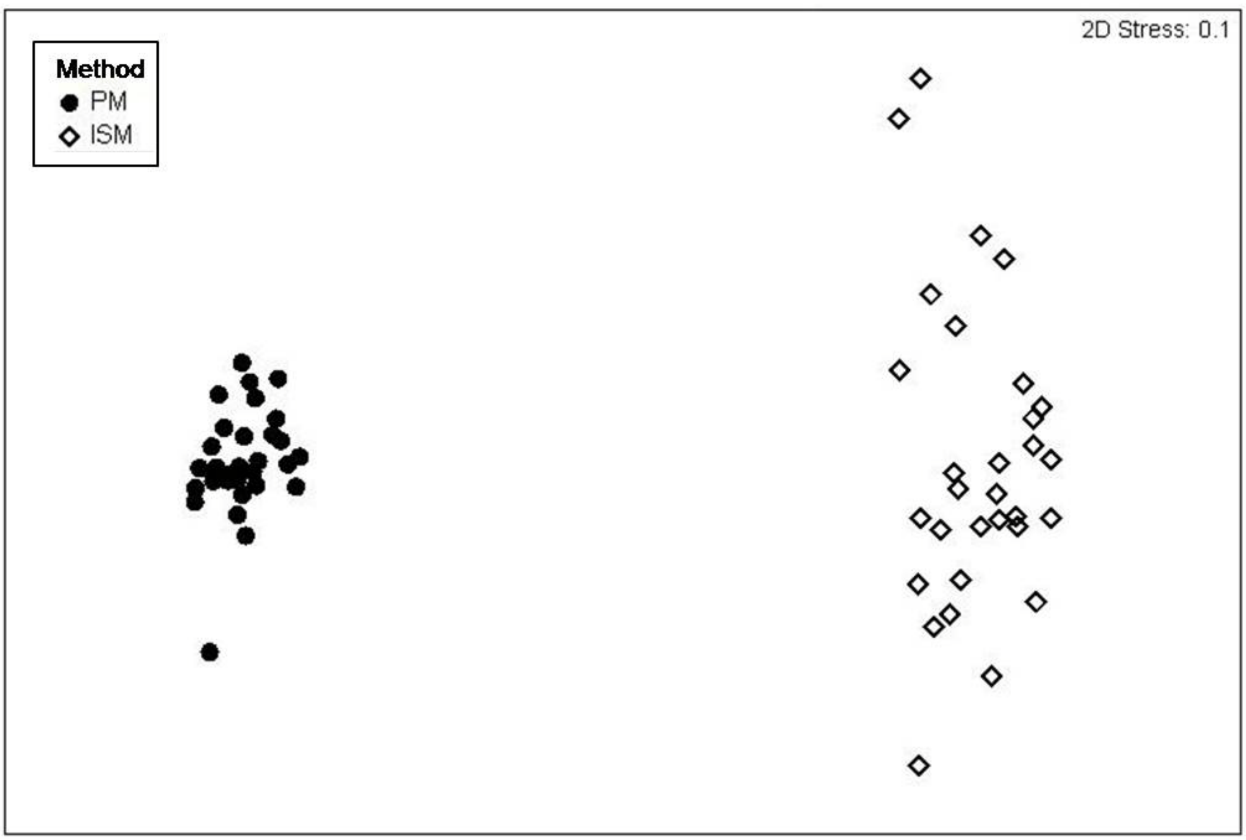


Figure 3.2. The nMDS plot for Taxon Richness. Symbols represent the benthic community described by either the ISM or PM at a survey site. The stress value is a measure of the distortion between the distance of the rankings in the nMDS configuration and the analogous rankings in the similarity matrix. A stress value of 0.1 falls within the range indicating that the plot represents a useful two-dimensional representation.

found significant differences among the strata (ANOSIM; R=0.213; p=0.003), but the PM did not. The ISM distinguished the Direct from Indirect strata. Analysis of the nMDS plot for the ISM data showed some overlap of the Direct and Indirect clusters (Figure 3.3). Examining the three "anomalous" Indirect points, it is apparent that these points have clustered where expected considering the environmental conditions at these three sites. Sites 1 and 2 are on a deepwater patch reef and have clustered with Site 5, which is on the same patch reef but happens to be within the dredge area (see Figure 1.1). Site 56 is in deep water at the mouth of the inner harbor channel and has clustered with other deep water sites in the vicinity (*e.g.*, Sites 46, 55 etc.).

The tighter clustering of the Direct Impact points compared to the Indirect points would be consistent with a biological community that has lower natural variability than the community within the Indirect strata. The overall greater spread of Indirect points and the apparent presence of four smaller clusters (Figure 3.3) are consistent with survey sites scattered across multiple patch reefs and on different sides (*e.g.*, windward vs. leeward) of the patch reefs. The heterogeneity of both Direct and Indirect sites as shown by their spread in the nMDS plot was consistent with personal observation.

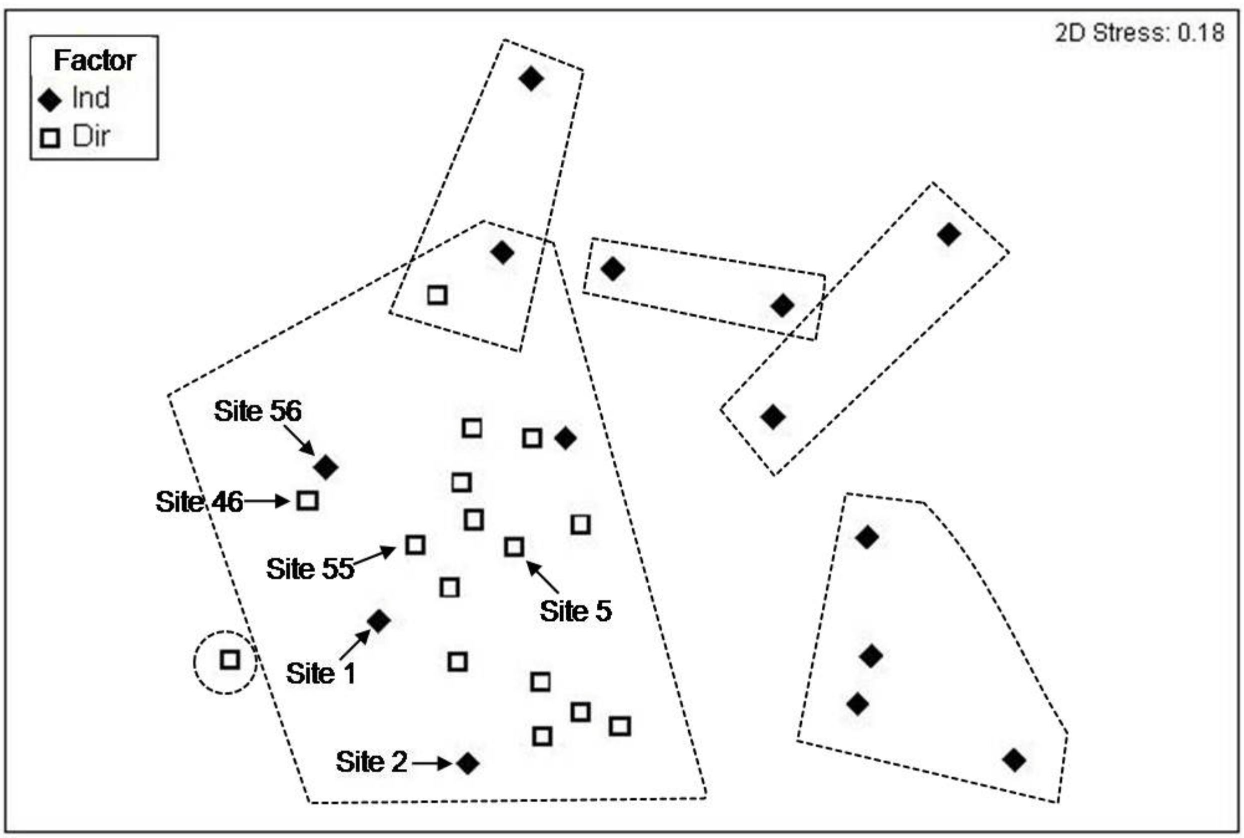


Figure 3.3. The nMDS plot for Taxon Richness by Indirect and Direct factors using the ISM data only. Each symbol represents the benthic community described by the ISM at a specific survey site. Dashed lines enclose clusters with at least 40% similarity, showing similarity among the Direct Impact sites, and higher heterogeneity among the Indirect sites. See text for discussion of Sites 1, 2, 5, 46, 55, and 56. A stress value of 0.18 falls within the range indicating that the plot represents a useful two-dimensional representation.

3.1.2.2 Coral

When only coral Taxon Richness was analyzed, the coral communities described by the PM were significantly different from those described by the ISM (ANOSIM; R=0.385; p=0.001). Examination of the nMDS (Figure 3.4) showed that the method-site pairs do not lie close to each other. Also, two ISM sites were clustered among the PM sites. These two sites (Sites 8 and 28) had fewer coral taxa (Site 6 = 1 coral taxon; Site 8 = 4 coral taxa; Site 28= 2 coral taxa) than the other ISM sites (mean ± SE: 8 ± 0.6 coral taxa). This lower coral Taxon Richness is in line with that estimated by the PM (3 ± 0.3 coral taxa). No significant differences were found among the strata.

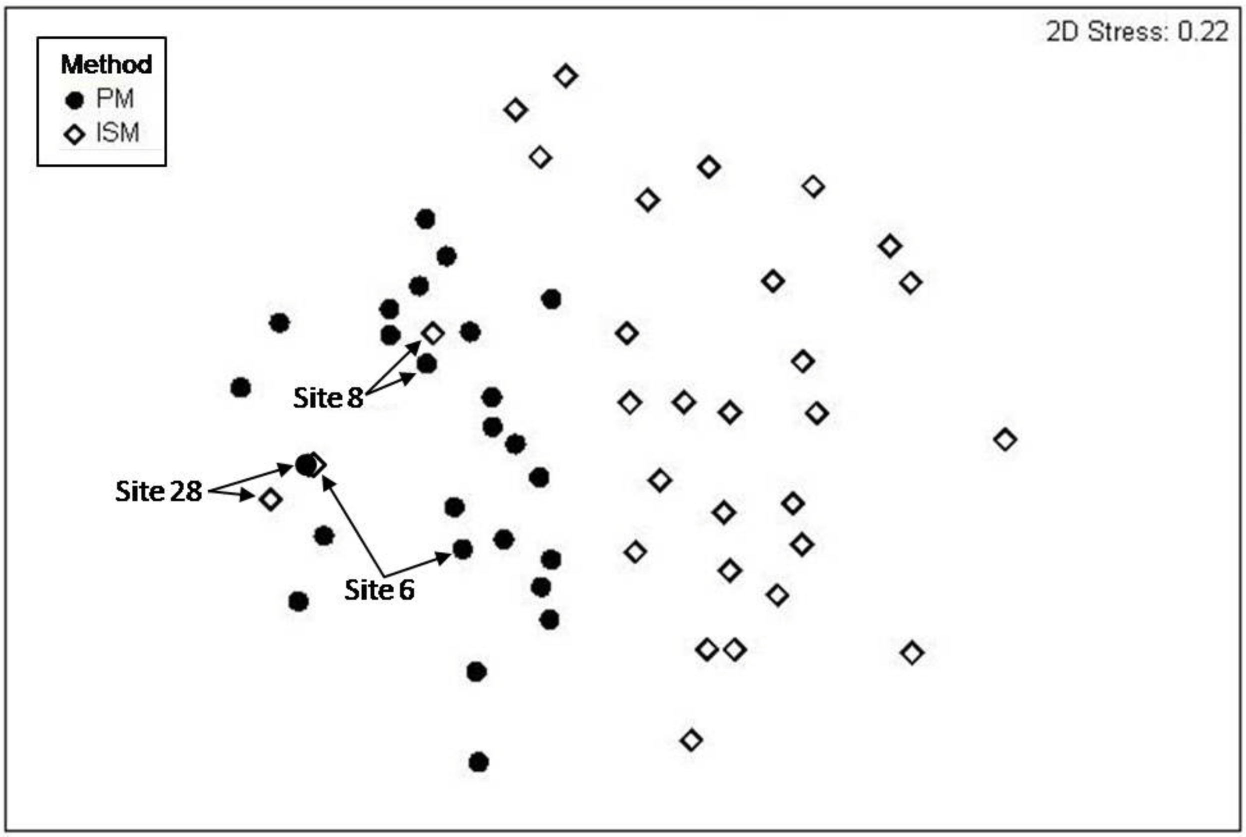


Figure 3.4. The nMDS plot for Coral Taxon Richness. Symbols represent the coral community described by either the ISM or PM at a survey site. See text for discussion of Sites 6, 8, and 28. Due to the high stress value, this figure should be viewed with caution.

3.2 Benthic Cover

3.2.1 Comparison of Methods

Benthic Cover is best analyzed using a multivariate approach that takes into account all of the data simultaneously. Therefore no summary statistics (*e.g.*, overall totals) were calculated or compared using univariate pair-wise statistical approaches. While extensive tables of percent cover means could be generated, they would create extensive tables that would have little relevance to this study. For this reason, only multivariate statistical approaches were conducted for the Benthic Cover data.

A 60x60 Bray-Curtis Similarity matrix was generated using square-root transformed data from all method-sites. If the methods were directly comparable, the similarity value between the community described by the ISM and PM at the same site (*i.e.*, method-site pair) would be equal to one and would have a rank of one for that method-site.

At each level of taxonomic resolution examined, the method-site pairs ranked significantly lower than one (Table 3.3). The similarity of the two methods increased from 0.36 to 0.89 as the taxonomic resolution became more coarse. However, even at the coarsest taxonomic grouping (*i.e.*, Grouped), the two methods did not achieve the top-ranked similarity.

For cover of coral by colony morphology, the comparability between the two methods improved, but the rank was still significantly greater than one (Wilcoxon; W=595; $p<0.001$). While still having a median rank significantly higher than one, the inter-quartile range encompassed the expected value, showing that at some sites the two methods are comparable in describing the coral community by colony morphology.

Table 3.3. The mean (±SE) similarity between the method-site pairs and its median (with interquartile range) rank when compared to the 59 other similarity values for the method-site. If the methods are directly comparable, the method-site pairs would have a similarity value of one and a rank of one. All = finest taxonomic resolution, Reduced = intermediate taxonomic resolution, Grouped = coarsest taxonomic resolution (*i.e.*, Algae, Coral, Sponge, ect.); Coral Only = finest taxonomic resolution specific to corals; Coral Morph = groupings based on general morphological form.

Taxa Resolution	Similarity	Rank	Wilcoxon Test
All	35.7 ± 1.9	25.5 (13-33)	W=1830, p<0.001
Reduced	56.8 ± 2.0	11.0 (2.3-18)	W=1326, p<0.001
Grouped	85.7 ± 0.8	6.0 (2-12)	W=1431, p<0.001
Coral Only	66.8 ± 3.0	3.0 (1-10)	W=820, p<0.001
Coral Morph	74.8 ± 3.0	2.0 (1-5)	W=595; p<0.001

3.2.2 Comparison of Communities

3.2.2.1 All Taxa (Finest Taxonomic Resolution [*e.g.*, finest resolution achievable by each method])

When All Taxa were analyzed, a significant difference was found between the communities described by the ISM and PM (ANOSIM; R=0.803; p=0.001). The nMDS plot (Figure 3.5) showed two distinct clusters of points, one corresponding with each of the methods. A significant strata effect was observed (ANOSIM; R=0.194; p=0.001). No evidence of an interaction between the factors was found. Multiple comparisons revealed that the strata sorted

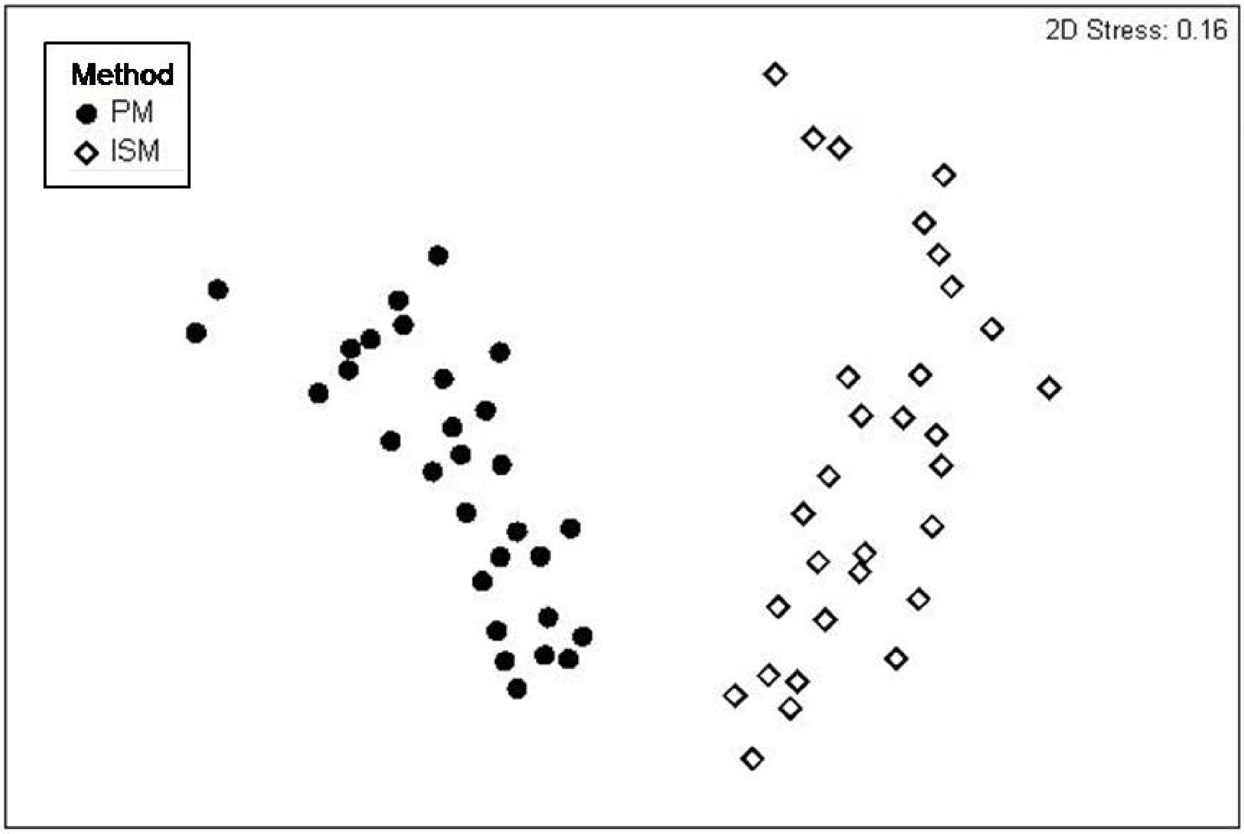


Figure 3.5. The nMDS plot for Benthic Cover of All Taxa. Symbols represent the benthic community described by either the ISM or PM at a survey site. A stress value of 0.16 falls within the range indicating that the plot represents a useful two-dimensional representation.

primarily by impact type with the exception of the Indirect-Flat and Direct-Slope strata, which did not differ. A SIMPER analysis showed that no single taxa explained a majority of the difference between the methods or among the strata, rather the differences between the methods and among the strata were associated with differences in taxonomic resolution. The ISM found more taxa, many of which were presumably lumped into higher taxonomic groupings by the PM (*e.g.*, *Halimeda* spp., algae spp. etc.)

3.2.2.2. Reduced Taxa (Intermediate Taxonomic Resolution [*e.g.*, mainly genera and broader])

When the Reduce Taxa were analyzed, the same patterns as observed for the All Taxa analysis persisted. The two methods continued to be significantly different (ANOSIM; R=0.538; p=0.001). In the nMDS plot (Figure 3.6), the distance between the cluster of points for each method has decreased when compared to the All Taxa analysis (Figure 3.5). The lower edges of the two clusters were nearly touching. The distance between the clusters is related to their similarity, so the sites along the bottom of the two clusters are more similar than those at the top. However, even with this apparent lessening of distance between the clusters, the two methods still described significantly different communities.

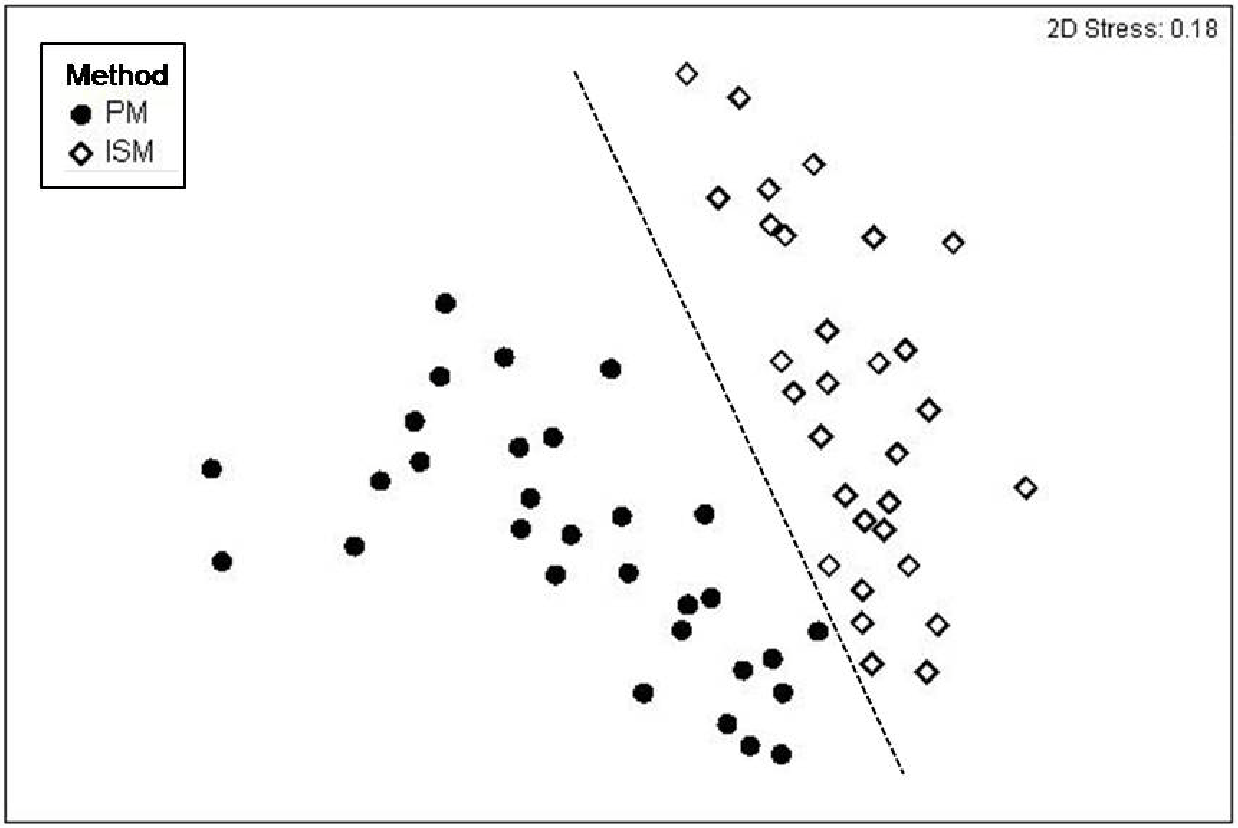


Figure 3.6. The nMDS plot for Benthic Cover of Reduced Taxa. Symbols represent the benthic community described by either the ISM (right of dotted line) or PM (left of dotted line) at a survey site. A stress value of 0.18 falls within the range indicating that the plot represents a useful two-dimensional representation, but is sufficiently high that the figure should be viewed with caution.

The distance between the two clusters was related to the abundance of *Porites rus* at a site. At sites dominated by *P. rus*, the communities described by the two methods were more similar than at sites with low *P. rus* abundance (Figure 3.7b). The communities described by each method became less similar as the amount the *P. rus* decreased and other organisms, primarily marine algae (Figure 3.7a, c, and d) replaced it. This increasing difference between the two methods was associated with the greater taxonomic resolution possible with the ISM compared with the PM (Figure 3.8). As these taxa became more abundant in the community, the similarity between the communities described by the two methods decreased.

Both methods showed significant differences among the strata (ANOSIM; R=0.173; p=0.002). Multiple comparisons showed a similar pattern of differences as that observed with All Taxa, but the differences were not as pronounced (*e.g.*, smaller R-values). In general, communities at Direct Impact sites were significantly different from those at Indirect Impact sites, with the exception of the Indirect-Flat and Direct-Slope strata, which did not significantly differ.

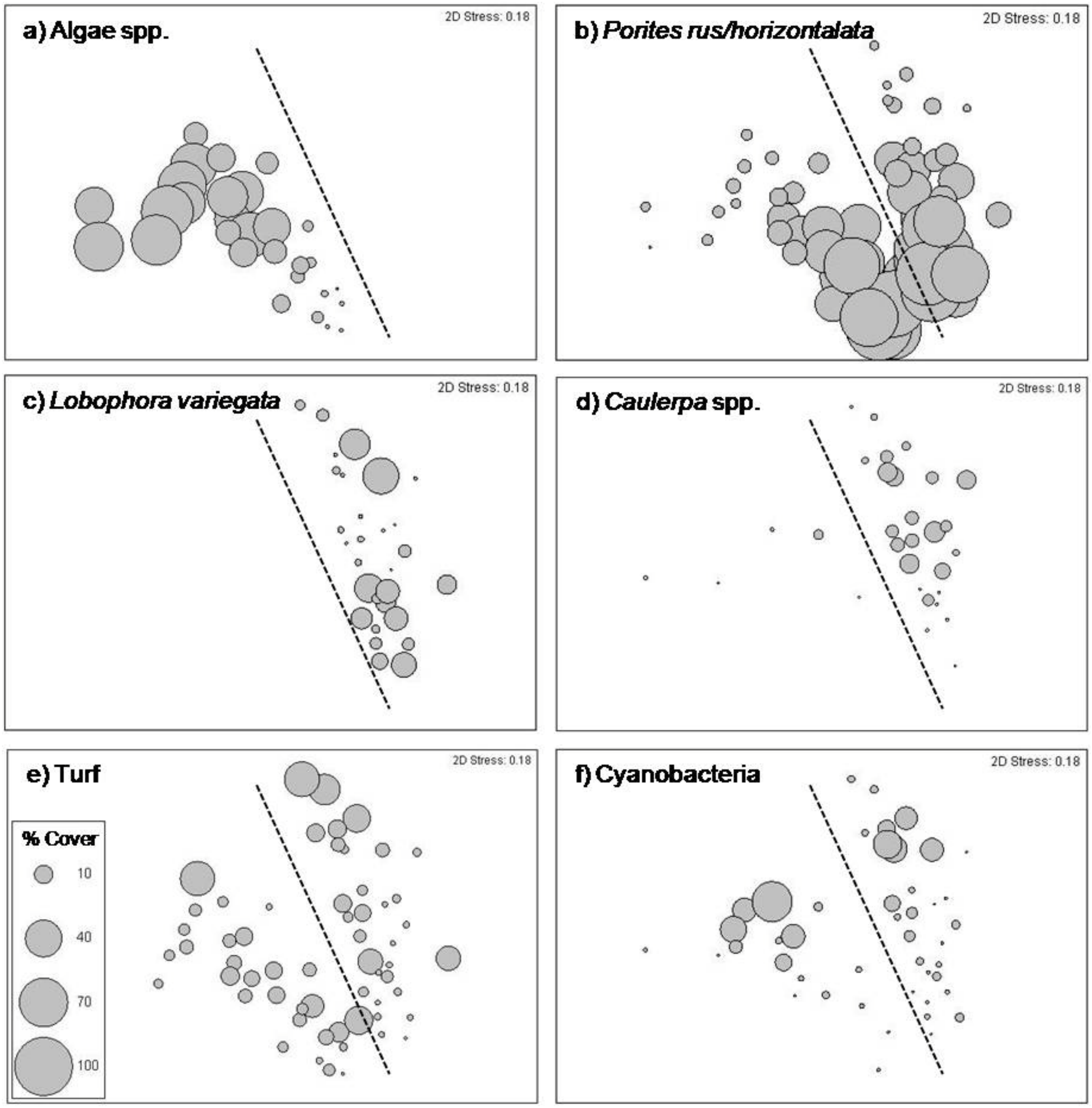


Figure 3.7. The percent cover of six taxa that explained >5% of the difference between the ISM (right of dotted line) and PM (left of dotted line) methods overlain on the nMDS plot from Figure 3.6. a) algae spp. (17.9% of the difference explained); b) *Porites rus/horizontalata* (10.4%); c) *Lobophora variegate* (6.8%); d) *Caulerpa* spp. (5.6%); e) turf (5.4%); f) cyanobacteria spp. (5.2%). Differences in the percent cover of these taxa accounted for 51.3% of the observed dissimilarity between the two methods. Additionally, *P. rus/horizontalata* and algae spp. account for approximately 30% of the observed dissimilarity between the strata.

Differences in the strata appear to be related to changes in cover of *P. rus* and algae (Figure 3.7a, b). As *P. rus* decreased, it was replaced primarily by algae taxa (algae spp. for PM and numerous algae taxa for ISM). Changes in the cover of *P. rus* and algae spp. accounted for approximately 30% of the difference among the strata.

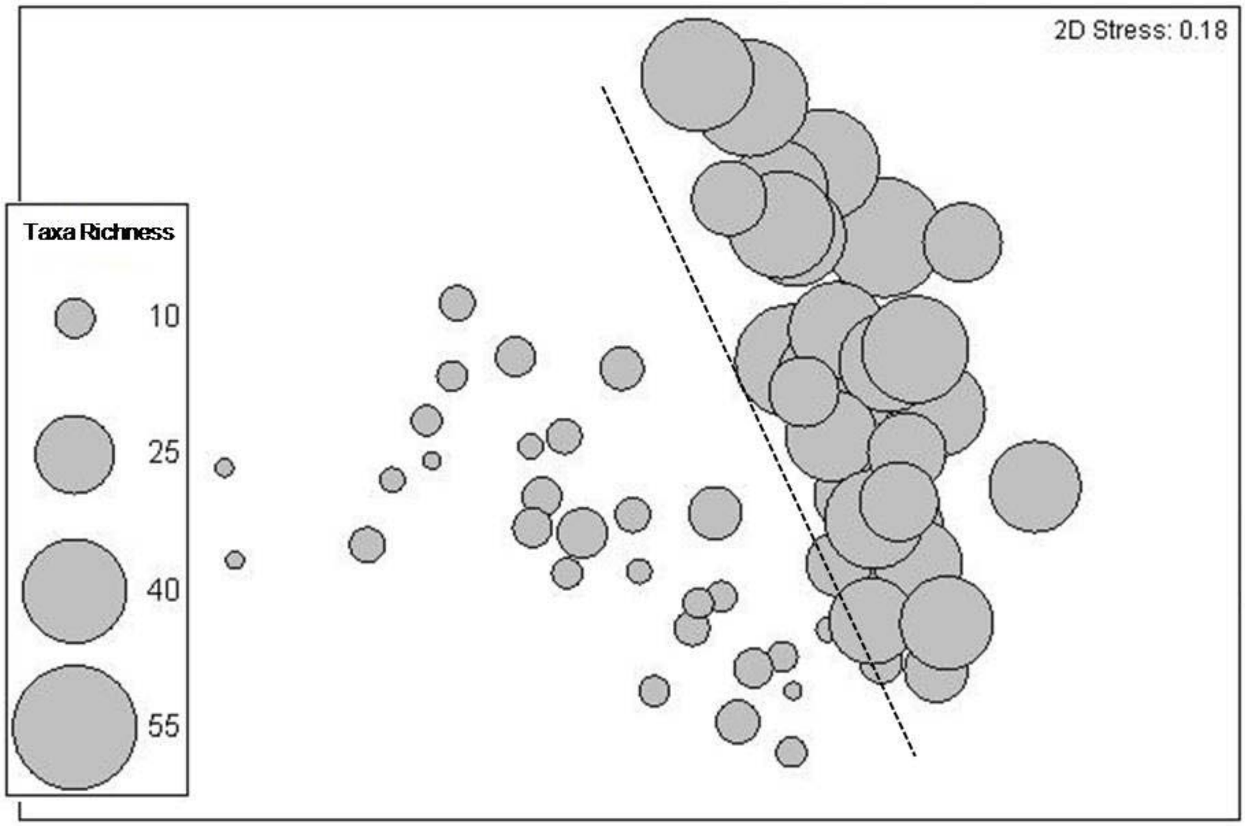


Figure 3.8. The difference between the ISM (right of dotted line) and PM (left of dotted line) is significantly correlated with Taxon Richness (ρ=0.402; p=0.01). The ISM identified more taxa than the PM.

3.2.2.3 Grouped Taxa (Coarsest Taxa Resolution [e.g., algae, coral, other etc.])

When the taxa were combined into coarse taxonomic groups, no significant difference was found between the ISM and PM (ANOSIM; R=0.022; p=0.299). The nMDS plot showed the clusters of points corresponding to the ISM and PM overlapped. However, even though the communities described by each method could not be distinguished, the direct comparability between the two methods was low. Rarely were method-site pairs nearest to each other (*e.g.*, see Site 7 as compared to Site 1 in Figure 3.9). A significant strata effect was found (ANOSIM; R=0.142; p=0.008), but only the Indirect-slope differed from all other strata. No other differences were found.

3.2.2.4 Coral Taxa

No significant difference was found between the ISM and PM when cover of coral taxa were analyzed (ANOSIM; R=-0.001; p=0.419). The nMDS plot (Figure 3.10) showed an unusual pattern of points. Points for the two methods overlap on the right side of the plot, showing a high amount of similarity in the communities described by the two methods. The sites had high cover of *P. rus*. The dominance of *P. rus* decreased moving left across the plot, and the communities described by the two methods began to show evidence of divergence as the points

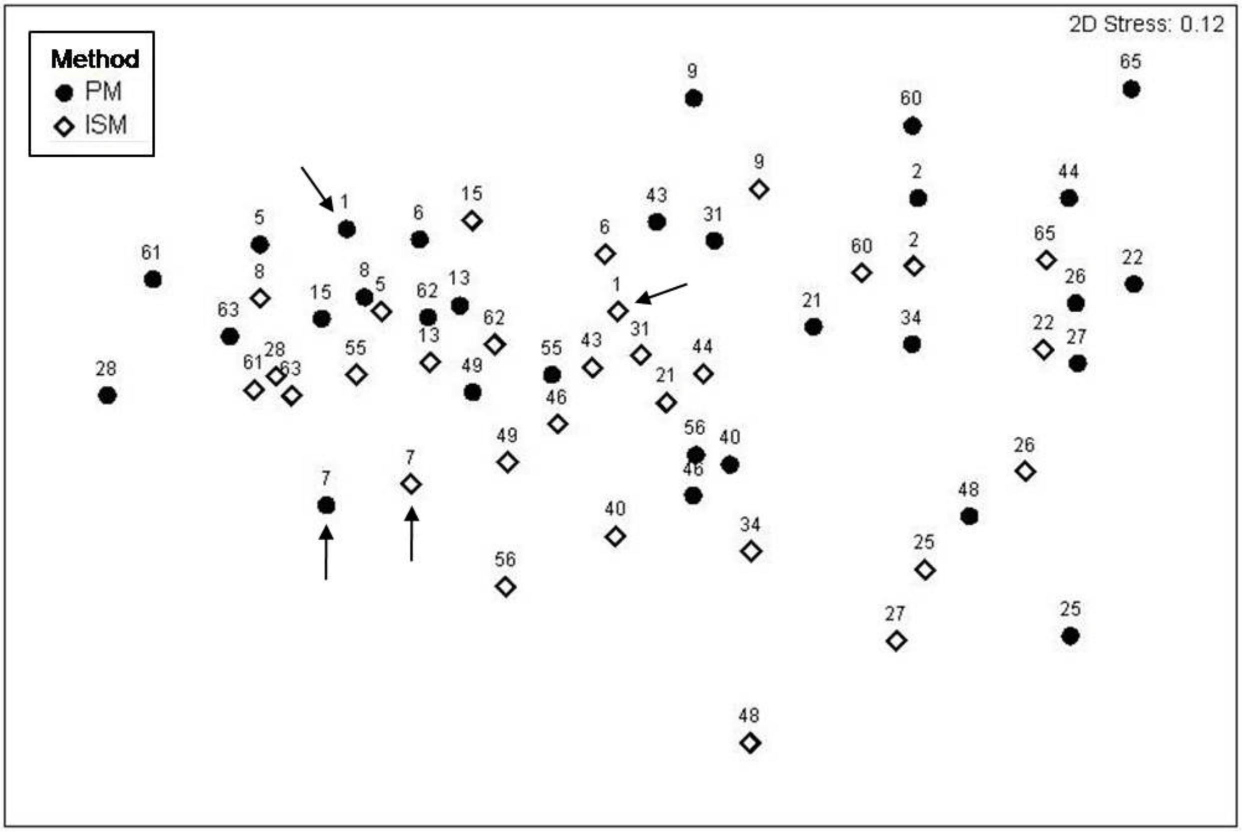


Figure 3.9. The nMDS plot for Benthic Cover of Grouped Taxa. Symbols represent the benthic community described by either the ISM or PM at a survey site. Numbers correspond to the survey site identification (see Figure 1.1). The communities described by the two methods did not differ. However, method-site pairs were not nearest to each other for most sites (*e.g.*, compare Site 7 with Site 1 [marked with arrows]), showing poor direct comparability between the ISM and PM. A stress value of 0.12 falls within the range indicating that the plot represents a useful two-dimensional representation.

began to "fan" apart. This divergence is associated with taxonomic richness, which increases toward the top of the plot (Figure 3.10).

No significant differences were found among the strata (ANOSIM; R=0.055; p=0.075), but a second order analysis revealed an interaction among the factors. When the methods were examined independently, no significant strata effect was found for the PM. For ISM significant effect was found (ANOSIM; R=0.095; p=0.001); coral communities on the Indirect-Slopes significantly differed from all other strata. No other differences were observed.

3.2.2.5 Coral Morphological Groups

When the coral community was examined at the morphological level, the ISM and PM showed no significant difference between the methods (ANOSIM; R=-0.068; p=0.986) or among the strata (ANOSIM; R=0.056; p=0.093). Agreement between the two methods was associated with the percent cover of *P. rus* at a site (Figure 3.11). The comparability of the two methods increased as the percent cover of *P. rus* increased.

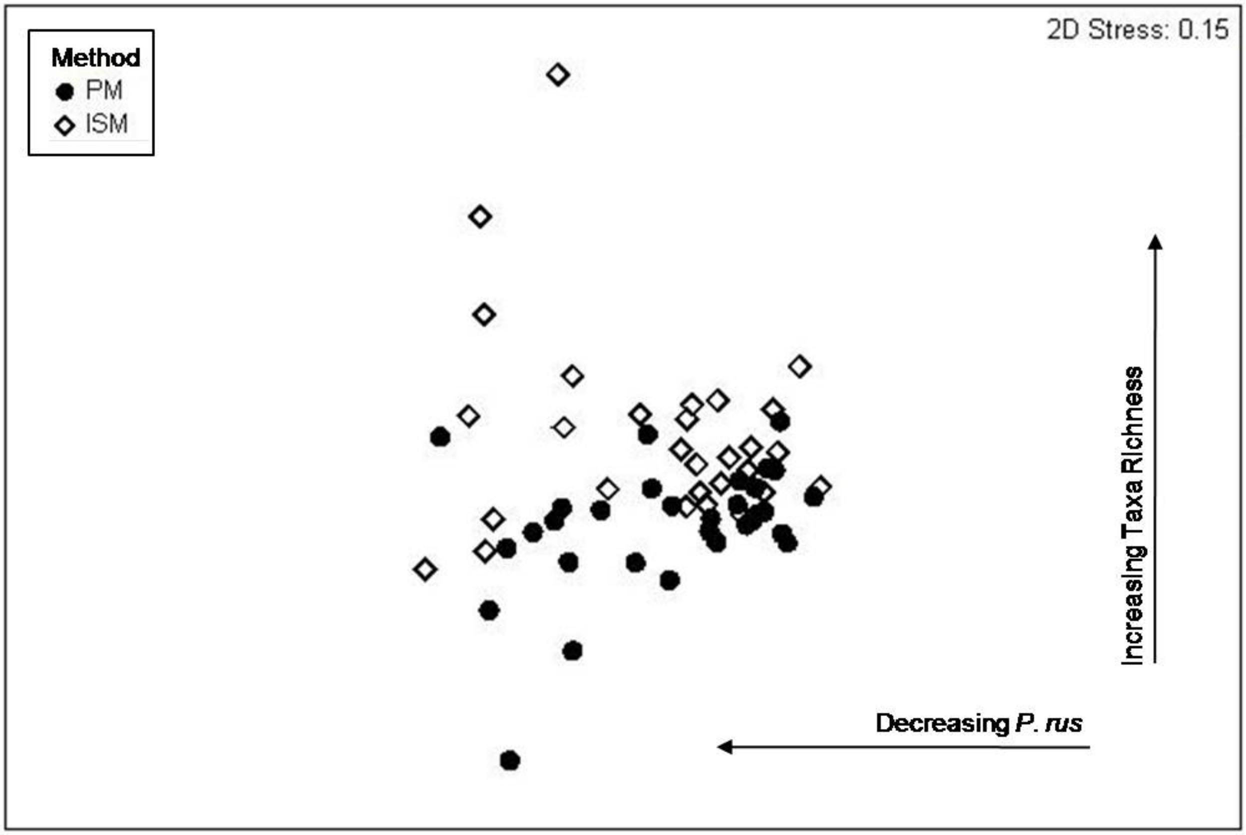


Figure 3.10. The nMDS plot for percent cover of Coral Taxa. Symbols represent the benthic community described by either the ISM or PM at a survey site. The communities described by the two methods did not differ. A stress value of 0.15 falls within the range indicating that the plot represents a useful two-dimensional representation.

3.3 Coral Colony Density

The PM systematically overestimated the true Coral Colony Density (see section 2.4.1). While not ideal, a known overestimation in one set of data does not necessarily preclude a statistical analysis because the overestimation can be incorporated into the interpretation of the results. An initial analysis was conducted on the Coral Colony Density data, but additional problems with the PM data set were found. Specifically, a data inconsistency, separate from the overestimation described above, was identified. The inconsistency was corrected but not the systematic overestimation. The new data was received too late (24 days after the agreed upon date) to re-run the analyses in time for inclusion in this report. While no statistical comparison could be run, the failure of the PM to produce timely and appropriate Coral Colony Density data demonstrates that the two methods are not directly comparable within the scope of this study and, therefore, it is concluded at this time that the PM was unable to describe the coral community using Coral Colony Density.

3.4 Coral Colony Size

Multiple methodological problems were identified with the Coral Colony Size data collected by the PM (see section 2.4.1). In addition to the overestimation error associated with the Coral

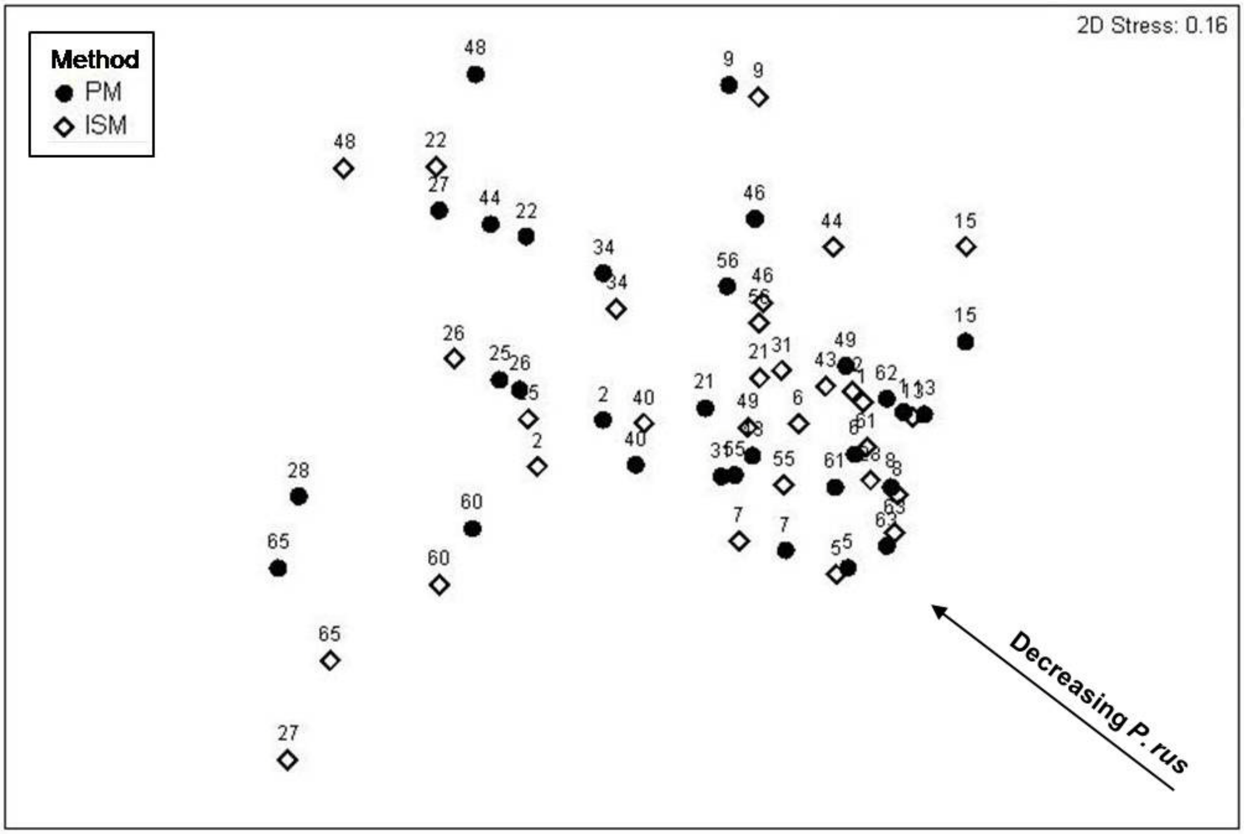


Figure 3.11. The nMDS plot for percent cover of coral taxa by general morphology. Symbols represent the benthic community described by either the ISM or PM at a survey site. Numbers correspond to the survey site identification (see Figure 1.1). The communities described by the two methods did not differ. Based on the proximity of the method-site pairs, the direct comparability between the methods was good for some sites (e.g., Sites 5, 6, 9, 34 etc.), but not all. However, overall methods were not directly comparable. A stress value of 0.16 falls within the range indicating that the plot represents a useful two-dimensional representation.

Colony Densities, the size estimates as provided by the PM do not actually measure individual coral colony size. Size measurements were not made of the coral colony, only the longest visible dimension within the photo-quadrat. This artificially truncated any colony that extended beyond the border of the photo frame into a randomly-selected smaller size class with a maximum size limitation of 120 cm (the diagonal dimension of the photo-quadrat). As a result, the data collected has no easily interpretable biological or ecology meaning.

This issue may not be correctable without collecting additional photo-quadrats adjacent to the original ones in order to assess border colonies. While no analysis could be run, the lack of appropriate Coral Colony Size data resulting from the PM demonstrates that the two methods are not directly comparable in this study and that the PM was unable to describe the size frequency distribution of the coral community.

<u>3.5 Coral fragments</u>

A total of 1588 coral fragments from nine species were found (Table 3.4.), but the number of fragments found by the PM is known to be overestimated (see section 2.3.1). *Porites* *rus/horizontalata* accounted for over 54% of all observed fragments. Fragments were observed at every site but one (site 22), but the ISM found fragments at more sites (26 of 29) than the PM (22 of 29 sites).

The ISM found significantly more total fragments at a site than the PM (1-sample Wilcoxon; W=107; p=0.030). The ISM found more fragments for every species except *Pavona cactus* and *P. varians* (only one fragment found). Due to insufficient bottom time, the ISM was unable to count *P. cactus* fragments at Sites 1, 13, and 15, which were three of the six sites where *P. cactus* fragments were found by the PM and accounted for 60% of the *P. cactus* fragments counted by the PM. At sites where fragments of *P. cactus* were counted by both methods, nearly identical fragment total were found by the ISM (111 *P. cactus* fragments) compared to the PM (108 *P. cactus* fragments).

However, when the known overestimation present in the PM coral fragment data is considered, the differences between the two methods may be magnified. The true difference in the coral fragment data collected by the ISM and PM is larger than is shown here. Unfortunately, without correcting the PM coral fragment data it is impossible to guess at the magnitude of overestimation.

The comparability between the methods was significantly affected by strata (ANCOVA; F=3.07, df= 3,24; p=0.047), but follow-up pairwise multiple comparisons were not sensitive enough to detect differences among them.

Comparability between the methods decreased with increasing rugosity (ANCOVA; F=8.82, df= 1,24; p=0.007). At low rugosity, the two methods found similar numbers of fragments, but the

Table 3.4. Total number of fragments (n) and their percent of the total (%) found using the PM and ISM.

	PM		ISM	
Taxa	n[1]	%	n	%
Acropora formosa	0	0	1	0.1
Acropora spp. (corymbose)	12	1.8	34	3.6
Pavona cactus	268	40.4	111[2]	11.7
Pavona decussata	0	0	26	2.7
Pavona varians	1	0.2	0	0
Pectinia paeonia	0	0	5	0.5
Pocillopora damicornis	3	0.5	13	1.4
Porites cylindrica	125	18.8	141	14.8
Porites rus/horizontalata	254	38.3	620	65.2
TOTAL	663		951	

[1]Counts made by the PM are known to be overestimates (see section 2.4.1).
[2]Fragments were too numerous to count at Sites 1, 13, and 15 and are not included in this value.

difference between the methods increased as rugosity increased. When examined, the total number of coral fragments found using the PM was uncorrelated with rugosity (Pearson Product Moment; r= 0.250, p=0.190), whereas fragments found with the ISM increased with rugosity (Pearson Product Moment; r= 0.609, p<0.001).

Cover of *Porites rus* was significantly correlated with rugosity (Pearson Product Moment; r= 0.656, p<0.001) and was most likely the primary source of increasing topographic complexity within the survey area. For both methods, *P. rus* was a significant source of coral fragments (Table 3.4). The slope of the relationship between *P. rus* fragments and *P. rus* cover was steeper for the ISM than the PM (Figure 3.12). The correlation was also weaker for the ISM, as shown by the greater scatter of points. This different relationship between the two methods for the detection of *P. rus* fragments with changes in *P. rus* cover was responsible for lower comparability between the two methods at higher rugosity..

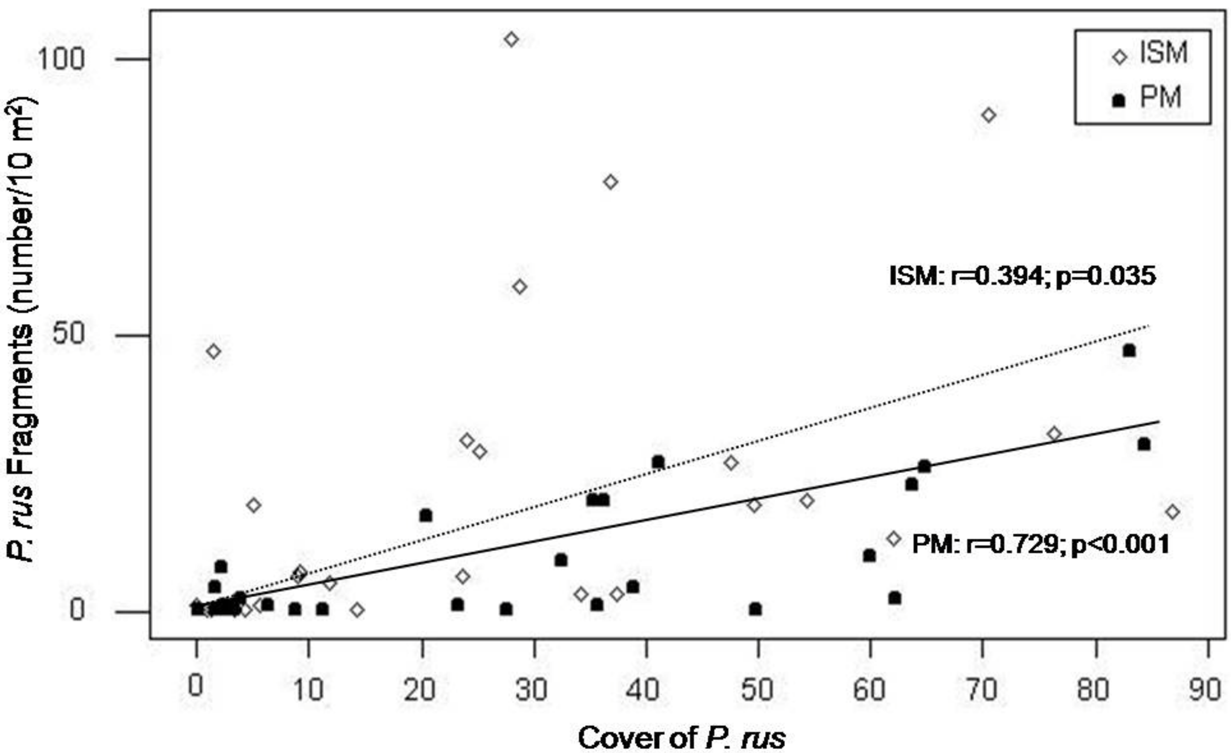


Figure 3.12. The slope of the relationship between *Porites rus* fragments and *P. rus* cover is steeper (yet more variable) for the ISM (dotted line) than for the PM (solid line). Both ISM and the PM correlations are significant.

3.6 Percent Colonies with Complete Fission and Percent Colony Mortality

The ISM found a significantly higher proportion of the colonies at a site that had undergone complete fission than did the PM (Paired t-test; t=-8.22; df=28; p<0.001). The ISM identified 20 taxa having undergone complete fission, whereas the PM identified five taxa (Table 3.5). Of the colonies undergoing complete fission, the ISM estimated a significantly higher percent mortality that the PM (Paired t-test; t=-7.96; df=28; p<0.001).

Two taxa for which more than one colony was identified having undergone complete fission were identified by both methods. For *Pavona cactus*, the ISM found over five times more colonies undergoing fission than did the PM. For *Porites rus*, this value was even higher; the ISM identified 34 times more colonies having undergone complete fission compared to the PM. For both taxa, the average percent mortality of those colonies that had undergone complete fission did not differ.

Table 3.5. Mean (±SE) percent of colonies per site undergoing complete fission and mean (±SE) percent mortality of colonies that have undergone complete fission.

	% Fission		% Mortality[1]	
Taxa	PM	ISM	PM	ISM
Acropora formosa/aspire	-	0.3 ± 0.3	-	15
Astreopora myriophthalma	-	2.2 ± 1.8	-	60.8 ± 2.2
Favites russelli	-	3.4 ± 3.4	-	65
Galaxea fascicularis	-	4.3 ± 3.5	-	5.0 ± 0.8
Herpolitha weberi	-	3.4 ± 3.4	-	6
Hydnophora exesa	-	0.5 ± 0.5	-	4
Lobophyllia hemprichii	-	1.7 ± 1.7	-	35
Montipora grisea	-	0.5 ± 0.5	-	2
Montipora sp.	0.4 ± 0.4	-	25	-
Pachyseris speciosa	1.1 ± 1.1	3.4 ± 3.4	6	2
Pavona cactus	0.3 ± 0.2	1.6 ± 0.9	40.3 ± 10.1	38.7 ± 4.7
Pavona cf. bipartita	-	3.4 ± 3.4	-	7
Pavona decussata	-	0.1 ± 0.1	-	2
Pectinia paeonia	-	0.5 ± 0.5	-	25
Pocillopora damicornis	-	1.3 ± 1.2	-	55.0 ± 5.3
Porites cf. solida	-	1.7 ± 1.7	-	55
Porites cylindrica	-	11.9 ± 3.7	-	36.7 ± 5.0
Porites lobata	-	2.3 ± 2.3	-	7
Porites lutea	<0.1 ± <0.1	10.1 ± 5.0	7	27.4 ± 4.7
Porites rus/horizontalata	0.3 ± 0.2	10.1 ± 1.6	32.8 ± 7.8	38.6 ± 4.9
Psammocora contigua	-	0.3 ± 0.3	-	8

[1]No SE for n=1 colony

3.7 Coral Growth Anomalies

Neither method noted the presence of gross growth anomalies at any site. The PM noted the presence of several "unusual" conditions (Table 3.6). These "unusual" conditions were not collected as part of the data for the ISM. The PM observed these unusual conditions in photographs at 13 of the 30 survey sites.

Table 3.6. "Unusual" coral conditions noted by the PM.

Site	Symptom	Coral	Note
5	"blue nodes" "pink spot"	*Porites lutea* *Porites rus*	- Observed on 2 colonies
7	discoloration "pink spot" "pink discolor"	*P. lutea* *P. lutea* *P. lutea*	4 colonies 2 colonies -
21	bleaching	No ID provided	-
22	bleaching	*P. rus*	2 colonies
25	bleaching	*P. rus*	3 colonies
26	bleaching	*P. rus*	3 colonies
27	bleaching	*P. rus*	1 colony
31	"pink spot" bleaching	*P. rus* *P. rus*	5 colonies 2 colonies
34	bleaching	*P. rus*	1 colony
40	bleaching	*P. rus*	3 colonies
43	bleaching	*P. rus*	1 colony
46	bleaching	No ID provided	-
65	bleaching	*P. lutea*	1 colony

4.0 Discussion

One of the most important decisions a field researcher must make is the selection of a survey method that will perform in the site-specific conditions of the study area to collect the target data with the resolution, precision, and accuracy necessary to achieve the research or survey objectives. This study compared the performance of a photo-quadrat method and an *in situ* quadrat method in the collection of a suite of coral reef benthic data within a heterogeneous coral reef ecosystem. While the primary goal of this study was to assess how well the two methods compared in a specific location (near Polaris Point, Apra Harbor, Guam), it was hoped that the study would also reveal some general insights into the wider applicability of each method. It is important to note that this report draws no conclusion about which method is "better." This conclusion involves a value judgment that can only be made after considering the project-specific objectives; the type, resolution, and precision of the data to be collected; and the site-specific conditions of the study area.

4.1 Method Comparison

Overall, the data collected by the PM and ISM at the same sites compared poorly (Table 4.1). This poor comparability resulted primarily from the different taxonomic resolutions achievable with each method. Almost seven times more taxa were identified by the ISM than were identified by the PM (an average of 25 more taxa per site). Not surprisingly, similarities in the data collected by the two methods increased as data were lumped into coarser taxonomic groups. However, even at the coarsest taxonomic resolution (*i.e.*, Grouped Taxa, where data were combined into broad categories as simple and encompassing as coral, algae, sponge etc.), a statistically significant difference remained between the two methods (Table 3.2).

The simplest explanation for the discrepancy in taxonomic resolution between the PM and ISM is that many taxa could not be identified from the photographs. This has been observed in other studies, where taxonomic richness from a PM approach is low relative to other *in situ* methods (Foster et al. 1991, Miller et al. 2003). When making observations *in situ*, it is possible for observers to examine organisms from multiple angles, pick them up, and collect specimens, if necessary, for later laboratory identification by taxonomic specialists. This is not possible with the PM alone.

In this particular study, it is also possible that the observers conducting the ISM had more experience working in Guam and a wider range of taxonomic expertise than the observers who employed the PM. The ISM team included a phycologist, a sponge expert, a general invertebrate specialist, and multiple coral biologists. All of these individuals had considerable experience working in Guam and the Mariana Islands. The PM team was limited only to several experienced coral biologists and this may have resulted in reduced taxonomic resolution for the non-coral taxa. However, even the coral Taxon Richness revealed by the PM was approximately a quarter of that revealed by the ISM, so differences in taxonomic expertise alone do not seem to fully explain the discrepancies between the two methods. The only way to fully address this particular issue is to have the same personnel conduct both the ISM and PM, which was not possible given the project-specific limitations underlying this study.

On coral reefs, rugosity is often correlated with species richness and community structure (Idjadi & Edmunds 2006, Pratchett et al 2008 and references therein, Alvarez-Philip et al. 2009). A potential shortcoming of the PM is its reduction of a three-dimensional habitat into a flat, two-dimensional planar projection (Hill and Wilkinson 2004). As a result, the performance of the PM can decrease with increasing rugosity (Hill and Wilkinson 2004). In contrast, the ISM can accommodate changes in rugosity because observers are able to examine vertical surfaces from multiple angles, look beneath overhanging features, and spot organisms in interstitial spaces in the reef.

In this study, benthic rugosity had an important and somewhat unexpected influence on the results of the analysis. The coral *P. rus*, which has a variable and highly rugose growth form, was significantly correlated with rugosity. As *P. rus* increased in dominance, however, Taxon Richness at the site tended to decline for the ISM or remain constant in the case of the PM. As a result, the comparability of the methods was often uncorrelated with rugosity because the potential difficulties for the PM associated with higher rugosity were off-set by improved

Table 4.1. Summary of the findings for the direct comparison of the ISM and PM. These analyses examined whether the data collected by the two methods at the same site were statistically different. "Data Different" summarizes the result of the statistical analyses that tested for significant differences in the data collected for the ISM and PM (Yes=data were significantly different; No=data were not significantly different.

Variable	Data Different? Yes	No	Notes
Taxon Richness			
Total Taxon Richness	X		ISM>PM; rugosity significant
Shannon-Weiner Index	X		ISM>PM; strata significant
All Taxa	X		
Coral Taxa	X		
Benthic Cover			
All	X		
Reduced	X		
Grouped	X		
Coral	X		
Coral Morph	X		
Coral Colony Density			
Coral Taxa	†		PM was unable to provide revised data within the agreed study timeline
Coral Morphology	†		PM was unable to provide revised data within the agreed study timeline
Coral Colony Size			
Size Frequency	†		PM was unable to provide required measures of coral colony size for comparison
Coral Fragments			
Total Fragments	X		ISM>PM; rugosity and strata significant
Percent Fission			
% Fission	X		ISM>PM
Percent Mortality			
% Mortality	X		ISM>PM
Coral Growth Anomalies			
% Occurrence		X	Gross anomalies were not identified within the communities by either method

†No statistical comparison of the methods was conducted for data on Coral Colony Density (section 3.3) and Coral Colony Size Class (section 3.4), but a determination of not comparable was made for this study based on the failure of the PM to produce appropriate data for analysis. See appropriate results section for additional information on each analysis.

performance of the PM with the decrease in Taxon Richness. When rugosity effects were seen (*i.e.*, decrease in Taxon Richness, increase in number of coral fragments), they were consistent with what would be expected when a three-dimensional structure is reduced into a planar view: for the PM, data changed little or not at all with changes in rugosity while the ISM did change.

4.2 Community Comparisons

Ultimately, the goal of any comparison of methods comparison should be to determine whether the communities described by each method are similar. At finer taxonomic resolutions, the two methods failed to describe the same coral reef benthic community (Table 4.2) when using either Taxon Richness or Benthic Cover data. Only when taxa were lumped into coarse groups (*i.e.*, Grouped Taxa and Coral Morphology) did the methods describe similar communities. However, based on the direct comparison of the methods, this positive result should be viewed with caution

Table 4.2. Summary of the findings for comparison of the communities described by the ISM and PM. These analyses examined whether the two methods described statistically different communities over the study area. "Data Different" summarizes the result of the statistical analyses that tested for significant differences between the communities described by the ISM and PM (Yes= communities described by the two methods were significantly different; No= communities described by the two methods were not significantly different).

Variable	Data Different? Yes	No	Notes
Taxon Richness			
All Taxa	X		strata significant (ISM only)
Coral Taxa	X		
Benthic Cover			
All	X		strata significant
Reduced	X		strata significant
Grouped		X	strata significant
Coral	X		strata significant (ISM only)
Coral Morph		X	
Coral Colony Density			
Coral Taxa	†		PM was unable to provide revised data within the agreed study timeline
Coral Morphology	†		PM was unable to provide revised data within the agreed study timeline
Coral Colony Size			
Size Frequency	†		PM was unable to provide required measures of coral colony size for comparison

†No statistical comparison of the methods was conducted for data on Coral Colony Density (section 3.3) and Coral Colony Size Class (section 3.4), but a determination of not comparable was made for this study based on the failure of the PM to produce appropriate data for analysis. See appropriate results section for additional information on each analysis.

because it represents an "inconclusive" outcome (see section 2.6.1), which has resulted most likely from insufficient sampling within the study area. Adequate statistical sampling could result in a significant difference being found for both the Grouped Taxa and the Coral Morphology. It is currently unclear as to what sampling effort would be.

It was apparent from the analyses conducted at different levels of taxonomic resolution, that identifying Taxon Richness is important for distinguishing spatial variability within the study area. As the taxa resolution became more coarse, the ability to detect differences between strata decreased (*i.e.*, the R-statistic of the ANOSIM decreases). When using benthic cover data, both methods were able to similarly distinguish the Indirect-Slope from the other strata. When only the coral taxa were considered, however, the PM was no longer able to distinguish and strata, whereas the ISM continued to distinguish the Indirect-Slope from the others (Figure 4.1). This result is troubling considering the widespread use of photographic methods to collect coral cover data in the absence of non-coral taxa. Whether this result is specific to this study is unclear and warrants additional investigation from the scientific community.

The similarity of the communities described by the PM and ISM improved when *P. rus* was a dominant component of the reef community. The PM did well identifying the benthic cover provided by *P. rus* and the method may perform similarly to ISM in situations where the benthic community has low Taxon Richness and the common organisms can be easily identified in photographs. However, even when *P. rus* was dominant, the community described by the PM was still significantly different from the ISM. While *P. rus* may have dominated at a site, it did not exclude all other taxa, and this remaining Taxon Richness appears to have been captured by the ISM but not the PM.

4.3 Density-based and Coral Colony Size Data

One of the primary objectives of this study was to compare the performance of the PM and ISM across a wide variety of data types. The PM traditionally has been used for collection of benthic cover data, which continues to be a mainstay of coral reef ecology. Data on coral colony density and colony size have become more common because of the potential demographic information they contain (Hall and Hughes 1996, Bak and Meesters 1998, Birkeland 1999, Meesters et al. 2001), which is missing from benthic cover data alone (Bak and Meesters 1998). Collection of density-based data requires that observers delineate coral colonies and use appropriate quadrat sampling methods to avoid over- or underestimations.

In this study it was not possible and/or appropriate to compare Coral Colony Density and Coral Colony Size data collected by the two methods. Methodological issues (see section 2.4.1) and data inconsistencies either precluded analysis entirely (in the case of the Coral Colony Size data) or left insufficient time to complete the analysis for inclusion in this report (in the case of Coral Colony Density data).

Concerns about insufficient quadrat size and criteria for delineating certain coral taxa have been raised and are valid for consideration and discussion. The optimal quadrat size would sample enough area to capture sufficient numbers of individuals to achieve high statistical

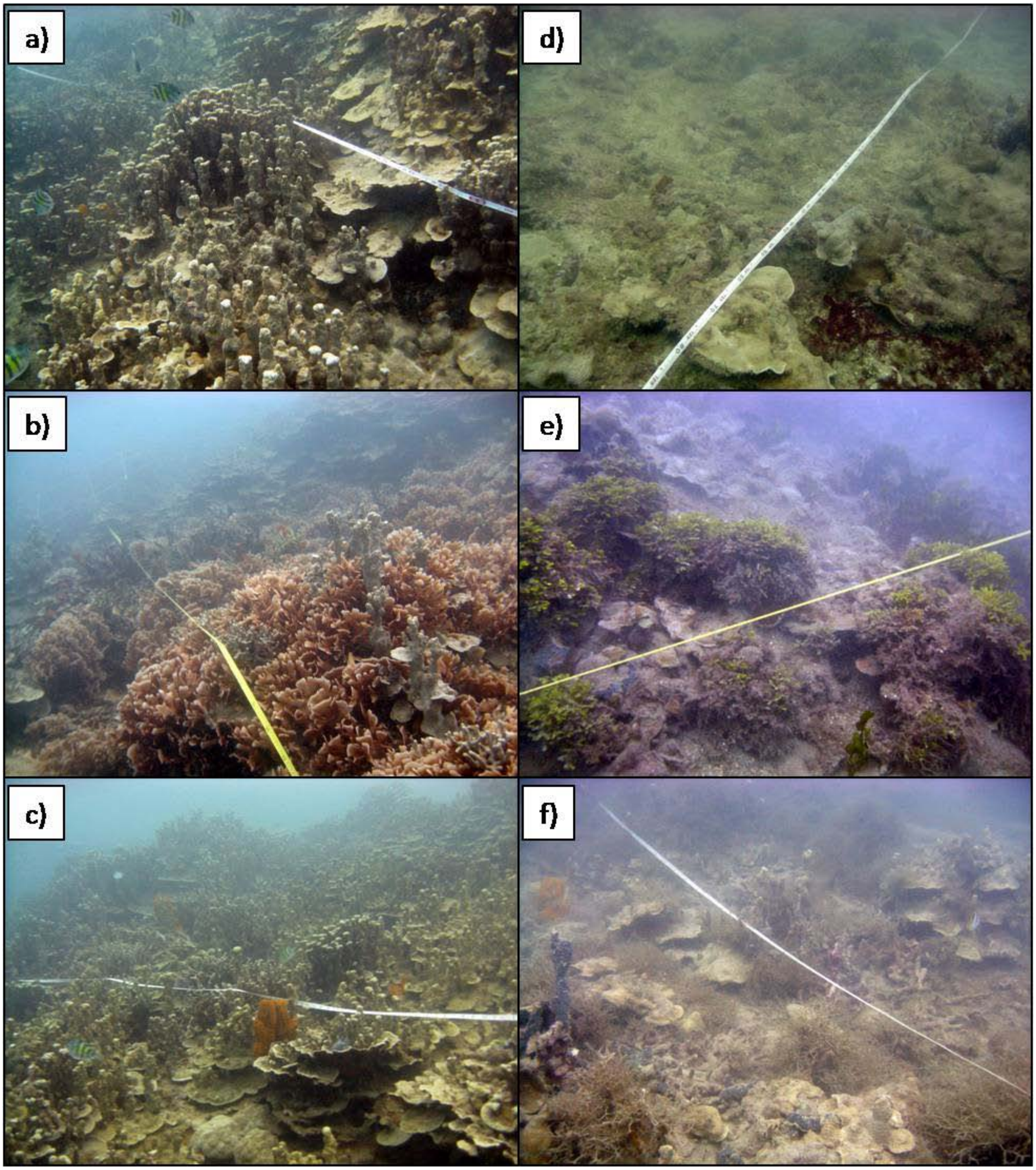


Figure 4.1. Habitat photos taken at three Indirect-Slope (a,b,c) and three Direct-Slope (d,e,f) sites. When only the benthic cover of coral taxa were used in the analysis, the PM was unable to distinguish between the coral communities within these two strata, whereas the ISM showed significant differences. Representative photos for each site were selected for clarity. Sites were selecting by ordering all sites within a strata from "nicest" to "worst" and selecting the middle three sites. a) Site 8 (Indirect-Slope), b) Site 15 (Indirect-Slope), c) Site 61 (Indirect-Slope), d) Site 21 (Direct-Slope), e) Site 22 (Direct-Slope), f) Site 44 (Direct-Slope).

precision (Krebs 1989). Thus, quadrat size should be directly related to the size of the organisms being sampled. Using the center of the colony as the sole determinant of whether a colony is included within the quadrat (as per the ISM in this study) reduces the effective size of all colonies to a single point. Therefore, density sampling is unbiased regardless of quadrat size when using the colony-center rule. In this case, quadrat size affects only the precision of the density estimate. Quadrats that are too small will vary widely in number of colonies captured and result in a higher variance for the estimated mean density. Quadrats that are too large limit the sample size, resulting in lower precision of the estimates. Optimal quadrat size can be calculated following the methods of Hendricks or Wiegert, as detailed in Krebs (1989), but such calculations were beyond of the scope of this study. In this study, the ISM employed the colony-center rule and also had an effective quadrat size of 10 m^2 for all density-based data.

Because colonies along the edges of the photo-quadrats were not entirely visible, the PM as employed in this study, was unable to use the colony-center rule to determine if a colony should be included within a quadrat. However, counting colonies in which any part is within the quadrat leads to disproportionate sampling of larger colonies and overestimation of colony density, which Zvuloni et al. (2008) refer to as a Type II condition. The only way to correct the resulting error is to count corals that occur exclusively within the quadrat frame, leading to a Type I condition (Zvuloni et al 2008). With a Type I condition, quadrat size become significant for the PM, because any coral that is larger than that quadrat frame will be excluded from any density and colony size estimate, making any correction to the Type I bias (underestimation of true density) problematic. Zvuloni et al. (2008) conclude that "…the method of photo-quadrats combined with the corrected type I approach is best for reefs with coral colonies that are small relative to the size of the sampling units" [page 151].

Potential solutions may exist to correct the problems observed with the PM density-based and Coral Colony Size data and allow for a statistical comparison in the future (Zvuloni et al. 2008), but caution should used when applying any mathematical correction for density estimates because corrected estimated densities may not result in an increase in accuracy (Bakus et al. 2007). These mathematical corrections (Zvuloni et al. 2008) would require re-analysis of all photographs, introduce a different form of error into the estimates, and, in the case of this study, may not even be possible to use. A better approach may be to alter the PM to allow for a larger area of view of the bottom (*e.g.*, take additional photos around each photo-quad) so that it can be determined if a colony's center is within the photo-quadrat. This solution, as demonstrated by Zvuloni et al. (2008), is the simplest approach to handle the methodological error that resulted in density overestimates by the PM in this study. This "colony-center" solution would also allow for appropriate sizing of coral colonies, because the colonies whose centers appear in the quadrat would be entirely visible to the photo-analyst and could be appropriately sized.

Three coral taxa present in the study area have the potential to be problematic for delineating individual colonies. We consulted with numerous coral scientists experienced in Apra Harbor or with these specific species regarding colony delineation of these species. The general consensus of these scientists was that while difficult, if given adequate time, colonies of these taxa could be successfully delineated. Additionally, three *in situ* surveys, one conducted directly within the project area (Smith 2007), and two in a nearby area within Apra Harbor that has the same taxa (Smith 2004, Smith and Marx 2006), were conducted by Navy biologists using methods that required successful colony delineation. Some of these documents have been used as supporting studies for Navy environmental compliance documents, including for conducting assessments of project impacts (Marine Resource Consultants 2007) and associated habitat equivalency analysis (Del Vecchi and Donlon 2007). In none of these documents do the authors or contributing coral reef scientists express concerns about using the colony-based information in Apra Harbor. While errors of subjectivity are certain to exist (subjective errors are not restricted to any single method), the authors of this report are confident that with consistent and careful application of the described boundary delineation rules (see section 2.5), that coral colonies were consistently delineated at all sites unless otherwise noted. Regardless, concerns about quadrat size and criteria for delineating certain coral taxa does not preclude analysis of the density-based data.

4.4. Selecting a Method

When conducting benthic surveys of coral reefs, no single method is the proverbial "silver bullet." Every method has its limitations in what types of data can be provided and under what field conditions it can adequately perform. It is important to understand these limitations and to select the most appropriate method to meet specific requirements of each individual project.

Overall, the PM and ISM compared poorly in this study. Not only did the two methods fail to compare well when collecting data within the same site, but they often described significantly different coral reef communities over a larger spatial scale.

To achieve the level of resolution described in this report, the ISM required considerable field expertise. Compared to the PM, more time was needed in the field to collect data using the ISM, but depending upon the desired taxonomic resolution (*e.g.*, fine or coarse) and the type of data collected (*e.g.*, benthic cover or organism density), the in-field time may not be significantly higher. However, in a heterogeneous environment, or an environment that allows for limited time in the field (*e.g.*, deep water surveys), the PM may be a preferable method to collect some types of data (*i.e.*, benthic cover) provided the desired taxonomic resolution is coarse and the common organisms at the study site are readily distinguishable in the photographs. Under these conditions, the PM may provide more precise estimates of benthic cover because of the greater replication that would be possible over a given time compared to the ISM.

In this study, cost and time savings were not achieved by using the PM compared to the ISM for collecting the desired data. The PM failed to produce the complete data set and for three of the eight variables, the data were known to be overestimated or failed to actually measure the target variable. Data provided by the PM took longer overall to obtain than with the ISM, which is consistent with findings from other studies (Leonard and Clarke 1993) and in the review of methods provided by Hill and Wilkinson (2004). Additionally, the primary purposes for collecting the data in Apra Harbor using the PM was to obtain information that could be used to describe the marine environment potentially impacted by the proposed CVN project. Any marine survey intended to describe the coral reef community should include a comprehensive assessment of Taxon Richness, which was not achieved with the PM.

When one of the primary goals of a project is to survey Taxon Richness, the ISM has the added flexibility to easily incorporate surveys for other organisms, such as mobile invertebrate taxa and fish. In some cases, these organisms can be surveyed by the same divers conducting benthic work (provided they have the taxonomic expertise) or can be conducted at the same time and from the same support platform. This will achieve greater cost efficiency for field work. The photographic method makes this integration more problematic because many of these mobile organisms cannot be effectively sampled using the PM as employed here, and efforts to combine the survey methods together will result is substantially longer in field times, thus eliminating a potential strength of the PM.

The ISM, while able to collect all of the planned data types without known methodological issues and within the timeframe of the project, did have shortcomings. Limits on diver bottom time resulted in data collection occurring in smaller belt transects within some sites for density-based data (5 of 29 Coral Colony Density sites) and at all sites for the Benthic Cover data. While this may not be an issue depending upon the natural variability within a site, it could result in increased variability in estimates made over multiple sites over a larger spatial scale. Additionally, in some situations and locations, there may not be sufficient time to complete the entire data collection on a single dive. However, with adequate attention to detail and time, the ISM should result in data that is unbiased as a result of systematic methodological problems.

Photographic methods are usually considered to have high precision and accuracy when compared to *in situ* methods. While the accuracy of both method was not directly assessed here, the precision of each method can be examined. In all cases in this study where precision was directly estimated (*i.e.*, a standard error of the mean calculated), the ISM had greater or similar precision than the PM. This has been shown elsewhere (Dethier et al 1993), but this result may be study-specific.

Finally, photographic methods are generally considered to have less subjectivity than *in situ* methods, but this may not always be the case (Dethier et al. 1993). However, all data collection that requires observers to make a decision (*e.g.*, visually estimates of cover, taxa identification) has some level of subjectivity associated with it. If either method is employed conscientiously and observers are trained and experienced, this subjectivity should be reduced.

In reality, the most likely preferred option for collecting data to determine proposed project impacts will be some combination of methods. For example, many protocols combine *in situ* and photographic quadrat methods to achieve their project objectives. While only *in situ* data collected by the ISM team and photographic data collected by the PM team were compared in this study, it is important note that both teams collected data with a mixture of photography and *in situ* methods. This highlights the importance combining methods as appropriate to take advantage of each method's individual strengths.

4.5 Adjustment Functions

Limited availability of resources, especially in-field expertise and funding, may be a driving consideration when choosing the best available method and may result in the selection of method that is not the best to meet the project objectives. In this situation, it is logical to wonder if an adjustment factor could be used to convert the data collected by one method into that provided by another method that may have collected data more appropriate to the project-specific objectives but which was not used for other reasons (*e.g.*, cost, lack of trained staff etc.).

Given the results of this study, it would seem theoretically possible to adjust one method to reflect another, but such effort would present numerous challenges. First, it would not be practicable to account for taxa that were not observed, and any adjusted data would still have lower taxonomic diversity and would be missing other data types for those taxa. Second, a series of adjustments would be needed because the differences between the methods are likely not consistent across taxa or community types. Additionally, each data type collected (*e.g.*, Taxon Richness, Benthic Cover etc.) would require its own adjustment function. These functions would be variable-, taxa-, and site-specific and considerable up-front investment would be needed to generate them. It would be more efficient to use the method that produces the appropriate data at the desired resolution from the beginning and forego any adjustment unless the cost to sample adequately across the project area is prohibitive enough to warrant the up-front investment in order to use the less appropriate method.

5.0 Acknowledgements

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Appendix A

Site Characteristics for all thirty survey sites used in this study. Data include Latitude, longitude, strata designation, measured rugosity and depth.

Site	Lat.	Long.	Impact	Slope-Flat	Strata	Rugosity	Depth (m)
1	13.4564757	144.657779	Ind	Slope	Ind-Slope	1.20	15
2	13.4564106	144.65778	Ind	Flat	Ind-Flat	1.11	17
5	13.4545173	144.657067	Dir	Flat	Dir-Flat	1.41	18
6	13.4542649	144.660238	Ind	Flat	Ind-Flat	1.29	5
7	13.4532235	144.660182	Ind	Flat	Ind-Flat	1.54	2
8	13.4532929	144.655993	Ind	Slope	Ind-Slope	1.79	9
9	13.4524357	144.654761	Ind	Flat	Ind-Flat	1.23	3
13	13.4513168	144.658029	Ind	Flat	Ind-Flat	1.21	14
15	13.4501143	144.659303	Ind	Slope	Ind-Slope	1.17	14
21	13.4513924	144.661484	Dir	Slope	Dir-Slope	1.14	17
22	13.4510526	144.662263	Dir	Slope	Dir-Slope	1.03	17
25	13.4488413	144.662329	Dir	Flat	Dir-Flat	1.02	14
26	13.4492632	144.663388	Dir	Flat	Dir-Flat	1.02	14
27	13.4492185	144.665582	Dir	Slope	Dir-Slope	1.05	17
28	13.4492096	144.666956	Ind	Slope	Ind-Slope	1.48	7
31	13.4478152	144.661586	Dir	Flat	Dir-Flat	1.18	15
34	13.4480385	144.664619	Dir	Flat	Dir-Flat	1.51	15
40	13.44691	144.664519	Dir	Flat	Dir-Flat	1.25	14
43	13.4462403	144.662465	Dir	Flat	Dir-Flat	1.54	14
44	13.4456241	144.661496	Dir	Slope	Dir-Slope	1.19	15
48	13.4457521	144.668274	Dir	Slope	Dir-Slope	1.02	17
49	13.4449795	144.669146	Dir	Slope	Dir-Slope	1.84	9
55	13.442889	144.663539	Dir	Slope	Dir-Slope	1.36	9
56	13.4434443	144.664951	Ind	Flat	Ind-Flat	1.10	17
60	13.4492142	144.658116	Ind	Flat	Ind-Flat	1.18	1
61	13.4488759	144.65905	Ind	Slope	Ind-Slope	1.66	12
62	13.4492118	144.660198	Dir	Flat	Dir-Flat	1.47	9
63	13.4480662	144.65826	Ind	Slope	Ind-Slope	1.55	12
65	13.4448671	144.659377	Ind	Slope	Ind-Slope	1.00	2

Appendix B

Coral colony morphology assigned to coral taxa found in this study.

<table>
<tr><th>Branching, Large</th><th>Corymbose/Tabulate</th><th>Encrusting</th><th>Massive/lobate</th></tr>
<tr><td>Acropora aspera
Acropora formosa
Porites cylindrica</td><td rowspan="5">Acropora latistella group
Acropora nasuta group
Acropora cf. aculeus</td><td rowspan="11">Caryophylliidae sp.
Cyphastrea serailia
Cyphastrea spp.
Favites russelli
Hydnophora exesa
Hydnophora microconos
Leptoseris incrustans
Leptastrea purpurea
Leptastrea sp.
Montipora cf. danae
Montipora cf. verrilli
Montipora grisea
Montipora verrilli
Montipora spp.
Pavona cf. bipartita
Pavona meandrina
Pavona sp.
Pavona varians/venosa
Pachyseris speciosa
Pectinia paeonia
Stylocoeniella armata</td><td rowspan="11">Astreopora gracilis
Astreopora myriophthalma
Astreopora randalli
Astreopora spp.
Astreopora spp.
Diploastrea heliopora
Favia favus/mathaii/pallida
Lobophyllia corymbosa
Lobophyllia hemprichii
Porites australiensis
Porites lobata
Porites lutea
Porites murrayensis
Porites solida
Porites cf. stephensoni
Porites sp.
Porites spp. (massive)</td></tr>
<tr><th>Branching, Medium</th></tr>
<tr><td>Psammocora contigua</td></tr>
<tr><th>Branching, Small</th></tr>
<tr><td>Galaxea horrescens
Pocillopora damicornis
Psammocora sp.</td></tr>
<tr><th>Disk</th><th>Folaceous</th></tr>
<tr><td>Ctenactis echinata
Fungia scutaria
Fungia sp.
Fungia sp.1
Fungiidae spp.
Herpolitha limax
Herpolitha weberi</td><td>Pachyseris speciosa</td></tr>
<tr><th>Mixed</th><th>Frond</th></tr>
<tr><td>Montipora cf. undata
Porites horizontalata
Porites rus</td><td>Pavona cactus
Pectinia paeonia</td></tr>
<tr><th>Submassive</th><th>Submassive with fronds</th></tr>
<tr><td>Galaxea fascicularis
Montipora floweri</td><td>Pavona decussata</td></tr>
</table>