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High-Resolution Landscape (2-D) Mosaics for Improved Coral Reef Monitoring Capability

Cheryl Ann Cooke
Wild, William
NIWC Pacific

R. Pamela Reid
University of Miami

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Cheryl Cooke and Bill Wild, NIWC Pacific/Space and Naval Warfare Systems Command (SPAWAR)
R. Pamela Reid, University of Miami

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The overall objective of this project was to demonstrate the utility of underwater image mosaics for coral reef monitoring. The problem of efficiently mapping and monitoring coral reef resources has relevance to the DoD for several reasons. First, at least 46 US military facilities have adjacent coral reef sites. Second, federal policy mandates that DoD characterize, assess, and monitor underwater benthic communities at these sites to ensure that DoD operations do not lead to natural resource degradation. Third, coral reef ecosystems worldwide are presently threatened by increasing levels of both human and natural disturbance.Thus, monitoring efforts that can efficiently provide data that will help distinguish between reef degradation that can be directly attributed to DoD activities versus those that that are correlated with region-wide decline are of primary concern.

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Cheryl Ann Cooke
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R. Pamela Reid
University of Miami

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NIWC Pacific
San Diego, CA 92152-5001

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NIWC Pacific
San Diego, California 92152-5001

A. D. Gainer, CAPT, USN
Commanding Officer

W. R. Bonwit
Executive Director

ADMINISTRATIVE INFORMATION

The work described in this report was performed by the Environmental Sciences Branch of the Basic and Applied Research Division, Naval Information Warfare Center Pacific (NIWC Pacific), San Diego, CA. The DoD's Strategic Environmental Research and Development Program (SERDP) and Environmental Security Technology Certification Program (ESTCP) Programs provided funding for this project. Further assistance was provided by The University of Miami's Rosensteil.

Released by
Patrick Earley, Head
Environmental Sciences Branch

Under authority of
Ayax D. Ramirez, Head
Basic and Applied Research Division

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EXECUTIVE SUMMARY

OBJECTIVES OF THE DEMONSTRATION

The overall objective of ESTCP project RC-201021 was to demonstrate the utility of underwater image mosaics for coral reef monitoring. The problem of efficiently mapping and monitoring coral reef resources has relevance to the Department of Defense (DoD) for several reasons. First, at least 46 US military facilities have adjacent coral reef sites. Second, federal policy mandates that DoD characterize, assess, and monitor underwater benthic communities at these sites to ensure that DoD operations do not lead to natural resource degradation. Third, coral reef ecosystems worldwide are presently threatened by increasing levels of both human and natural disturbance. Thus, monitoring efforts that can efficiently provide data that will help distinguish between reef degradation that can be directly attributed to DoD activities versus those that that are correlated with region-wide decline are of primary concern.

SERDP had previously supported a team from the University of Miami's Rosenstiel School of Marine and Atmospheric Research (UM/RSMAS) to research the creation and use of underwater image mosaics. The result of the SERDP-supported research was a suite of image processing algorithms, software, and best-practices that together enabled new capability for mapping and monitoring coral reef resources. The SERDP project projected that use of meso-scale, 2-D, mosaicked images of reef plots could circumvent the limitations of current state-of-the-art methods in coral reef monitoring (i.e., diver transects, photo-quadrats, strip mosaics), while simultaneously maintaining the strengths of a diver-based approach. Testing this premise was the overall objective of this ESTCP project.

In order to demonstrate the capabilities of the underwater landscape mosaic technology, the approach was to determine potential end users' specific applications and needs that could benefit from these new capabilities. Five field demonstrations were conducted to test 18 performance objectives that had been identified in response to the needs assessment. Most of the performance objectives had more than one metric to test, so there were a total of 57 metrics that were assessed during the project. Of the 18 performance objectives, nine were considered completely successful, nine were a partial success, and zero were failures. Of the 57 metrics, 45 were considered completely successful, 12 were a partial success, and 0 were failures. Eight of the 12 metrics that were partial successes were technically not complete successes due to the way the performance tests were designed, but for practical purposes were still quite acceptable.

TECHNOLOGY DESCRIPTION

A mosaic is a single large image composed of many smaller overlapping images, each covering a small portion of the total area. Individual underwater images are taken close (~1–2 m) to the seabed; they have high spatial resolution and minimal water column attenuation. A mosaic of such underwater images enables a high-resolution "landscape view" of the seabed. The RSMAS team has developed techniques to construct spatially accurate mosaics covering areas up to 20 × 20 m with millimeter-scale resolution. First-generation mosaics were created with video images only and provided millimeter-scale resolution in 2004. In 2007, a second-generation system with sub-millimeter scale resolution was developed by integrating a high-resolution still camera with the original video acquisition system. This demonstration used the second-generation system.

The innovative aspect of the current mosaic technology is that the images provide both landscape-level maps and high resolution (sub-millimeter) images of individual coral colonies. Users can, moreover, collect imagery at both landscape and colony-levels for areas of several hundred square meters in under an hour of in-water dive time, creating mosaic products that provide increased information on coral colony health and small scale competitive interactions.

Landscape mosaics address several limitations of traditional, diver-based, coral reef monitoring techniques:

- Mosaics provide a landscape view of coral reefs that has previously been unobtainable;
- Mosaics are efficient tools for tracking patterns of change over time; and
- Mosaics have high spatial accuracy and precision.

The overall goal of RC-201021 was to demonstrate that landscape mosaics extend traditional methods of coral reef monitoring by providing new capabilities, while simultaneously retaining the strengths of diver-based methods (Table 1) Four field demonstrations were designed to test the mosaic capabilities relative to other techniques currently used for coral reef assessment. In addition, a fifth demonstration was conducted under controlled conditions in a pool using man-made targets of known size in order to assess the absolute spatial accuracy of the mosaics (as opposed to the field demonstrations, which assessed mosaic accuracy relative to diver-based measurements).

Table 1. Mapping between mosaic capabilities, end-user applications or needs, and the demonstration in which each was tested.

Mosaic Capabilities	End User Applications / Needs	Demonstration
Addresses limitations of the diver transect	**NOT adequately addressed solely by divers**	
Landscape view	Assessment and monitoring ESA-listed species	ESA
Monitor without tagging	Monitoring coral community trends	Long-Term Monitoring
Relative Spatial accuracy	Assessment of acute physical damage	Grounding
Archive potential	Response to challenges of methodology	Traditional Metrics
Ease of use	Practical implementation of new technology	Multiple
Retains strengths of the diver transect	**Adequately addressed solely by divers**	
Traditional measurements (% cover, diversity, condition, size, juvenile denisty)	Assessment of coral community status New technology must not degrade what already works well	Traditional Metrics / Grounding
Absolute Accuracy		
Spatial accuracy (cm scale)	Need to know limits of technology	Pool
Spatial accuracy (m scale)	Need to know limits of technology	Grounding

- Table Detail:
  - Left column - Mapping between mosaic capabilitie.s
  - Center column - End-user applcations or needs.
  - Right column - the demonstration in which each was tested.
  - **Red** Text –indicates needs filled by the technology.
  - **Blue** Text – indicates applications of the technology.

DEMONSTRATION RESULTS

Four field demonstrations and one pool demonstration were completed to evaluate 57 metrics organized under 18 performance objectives (Table 2).

Long-term Monitoring Demonstration- The goal of this demonstration was to assess the potential benefits of using landscape mosaic technology in a long-term coral reef monitoring program. In particular we assessed the effectiveness of using mosaics to extract (1) colony-based metrics of coral reef condition, and (2) the metrics needed to map and monitor large-scale reef plots for change-detection purposes. In addition, we also evaluated the ease of use of the mosaicing technology in terms of data collection. The results showed that measurements of colony size and percent cover made by divers in the water were not significantly different than those made from mosaic image analysis. Mosaic imagery was also capable of providing the same information as from hand-mapping reef areas. In addition, mosaic imagery and the process of mosaic analysis was found to be as consistent as using multiple diver observations. Finally, non-scientific divers were trained in mosaic image acquisition and acquired useable data. In terms of cost, there was little difference in mosaicing and diver methods of measuring coral colony sizes. However, given the same cost per unit effort (four days of sampling, two divers) we estimated that divers would be able to map 62 m^2 of reef resources using hand-mapping techniques as compared to ~3,800 m^2 using landscape mosaics.

Endangered Species Demonstration- The goal of this demonstration was to evaluate the utility of mosaics for monitoring populations of threatened corals, particularly the species *Acropora palmata*. We evaluated the technology in its ability to replicate diver metrics of (1) coral location and abundance, (2) coral colony size, and (3) colony condition. Mosaic imaging technology was able to replicate diver assessments of coral colony counts, location information, colony size estimates, and provide mosaic analysts with the information to accurately assess colony health information such as % live cover and colony type. When comparing the cost of assessing coral colonies for the above metrics image mosaicing was less expensive than traditional diver methods.

Grounding Demonstration- The goal of this demonstration was to evaluate the utility of mosaics for assessing damage to reefs caused by vessel groundings. We evaluated the utility of using mosaics to measure (1) large areas of damage, (2) long linear-distances, (3) multiple methods of damage assessment, and 4) reef health. A fifth performance objective was devised to assess whether new users can extract data from image mosaics. We found no significant differences in measures of long-linear distances between divers and mosaics. GPS information was found to be less accurate than either divers or mosaics for the purpose of damage assessment. Measures of reef health agreed with mosaic-derived indices with the exception of categories such as sand and gorgonian cover that varied greatly between observers and methods. Novice analysts were able to derive estimates of coral colony sizes and percent cover of major categories that were indistinguishable from diver estimates. When comparing the cost of assessing reef damage, GPS methods were the least expensive followed by mosaic imaging. Diver –based assessment of reef damage was the most expensive method tested. The GPS method, although inexpensive was also the least accurate and most variable of the three methods tested. The mosaic is the most cost-effective method of measuring reef damage due to the accurate results and the increased ecological information provided over both diver-based and GPS methods.

Traditional Metrics Demonstration - The goal of this demonstration was to evaluate the utility of mosaics for coral reef monitoring efforts traditionally performed using diver-transect surveys. The performance objectives of this demonstration examined if (1) mosaics could replicate ecological information extracted from diver surveys, (2) mosaics could estimate metrics obtained through multiple diver methods of reef health assessment, and (3) novice users can be trained to create image mosaics using a manual. In cases where we replicated the exact diver-based transect directly on a mosaic image, there was no significant difference found in estimating coral reef health parameters. However, some differences in methods were detected based on differences in the areas sampled by various diver transects and the variability of the reef itself. Novice users were trained to use mosaic software and create mosaic image data that was indistinguishable from those created by expert analysts. When comparing diver and mosaic methods of estimating ecological metrics we found that single-variable diver methods of estimating coral health are less costly than mosaic surveys. However, if end-users are interested in estimating more than one health parameter in a given survey, such as coral cover, coral size frequency, and species diversity, mosaic imaging is less expensive since all of these metrics can be obtained from a single mosaic survey. In addition, the ability to measure multiple variables at a later date, without advance planning, is a distinct advantage of mosaic imaging over diver surveys.

Absolute Accuracy Demonstration - The absolute accuracy demonstration was designed to evaluate the accuracy and precision of size measurements made from mosaic image analysis and diver surveys. Unlike the previous performance objectives, the success criteria in this demonstration are based on the known sizes of objects and not the performance relative to diver surveys. For this demonstration we evaluated the (1) absolute accuracy of mosaic and diver size measurements, (2) precision of multiple mosaic and diver size measurements, (3) the precision of multiple mosaic analysts and diver size measurements, and (4) the bias of pool and field derived mosaic imagery. The average bias of measuring targets of known size between 5 and 120cm was approximately 1cm for both diver and mosaic methods. The same was true for estimating the projected length of inclined targets. No differences were observed when comparing results over multiple mosaics or when using multiple mosaic analysts. In addition, the measurement bias of objects placed in a pool was not significantly different than the bias measured in field mosaics. Thus mosaics were found to be highly accurate methods of estimating coral colonies on the cm scale and these results were found to be repeatable over different images and using different observers to carry out the analysis.

IMPLEMENTATION ISSUES

Perhaps the most important question addressed during this project was “when are mosaics superior to traditional methods (as opposed to equaling performance of diver methods)?” Considering both performance and cost, we conclude mosaics are a superior approach:

- When dive or field time is relatively expensive
- For measuring sizes, distances, or areas
- For measuring multiple variables, or when you are not sure what to measure
- For low impact monitoring studies (no tagging)
- To leverage availability of non-biologist divers for data collection
- For long-term studies of a specific plot
- For archiving the state of the reef at a given time
- To communicate results visually, particularly to non-specialists

One intended end-user community includes the marine/coral reef ecologists with the SSC Pacific’s Scientific Diving Services. Transfer of this technology to that group has completed and they have executed several field surveys already. The University of Miami continues to partner with other federal, state, local, and private organizations to expand the pool of users of this technology. Current UM/RSMAS partners include: NOAA (Restoration and Southeast and Pacific Fisheries Science Centers), Biscayne National Park, The Nature Conservancy, New England Aquarium, American Museum of Natural History, Scripps Institute of Oceanography, U. North Carolina Wilmington, Coral Restoration Foundation, and Dial Cordy, Inc.

Table 2. Summary of results for each metric tested during the project.

Mosaic Capabilities	End User Applications / Needs	Demonstration	Status	Notes
Addresses limitations of the diver transect	**NOT adequately addressed solely by divers**			
Landscape view	Assessment and monitoring ESA-listed species	ESA		
Performance Objective 1: Coral Colony Location and Abundance				
Colony abundance			Partial	1
Colony location			Success	
Performance Objective 2: Coral Colony Size				
Colony size: Diver = Mosaic			Success	
Colony size: (DiverA - Mosaic) <= (DiverA - DiverB)			Success	
Performance Objective 3: Coral Colony Descriptors				
% Coral cover: DiverA = Mosaic			Success	
% Coral cover: (DiverA - Mosaic) <= (DiverA - DiverB)			Success	
Colony type: Diver = Mosaic			Partial	2
Monitor without tagging	Monitoring coral community trends	Long-Term Monitoring & Trad. Metrics		
Performance Objective 1: Provide colony-based metrics of coral reef condition.				
Colony size: Diver = Mosaic			Success	
Colony size: (DiverA - Mosaic) <= (DiverA - DiverB)			Success	
Colony size: (AnalystA - AnalystB) <= (DiverA - DiverB)			Success	
Colony size: (MosaicA - MosaicB) <= (DiverA - DiverB)			Success	
Colony size: AnalystA = AnalystA			Success	
Bleaching prevalence			Success	
Disease prevalence			Success	
% Bleached			Success	
% Recent Mortality			Success	
% Old Mortality			Success	
Performance Objective 2: Maintain continuity with long-term, map-based, coral reef monitoring data sets				
Colony size: Map = Mosaic			Success	
Colony size: (MapA - Mosaic) <= (MapA - MapB) and <= (DiverA - DiverB)			Success	
Colony size: (AnalystA - AnalystB) <= (MapA - MapB) and <= (DiverA - DiverB)			Success	
Colony size: (MosaicA - MosaicB) <= (MapA - MapB) and <= (DiverA - DiverB)			Success	
Colony size: AnalystA = AnalystA			Success	
% Coral cover: Map = Mosaic			Success	
% Coral cover: (MapA - Mosaic) <= (MapA - MapB) and <= (DiverA - DiverB)			Success	
% Coral cover: (AnalystA - AnalystB) <= (MapA - MapB) and <= (DiverA - DiverB)			Success	
% Coral cover: (MosaicA - MosaicB) <= (MapA - MapB) and <= (DiverA - DiverB)			Success	
% Coral cover: AnalystA = AnalystA			Success	
Relative Spatial accuracy	Assessment of acute physical damage	Grounding		
Performance Objective 1: Map the areal extent of damage				
Total damaged area diver = mosaic = gps			Partial	3
Performance objective 2: Comparison of Linear Damage Measurements				
Linear distances: Diver = Mosaic			Success	
Linear distances: (DiverA - Mosaic) <= (DiverA - DiverB)			Success	
Archive potential	Response to challenges of methodology	Traditional Metrics		
Performance Objective 2: Extract ecological measurements from mosaics using multiple methods				
% Cover: Mosaic virtual transects = Diver transects			Partial	
Coral Species richness: Mosaic virtual transects = Diver transects			Success	
Ease of use	Practical implementation of new technology	Multiple		
Performance Objective 1: Minimum training required for mosaic data acquisition		Long-Term Monitoring		
Incorporation %			Success	
Visual quality			Success	
Performance Objective 2: Minumum training required for creating mosaics from raw data		Traditional Metrics		
Incorporation %			Success	
Visual quality			Success	
Performance Objective 3: Minimum training required to extract ecological measurements from mosaics		Grounding		
Coral Size: Navy analyst = RSMAS analyst			Success	
% Coral Cover: Navy analyst = RSMAS analyst			Partial	

- Table shows the comparison of the capabilities of diver-based methods and landscape mosaics for coral reef monitoring. The high-level structure of the table matches rows from Table 1, but additional rows have been added for each metric.
- The objective of this project was to demonstrate that mosaics retain the strengths but circumvent the limitations of traditional diver-only approaches.
- The "status" column shows the success level attained:
    - **Green** shading indicates full capability
    - **Yellow** shading indicates partial capability
    - **Red** text indicates poor capability.
    - Blue indicates applications of the technology.

Table 2. Summary of results for each metric tested during the project. (Continued)

Mosaic Capabilities			End User Applications / Needs	Demonstration	Status	Notes
Retains strengths of the diver transect			**Adequately addressed solely by divers**			
Traditional measurements (% cover, diversity, condition, size, juvenile denisty)			Assessment of coral community status New technology must not degrade what already works well			
	Performance Objective 1: Extract ecological measurements from mosaics comparable with diver-based metrics			Traditional Metrics		
	Performance Objective 4: Assess reef condition within scar and in unimpacted reference areas			Grounding		
		% Cover: Mosaic = Diver			Partial	
		Coral Species Richness: Mosaic = Diver			Success	
		Size frequency distribution: Mosaic = Diver			Success	
		% Diseased: Mosaic = Diver			Success	
		% Bleached: Mosaic = Diver			Success	
		% Recent Mortality: Mosaic = Diver			Success	
		% Old Mortality: Mosaic = Diver			Success	
		Juvenile Density: Mosaic = Diver			Partial	
Absolute Accuracy						
Spatial accuracy (cm scale)			Need to know limits of technology	Pool		
	Performance Objective 1: Absolute Accuracy of Mosaic and Diver Size Measurements					
		Size - truth not different from zero for mosaics, divers			Partial	4
		Mosaic bias <= diver bias			Partial	5
		Size - truth not different from zero for mosaics, divers (inclined)			Partial	6
		Mosaic bias <= diver bias (inclined)			Success	
	Performance Objective 2: Precision of Multiple Mosaic and Diver Size Measurements					
		Bias of multiple mosaics not significantly different from each other			Success	
		Variance of multiple mosaics <= variance of multiple divers			Success	
	Performance Objective 3. Precision of Multiple Mosaic Analyst and Diver Size Measurements					
		Bias of multiple analysts not significantly different from each other			Success	
		Variance of multiple analysts <= variance of multiple divers			Success	
	Performance Objective 4. Comparison of mosaic bias in the pool vs. in the field					
		Mosaic bias in field is not significantly greater than mosaic bias in pool (square tiles)			Success	
Spatial accuracy (m scale)			Need to know limits of technology	Grounding		
	Performance objective 3: Accuracy of the Measurement of Large Linear Targets					
		Size - truth not different from zero for mosaics, divers, gps			Partial	7
		Mosaic bias = diver bias = GPS bias			Partial	8
		% Coral cover: (AnalystA - AnalystB) <= (MapA - MapB) and <= (DiverA - DiverB)			Success	
		% Coral cover: (MosaicA - MosaicB) <= (MapA - MapB) and <= (DiverA - DiverB)			Success	
		% Coral cover: AnalystA = AnalystA			Success	

- Table shows the comparison of the capabilities of diver-based methods and landscape mosaics for coral reef monitoring. The high-level structure of the table matches rows from Table 1, but additional rows have been added for each metric.
- The objective of this project was to demonstrate that mosaics retain the strengths but circumvent the limitations of traditional diver-only approaches.
- The "status" column shows the success level attained:
    - **Green** shading indicates full capability
    - **Yellow** indicates partial capability
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ACRONYMS

2-D	Two-dimensional
3-D	Three-dimensional
AGRRA	Atlantic and Gulf Rapid Reef Assessment
ANOVA	Analysis of variance
AUTEC	Atlantic Undersea Testing and Evaluation Center
AUV	Autonomous Underwater Vehicle
BNP	Biscayne National Park
cm	Centimeter
CRTF	Coral Reef Task Force
CPCe	Coral Point Count with Excel extensions
DoD	Department of Defense
EO	Executive Order
ESA	Endangered Species Act
ESTCP	Environmental Security Technology Certification Program
FKNMS	Florida Keys National Marine Sanctuary
Ft	Feet
GPS	Global Positioning System
HDV	High definition video
m	Meters
m^2	Meters squared
mm	Millimeter
MILCON	Military Construction
MP	Megapixel
NAVFAC ESC	Naval Facilities Engineering Command Engineering Service Center
NEPA	National Environmental Policy Act
NOAA	National Oceanic and Atmospheric Administration
Obs	Observed
p	Probability
PO	Performance Objective
ROV	Remotely operated vehicle
RSMAS	Rosenstiel School of Marine and Atmospheric Science

SDS	Scientific Diver Services
SERDP	Strategic Environmental Research and Development Program
SIFT	Scale Invariant Feature Transform
SLR	Single-lens reflex
SPAWARSYSCEN	Space and Naval Warfare Systems Center Pacific
UM	University of Miami

CONTENTS

APPENDICES

Figures

Tables

1. INTRODUCTION

ESTCP project RC-201021 demonstrated a high-resolution, landscape, two-dimensional (2-D) mosaicing capability for coral reef monitoring developed by the Rosenstiel School of Marine and Atmospheric Sciences (RSMAS) at the University of Miami with funding from the Department of Defense's Strategic Environmental Research and Development Program (SERDP). During the project, the technology was transferred to Marine/Coral Reef Ecologists with the Navy's Scientific Diving Services.

Recent declines in coral reefs across the globe underscore the need for new scientific tools to better understand ecological patterns and rates of change. Given that multiple factors are typically responsible for changes within reef ecosystems, the monitoring of reef health must be carried out at multiple spatial and temporal scales, rather than relying on measuring only a few parameters. Comprehensive assessment of coral reef resources demands a hierarchical mapping strategy involving micro-scale to macro-scale measurements. Of immediate interest to the Department of Defense are types of changes within DoD reef systems that can be monitored at the meso-scale level.

The research on landscape mosaics is based on the premise that use of meso-scale, 2-D images of reef plots can circumvent the limitations of current state-of-the-art methods in coral reef monitoring (i.e. diver transects, photo-quadrats, strip mosaics), while simultaneously maintaining the strengths of a diver-based approach. RSMAS developed techniques to construct spatially accurate mosaics covering areas up to 20 ×20 m with millimeter-scale resolution. First-generation mosaics, ca. 2004, were created with video images only and provided millimeter-scale resolution. In 2007, a second-generation system with sub-millimeter scale resolution was developed by integrating a high-resolution still camera with the original video acquisition system. This demonstration used the second-generation system.

Landscape mosaics address several limitations of traditional, diver-based, coral reef monitoring techniques:

- Mosaics provide a landscape view of coral reefs that has previously been unobtainable;
- Mosaics are efficient tools for tracking patterns of change over time; and
- Mosaics have high spatial accuracy and precision.

The overall goal of RC-201021 was to demonstrate that landscape mosaics extend traditional methods of coral reef monitoring by providing new capabilities, while simultaneously retaining the strengths of diver-based methods. Five field demonstrations and one pool demonstration were completed as follows:

Long-term Monitoring Demonstration

The goal of this demonstration was to assess the potential benefits of using landscape mosaic technology in a long-term coral reef monitoring program. In particular we assessed the effectiveness of using mosaics to extract (1) colony-based metrics of coral reef condition, and (2) the metrics needed to map and monitor large-scale reef plots for change-detection purposes. Additionally, we also evaluated the ease of use of the mosaicing technology in terms of data collection.

Endangered Species Demonstration

The goal of this demonstration was to evaluate the utility of mosaics for monitoring populations of threatened corals, particularly the species *Acropora palmata*. We evaluated the technology in its ability to replicate diver metrics of (1) coral location and abundance, (2) coral colony size, and 3) colony condition.

Grounding Demonstration

The goal of this demonstration was to evaluate the utility of mosaics for assessing damage to reefs caused by vessel groundings. We evaluated the utility of using mosaics to measure (1) large areas of damage, (2) long linear-distances. We also evaluated the ease of use of the mosaicing technology in terms of extracting data from image mosaics.

Traditional Metrics

The goal of this demonstration was to evaluate the utility of mosaics for coral reef monitoring efforts traditionally performed using diver-transect surveys. Unlike the first three demonstrations, which focused on how mosaics could address limitations of a traditional diver-only approach, this demonstration tested whether mosaics could retain the strengths associated with direct expert observations. The performance objectives of this demonstration examined if (1) mosaics could replicate ecological information extracted from diver surveys, (2) mosaics could estimate metrics obtained through multiple diver methods of reef health assessment, and (3) novice users can be trained to create image mosaics using a manual.

Absolute Accuracy

The absolute accuracy demonstration was designed to evaluate the accuracy and precision of size measurements made from mosaic image analysis and diver surveys. Unlike the other demonstrations, the success criteria in this demonstration were based on the known sizes of objects and not only the performance relative to diver surveys. For this demonstration we evaluated the (1) absolute accuracy of mosaic and diver size measurements, (2) precision of multiple mosaic and diver size measurements, (3) the precision of multiple mosaic analysts and diver size measurements, and 4) the bias of pool and field derived mosaic imagery.

1.1 BACKGROUND

At least 46 military facilities, including Air Force, Army, and Navy bases, have adjacent coral reef resources (SPAWARSYSCEN PAC, 2009). Federal policy mandates that the DoD characterize, assess, and monitor underwater benthic communities at these sites in order to document compliance with promulgated national policy and to ensure that the DoD operations do not lead to natural resource degradation, particularly with respect to coral reefs. Coral reef ecosystems worldwide are presently threatened by increasing human and natural levels of disturbance (Gardner *et al.* 2003; Pandolfi *et al.* 2005; Aronson and Precht 2006), thereby this emphasizes the need for monitoring efforts to distinguish between reef degradation that can be directly attributed to DoD activities versus that correlated with region-wide decline.

As a participant in the U.S. Coral Reef Task Force (CRTF), the DoD supports coral reef preservation and E.O. 13089. One of DoD's responsibilities as a CRTF member is to map and assess the coral reef ecosystems under its control. Efficient survey methodologies that provide comprehensive assessment of reef condition are fundamental to this effort. Current state-of-the-art techniques in coral reef assessment rely on highly trained scientific divers to measure indices of reef health (*e.g.*, substrate cover, species richness, coral size, and coral mortality). These indices are commonly derived from line or belt transects, photo-quadrats, or strip video mosaics. Limitations of these approaches include restricted dive time and spatially inaccurate underwater imagery with a limited footprint. A capability to reduce these limitations is addressed by the proposed mosaic technology.

A mosaic is a single large image composed of many smaller overlapping images, each covering a small portion of the total area. Individual underwater images are taken close (~1–2 m) to the seabed; they have high spatial resolution and minimal water column attenuation. The mosaic of these images enables a high-resolution "landscape view" of the seabed. The innovative aspect of the current mosaic technology is that the images provide both landscape-level maps and high-resolution (sub-millimeter) images of individual coral colonies. Users can, moreover, collect imagery at both landscape and colony-levels for areas of several hundred square meters in under an hour of in-water dive time, creating mosaic products that provide increased information on coral colony health and small scale competitive interactions. This project has been in development for the past several years under SERDP, where the value of using mosaics for extracting ecological indicators of reef health and for damage assessment has been documented. The mosaic products have excellent archive potential and appear to be superior tools for tracking changes over time.

The mosaicing technology is expected to bring significant benefits to the DoD and other governmental agencies, such as NOAA, which are currently engaged in costly and labor- intensive programs of coral reef monitoring and damage assessment. The mosaicing technology is expected to reduce costs of obtaining coral reef and benthic habitat data and to improve the quality and archive potential of ecological data. The mosaicing technology will provide additional capability to complement and augment direct expert observations for benthic habitat analysis, and add important capabilities for analyzing, storing, and sharing important time-series data for the purpose of natural resource management. Underwater mosaics will retain the strengths associated with direct expert observations while, at the same time, circumventing the limitations of a traditional diver-only approach. The expected benefits to the DoD from this project are increased capability and, in many situations, reduced cost.

Increased capability includes the following:

(a) Accurate spatial measurements;
(b) Ability to monitor individual colonies without tagging;
(c) Outstanding data archival potential;
(d) Increased ability to assess and monitor the condition of benthic resources using multiple desktop analytical methods;
(e) A visual means of conveying reef condition to a non-expert;
(f) Increased capability to evaluate comprehensive in situ landscape data with stakeholders and regulators;
(g) Inventory and monitoring of ESA-listed species *A. palmata* and A. cervicornis and their designated critical habitat within DoD submerged lands;
(h) Objective products for environmental resource management and conservation planning, and
(i) The possibility of monitoring deep or hazardous plots.

Reduced cost is expected because:

(a) Special biological training is not necessary for acquiring the video;
(b) Reduced time in the water will increase efficiency of field work, permit monitoring of deeper sites, and

(c) Accurate measurement of accidental damage on reefs should minimize restoration costs. For example, effective communication with a jury in a lawsuit following a ship grounding is an example of where this technology could pay for itself.

1.2 OBJECTIVES OF THE DEMONSTRATIONS

The overarching objective of ESTCP project RC-201021 was to demonstrate, validate, and transition an innovative image mosaicing technology for coral reef assessment. The overall objective of the project was to test the assertion that landscape mosaics expand capability by allowing users to monitor coral reef resources in new ways, while simultaneously retaining the ability to extract metrics traditionally obtained using diver-based methods. The first three demonstrations focused on expanded capability. The fourth demonstration addressed the capability to retain traditional strengths of a diver approach. The fifth demonstration was added during the course of the project to compare the absolute performance of mosaic and diver size measurements. The objectives of each demonstration are described in the sections below.

1.2.1 Objective of the Long-Term Monitoring Demonstration

The purpose of the long-term monitoring demonstration, in particular, was to validate the capability of mosaics to assess changes in individual coral colony condition over time. Three Performance Objectives (POs), each with several specific metrics, were devised for this validation:

1. Provide colony-based metrics of coral reef condition.
2. Maintain continuity with long-term, map-based, coral reef monitoring data sets.
3. Evaluate ease of use of the technology.

For assessment of the first and second POs, measurements of coral sizes and metrics of coral condition as acquired from the mosaics were compared with size and condition estimates performed by divers. The assessment for PO 1 applied to permanent reef plots in general, whereas the assessment for PO 2 was tailored to apply to the long-term sites surveyed at AUTEC. Additionally, evaluation of the ease of use of mosaics (PO 3) was achieved by comparing mosaics created from data acquired by divers with no prior mosaicing experience with mosaics created from data acquired by experts.

For all activities, times for conducting the various monitoring operations were recorded and costs for the landscape mosaic technique versus traditional methods calculated to compare the efficiency (i.e., cost effectiveness) of the methods. Overall, the demonstration was conducted in a manner to test the proposition that mosaics create new monitoring and mapping capabilities, including the rapid monitoring of coral colonies without tagging or the photographic mapping of reef damage for restoration assessments and monitoring. Mosaics were therefore expected to provide a cost-effective alternative to diver-based methods for continuing the long-term AUTEC coral reef monitoring program or for establishing similar programs to acquire spatially explicit benthic data at other sites.

1.2.2 Objective of the Endangered Species Demonstration

The purpose of the Endangered Species (ESA) demonstration was to validate that mosaics can improve the efficiency of demographic monitoring for ESA-listed Caribbean *Acropora spp*. corals. NOAA has implemented a protocol for monitoring *Acropora spp*. in the Florida Keys (Williams *et al.* 2006) and is promoting the adoption of these methods in other U.S. territories such as Puerto Rico and the US Virgin Islands (Margaret Miller, personal communication). Currently, all of the parameters described by Williams *et al.* (2006) are measured in the field directly by divers. The performance objectives of this demonstration tested the premise that ecological information extracted from mosaics of *Acropora palmata* colonies is comparable to that measured directly by divers. These objectives are relevant because if mosaics can be shown to produce the same data as divers, especially if at lower cost, then they could be used in place of diver measurements for monitoring these threatened coral species. Mosaics have the potential to benefit *A. palmata* monitoring efforts by facilitating the tracking of colonies over time, an activity which is now done by hand-mapping the locations and sizes of individual colonies within permanent study sites (Williams *et al.* 2006).

Three performance objectives (POs) have been defined to assess the ability of mosaics to replicate hand mapping of *A. palmata* populations:

1. Coral colony location and abundance
2. Coral colony size
3. Coral colony descriptors

1.2.3 Objective of the Grounding Demonstration

The objectives of the grounding demonstration were to demonstrate, (1) that areas on the order of 10's to 100's of m^2 can be accurately measured from mosaics, (2), that reef status metrics extracted from mosaics are comparable to those acquired from diver transects (i.e., mosaics can simultaneously acquire the data needed to assess both area and severity of damage), and (3) that data extraction from the mosaics is possible following suitable training. Five performance objectives (POs), were devised for this validation:

1. Comparison of the area of damage
2. Comparison of linear damage measurements
3. Accuracy of the measurement of large linear targets
4. Extraction of ecological measurements from mosaics both inside and outside damaged areas that are comparable with diver-based metrics
5. Evaluation of ease of use of the technology

1.2.4 Objective of the Traditional Metrics Demonstration

The purposes of the traditional metrics demonstration were to demonstrate (1), that reef status metrics extracted from mosaics are comparable to those acquired from diver transects (i.e., mosaics retain the strengths of diver transects), (2) that mosaics improve on the diver transect approach by providing a more useful data archive. Three performance objectives (POs), each with several specific metrics, were devised for this validation:

1. Extract ecological measurements from mosaics that are comparable with diver-based metrics.
2. Extract ecological measurements from mosaics using multiple methods.
3. Evaluate ease of use of the technology.

For assessment of the first and second performance objectives (POs), measurements of coral sizes and metrics of coral condition as acquired from the mosaics were compared with size and condition estimates performed by divers. Additionally, evaluation of the ease of use of mosaics (PO 3) was achieved by comparing mosaics created by analysts with no prior mosaicing experience with mosaics created by analysts who have experience using the mosaicing software.

Times for conducting the various operations were recorded and costs for the landscape mosaic technique versus traditional methods were calculated to compare the efficiency (i.e., cost effectiveness) of the methods. Overall, the demonstration was conducted in a manner to test the proposition that mosaics can replicate the data produced by diver transects and in addition provide new monitoring and mapping capabilities.

1.2.5 Objective of the Absolute Accuracy Demonstration

The purposes of the absolute accuracy demonstration were to assess the accuracy and precision of size measurements made from mosaics and by divers. Four POs, each with several specific metrics, were devised for this validation:

1. Absolute accuracy of mosaic and diver size measurements
2. Precision of multiple mosaic and diver size measurements
3. Precision of multiple mosaic analysts' extraction of size measurements
4. Comparison of mosaic bias in the pool vs. in the field

1.3 REGULATORY DRIVERS

Executive Order (E.O.) 13089 "Protection of Coral Reefs" dated June 11, 1998 directs Federal agencies including the DoD to study, restore, and conserve U.S. coral reefs. Moreover, E.O. 13089 directs Federal agencies whose actions may affect U.S. coral reef ecosystems, to take the following steps: (1) identify actions that may affect U.S. coral reef ecosystems, (2) utilize programs and authorities to protect and enhance the conditions of such ecosystems, and (3) to the extent permitted by law, ensure that any actions they authorize, fund, or carry out, will not degrade the conditions of such ecosystems. The National Environmental Policy Act (NEPA) and the Clean Water Act (404 permits) require assessment of special aquatic resources in proximity to project sites. In addition to protection of U.S. coral reef resources, E.O. 12114, Environmental Effects Abroad of Major Federal Actions, requires Federal agencies to conduct environmental impacts of major actions or activities occurring outside the U.S. Use of landscape mosaics in coral reef monitoring programs will provide spatially-accurate permanent records of reef condition with increased information content in a cost effective manner. The enhanced capabilities afforded by the mosaicing technology will allow the DoD to meet NEPA assessment requirements, obtain compliance status with the Clean Water Act, and qualify for permits for future DoD MILCON efforts.

2. TECHNOLOGY/METHODOLOGY DESCRIPTION

Landscape mosaics are single composite images comprised of hundreds to thousands of individual overlapping images. Mosaics have been used for many years for underwater exploration and archaeology, but they have not routinely been used for ecological purposes because mosaics have traditionally been expensive to construct. In order to construct a mosaic one needs to know the relative position and scale of every component image. Traditionally, this has been done either by hand or through the use of some sort of external navigation information, such as an acoustic transponder network or inertial navigation unit fixed to the camera. Both of these approaches are usually too expensive for routine use by coral reef ecologists.

Under SERDP Project RC-1333, RSMAS scientists developed techniques to construct spatially accurate mosaics up to a size of about 20 m×20 m with millimeter-scale resolution. A key advantage of the RSMAS technology, and one that distinguishes it from underwater imaging efforts by other groups, is that RSMAS mosaic construction is based entirely on the image data, with no requirement for manually positioning the images or for external navigation data. Automated construction of mosaics reduces the hardware and labor costs to the point where it becomes feasible for ecological applications of mosaics.

2.1 TECHNOLOGY/METHODOLOGY OVERVIEW

A mosaic is a single large image composed of many smaller overlapping images, each covering a small portion of the total area. Individual underwater images are taken close (~1-2 m) to the seabed; they have high spatial resolution and minimal water column attenuation. The mosaic of these images enables a high resolution “landscape view” of the seabed. The innovative aspect of the current mosaic technology is that the images provide both landscape-level maps and high resolution (sub-millimeter) images of individual coral colonies. Users can, moreover, collect imagery at both landscape and colony-levels for areas of several hundred square meters in under an hour of in-water dive time, creating mosaic products that provide increased information on coral colony health and small scale competitive interactions. This project has been in development for the past several years under SERDP, where the value of using mosaics for extracting ecological indicators of reef health and for damage assessment has been documented. The mosaic products have excellent archive potential and appear to be superior tools for tracking changes over time.

Mosaics enable a large area to be viewed in a single image, thereby providing the clarity and resolution of individual pictures but also affording a landscape view of the seabed. In the most general case, underwater mosaics can be made with oblique images, but the technology described here uses near-nadir (downward looking) images to create a map-like overhead view of the seabed in which scale does not appreciably vary across the mosaic.

Pizarro and Singh 2003, Singh *et al.* (2004), and Ludvigsen *et al.* (2007) provided brief histories of the development of underwater mosaics. Despite the fact that underwater mosaics have been made for many years, they have not been used routinely for ecological studies until recently for two reasons. First, mosaics have historically required tremendous manual effort to construct, using either physical manipulation of images (Ballard 1987), digital “photoshopping” (Anonymous 2001), or interaction with photogrammetric software (Gifford 1997). Second, imagery used to create underwater mosaics has traditionally been acquired from submersibles or remotely operated vehicles (e.g., Ballard *et al.* 2002), most often requiring the deployment of acoustic positioning arrays or frames placed on the seabed to guide the camera for data acquisition. Both manual mosaicing and sophisticated underwater vehicle engineering are expensive and therefore beyond the reach of the majority of coral reef ecologists.

Due to recent advances in technologies, the time is ripe for the application of underwater mosaics to coral reef ecology. Developments in computer vision (Gracias and Santos-Victor 2001; Gracias *et al.* 2003; Pizarro and Singh, 2003; Singh *et al.* 2004) have freed underwater mosaics from the burden of being stitched together by hand. In addition, recent advances in consumer-grade electronics and optics, including cameras, housings, lights, and batteries, mean that high-quality underwater images do not necessarily need to be acquired by expensive submersibles. Taking advantage of these developments, our team developed software under SERDP project SI-1333 to create underwater mosaics that have four appealing features for coral reef ecologists (Lirman *et al.* 2007). First, processing is automated, converting input video frames to an output mosaic with little to no user intervention. Second, the algorithm is camera and platform independent, requiring only images with a high degree of overlap. Third, the motion model is general enough to deal with unstructured motion including tolerance to moderate off-nadir views. Fourth, the characteristics of the resulting mosaics have been validated against diver data.

Two generations of underwater landscape mosaics were developed under SI-1333 (Reid *et al.* 2010). The first-generation mosaics used underwater video to construct large-scale (up to 400 m^2), spatially-accurate, images of the reef benthos without extensive survey times, a need for scientific divers, or tedious manual intervention in the mosaicing process (Lirman *et al.* 2007). Despite these advances, the first-generation mosaics were insufficient for species-level identification of many benthic taxa, thereby limiting the monitoring potential of the technique to broader taxonomic categories (e.g., coral, algae, sand). Therefore, a second-generation mosaic survey technology was developed, integrating high-resolution still-images with high-definition video surveys of the reef benthos. The second-generation mosaic products have sub-millimeter benthic resolution, allowing for species identification of coral colonies as small as 3 cm, identification of macroalgal genera, and increased information on coral colony health and small-scale competitive interactions (Gintert *et al.* 2009). This advanced survey technology allows users to collect imagery on both a landscape and colony level over 100's of square meters in under an hour of in-water dive time. The resulting product has excellent archive potential and is a superior tool for tracking changes over time.

2.2 TECHNOLOGY/METHODOLOGY DEVELOPMENT

The software developed under SI-1333 for creating landscape mosaics consists of a set of image processing and numerical optimization modules that work with little to no user intervention. As input, the processing takes a time-ordered set of images from one or more underwater video sequences. The relative displacement of all the images is obtained without need for user input by iteratively registering images and estimating the camera trajectory. The output is a composite image generated by fusing the registered images together. Additionally, sets of tools have been developed to analyze the spatial accuracy of the resulting image, and to minimize the impact of illumination inconsistency in underwater imagery. The geometric accuracy, information content, and dramatic visual presentation of the mosaics have been demonstrated in scientific publications, which document the potential utility of mosaics for long-term monitoring (Lirman *et al.* 2007) and damage assessment (Gleason *et al.* 2007). Important technical contributions were made in filtering out the effects for refracted sunlight in shallow water imagery (Gracias *et al.* 2008b) and in devising an efficient way to eliminate the visibility of seams among neighboring images in the final mosaics (Gracias et al 2008a).

Other researchers have recognized the potential application of mosaicing technology to coral reefs and some underwater mosaics of coral reefs created using alternative techniques have been published (Kupfner and Lybolt, 2003; Armstrong, 2007; Camilli *et al.* 2007; Ludvigsen *et al.* 2007). These mosaicing efforts differ from the landscape mosaics developed under SERDP in several ways.

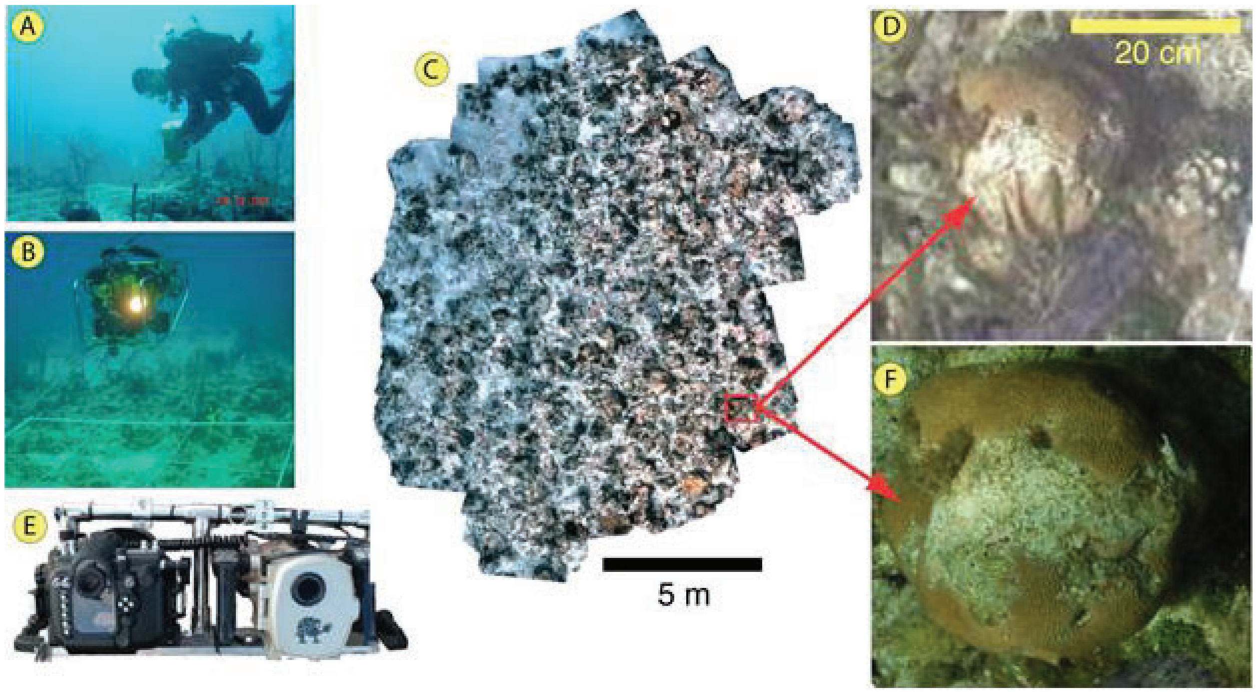
Almost all of these other examples (e.g. Kupfner and Lybolt, 2003; Camilli *et al.* 2007; and Armstrong, 2007) are strip mosaics, created along transects, rather than landscape mosaics of a plot; strip mosaics lack the spatial accuracy and spatial context of a landscape view (Lirman *et al.* 2007; Gleason *et al.* 2007). Other efforts, such as Ludvigsen *et al.* (2007) used a still camera with very slow frame rates for mosaic creation, necessitating use of a 400 kg Remotely Operated Vehicle (ROV) with artificial lights as an imaging platform, and a closed-loop control system that incorporated multiple navigation technologies. Such complex imaging platforms are typically both expensive and unavailable to coral reef biologists.

The underwater mosaicing technology has been under development for approximately 10 years, most recently with support from SERDP. Funding for the past six years under SI-1333 (June 2003-2009) has enabled development of the capability for constructing underwater landscape mosaics of reef plots and has documented the usefulness of these mosaics for coral reef monitoring (Figure 1). Examples of mosaics are included in Appendix B. Other examples can be seen at http://www.rsmas.miami.edu/groups/reidlab/. The reason the landscape mosaic approach had not previously been used for coral reef monitoring is that commercially available mosaicing algorithms and software packages do not work in the underwater environment except with supplementary navigation information or extensive manual user intervention. The software used to create landscape mosaics under SI-1333 provides innovative solutions to these limitations, as outlined above.

In addition to a basic mosaicing capability with limited user intervention, the mosaicing software includes modules for the following four capabilities:

1. Combining video and high-resolution photo stills - this module increases the spatial resolution of the mosaics, thereby increasing taxonomic resolution;
2. Using additional positioning information when available - this module improves geometric accuracy of the mosaics over high topography areas;
3. Improved blending - this module reduces the visibility of the seams between neighboring images when rendering the final mosaics; and
4. Removing refracted sunlight - this module strongly attenuates or eliminates the disruptive patterns of refracted sunlight for very shallow water surveys.

In November 2008, SERDP sponsored a Coral Reef Monitoring and Assessment Workshop at the University of Miami Rosenstiel School of Marine and Atmospheric Science (RSMAS). One of the goals for the workshop was to better understand coral reef monitoring and assessment needs for a variety of governmental and non-governmental organizations and to determine how the SERDP-developed mosaicing technology might help to address those needs. Presentations and discussion involving a number of scientists in coral reef management and research positions from other agencies indicated a strong interest in incorporating high-resolution landscape mosaics in reef monitoring and damage assessment programs (SPAWARSYSCEN PAC, 2009). As a result of interest generated by the workshop and also based on recommendations from the ESTCP program office, three NOAA offices (NOAA Marine Sanctuaries, NOAA Coast, and NOAA Damage Assessment and Restoration) have indicated an interest in partnering with the DoD to participate in and evaluate the proposed coral reef mosaicing demonstration and transition efforts.



- (A) Other platform such as an ROV
- (B) Automatically stitched together to form a landscape mosaic
- (C) Covering a large area (about 100 m2 in this case). First-generation mosaics (i.e. those produced with video only) have mm-scale resolution
- (D). In second-generation mosaics,
- (E) Still imagery is acquired simultaneously with the video
- (F). Achieved sub-mm resolution

Figure 1. Mosaic overview: Video images acquired by a diver.

2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY/METHODOLOGY

Given the complexity of coral reef ecosystems, the breadth of DoD activities, and the suite of natural and anthropogenic stressors affecting reef-associated organisms, no single survey protocol can be used in all situations to monitor reefs under DoD purview. Underwater landscape mosaics should not therefore be viewed as a single technological solution to DoD coral reef monitoring requirements. Nevertheless, mosaics do address certain limitations of the state-of-the-art in reef monitoring methods. The advantages of landscape mosaics are that they retain the strengths associated with direct expert observations while circumventing the limitations of a traditional diver-only approach (Table 3).

Traditional coral reef monitoring approaches depend on the experience of trained scientific divers to measure indices of reef condition underwater. This methodology, while excellent at providing metrics that are considered the "gold standard" of coral reef monitoring, may not be the most efficient for use in DoD operations. Data collection using Navy divers may be more practical than using marine ecologists, who may not always be available. Imagery for underwater landscape mosaics can be collected by these skilled divers, without requiring that every diver be trained in marine ecology.

Table 3. Comparison of the capabilities of diver-based methods and landscape mosaics for coral reef monitoring.

	Capability of Technique	
	Traditional: Diver Survey	**SERDP: Landscape Mosaics**
Strengths of the diver transect		
Percent cover of benthic organisms	[green]	[green]
Diversity indices	[green]	[green]
Disease / Bleaching / Partial Mortality	[green]	[green]
Coral colony size	[green]	[green]
Juvenile coral density	[green]	[yellow]
Limitations of the diver transect		
Permanent record for reanalysis	[red]	[green]
Landscape view (map large features)	[red]	[green]
Repeatability (monitor without tagging)	[red]	[green]
Spatial accuracy	[red]	[green]
Long dive times	[red]	[green]
Scientific diver required	[red]	[green]

- The objective of this project was to demonstrate that mosaics retain the strengths but circumvent the limitations of traditional diver-only approaches.
- Table colors are defined as follows:
  - **Green** table fill – indicates full capability.
  - Yellow table fill – indicates partial capability.
  - Red table fill – indicates poor capability.

An additional benefit of the mosaicing approach is the data archive provided by the technology. Once a mosaic has been rendered, the user has a digital electronic photographic record of the state-of-the reef at the time of the survey. These images can be independently analyzed by DoD and other stakeholders to provide documented proof of reef condition at the time of the survey. In contrast, traditional diver surveys typically offer limited to no ability to verify the data after it has been collected.

Reid *et al.* (2010, Section A2.3.4) outlined environmental limitations on using mosaic technology and provided recommendations to minimize these limitations. Three potential limitations have simple solutions:

(1) Fast camera motion will cause blurry images, which hinder both mosaic creation and analysis of the images. The recommendations were to avoid conditions in which high surge or currents cause rapid shifts in position along the survey track and to avoid sudden turns or movements of the camera during acquisition. Diver training is the solution to this limitation.

(2) Excessive motion of organisms on the bottom or fish in the field of view can adversely affect the automated matching algorithm used for mosaic creation. Different approaches to address this limitation are needed depending on the circumstances. (A) For single large objects that fill the field of view, such as occasional gorgonians, data can be acquired higher from the bottom near the object. (B) For large fields of sessile moving organisms, such as dense gorgonians or

macroalgae, surveys should be conducted at times of minimal surge and current. Manual matching of images can also be used. (C) For objects in the water column, such as fish or another diver, the person acquiring the data can wait until they move (or a dive buddy encourages them to move). Diver training is the primary solution to this limitation, though manual matching of images can also help.

(3) Refracted sunlight, most prominent in shallow water under direct sunlight, produces visual artifacts in the mosaics. One recommendation was to collect shallow-water imagery at times or conditions when lighting of the benthos is even, such as overcast days or early/late in the day. Another alternative is to use the sunflickering removal software developed during RC-1333. Diver and analyst training are the solutions to this limitation.

(4) Visibility is a fourth potential limitation of the mosaicing technology. For the vast majority of coral reef sites, timing of data acquisition is an effective solution to temporarily low visibility conditions. Reid *et al.* (2010) compiled mosaics from almost 40 sites in Florida, the Bahamas, Puerto Rico, Navassa Island, and the Virgin Islands and encountered only one instance when visibility was too low for mosaicing. That occasion was on two days following tropical storm Olga. Reid *et al.* (2010) recommended that video mosaic data only be acquired when average wind speeds are less than 15 knots and that sufficient time be given after multiple high wind days to allow for sediment to settle before mosaic acquisition is attempted.

3. PERFORMANCE OBJECTIVES

3.1 LONG-TERM MONITORING DEMONSTRATION

In order to evaluate the potential benefits and costs of landscape mosaic technology, we compared the mosaic approach with traditional methods for long-term monitoring coral reefs. In particular, we assessed the effectiveness of using mosaics to extract (1) colony-based metrics of coral reef condition, and (2) metrics needed to maintain the long-term continuity of the AUTEC coral reef monitoring program or to establish similar programs acquiring spatially explicit benthic data at other sites. We also (3) evaluated mosaics technology and its ease of use to capture valuable reef monitoring data. Comparison of operational costs for both the mosaic approach and traditional methods served as a basis for cost-benefit analysis.

The long-term monitoring demonstration was designed to validate the utility of mosaics for assessing changes in individual coral colonies over time. The overall goal of the demonstration was to validate that mosaics provided increased capability relative to existing technologies for monitoring specific colonies over time. Evaluation of mosaic performance versus traditional methods relied on a suite of metrics (Table 4). The following sections describe, for each performance objective, (a) the relevance of the objective, (b) the metrics used to evaluate the objective, (c) the data required to test each metric, and (d) the criteria for determining success.

Table 4. Performance objectives for the long-term monitoring demonstration.

Metric	Data Requirements	Analysis	Success Criteria	Results
Performance Objective 1: Provide colony-based metrics of coral reef condition				
Coral colony size	(1) Maximum length and width (cm) of tagged coral colonies as measured by divers (2) Maximum length and width (cm) of tagged coral colonies as extracted from the mosaics.	(1) Paired-sample t-test (single observer in field and from mosaic) (2) Two-way ANOVA with coral size and method as factors	No significant differences ($p<0.05$) in the size of tagged coral colonies between diver and mosaic estimates	No significant differences ($p=0.35$) There was a significant difference in the error of size measurements based on colony size ($p=0.00$) but no difference between measurement methods ($p=0.38$) or any interaction between size and method ($p=0.32$)

Table 4. Performance objectives for the long-term monitoring demonstration. (Continued)

Metric	Data Requirements	Analysis	Success Criteria	Results
Performance Objective 1: Provide colony-based metrics of coral reef condition				
Coral colony condition: Prevalence of bleaching	(1) # of bleached colonies as counted by divers. (2) # of bleached colonies as counted from the mosaic.	Compute max-diver = the greater of # of bleached colonies as counted by diver 1 or diver 2. Compute min-diver = the lesser of # of bleached colonies as counted by diver 1 or diver 2. Computediver = max-diver - min-diver. Compute threshold as the larger ofdiver or 0.1 × min-diver.	# of bleached colonies as counted from the mosaic. must be ≥ min-diver - threshold, and # of bleached colonies as counted from the mosaic must be ≤ max-diver + threshold,	# of bleached colonies identified by mosaics = the number identified by divers in the field
Coral colony condition: Prevalence of disease	(1) # of diseased colonies as counted by divers. (2) # of diseased colonies as counted from the mosaic.	Compute max-diver = the greater of # of diseased colonies as counted by diver 1 or diver 2. Compute min-diver = the lesser of # of diseased colonies as counted by diver 1 or diver 2. Compute diver = max-diver - min-diver. Compute threshold as the larger ofdiver or 0.1 × min-diver.	# of diseased colonies as counted from the mosaic must be ≥ min-diver - threshold, and # of diseased colonies as counted from the mosaic must be ≤ max-diver + threshold,	Only 7 colonies identified with disease were encountered across all demonstrations. 6 of these 7 were identified as diseased from mosaic observers.

Table 3. Performance objectives for the long-term monitoring demonstration. (Continued)

Metric	Data Requirements	Analysis	Success Criteria	Results
Performance Objective 1: Provide colony-based metrics of coral reef condition				
Coral colony condition: % colony bleaching	(1) Estimate made by divers of the % of each colony that is bleached (2) Estimate of % of each colony that is bleached from mosaic	Two-way ANOVA with coral size and method as factors	No significant differences ($p<0.05$) in the % bleached of tagged coral colonies between diver and mosaic estimates	Data was combined across multiple demonstrations and is discussed in the traditional metrics demonstration
Coral colony condition: % recent coral mortality	(1) Estimate made by divers of the % of new colony mortality (2) Estimate of % of new colony mortality from mosaic	Two-way ANOVA with coral size and method as factors	No significant differences ($p<0.05$) in the % recently dead of tagged coral colonies between diver and mosaic estimates	Data was combined across multiple demonstrations and is discussed in the traditional metrics demonstration
Coral colony condition: % old coral mortality	(1) Estimate made by divers of the % of each colony that is old dead (2) Estimate of % of each colony that is old dead from mosaic	Two-way ANOVA with coral size and method as factors	No significant differences ($p<0.05$) in the % old dead of tagged coral colonies between diver and mosaic estimates	Data was combined across multiple demonstrations and is discussed in the traditional metrics demonstration
Coral colony size	(1) Maximum length and width (cm) of all coral colonies in 2×2 m quadrats as measured by divers (2) Maximum length and width (cm) of all coral colonies as extracted from mosaics of the 2×2 m quadrats. (3) Maximum length and width (cm) of all coral colonies as measured from diver-drawn maps of the 2×2 m quadrats	(1) Paired-sample t-test (2) Two-way ANOVA with method and coral size as factors	No significant differences ($p<0.05$) in the sizes of coral colonies between diver, map, and mosaic estimates	There was no significant difference in measurement methods between hand drawn mapping of coral colonies and mosaic digitizing of corals.

Table 3. Performance objectives for the long-term monitoring demonstration. (Continued)

Metric	Data Requirements	Analysis	Success Criteria	Results
Performance Objective 2: Maintain continuity with long-term, map-based coral reef monitoring data sets				
Coral cover	(1) % cover of corals measured from diver-made maps of 2×2 m quadrats (2) % cover of corals, measured from mosaics of 2×2 m quadrats	(1) Paired-sample t-test on cover of 1×1 m quadrats (2) One-way ANOVA with method as factor	No significant differences ($p<0.05$) in the percent coral cover between diver and mosaic estimates	There was no significant difference in the estimation of coral cover from hand drawn maps or from digitizing of mosaic images.
Incorporation percentage	# of input images and # of images rejected in the global optimization step when creating a mosaic with data collected by RSMAS divers # of input images and # of images rejected in the global optimization step when creating a mosaic with data collected by Navy divers	Compute incorporation percentage = # of images input to blending / # images input to global matching. Compute relative incorporation percentage = incorporation percentage (Navy)/ percentage (RSMAS)	Average relative incorporation percentage of all Navy mosaics ≥90%	Following in-water training and two mosaic acquisition trials, Navy personnel were able to acquire mosaic image data that had the same incorporation percentage as expert users.
Visual quality rating	Visual assessment of the mosaic on scale of 1–5.	None	Average visual quality rating of all Navy mosaics ≥4	Following in-water training and two mosaic acquisition trials, Navy personnel were able to acquire mosaic image data that was indistinguishable from expert users.

3.1.1 Performance Objective 1: Provide Colony-Based Metrics of Coral Reef Condition

Relevance of the objective: The current state-of-the-art technique for monitoring individual coral colonies consists of divers periodically measuring the size and condition of each colony. The data gathered through colony-based monitoring is valuable, but this approach has several drawbacks:

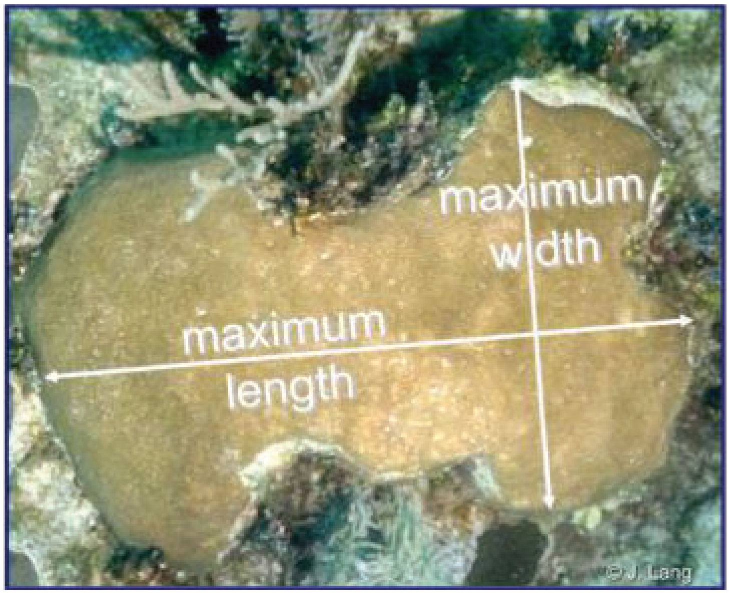
- Establishing a plot where individual colonies are tagged and measured is labor intensive due to the need to tag every colony.
- The process of affixing tags may involve inadvertent damage and requires leaving gear permanently attached to the seafloor (e.g., nails, tags, markers).
- Revisiting the plot is labor intensive due to the need to verify the ID of every colony, which can be difficult when biological fouling obscures the markings on tags.
- Loss of tags represents loss of data as colonies can no longer be identified

Mosaics have the potential to improve the efficiency of colony-based monitoring because colonies can be identified and tracked through time directly from the mosaics, eliminating the need for underwater tagging and identification. Also, measurement of the size and condition of the colonies is moved from underwater into the lab. Use of mosaics is therefore expected to yield time savings in the field, eliminating the need to install or relocate tags and allowing data extraction to take place in the lab. Eliminating diver contact with the corals, and therefore the potential to damage colonies and removing the need to leave permanent equipment on the seabed are additional benefits of using mosaics. Documenting that data on size and coral condition extracted from mosaics is comparable to data recorded by a diver was a relevant performance objective because it would demonstrate the utility of mosaics for providing colony-based metrics.

Description of metrics: Six metrics were used to assess performance: (1) coral colony size, (2) prevalence of coral disease, (3) prevalence of coral bleaching, (4) the % bleaching of coral colonies, (5) the % new mortality, and (6) the % old mortality.

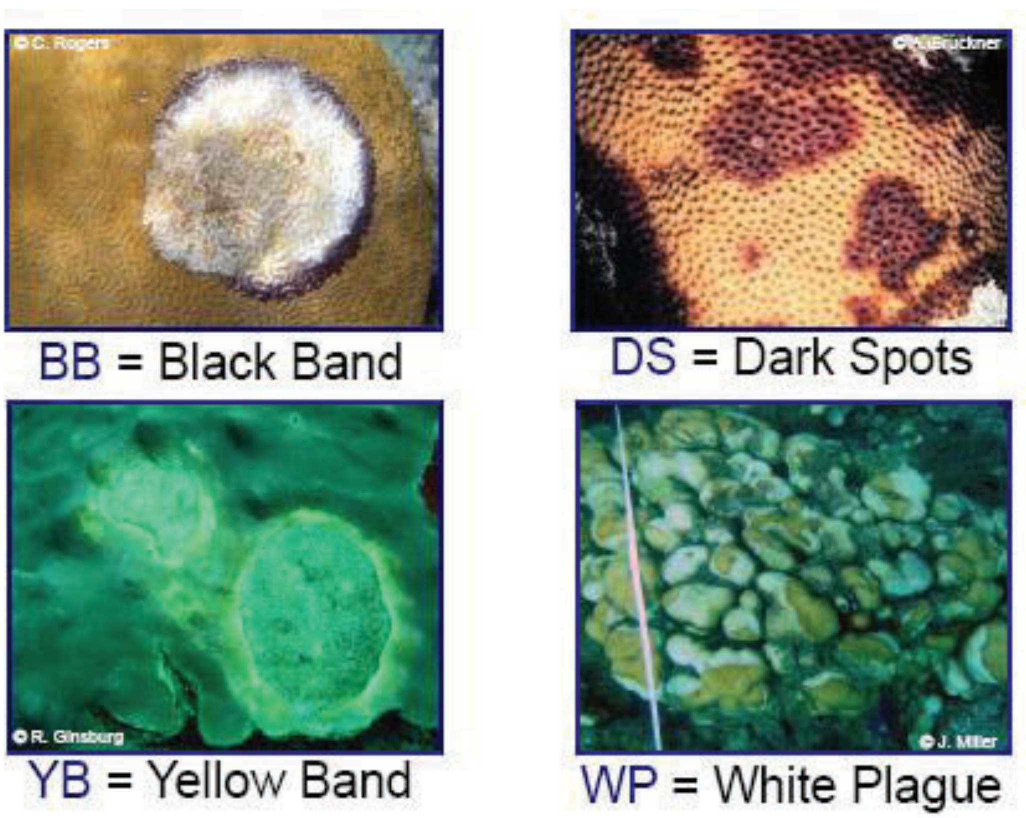
Coral colony size was measured along two axes (longest length and, perpendicularly, widest width of live tissue) of each colony (Figure 2).

To determine prevalence of disease, each surveyed colony was classified as either diseased or not diseased. The presence of coral disease is usually indicated by discoloration of the coral tissue. The following images represent some of the most common diseases seen on present day reefs along with the code used in the field to identify the particular disease (Figure 3). Black Band disease is identified by the discrete dark band at the interface of live tissue and base skeleton. Dark Spots Disease is identifiable by colored irregular or round spots on the coral colony. These areas may be slightly depressed. Yellow Band Disease is identifiable from the yellow to white areas that develop into rings and extend outward. There can be multiple rings on a single colony. This disease is most readily identified with *Montastraea species*. White plague is identifiable by the characteristic white band of exposed skeleton next to healthy coral tissue. In the field we identified coral diseases when encountered. A set of reference images were available to help identify the condition of the coral underwater (Figure 3).



- Adapted with permission from the Atlantic and Gulf Rapid Reef Assessment Protocols (AGRRA) and training materials
- Source html reference: http://www.agrra.org/method/trainingid.html.

Figure 2. Diagram of 2-D size measurements of coral colonies.



- Adapted with permission from the Atlantic and Gulf Rapid Reef Assessment Protocols (AGRRA) and training materials, http://www.agrra.org/method/trainingid.html.

Figure 3. Common coral diseases.

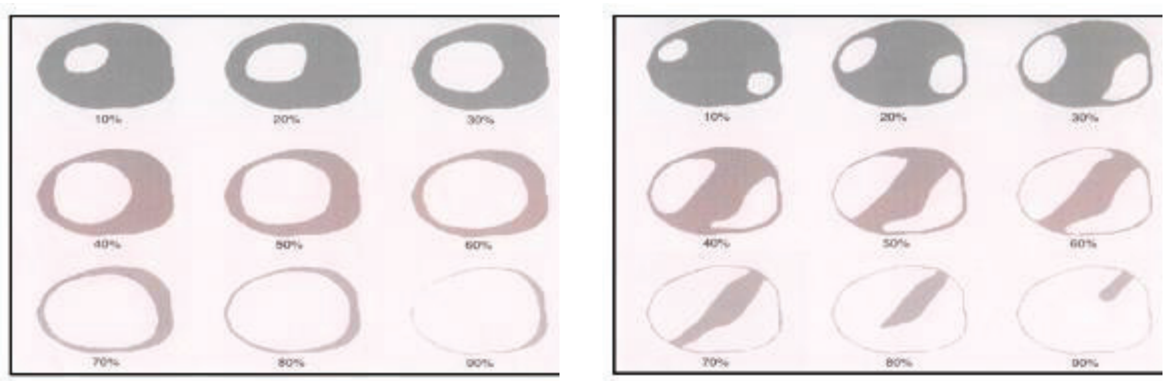
Coral bleaching refers to the breakdown of the relationship between a coral host and the microscopic algae, zooxanthellae, which live in their tissues. Under stressful conditions, most notably prolonged high temperatures, zooxanthellae are expelled from coral tissues revealing the bright white coral skeleton underneath. Coral bleaching is a recognized indicator of coral stress and has been noted on reefs worldwide. For this demonstration we identified bleached corals visually to determine prevalence and estimate the % of the downward looking surface area that was bleached at the time of the survey.

To determine prevalence of bleaching, each surveyed colony was classified as either bleached or not bleached. Corals were considered bleached if their tissues had expelled their algal symbionts leaving only translucent tissues (Figure 4). When bleaching occurs, the color of the skeleton shows through the transparent tissue making the coral appear bright white or bluish depending on the coral species (Figure 4)

- A close-up of the translucent tissues of a coral colony (left).
- The bright white (center) and bluish (right) appearance of coral skeletons that have bleached.
- Figures adapted with permission from the Atlantic and Gulf Rapid Reef Assessment Protocols (AGRRA) and training materials (http://www.agrra.org/method/trainingid.html).

Figure 4. Images showing coral bleaching.

The percentage of the colony affected by bleaching was estimated visually both in the field and from mosaic images. The following two images in (Figure 5) were provided underwater to aid in the accuracy of each visual assessment. In this demonstration we used these images to help to train the observer to visually assess the % of the colony that is bleached, the % of the colony that has new mortality, and the % of the colony that has old mortality.



- Adapted with permission from the Atlantic and Gulf Rapid Reef Assessment Protocols (AGRRA) and training materials (http://www.agrra.org/method/trainingid.html).

Figure 5. Visual representations of a range of possible mortality or bleaching conditions seen in the field.

New Mortality (NM) is defined as non-living part(s) of the coral in which the corallite (surficial skeletal) structures are still intact, unless they have just been bitten by a fish or abraded, and the freshly exposed, white surface is free of any sediment, microbial/diatom biofilms, other microalgae, etc. The coral's soft tissues would have died within the previous minutes-several days at most and, in some cases, may not have completely sloughed off the skeleton. New mortality gives important temporal information during prolonged disturbances like the outbreaks of disease that can follow mass bleaching events (Kramer 2003). The discerning visual characteristic of new mortality as opposed to bleaching is that the tissue is no longer intact in the area of mortality, whereas the tissue remains intact if the coral is only bleached but not dead (Figure 6).

- Corallite structures are free from any sediment, microbial/diatom biofilms or macroalgae (left).
- Adapted with permission from the Atlantic and Gulf Rapid Reef Assessment Protocols (AGRRA) and training materials (http://www.agrra.org/method/trainingid.html).

Figure 6. Images showing the bright white appearance of new coral mortality (left and right).

Old Mortality (OM) is defined as any non-living parts of the coral in which the corallite structures are: (a) covered over by organisms that are not easily removed (e.g., thick turf algae, dense macroalgae, attached invertebrates, other corals); or (b) the overgrowing organisms (and the outer corallite structures) have been removed by a scraping herbivore (e.g., the stoplight parrotfish *Sparisoma viride*), or abraded by a storm, exposing the underlying skeleton (Figure 7). The coral's soft tissues are presumed to have died within the previous months-years or decades

Figure 7. Old mortality of a coral colony. Tissue has died and been replaced by sediment and turf algae.

Data required: The six metrics described above were measured by divers and from the mosaics. All measurements of coral colony size were made to the nearest centimeter by divers in the water and from mosaic images that had been scaled by reference to meter sticks placed within the image. The number of colonies within the sample of tagged corals showing signs of bleaching or disease were noted by divers in the field and ecologists in the lab in order to determine the prevalence of coral bleaching and mortality.

Coral condition was assessed by a visual assessment of the percentage of total coral affected in the field and visual assessment of the percentage of the total coral area affected from mosaic images in the laboratory.

Criteria for determining success: Mosaics were considered effective tools for measurement of colony-based indicators of reef condition if size and condition of coral colonies extracted from the mosaics did not significantly differ from size and condition measured by divers.

3.1.2 Performance Objective 2: Maintain Continuity with Long-Term, Map-Based, Coral Reef Monitoring Data Sets

Relevance of the objective: Performance Objective 1 (PO 1) assessed metrics of coral size extracted from mosaics by comparison to measurements made by divers with a tape measure, which is how a current, plot-based monitoring program would measure coral size. In contrast, Performance Objective 2 (PO 2) assessed metrics of coral size extracted from mosaics by comparison to hand-drawn maps made by divers, which is relevant for determining if mosaics can be seamlessly integrated into an existing, long-term monitoring program based on diver maps. Specifically, a long-term monitoring dataset of interest to the Navy was established in the early 1970s at Andros Island.

Between 1970 and 1975 AUTEC established 36 permanent reef monitoring sites along the eastern coast of Andros Island. The existing monitoring plots at AUTEC differ from how one would establish new plots today because they were not created with the current colony tagging method. Instead, the monitoring plots at AUTEC were established by divers creating hand-drawn underwater maps. Within these permanent monitoring stations, 10 × 10 m or 5 × 5 m reef plots were established in which all benthic organisms (stony corals, zoanthids, sponges, and gorgonians) were mapped and identified. These complete benthic surveys of large areas represent the best diver-based analogue for modern landscape mosaics because both catalog the entire benthic community within a plot in a spatially explicit way. Since their establishment these sites have undergone changes due to both local and region-wide disturbances including the 1983 loss of the herbivorous urchin *Diadema antillarum* and the 1998 Caribbean-wide mass bleaching event (Kramer 2003). Therefore these sites provide the opportunity for detection and analysis of long-term changes.

Description of metrics: Two metrics were used to assess performance. The first, coral colony size, was the same metric as described above for PO 1. The second was total coral cover which is the two-dimensional area occupied by corals within the defined area of interest.

Data required: To assess the ability of mosaics to collect the same information as hand drawn maps created by divers, a 2 × 2 m plot was established and all benthic organisms within the area of interest were mapped by both hand and using mosaic techniques. From these hand-drawn maps, the two data metrics (1) coral colony size (maximum width (cm) and maximum length (cm)) and (2) the total area occupied by live coral (cm^2) were extracted for data analysis. These data were also be extracted from scaled mosaic images of the 2 × 2 m areas of interest. Replicate 2 × 2 m plots were evaluated and mosaics were collected with markers showing the 2 × 2 m areas of interest. The time to collect this data was collected and scaled to reflect that of an entire 10 × 10 m site. Size estimates, coral cover estimates and efficiency were compared to determine the performance of both methods. In addition the sizes of all corals within each 2 × 2 m plot were measured by divers for comparison to traditional methods of coral size measurements.

Criteria for determining success: Mosaics were considered effective tools for maintaining the continuity of the long term AUTEC data set if coral size and coral cover estimates from the mosaics did not significantly differ from size and condition measured from diver-drawn maps.

3.1.3 Performance Objective 3: Ease of Use

Relevance of the objective: One of the potential benefits of using mosaics rather than diver-based observations is that the need for biological/ecological expertise in the field may be reduced. This is expected to be beneficial for the Navy, in particular, which employs many more skilled technical divers than trained marine biologists/ecologists. The purpose of this performance objective was to evaluate whether mosaic data collected by newly trained personnel differed in a meaningful way from mosaic data compared to that obtained by experienced mosaic-makers.

Three components of ease-of-use were evaluated over the course of the entire project: (a) the training required to acquire data that can subsequently be successfully made into a mosaic; (b) the training required to successfully utilize the mosaic creation software; and (c) the training required to extract ecological information from the mosaics. The long-term monitoring demonstration addressed component (a) of ease-of-use, namely the in-water, data acquisition component. The grounding and traditional metrics demonstrations addressed the other aspects of ease-of-use after Navy Divers had training on the mosaic creation software (for component b) and on the software used to extract ecological information from the mosaics (for component c).

Description of metrics: The performance characterization was based on a comparison between mosaics acquired by newly trained personnel and by experienced users. Two metrics were used:

The first metric was the percentage of the video survey successfully incorporated into the video mosaic. This metric, referred to as incorporation percentage, is one indicator of the mosaic quality. Incorporation percentage is the ratio of the number of video frames input to phase IV of the algorithm (blending) relative to the number of frames input to phase II (global matching; see Section 5.3 for details on the algorithm steps). Incorporation percentage quantifies the number of frames that can be linked together by cascading successfully matched images. In practice, this means that if the survey area is poorly covered during data acquisition such that there are "holes" in the data, then only the largest contiguous portion of the mosaic will come out at the end of the optimization and many frames will be discarded during the optimization step. Well-conducted surveys tend to have a high incorporation percentage (typically above 90%), whereas poorly conducted surveys will be considerably lower. This metric also has the advantage of being useful for comparing mosaics from different surveys.

The second metric was a rating on the visual quality of the mosaic, performed by an experienced user. This rating ranged from one to five, and increased with the quality. The meanings of the numerical ratings are detailed below:

- 5 – **Excellent** – All parts of the mosaic are focused and no motion blur is detected. The mosaic presents no internal holes (i.e., the survey covers all of the site area). The survey pattern was conducted as prescribed, so that the intersections among strips are well distributed in the mosaic area.
- 4– **Good** – Most parts of the mosaic are well focused and motion blur is marginal. The mosaic presents no internal holes. The survey pattern was conducted as prescribed, so that the intersections among strips are well distributed in the mosaic area.
- 3 – **Fair** – Some parts of the mosaic may be out of focus or present noticeable motion blurs, but the automated image registration process is still successful. The mosaic contains no internal holes. The survey pattern may have been impacted by currents, but still provides enough overlap for all strips to be visually well placed and oriented.
- 2 – **Poor** – Several parts of the mosaic are out of focus or present noticeable motion blurs, thus impacting the ability of the automated image registration process to join all images. The mosaic may contain internal holes or missing areas. The survey pattern does not provide enough overlap for all strips to be visually well placed and oriented. User intervention is needed to manually join strips, however parts of the mosaic are still usable for coral assessment.
- 1 – **Very poor** – Strong focusing and blurring effects. Only small areas or strips can be automatically registered, but they are clearly misplaced or bent. Few parts to none can be used for coral assessment.

Data required: The required data were a set of raw imagery from the survey, in the standard input format used by the mosaicing software. We had two to three mosaics taken at each site each by a different diver. The average score was used for the success criterion.

Criteria for determining success: The criteria for determining success were based on both the incorporation percentage and visual quality metrics. Success will be considered achieved if the average relative incorporation percentage of all Navy mosaics ≥ 90% and the average visual quality rating of all Navy mosaics ≥ four.

3.2 ENDANGERED SPECIES DEMONSTRATION

The Endangered Species demonstration was designed to evaluate the utility of mosaics for monitoring populations of particular corals of interest. The specific focus of the demonstration was *Acropora palmata*, which is one of two ESA-listed coral species in the Caribbean. Mosaics have the potential to benefit *A. palmata* monitoring efforts by facilitating the tracking of colonies over time, an activity which is now done by hand-mapping the locations and sizes of individual colonies within permanent study sites (Williams *et al.* 2006).

The Williams *et al.* (2006) protocol outlined two types of surveys, one performed on a quarterly basis and one performed on an annual basis. With the exception of coral colony size, which is readily extracted from a mosaic, the types of measurements performed during the quarterly survey are not appropriate for monitoring with 2-D mosaics because they require a full 3-D assessment of the colony. For example, one quarterly parameter is the number of damselfish bite marks found on the colony. Bite marks can't be directly measured from 2-D mosaics since counting the number of bite marks requires inspection of the undersides of colony branches and mosaics only capture a nadir - view of the colony. All of the parameters measured during the Williams *et al.* (2006) annual surveys, however, are suitable for measurement by mosaics. The annual surveys focus on mapping the colonies within permanent monitoring plots. Therefore, three performance objectives (POs) were defined to assess the ability of mosaics to replicate hand mapping of *A. palmata* populations for the purpose of extracting ecological parameters defined by the Williams *et al.* (2006) annual surveys. The following sections describe, for each performance objective, (a) the relevance of the objective, (b) the metrics used to evaluate the objective, (c) the data required to test each metric, and (d) the criteria for determining success. These items are also summarized in Table 5.

Table 5. Performance objectives for the ESA demonstration.

Metric	Data Requirements	Analysis	Success Criteria	Results
Performance objective 1: Coral Colony Location and Abundance				
Colony location	Distance and bearing to all colonies from center marker within survey plot measured by 2 divers. Cartesian coordinates of all colonies within survey plot as measured from mosaic.	Convert diver distance and bearing to Cartesian coordinates. Compute diver-diver difference in position for each colony. Compute diver-mosaic difference in position for each colony. Two-sample t-test of mean diver-diver and diver-mosaic differences.	No significant difference (p<0.05) between mean diver-diver and diver-mosaic differences.	There was no significant difference (p=0.07) in absolute error between the measurement methods.

Table 5. Performance objectives for the ESA demonstration. (Continued)

Metric	Data Requirements	Analysis	Success Criteria	Results
Performance objective 1: Coral Colony Location and Abundance				
Colony abundance	Counts by 2 divers of the number of colonies within survey plot. Count from a mosaic of the number of colonies within survey plot.	Compute max-diver = the greater of # of colonies as counted by diver 1 or diver 2. Compute min-diver = the lesser of # of colonies as counted by diver 1 or diver 2. Compute diver = max-diver - min-diver. Compute threshold as the smaller of diver or 0.1 x min-diver.	# of colonies as counted from the mosaic must be ≥ min-diver - threshold	The counts of threatened coral colonies made from mosaics were greater than the minimum threshold.
Performance objective 2: Coral Colony Size				
Colony size	Projected maximum length and maximum width of all colonies within survey plot measured by 2 divers. Maximum length and maximum width of all colonies within survey plot as measured from mosaic.	Two-sample t-test of mean diver-diver and diver-mosaic differences.	No significant difference ($p<0.05$) between measurement method. Test applied separately to length and width.	There was no significant difference ($p=0.28$) in absolute error between measurement methods.
Performance Objective 3: Coral Colony Descriptors				
% live tissue	% live tissue of all colonies within survey plot measured by 2 divers. % live tissue of all colonies within survey plot as measured from mosaic.	Two-sample t-test of mean diver-diver and diver-mosaic differences.	No significant difference ($p<0.05$) between measurement method	There was no significant difference ($p=0.98$) in the estimation of % live tissue of threatened species when measured in-situ by a diver or from a mosaic.

Table 5. Performance objectives for the ESA demonstration. (Continued)

Metric	Data Requirements	Analysis	Success Criteria	Results
Performance Objective 3: Coral Colony Descriptors				
Colony Type	Assessment of type by 2 divers for all colonies within survey plot. Assessment of type from the mosaic for all colonies within survey plot.	For each colony type: compute max-diver = the greater of # of colonies of that type as counted by diver 1 or diver 2. Compute min-diver = the lesser of # of colonies of that type as counted by diver 1 or diver 2. Compute diver = max-diver - min-diver. Compute threshold as the smaller of diver or 0.1 x min-diver.	# of colonies of a given type as counted from the mosaic must be ≥ min-diver - threshold and ≤ max-diver + threshold for that type.	Diver and mosaic assessments of *A. palmata* colony type were not significantly different.

3.2.1 Performance Objective 1: Coral Colony Location and Abundance

Relevance of the objective: One strength of colony-based monitoring schemes is the ability to estimate population demographic parameters such as recruitment and mortality by tracking colonies over time. Currently, tracking is done through a combination of hand-mapping and tagging colonies. The question addressed by PO 1 was the following: are maps of coral colonies generated from a mosaic comparable to diver-based measurements?

Description of metrics: Two metrics were evaluated: colony location and colony abundance. Colony location is the spatial position of the center of the coral colony relative to a permanent stake marking the center of the monitoring plot. Colony abundance is a count of the number of colonies in the monitoring plot. Monitoring plots for this demonstration were as specified by Williams *et al.* (2006), namely 7-m radius fixed sites, marked with a pin at the center to enable replication. Three plots were mapped for this demonstration.

Data required: Data requirements were diver measurements of distance and bearing from a center stake to all colonies within survey plot, diver counts of the total number of colonies in the survey plot, and a mosaic of the survey plot from which colony location and abundance were estimated.

Criteria for determining success: For the colony location metric, a two-sample t-test of mean diver-diver and diver-mosaic differences was conducted to determine if there were any bias in position estimates between the two techniques. Differences for this metric were defined as the geometric difference in position as estimated by the two methods. For example, if diver one measured the position of coral colony one as (X_1, Y_1) and diver two measured the position of coral colony one as (X_2, Y_2), then the difference $D_1 = ((X_1-X_2)^2 + (Y_1-Y_2)^2)^{0.5}$. For the abundance metric, a threshold technique (see Table 5) was used to determine if there were a significant difference between diver and mosaic estimates of abundance.

3.2.2 Performance Objective 2: Coral Colony Size

Relevance of the objective: Coral colony size is an important measurement because it is used to derive population age structure, when tracking individuals over time, and to estimate live tissue area. The importance of coral colony size is reflected in the fact that it was included as a metric on every demonstration in this project. The reasons to include it again in the ESA demonstration were, first, that the branching morphology of *A. palmata* is very different from the encrusting or mounding shapes encountered at other demonstration sites. Second, it was likely that we would encounter relatively more "large" (i.e. > 50 cm) colonies in this demonstration than at the other sites visited in this project.

Description of metrics: The coral size metric was described in the long-term monitoring demonstration (Section 3.1.1).

Data required: Projected length and width of all colonies within survey plot measured by two divers. Length and width of all colonies within survey plot as measured from mosaic.

Criteria for determining success: A two-sample t-test of mean diver-diver and diver-mosaic differences was conducted to determine if there were any bias in length or width estimates between the two techniques.

3.2.3 Performance Objective 3: Coral Colony Descriptors

Relevance of the objective: Numbers, location, and sizes of coral colonies (i.e. POs 1 and 2) will be basic data required for any colony-based monitoring protocol. Other data may also be collected for each colony depending on the specific objectives of any particular monitoring program. The percent of each colony covered with live tissue and the colony type (defined below) are the two additional metrics that are collected during the annual surveys of *A. palmata* plots using the Williams *et al.* (2006) protocol.

Description of metrics: Percent live tissue is a visual estimate of how much of the colony is covered by live tissue. Colony type is one of the following: branched colony, remnant crust, attached fragment, stable fragment, or loose fragment. The colony type definitions are as follows (Williams *et al.* 2006):

- Branched colony: A "normal" looking colony with branches, may have some partial mortality.
- Remnant colony: Live tissue that is mostly encrusting; no or few branches.
- Attached fragment: A live fragment (usually a branch) with some signs of attachment to the reef. If attachment of a fragment cannot be determined visually, map it and note the uncertainty. It is important not to touch fragments since they may be in the early stages of forming and attachment.
- Stable fragment: Occasionally, large (> 75 cm) portions of colonies are broken off and found "loose" in the plot. While they may not be attached to the substrate they can be considered "stable" due to their weight, structure, and location.
- Loose fragment: A live fragment (usually a branch) loose in a rubble pile or on the reef with an obvious fresh break. Note that occasionally loose fragments land on living tissue, these should not be considered separate fragments, but rather part of the colony on which they have landed.

Data required: % live tissue of all colonies within survey plot measured by two divers. % live tissue of all colonies within survey plot as measured from mosaic. Assessment of type by two divers for all colonies within survey plot. Assessment of type from the mosaic for all colonies within survey plot.

Criteria for determining success: The criterion for success for percent live tissue was no significant difference ($p < 0.05$) between diver-diver and diver-mosaic measurement methods. The criterion for success for colony type used a threshold technique (see Table 5) to determine if there were a significant difference between diver and mosaic classifications of colony type.

3.3 GROUNDING DEMONSTRATION

The grounding demonstration was designed to evaluate the utility of mosaics for assessing damage to reefs caused by vessel groundings. Damage following vessel groundings has two components: the areal extent and the severity. Mosaics have the potential to benefit grounding assessment because both the areal extent and the severity of damage can be extracted from the same raw data source, thereby saving field time and increasing data archival potential.

Three performance objectives (POs) were defined to assess the ability of mosaics to accurately measure large areas. The fourth performance objective was defined to assess the ability of mosaics to quantify magnitude of damage. Finally, a fifth performance objective was defined to assess whether new users can extract data from the mosaics successfully. The following sections describe, for each performance objective, (a) the relevance of the objective, (b) the metrics used to evaluate the objective, (c) the data required to test each metric, and (d) the criteria for determining success. These items are also summarized in Table 6.

Table 6. Performance Objectives for the grounding demonstration.

Metric	Data Requirements	Analysis	Success Criteria	Results
Performance Objective 1: Comparison of the Area of Damage				
Total Damaged Area	Total damaged area as measured with: 1) Divers in the water (fishbone method) 2) From an outline of the damage from a mosaic image 3) Using surface GPS	Are the measured areas within 10% using each measurement method?	Methods are within 10% of each other	Average mosaic and GPS estimates of damage size were within 6% of each other while the average estimate of damage as estimated by the fishbone method was 19% higher than the average mosaic estimate.

Table 6. Performance Objectives for the grounding demonstration. (Continued)

Metric	Data Requirements	Analysis	Success Criteria	Results
Performance Objective 1: Comparison of the Area of Damage				
Linear Damage Size	Absolute Error (Mosaic-Diver1) measurement of linear damage (using fishbone methods) Absolute Error (Diver 1 –Diver 2) measurement of linear damage (using fishbone methods)	Paired t-test	No significant difference ($p<0.05$) between measurement method	There was no significant difference in linear measurements of damaged areas recorded in situ by a diver or from a mosaic analyst ($p=0.43$)
Performance Objective 3: Accuracy of the Measurement of Large Linear Targets				
Large Linear Target Size (A)	Diver, Mosaic, and GPS measurements of Linear Targets of known size (1-10m)	One-Sample t-test of differences	Not significantly different from zero ($p< 0.05$)	Mosaic bias was not significantly different from zero ($p=0.06$), Diver bias was contradictory (diver1 $p=0.43$ diver2 $p=0.01$) and GPS was significantly different $p=0.00$).
Large Linear Target Size (B)	Diver, Mosaic and GPS bias of Linear Targets of known size (1-10m)	ANOVA of measurement biases	Mosaic bias is not significantly greater than Diver or GPS bias ($p< 0.05$)	The GPS measurement bias was significantly different than divers or mosaics when measuring long-linear distances

Table 6. Performance Objectives for the grounding demonstration. (Continued)

Metric	Data Requirements	Analysis	Success Criteria	Results
Performance Objective 4; Extract Ecological Measurements from Mosaics both Inside and Outside Damaged areas that are Comparable with Diver-Based Metrics				
Benthic cover	(1) % cover of live coral, turf algae, macroalgae, crustose coralline algae, milleporans, gorgonians, zoanthids, and sponges measured from mosaics using random point counts. (2) % cover of live coral, turf algae, macroalgae, crustose coralline algae, milleporans, gorgonians, zoanthids, and sponges measured by divers using PIT. Cover will be computed both inside and outside the damaged area.	Two-way ANOVA with method and category (*i.e.*, coral, algae, substrate) as factors.	no significant differences ($p < 0.05$) between diver and mosaic estimates of percent cover for each benthic category.	Benthic cover estimates of corals, sponges, macroalgae, and coralline algae were not significantly different. However some differences were found between gorgonian and sand cover estimates between divers and mosaics.
Coral species richness	(1) # of coral species as counted from mosaics using random point counts and image inspection. (2) # of coral species as counted by divers using BT. Species richness will be computed both inside and outside the damaged area.	Compute max-diver = the greater of # of coral species as counted by diver 1 or diver 2. Compute min-diver = the lesser of # of coral species as counted by diver 1 or diver 2. Compute diver = max-diver - min-diver. Compute threshold as the smaller of diver or 0.1 × min-diver.	# of coral species as counted from the mosaic. must be ≥ min-diver - threshold	The mosaic point count method of assessing species richness was not equivalent to information collected by divers in the field. Mosaic visual inspection was equivalent to diver methods of estimating species richness.

Table 6. Performance Objectives for the grounding demonstration. (Continued)

Metric	Data Requirements	Analysis	Success Criteria	Results
Performance Objective 4; Extract Ecological Measurements from Mosaics both Inside and Outside Damaged areas that are Comparable with Diver-Based Metrics				
Coral colony size frequency distribution	(1) Size frequency distribution for corals ≥ 4 cm maximum dimension created from maximum length and width (cm) of coral colonies as measured from mosaics using scaled pixels. (2) Size frequency distribution for corals ≥ 4 cm maximum dimension created from maximum length and width (cm) of coral colonies as measured by divers using PCQT.	Chi-squared test comparing the diver-derived and mosaic-derived size frequency distributions.	no significant differences ($p < 0.05$) between diver and mosaic estimates.	There was no significant difference ($p=0.72$) in the estimates of coral colony size frequency as recorded in-situ by divers or estimated from a mosaic image.
% diseased of coral colonies	(1) Estimate of % of each colony that is diseased as measured from mosaics using random point counts and image inspection. (2) Estimate of % of each colony that is diseased as measured by divers using PCQT.	One-way ANOVA comparison of methods using the average value of % diseased over the site derived from divers and from the mosaic as inputs.	no significant differences ($p < 0.05$) between diver and mosaic estimates	These results were combined over multiple demonstrations and are discussed in the traditional metrics demo results section.

Table 6. Performance Objectives for the grounding demonstration. (Continued)

Metric	Data Requirements	Analysis	Success Criteria	Results
Performance Objective 4; Extract Ecological Measurements from Mosaics both Inside and Outside Damaged areas that are Comparable with Diver-Based Metrics				
% bleached of coral colonies	(1) Estimate of % of each colony that is bleached as measured from mosaics using random point counts and image inspection. (2) Estimate of % of each colony that is bleached as measured by divers using PCQT.	One-way ANOVA comparison of methods using the average value of % bleached over the site derived from divers and from the mosaic as inputs.	no significant differences ($p < 0.05$) between diver and mosaic estimates	These results were combined over multiple demonstrations and are discussed in the traditional metrics demo results section.
% mortality of coral colonies	(1) Estimate of % of each colony that is (old or new or both) dead as measured from mosaics using random point counts and image inspection. (2) Estimate of % of each colony that is (old or new or both) dead as measured by divers using PCQT.	One-way ANOVA comparison of methods using the average value of % mortality over the site derived from divers and from the mosaic as inputs.	no significant differences ($p < 0.05$) between diver and mosaic estimates	These results were combined over multiple demonstrations and are discussed in the traditional metrics demo results section.
Juvenile coral density	(1) # of juvenile corals (< 4 cm maximum length) as counted from mosaics using inspection of random subquadrats. (2) # of juvenile corals (< 4 cm maximum length) as counted by divers using recruitment quadrats.	Compute juvenile density = average # of juvenile corals per m2 for both diver and mosaic estimates.	no significant differences ($p < 0.05$) between diver and mosaic estimates	There was no significant difference in the mean juvenile coral density as estimated bin in-situ by divers and from mosaic images ($p=0.06$ outside the damage, $p=0.24$ inside the damaged area)

Table 6. Performance Objectives for the grounding demonstration. (Continued)

Metric	Data Requirements	Analysis	Success Criteria	Results
Performance Objective 5: Data Analysis Ease of Use				
Coral Size	Navy Personnel measures of coral colony size using mosaics extraction techniques RSMAS Personnel measures of coral colony size using mosaic extraction techniques	Paired t-test	Differences are not significantly different than zero ($p<0.05$)	There was no significant difference in the estimate of coral colony size as recorded by RSMAS and Navy analysts ($p=0.17$)
Percent Coral Cover	Navy Personnel measures of Percent Cover using mosaic extraction techniques RSMAS Personnel measures of Percent Cover using mosaic extraction techniques	Binomial test	Differences are not significantly different than zero ($p<0.05$)	Estimates of percent cover obtained by UM and Navy analysts were not significantly different for corals, gorgonians, sponges, zoanthids and macroalgae. The category of sand was significantly different.

3.3.1 Performance Objective 1: Comparison of the Area of Damage

Relevance of the objective: Total damaged area is a critical measurement for damage assessment because it directly affects penalties and restoration efforts. The question addressed by PO 1 was the following: is the total area of a grounding scar as measured from a mosaic comparable to diver-based measurements?

Description of metrics: The metric was total damaged area (m^2), i.e. the spatial extent of the impacted portion of the reef.

Data required: Data requirements were total damaged area (m^2) as measured by a) the mosaics, b) divers using transect tapes and the "fishbone" method (Hudson and Goodwin 2001), and c) GPS.

Criteria for determining success: The criterion for success was that the mosaic should give an estimate of the damaged area within 10% of the diver or the GPS (Table 6). The 10% threshold criterion was chosen in lieu of a statistical test for cost considerations. There is no statistical test possible for comparing these methods for total area because we had a sample size of N = 1. Generating an adequate sample size for a traditional statistical test would require surveying multiple grounding sites and therefore be cost-prohibitive. PO 2 and PO 3 were designed to complement PO 1 by addressing this sample-size limitation.

3.3.2 Performance Objective 2: Comparison of Linear Damage Measurements

Relevance of the objective: Total damaged area is ultimately the most important size metric for damage assessment, which is why it was defined as PO 1. Linear measurements (m) rather than area (m^2) are also relevant to damage assessment, however, because if one can measure linear distances accurately then they can be combined to derive area. The Hudson and Goodwin (2001) "fishbone" diver-based technique for quantifying large areas, for example, relies on a series of linear measurements to estimate area. In the fishbone method, a single transect line is laid down the center of the area to be assessed, then the perpendicular distance from that base line to the edge of the scar is measured at 1 m intervals. The end result is a wire-frame, or fishbone pattern, from which the outline of the scar can be traced to derive an estimate of the damaged area. If mosaics can be shown to give the same measurement that divers give of linear distances on the order of several m, then one can be confident that areal measurements will be comparable also. The question addressed by PO 2 was the following: are linear measurements of the dimensions of a grounding scar as measured from a mosaic comparable to diver-based measurements from transect tapes?

Description of metrics: The metric to be evaluated was length (m) on the scale of several to 10's of meters.

Data required: Data requirements were dimensions of the scar as quantified by divers using transect tapes; *i.e.*, the "fishbone" method (Hudson and Goodwin 2001), and dimensions of the scar as derived from a mosaic.

Criteria for determining success: The criterion for success was that the average mosaic-diver difference should be less than or statistically equal to the average diver-diver difference for the same linear measurements.

3.3.3 Performance Objective 3: Accuracy of the Measurement of Large Linear Targets

Relevance of the objective: The relevance of linear measurements (m) to damage assessment and a test for comparing the relative agreement of diver-based and mosaic-based linear measurements on the scale of m was outlined for PO 2. Relative comparisons of the real grounding scar need to be used for PO 2 because the true answer is not known. For PO 3, however, we used known targets (PVC pipe) against which the absolute accuracy of different measurement techniques could be tested. The question addressed by PO 3 was the following: what is the absolute accuracy of GPS, diver, and mosaic measurements for making large linear measurements? This question was addressed in two ways: (A) the average difference (*i.e.* the bias) between the size of known targets and measurements made using mosaics, divers, and GPS was evaluated independently, to see which if any of them deviate from zero, and (B) the biases computed using these three techniques were compared to check that the value from the mosaics was no larger than for the other techniques.

Description of metrics: The metric to be evaluated was length (m) on the scale of several to 10s of meters.

Data required: Data requirements were dimensions of known targets as measured using GPS, transect tapes, and mosaics. The targets were markers placed on the seabed separated by random distances from 1-10 m apart.

Criteria for determining success: (A) The criterion for success for each method (GPS, diver, mosaic) was that the average difference from the known size should not be statistically different from zero, and (B) The criterion for success was that the mosaic bias should not be significantly greater than the diver or GPS bias.

3.3.4 Performance Objective 4: Extract Ecological Measurements from Mosaics that are Comparable With Diver-Based Metrics

Relevance of the objective: In addition to total affected area, the condition of the benthic community is the other important parameter to measure when assessing vessel groundings. Typically, diver transect methods are used to assess community condition within the vessel scar relative to nearby control areas outside of the scar. The question addressed by PO 4 was the following: are metrics of community composition and condition extracted from a mosaic of a particular site statistically the same as those extracted by diver transects from the same site?

We assessed one area within and one area outside of a vessel scar, The metrics, data requirements and criteria for success proposed for this demonstration are identical to the traditional metrics demonstration (Section 3.4), however, so that in the end, the data from both demonstrations were pooled to increase sample size (Section 6.4).

Description of metrics: Seven metrics were used to assess performance: (1) benthic cover, (2) coral species richness, (3) coral colony size frequency distribution, (4) % diseased of coral colonies, (5) % bleaching of coral colonies, (6) % mortality of coral colonies, (7) juvenile coral density (Table 6).

Benthic cover was determined as a percentage for the following taxonomic groups: live coral, turf algae, macroalgae, crustose coralline algae, milleporans, gorgonians, zoanthids, and sponges. Coral species richness was the number of distinct coral species observed in the sample area. Coral colony size frequency distribution was determined by coral colony size measured along two axes (longest length and, perpendicularly, widest width of live tissue) of each colony (Figure 2). The determination of coral health indices for this demonstration followed the guidelines presented in the long-term monitoring demonstration (Section 3.1.1). Juvenile coral density was defined as the number of coral colonies < 4 cm in maximum length per unit area and was used as a measure of recruitment to the site.

Data required: The seven metrics described above were measured both by divers and from the mosaics. The divers used Belt Transects (BT) to measure species richness, point intercept transects (PIT) to measure benthic cover, and the Point Centered Quarter Transects (PCQT) to measure all other metrics (see Section 5.4.4.). From the mosaics, analysts used random point counting and image inspection to measure all variables except sizes (see Section 5.4.4). Coral colony sizes were measured from the mosaics in units of pixels and then scaled to cm by reference to meter sticks placed within survey area (see Section 5.4.4). All measurements of coral colony size were made to the nearest centimeter.

Criteria for determining success: The criteria for success were that the seven ecological metrics extracted from the mosaics did not significantly differ from those measured by divers (Table 6).

3.3.5 Performance Objective 5: Ease of Use

Relevance of the objective: Ultimately, the mosaicing technology may be transitioned to users for operational purposes. The purpose of this performance objective was to evaluate whether data extracted from a mosaic by newly trained analysts differed in any meaningful way from data extracted from mosaics by experienced analysts.

There are three components of ease-of-use that were evaluated over the course of the entire project. These were: (1) the training required to acquire data that can subsequently be successfully made into a mosaic; (2) the training required to successfully utilize the mosaic creation software; and (3) the training required to extract ecological information from the mosaics. This performance objective addressed component (3) of ease-of-use, namely the extraction of ecological information from the mosaics. The long-term monitoring demonstration addressed component (1) of ease-of-use, and the traditional metrics demonstration addressed component (2) of ease-of-use.

Description of metrics: Coral size (Figure 2) and the percentage of the seabed covered with live coral were used as metrics.

Data required: The required data were coral size and coral cover extracted from a mosaic by an experienced analyst (i.e. a RSMAS person) and by a newly trained analyst (i.e. a Navy person) from the same raw data.

Criteria for determining success: The criteria for success were that the RSMAS and Navy estimates of size and coral cover should not be significantly different.

3.4 TRADITIONAL METRICS DEMONSTRATION

The traditional metrics demonstration was designed to evaluate the utility of mosaics for wide-area coral reef monitoring efforts traditionally performed using diver-transect surveys. This demonstration tested the propositions, first, that reef status metrics extracted from mosaics were comparable to those acquired from diver transects (i.e., mosaics retained the strengths of diver transects), second, that mosaics improved on the diver transect approach by providing a more useful data archive, and, third, that new users could operate the mosaicing software with minimal training. Three performance objectives were defined, each evaluating one of these three aspects of the demonstration.

The first objective of the traditional metrics demonstration was designed to quantify the degree to which mosaics retained the strengths of traditional diver-based surveys. This objective tested whether classic metrics such as percent cover of benthic organisms and species diversity that are used in many surveys of coral reef health can be accurately extracted from mosaics.

The second objective of this demonstration was to evaluate the powerful data archive capability of landscape mosaics, thereby addressing an important limitation of the traditional diver-based approach. Stakeholders and environmental regulating agencies frequently challenge the data that Navy divers generate from their coral reef surveys. Landscape mosaics will provide an objective source of data that multiple parties can analyze as required. The mosaics thus have a strong potential for facilitating external validation of Navy survey results and enabling science-based resolution of environmental concerns.

The third objective of this demonstration was to test whether newly trained analysts can use the mosaicing software adequately.

Evaluation of mosaic performance versus traditional methods relied on a suite of metrics (Table 7). The following sections describe, for each performance objective, (a) the relevance of the objective, (b) the metrics used to evaluate the objective, (c) the data required to test each metric, and (d) the criteria for determining success.

Table 7. Performance objectives for the traditional metrics demonstration.

Metric	Data Requirements	Analysis	Success Criteria	Results
Performance Objective 1; Extract ecological measurements from mosaics that are comparable with diver-based metrics				
Benthic cover	1) % cover of live coral, turf algae, macroalgae, crustose coralline algae, milleporans, gorgonians, zoanthids, and sponges measured from mosaics using random point counts. 2) % cover of live coral, turf algae, macroalgae, crustose coralline algae, milleporans, gorgonians, zoanthids, and sponges measured by divers using PCQT.	Two-way ANOVA with method and category (*i.e.*, coral, algae, substrate) as factors.	no significant differences ($p < 0.05$) between diver and mosaic estimates of percent cover for each benthic category.	Site-level comparisons of benthic cover from divers and mosaics differed for most categories. At the transect level, benthic cover was as accurate as diver estimates for all benthic categories.
Coral species richness	(1) # of coral species as counted from mosaics using random point counts and image inspection. (2) # of coral species as counted by divers using BT.	Compute max-diver = the greater of # of coral species as counted by diver 1 or diver 2. Compute min-diver = the lesser of # of coral species as counted by diver 1 or diver 2. Compute diver = max-diver - min-diver. Compute threshold as the larger of diver or 0.1 × min-diver.	# of coral species as counted from the mosaic. must be ≥ min-diver - threshold	The visual mosaic inspection method produced equivalent metrics of species richness when compared to diver estimates. Mosaic point counts did not replicate diver belt transect information on species richness.

Table 7. Performance objectives for the traditional metrics demonstration. (Continued).

Metric	Data Requirements	Analysis	Success Criteria	Results
Performance Objective 1; Extract ecological measurements from mosaics that are comparable with diver-based metrics				
Coral colony size frequency distribution	1) Size frequency distribution for corals ≥ 4 cm maximum dimension created from maximum length and width (cm) of coral colonies as measured from mosaics using scaled pixels. 2) Size frequency distribution for corals ≥ 4 cm maximum dimension created from maximum length and width (cm) of coral colonies as measured by divers using PCQT.	Chi-squared test comparing the diver-derived and mosaic-derived size frequency distributions.	no significant differences ($p < 0.05$) between diver and mosaic estimates.	There was no significant difference in the estimates of coral colony size frequency as recorded in-situ by divers or from mosaic images.
% diseased of coral colonies	1) Estimate of % of each colony that is diseased as measured from mosaics using random point counts and image inspection. 2) Estimate of % of each colony that is diseased as measured by divers using PCQT.	One-way ANOVA comparison of methods using the average value of % diseased over the site derived from divers and from the mosaic as inputs.	no significant differences ($p < 0.05$) between diver and mosaic estimates	There was no significant difference in the absolute error of diver or mosaic methods of estimating the percentage of disease infecting a coral colony ($p=0.74$)

Table 7. Performance objectives for the traditional metrics demonstration. (Continued).

Metric	Data Requirements	Analysis	Success Criteria	Results
Performance Objective 1; Extract ecological measurements from mosaics that are comparable with diver-based metrics				
% bleached of coral colonies	1) Estimate of % of each colony that is bleached as measured from mosaics using random point counts and image inspection. 2) Estimate of % of each colony that is bleached as measured by divers using PCQT.	One-way ANOVA comparison of methods using the average value of % bleached over the site derived from divers and from the mosaic as inputs.	no significant differences (p< 0.05) between diver and mosaic estimates	There was no significant difference between diver and mosaic methods of estimating the % bleached condition metric (p=0.68).
% mortality of coral colonies	1) Estimate of % of each colony that is (old or new or both) dead as measured from mosaics using random point counts and image inspection. 2) Estimate of % of each colony that is (old or new or both) dead as measured by divers using PCQT.	One-way ANOVA comparison of methods using the average value of % mortality over the site derived from divers and from the mosaic as inputs.	no significant differences (p< 0.05) between diver and mosaic estimates	There was no significant difference between diver and mosaic methods of estimating the % new mortality condition metric (p=0.92) There is no significant difference in the absolute error of the % old mortality metric when comparing measurement methods (p=0.32).
Juvenile coral density	1) # of juvenile corals (< 4 cm maximum length) as counted from mosaics using inspection of random subquadrats. 2) # of juvenile corals (< 4 cm maximum length) as counted by divers using PCQT.	Compute juvenile density = average # of juvenile corals per m2 for both diver and mosaic estimates.	no significant differences (p< 0.05) between diver and mosaic estimates	Corals smaller than 4 cm were visible from mosaic images and diver and mosaic methods produced similar average density estimates of juvenile corals at 3 of the 4 test sites.

Table 7. Performance objectives for the traditional metrics demonstration. (Continued)

Metric	Data Requirements	Analysis	Success Criteria	Results
Performance Objective 2: Extract ecological measurements from mosaics using multiple methods				
Benthic Cover	1) % cover of live coral, turf algae, macroalgae, crustose coralline algae, milleporans, gorgonians, zoanthids, and sponges measured from mosaics using simulated PCQT, LPIT, and VT. 2) % cover of live coral, turf algae, macroalgae, crustose coralline algae, milleporans, gorgonians, zoanthids, and sponges measured by divers using PCQT, LPIT, and VT.	Two-way ANOVA comparison with survey methods and benthic category as factors.	no significant differences ($p < 0.05$) between diver and mosaic estimates of percent cover for each benthic category for at least 90% of transects measured.	Mosaic methods of estimating benthic cover were as good as divers performing linear intercept transect or video transects.
Coral species richness	1) # of coral species as counted from mosaics using simulated PCQT, LPIT, and VT. 2) # of coral species as counted by divers using PCQT, LPIT, and VT.	For each method: Compute max-diver = the greater of # of coral species as counted by diver 1 or diver 2. Compute min-diver = the lesser of # of coral species as counted by diver 1 or diver 2. Compute diver = max-diver - min-diver. Compute threshold as the larger of diver or 0.1 × min-diver.	For each method: # of coral species as counted from the mosaic. must be ≥ min-diver - threshold and for at least 90% of transects measured.	Visual inspection of mosaic images was as accurate as diver surveys for estimating coral species diversity. Visual inspection of video transects and mosaic point counts did not accurately replicate species diversity information obtained by divers.

Table 7. Performance objectives for the traditional metrics demonstration. (Continued)

Metric	Data Requirements	Analysis	Success Criteria	Results
Performance Objective 3: Ease of use				
Incorporation percentage	# of input images and # of images rejected in the global optimization step when RSMAS analysts create a mosaic. # of input images and # of images rejected in the global optimization step when Navy analysts create a mosaic.	Compute incorporation percentage = # of images input to blending / # images input to global matching. Compute relative incorporation percentage = incorporation percentage (Navy)/incorporation percentage (RSMAS)	Average relative incorporation percentage of all mosaics created by Navy analysts ≥90%	Navy analysts with a few days training and the use of a mosaic creation manual were able to produce mosaic images that were indistinguishable from expert operators in terms of area content and incorporation percentage.
Visual quality rating	Visual assessment of the mosaic on scale of 1-5.	None	Average visual quality rating of all mosaics created by Navy analysts ≥4	Navy analysts with a few days training and the use of a mosaic creation manual were able to produce mosaic images that were indistinguishable from expert operators in terms of visual quality.

3.4.1 Performance Objective 1: Extract Ecological Measurements from Mosaics That Are Comparable With Diver-Based Metrics

Relevance of the objective: Performance Objective 1 (PO 1) was designed to test the hypothesis that metrics of coral condition extracted from mosaics are comparable to those extracted from diver transects at the site level. The reason this is an important question is that diver transects are commonly used to sample the benthic community in the vicinity of certain points of interest. These points of interest might be randomly, haphazardly, or systematically distributed across a given area depending on the needs of a particular survey, the goal at each point always the same: to sample the area around the point for the purpose of estimating various ecologically relevant metrics. The question addressed by PO 1 was the following: are metrics extracted from a mosaic of a particular site statistically the same as those extracted by diver transects from the same site?

Description of metrics: Seven metrics were used to assess performance: (1) benthic cover, (2) coral species richness, (3) coral colony size frequency distribution, (4) % diseased of coral colonies, (5) % bleaching of coral colonies, (6) % mortality of coral colonies, (7) juvenile coral density (Table 7).

Benthic cover was determined as a percentage for the following taxonomic groups: live coral, turf algae, macroalgae, crustose coralline algae, milleporans, gorgonians, zoanthids, and sponges. Coral species richness is the number of distinct coral species observed in the sample area. Coral colony size frequency distribution was determined by coral colony size measured along two axes (longest length and, perpendicularly, widest width of live tissue) of each colony (Figure 2). Coral health indices of bleaching, disease, old and new mortality have been described previously (see 3.3.1). Juvenile coral density was defined as the number of coral colonies < 4 cm in maximum length per unit area and is used as a measure of recruitment to the site.

Data required: The seven metrics described above were measured both by divers and from the mosaics. The divers used Belt Transects (BT) to measure species richness and the Point Centered Quarter Transect (PCQT) method to measure all other metrics. From the mosaics, analysts used random point counting and image inspection to measure all variables except sizes. Coral colony sizes were measured from the mosaics in units of pixels and then scaled to cm by reference to meter sticks placed within survey area. All measurements of coral colony size were made to the nearest centimeter.

Criteria for determining success: The criteria for success were that the seven ecological metrics extracted from the mosaics should not significantly differ from those measured by divers (Table 7).

3.4.2 Performance Objective 2: Extract Ecological Measurements from Mosaics Using Multiple Methods

Relevance of the objective: Performance objective 2 (PO 2) tested the ability of mosaics to improve the data archive potential of diver-based transects by providing the capability to extract data from the mosaics using multiple methods. Since there are many different ways to run diver transects, critics sometimes point to the methods used in any particular study and argue that a different type of transect might have given a different answer. Navy ecologists have incurred this problem in the past, having been criticized for using PCQT when (it is argued) a line point intercept transect (LPIT) or some other transect type would have been more appropriate. Given only the transect data, it is not possible to fully deflect criticism of this type without going back to the field and collecting data in a different way. Given a mosaic, however, one can run “virtual” transects of different types across the imagery to test if, in fact, the specific transect type makes any difference. The objective of PO 2 was to compare multiple types of virtual transects run on the mosaics with the corresponding diver-based transects.

Description of metrics: Two metrics were used to assess performance: (1) benthic cover, and (2) coral species richness. These have been defined above, under PO 1 (Section 3.4.1). These two metrics were chosen as a subset of the 7 metrics proposed for PO 1 because they are the most commonly used out of that group, and they can be measured from all of the proposed transect types.

Data required: Benthic cover and coral species richness were measured by divers and from the mosaics. The divers used Point Centered Quarter Transect (PCQT), and video transect (VT) methods to measure both metrics. Analysts used virtual PCQT and VT methods to extract data from a mosaic covering each transect. The beginning and end of the actual transect measured by the diver was marked so that the same area could be sampled from the mosaic.

Criteria for determining success: The ability of mosaics to replicate virtual versions of each type of transect was demonstrated for each metric if the values extracted from at least 90% of the virtual transects of a given type did not significantly differ from those measured by divers (Table 7).

3.4.3 Performance Objective 3: Ease of Use

Relevance of the objective: One of the potential benefits of using mosaics rather than diver-based observations is that the need for biological/ecological expertise in the field may be reduced. This is expected to be beneficial for the Navy, in particular, which employs many more skilled technical divers than trained marine biologists/ecologists. The purpose of this performance objective was to evaluate whether mosaics created by newly trained analysts differed in a meaningful way from mosaics created by experienced analysts.

There are three components of ease-of-use that were evaluated over the course of the entire project: (1) the training required to acquire data that can subsequently be successfully made into a mosaic; (2) the training required to successfully utilize the mosaic creation software; and (3) the training required to extract ecological information from the mosaics. This performance objective addressed component (2) of ease-of-use, namely the use of the mosaicing software to turn raw data (images) into mosaics. The long-term monitoring demonstration addressed component (1) of ease-of-use and the grounding demonstration addressed aspect (3) of ease-of-use.

Description of metrics: The performance characterization was based on a comparison between mosaics created by newly trained personnel and by experienced users. Two metrics were used: the incorporation percentage and the visual quality. These were described in Section 3.1.3 1.

Data required: The required data were pairs of mosaics created by an experienced analyst (*i.e.* a RSMAS person) and by a newly trained analyst (i.e. a Navy person) from the same raw data. The average score of all the mosaics created during the demo were utilized for the success criterion

Criteria for determining success: The criterion for determining success was based on both the incorporation percentage and visual quality metrics. Success was considered achieved if the average relative incorporation percentage of all Navy mosaics was ≥ 90% and the average visual quality rating of all Navy mosaics was ≥ four.

3.5 ABSOLUTE ACCURACY DEMONSTRATION

The Absolute Accuracy demonstration was designed to evaluate the accuracy and precision of size measurements made from mosaics and made by divers. The approach was to make size measurements of objects of known dimensions. Four performance objectives were defined for this demonstration. Evaluation of mosaic and diver performance versus known standards relied on a suite of metrics (Table 8). The following sections describe, for each performance objective, (a) the relevance of the objective, (b) the metrics used to evaluate the objective, (c) the data required to test each metric, and (d) the criteria for determining success. Note that all tests for PO 1 A/B, 2 A/B, and 3 A/B were repeated for three classes of objects (flat, mounding, and branching) and two size categories within each class of objects.

Table 8. Performance objectives for the absolute accuracy demonstration.

Metric	Data Requirements	Analysis	Success Criteria	Results
Performance Objective 1. Absolute Accuracy of Mosaic and Diver Size Measurements				
Colony size (A)	(1) Absolute size of known target (2) Diver measurement of known target (3) Mosaic measurement of known target	One-sample t-test of differences	Not significantly different from zero ($p< 0.05$)	The mean bias was within 1 cm of the true value for both mosaics and divers. There was no significant bias in estimating object size from 3 mosaics or 3 divers in the water.
Colony size (B)	(1) Average mosaic bias (2) Average diver bias	Two-sample t-test of mosaic vs. diver bias	Mosaic bias is not significantly greater than Diver bias ($p< 0.05$)	Mosaic and diver methods of estimating object size were not significantly different from one another ($p=0.56$)
Colony size (C)	(1) Horizontally projected sizes of known, inclined targets (2) Diver measurement of projected target size (3) Mosaic measurement of projected target size	One-sample t-test of differences	Not significantly different from zero ($p< 0.05$)	The bias in the estimate of inclined coral colony size was significantly different than zero as measured from mosaics ($p=0.05$) and divers ($p = 0.00$).
Colony size (D)	(1) Average mosaic bias of inclined targets (2) Average diver bias of inclined targets	Two-sample t-test of mosaic vs. diver bias	Mosaic bias is not significantly greater than diver bias ($p< 0.05$)	The bias in the estimate of inclined objects as measured from mosaics was not significantly greater than the bias as measured by divers ($p = 0.31$).
Performance Objective 2. Precision of Multiple Mosaic and Diver Size Measurements				
Colony size (A)	Mean error of multiple mosaics	Single factor ANOVA	Mean error of each mosaic not significantly different from each other ($p< 0.05$).	There was no significant difference in the size bias as estimated from a single observer over multiple mosaics ($p=0.28$)

Table 8. Performance objectives for the absolute accuracy demonstration. (Continued)

Metric	Data Requirements	Analysis	Success Criteria	Results
Performance Objective 2. Precision of Multiple Mosaic and Diver Size Measurements				
Colony size (B)	(1) Average mosaic variance (2) Average diver variance	Two-sample F-test	Mosaic variance is not significantly greater than diver variance ($p<0.05$)	The variance in size measurement bias as measured from multiple mosaics was significantly less than the bias measured by multiple divers.
Performance Objective 3. Precision of Multiple Mosaic Analyst and Diver Size Measurements				
Colony size (A)	Mean Error of Multiple Analysts	Single factor ANOVA	Mean error of measurements from each analyst not significantly different from each other ($p< 0.05$).	There was no significant difference in the size bias of known targets as estimated by multiple analysts ($p = 0.32$).
Colony size (B)	(1) Average mosaic analyst variance (2) Average diver variance	Two-Sample F-test	Mosaic variance is not significantly greater than diver variance ($p<0.05$)	The variance in bias as measured from multiple mosaics was not significantly different than the bias measured by multiple divers ($p = 0.79$).
Performance Objective 4. Comparison of mosaic bias in the pool vs. in the field				
Colony size	(1) Average mosaic bias in pool (2) Average mosaic bias in field	Two-sample t-test of field vs. pool bias	Mosaic bias in field is not significantly greater than mosaic bias in pool ($p< 0.05$)	The bias of objects as measured from pool mosaics were not significantly greater than the bias measured from field mosaics ($p = 0.22$).

3.5.1 Performance Objective 1: Absolute Accuracy of Mosaic and Diver Size Measurements

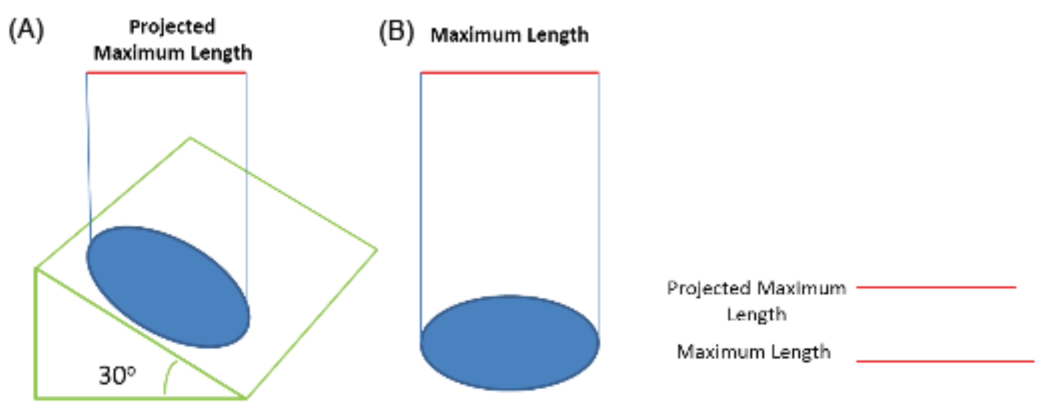
Relevance of the objective: Performance Objective 1 (PO 1) was designed to assess the accuracy of size measurements made from a mosaic and those made by a diver. This question was addressed in the other demonstrations using natural targets (i.e., coral colonies), but the question can be posed only in a relative way with natural targets because the true answer, which is the actual size of the colonies being measured, is unknown in the case of natural objects. By using man-made targets in a controlled setting the absolute accuracy of the system can be assessed. In addition to the measurements from the mosaics, divers also measured the sizes of targets so the absolute performance of both techniques can be compared. There were three datasets (diver, analyst, and known).

The question addressed by PO 1 (A) was the following: did the average error of the sizes of test objects as measured from mosaics or by divers differ from zero? The question addressed by PO 1(B) was the following: was the average error of the sizes of test objects as measured from mosaics less than or equal to the average error of the sizes of test objects as measured by divers?

The questions addressed by PO 1 (C and D) were identical to (A) and (B) except C and D applied to inclined objects whereas A and B applied to horizontal objects.

Description of metrics: The metric being assessed was the size of known test objects, which was analogous to coral colony size (Table 8). Coral colony size (i.e., test object size) was measured along two axes (longest length and, perpendicularly, widest width of live tissue) of each colony Figure 2). The artificial "coral colonies" used during the demonstration did not have live tissue. Instead, objects that could be measured absolutely in the lab were used in this demonstration in place of real coral colonies.

Coral colony size is listed as four metrics under PO 1 (Table 8). The difference between colony size (A) and colony size (B) relates to the analysis. For the colony size (A) metric, the sizes of each object were compared to the known size and a difference computed. The average difference across all objects was considered the bias in measurement. For the colony size (B) metric, the bias (i.e. the average difference) of the mosaic measurements was compared with the bias of the diver measurements to test which one was smaller. Ideally, neither the diver nor the mosaic bias would be significantly different from zero, which was the success criterion of the colony size (A) test. In that case, the colony size (B) test would have little relevance. If there were a bias in the mosaic measurements, however, they may still be valuable if the bias is not significantly larger than those measured by divers, which was the success criterion for the colony size (B) test. Colony size (C) and (D) were parallel metrics to (A) and (B) except (C) and (D) applied to inclined objects whereas (A) and (B) applied to horizontal objects. When testing coral colony size (C) and (D) we compared the projected 2-(D) size of a known object when placed on an incline to the projected size measured by divers and from a mosaic under pool conditions (Figure 8).



- (A) and on a flat horizontal surface (B). For PO 1 (A and B) the projected maximum length of the object equals the actual maximum length.
- For PO 1 (C and D) the projected maximum length was less than the objects' true maximum lengths due to the incline.

Figure 8. Diagram of the difference between the maximum length of an object on an incline.

Data required: The maximum length and maximum width of artificial targets representing coral colonies were measured by divers using tape measures and from mosaics of the objects in units of pixels and then scaled to cm by reference to meter sticks placed within survey area (see Section 5). All diver, analyst and truth measurements of coral colony size were made to the nearest centimeter. The projected maximum length of known targets on an inclined plane were calculated as cos(x) where x was the angle of inclination (x =30° in this case).

Criteria for determining success: Success for (A) and (C) was a bias not significantly different from zero. Success for (B) and (D) was a bias of the mosaic measurements not significantly larger than the bias for diver measurements (Table 8).

3.5.2 Performance Objective 2: Precision of Multiple Mosaic and Diver Size Measurements

Relevance of the objective: The objective of PO 2 was to compare the repeatability of size measurements made from multiple mosaics with those made by multiple divers. Whereas PO 1 tested the accuracy of size measurements, PO 2 tested the precision of multiple, repeat mosaic measurements.

Description of metrics: Precision was tested in two ways. First, the bias, as defined above for PO 1, in absolute size measurements was measured by one analyst from three replicate mosaics of the test objects. Colony size metric (A) tested whether the average bias was the same for all three replicates. Second, the bias in absolute size measurements was also be measured by three different divers. Colony size metric (B) tested whether the variance in the bias was any larger for the replicate mosaic measurements than for the diver measurements.

Data required: The maximum length and maximum width of artificial targets representing coral colonies were measured by 3 divers using tape measures and by one analyst from three mosaics of the objects in units of pixels and then scaled to cm by reference to meter sticks placed within survey area. All measurements of coral colony size were made to the nearest centimeter.

Criteria for determining success: Success for (A) was three replicate bias measurements that were not significantly different from each other. Success for (B) was that the variance in the bias for the replicate mosaic measurements was not significantly greater than for the diver measurements (Table 8).

3.5.3 Performance Objective 3: Precision of Multiple Mosaic Analyst and Diver Size Measurements

Relevance of the objective: The objective of PO 3 was to compare the repeatability of size measurements made by multiple analysts with those made by multiple divers. Whereas PO 1 tested the accuracy of size measurements, and PO 2 tested the precision of multiple repeated mosaic measurements, PO 3 tested the precision of multiple analysts making replicate measurements from a single mosaic.

Description of metrics: Precision was tested in two ways. First, the bias, as defined above for PO 1, in absolute size measurements was measured by three analysts from one mosaic of the test objects. Colony size metric (A) tested whether the average bias was the same for all three replicates. Second, the bias in absolute size measurements was also be measured by three different divers. Colony size metric (B) tested whether the variance in the bias was any larger for the replicate mosaic analyst measurements than for the diver measurements.

Data required: The maximum length and maximum width of artificial targets representing coral colonies were measured by three divers using tape measures and from replicate measurements of the objects by three analysts looking at a single mosaic. Mosaic measurements were in units of pixels and then scaled to cm by reference to meter sticks placed within survey area. All measurements of coral colony size were made to the nearest centimeter.

Criteria for determining success: Success for (A) was three replicate bias measurements that were not significantly different from each other. Success for (B) was that the variance in the bias for the replicate analyst measurements was not significantly greater than for the diver measurements (Table 8).

3.5.4 Performance Objective 4: Comparison of Mosaic Bias in the Pool vs. in the Field

Relevance of the objective: The objective of PO 4 was to determine if the bias of measurements made from a mosaic in the pool setting were significantly different than the bias of mosaics taken in the field

Description of metrics: The metric in question during this test was the size of a known target as measured from mosaics taken in a pool as well as from mosaics acquired in the field. The mosaics in the pool were acquired with 25 square ceramic tiles (10.7 cm on each side) visible on the bottom of the pool. A mosaic analyst measured the dimensions of each ceramic tile directly from the mosaic of the absolute accuracy demonstration area. Mosaics taken in the field from other ESTCP demonstrations were combined and 25 ceramic tiles from these images were selected and measured. Mosaic measurements were subtracted from the true values and an estimate of the pool and field mosaic bias was made.

Data required: Mosaic measurements of 25 ceramic tiles from the pool and 25 ceramic tiles in the field. All measurements of target size were made to the nearest centimeter.

Criteria for determining success: Success of PO 4 was be that there were no significant differences between the mosaic bias of known targets in the pool and the mosaic bias of known targets from the field.

4. SITE DESCRIPTIONS

4.1 LONG-TERM MONITORING DEMONSTRATION

4.1.1 Site Selection

Selection criteria included access to appropriate areas to test the performance objectives, minimizing total cost of the demonstration, and operating in a site of interest to the technology transfer recipients, specifically the Navy coral reef ecologists with the Navy's Scientific Diving Services and similarly qualified scientists with NOAA's Marine Sanctuary Office.

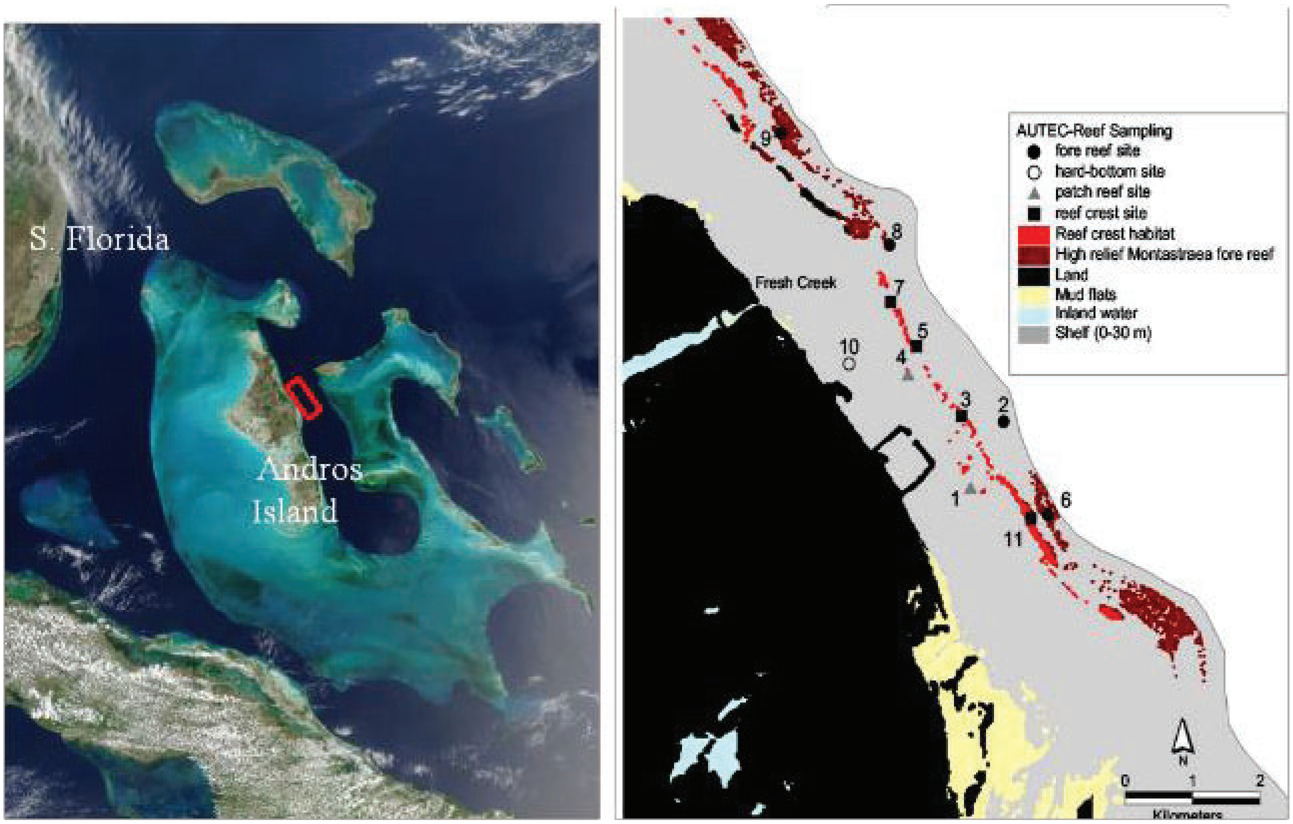
Andros was an appropriate location to test the performance objectives for this demonstration. Requirements for PO 1 were simply a diverse coral community. The Andros barrier reef is the third largest in the world and is representative of the broader Caribbean coral community. Requirements for PO 2 included working at one of the historically monitored AUTEC plots. AUTEC provided the opportunity for outstanding logistical support; the ESTCP field team was large by benthic ecologist standards, but small relative to the size of other types of experiments AUTEC accommodates. The Navy interest in this site is high, AUTEC has a long-established coral reef monitoring program, and the RSMAS team has worked there before.

4.1.2 Site Location and History

AUTEC is a U.S. Naval facility located on the east coast of Andros Island in the Bahamas (Figure 9) and has a long history of monitoring coral reef communities. Following the installation of Site 1 in 1965, AUTEC personnel were charged with monitoring the coral reef communities of the Andros Island reef tract for the purposes of (1) providing baseline information from which changes in the coral reef communities adjacent to the AUTEC sites can be detected and identified and (2) to monitor reef condition with respect to specific AUTEC activities such as dredging, oil spills, and marine construction and (3) providing environmental information that will help prevent or minimize ecological damage (Huddell *et al.* 1976). Coral reef monitoring has continued at AUTEC since the inception of the program in 1968 providing over 40 years of baseline information and data on coral community composition and condition information.

4.1.3 Site Characteristics

PO 1 and PO 2 did not need to be evaluated at precisely the same location. PO 1 could have been done anywhere with moderate coral cover. Because the area used for PO 1 will not be a permanent monitoring station for AUTEC in the future, the site selection was determined by AUTEC personnel and was driven by the ease of accessing the location and sea states at the time of the survey. We used site S1-10, an inshore patch reef station that has been part of the coral reef monitoring program at AUTEC since 1970. Site S1-10 is located within 600 m of shore and is the closest historical inshore patch reef station to the main AUTEC harbor. S1-10 is shallow and contains areas of considerable relief. The reef structure itself lies in water depths between 1.5–4.0 m. The coral community was dominated by large *Porites porites*, but significant numbers of *Porites astreoides* and *Montastraea annularis* were also found here. Three of the four historical markers (concrete blocks) that were used to originally define the site in are still visible. These markers allowed us to orient our surveys within the area of historical significance.



- Location is marked by the red rectangle (left).
- General locations of AUTEC permanent monitoring sites along the Andros Island Reef Tract (right).
- Site S1-10 (labeled #10) was the location of the long-term monitoring demonstration.
- Photo supplied by Google Earth.

Figure 9. Location of Andros Island and Site 1.

Sea state and consequently underwater visibility were the relevant conditions that could affect the demonstration. At the sites of interest they are correlated, meaning that if the sea state is calm, visibility should not be a problem. However, wind/sea states greater than 3 (Beaufort scale) can preclude diving either from a safety standpoint or by severe degradation of visibility. Both performance objectives were tested within the outer barrier reef, thereby providing some protection from winds and the waves.

4.1.4 Site-Related Permits and Regulations

Permits were not required for this demonstration.

4.2 ENDANGERED SPECIES DEMONSTRATION

The sites used for this demonstration were off of Key Largo, Florida. The marine environment of the Florida Keys includes the only coral reef tract adjacent to the continental United States. The Florida reef tract lies within the boundaries of the Florida Keys National Marine Sanctuary (FKNMS) and Biscayne National Park (BNP).

4.2.1 Site Selection

In the upper Florida Keys, NOAA has a permanent monitoring site for *Acropora palmata* at Molasses Reef. Molasses Reef was selected because permanent monitoring plots were established there by NOAA almost a decade ago.

4.2.2 Site Location and History

The site for the demonstration was Molasses Reef (Figure 10). Specifically, the location was three 7-m radius plots marked for permanent study by NOAA scientists. (Figure 11).

- Photo supplied by Google Earth.

Figure 10. Location of Molasses Reef, offshore Key Largo, FL.

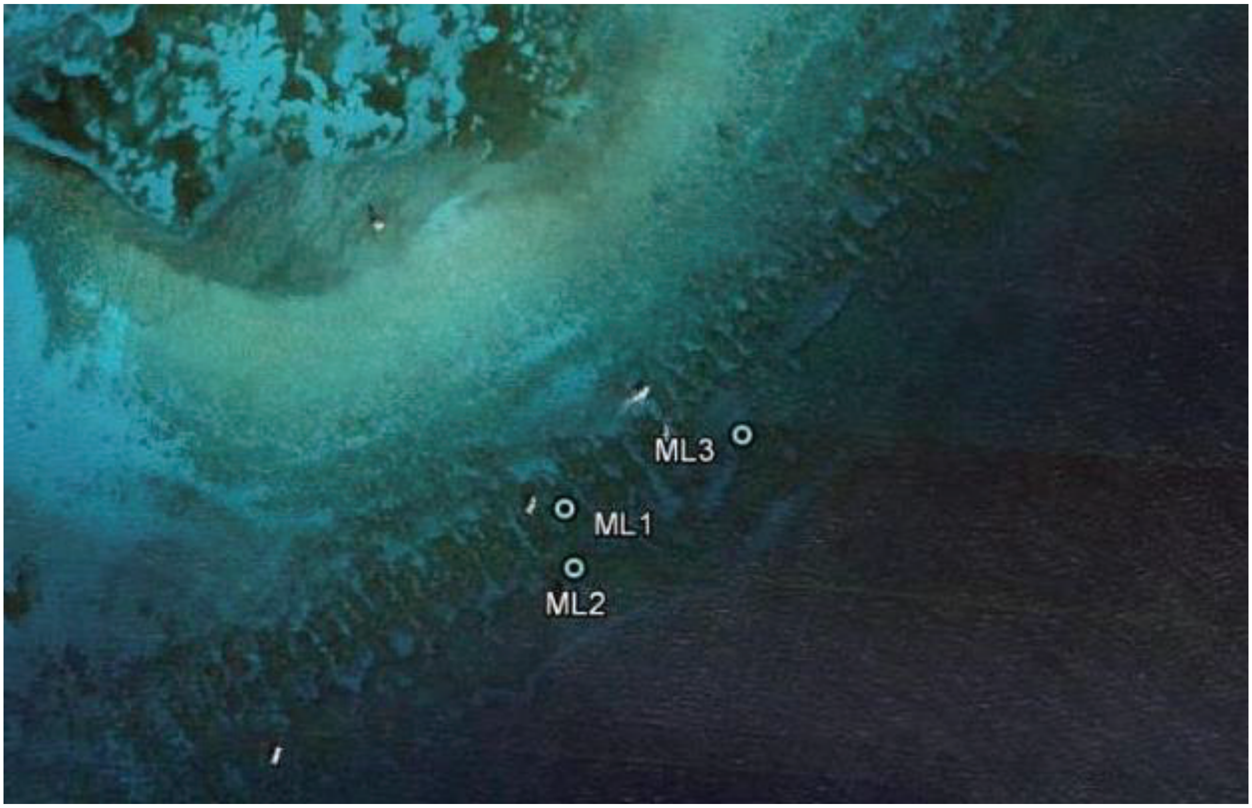
4.2.3 Site Characteristics

The Florida reef tract is formed by a discontinuous set of shelf-margin reefs that rim the windward (southeast) margin of the Florida platform. The reef tract defines the shelf edge, rises to the surface in places, and forms all of the named offshore reefs. Seaward of the shelf-margin reefs, the water depth drops rapidly to ~30 m, then gradually from 30 - 40 m. At approximately 40 m there is a sharp break in slope between the nearly flat 30 - 40 m terrace and the steeper continental slope extending farther offshore. Landward of the shelf-margin reefs, depths are generally less than 10 m (Lidz *et al.* ; 2003, 2006).

The Florida Keys are subject to mixed semidiurnal tides (i.e., generally two high and two low tides per day) with a mean range of 1.3 feet (0.4 meters) and spring tide range of 1.8 feet (0.5 meters). During flood tide, the tidal current flows toward the Gulf of Mexico, and during ebb tide, the current direction is toward the Atlantic Ocean. Currents can occasionally be strong in the planned field site, both due to tides as well as the Florida current, which travels SW to NE seaward of the bank-margin reefs (Lee, 1986). Wave and current conditions were considered daily during the field work. Depths of the monitoring plots (ML1–3 on Figure 11) ranged from 3–6 m.

4.2.4 Site-Related Permits and Regulations

A research permit from the Florida Keys National Marine Sanctuary was required and we were added to an existing permit previously obtained by NOAA. (See FKNMS-2010 – 130 in Appendix C).



- Darker areas to the east and southeast (right and lower right of the image) are deeper than the lighter areas to the north and west (upper left).
- The broad, light brown, arcuate swath near the center of the image is the shallowest part of the reef, the reef crest, slightly landward (toward the northwest) on which can be seen the Molasses Reef lighthouse.
- Seaward of the reef crest, three anchored boats are visible and the locations of the three permanent monitoring sites have been marked (ML1, 2, and 3).
- Photo oriented North up, photo supplied by Google Earth.

Figure 11. Aerial image of Molasses Reef, FL.

4.3 GROUNDING DEMONSTRATION

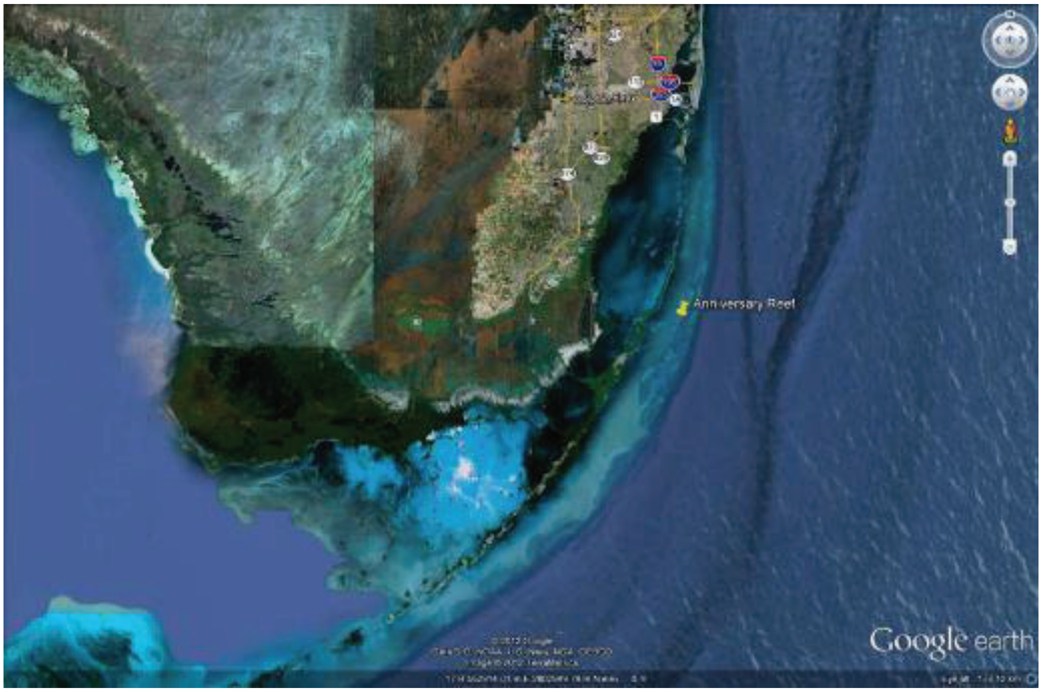
The site for this demonstration was off the northern end of Key Largo, Florida. The marine environment of the Florida Keys includes the only coral reef tract adjacent to the continental United States. The Florida reef tract lies within the boundaries of the Florida Keys National Marine Sanctuary (FKNMS) and Biscayne National Park (BNP).

4.3.1 Site Selection

The intent when this demonstration was conceived was to map a new grounding scar within the FKNMS or BNP, which meant that the exact dates and times for the demonstration could not be planned ahead of time. There have been no new vessel groundings of sufficient size in this area since the start of this project. Therefore, in order to complete the demonstration, we mapped an existing site. All of the performance objectives were accomplished on an existing site.

4.3.2 Site Location and History

The site for the demonstration was Anniversary Reef (Figure 12). Specifically, the location was be the scar left by the grounding of the vessel Evening Star in 2002 (Figure 13).



- Photo supplied by Google Earth

Figure 12. Location of Anniversary Reef, northeast of Key Largo and east of Elliot Key, FL.

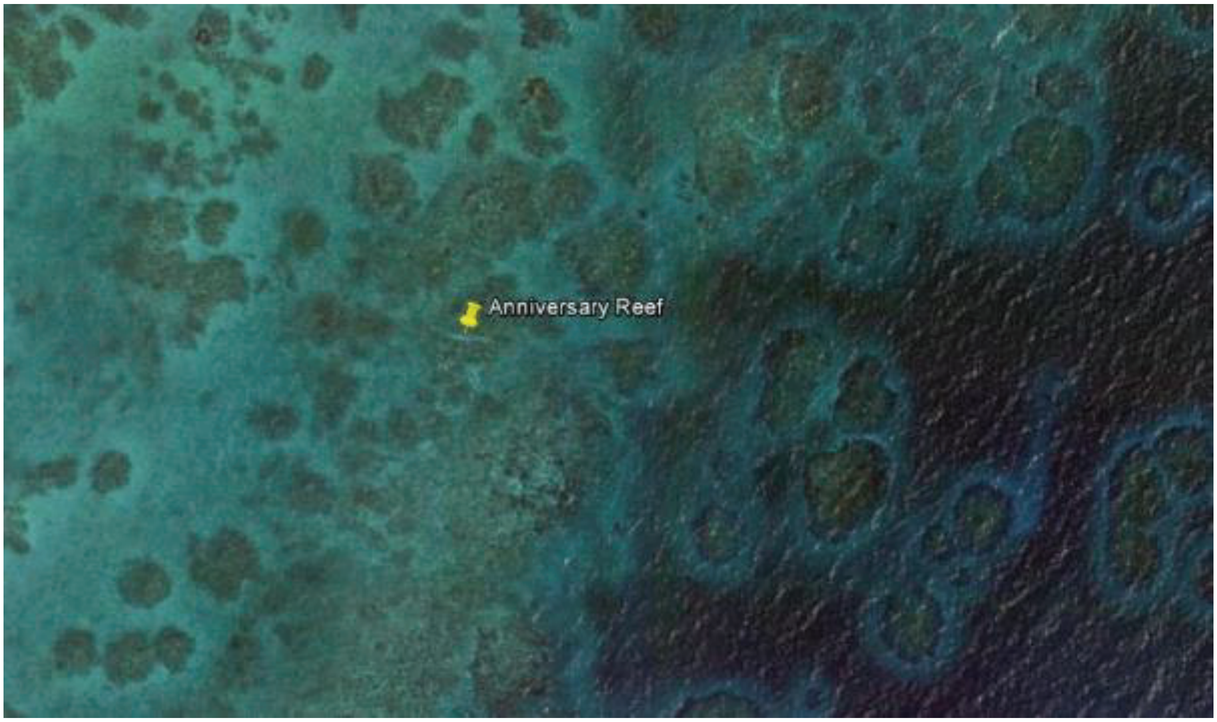
4.3.3 Site Characteristics

Section 4.2.3 contains general information regarding the Florida reef tract. Anniversary Reef occurs in a portion of the upper Florida Keys characterized by numerous aggregated patch reefs and individual patch reefs. Patch reefs are discrete coral communities that are typically dome-shaped and circular, although they may form a line. They may range in size from tens to thousands of square meters. In the vicinity of Anniversary Reef depths range from 2–10 m. Aggregated patch reefs are clustered patch reefs that individually are too close together to map separately, and individual patch reefs are distinctive single patch reefs.

The actual scar created by the 15 m (49 ft) long vessel Evening Star is approximately 50 m long and 5–8 m wide. Depth at the site of the scar is approximately 2 m.

4.3.4 Site-Related Permits and Regulation

A research permit from Biscayne National Park was required (See FKNMS-2011 – 131 in Appendix C).



- The scar created by the Evening Star grounding is visible as a white line running nearly east to west under the yellow marker on this image.
- Patch reefs are the relatively dark, greenish-brown, roughly circular features visible on the images.
- Bare sand or sparse seagrass appear as light areas surrounding the patch reefs.
- Darker areas to the east and southeast (right and lower right of the image) are deeper and covered with denser seagrass than the lighter areas to the northwest (upper left).
- Photo supplied by Google Earth.

Figure 13. Aerial image of Anniversary Reef, FL.

4.4 TRADITIONAL METRICS DEMONSTRATION

The proposed site for this demonstration was in the vicinity of NAS Key West, Key West, Florida. However, due to weather and booking constraints this demonstration was later moved to the northern portion of the Florida Reef Tract in the vicinity of the University of Miami's Rosenstiel School of Marine and Atmospheric Sciences (RSMAS).

4.4.1 Site Selection

Selection criteria for choosing sites for this and the other planned demonstrations included access to appropriate areas to test the performance objectives, and minimizing total cost of the demonstration. The site chosen was seaward of the northern end of Key Largo, FL.

4.4.2 Site Characteristics

Section 4.2.3 contains general information regarding the Florida reef tract. Sites used for the traditional metrics demonstration were located on the outer reef tract itself and on patch reefs in the depression behind the outer reefs, known locally as Hawk Channel. In Hawk Channel, both aggregated patch reefs and individual patch reefs occur. Patch reefs are discrete coral communities that are typically dome-shaped and circular, although they may form a line. They may range in size from tens to thousands of square meters and occur in depths less than approximately 10 m. Aggregated patch reefs are clustered patch reefs that individually are too close together to map separately, and individual patch reefs are distinctive single patch reefs.

4.4.3 Site-Related Permits and Regulations

A research permit from the Florida Keys National Marine Sanctuaries was required for the initial site selection of Key West (See FKNMS-2010 – 130). No additional permits were required for the alternate sites located near UM/RSMAS.

4.5 ABSOLUTE ACCURACY DEMONSTRATION

The site for this demonstration was a pool on the campus of the University of Miami.

4.5.1 Site Selection

The proposed tests were conducted in a pool due to the advantages of easy deployment and lower cost. The pool also represented a best-case scenario in terms of visibility, contrast with the seabed, and flat bottom. The advantage of a field trial would have been more realistic conditions, but this was offset by increased logistics (transporting many objects to the site, deploying and retrieving them) and cost (labor and boat rental). Furthermore, performing the test in realistic field conditions complicates interpretation of the results. Waves, for example, might potentially decrease accuracy (of either the mosaic or diver method) but the magnitude of any such effect would not be quantified unless we performed many identical experiments under variable wave conditions. Such replicate experiments would need to be completed for any variables that might affect accuracy, such as currents, visibility, rugosity, depth etc… in addition to waves. The time required and logistical challenge adds up quickly under the field approach. The pool approach, albeit under somewhat artificial conditions, at least provided a baseline that can be considered a "best case" scenario.

4.5.2 Site Location and History

Not applicable.

4.5.3 Site Characteristics

Not applicable.

4.6 SITE-RELATED PERMITS AND REGULATIONS

No permits were required to work in the UM pool.

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5. TEST DESIGN

5.1 CONCEPTUAL TEST DESIGN

5.1.1 Long-Term Monitoring

Conceptually, the tests for PO 1 and PO 2 were similar; data measured from mosaics were compared with data measured by divers to assess inter-methodological agreement, which is a measure of precision. Absolute accuracy of size measurements were evaluated during a separate demonstration. The concept for the test of PO 3 was different; mosaics created by an experienced operator and by a newly trained operator were compared to assess differences in final products based on the level of experience of the divers who collected the raw data.

5.1.1.1 Performance Objective 1: Provide Colony-Based Metrics of Coral Reef Condition.

The question asked in this test was whether data extracted by divers and obtained from mosaics on (a) coral size and (b) coral condition were statistically different. To answer this question, a test plot was surveyed within a shallow reef using both divers and mosaics. Within the test plot, two dive teams located and identified coral colonies and tagged them as if they were establishing a permanent plot as part of a coral colony monitoring program. Members of each dive team then measured the coral colony lengths and widths and assessed the corals' condition in the field as a measure of coral health at the time of the survey. The assessment of coral condition consisted of each diver evaluating if the colony were bleached, partially bleached, or pale, shows signs of coral disease, and visually estimating the percentage of the surface area of each colony showing signs of bleaching, disease, and recent or old tissue mortality.

Once both dive teams completed the coral survey, both teams then completed a separate mosaic survey using a second-generation mosaicing system (Gintert *et al.* 2009). Both 10MP still and HDV video imagery were acquired in a down-looking position over the area of interest from approximately 2 m. Divers swam a double-lawn-mower pattern (Lirman *et al.* 2007) to acquire adequate coverage for the mosaicing algorithms.

Once data were collected in the field, coral colony size and condition estimates were made from the mosaics. These metrics were compared, on a colony-per-colony basis: (a) between divers, and (b) between divers and mosaics. Estimates of inter-observer and inter-method differences were compared statistically using t-tests and ANOVA as described in later sections

5.1.1.2 Performance Objective 2: Maintain Continuity with Long-Term, Map-Based, Coral Reef Monitoring Data Sets.

The question asked in this test was whether or not landscape mosaics were a more efficient means of reef monitoring than traditional mapping done by divers using an underwater frame and tapes. To complete this task a 10 ×10 m permanent reef plot that was originally surveyed by divers at AUTEC in the 1970's was used as the site of interest. Divers divided into two teams and each diving team:

- Created a detailed species-specific map of the position and areal extent of benthic invertebrates within a 2 × 2 m subsection of the permanent plot. This provided an estimate on coral colony size and total coral cover based on the mapped areal extent of coral colonies within the 2 × 2 m plot.

Based on the time required to survey the subsection, costs for the full 10 × 10 m area were estimated by scaling up:

- Measured the sizes of every coral colony in the 2 × 2 m area
- Marked the area surveyed so that it could be detected by subsequent mosaic surveys; and
- Took video-mosaic data of the entire 10 × 10 m area (including the 2 × 2 m areas that had been hand-mapped by divers.

The hand-drawn maps created by the divers were digitized on the computer. Additionally, divers time that was taken to map the colonies in the field and in the lab was documented and scaled up to estimate the total time it would take to map and convert the entire 10 × 10 m area into a useable form for future change detection analyses. In addition, the HDV video and high-resolution stills were used to create a second-generation landscape mosaic with integrated stills. This image was then georeferenced using the GPS point and relative distance and heading measurements derived in the field. From this, coral colonies were digitized to create a representative 2-D map of the focus area. For this comparison only the 2 × 2 m areas surveyed by divers were digitized in the lab for the cost and efficiency analysis. Metrics obtained by divers within the 2 × 2 m subplot (Table 2) were be compared with the same metrics obtained from mosaics to determine if significant differences exist between the methods.

5.1.1.3 Performance Objective 3: Ease of Use

The question asked in this test was whether competent divers with minimal training specific to mosaics could acquire adequate image data for mosaicing. The concept of the test was for a member of the RSMAS team to acquire the data for a mosaic and then for a member or members of the Navy team, who had one day of training on the mosaic capture procedure, to acquire another dataset for the same area. The mosaics from these two data sources were compared to see if there were any quantifiable differences in terms of the incorporation percentage and visual quality of the resulting mosaics

5.1.2 Endangered Species Demonstration

Conceptually, the tests for all three POs were similar; ecological data measured from mosaics were compared with the same metrics measured by divers to assess inter-methodological agreement. The ecological variables to be measured were those defined by Williams *et al.* (2006) for their annual surveys.

5.1.2.1 Performance Objective 1: Coral Colony Abundance and Location

The conceptual basis for mapping *Acropora palmata* colonies was laid out by Williams *et al.* (2006). One purpose of mapping is to establish a subset of individual colonies that can be assessed over time. By tracking individual colonies, the relative importance of many sources of mortality can be evaluated by comparing the prevalence of a particular threat with the subsequent fate of affected colonies. The tracking of individual colonies results in estimates of threat prevalence, threat impact (i.e. mortality) and change in colony size (growth and fragmentation). Williams *et al.* (2006) used the annual mapping process in order to ensure that the same colony is in fact being tracked through time.

A second aspect of mapping that is used for monitoring is to estimate recruitment, the establishment of new colonies in a population in order to potentially offset mortality. Tracking recruitment of *A. palmata* is difficult, and Williams *et al.* (2006) use periodic mapping to detect the presence of new colonies, including fragments of existing colonies that have broken off.

The approach was for divers to follow the mapping procedures from Williams *et al.* 2006 (described below) to create a map of the existing permanent plots. Mosaics of each of the permanent plots were constructed, and ecological metrics extracted from the mosaics. For PO 1, the metrics were the total number of colonies within the plot and their locations relative to a stake marking the center of the plot.

5.1.2.2 Performance Objective 2: Coral Colony Size

Coral colony size is an important measurement because it is used to derive population age structure, when tracking individuals over time, and to estimate live tissue area. The importance of coral colony size is reflected in the fact that it has been included as a metric on every demonstration in this project. The reasons to include it again in the ESA demonstration were, first, that the branching morphology of *Acropora palmata* is very different from the encrusting or mounding shapes encountered at other demonstration sites. Second, it was likely that we would encounter relatively more "large" (i.e. > 50 cm) colonies in this demonstration than at the other sites visited in this project.

The approach was the same as for PO 1. Part of the Williams *et al.* (2006) mapping methodology is to measure the sizes of every mapped colony. Sizes will also be measured from the mosaics and then compared with those measured by divers.

5.1.2.3 Performance Objective 3: Coral Colony Descriptors

In addition to the abundance, location, and sizes of colonies in the monitoring plots, the Williams *et al.* (2006) protocol also specifies that the percent of each colony covered with live tissue and the colony type (defined below) should also be collected during the annual surveys. The approach for testing these descriptive metrics of colony condition was the same as for PO 1 and 2. Divers estimated % live cover and colony type as part of the mapping process and then these metrics were also be estimated by looking at the mosaics.

5.1.3 Grounding Demonstration

Conceptually, the tests for POs 1, 2 and 4 were similar; data measured from mosaics were compared with data measured by divers to assess inter-methodological agreement. The concept for the test of PO 5 was to assess whether a newly trained user can successfully extract information from the mosaics. In concept, therefore, POs 1, 2, 4, and 5 were similar to the general approaches taken in the long-term monitoring and traditional metrics demonstrations. The concept for PO 3 was different. For PO 3 both the diver and mosaic performance were compared to an independent, known baseline to assess absolute accuracy. PO 3 was therefore conceptually similar to the objectives in the absolute accuracy demonstration.

PO 1, 2, and 3 all measured sizes, and size was one parameter measured in both the long-term monitoring and traditional metrics demonstrations. What was the difference here? Even though the variable tested in this demonstration (size) was the same as the other demos, the difference has to do with the scale of measurement. During the long-term monitoring and traditional metrics demonstrations, the relevant sizes were at the scale of Caribbean coral colonies, which varied from 4 cm to approximately 1 m in maximum length. Here the relevant scale was much larger, on the order of several to 10's of m. It was important to test the accuracy of sizes on these larger spatial scales for two reasons. First, the spatial integrity of the mosaics should be tested. It is possible that small errors over small distances could add up to large errors over large distances. Second, the cost aspects of the work should be documented. Measuring large areas by a diver requires very different techniques than measuring small objects, thus the time and therefore cost required may differ greatly even though the variable (length or area) is nominally the same.

5.1.3.1 Performance Objective 1: Comparison of the Area of Damage

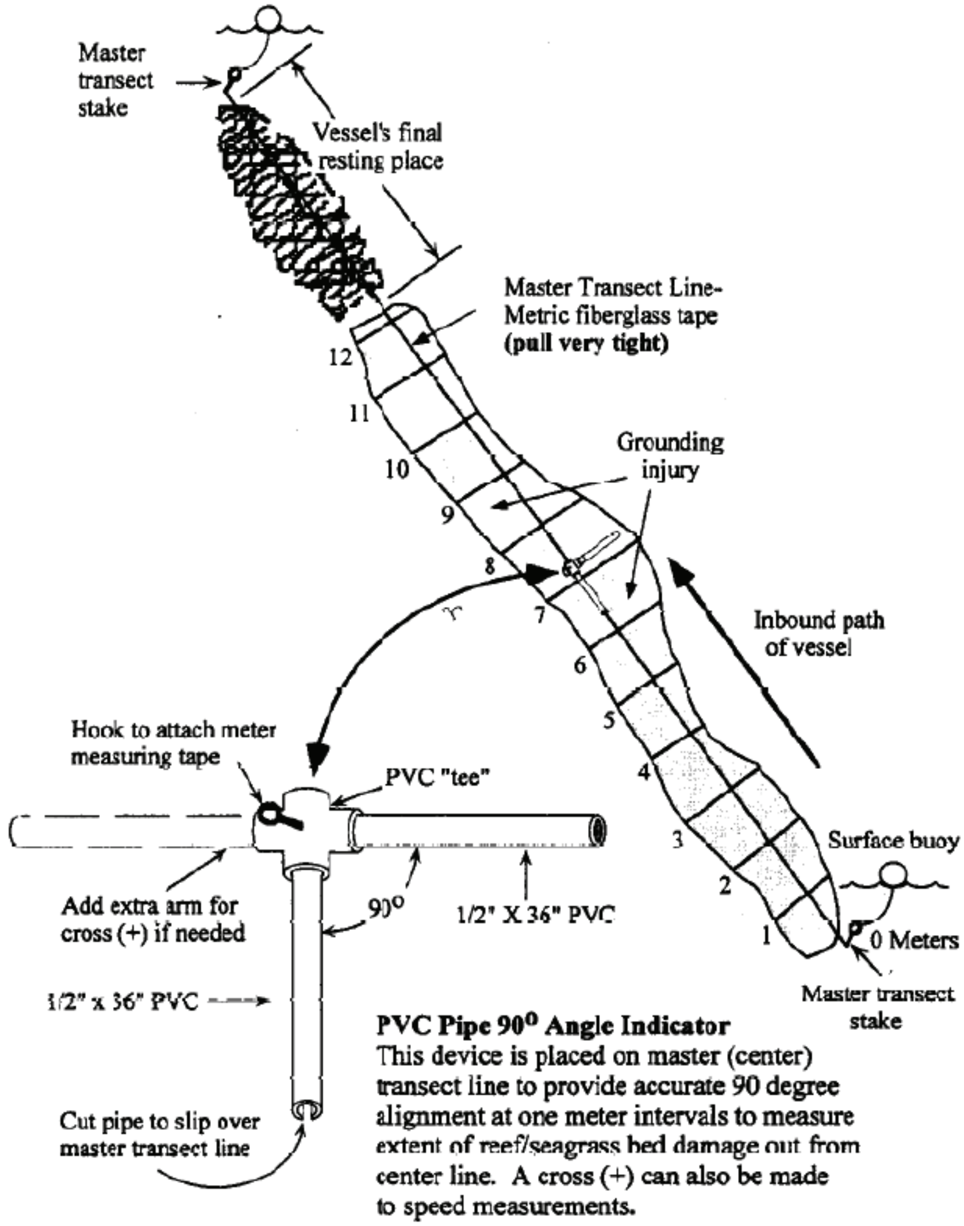
Total damaged area is a critical measurement for damage assessment because it directly affects penalties and restoration efforts. The concept for PO 1 was to compare the total area of the scar as measured by three methods: mosaics, transect tapes, and GPS. At the start of the test, divers marked the overall survey area with meter sticks and quadrats. The purpose of this first step was not to delineate the damaged area, but rather to provide an overall boundary for the working area and to help the divers navigate a relatively large working area (~50 x 10 m).

Once the boundaries of the survey were defined, data for a mosaic was acquired over the scar. After the mosaic data were acquired, the edge of the scar was traced by a snorkeler at the surface with a GPS. Once the mosaic and GPS surveys were completed, divers used the "fishbone" technique (Figure 14; Hudson and Goodwin 2001) to measure the dimensions of the scar with transect tapes.

As the "fishbone" technique was being performed, the points where the divers measured were marked with 4″ × 4″ ceramic tiles such that the diver measurements extend from the center transect to the edge of the tiles along the border of the scar (All measurements were made to the edge of the tile/marker that lied on the edge of the disturbed area). Following the fishbone measurements, the scar was surveyed with mosaic and GPS techniques a second time. By marking the diver transects, they were visible in the mosaic and to the person swimming the GPS the second time. This was useful because if the mosaic, GPS, and fishbone measurements of the scar area differed, having the second set of mosaic and GPS data would help determine if the differences were really due to the methods or whether they were due to the mosaic, GPS and diver transects measuring different areas.

5.1.3.2 Performance Objective 2: Comparison of Linear Damage Measurements

Total damaged area is ultimately the most important size metric for damage assessment, but logistical constraints limited us to surveying only one scar, so there was only a single mosaic, GPS, and diver transect measurement for PO 1. Therefore statistical tests for the difference between the area measured by the three methods was be possible. Having made a second mosaic of the scar after marking the ends of the diver transects however, it was possible to compare many linear diver measurements with the same distances measured from the mosaics.



- Source: Hudson and Goodwin, 2001.

Figure 14. Fishbone mapping technique.

5.1.3.3 Performance Objective 3: Accuracy of the Measurement of Large Linear Targets

The concept for PO 3 was to address the absolute accuracy of distance measurements on the scale of m to 10's of m. PO 2 gave a measurement of the precision and the relative agreement between the diver transect and mosaic measurements of distance, but not of the absolute accuracy because the "true" sizes were not known. In PO 3 we used PVC pipe that was marked at random lengths to position markers on the seabed a known distance apart. Divers then measured the distance between the markers using both transect tapes and a GPS on the surface. After making a mosaic over the markers we measured the distances from the mosaic also.

5.1.3.4 Performance Objective 4: Extract Ecological Measurements from Mosaics both Inside and Outside Damaged areas that are Comparable with Diver-Based Metrics

The question asked in this test was whether data obtained by divers and extracted from mosaics were statistically different at the scale of a survey site. To answer this question, a set of test plots were surveyed using both approaches (i.e., divers and mosaics). Within each test plot, two dive teams (one Navy and one RSMAS) set up four, parallel, 10 m-long transects spaced about 2 m apart. Members of each dive team then measured the seven metrics using Point Centered Quarter Transects (PCQT) and Belt Transects (BT). Each transect was replicated by one diver from the Navy team and one from the RSMAS team so that diver-diver variability could be assessed.

Once both dive teams completed the coral survey, a third pair of divers conducted a mosaic survey using a second-generation mosaicing system (Gintert *et al.* 2009). Both 10MP still and HDV video imagery were acquired in a down-looking position over the area of interest from approximately 2 m. Divers swam a double-lawn-mower pattern (Lirman *et al.* 2007) to acquire adequate coverage for the mosaicing algorithms.

Diver and mosaic-derived estimates of the seven metrics (Table 6 were computed for the site as a whole (i.e., a single value from the mosaic and a single average value from the four transects. Differences between the diver and mosaic-derived estimates were then compared statistically as described in Section 6.3.

This test was the same as the area-based test used for the traditional metrics demonstration. By using the same test methodology were able to expand the number of habitats for which we could make the mosaic-diver comparison. In particular, measurements in a disturbed area (i.e. within the scar) were the unique contribution from this demonstration that would not have been possible as part of the traditional metrics demo effort.

5.1.3.5 Performance Objective 5: Ease of Use

The question asked in this test was whether the existing user interface and instructional materials were sufficient to enable a new user to extract data from mosaics with the analysis tools available. The concept of the test was for a member of the RSMAS team to extract basic cover and size metrics from a mosaic and then for a member or members of the Navy team, who had two days of training on the analysis software, to also extract the same metrics from the same raw data source. The metrics from these two analysts were compared to see if there are any quantifiable differences.

5.1.4 Traditional Metrics Demonstration

Conceptually, the tests for PO 1 and PO 2 were similar; data measured from mosaics were compared with data measured by divers to assess inter-methodological agreement. The concept for the test of PO 3 was different; mosaics created by an experienced user of the mosaicing software and by a newly trained user were compared to assess differences in final products based on the level of experience of the person running the software.

5.1.4.1 Performance Objective 1: Extract Ecological Measurements from Mosaics that are Comparable with Diver-Based Metrics

The question asked in this test was whether data obtained by divers and extracted from mosaics were statistically different at the scale of a survey site. To answer this question, a set of test plots were surveyed using both divers and mosaics. Within each test plot, two dive teams (one Navy and one RSMAS) set up four, parallel, 10 m-long transects spaced about 2 m apart. Members of each dive team then measured the seven metrics using Point Centered Quarter Transects (PCQT) and Belt Transects (BT). Each transect was replicated by one diver from the Navy team and one from the RSMAS team so that diver-diver variability can be assessed.

Once both dive teams completed the coral survey, a third pair of divers conducted a mosaic survey using a second-generation mosaicing system (Gintert *et al.* 2009). Both 10MP still and HDV video imagery were acquired in a down-looking position over the area of interest from approximately 2 m. Divers swam a double-lawn-mower pattern (Lirman *et al.* 2007) to acquire adequate coverage for the mosaicing algorithms.

Diver and mosaic-derived estimates of the seven metrics (Table 7) were computed for the site as a whole. Differences between the diver and mosaic-derived estimates were then compared statistically as described in Section 6.4.

5.1.4.2 Performance Objective 2: Extract Ecological Measurements from Mosaics Using Multiple Methods

The question asked in this test was whether data obtained by divers and extracted from mosaics were statistically different at the scale of a single transect when the data extraction from the mosaic was performed using a "virtual" version of the diver transect. Answering this question used all of the data collected for PO 1 and, in addition, another type of diver-based data collection, Video Transects (VT). Conceptually, PO 2 differed from PO 1 in the method of data extraction from the mosaics, the variables tested, and the scale of analysis.

The most significant difference between PO 2 and PO 1 was the method of data extraction from the mosaics. In PO 1, metrics were extracted from the mosaics using point counting and visual inspection of the images, which is our preferred method because it is fast and intuitive, takes advantage of existing third-party software, and exploits the complete, landscape-view afforded by the mosaics. PO 2, in contrast, was designed to test whether data can be extracted from the mosaics using techniques that are analogous to traditional diver-transect approaches. For example, when comparing mosaic-derived estimates to data acquired by a diver using the PCQT, we used a "virtual" PCQT to extract data from the mosaic rather than point counts. Likewise we used "virtual" BTs and VTs for comparison with the other diver-transect methods.

A second difference between PO 2 and PO 1 was the set of variables tested. PO 2 tested only a subset of the metrics used for PO 1. Percent cover and species richness were chosen since they were the most commonly used of the suite of seven metrics tested in PO 1. Given limited field time, we prioritized testing fewer variables from more transects in more habitats than more variables from fewer transects. Furthermore, computing a confidence interval for some of the other variables (bleaching, mortality, disease, and juvenile density) was difficult to do from a single transect due to limited sample size.

The third difference between PO 2 and PO 1 was the comparison unit. PO 1 compared mosaics to diver data at the site level, which in this case was sampled by four diver transects. PO 2 compared mosaics to diver data at the individual transect level.

5.1.4.3 Performance Objective 3: Ease of Use

The question asked in this test was whether the existing user interface and instructional materials were sufficient to enable a new user to process data with the mosaicing software. The concept of the test was for a member of the RSMAS team to create the mosaics for this demo and then for a member of the Navy team, who had one day of training on the mosaic software, to also create the mosaics for this demo from the same raw data source. The mosaics from these two analysts were compared to see if there are any quantifiable differences in terms of incorporation percentage or visual quality.

5.1.5 Absolute Accuracy Demonstration

The general approach to assessing the absolute accuracy of sizes measured from mosaics was to take measurements of targets of known size. Three categories of targets were used in order to mimic three basic coral morphologies: encrusting (i.e. nearly flat), mounding, and branching corals of varying sizes. The goal was to measure the precision and accuracy of size measurements of these targets obtained by divers from the mosaics and compare them to known measurements obtained before or after the demo to be held by a trusted agent.

Objects of varying size within each morphological category were fabricated. The materials used to do this consisted of patterns for flat objects printed out on paper that were then laminated and used directly underwater or cut into stencils and used to paint patterns on tiles. Dishes or platters of varying sizes were also used for the flat objects. Bowls made good targets for the mounded morphology, at least up to ~50 cm diameter. Boxes and buckets were used as larger mounded objects up to ~ 1.5 m diameter. Branching objects were individually constructed in "tree" shapes, using wood or PVC and cement.

All of the objects were placed horizontally on the seabed. The flat objects were also used for a separate experiment in which they were placed at known, inclined angles. For all objects, the projected horizontal area was known, as well as measured by divers, and then compared with measurements made from the mosaics.

In addition to the unique objects, we also placed many identical objects (4-inch ceramic tiles) in the area of the mosaic. We computed metrics for performance objectives 1A, 2A, 3A using the tiles, but not 1B, 2B, or 3B because the divers would know the sizes are all the same. These same tiles are in many, if not all, of our existing mosaics from the other demonstrations, so we used them to make an estimate of how much the accuracy degrades when going from the ideal conditions of the pool to real conditions on the reef.

5.2 BASELINE CHARACTERIZATION AND PREPARATION

No baseline preparation was required for any demonstration except to identify the locations of permanent sites created at AUTEC (for use in the long-term monitoring demonstration) and by NOAA (for use in the ESA demonstration).

5.3 DESIGN AND LAYOUT OF TECHNOLOGY AND METHODOLOGY COMPONENTS

The technology evaluated during these demonstrations was the second-generation landscape mosaicing system (Gintert *et al.* 2009; Reid *et al.* 2010). The second-generation system was designed and built to incorporate high resolution still imagery and real time heading information into a standardized video acquisition system that would be easily deployed and utilized by a single research diver for the purpose of creating high resolution landscape mosaic images. The second-generation mosaicing system was created using commercially available imaging components including: a Nikon® D200® 10 MP (Mega Pixel) Digital SLR camera and Ikelite® underwater housing, Sony HDV video camera and Amphibico® housing (Figure 15). All components of the enhanced mosaicing system were mounted in an aluminum/stainless steel frame. The two-camera design was created to allow continuous acquisition of high frame rate, low-resolution images for mosaic processing (the HDV camera) and high-resolution images at a lower frame rate for benthic identification and health monitoring (10 MP still camera).

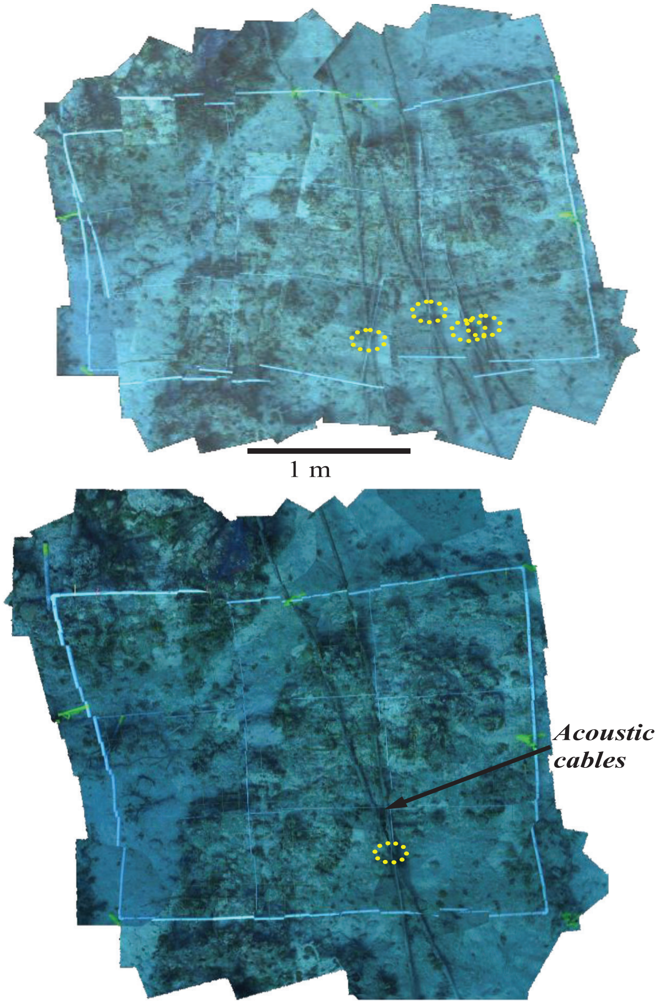
Figure 15. Second-generation imaging hardware.

The result of this design is that we were able to provide the high frame rate needed to construct a mosaic map of the area and the sub-millimeter resolution of the still images to allow for species-level identification of colonies as small as 3 cm in diameter. In addition, macroalgal groups are now identifiable to genus with species level identification possible for macroalgae with obvious defining characteristics such as *Halimeda tuna* and H. *opuntia.* Coral colony health information such as partial mortality boundaries and evidence of bleaching and disease were all recognizable using the still images. Small-scale indicators of reef health such as cyanobacteria, macroalgal, and sponge competition were also visible using high-resolution still data. The benefits of the second-generation landscape mosaic system were reviewed in (Gintert *et al.* 2009).

In addition to the specific hardware requirements, the ability to create underwater 2D video mosaics relies on the mosaic algorithms developed to combine the images together. Our 2D video mosaic approach was initially built on the Ph.D. work of project member Nuno Gracias (Gracias *et al.* 2003) and was later extended during SERDP project RC-1333 (Reid *et al.* 2010). The current technique involves four processing steps, as follows:

1. Sequential Image Selection. In this step, image motion between time-consecutive video frames is estimated by finding corresponding image points across pairs of images. This results in a set of ordered image-to-image mappings. The correspondences are found using a mixture of Scale Invariant Feature Transform (SIFT) (Lowe 2004) and the Harris corner detector (Harris and Stephens 1988) with normalized cross-correlation. Robust estimation techniques are used to filter out wrongly matched pairs of points, which may appear due to strong parallax effects resulting from 3-D structure in the scene or to moving algae or fish. These techniques make the newer mosaicing capability much more resilient to a non-flat benthos. Although these mappings could be cascaded to infer the approximate camera trajectory, the accuracy of such a trajectory estimate would be very poor since small unavoidable errors in motion estimation lead to growth of errors in camera trajectory. These mapping techniques allow for computing the amount of overlap among sequential images. Images with very high overlap are discarded (typically above 70%), thus lowering the complexity of the mosaicing process without impacting the quality of the final result.
2. Global Matching. In this step, the selected images are matched against each other, also using SIFT matching. This is the most time consuming step of all the mosaicing process. However, significant time savings are obtained by only performing the full image matching on the images that are highly similar at the SIFT descriptor level. Such SIFT descriptors have been computed on the previous step, and the similarity can be rapidly checked by taking advantage of parallel multi-core processing.
3. Global Alignment. This step deals with finding the best spatial arrangement for the location of all selected images. Each successful match between two images (conducted in the previous step) gives rise to a geometric constraint on the relative spatial displacement of those two images. Since there will typically be a much larger number of constraints than number of images, this leads to an over-constrained problem. This Global Alignment step performs a non-linear least squares batch optimization on the global set of image constraints. (Gracias *et al.* 2003; Lirman *et al.* 2007) in order to determine the optimum arrangement of each image.
4. Image Blending. The final mosaic image is created by warping and blending the original video frames, using the optimization result of the previous step. This step uses a graph-cut/gradient blending approach illustrated below, and detailed in Gracias *et al.* (2008a).

Figure 16 shows results of the complete mosaicing algorithm. To illustrate the need for the Global Matching and Global Alignment steps, the upper image was rendered using just the outcome of the Sequential Selection part (i.e., steps 1. and 4. only), while the lower one was created with the full algorithm. The error accumulation is visible on the repetitive pattern (marked by the dotted lines), which corresponds to the same area of the seabed: a single cross over point of two cables.

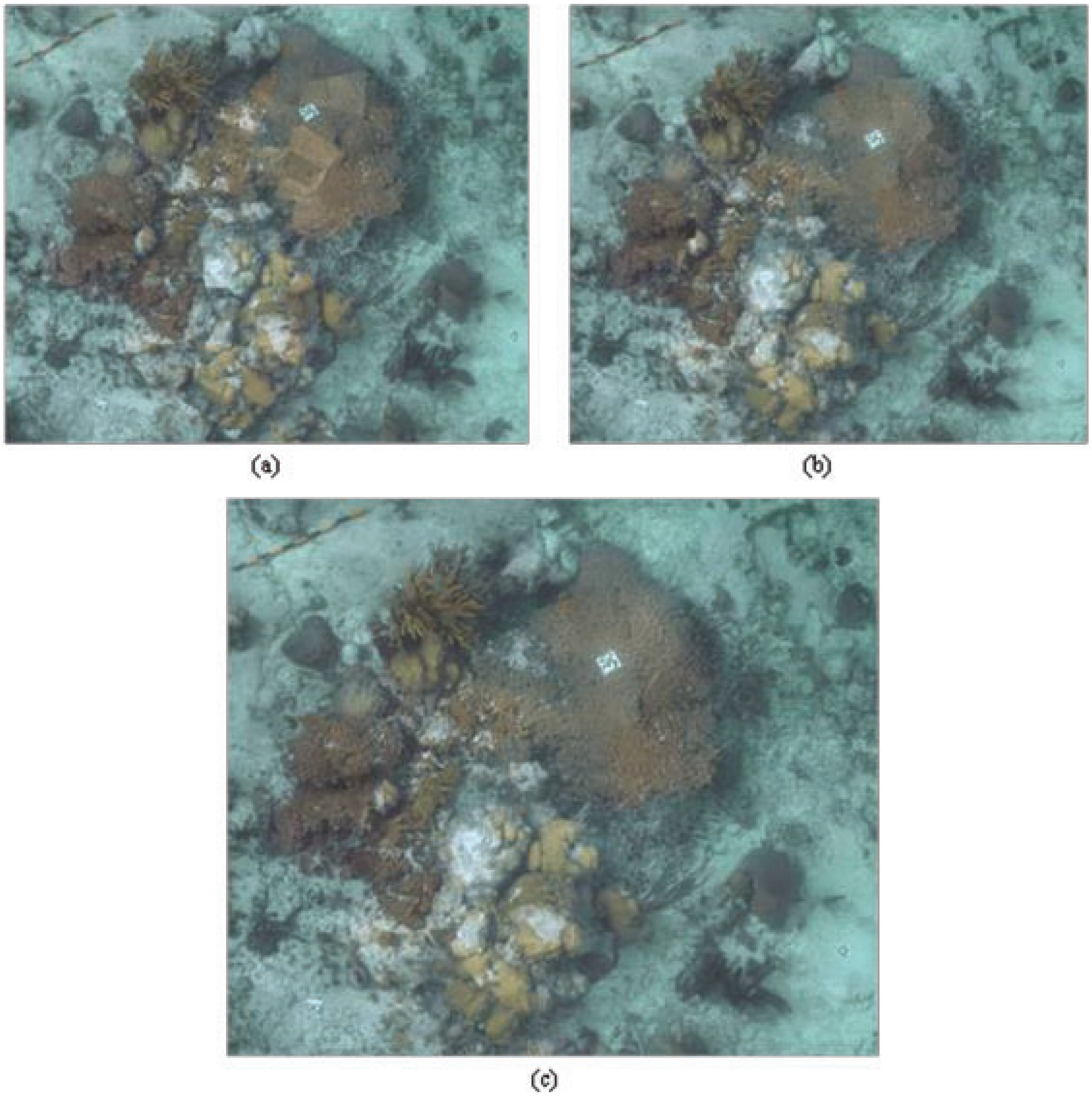


- Top: Mosaic created using only sequential image selection and rendering. Bottom: Mosaic incorporating global matching and global alignment.
- The circled areas designate a single cross-over point of two cables.
- This single point is repeated several times in the top, unaligned mosaic due to accumulated error.

Figure 16. Mosaic creation example using Andros data.

Image blending (step 4.) is an integral final step in mosaic processing in which information from the hundreds or thousands of component frames used in the image matching steps are combined to create a single large image. The most straightforward method for assembling a single mosaic from multiple registered images is to simply fill the mosaic with the portion of each single image closest to its center. This approach allows for very fast results but often leaves visible seams in the mosaic at the sudden transitions between component images.

During the last two years of the SERDP project, a new approach was devised to blend images using a combination of three techniques: watershed segmentation, graphcut optimization and gradient blending. (1) Watershed segmentation allows for grouping sets of neighboring pixels into clusters which are then treated as indivisible units in the blending process. This leads to a substantial time saving since the number of clusters is much smaller than the number of pixels. (2) Graphcut optimization is a recent energy minimization method that is particularly well adapted to image segmentation applications. It allows for assigning the watershed segments to each image in order to minimize the visibility of the inter-image seam lines. (3) Finally the gradient blending uses the derivatives of the image values to impose smooth transitions between neighboring images. An example of the effect of these three blending components is given in Figure 17.



- (a) This photograph was obtained with the standard blending using all images. For each point in the mosaic, the standard method selects the contribution from the closest image, which results in a large number of visible seams.
- (b) This photograph presents the result of the watershed/graph-cut method after selecting a subset of representative images (see text). The watershed/graph-cut method places the seams over the areas where they are the least visible. However, seams are still visible between images captured under different illumination.
- (b). This photograph shows the image transitions smoothed out, thus making the seams practically invisible.
- (c) This photograph represents the result of the new gradient blending module applied to the result of

Figure 17. Comparison of the effect of the blending components.

5.4 FIELD TESTING

5.4.1 Long-Term Monitoring Demonstration

5.4.1.1 Performance Objective 1: Provide Colony-Based Metrics of Coral Reef Condition.

The overall approach was:

(A) Select a reef plot with high abundance of coral colonies and a wide range of colony sizes and morphologies.
(B) Identify, tag, measure, and assess coral colonies within the plot by divers.
(C) Mosaic the area that was assessed by divers.
(D) Extract coral colony sizes from the mosaic.
(E) Extract species identification, bleaching, disease, and mortality metrics from the mosaic.
(F) Compare the size and condition of the colonies in the test plot as derived from diver data with the size and condition of the colonies derived from the mosaic.
(G) Compute the costs of diver and mosaic methods.

Steps A–E are described in this section along with instructions for setting up the cameras. Step F is described in Section 6.1.1, and Step G is described in Section 7.0.

5.4.1.2 System Set Up (Video)

- Wide Angle Zoom:
  - Use the ZOOM radial button on the exterior of the camera to the widest possible angle zoom.

- Slide the power switch down to CAMERA-TAPE mode. Touch P-MENU → [MENU]. Select the CAMERA SET menu.

- Turn off automatic camera stabilization:
  - Move down in the CAMERA SET menu and select STEADYSHOT.
  - Set STEADYSHOT to OFF.
  - Then press [OK].

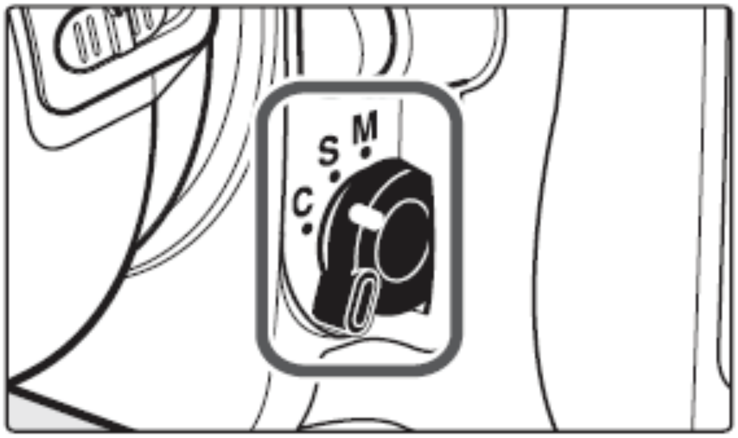
- Set shutter speed to 1/250:
  - Move down in the CAMERA SET menu and select the SHUTTER SPEED.
  - Select the MANUAL setting and use the -/+ buttons to scroll through the different options and select the shutter speed of 250.
  - Then press [OK].

- Set the exposure to AUTO:
  - Move down in the CAMERA SET menu and select the EXPOSURE.
  - Select the AUTO setting.
  - Then press [OK].

- Set white balance to highest color temperature:
  - Move down in the CAMERA SET menu and select the WHITE BAL.
  - Frame a blue paper/object in front of the camera, the paper/object should take up the entire view of the camera.
  - Select the ONE PUSH option which looks like a rectangle over two symmetrical triangles.
  - Touch the ONE PUSH symbol once again.
  - The ONE PUSH symbol will begin to flash quickly. When the white balance has been adjusted and stored in the memory, the indicator stops flashing.
  - After the white balanced has been stored, push [OK]

5.4.1.3 System Set Up (Still Camera)

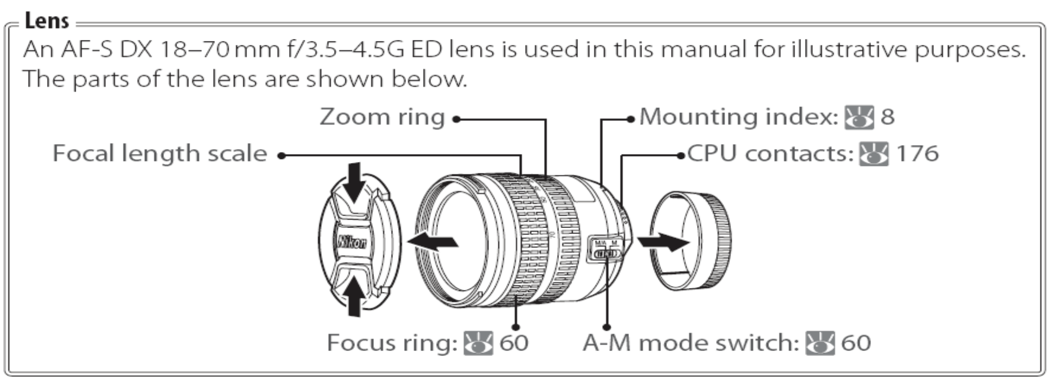
- Verify the camera is in auto focus:
  - The Focus mode should be set at C mode on the exterior button of the camera, see Figure 18.



- Source: https://cdn-10.nikon-cdn.com/pdf/manuals/dslr/D7100_EN.pdf.

Figure 18. Camera focus settings.

- Set camera to desired zoom:
  - Use the ZOOM RING to adjust the zoom to 52 mm, see Figure 19.



- Source: https://cdn-10.nikon-cdn.com/pdf/manuals/dslr/D7100_EN.pdf

Figure 19. Camera zoom ring.

The following settings will require entering the cameras menu, camera settings available at various dial settings are shown in Figure 20:

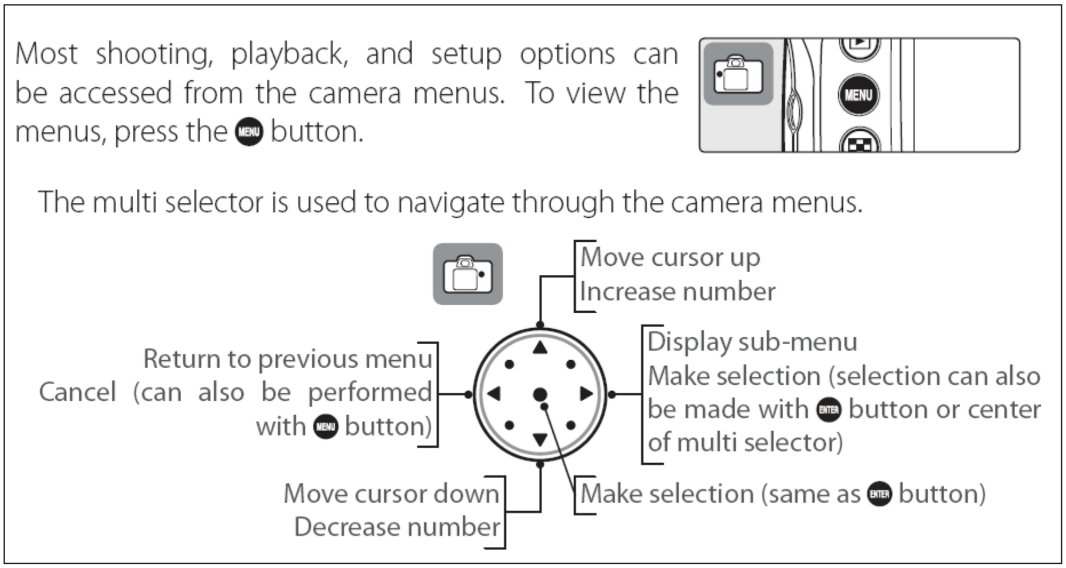
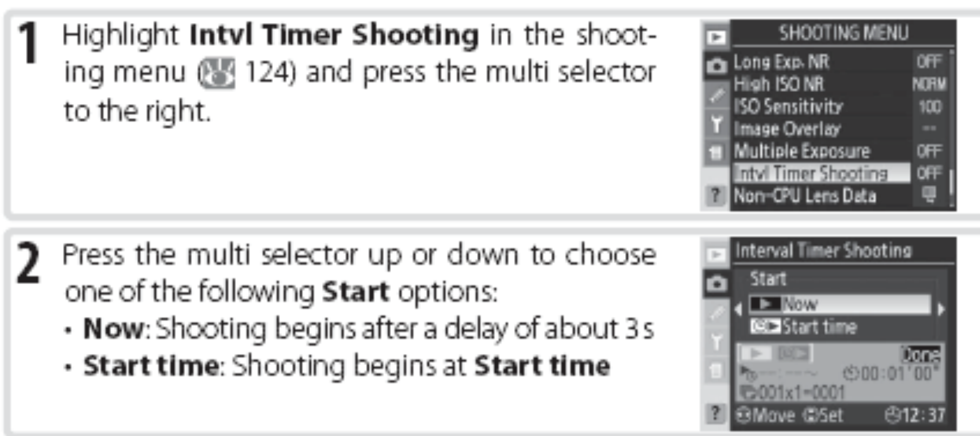


Figure 20. Camera navigation controls.

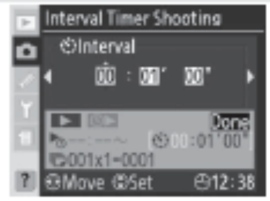
- Following are steps to program the camera to be set up for one frame per second:
  - In the MENU select the SHOOTING MENU highlighted as a small camera icon, see Figure 21 to 23 for camera interval time set-up settings.



- Source: https://cdn-10.nikon-cdn.com/pdf/manuals/dslr/D7100_EN.pdf.

Figure 21. Camera interval time set-up settings p1.

3 Press the multi selector left or right to highlight the following options and press the multi selector up or down to change interval timer settings.



Option	Description
Start time	Enter start time for interval timer photography when **Start time** is selected for **Start**. Press multi selector left or right to highlight starting hour or minute, press up or down to change. Not available when **Now** is selected for **Start**.
Interval	Enter time between shots. Press multi selector left or right to highlight hour, minute, or second, press up or down to change. Note that camera will not be able to take photographs at specified interval if interval is shorter than shutter speed or time required to record images.
Select Intvl*Shots	Choose number of intervals and number of shots taken at each interval. Press multi selector left or right to highlight number of intervals or number of shots, press up or down to change. Total number of shots that will be taken appears to right.
Remaining (intvl*shots)	Shows number of intervals and total shots remaining in current interval program. This item can not be edited.
Start	Choose **Off** to adjust settings without starting interval timer. To start interval timer, select **On** and press OK. Shooting will start at selected start time and will continue for specified number of intervals.

- Source: https://cdn-10.nikon-cdn.com/pdf/manuals/dslr/D7100_EN.pdf

Figure 22. Camera interval time set-up settings p2.

4 Highlight **Start** at the bottom of the interval timer menu and press the multi selector up or down to select **On**, then press the OK button. The first series of shots will be taken at the specified starting time. Shooting will continue at the selected interval until all shots have been taken. If shooting can not proceed at current settings (for example, if a shutter speed of bulb is currently selected in manual exposure mode, or the starting time is less than one minute from the current time), a warning will appear and the interval timer menu will be displayed again.

- Source: https://cdn-10.nikon-cdn.com/pdf/manuals/dslr/D7100_EN.pdf.

Figure 23. Camera interval time set-up settings p3.

- Set ISO to AUTO:
  - In the SHOOTING MENU select the ISO SENSITIVITY menu.
  - Use the multi selector to set the ISO to AUTO.

- Set image quality setting (Large; High Quality; JPEG):
  - In the SHOOTING MENU select the IMAGE QUALITY menu.
  - Highlight the 'JPEG FINE' option of the image quality list and press the multi selector to the right.

- Set the white balance to 10,000K color temperature:
  - In the SHOOTING MENU select the WHITE BALANCE menu.
  - Select the CHOOSE COLOR TEMP menu.
  - Select the 10,000K option and right click [OK].

- Set Exposure program to shutter priority with shutter speed 1/320:
  - Press the exterior button MODE and use the main command dial until the
  - P (Program Auto) option shows up.

5.4.1.4 Plot selection (Step A)

The first field step was to identify a convenient plot for the test in consultation with AUTEC personnel. Sites were chosen to have a high abundance of coral colonies and a wide range of colony sizes (from < 5 cm to > 50 cm in diameter) and morphologies (branching, encrusting, or massive). Plot selection was directed towards shallow protected reefs with relatively high density of coral colonies (above 5% cover).

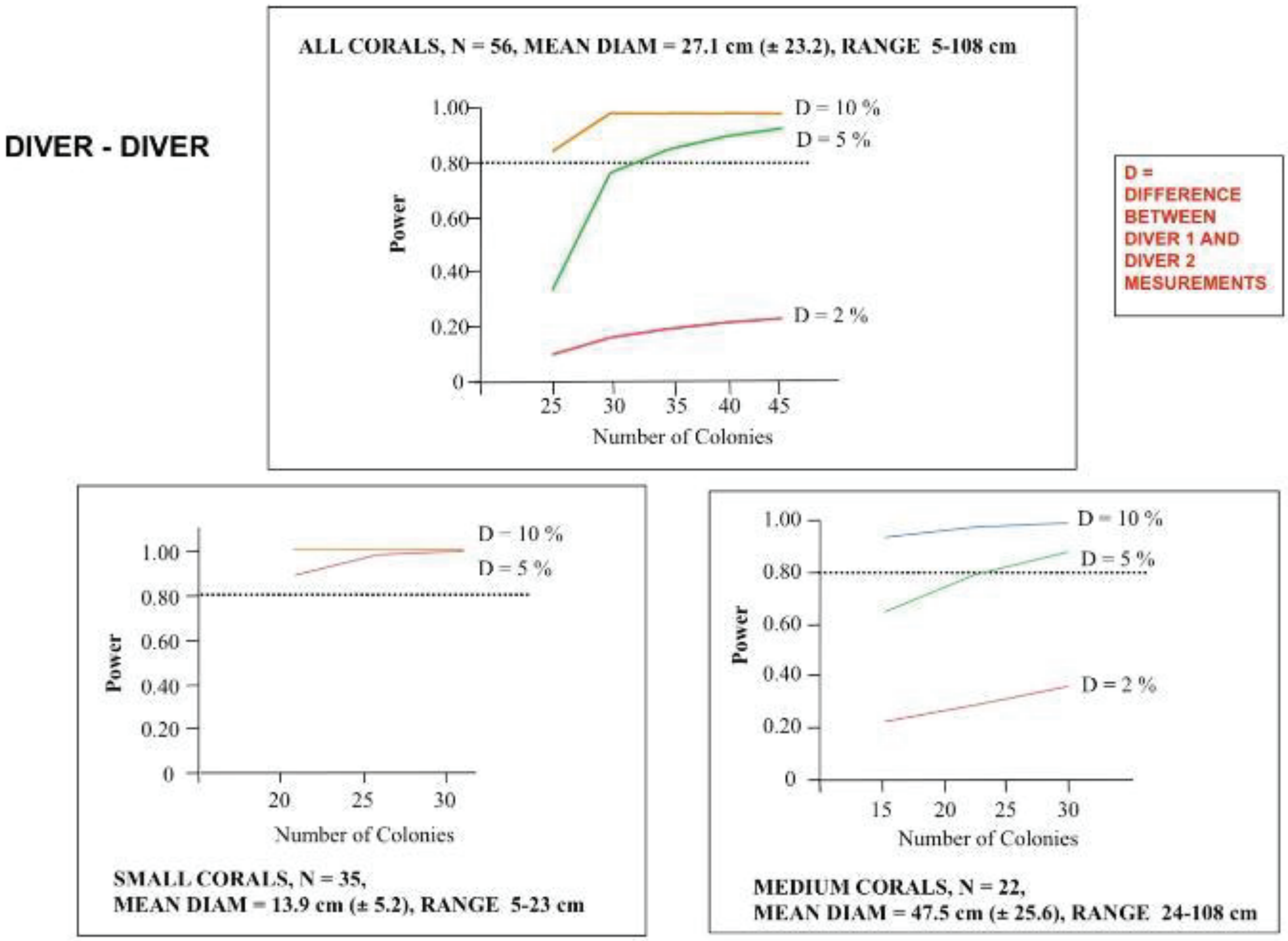
5.4.1.5 Diver setup and measurements (Step B)

Prior to any measurements taken in the field the dive team performed a calibration exercise in which the team agreed upon the axes of coral colonies that will be measured and how to define the boundary of the colony in the field. Additional calibration was conducted to consistently identify coral bleaching, old and new mortality between divers in the field. Once a specific plot had been chosen (Step A), divers from each team (RSMAS and Navy) tagged colonies within the defined area of interest.

To evaluate statistical differences between diver-diver measurements and diver-mosaic measurements, an a priori power analysis was used to estimate the desired number of corals to tag. Existing paired measurements of coral size (i.e., where size measurements from two divers and a mosaic were available for the same coral) were available from the data used for Lirman *et al.* (2007) and other unpublished sources. Power was computed using the JMP software package based on the complete dataset and subsets of the dataset divided into small (< 25 cm in diameter) and medium (> 25 cm) colonies. This provided minimum samples required based on colony sizes, as measurement error commonly increases with colony size, as shown for example in Lirman *et al.* (2007). provide the results from the power analyses. A power level of 80% is commonly accepted as adequate. The effect size (difference between measurements of the same colony) that was used ranged from 1 % to 15%. To put this in perspective, to expect a 1% difference in 2 measurements of a colony 25 cm in diameter (i.e., a difference of 2.5 mm) would be overkill, requiring, in most cases, 100s to 1000s of colonies to be measured. A more realistic and practical desired maximum effect size would be 10–15 % of the colony diameter. For a colony of 25 cm, this translates into a difference of 2.5 cm between observers. This would be roughly the amount of radial growth expected for a colony of mounding morphology (such as *Porites astreoides* or *Siderastrea siderea)* over a 2 to 3-year period.

With a maximum effect size of 10-15% and for the range of colony sizes we have sampled (and expect to sample in the future), a minimum of 25 colonies per size category (25 small, 25 medium) will provide, based on existing data, a power > 0.8 (or higher most of the time) to detect significant differences (at the p = 0.05 level) in coral sizes between observers (diver-to-diver, diver-to-mosaic), which is quite good for field data (Figure 24 and 25).

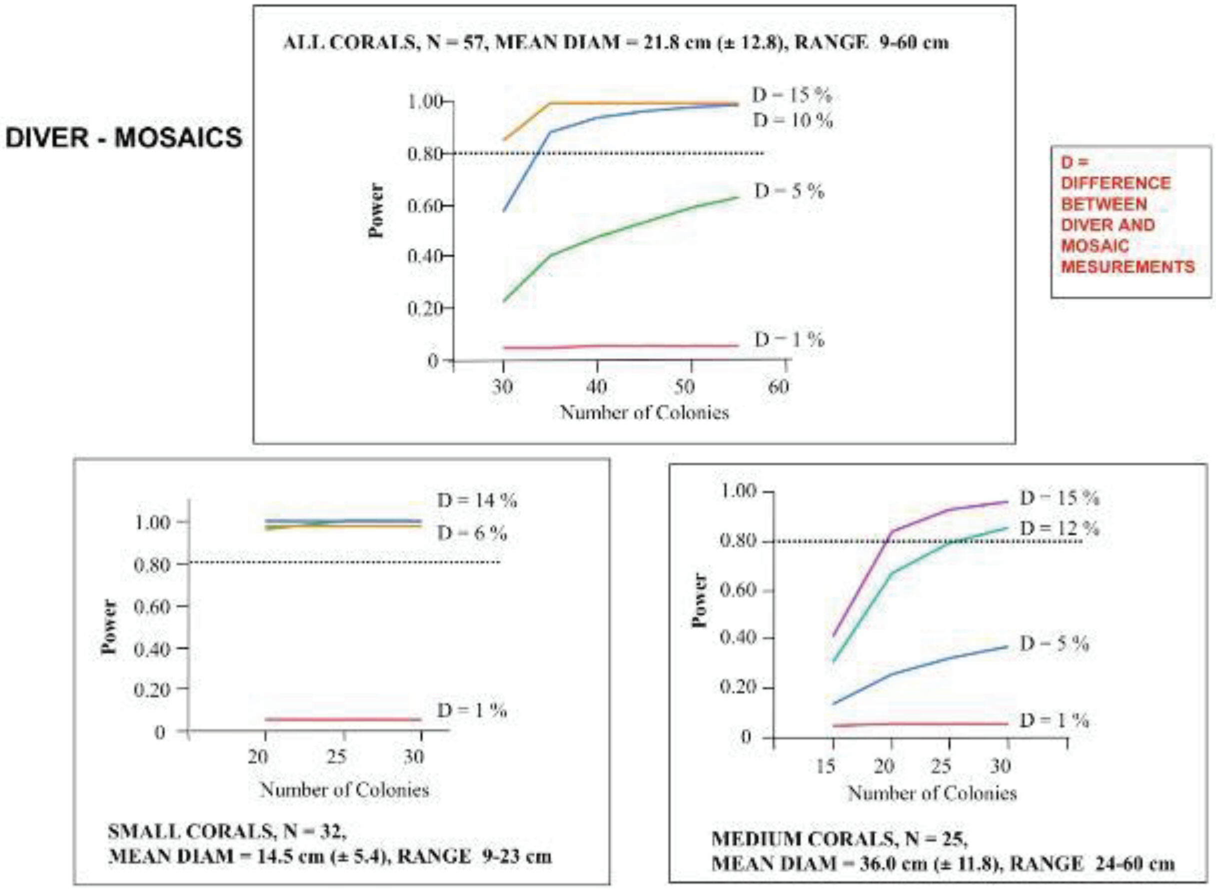
These existing data were collected by well-trained researchers. Data collected by less experienced observers are expected, at least initially, to be more variable and contain a higher sampling error. This will directly impact the sample size needed to attain the same power level. The best way to approach this issue is through observer training, which will reduce measurement error, reduce variance, and increase power (thereby reducing the need to measure additional colonies). Thus, calibration exercises were completed on the first day of this demonstration.



- Note that power is > 0.8 for an effect size of 10% and sample size of N = 25 colonies for the entire dataset (top panel) and subsets of the dataset (top panel) and subsets of the dataset based on colony size (bottom panels).

Figure 24. Statistical power computed from a pilot dataset of 57 corals for a sample size that was measured by two divers.

There were not many observations for large colonies (> 60 cm) in this dataset. Due to the inherent variability in measuring large things underwater, it is expected that a large number of colonies will need to be included to achieve the desired power for the largest colonies. Unfortunately, given present levels of coral health, we did not find many large colonies within our plots. The only remedy for this was to pool all data on coral sizes at the end of the project, which was be possible because coral size was a variable in other demonstrations (e.g., the grounding, ESA, and traditional metrics demos).



- Note that power is > 0.8 for an effect size of ~12% and sample size of N=25 colonies for subsets of the dataset based on colony size (bottom panels).

Figure 25. Statistical power computed from a pilot dataset of 57 corals for a sample size that was measured by one diver and an analyst using a mosaic.

Finally, it should be noted that this power analysis was only for colony sizes. We did not have any pilot data for other metrics such as % bleached or % dead, so it was impossible to estimate how many samples are needed for these variables before the demo. The statistical power of the dataset can be quantified after the fact, however.

Once colonies were tagged, each diver identified the coral to species level and made measurements of the colony's maximum length and width and recorded that measurement on their own datasheet. Following each size measurement, the coral was assessed visually for (1) the presence of bleaching and disease and (2) "condition," which consists of the amount of coral bleaching, the amount of new mortality and the amount of old mortality present on each colony. The metrics acquired during this task are listed in Table 9. All tagged colonies were assessed independently by each diver of the team. Datasheets were converted to electronic format as soon as possible following the dive on which they were collected.

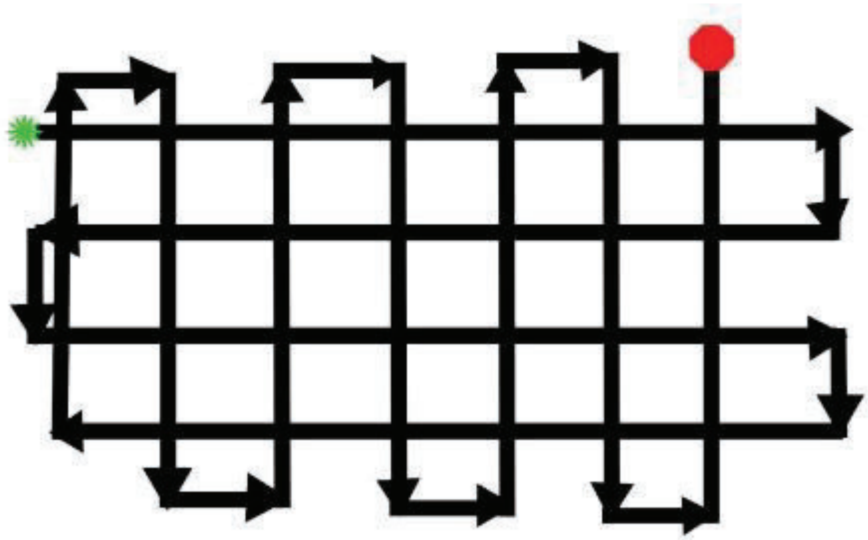
Table 9. Coral size and condition metrics and the measurements to be made by each diver.

Metric	Data Measurement in the field
Coral colony size	Maximum length (cm), Maximum width (cm)
Prevalence of coral bleaching and disease	Number of bleached colonies and number of diseased corals
Percent Colony Bleaching	Diver estimate of the % of each colony that is bleached
Recent Coral Mortality	Diver estimate of the % of each colony that is new coral mortality
Old Coral Mortality	Diver estimate of the % of each colony that is old coral mortality

5.4.1.6 Mosaic acquisition and construction (Step C)

Following the in situ measurement of coral sizes and condition, each dive team conducted a landscape mosaic survey of the area containing the tagged colonies. Markers were placed on the seabed next to each tagged colony in the test plot to ensure that specific colonies could be correlated between the diver and mosaic measurements. Colored quadrats and half meter sticks were placed at the corners and along the edges of the area of interest to provide a visual border of the area of interest for the mosaic surveys and to enable scaling the size of the pixels in the final mosaic to meters. Both the RSMAS and Navy dive teams then used a second-generation landscape mosaic system to survey the area of interest. The mosaic created from the RSMAS data was used to evaluate PO1 and both mosaics were used to evaluate PO 3.

The goal was to swim over the survey area with the cameras pointing as vertically down as possible while covering the area using a double "lawn mower" pattern (Figure 26). The pattern consisted of a set of parallel transects followed by a second set of "tie lines". The parallel transects in the primary direction should have substantial side-to-side overlap (60–80%), the tie lines in the other direction do not need much side to side overlap, if any.



- The camera remains in one orientation during the entire acquisition period. All changes in direction area accomplished by divers only.

Figure 26. Sketch of the pattern to swim while acquiring data for mosaics.

A good rule of thumb is to swim 1.5 to 2 times the height of the largest object in the survey area. In this case we found about 1 m of relief in the plot, so data were acquired 1.5–2 m above the tops of the colonies, or 2.5–3 m above the bottom. Exact heights were determined by the conditions encountered at the site. This protocol was followed by both the RSMAS dive team and Navy divers who will be trained in mosaic acquisition. Both dive teams conducted a survey of the area of interest.

At the end of each day in the field, the images acquired were backed up and cameras prepared for the next day's dives (batteries charged, housings cleaned etc.) Upon return to Miami, the mosaicing software was used to assemble landscape mosaics from the raw data acquired by both the RSMAS and Navy teams. Mosaic creation followed the instructions in the mosaic creation manual. The mosaics created by the RSMAS team were used for the analysis of both PO 1 and PO 3. The mosaics made from the Navy data were only be used for PO 3.

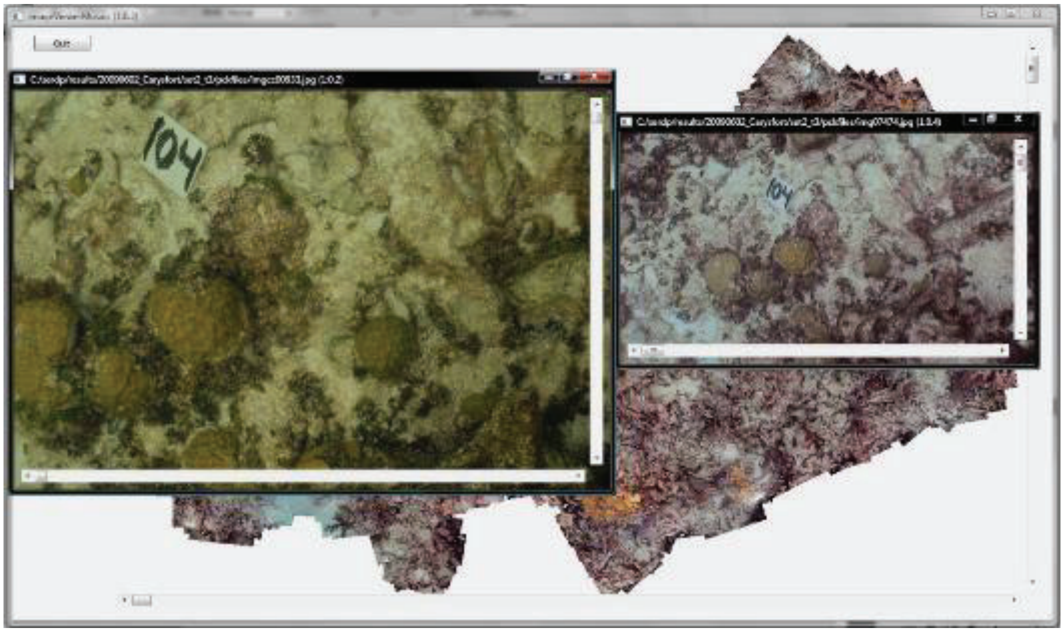
5.4.1.7 Extraction of Metrics (Measurement of Coral Colony Size) from the Mosaic for PO1 (Step D)

After the mosaics were created, the six metrics for PO 1 were extracted by an analyst (Table 10). Analysis was performed using "Coral Point Count" (CPCe; Kohler and, Gill; 2006), a freeware program, and the mosaic viewer software created in RC-1333. The mosaic viewer software integrates the final mosaic with a "point and click" interface that brings up the corresponding still images when a point is clicked in the mosaic (Figures 27 and 28). Table 10 shows the coral size and condition metrics and the measurements made from each mosaic.

Table 10. Coral size and condition metrics and the measurements made from each mosaic.

Metric	Data Measurement from mosaic	Method of measurement
Coral colony size	Maximum length (# pixels), Maximum width (# pixels); convert pixels to cm using the known size of each pixel.	CPCe
Prevalence of coral disease	Number of diseased corals counted by an analyst looking at the mosaic.	Mosaic Viewer
Prevalence of coral bleaching	Number of bleached colonies counted by an analyst looking at the mosaic.	Mosaic Viewer
Percent colony Bleaching	Analyst estimate of the % of each colony that is bleached	Mosaic Viewer
Recent coral mortality	Analyst estimate of the % of each colony that is new coral mortality	Mosaic Viewer
Old coral mortality	Analyst estimate of the % of each colony that is old coral mortality	Mosaic Viewer

Figure 27. Mosaic viewer interface showing a completed mosaic.



- Clicking on a point within the mosaic calls up two additional windows containing the closest still image (shown in the left window) and the closest video frame (shown in the right window) to the point where the mouse was clicked.
- All three views of the seabed can be used for assessment and measurement.

Figure 28. Detailed view afforded by linking the high-resolution still imagery with the full mosaic within the viewer.

To extract coral colony size from the mosaics, the maximum length and maximum width of each marked colony was measured using the tools built into Coral Point Count. The CPCe tools simply measure the number of pixels crossed by a straight line drawn by the user. This distance measurement in pixel units is converted to a distance measurement in centimeters by measuring the scale bars placed on the seabed during image acquisition. All of the scale bars visible in the image were measured and an average value of cm/pixel used for the conversion factor.

Step-by-step instructions for measuring length and width of colonies in CPCe 4.0 are as follows:

1. Open IRFANVIEW image viewer software.
2. Pull down the "FILE | Open" menu and select the mosaic desired for analysis.
3. Pull down the "FILE | Save as" menu and save the mosaic in .jpg format.
4. Open CPCe 4.0
5. On the menu bar at the top of the program window click on Measurement and select Area/Length Analysis from the drop-down menu
6. Open the converted mosaic image.
7. From the menu bar click on 'Scaling calibration' and select Perform Image Scaling/Calibration
8. Locate the scale bars placed within the area of the mosaic.
9. Follow the onscreen prompts to select two points on the scale for which the spanned distance is known.
10. Enter the known distance between the points and select the unit of measure. Cm will be used for this demonstration. The resolution of the image will be calculated and displayed on the upper left corner of the image.
11. Click 'Area/Length Analysis' and a box containing the tools for the analysis will appear in the upper right corner of the window.
12. For length analysis, select the radial button for length.

13. Locate the item that will be measured and left-click at one extreme of the width or length and right-click at the opposite extreme. A line will appear on the mosaic with a distance measurement and a window will open with a chart displaying the lengths of the lines that have been created. If desired, comments and species codes can be included on the chart.
14. Click 'Save data and Exit'. The chart will disappear
15. Repeat steps 10 and 11 for each remaining object.
16. Use the 'File' dropdown menu choices to save your work. You can save the image with or without length markers. Save the .ara file to be able to come back at a later date and continue work on the same image or export the .ara file to a plain text data file to be used in the statistical analysis.

5.4.1.8 Extraction of Metrics (Species identification, Bleaching, Disease, Mortality) from the Mosaic for PO1 (Step E)

The extraction of all of the other metrics from the mosaic was completed through visual inspection of colonies using the mosaic viewer software. Once a tagged colony had been located in the external mosaic viewer, the analyst then clicked on the area of interest and the program retrieved the closest still image for condition assessment Figures 27 and 28). Analysts identified corals to species, determined if colonies were bleached, if disease was present, and estimated the amount of bleaching, old, and new mortality affecting the colony at that time. Analysts used the same visual references for estimating % bleaching, % new mortality, and % old mortality as they did in the field. Step-by-step instructions for using the Image Viewer Mosaic Program for extracting estimates of coral bleaching and disease are as follows:

1. Open the "imageViewerMosaic-0.5\windows" folder.
2. Double click on imageViewerMosaic.exe to open the program.
3. Once the program is open, you will be prompted to open your .pck file.
4. Locate the folder that contains the files created for the viewer when the mosaic was made.
5. Select file that ends with the ".pck" extension. The mosaic will load into a new window.
6. Click anywhere in the mosaic to pull up the matching still and video images for that point of the mosaic. Two new windows will open up with images in them and boxes will be outlined on the mosaic to show the orientation of the images that have been selected.
7. Zoom in and out on the images using the scroll wheel on your mouse.
8. Close unwanted images by clicking the 'X' in the corner of the image window.
9. To select a different point, click again on the mosaic and new images will appear.
10. Once the external viewer is open, the analyst will then pan over the image and locate all coral colonies marked by ceramic tile markers. Each marker will correspond to a colony that has been measured and assessed for indices of reef health by divers in the field. The mosaic analyst will then zoom in on the coral colony and determine the following information: (1) species name, (2) presence/absence of bleaching, (3) presence/absence of coral disease, (4) visual estimate of the % of the colony with new mortality, (5) visual estimate of the % of the colony with old mortality, and (6) a visual estimate of the % of the colony that is bleached.

Field activities were timed to enable cost calculations. In particular, the following six tasks were timed for each individual diver in the field:

1. Staging time on shore required to prepare equipment.
2. Locating, identifying and tagging colonies.
3. Measuring and assessing the condition of all tagged colonies.
4. Setup and acquisition of mosaic data over the area of interest.
5. Data download and backup on shore at the end of the day
6. Converting diver data sheets to electronic format.

The following two tasks were timed for each mosaic back in the lab:

1. Mosaic creation.
2. Extraction of each metric from the mosaic.

5.4.1.9 Performance Objective 2: Maintain Continuity with Long-Term, Map-Based Coral Reef Monitoring Data Sets.

The overall approach was:

(A) Select one of the plots for which AUTEC has historical data.
(B) Create hand-drawn maps of subsections of the selected plot and measure the sizes of all coral colonies within the subsection by divers
(C) Extract coral cover and sizes of individual colonies from the hand-drawn map.
(D) Mosaic the entire plot.
(E) Extract coral cover and sizes of individual colonies from the mosaic, using the subsection mapped by divers as a guide.
(F) Compare the sizes and estimates of total coral cover within the test plot as derived from hand-drawn map data with the size and percent coral cover estimated from scaled mosaic images.
(G) Compute the costs of diver and mosaic methods.

Steps A–E are described in this section. Step F is described in Section 6.1.2 and Step G is described in Section 7.0.

5.4.1.10 System Set Up

System set up was the same as for PO 1.

5.4.1.11 Plot Selection (Step A)

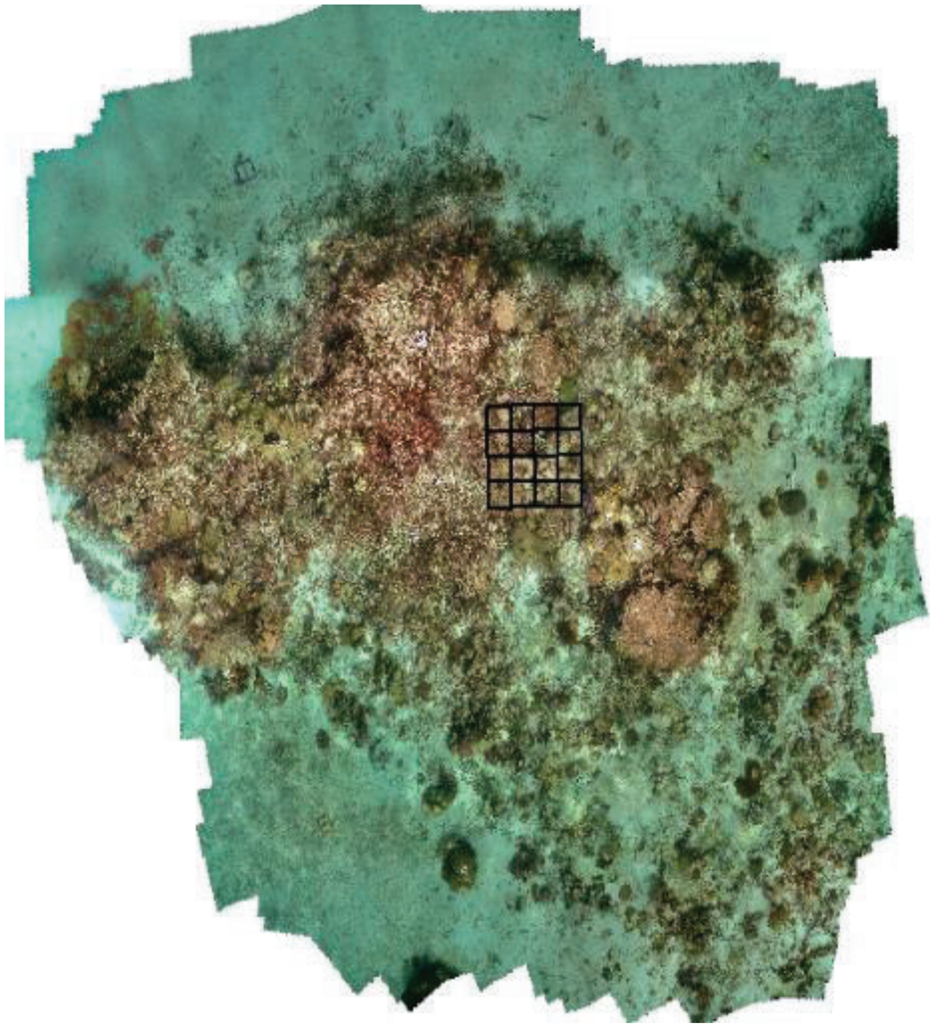
This demonstration was completed at site S1-10; an inshore patch reef site that has been part of the AUTEC coral reef monitoring program since 1972. This site was chosen due to its close proximity to the AUTEC naval base and its relatively protected location.

5.4.1.12 Diver Setup and Measurements (Step B)

To compare the efficiency of coral reef mapping technologies for the purpose of continuing the long-term mapping of the AUTEC coral reef monitoring program, or for establishing similar programs to acquire spatially explicit benthic data at other sites, three in-situ methods were deployed at the site of interest: (1) hand-drawn mapping of small sections of the area of interest, (2) size measurements of mapped colonies, and (3) mosaic surveys of the entire site.

The historical data of coral community composition at AUTEC consists of hand-drawn, species-specific maps that detail the relative location, size, and spatial arrangement of all benthic organisms within the area of interest. To generate a similar, modern dataset for comparison with the mosaics, divers placed two replicate 2 × 2 m grids within the area of interest. The grids were placed within the

S1-10 site in both high coral cover and low coral cover areas. An example of a random 2 × 2 m quadrat within the S1-10 site is shown in Figure 29. One diver from each team (RSMAS and Navy) was used for this demonstration. Each diver independently mapped all four 1 × 1 m sub-quadrants (using a.1 × .1m gridded quadrat) within each 2 × 2 m area in order to record the locations and areal extent of each macrobenthic organism within the designated area of interest. All macrobenthic organisms such as scleractinian corals, sponges and gorgonians were recorded. Corals were identified to species and sponges and gorgonians were identified to type (i.e., barrel, rope, and ball sponges and encrusting vs. erect gorgonians).

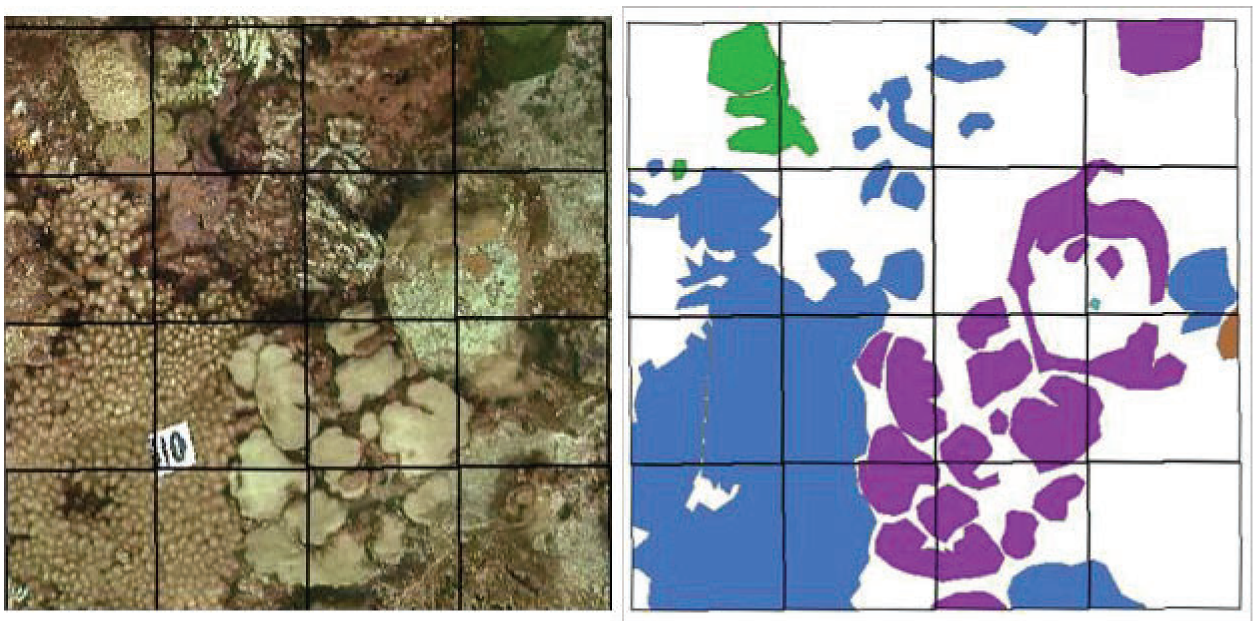


- The 2 × 2 m quadrat above is subdivided into 0.25 m2 subsections to illustrate the concept. In the field 0.1 × 0.1 m gridded sub quadrats were used for the mapping, which would be too small to show up clearly on this image.

Figure 29. Example of 2 × 2 m sub-quadrat for hand-mapping placed within a larger test plot.

Each 2 × 2 m area was mapped using gridded 1 × 1 m sub-quadrats in which 10 × 10 cm sections were delineated by thin nylon line. Divers were equipped with datasheets pre-marked with a 5 × 5 grid of squares, where each square represents one of the 10 × 10 cm sections of the quadrat. To map each 1 × 1 m quadrat therefore required four datasheets. Divers visually noted the sub-quadrant location and approximate areal extent of each macrobenthic organism within each 10 × 10 cm section of the grid. Once each diver had independently mapped one of the two 2 × 2 m quadrats they switched and mapped the other quadrat. A visual example of the output from this mapping methodology is shown in Figure 30. Here, a 2 × 2 m quadrat has been defined in the field and divers have approximated the location and areal extent of all corals within the 2 × 2 m quadrat. Organisms have been color coded by species to show the spatial arrangement of various coral species. This is an illustration of the type of data collected at site S1-10. Following the mapping of these sections by hand each diver numbered the colonies within their mapped quadrat and measured the maximum diameter and length of all mapped colonies.

The hand-drawn maps were brought back to the lab and digitized using ArcGIS 9.3 for areal coverage (as shown in Figure 30). Length and width information as well as estimates of total coral cover within each 1 × 1 m square of the mapped area were obtained from the digitized hand drawn maps. Differences in observer measurements were compared to differences in size and coral cover measurements obtained from the hand drawn maps and from scaled mosaic images. The statistical analysis of these comparisons is described in Section 6. Table 11 shows the relative x-map and y-map coordinates for each corner of the 0.5 × 0.5 m hand-drawn datasheets.



- The area was gridded (left) and colonies within the boundary were identified to species and their boundaries outlined and recorded. Maps of individual 1 × 1 m sub-quadrats were combined to re-create the entire 2 × 2 m quadrat (right).

Figure 30. Example of a 2×2 m grid hand-mapped by each dive team.

Table 12 shows coral size and cover metrics for Performance Objective 2 and the ways these were assessed in the field. The step-by-step instructions for performing the measurements were as follows: (before beginning, scan and crop the hand-drawn maps).

1. Place a hand-drawn map datasheet on a flatbed scanner
2. Using Windows Fax and Scan, scan the image
   a. Select New Scan from the toolbar
   b. Select Okay to scan the image
3. Open scanned image using Paint
4. Click the select button from the toolbar
5. Click on one corner of the gridded area and drag the selection box to the opposite corner of the grid making sure the entire gridded area is contained in the selection box
6. Click 'Crop' on the toolbar.
7. Save resulting image as a JPEG
8. Repeat for each datasheet of the hand-drawn maps

Second, georeference the maps:

1. Open ArcMap.
2. Click File-> Add Data. Select desired scanned image and click Ok. The image will appear in the map viewing window.
3. Open the 'Define Projection' Tool.
4. Select the mosaic you are working with from the 'Input Dataset' dropdown menu.
5. Click on the button at the right end of the 'Coordinate System' field to bring up the 'Spatial Reference Properties' Window.
6. Click the 'Select' button to bring up the file browser. Select Projected Coordinate Systems->UTM-> NAD 1983 ->NAD 1983 UTM Zone 18N.prj and click 'Add' and you will return to the 'Spatial Reference Properties' window, which can be closed by clicking 'Okay'. 'NAD_1983_UTM_Zone_18N' should appear in the Coordinate System box.
7. Click 'Okay' to run the tool and close the window.
8. Steps 1–8 should be repeated for each scanned hand-drawn map.
9. Use the Georeferencing toolbar to align the hand-drawn subsections of each 2 × 2 m quadrat.
   a. Select the hand drawn map as the layer to work on in the Georeferencing toolbar.
   b. Select the button on the toolbar with green and red x connected by a diagonal line. 
   c. Click twice on each corner of the map to add control point to the map. Go in a clockwise motion starting from the bottom left corner (the origin)
   d. Click on the 'View Link Table' button in the Georeferencing toolbar to open a chart containing the control points.
   e. The values in the 'X Map' and 'Y Map' columns will be replaced with the distances to each corner according to the coordinates in the following chart and layout (Figure 31, Table 11).
   f. Click Okay to exit the table.
   g. On the Georeferencing toolbar, click on the Georeferencing pull-down and select Update Georeferencing.
   h. Repeat Steps 9 (a–g) for the control points of each portion of the hand-drawn map.

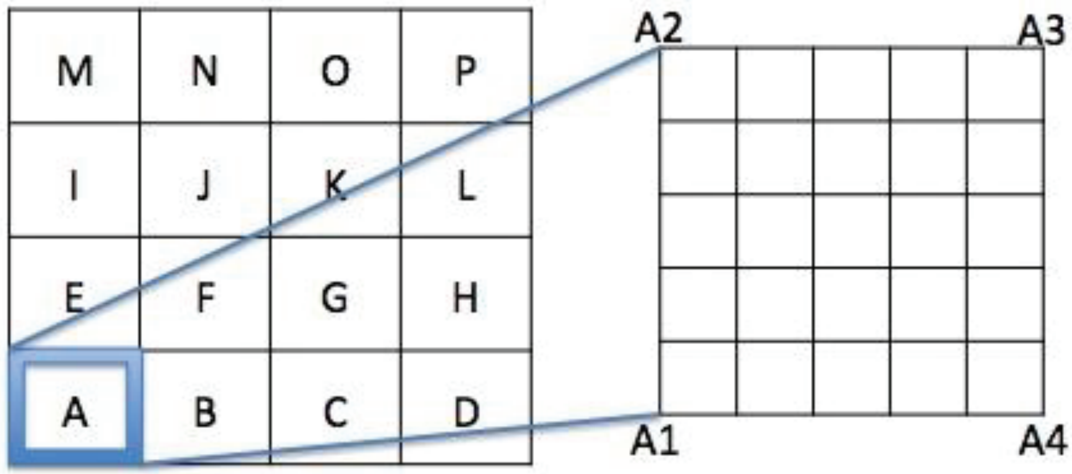


Figure 31. Diagram showing layout of relative locations of each portion of the hand-drawn map relative to the 2 × 2 m quadrat and the numbering of each corner.

Table 11. The relative x-map and y-map coordinates for each corner of the 0.5 × 0.5 m hand-drawn datasheets.

4 Corner Abbreviation	A	B	C	D	E	F	G	H
LL (x,y)	(0,0)	(0.5,0)	(1,0)	(1.5,0)	(0,0.5)	(0.5,0.5)	(1.0,0.5)	(1.5,0.5)
UL (x,y)	(0,0.5)	(0.5,0.5)	(1,0.5)	(1.5,0.5)	(0,1)	(0.5,1)	(1.0,1)	(1.5,1)
UR (x,y)	(0.5,0.5)	(1,0.5)	(1.5,0.5)	(2,0.5)	(0.5,1)	(1.0,1)	(1.5,1)	(2,1)
LR (x,y)	(0.5,0)	(1,0)	(1.5,0)	(2,0)	(0.5,0.5)	(1.0,0.5)	(1.5,0.5)	(2,0.5)
	I	J	K	L	M	N	O	P
LL (x,y)	(0,1)	(0.5,1)	(1,1)	(1.5,1)	(0,1.5)	(0.5,1.5)	(1.0,1.5)	(1.5,1.5)
UL (x,y)	(0,1.5)	(0.5,1.5)	(1,1.5)	(1.5,1.5)	(0,2)	(0.5,2)	(1.0,2)	(1.5,2)
UR (x,y)	(0.5,1.5)	(1,1.5)	(1.5,1.5)	(2,1.5)	(0.5,2)	(1.0,2)	(1.5,2)	(2,2)
LR (x,y)	(0.5,1)	(1,1)	(1.5,1)	(2,1)	(0.5,1.5)	(1.0,1.5)	(1.5,1.5)	(2,1.5)

- LL, UL, UR, and LR are abbreviations for the four corners of the datasheet, representing Lower or Upper (first letter) Left or Right (second letter).

Third, draw polygons around the corals on the georeferenced hand-drawn maps:

1. Create new files for the bounding box and coral digitizing layers
    a. Open ArcCatalog 10
    b. Navigate to the folder containing the georeferenced hand-drawn maps that will be digitized
    c. Right-click in the folder and select ‘Shapefile’ from the drop-down menu
    d. Create a name for the new shapefile. For the bounding box it should read “Areaofinterest_*sitename*”. For the digitizing layer use an appropriate name to describe the map.
    e. Select ‘Polygon’ from the Feature Type drop-down menu
    f. Click the ‘Edit’ Button and select Projected Coordinate Systems->UTM-> NAD 1983 ->NAD 1983 UTM Zone 17N.prj and click ‘Add’ and you will return to the ‘Spatial Reference Properties’ window, which can be closed by clicking ‘Okay’. ‘NAD_1983_UTM_Zone_17N’ should appear in the Coordinate System box.
    g. Click Okay to create the shapefile
    h. Repeat Step 1 for each map to be digitized.
2. Draw the bounding box for the area of interest.
    a. On the Editor toolbar select ‘Start Editing’ from the drop-down menu
    b. Under the ‘Create Features’ window click the ‘Organize Template’ button 
    c. Click ‘New Template’
    d. Select the box for the layer you wish to edit and click ‘Finish’
    e. Highlight the template you just created and click ‘Properties’.
    f. At the bottom of the window that opened ensure that the default tool reads ‘Polygon’
    g. Click close
    h. Select the template you just created in the Create Features window
    i. Draw the bounding box by clicking on the map where you want the shape to start and continue clicking along the outline of the area you want to analyze. In this instance you will create a square by clicking at each corner of the map.
    j. Double click on the last point to finish the sketch
3. In the Editor toolbar click stop editing and save your edits.
4. Right-click on the name of the map layer you are working with on the Table of Contents window and open the attribute table.
5. Repeat step 1 for each map digitizing layer using individual templates for each portion of the hand-drawn map (i.e. each data sheet). Make a bounding box for digitizing the mosaic. To digitize individual corals, trace around the boundaries of each coral colony, creating a separate shape for each individual.
6. After each shape is completed, click in the Id field on the Table for that item and enter the corresponding species code for that colony.
7. Once all colonies are digitized, stop editing and save your edits.

Fourth, measure the area of coral colonies:

1. Add a shapefile containing the digitized coral colonies to ArcMap
2. Right-click on the name of the map layer you are working with on the Table of Contents window and open the attribute table.
3. Add an additional field for area
    a. Click on the Table Options button 
    b. Select ‘Add Field’
    c. Name field ‘Area’
    d. Select ‘Double’ as the type
    e. Click OK
4. Calculate each polygon's area
    a. Right click on the Area field in the attribute table
    b. Select ‘Calculate Geometry’
    c. Choose Area from the 'Property' Dropdown menu
    d. Select the desired units from the dropdown menu
    e. Click OK. The Table will automatically populate the field with the areas of each shape.

Fifth, measure sizes of colonies

1. Add a shapefile containing the digitized coral colonies to ArcMap
2. Right-click on the name of the map layer you are working with on the Table of Contents window and open the attribute table.
3. Add an additional field for colony measurements
    a. Click on the Table Options button 
    b. Select Add Field
    c. Name field Length’
    d. Select ‘Double’ as the type
    e. Click OK

4. Repeat Step 3, replacing 'Length' with 'Width'
5. Measure the length and width of each colony
    a. On the Editor toolbar select 'Start Editing' from the dropdown menu
    b. Right-click on the blank box next to the FID for each shape and select 'Zoom to' from the menu. The feature will appear highlighted and zoomed in.
    c. Click on the 'Measure' button  on the toolbars at the top of the screen. A new Measure window will open
    d. Select the Measure Line button
    e. Click on one edge of the highlighted coral and drag the cursor over the other edge of the coral and double click, The distance of that segment will be listed in the Measure window

f. Go the attribute table and Click on the empty field for the corresponding measurement and type in the distance of the segment
g. Repeat this for the length and width of each coral colony
h. Stop and save your edits in the editor toolbar once you are finished measuring the corals.

Table 12. Coral size and cover metrics for Performance Objective 2 and the ways these were assessed in the field.

Metric	Method of obtaining metric in the field
Colony size (A)	Hand drawn maps of 2 × 2 m quadrats noting the species and areal extent of all coral colonies.
Colony size (B)	Measuring the max length and width of mapped colonies (cm)
Coral cover	Hand drawn map of the areal extent of all live coral within the 2 × 2 m area of interest

5.4.1.13 Extraction of Metrics (Measurement of Coral Colony Size and live coral cover) from Mosaics for PO 2 (Step E)

After the mosaics were created, the two metrics for PO 2 were extracted by an analyst (Table 13). The first step in the data extraction was to import the mosaics into ArcGIS. The second step was to digitize the outlines of live coral within the 2 × 2 m areas mapped by the divers (Figure 24). The third step was to use the ruler tool within ArcGIS to measure the maximum length and width of each colony (colony size). The fourth step was to divide the total area of the digitized polygons by the area of the quadrat to quantify coral cover.

Table 12 shows coral size and cover metrics for Performance Objective 2 and the ways these were assessed in the field. Table 13 shows coral size and cover metrics for Performance Objective 2 and the ways these were assessed from mosaics.

Table 13. Coral size and cover metrics for Performance Objective 2 and the ways these were assessed from mosaics.

Metric	Method of obtaining metric from mosaics
Colony size	On-screen digitizing (i.e., tracing the outlines of the coral colonies) within the portion of the mosaic covering the 2 × 2 m quadrats. Species will be noted and areal extent of all coral colonies calculated from the digitized polygon.
Coral cover	Computed from the area of the digitized polygons relative to the 2 × 2 m mapped quadrat.

Step-by-step instructions are as follows:

First, georeference the mosaic:

1. Open ArcMap
2. Click File-> Add Data. Select desired mosaic image and click Ok. The image will appear in the map viewing window.

3. Open the ‘Define Projection’ Tool.
4. Select the mosaic you are working with from the ‘Input Dataset’ dropdown menu.
5. Click on the button at the right end of the ‘Coordinate System’ field to bring up the ‘Spatial Reference Properties’ Window
6. Click the ‘Select’ button to bring up the file browser. Select Projected Coordinate Systems->UTM-> NAD 1983 ->NAD 1983 UTM Zone 18N.prj and click ‘Add’ and you will return to the ‘Spatial Reference Properties’ window, which can be closed by clicking ‘Okay’. ‘NAD_1983_UTM_Zone_18N’ should appear in the Coordinate System box.
7. Click ‘Okay’ to run the tool and close the window.
8. Use the Georeferencing toolbar to georeference the mosaic image. In this instance we will have known GPS points for control points in the mosaic
9. Select the mosaic image as the layer to work on in the Georeferencing toolbar.
10. Select the button on the toolbar with green and red x connected by a diagonal line.
11. Click twice on each corner of the map to add control point to the map.
12. Click on the “View Link Table” button  in the Georeferencing toolbar to open a chart containing the control points.
13. The values in the ‘X Map’ and ‘Y Map’ columns will be replaced with the GPS points for each control point.
14. Click on the ‘X map’ and ‘Y Map’ values in each column to highlight and edit them.
15. On the Georeferencing toolbar, click on the Georeferencing pull-down and select Update Georeferencing.

Second, draw polygons around the corals on the georeferenced hand-drawn maps. Third, measure the area of coral colonies. Fourth, measure sizes of colonies. The instructions for steps 2–4 are identical to those given above for the hand-drawn maps.

Field activities were timed to enable cost calculations. In particular, the following tasks were timed for each individual diver in the field:

a) Staging time on shore required to prepare equipment
b) Making the hand-drawn map underwater.
c) Digitizing the hand-drawn map in the lab.
d) Setup and acquisition of mosaic data over the area of interest.
e) Data download and backup on shore at the end of the day

The following tasks were timed for each mosaic back in the lab:

a) Mosaic creation.
b) Extraction of each metric from the mosaic.

5.4.1.14 Performance Objective 3: Ease of Use

Day 1 of the field work was devoted to mosaicing training of Navy personnel. Beyond that there were no special requirements for the field for PO 3. The data necessary for evaluating PO 3 were acquired as part of the work for PO 1 and PO 2. During the field work for PO 1 and PO 2, mosaic datasets were collected by both (1) RSMAS divers with extensive experience acquiring data for creating landscape mosaics and (2) Navy divers newly trained in mosaic surveys. At each field site a minimum of two and maximum of four mosaic datasets were collected by each survey team. The purpose of this objective was to determine if newly trained divers can acquire video mosaic data that has enough overlap and resolution to create a useable video mosaic.

5.4.2 Endangered Species Demonstration

5.4.2.1 Performance Objective 1: Coral Colony Abundance and Location

For each monitoring plot, the overall approach was:

(A) Map the plot using the procedure defined by Williams *et al.* (2006).
(B) Collect imagery for a mosaic of the plot.
(C) Extract the number and locations of each colony within the plot from the mosaic.
(D) Compare the colony abundance and locations as derived by each method.
(E) Compute the costs of each method.

Steps A–C are described in this section. Step D is described in Section 6.2.1 and Step E in Section 7.0.

System set up (video) - The system setup was the same as described in the Long-term Monitoring demonstration (Section 5.4.1).

5.4.2.2 Diver Mapping of the Plot (Step A)

Diver mapping of the plot followed the instructions provided in Williams *et al.* (2006), reprinted here for reference:

Plot mapping will require at least two divers (referred to here as "A" and "B"). Use the field sheet titled "Annual Plot Map" (Figure 26) to record the coordinates (distance from stake and compass bearing) of all *A. palmata* colonies within each plot, including tagged and untagged colonies, very small colonies, and attached fragments. Loose fragments that are not mapped should be tallied as they are encountered in the mapping process.

Use the following rules to distinguish individual colonies:

(a) Any continuous live tissue should be considered a single colony (Figure 33)

(b) If live tissue is not continuous, physically separated units of live tissue that are growing on the same underlying skeletal colony structure should be considered the same colony (Figure 33)

(c) If live tissue is not continuous and is located on underlying remnant/dead structure that is difficult to distinguish (*i.e.* one "stem" or two?), patches of tissue within one meter of each other should be considered a single colony. Patches more than 1 m from surrounding tissue should be considered a separate colony (Figure 33).

(d) If the center of the colony is outside the 7 m radius of the plot, it should not be counted.

Figure 32 shows field data sheet titled “Annual Plot Map.” Figure 33 shows an illustration of the rules used to distinguish colonies. Figure 34 shows an overview of the mosaic viewer software.

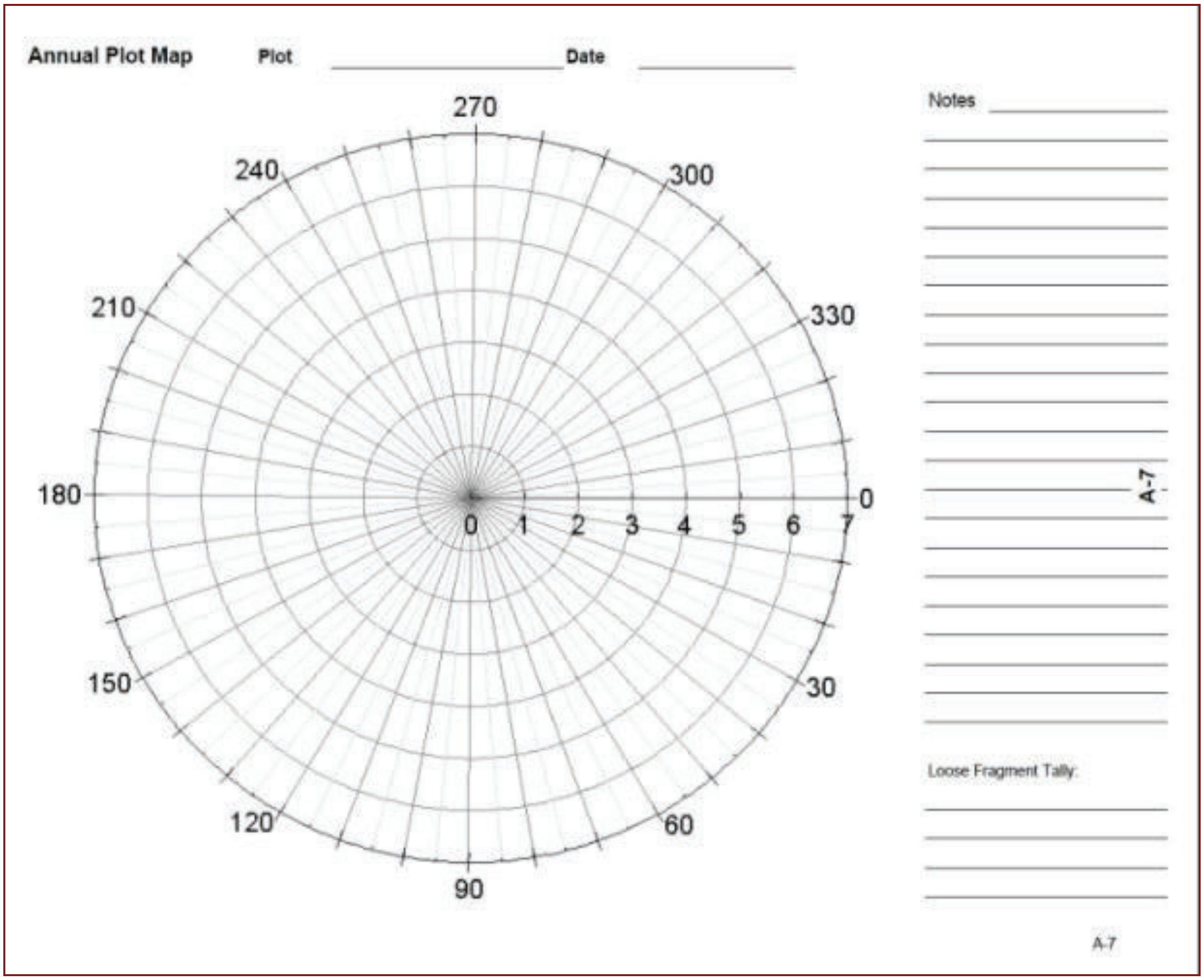
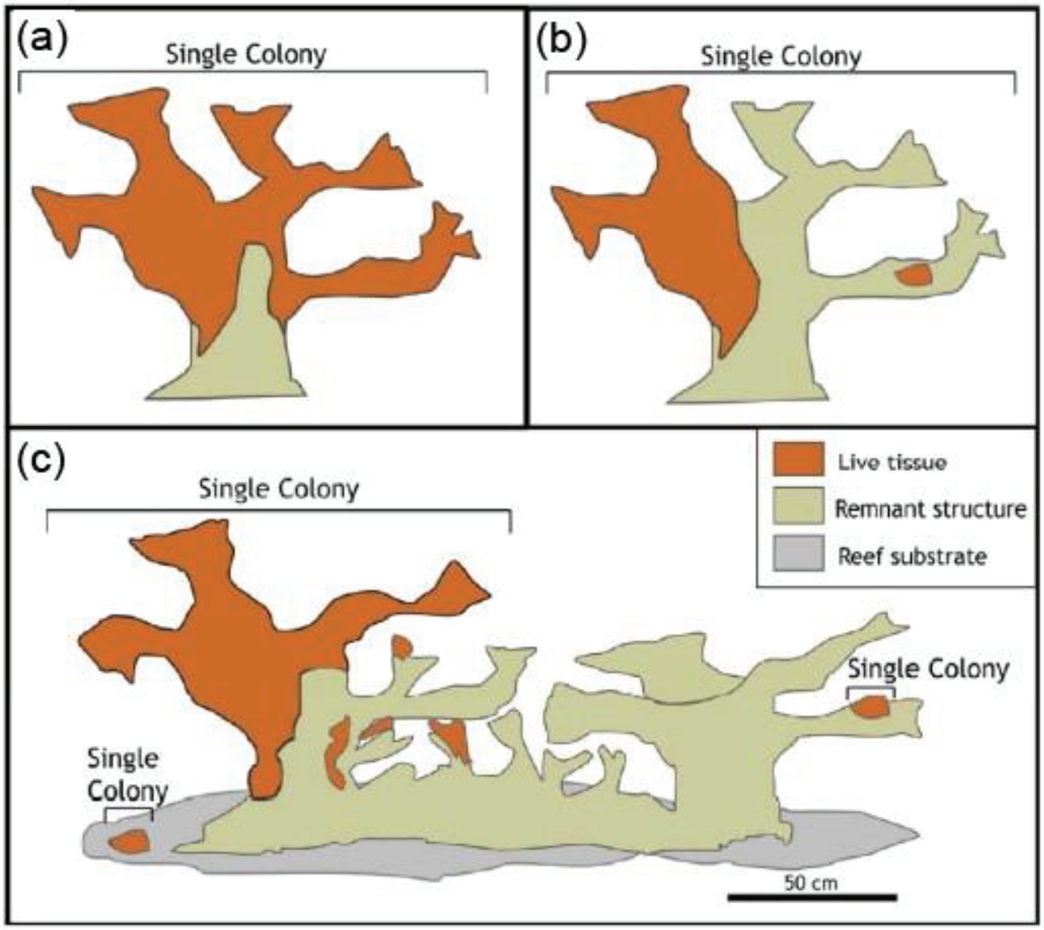


Figure 32. Field data sheet titled “Annual Plot Map.”



- In (a) live tissue is clearly continuous. In (b) live tissue is not physically connected, but the two patches of live tissue are on the same remnant structure, so they should be considered the same colony. In (c), the three regions of live tissue should be considered separate colonies.
- Some ambiguity exists in distinguishing whether the remnant structures of the remaining tissue patches are related, and because the tissue patch on the right is more than 1 meter from the larger tissue patch on the left, these two patches should be considered separate colonies.
- The small patch of live tissue on the lower left is within 1 m of the larger live patch on the left, but it is clearly not on the same remnant structure, so should therefore be considered a separate colony.
- Source: Williams *et al.* 2006

Figure 33. Illustration of the rules used to distinguish colonies.

During the mapping dive(s), Diver B should remain over the central stake and hold the measuring tape in place while diver A extends the measuring tape to the center of each colony. Diver B should read the compass heading from the central stake to the colony and signal it to diver A. Diver A should assign sequential numbers to each untagged colony, and record the distance from the central stake to the center of each colony, the size (length, width, and height), % live tissue, and colony type for each colony on the field sheet "Annual Plot Map:. This process should be repeated for all *Acropora palmata* colonies within a plot, including very small ones and attached fragments. As the diver team comes across a tagged colony, the original coordinates (determined when the plot was initially established) can be verified.

When assigning "colony type" for each colony on the data sheet, diver A should avoid touching the colonies or fragments as the re-attachment process can be easily interrupted. Try to assess the nature of each fragment visually only!

On the data sheet, “type” should be recorded as follows:

- Branched colony: A “normal” looking colony with branches, may have some partial mortality.
- Remnant colony: Live tissue that is mostly encrusting; no or few branches.
- Attached fragment: A live fragment (usually a branch) with some signs of attachment to the reef. If attachment of a fragment cannot be determined visually, map it and note the uncertainty. It is important not to touch fragments since they may be in the early stages of forming and attachment.
- Stable fragment: Occasionally, large (greater than 75 cm) portions of colonies are broken off and found “loose” in the plot. While they may not be attached to the substrate they can be considered “stable” due to their weight, structure, and location.
- Loose fragment: A live fragment (usually a branch) loose in a rubble pile or on the reef with an obvious fresh break. Note that occasionally loose fragments land on living tissue, these should not be considered separate fragments, but rather part of the colony on which they have landed.

5.4.2.3 Mosaic Acquisition and Construction (Step B)

The next step of data acquisition was to conduct a landscape mosaic survey of the monitoring plot. Markers were placed on the seabed surrounding the plot to ensure that the entire area is covered. Colored quadrats and half-meter sticks were placed at the corners and along the edges of the area of interest to provide a visual border of the area of interest for the mosaic surveys and to enable scaling the size of the pixels in the final mosaic to meters. Divers also used a compass to place 10-cm ceramic tiles around the stake marking the center of each plot. The tiles were placed at 90 degree intervals, i.e., to magnetic north, south, east, and west of the stake. This enabled orientation of the final mosaic as described in Step C, below. The mosaic survey was acquired in the same manner as described in the long-term monitoring demonstration (Section 5.4.1).

5.4.2.4 Extracting the Number and Locations of each Colony within the Plot from the Mosaic (Step C)

Counting the number of colonies present in the plot from the mosaic was completed through visual inspection of colonies using the mosaic viewer software. The mosaic viewer software allows panning over the entire mosaic as well as zooming in to the individual still images by clicking on a point in the mosaic (Figure 34).

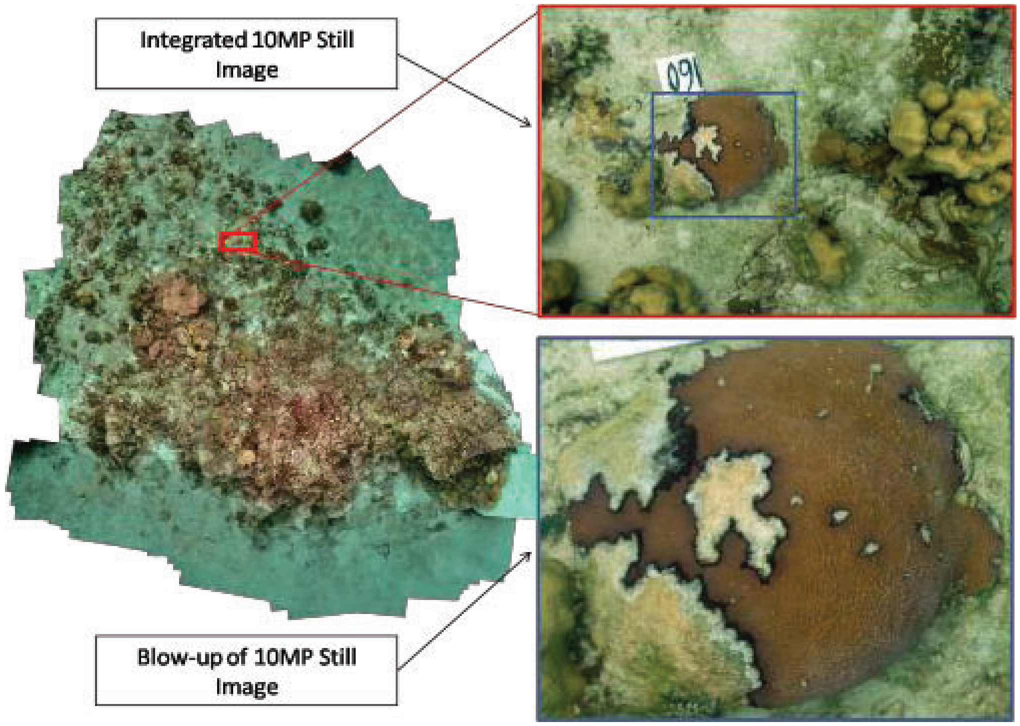


Figure 34. Overview of the mosaic viewer software.

Analysts counted the number of *Acropora palmata* colonies found in the survey plot. Step-by-step instructions for using the Image Viewer Mosaic Program for extracting estimates of coral bleaching and disease are as follows:

1. Open the "imageViewerMosaic-0.5\windows" folder.
2. Double click on imageViewerMosaic.exe to open the program.
3. Once the program is open, you will be prompted to open your .pck file.
4. Locate the folder that contains the files created for the viewer when the mosaic was made.
5. Select file that ends with the ".pck" extension. The mosaic will load into a new window.
6. Click anywhere in the mosaic to pull up the matching still and video images for that point of the mosaic. Two new windows will open up with images in them and boxes will be outlined on the mosaic to show the orientation of the images that have been selected.
7. Zoom in and out on the images using the scroll wheel on your mouse.
8. Close unwanted images by clicking the 'X' in the corner of the image window.
9. To select a different point, click again on the mosaic and new images will appear.
10. Once the external viewer is open, the analyst will then pan over the image and locate all *A. palmata* colonies. The zooming feature of the mosaic viewer can be used if more detail is needed in a particular area.

Measuring the locations of the colonies requires scaling the mosaic using the sizes of known targets placed on the seabed at the time of data acquisition. The scaling was computed using tools built into the software "Coral Point Count" (CPCe; Kohler and Gill 2006). The CPCe tools simply measure the number of pixels crossed by a straight line drawn by the user. This distance measurement in pixel units is converted to a distance measurement in centimeters by measuring the scale bars placed on the seabed during image acquisition. All of the scale bars visible in the image were measured and an average value of cm/pixel used for the conversion factor. Step-by-step instructions for measuring length and width of colonies in CPCe 4.0 are as follows:

1. Open IRFANVIEW image viewer software.
2. Pull down the "FILE | Open" menu and select the mosaic desired for analysis.
3. Pull down the "FILE | Save as" menu and save the mosaic in .jpg format.
4. Open CPCe 4.0
5. On the menu bar at the top of the program window click on Measurement and select Area/Length Analysis from the drop-down menu
6. Open the converted mosaic image.
7. From the menu bar click on 'Scaling calibration' and select Perform Image Scaling/Calibration
8. Locate the scale bars placed within the area of the mosaic.
9. Follow the onscreen prompts to select two points on the scale for which the spanned distance is known.
10. Enter the known distance between the points and select the unit of measure. Cm will be used for this demonstration. The resolution of the image will be calculated and displayed on the upper left corner of the image.
11. Click 'Area/Length Analysis' and a box containing the tools for the analysis will appear in the upper right corner of the window.
12. For length analysis, select the radial button for length.
13. Locate the colony to be measured. Left-click at the center stake of the plot then right-click on the center of the tile placed by diver A for this colony. A line will appear on the mosaic with a distance measurement and a window will open with a chart displaying the lengths of the lines that have been created. If desired, comments can be included on the chart. CPCe records both the distance from the center stake to the colony in question and the angle of the measurement relative to the top of the image.
14. Click 'Save data and Exit'. The chart will disappear
15. Repeat steps 11-14 for each remaining colony in the image.
16. Repeat steps 11-14 for the four tiles indicating magnetic N, S, E, and W. These measurements will give the angle of each tile from the center stake (they will also give the sizes and distances of the tiles from the center pin, but all we are interested in for these markers is their angles from the top of the image). Subtracting the actual measured angle from the angle that would be expected if the mosaic were rendered north-up gives a correction angle to convert the coordinates of the other points from image-up to north-up. In this case we will have four estimates of the correction angle, so we will use the average of these as the actual correction angle.

17. Use the 'File' dropdown menu choices to save your work. You can save the image with or without length markers. Save the .ara file to be able to come back at a later date and continue work on the same image or export the .ara file to a plain text data file to be used in the statistical analysis.
18. Convert all angle measurements to north-up using the average correction angle derived in step 16, above.

5.4.2.5 Performance Objective 2: Coral Colony Size

The overall approach was:

(A) Measure the sizes of each colony in the plot using the procedure defined by Williams *et al.* (2006).
(B) Collect imagery for a mosaic of the plot.
(C) Extract the sizes of each colony within the plot from the mosaic.
(D) Compare the colony sizes as derived by each method.
(E) Compute the costs of each method.

Steps A–B along with instructions for setting up the cameras were described above. Step C is almost identical to the procedure for measuring the location of the colonies described in Step C of PO 1. Locate the colony to be measured. Left-click at one extreme of the width or length and right-click at the opposite extreme. A line will appear on the mosaic with a distance measurement and a window will open with a chart displaying the lengths of the lines that have been created. If desired, comments can be included on the chart. CPCe records both the length (or the width, whichever is being measured) of the colony in question and the angle of the measurement relative to the top of the image." Step D is described in Section 6.2.2 and Step E in Section 7.0. .Performance Objective 3: Coral Colony Descriptors

The overall approach is:

(A) Estimate the % live cover and colony type for each colony in the plot using the procedure defined by Williams *et al.* (2006).
(B) Collect imagery for a mosaic of the plot.
(C) Extract the % live cover and colony type for each colony within the plot from the mosaic.
(D) Compare the % live cover and colony type as derived by each method.
(E) Compute the costs of each method.

Steps A–B along with instructions for setting up the cameras were described above. Step C is almost identical to the procedure for counting the number of colonies as described in in Step C of PO 1, except that rather than counting colonies, the analyst will visually estimate the % live coral cover and colony type using the same rules that the divers use for visual estimation. Step D is described in Section 6.2.3 and Step E in Section7.0.

5.4.3 Grounding Demonstration

5.4.3.1 Performance Objective 1: Comparison of the Area of Damage

The overall approach was:

(A) Collect a mosaic of the grounding scar including a buffer of unaffected area surrounding the damage.

(B) Collect a GPS track of the boundary between the damaged and undamaged area.
(C) Collect linear measurements of the width of the scar using the "fishbone" technique.
(D) Reacquire mosaic and GPS data over the scar including markers left by the fishbone measurements delineating the edges.
(E) Compute and compare the area of the damage as measured by all three techniques.
(F) Compute the costs of each method.

Step A and instructions for setting up the cameras were described in Section 5.4.1. Steps B–D are described here. Step E is described in Section 6.3.1 and step F is described in Section 7.0.

5.4.3.2 GPS data acquisition (Step B)

After the mosaic was acquired, a snorkeler swam around the perimeter of the scar with a GPS to collect a boundary of the affected area. This was repeated three times in order to assess the diver's ability to consistently assess the same boundary.

5.4.3.3 Diver measurements of scar size (Step C)

After collecting the mosaic and GPS data, divers surveyed the area of the scar using the "fishbone" technique of Hudson and Goodwin (2001; see Source: Hudson and Goodwin, 2001; Figure 14). The fishbone technique works by first establishing a baseline transect along the long axis of the damaged area, then measuring perpendicular distances at 1 m intervals from the baseline to the edge of the damaged area (Figure 14).

In addition to the standard fishbone method, we took two additional steps. First, after the diver measured the distance to the edge of the scar, he marked the seabed with a temporary marker (ceramic tile) to show where the measurement was taken. Second, another diver, using the tile as a guide to show where to measure, repeated the measurements.

5.4.3.4 Reacquire mosaic and GPS data over the scar (Step D)

After finishing the fishbone measurements, a second mosaic and GPS data collection effort was performed. This was identical to step A, but for these data, the divers were be guided by the tiles placed during the fishbone measurements.

5.4.3.5 Performance Objective 2: Comparison of Linear Damage Measurements

The overall approach was:

(A) Collect linear measurements of the width of the scar using the "fishbone" technique.
(B) Acquire mosaic data over the scar including markers left by the fishbone measurements delineating the edges.
(C) Compare the lengths from the baseline to the edge of the scar as measured by the diver and by the mosaic.

Steps A–B were described under PO 1. Step C is described in Section 6.3.2.

5.4.3.6 Performance Objective 3: Accuracy of the Measurement of Large Linear Targets

The overall approach was:

(A) Place markers on the seabed separated by known, random distances.
(B) Measure the distances between the markers using mosaics, GPS, and diver transects.
(C) Compare the distances as measured by each method to the known values.

Steps A–B are described here. Step C is described in Section 6.3.3.

Place markers on the seabed (Step A)

PO 3 measured known targets, but the size of the targets (1–10 m long) made it logistically difficult to construct numerous objects of that scale and transport them to the field site. Instead, placed markers at known distances from each other. The distances were randomly selected in the range of 1–10 m. In order to accurately place the markers we used a long, rigid fiberglass pole as a measuring stick. A rigid measuring stick can be used underwater to measure distances without the problem of sagging associated with a tape measure. The pipe was disassembled into smaller pieces for transport to the site and then reassembled underwater. A pair of divers used the measuring stick to place the markers. Different divers who did not know the distances then made the measurements (Step B).

Measure the distances between the markers (Step B)

Once the markers were placed, divers who did not know the distances between the markers measured those distances using (a) mosaics, (b) GPS, and (c) tape measures The mosaic measurements required acquiring image data over the area containing the markers. Sizes were extracted from the mosaics back in the lab using the instructions given in Step D of Section 5.4.1. The GPS measurements required collecting waypoints from the surface over the markers. The tape measurements required two divers to stretch a flexible tape between the markers and record the distance.

5.4.3.7 Performance Objective 4: Extract Ecological Measurements From Mosaics that are comparable with diver-based metrics

The overall approach was:

(A) Select sites within and outside of the scar on the order of 10 x 10 m.

(B) Lay out four 10 m transects within the site, assess each transect using PCQT, and BT diver methods.

(C) Mosaic the area that was assessed by divers

(D) Extract metrics from the mosaic.

(E) Compare the metrics derived from diver data with those derived from the mosaic.

(F) Compute the costs of diver and mosaic methods.

Steps A–D were identical to those used for PO 1 in the traditional metrics demonstration and were described in Section 5.4.4. Step E is described in Section 6.3.4 and Step F in Section 7.0. These steps were repeated for one site within and one outside of the damaged area.

5.4.3.8 Performance Objective 5: Ease of Use

There were no field activities specifically required for PO 5. The data necessary for evaluating PO 5 were acquired as part of the work for PO 4. At the conclusion of the field component of this demo, Navy analysts spent 2 days in the lab at U. Miami receiving training on how to run the extraction software. They then analyzed the mosaics in parallel with the RSMAS team.

5.4.4 Traditional Metrics Demonstration

5.4.4.1 Performance Objective 1: Extract Ecological Measurements from Mosaics that are Comparable with Diver-Based Metrics

The overall approach was:

(A) Select a site with visually homogenous bottom cover over the scale of 10 × 10 m.
(B) Lay out four 10 m transects within the site, assess each transect using PCQT / LPIT, BT, and juvenile survey diver methods.
(C) Mosaic the area that was assessed by divers
(D) Extract metrics from the mosaic.
(E) Compare the metrics derived from diver data with those derived from the mosaic.
(F) Compute the costs of diver and mosaic methods.

Steps A-D are described in this section. Step E is described in 6.4.1 and step F is described in Section 7.0.

5.4.4.2 System set up (video)

The camera setup was the same as described in the Long-term Monitoring Demonstration (Section 5.4.1).

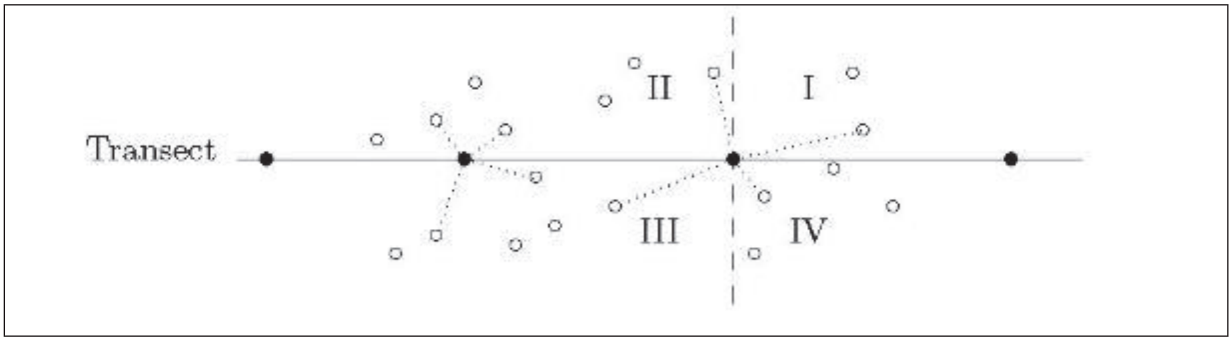
5.4.4.3 Site selection (Step A)

The first field step was to identify a convenient site for the test. As a reminder, in this context, "site" means an approximately 10 × 10 m area with visually homogenous bottom cover. By homogenous we mean that we wanted to avoid edges between habitats, such as a site in which half the area is on a patch reef and half is over sand surrounding the patch. Potential sites were selected in consultation with the NAS and FKNMS personnel using existing habitat maps of the Florida Keys and their experience working in the area. The exact 10 × 10 m plots were chosen in the field on the days of the test.

5.4.4.4 Diver setup and measurements (Step B)

Four divers, two RSMAS and two Navy, laid out four, parallel, 10-m long transects at the site. The transects were separated approximately 3 m apart. Each diver selected one of the transects and performed Point Centered Quarter Transect (PCQT) and Belt Transect (BT) measurements (described below). After finishing these measurements the divers switched and repeated the measurements on another one of the four transects so that there were one Navy and one RSMAS replicate measurement for each transect.

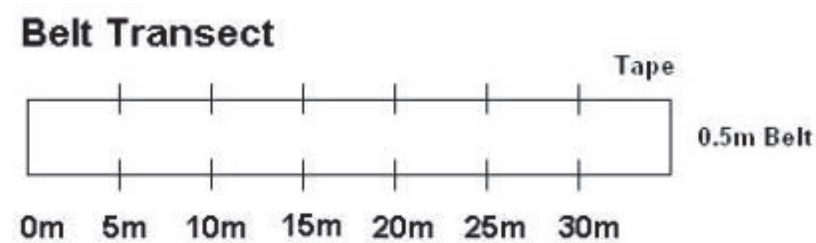
Using the point centered quarter transect (PCQT) method (Figure 35), samples were collected at 1 m intervals along the transect. A small movable cross formed with two 1 m long PVC pipes was placed along the transect with the center point at each interval, two opposite ends being parallel to the transect tape, and two ends perpendicular to the transect. The cross defined four quadrats. The cross was placed every meter along the transect. The diver then used another small transect tape to measure the distance from the center point of the cross to the nearest coral colony or a maximum distance of 50 cm within each quadrat. The distance to the nearest coral colony in each quadrat was recorded. The length and width of the coral colony in each quadrat was measured and the colony visually assessed for bleaching, disease, and mortality. This method provided information on coral colony density, size, condition, and distribution. Finally, benthic cover was assessed every 10 cm along the length of the transect.



- In the figure where I, II, III & IV represent the different quadrats.
  dapted from Mitchell, 2011

Figure 35. Point-centered Quarter Transect (PCQT) Method.

The observation area using the belt transect (BT) method (Figure 36) included a specified distance on either side of the transect line. In the BT, a tape was draped on top of coral for a distance of 10 meters (in this case). The diver then made observations within a specified width, in this case 1 m, on either side of the transect. The number and taxa identification of each coral was recorded within the sampled area. This method provided data on species richness.



- Modified from Herrick *et al.* 2009

Figure 36. The Belt Transect method.

5.4.4.5 Mosaic acquisition and construction (Step C)

After the divers completed the PCQT and BT measurements, a third diver team conducted a landscape mosaic survey of the area containing the four transects. Markers were placed on the seabed at the ends of each transect to ensure that the entire area was covered. Colored quadrats and half meter sticks were placed at the corners and along the edges of the area of interest to provide a visual border of the area of interest for the mosaic surveys and to enable scaling the size of the pixels in the final mosaic to meters.

The mosaic acquisition was completed in the same manner described in the Long-term monitoring demonstration (Section 5.4.1).

5.4.4.6 Extraction of Metrics from the Mosaic for PO 1 (Step D)

After the mosaics were created, the seven metrics for PO 1 were extracted by an analyst. Analysis used “Coral Point Count” (CPCe; Kohler and Gill, 2006), a freeware program, and the mosaic viewer software created in RC-1333. The mosaic viewer software integrates the final mosaic with a “point and click” interface that brings up the corresponding still images when a point is clicked in the mosaic (see Figure 27, and 28).

CPCe was the primary program used to extract benthic cover and to identify coral species richness from the mosaics. The mosaic viewer, however, was used to "zoom in" on the still images acquired during the survey in order to aid identification if necessary. Step by step instructions for point counting the mosaic in CPCe and the mosaic viewer are as follows:

1. Open IRFANVIEW image viewer software.
2. Pull down the "FILE | Open" menu and select the mosaic desired for analysis.
3. Pull down the "FILE | Save as" menu and save the mosaic in .jpg format.
4. Open CPCe 4.0
5. File | open | raw image file. Select the .jpg version of the mosaic.
6. Select "manually size and position the border" on the dialog box that appears. Follow the on-screen instructions to delineate the area in which the random points should be placed.
7. On the next dialog box specify 400 simple random points.
8. Identify the benthic cover underneath each point following the instructions in Kohler *et al.* (2006).
9. If all points can be identified directly from the mosaic no further steps are necessary. In most cases, however, viewing the stills as reference will help with identification. To do so, follow the steps in the mosaic creation manual (Appendix B) entitled "Guidelines for point and click with video frame and still image matching."

To extract coral colony size from the mosaics, the maximum length and maximum width of each marked colony will be measured using the tools built into Coral Point Count. The CPCe tools simply measure the number of pixels crossed by a straight line drawn by the user. This distance measurement in pixel units is converted to a distance measurement in centimeters by measuring the scale bars placed on the seabed during image acquisition. All of the scale bars visible in the image were measured and an average value of cm/pixel used for the conversion factor.

Step-by-step instructions for measuring length and width of colonies in CPCe 4.0 are as follows:

1. Open IRFANVIEW image viewer software.
2. Pull down the "FILE | Open" menu and select the mosaic desired for analysis.
3. Pull down the "FILE | Save as" menu and save the mosaic in .jpg format.
4. Open CPCe 4.0
5. On the menu bar at the top of the program window click on Measurement and select Area/ Length Analysis from the drop-down menu
6. Open the converted mosaic image.
7. From the menu bar click on 'Scaling calibration' and select Perform Image Scaling/ Calibration
8. Locate the scale bars placed within the area of the mosaic.
9. Follow the onscreen prompts to select two points on the scale for which the spanned distance is known.

10. Enter the known distance between the points and select the unit of measure. Cm will be used for this demonstration. The resolution of the image will be calculated and displayed on the upper left corner of the image.
11. Click ‘Area/Length Analysis’ and a box containing the tools for the analysis will appear in the upper right corner of the window.
12. For length analysis, select the radial button for length.
13. Locate the item that will be measured and left-click at one extreme of the width or length and right-click at the opposite extreme. A line will appear on the mosaic with a distance measurement and a window will open with a chart displaying the lengths of the lines that have been created. If desired, comments and species codes can be included on the chart.
14. Click ‘Save data and Exit’. The chart will disappear
15. Repeat Steps 10 and 11 for each remaining object.
16. Use the ‘File’ dropdown menu choices to save your work. You can save the image with or without length markers. Save the .ara file to be able to come back at a later date and continue work on the same image or export the .ara file to a plain text data file to be used in the statistical analysis.

The extraction of the disease, bleaching, and mortality metrics (Table 14) from the mosaic was completed through visual inspection of colonies using the mosaic viewer software Field activities were timed to enable cost calculations. In particular, the following tasks were timed for each individual diver in the filed:

1. Staging time on shore required to prepare equipment.
2. Laying out and measuring the data for the PCQT and BT methods.
3. Setup and acquisition of mosaic data over the area of interest.
4. Data download and backup on shore at the end of the day.
5. Converting diver data sheets to electronic format.

The following tasks were timed for each mosaic back in the lab:

1. Mosaic creation.
2. Extraction of each metric from the mosaic (Table 14).

Once a tagged colony had been located in the external mosaic viewer, the analyst then clicked on the area of interest and the program retrieved the closest still image for condition assessment (Figures 28 and 29). Analysts identified corals to species, determined if colonies were bleached, if disease was present, and estimated the amount of bleaching, old, and new mortality affecting the colony at that time. Analysts used the same visual references for estimating % bleaching, % new mortality, and % old mortality as they did in the field.

Ten step-by-step instructions for using the Image Viewer Mosaic Program for extracting estimates of coral bleaching and disease are as follows:

1. Open the “imageViewerMosaic-0.5\windows” folder.
2. Double click on imageViewerMosaic.exe to open the program.
3. Once the program is open, you will be prompted to open your .pck file.

4. Locate the folder that contains the files created for the viewer when the mosaic was made.
5. Select file that ends with the ".pck" extension. The mosaic will load into a new window.
6. Click anywhere in the mosaic to pull up the matching still and video images for that point of the mosaic. Two new windows will open up with images in them and boxes will be outlined on the mosaic to show the orientation of the images that have been selected.
7. Zoom in and out on the images using the scroll wheel on your mouse.
8. Close unwanted images by clicking the 'X' in the corner of the image window.
9. To select a different point, click again on the mosaic and new images will appear.
10. Once the external viewer is open, the analyst will then pan over the image and locate all coral colonies marked by ceramic tile markers. Each marker will correspond to a colony that has been measured and assessed for indices of reef health by divers in the field. The mosaic analyst will then zoom in on the coral colony and determine the following information: (1) species name, (2) presence/absence of bleaching, (3) presence/absence of coral disease, (4) visual estimate of the % of the colony with new mortality, (5) visual estimate of the % of the colony with old mortality, and (6) a visual estimate of the % of the colony that is bleached.

Extraction of juvenile coral density used CPCe and the mosaic viewer. The steps listed above were followed for extracting benthic cover, but using 10 random points instead of 400. Those 10 points were saved to a .cpc file and imported into the mosaic viewer, as specified above in the steps for extracting benthic cover. Zooming around the area near those ten blocks and using the scale bar in the mosaic viewer, a 1 m^2 area was inspected around each random point. Juvenile corals observed in those areas were counted.

Field activities were timed to enable cost calculations. In particular, the following tasks were timed for each individual diver in the field:

1. Staging time on shore required to prepare equipment.
2. Laying out and measuring the data for the PCQT and BT methods.
3. Setup and acquisition of mosaic data over the area of interest.
4. Data download and backup on shore at the end of the day
5. Converting diver data sheets to electronic format.

The following tasks were timed for each mosaic back in the lab:

1. Mosaic creation.
2. Extraction of each metric from the mosaic.

Table 14. Coral size and condition metrics and the measurements to be made from each mosaic.

Metric	Data Measurement from mosaic	Method of measurement
Benthic cover	Percent cover of live coral, turf algae, macroalgae, crustose coralline algae, milleporans, gorgonians, zoanthids, and sponges measured from mosaics using random point counts.	CPCe and Mosiac Viewer
Coral species richness	Number of coral species as counted from mosaics using random point counts and image inspection.	CPCe and Mosaic Viewer
Coral colony size	Maximum length (# pixels), Maximum width (# pixels); convert pixels to cm using the known size of each pixel.	CPCe
% of corals diseased	Analyst estimate of the % of each colony that is diseased	Mosaic Viewer
% of corals bleached	Analyst estimate of the % of each colony that is bleached	Mosaic Viewer
Recent coral mortality	Analyst estimate of the % of each colony that is new coral mortality	Mosaic Viewer
Old coral mortality	Analyst estimate of the % of each colony that is old coral mortality	Mosaic Viewer
Juvenile coral density	Number of juvenile corals (Less than 4 cm maximum length) as counted from mosaics using inspection of random subquadrats.	CPCe and Mosaic Viewer

5.4.4.7 Performance Objective 2: Extract Ecological Measurements from Mosaics Using Multiple Methods

To extract ecological measurements from Mosaics using multiple methods the overall approach was:

A. Select a site with visually homogenous bottom cover over the scale of 10 x 10 m.

B. Lay out four 10 m transects within the site, assess each transect using PCQT, LPIT, BT and VT diver methods.

C. Mosaic the area that was assessed by divers

D. Extract metrics from the VT data.

E. Extract metrics from the mosaic.

F. Compare the metrics derived from diver data with those derived from the mosaic.

G. Compute the costs of diver and mosaic methods.

Steps A–E are described here. Step F is described in Section 6.4.2, and Step G in Section 7.0..

5.4.4.8 System Set Up

System set up was the same as for PO 1.

5.4.4.9 Plot Selection (Step A)

The same plots selected for PO 1 were used for PO 2.

5.4.4.10 Diver Setup and Measurements (Step B)

The same transects selected for PO 1 were used for PO 2. The only additional diver-based data required was to collect video transect (VT) measurements on the four transects established as part of PO 1. With the VT method, a diver swims along the transect at a set distance above the bottom pointing a video camera down at the seabed. The Hawaii Coral Reef Assessment and Monitoring Program, for example, used 1 m altitude (Jokiel *et al.* 2005) whereas the Florida Keys Coral Reef Monitoring Project used 40 cm altitude (Porter *et al.* 2002). Even though the height varied between these programs, the swath width, i.e., the across-transect dimension, of the recorded frames was more consistent: ~0.5 m in Florida (Somerfield *et al.* 2008) and ~0.6 to 0.7 m in Hawaii (Jokiel *et al.* 2005). As the height above the seabed to cover a given area depends on the lens used, the zoom setting, and the housing port, the height that we swam for PO 2 was determined in the field with the objective of capturing an approximately 0.5 m wide swath along the length of each transect.

5.4.4.11 Mosaic Acquisition and Construction (Step C)

The same mosaic acquired for PO 1 was used for PO 2. No additional mosaic data collection was necessary.

5.4.4.12 Extraction of Metrics from Diver Video Transects for PO 2 (Step D)

The extraction of percent cover and species richness from the video transects required two steps. The first step was to extract non-overlapping frames from the continuous video stream. Numerous commercial software packages are available to do this. The CREMP program in Florida used a SONY® frame grabber board and software (model DVBK-2000) for analog video and the Observera® Ravenview® software for digital video (Somerfield *et al.* 2008). The CRAMP program in Hawaii used DVRaptor-RT Video® software by the Canopus® Corporation to extract their non-overlapping frames (Jokiel *et al.* 2005). We used our video mosaicing software for this purpose (Appendix B). The video mosaicing software computes the percent overlap between adjacent frames as part of its processing, so to extract non-overlapping frames the analyst needs only to specify a minimum superposition of 0% in the sequential selection step of the mosaicing process.

The second step was to point-count the non-overlapping frames for each transect. The CPCe software was used for this (CPCe was described in Section 5.4.1). 100 points were counted for each transect in order to have the same number of points as the PCQT transects and mosaic estimates.

5.4.4.13 Extraction of Metrics from Mosaics for PO 2 (Step E):

Data extraction from the mosaics for PO 2 replicated techniques used by the divers as closely as possible. For the PCQT method we first found the endpoints of each transect using the markers placed by the divers. The line between those points was divided into 100 sections. We marked each of the intersections on the mosaic and then for each intersection identify the benthic cover at that point.

For both the BT and VT methods we found the endpoints of each transect using the markers placed by the divers. For the BT transect, a rectangle 2 m wide, centered on that line, and 10 m long was defined within CPCe as the area sampled by the virtual BT. For the VT method, we also knew, from calibration of the video camera used for the VT, what the swath width of the diver VT was. A rectangle with the equivalent swath width, centered on the line between the endpoints, and 10 m long was defined as the area sampled by the virtual VT. Points were generated using CPCe and exported to the mosaic viewer as normal, just over the restricted subset of the mosaic. For the BT transect, the points simply serve as reference markers to delineate the search area in the mosaic viewer. For the VT transect, point counting in CPCe was used with the same number of points used on the actual VT will be used on the virtual VT.

5.4.4.14 Performance Objective 3: Ease of Use

There were no field activities specifically required for PO 3. The data necessary for evaluating PO 3 were acquired as part of the work for PO 1 and PO 2. At the conclusion of the field component of this demo Navy analysts spent two days in the lab at U. Miami receiving training on how to run the software. They then created mosaics for each of the field sites for comparison with the versions of the mosaics created by the RSMAS team from the same raw data.

5.4.5 Absolute Accuracy Demonstration

5.4.5.1 Performance Objectives 1–3: Absolute Accuracy and Precision

The overall approach to the test was:

A. Lay out objects on the bottom of the pool.

B. Three divers each measure the maximum length and width of the objects.

C. Three divers each made a mosaic of the area containing the objects.

D. Extract sizes from the mosaic.

E. Compare the metrics derived from diver data with those derived from the mosaic by analysts, and compare the diver and analyst data with the known data

Steps A–D are described in this section. All four steps A–D were performed twice, once for the objects arranged horizontally and once for the inclined objects. Data from steps A–D were used for all three performance objectives (PO 1–3), the difference among them being the analysis (see Sections 6.5.1, 6.5.2, and 6.5.3).

5.4.5.2 System Set Up (Video)

The camera setup needed for this demonstration is the same as described in the Long-term Monitoring demonstration (Section 5.4.1).

5.4.5.3 Lay Out Objects on the Bottom of the Pool (Step A)

The first field step was to place the artificial targets on the bottom of the pool. Objects were separated by 0.5 to 1.5 m. Colored quadrats and half meter sticks were placed at the corners and along the edges of the area of interest to provide a visual border of the area of interest for the mosaic surveys and to enable scaling the size of the pixels in the final mosaic to meters.

When performing this step with the inclined objects, a wedge was placed underneath the flat objects. The long dimension of the objects was oriented along the gradient of the wedge so that its projected area could be calculated accurately (Figure 37).

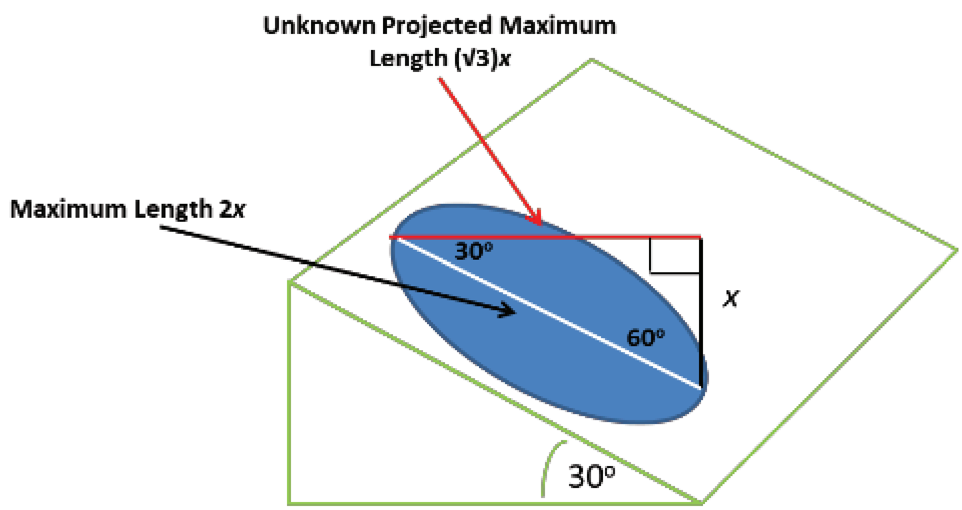


Figure 37. Illustration of the orientation of the objects on an inclined plane for the second set of measurements.

5.4.5.4 Divers Measure the Maximum Length and Width of the Objects (Step B)

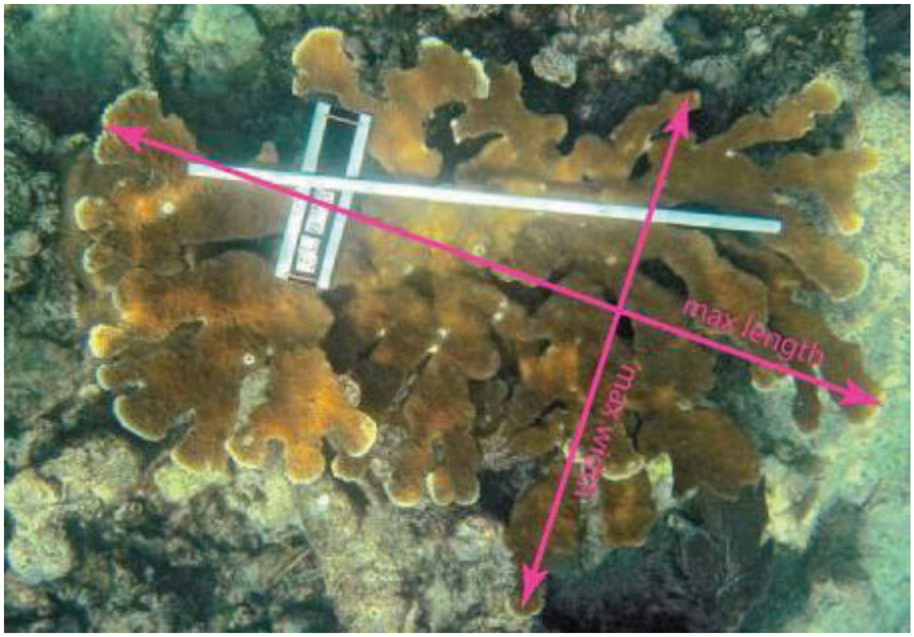
Three divers each measured the horizontally projected maximum length and maximum width of each of the objects in the pool. For the flat and mounded objects these are intuitive measurements to make (Figure 2). For the branching objects the approach was the same, although the complexity of some branching objects means that deciding on exactly which axes to measure can be open to interpretation by the diver (Figure 38).

5.4.5.5 Mosaic Acquisition and Construction (Step C)

After the divers completed the size measurements, three divers each collected data for a mosaic over the area of the pool containing the objects. The mosaic acquisition protocol was the same as that described in the Long-term Monitoring demonstration (Section 5.4.1).

5.4.5.6 Extraction of Sizes from the Mosaics (Step D)

The size extraction protocol was the same as described in the Long-term Monitoring demonstration (Section 5.4.1).



- Compare with Figure 2 illustrating a flat colony. Ideally, the technique is the same for flat and branching colonies, but determining how to measure the branching objects can be less obvious than for flat or mounded objects.

Figure 38. Measurement of maximum length and maximum width on a branching coral colony.

5.4.5.7 Performance Objective 4: Comparison of mosaic bias in the pool vs. in the field

The overall approach to the test was:

A. Extract sizes of standard targets from mosaics in the pool.

B. Extract sizes of standard targets from mosaics made in the field

C. Compare the bias of sizes of the standard targets in the pool and field.

Steps A and B are described in this section. Step C is described in Section 6.5.4.

5.4.5.8 Extract sizes of standard targets from mosaics in the pool (Step A)

In addition to the variable-sized objects used for PO 1–3, at least 25 white ceramic 10 x 10 cm square tiles were placed on the bottom of the pool when the mosaics are made for PO 1–3. The sizes of these were extracted using the same procedure as described in the Long-term Monitoring demonstration (Section 5.4.1).

5.4.5.9 Extract sizes of standard targets from mosaics made in the field (Step B)

The same white ceramic 10 x 10 cm square tiles used for step A were used in the other demonstrations to mark coral colonies in the field. The same number of tiles used for step A were be randomly selected from the mosaics used in the other demonstrations. The sizes of these tiles were extracted using the same procedure as described in the Long-term Monitoring demonstration (Section 5.4.1).

5.5 SAMPLING PROTOCOL

5.5.1 Long-Term Monitoring

5.5.1.1 Performance Objective 1: Provide Colony-Based Metrics of Coral Reef Condition.

The sampling plan for PO 1 required divers to locate and measure at least 15 colonies in each of the following size categories: greater than 10 cm, 10–25 cm, 25–50 cm, and greater than 50 cm. This ensured the minimum sample size of 25 small (less than 25 cm) and 25 medium (greater than 25 cm) colonies were sampled. These numbers were minimum values, more samples were taken in the size classes for which there were more corals (the smaller sizes). Colonies were chosen to represent both mounding and branching morphologies. One diver on each team measured and assess the condition of all of the marked colonies.

The divers placed a numbered tile next to each measured colony. The entire area containing all the marked colonies was then mosaiced by a RSMAS diver and then by a Navy diver. For PO 1, only mosaics from the RSMAS data were used; data from both RSMAS and Navy mosaics were used for PO 3. At least two and as many as four mosaics from each team were acquired.

After creating the mosaics, the measured colonies were identified by the numbered tiles, and their sizes and condition were also be evaluated from the mosaics. The number of analysts used matched the number of mosaics acquired. In this way, the variance associated with different divers and analysts were quantified.

The end result was up to 200 samples, in four size categories, measured by two different divers and 2-4 RSMAS analysts using the mosaics. These were submitted to paired t-tests and two-sample ANOVA analysis as described below (Section 6.1).

5.5.1.2 Performance Objective 2: Maintain Continuity with Long-Term, Map-Based, Coral Reef Monitoring Data Sets.

The sampling plan for PO 2 required divers to replicate hand-drawn maps of the relative location, size, and spatial arrangement of all benthic organisms within the area of interest. The original AUTEC maps created in the late 1960s and early 1970s covered 10×10 m plots at 36 locations. It was impractical and unnecessary to replicate this entire effort because the demonstration needs only to a) evaluate whether metrics such as coral colony size as measured from the mosaics are comparable to measurements from hand-drawn maps, and b) estimate the cost of each method. This was accomplished with a small subsample of the original mapped area.

The size of the subsample we used was two replicate 2×2 m quadrats placed within one of the original 10×10 m sites mapped in the 1970s. The 2×2 m size was chosen because we wanted to map the largest area possible in the time available. We estimated a hand-drawn map of 2×2 m area could be accomplished in one day of diving. As the divers recorded the data for these maps, they also measured the sizes of the corals within the quadrats.

After the hand-drawn maps were completed, landscape mosaics were created covering both 2×2 m quadrats. Data for the mosaics were collected by both RSMAS divers and Navy divers. Only the data from the RSMAS divers was used to evaluate PO 2; the Navy datasets were used for PO 3.

Divers recorded all macrobenthic organisms such as scleractinian corals, sponges and gorgonians within the 2×2 m quadrats. Corals were identified to species and sponges and gorgonians were identified to type (i.e., barrel, rope, and ball sponges and encrusting vs. erect gorgonians). Likewise, the entire area of the 2×2 m quadrats were imaged and analyzed in the lab. Statistics on coral colony size and minimum size of detection were computed from these three datasets (hand-drawn maps, diver measurements of size, and mosaics; see Section 6.1).

5.5.1.3 Performance Objective 3: Ease of Use

No additional sampling was necessary for PO 3. All of the required data had been collected during the field work for POs 1 and 2. PO 3 consisted of processing the mosaic data collected by the Navy divers and comparing the resulting mosaics with those created by the RSMAS divers. Data were collected on time an effort in conjunction with PO 1 and PO 2.

5.5.1.4 Calibration of Equipment

Calibration was required for the camera system. The purpose of this calibration was to correct the geometric image distortions created by both the lenses and the water/glass/air interfaces of the camera housings. The calibration procedure required acquiring a set of images of a checkered calibration grid (as shown in Figure 39) where the sizes of the squares were known a priori.

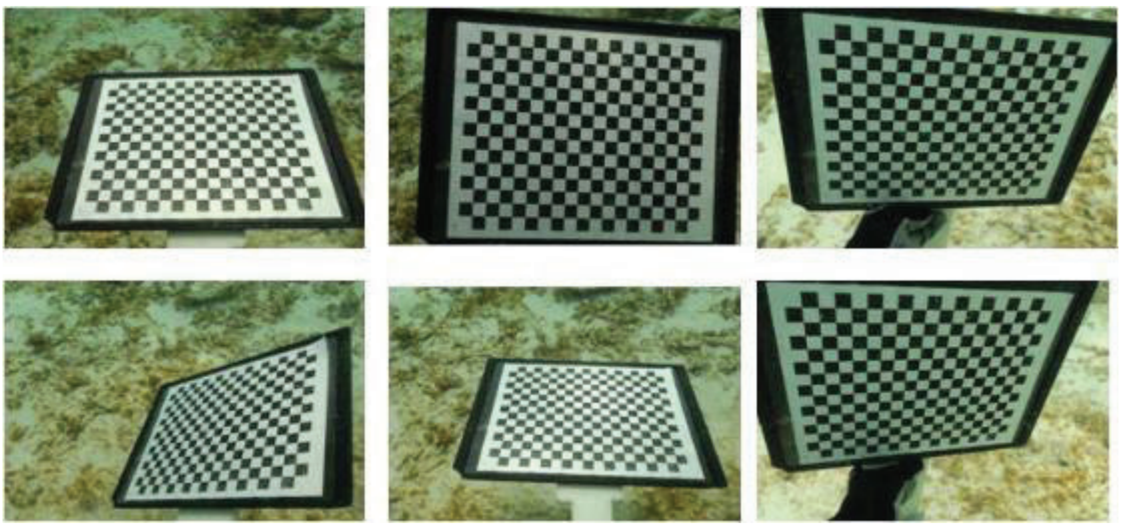


Figure 39. Example of camera calibration images.

Since the geometric camera settings (such as the focal length) tend to change over time, it was important to acquire a set of images of the flat calibration grid either immediately before or after the survey. The images have to be acquired underwater, and must contain the complete grid viewed under different orientations and distances to the camera. A minimum of 10 images were required. To reduce the motion blur, the grid was moved in front of the camera system and held still at different positions and orientations.

Preparation:

- Print grid pattern on waterproof paper. Grid is in http://www.vision.caltech.edu/bouguetj/calib_doc/htmls/pattern.pdf
- Affix to rigid surface. Artists' spray adhesive on the back of a clipboard works well.
- Measure the dimensions of the grid squares as printed (both dimensions in case it was stretched in printing) and *write the dimensions of the squares on the paper so it will be filmed in the video*.

Field procedure:

- Slowly move the grid around in the field of view, at different distances and orientations while recording underwater. Try to fill the frame with the grid, but also make sure that the entire grid is in the frame. The following frames show examples of the type of data that you are trying to collect. Note that without the actual dimensions of the squares the data are useless, the recommended practice is to mark this on the grid so that the sizes are recorded along with the images.

Processing of the calibration images was performed using a standard software package, available at http://www.vision.caltech.edu/bouguetj/calib_doc/index.html. Instructions are found on the above link.

5.5.1.5 Quality Assurance Sampling

All field metrics and mosaics were collected by both Navy divers and RSMAS personnel familiar with mosaicing technology and their applications for coral reef monitoring. All data were collected independently and recorded on separate datasheets.

5.5.1.6 Sample Documentation

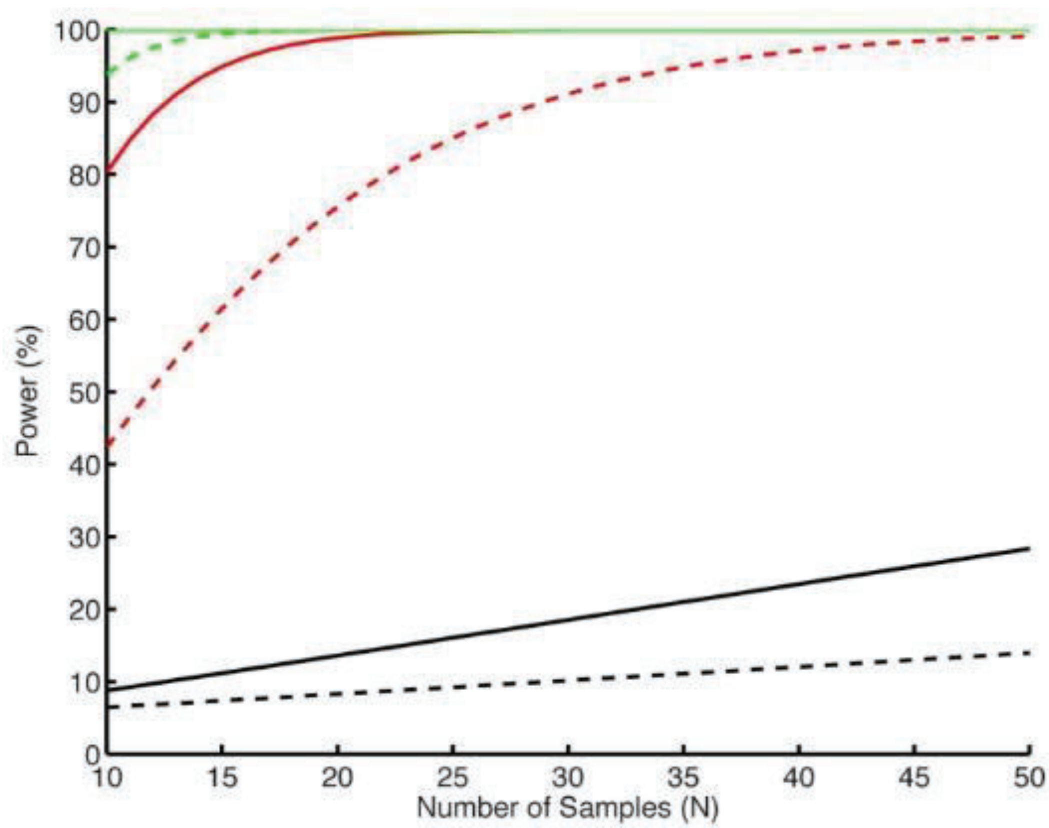
All images collected for the mosaic assessment were downloaded after each day of diving and at least one copy was made as a backup. All imagery was transported to RSMAS for processing prior to analysis.

5.5.2 Endangered Species Demonstration

Sampling occured at three 7-m radius plots in the vicinity of Molasses Reef, FL (Figure 10). Data from the three plots were pooled for evaluating the performance objectives. The exact number of colonies within each plot was unknown a priori, but 10–12 colonies in each plot were originally tagged for monitoring. Therefore, we estimated that the sample size would be at least 30 colonies total. The effect for each PO of using a minimum sample size of N = 30 colonies is discussed below.

5.5.2.1 Performance Objective 1: Coral Colony Abundance and Location

We estimated the statistical power, where power = 100*(1- β) and β is the probability of a type-II error, for the colony location comparison in PO 1 using pilot data available from the RC-1333 Final Report (Reid *et al.* 2010). In RC-1333 there were two tests of the mosaics' geometric accuracy over distances from ~1 m up to several m (Section A2.3.1 of Reid *et al.* 2010). In both tests, the mean mosaic - diver distance measurement was not significantly different from zero. The standard deviation of the mosaic - diver measurements was 5.1 cm in one test and 7.7 cm in the other test. Here, power has been computed using a probability threshold of $\alpha \leq 5\%$ to reject the null hypothesis mean of 0 cm, standard deviation of 5 cm (solid lines) or 8 cm (dashed lines), and effect sizes of 1, 5, and 10 cm (Figure 40) The results indicate that for the minimum N = 30 samples, the power will be > 95% to detect an actual difference between diver and mosaic measurements of at least 5 cm as a statistically significant difference if the diver-diver standard deviation is 5 cm or at least 10 cm if the diver-diver standard deviation is 8 cm.



- 5 cm (red lines)
- 10 cm (green lines)
- Lines come from a distribution with mean = 0 cm and standard deviation
- 5 cm (solid lines)
- 8 cm (dashed lines).

Figure 40. Statistical power (100*(1– β) to detect a mean difference of 1 cm (black lines).

It is worth noting that the ability of the divers to make length measurements was the only source of diver-diver variability for the pilot dataset available from the RC-1333 Final Report. For this dataset, divers measured both distance and bearing to compute the location of each colony, thus there were two sources of diver-diver variability (ability to make distance measurements and ability to make angular measurements).

5.5.2.2 Performance Objective 2: Coral Colony Size

The statistical effects of collecting a minimum of N = 30 samples for diver-mosaic size comparisons can be assessed using both (1) the pilot data used to estimate the desired number of targets or colonies to measure for the long-term monitoring demonstration in June 2011, and (2) an a posteriori analysis of the size data collected during the long-term monitoring demonstration.

Based on the pilot dataset, a minimum of 25 colonies was estimated to give a power ≥ 0.8 (and even higher most of the time) to detect significant (at the p = 0.05 level) differences between mosaic and diver measurements of coral size of at least 10-15% (Figure 24 and 25). Further details of this calculation were provided in Sections 5.4.1 and 5.5.1.

Based on the long-term monitoring data, the predictions of the sample size estimate were assessed. For example, there were actually N = 66 small (≤ 25 cm) corals measured during the long-term monitoring demonstration with mean ± standard deviation mosaic-diver differences of -0.25 ± 3.2 cm. The mean size of the colonies was = 18 cm, so a 15% effect size was 2.8 cm, and the power that a change of that magnitude would have been detected is > 0.99. If we had only measured N = 25 colonies, the power to detect a 15% effect size would have been 0.98 and the effect size detectable with a power of 0.8 would have been 1.9 cm or about 10%. These numbers were close to the predictions for small colonies (Figure 19). For the medium colonies at AUTEC, the mean size was = 37 cm, so a 15% effect size was 5.6 cm, and the power that a change of that magnitude would have been detected is > 0.99. If we had only measured N = 25 colonies, the power to detect a 15% effect size would still have been 0.99, and the effect size detectable with a power of 0.8 would have been 3.2 cm or about 9%. These numbers were also close to the predictions for medium colonies (Figure 19).

From the above calculations, the sample size estimates for the ESA demonstration of N ≥ 30 individuals is predicted to detect a biologically relevant effect size with a high power. From a biological standpoint a 10-15% effect size corresponds to 2-5 years coral growth, which is a reasonable sampling time frame for coral monitoring surveys. In addition, a common rule-of-thumb in environmental monitoring is that 10%, 30%, and 50% are considered “small”, “medium”, and “large” effect sizes, respectively (Cohen 1992; Fairweather 1991). Thus, our effect size of 10-15% is “small” relative to the suite of potential environmental impacts to corals. To accomplish the project goal of evaluating the use of mosaicing technology to monitor coral reefs, the sample size and effect size calculations determined using the long-term monitoring data should adequately meet the needs of the ESA demonstration as well.

5.5.2.3 Performance Objective 3: Coral Colony Descriptors

The sample size for PO 3 can be selected, but we had no prior data comparing visually estimated percent live tissue from mosaics vs. visually estimated percent live tissue by divers to compute statistical power.

5.5.2.4 Calibration of Equipment

Same as Section 5.5.1.

5.5.2.5 Quality Assurance Sampling

All field metrics and mosaics were collected by RSMAS personnel familiar with mosaicing technology and their applications for coral reef monitoring. All data were collected independently and recorded on separate datasheets.

5.5.2.6 Sample Documentation

Same as Section 5.5.1.

5.5.3 Grounding Demonstration

5.5.3.1 Performance Objective 1: Comparison of the Area of Damage

Sample size for PO 1 was limited to N = 1 scar for practical reasons.

5.5.3.2 Performance Objective 2: Extract Ecological Measurements from Mosaics that are Comparable with Diver-Based Metrics

Sample size for PO2 was determined by the length of the baseline transect, which in turn was defined by the length of the scar. The sample units for PO 2 were the perpendicular measurements made from the transect to the edge of the scar. These measurements were made at 1-m intervals on both sides of the transect, so if the centerline was X m long, the sample size will be 2X. For the Evening Star, X is at least 25 m, so the sample size was $N \geq 50$.

We estimated the statistical power, where power = 100*(1- ß) and ß is the probability of a type-II error, for the absolute error test in PO 2 using pilot data available from the RC-1333 Final Report (Reid *et al.* 2010). In RC-1333 there were two tests of the mosaics' geometric accuracy over distances from ~1 m up to several m (Section A2.3.1 of Reid *et al.* 2010). In both tests, the mean mosaic - diver distance measurement was not significantly different from zero. The standard deviation of the mosaic - diver measurements was 5.1 cm in one test and 7.7 cm in the other test. Power was computed using a probability threshold of $\alpha \leq 5\%$ to reject the hypothesis of no difference in percent cover, a null hypothesis mean of 0 cm, standard deviation of 5 cm (solid lines) or 8 cm (dashed lines), and effect sizes of 1, 5, and 10 cm (Figure 40). The results indicated that for the proposed N = 50 samples, the power will be > 95% to detect an actual difference between diver and mosaic measurements of at least 5 cm as a statistically significant difference. Over the length sampled (average of approximately 2 m), a 5 cm difference is only about 2.5%.

5.5.3.3 Performance Objective 3: Accuracy of the Measurement of Large Linear Targets

The sample size for PO 3 can be selected, but we had no prior data comparing mosaic distance measurements to measurements of known targets on the m-scale to estimate statistical power. If we assume that our mosaic - diver estimates have comparable variance to mosaic - target measurements, then we can use the statistical power calculations from PO 2 (Figure 40).

Under the assumption that mosaic - diver estimates have comparable variance to mosaic - target measurements, we reach the same conclusion for PO 3 as for PO 2, namely that N = 50 samples will result in statistical power ≥ 95% to detect an actual difference between mosaic measurements and known target size of at least 5 cm as a statistically significant difference.

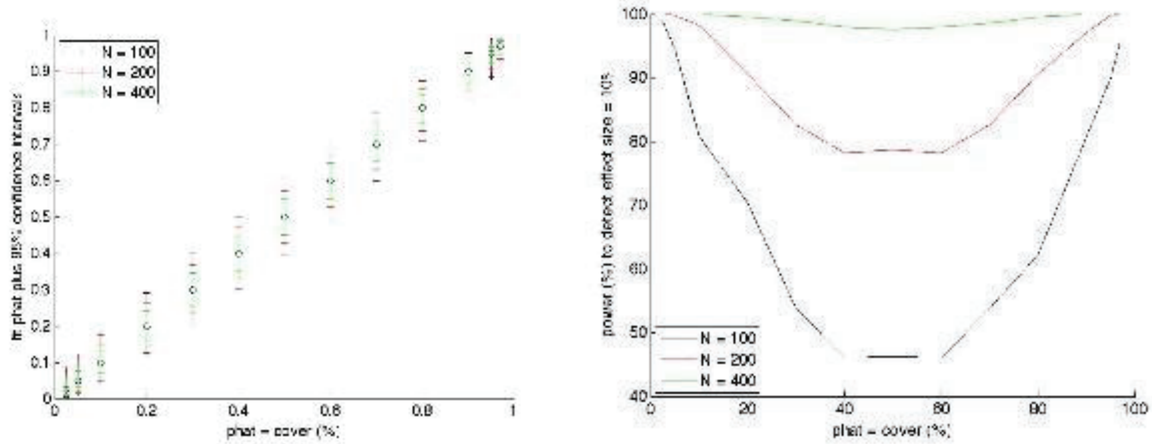
There are at least two reasons why N = 50 samples is probably a conservative estimate of the necessary sample size for PO 3. First, some unknown fraction of the mosaic - diver variance comes from errors in the diver estimate of distance. In PO 3, we expect that known targets will reduce that component of the variance, so the actual mosaic - target variance should be on the small side of our previously estimated mosaic - diver variance. In other words, the solid lines in Figure 40 are probably more applicable to the mosaic - target case than the dashed lines. Second, it may be true that mosaic - target variance does not grow with the target size as much as mosaic - diver variance. If that is true, then we can use longer baselines for PO 3 to achieve a higher precision for the same absolute error. In other words, a 5 cm difference for a 2 m measurement (as in PO 2) is a 2.5% error. If we use a longer baseline, say the 5.5 m baseline planned for PO 3, then a 5 cm difference is only 1% of the mean length. Given these plausible scenarios, we proposed to measure at least N = 30 samples for PO 3, with as many as N = 50 samples if time allowed.

5.5.3.4 Performance Objective 4: Extract Ecological Measurements from Mosaics that are Comparable with Diver-Based Metrics

Two sites were sampled for PO4, one within and one outside of the damaged area. Each site included four, parallel 10-m long diver transects. We pooled data across the four transects because PO 4 is a site-level comparison. Sample sizes were different for each metric tested, as described below.

The required sample size for benthic cover was the easiest of the PO 4 metrics to control because we could decide in advance how many samples to take within our plots. We would like to reject the hypothesis of no difference in percent cover for each cover category with a probability threshold of $\alpha = 5\%$ and power of $1-\beta \geq 80\%$. The minimum effect size considered is a change in percent cover of 10%. Brown *et al.* (2004) used the same values of these parameters when determining precision and statistical power among survey methods for detecting benthic change over time in Hawaii. Given these parameters, we computed the confidence limits and power for various sample sizes (N = 100, 200, and 400 samples) using the binomial distribution (Figure 41). Calculations were performed in Matlab® using the binocdf, binofit, and sampsizepwr functions (Matlab® R2010a, The Mathworks, Natick, MA).

The results showed that a samples size of N = 100 gives the desired power for low (≤ 10%) and high (≥90%) cover, a sample size of N = 200 will give the desired power across all possible values of % cover, and a sample size of N = 400 gives power > 95% at all values of % cover (Figure 41). We propose to use a sample size of N = 100 points along each of the four transects (i.e., N = 400 points total for the site). This may be overkill for PO 4, but it has the benefit that the data will be comparable with data collected for the traditional metrics demonstration.



- Measurements for levels of percent cover ranging from 5 - 95%, sample sizes of N = 100 (black), 200 (red), and 400 (green), and a detection level of 10% change in percent cover.

Figure 41. Confidence limits (left) and statistical power (β, right).

The sample size for metric 2, coral species richness, will be the N used for benthic cover (N = 400 per site) times the percent cover for coral at the site. Percent cover for live coral in the Florida Keys is on the order of 0 – 25%, with most sites having < 10 % (Somerfield *et al.* 2008). The sample size for metrics 3 – 6 will be variable, depending on the number of corals present in the site. The sample size for metric 7, juvenile coral density will be N = 40 per site. There are four diver transects, each with 10 quadrats. Therefore the comparison is 40 diver quadrats vs. 40 randomly selected quadrats from the mosaic. Replicate transects (the second 400 points for benthic cover and the second 40 quadrats for juvenile density) are to be used to verify consistency between the RSMAS and Navy divers.

5.5.3.5 Performance Objective 5: Ease of Use

No additional sampling was necessary for PO 5. All of the required data were collected during the field work for POs 4. PO 5 consists of having Navy personnel analyze the mosaic data collected for POs 4 and compare the resulting data with that extracted by RSMAS personnel.

5.5.3.6 Calibration of Equipment, Quality Assurance Sampling, and Sample Documentation

Same as Section 5.5.1.

5.5.4 Traditional Metrics Demonstration

5.5.4.1 Performance Objective 1: Extract Ecological Measurements from Mosaics that are Comparable with Diver-Based Metrics

Multiple sites in different habitats were sampled for PO 1. Each site was approximately 10 x 10 m and included four, parallel 10-m long diver transects. We pooled data across the four transects because PO 1 is a site-level comparison, as opposed to PO 2 which is a transect-level comparison. Sample sizes were different for each metric tested, and were identical to those described for PO 4 in the grounding demonstration (Section 5.5.3).

5.5.4.2 Performance Objective 2: Extract Ecological Measurements from Mosaics Using Multiple Methods

PO 2 used the same sites and transects as PO 1. The differences between PO 1 and 2 are:

- **Sampling area:** In PO 1 the mosaics sample an area including the transects themselves, plus the area between the transects, plus a small buffer around the transects; thus, in PO 1 the mosaics sample a larger area than the divers. In PO 2, metrics will be extracted from the mosaics over the same area sampled by the divers.
- **Metric extraction from the mosaics:** in PO 1 the mosaics will be sampled with a set of random points distributed across the image. In PO 2 these points will be systematically placed along the diver transect lines, thus mimicking the diver method as closely as possible.
- **Additional diver transect method:** In PO 1 the divers will use only the PCQT/BT method. In PO 2, we will use this same transect-level PCQT / BT data but in addition the divers will collect VT data for each of the four transects at the site.

Sample size for benthic cover in PO 2 followed the same analysis as for PO 1. We used 100 points per transect, which will be sufficient for low percent cover classes (i.e., coral, which is expected to be about 10% coverage) to achieve $1\text{-}\beta \geq 80\%$ for an effect size of 10% given $\alpha = 5\%$ (Figure 41 If coral cover is much greater than 10%, or for other benthic classes with higher percent coverage, we may pool the data for pairs of transects at each site to achieve a sample size of N = 200 points, thereby ensuring $1\text{-}\beta \geq 80\%$ (Figure 41)

5.5.4.3 Performance Objective 3: Ease of Use

No additional sampling was necessary for PO 3. All of the required data were collected during the field work for POs 1 and 2. PO 3 consists of having Navy personnel process the mosaic data collected for PO 1 and 2 and comparing the resulting mosaics with those created by the RSMAS personnel. There will be data collected on time and effort involved in collecting the data but it was collected in conjunction with PO 1 and PO 2.

5.5.4.4 Calibration of Equipment, Quality Assurance Sampling, and Sample Documentation

Same as Section 5.5.1.

5.5.5 Absolute Accuracy Demonstration

5.5.5.1 Performance Objective 1: Absolute Accuracy of Mosaic and Diver Size Measurements

For PO 1 (A) and (B) a number of known targets of each of three types (flat, mounding, and branching) were deployed in a pool of constant depth for accuracy assessments. To evaluate statistical differences between diver or mosaic measurements and the known sizes of the objects, the necessary sample size was estimated knowing; (a) variability within each size and morphological class and (b) a desired effect size.

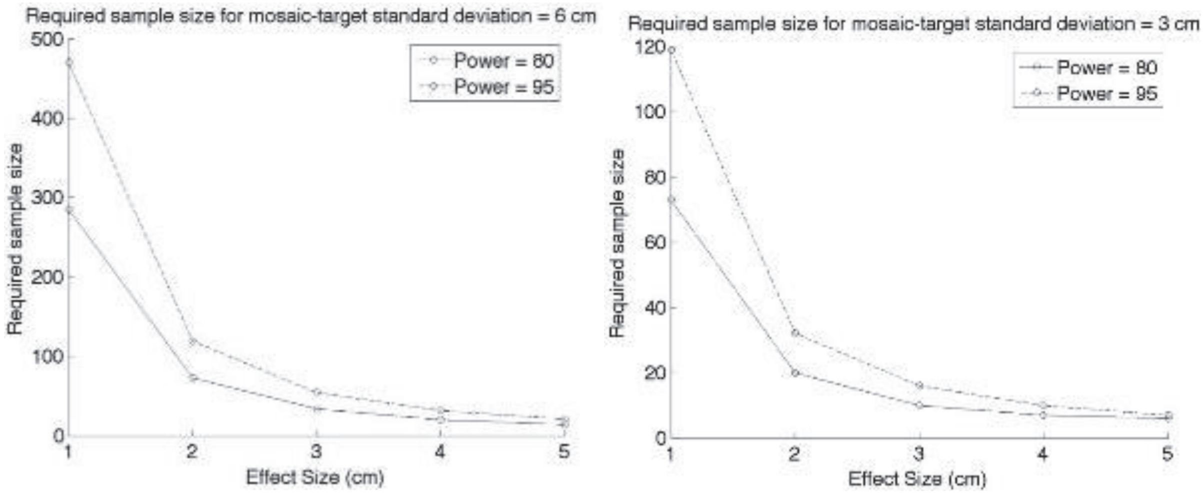
The proposed approach for the absolute accuracy demonstration was to collect N = 25 samples in each of 2 size classes and three morphological classes (N = 150 objects total). This sample size was determined using both (1) the pilot data used to estimate the desired number of targets or colonies to measure for the long-term monitoring demonstration in June 2011, and (2) an a posteriori analysis of the size data collected during the long-term monitoring demonstration.

Based on the pilot dataset, a minimum of 25 colonies per size category (25 small, 25 medium) was estimated to give a power ≥ 0.8 (and even higher most of the time) to detect significant (at the □ = 0.05 level) differences between mosaic and diver measurements of coral size of at least 10-15% (Figure 24 and Figure 25). Further details of this calculation were provided in descriptions of the long-term monitoring demonstration (Sections 5.4.1 and 5.5.1).

Based on the long-term monitoring data, predictions of the power available for the estimated sample size were assessed. For example, there were actually N = 66 small (≤ 25 cm) corals measured at AUTEC with mean ± standard deviation mosaic-diver differences of -0.25 ± 3.2 cm. The mean size of the colonies was = 18 cm, so a 15% effect size was 2.8 cm, and the power that a change of that magnitude would have been detected is > 0.99. If we had only measured N = 25 colonies, the power to detect a 15% effect size would have been 0.98 and the effect size detectable with a power of 0.8 would have been 1.9 cm or about 10%. These numbers are close to the predictions for small colonies (Figure 19). For the medium colonies at AUTEC, the mean size was = 37 cm, so a 15% effect size was 5.6 cm, and the power that a change of that magnitude would have been detected is > 0.99. If we had only measured N = 25 colonies, the power to detect a 15% effect size would still have been 0.99, and the effect size detectable with a power of 0.8 would have been 3.2 cm or about 9%. These numbers are also close to the predictions for medium colonies (Figure 19).

From the above calculations, the sample size estimates for the pool demonstration of 25 individuals in each of 2 size classes for 3 coral types was predicted to detect a biologically relevant effect size with a high power. From a biological standpoint a 10 – 15% effect size corresponds to 2 – 5 years coral growth, which is a reasonable sampling time frame for coral monitoring surveys. In addition, a common rule-of-thumb in environmental monitoring is that 10%, 30%, and 50% are considered “small”, “medium”, and “large” effect sizes, respectively (Cohen 1992; Fairweather 1991). Thus, our effect size of 10 – 15% is “small” relative to the suite of potential environmental impacts to corals. To accomplish the project goal of evaluating the use of mosaicing technology to monitor coral reefs, the sample size and effect size calculations determined using the AUTEC data should adequately meet the needs of the absolute accuracy demonstration as well.

It is recognized, however, that the absolute accuracy demonstration may have an additional motivation, which is to find the “breaking point” of the technology. The sample sizes required to achieve a power of both 80% and 95% with □= 5% for a range of effect sizes have been calculated (Figure 42). These figures show that the required sample size is a strong function of the variance of the sample. Our proposed sample size of N = 25 for a given size/morphology class would achieve a power of 80% with effect size of 1.8 cm if the mosaic-data standard deviation is 3 cm but only an effect size of 3.5 cm if the mosaic-data standard deviation is 6 cm (Figure 42).



- Plots show desired power, and effect size. Left plot shows results for mosaic-target standard deviation = 6 cm. Right plot shows results for mosaic-target standard deviation = 3 cm. p = 0.05 in both cases.

Figure 42. Minimum sample size as a function of mosaic-target standard deviation.

Our goal was to use sample sizes that will allow the completion of the performance objectives relative to the given success criteria (effect size = 15%) that are based on needs for coral reef monitoring. Once these data have been collected, the actual variance in each of the size/morphology classes can be calculated and an appropriate strategy for testing the "breaking point" of the mosaic size estimates can then be formulated. For example, if the mosaic-truth variance turns out to be smaller than the mosaic-diver variance (calculated from the long-term monitoring data), then N = 25 samples may allow significance testing with high power for effect sizes much smaller than 15%. Alternatively, if the mosaic-truth variance is similar for more than one of the size/morphology classes then those could be combined to easily increase sample size. On the other hand, if mosaic-truth variance is highly variable between classes or much worse than 6 cm, it may require a prohibitively large number of samples to test effect sizes smaller than 15%.

5.5.5.2 Performance Objective 2: Precision of Multiple Mosaic and Diver Size Measurements

PO 2 used the same targets and pool location as PO 1. The purpose of PO 2 was to determine if there is a significant difference in the mosaic bias from multiple surveys or from multiple diver measurements. Three separate mosaic surveys were performed in which all 150 objects were imaged. Following the creation of the 3 mosaics a single mosaic analyst separately measured each of the 150 objects in each of the 3 replicate mosaics. An estimate of the mosaic bias for each survey was calculated by subtracting the known size of the objects from that of the mosaic-based estimate. This procedure was carried out for each of the three mosaic samples. We tested if the average bias for each replicate mosaic was significantly different than the others. Similarly, to obtain an estimate of diver bias each of the 150 objects placed in the pool was measured independently by three divers who recorded their data on their own data sheet. An estimate of the diver-bias was calculated for each diver making size measurements. We then tested to determine if the average diver biases are significantly different than one another. Finally the overall mosaic variance from the three replicate mosaic and the overall diver variance from the three replicate divers were used to estimate if the mosaic variance was significantly greater than the diver variance.

5.5.5.3 Performance Objective 3: Precision of Multiple Mosaic Analyst and Diver Size Measurements

PO 3 also used the same targets and pool locations as PO 1 and PO 2. The purpose of PO 3 was to determine the precision of multiple analysis making repeat measurements from a single mosaic. To perform this test we first determined the bias of multiple mosaic analysts when extracting the same size data of known targets. The same 150 objects deployed in PO 1 were measured by each of three mosaic analysts from a single mosaic. We then tested if the mosaic analysts' biases were significantly different from one another. As a second test, we used the data obtained in PO 2 of 3 divers measuring the known objects to obtain an estimate of diver measurement variance. We then tested if the bias of multiple mosaic analysts was significantly greater than the bias of multiple diver measurements.

5.5.5.4 Performance Objective 4: Evaluation of Mosaic Bias of Known Targets in the Pool and in the Field

The purpose of PO 4 was to determine if the bias of measuring standard objects from mosaics created in a pool was significantly different than the bias of measuring the same standard targets from mosaics acquired in the ocean. In PO 4, square ceramic tiles were used to mark the known targets used in PO 1-PO 3. These tiles are of a known size and have been used throughout the ESTCP demonstration process to mark coral colonies of interest. Therefore, objects of known size are present in each mosaic created during the ESTCP demonstration. To determine if the bias that is being measured from mosaics in the pool setting is equivalent to that obtained during field acquisition we will compare the measurement of these standardized targets from mosaics created during the absolute accuracy demonstration as well as those acquired during field tests. A minimum of 25 ceramic tiles were measured by mosaic analysts from pool-derived mosaics acquired during PO 1-PO 3. Twenty-five tiles were similarly measured directly from ESTCP mosaics acquired in the field. We then compared the bias of measurements from pool generated mosaics and field generated mosaics to determine if there is a significant difference between bias measurements.

5.5.5.5 Calibration of Equipment

Same as Section 5.5.1.

5.5.5.6 Quality Assurance Sampling

All diver data and mosaics were collected by RSMAS personnel familiar with mosaicing technology and its applications for coral reef monitoring. All data were collected independently and recorded on separate datasheets.

5.5.5.7 Sample Documentation

Same as Section 5.5.1.

5.6 SAMPLING RESULTS

5.6.1 Long-Term Monitoring Demonstration

5.6.1.1 Performance Objective 1

For the completion of Performance Objective 1, providing colony-based metrics of coral reef condition, divers tagged and performed health assessments for 87 coral colonies across two survey sites. Mosaic images were then taken of each of the survey sites (Figure 43, Figure 44). The mosaic images were analyzed in the lab and used to survey the same colonies of interest to compare with diver measurements. The results of this performance objective are provided in Section 6.1.

- Mosaic image was used for assessment of colony-based metrics of reef condition.

Figure 43. Mosaic image of the first sampling site for long-term monitoring demonstration PO 1.

5.6.1.2 Performance Objective 2

For Performance Objective 2, divers created hand-drawn maps of 2 × 2 m reef plots (Figure 45) by hand-mapping 50 × 50cm sub-plots (Figure 46) and identifying and measuring the sizes of all coral colonies within the subsections. Coral cover and colony size information were extracted from hand-drawn maps by digitizing hand-drawn mapping images in the lab.

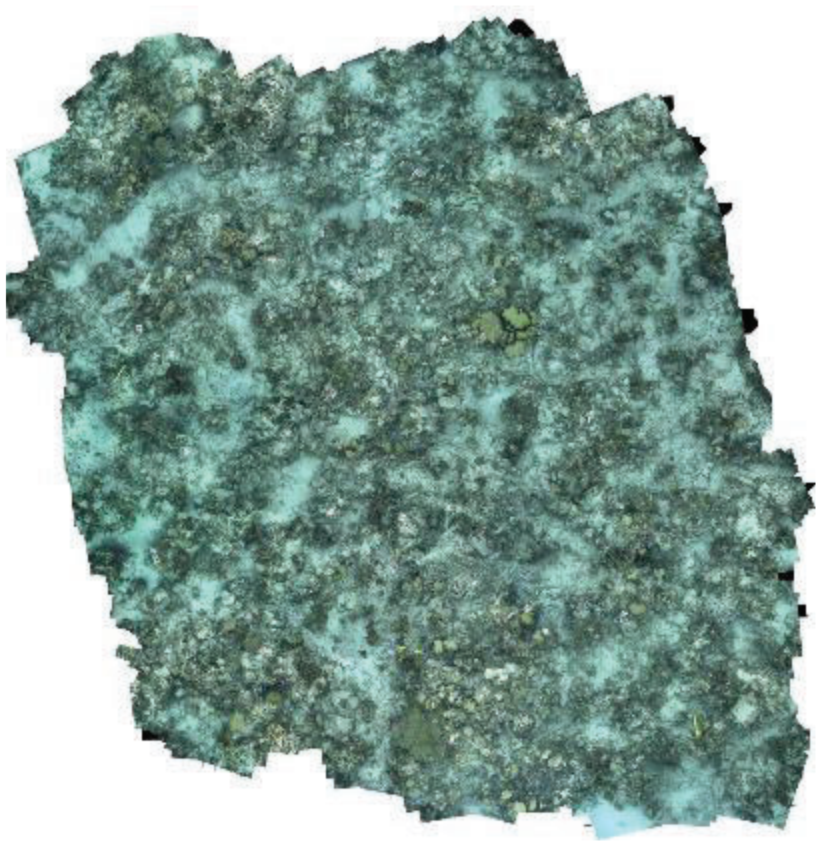


Figure 44. Mosaic image of second sampling site for long-term monitoring demonstration PO 1. Mosaic image was used for assessment of colony-based metrics of reef condition.

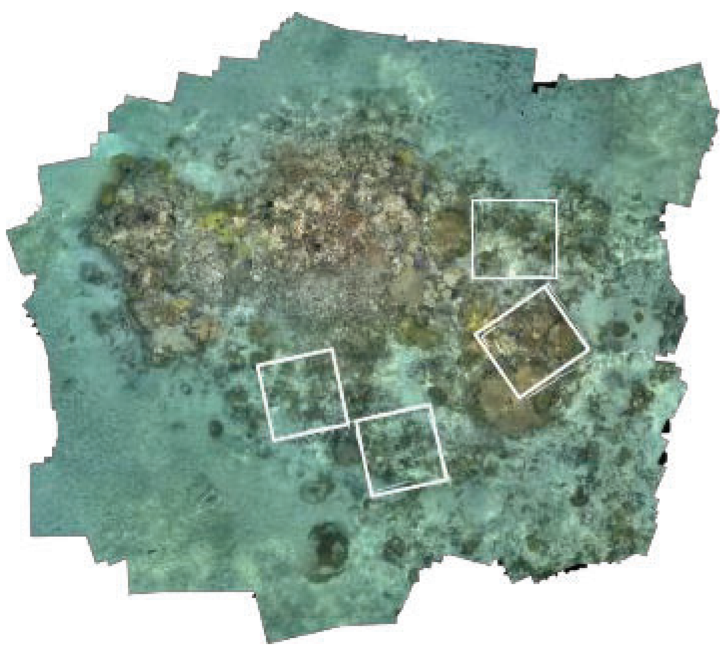


Figure 45. Mosaic image of PO 2 demonstration site with approximate locations of 2×2 m grids for hand-mapping shown in white.

- Corals were numbered and identified to species and coral cover and colony size were later compared to mosaic derived information. Each small square on the grid represents a 2 x 2 cm area.

Figure 46. Example of a hand-drawn map of a 50×50 cm area of reef plot as mapped by a diver in the field.

Image mosaics were then collected of the entire plot. Coral cover and colony size information were obtained through digitizing of the mosaic images (Figure 47.). A total of 55 50 × 50 cm sections were mapped by divers in the field and again in the lab from mosaic images. Results of this performance objective are provided in Section 6.1.

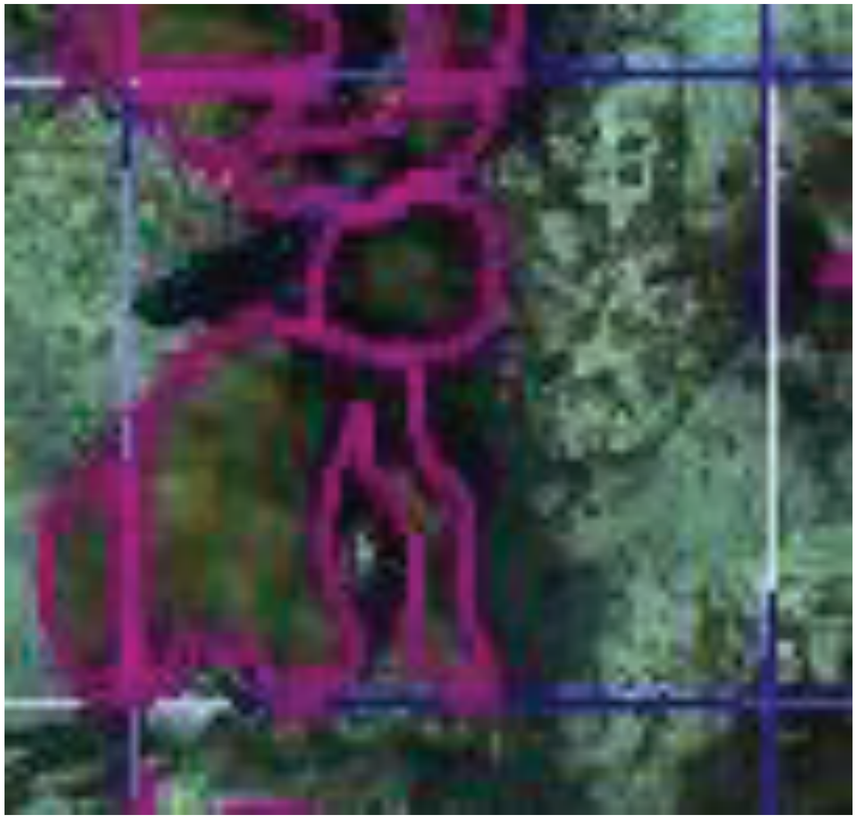


Figure 47. Example of a 50×50 cm mosaic area being digitized in ArcGIS for comparison with diver measurements of coral cover and colony size.

5.6.1.3 Performance Objective 3

For PO 3, image data of the mosaic sites needed for PO 1 and PO 2 were collected by both UM/RSMAS (expert) users and US Navy (novice) users. A total of 4 Navy divers were trained on using the mosaic imaging system and each diver performed two separate mosaic acquisition surveys. The results of this test in terms of the relative incorporation percentage and visual quality of the novice user mosaics are described in Section 6.1.

5.6.2 Endangered Species Demonstration

5.6.2.1 Performance Objective 1

For Performance Objective 1, divers first mapped existing populations of threatened coral species *Acropora palmata* following the procedure published by Williams *et al.* (2006). As a second step, we mosaicked the entire area containing the colonies of interest and then extracted the numbers of colonies and their locations from the mosaics for comparison with the diver data.

For this demonstration, three sites in which populations of threatened coral *A. palmata* were known to occur were selected and mapped by divers in the water and using mosaic imagery. The mosaic images of the three test sites are shown in Figure 48, Figure 49 and Figure 50. The results of the investigation of colony counts and colony location metrics are described in Section 6.2.

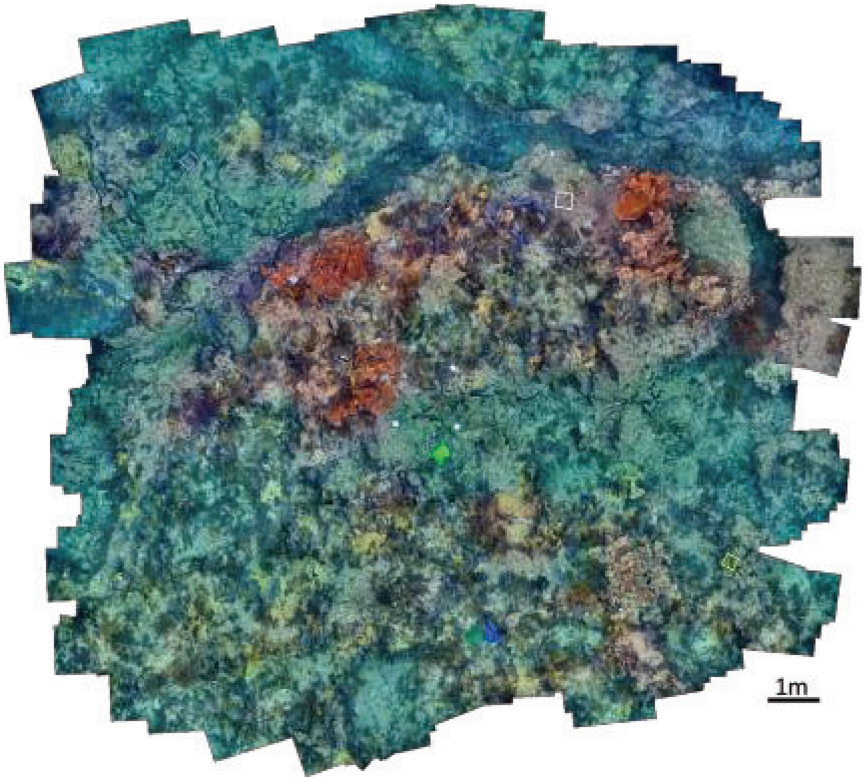


Figure 48. Mosaic image of test site 1 of the endangered species demonstration. Colonies of *Acropora palmata* were marked with ceramic tiles by divers for comparison with mosaic data.

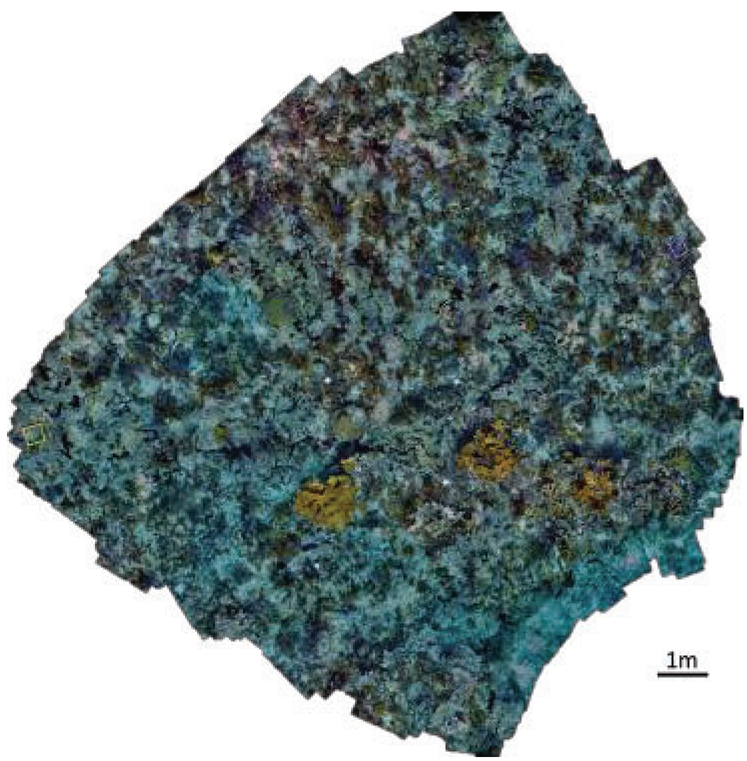


Figure 49. Mosaic image of test site 2 of the endangered species demonstration. Colonies of *Acropora palmata* were marked with ceramic tiles by divers for comparison with mosaic data.

5.6.2.2 Performance Objective 2

The goal of Performance Objective 2 was to compare colony sizes as estimated both by divers in the field and from mosaic imagery. The same three test sites that were used in PO 1 were also used in PO 2. Divers measured coral colony sizes of the threatened corals directly in the field and then the same colonies were located in the mosaic images of the test site and measured using scaled pixels. The results of this investigation are presented in Section 6.2.

5.6.2.3 Performance Objective 3

The goal of Performance Objective 3 was to estimate the % live cover and colony type for each coral tagged in PO 1 and PO 2 of this demonstration. Divers estimated the % living coral and type of colony visually in the field and mosaic analysts performed the same analysis by visual estimation directly from a mosaic image of the test site. The same three test sites that were used in PO 1 and PO 2 of this demonstration were also used in PO 3. The results of these investigations are detailed in Section 6.2.

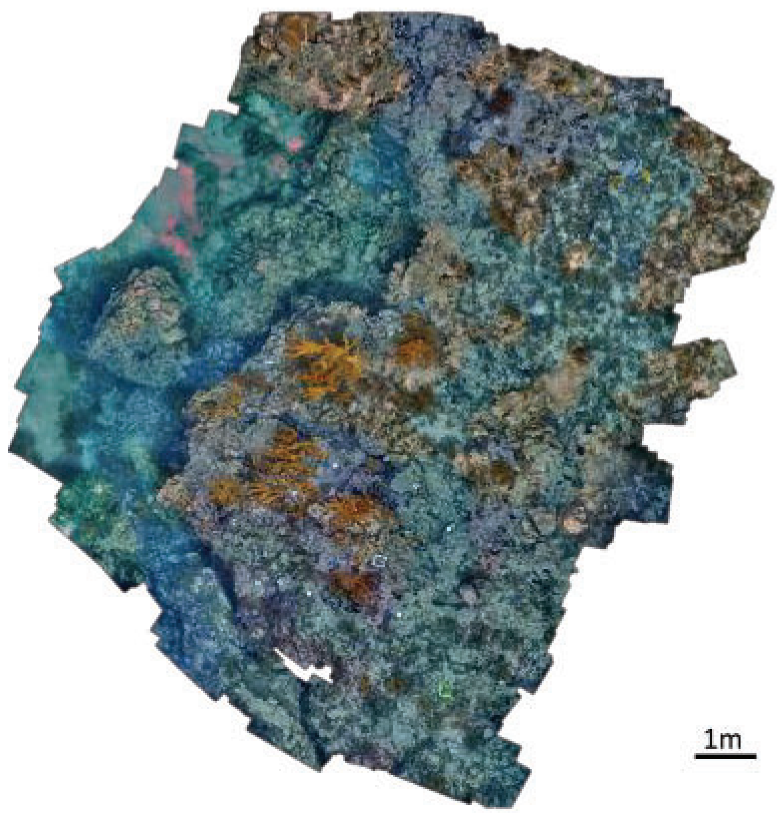
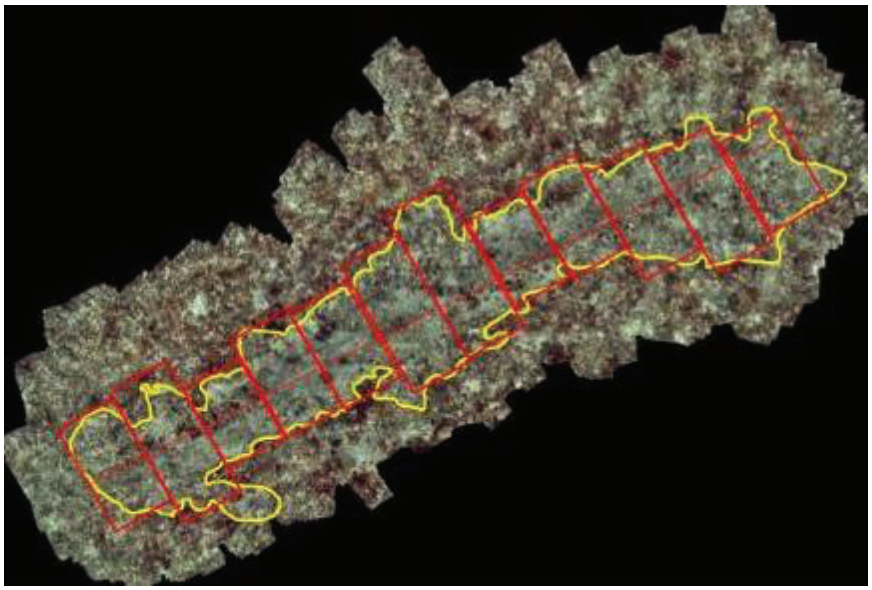


Figure 50. Mosaic image of test site 3 of the endangered species demonstration. Colonies of *Acropora palmata* were marked with ceramic tiles by divers for comparison with mosaic data.

5.6.3 Grounding Demonstration

5.6.3.1 Performance Objective 1

For this performance objective our goal was to compare methods of estimating the size of damage incurred during a ship grounding event on a coral reef. Information was collected by divers in the field using the fishbone technique described in Sections 5.1.3 and 5.4.3, using a handheld GPS, and by outlining the damaged area directly on a mosaic image. Two estimates of the area of damage were completed using the fishbone method and by a mosaic analyst measuring the outline of the damage scar from the mosaic image (Figure 51). Three tracklines of a snorkeler swimming the outline of the damaged area were collected for the GPS estimate. The three track lines from the GPS are shown in Figure 52. The results are provided in Section 6.3.



- Diver-based fishbone measurements of reef damage (red boxes) are estimated once per meter along the centerline of the damage.

Figure 51. Comparison of damaged area measurement methods. Mosaic measurements (yellow outline) can be more precise and define the entire area of the reef damage.

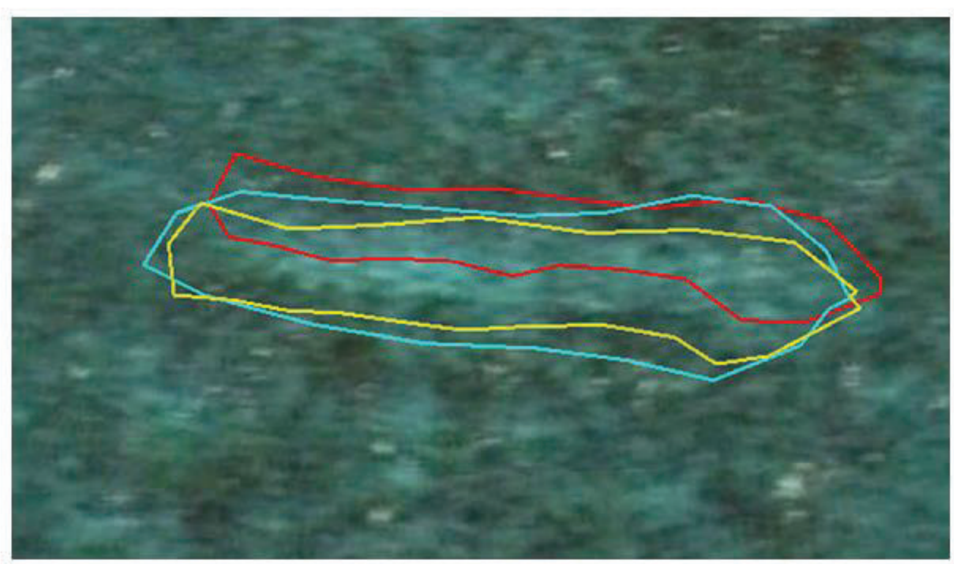


Figure 52. Three snorkeler-derived GPS measurements of the area of damage of the Evening Star ship grounding (red, blue, yellow outlines) overlain on aerial imagery of the scar taken from Google Earth.

5.6.3.2 Performance Objective 2

The goal of Performance Objective 2 was to compare estimates of making linear measurements of damage over the scale applicable to most grounding occurrences. Divers performed linear distance measurements once per meter along the length of the scar in accordance with the protocol established for the fishbone method. A mosaic of the scar was collected and analysts extracted the same linear distances from mosaic images (Figure 53). The results of this comparison are presented in Section 6.3.

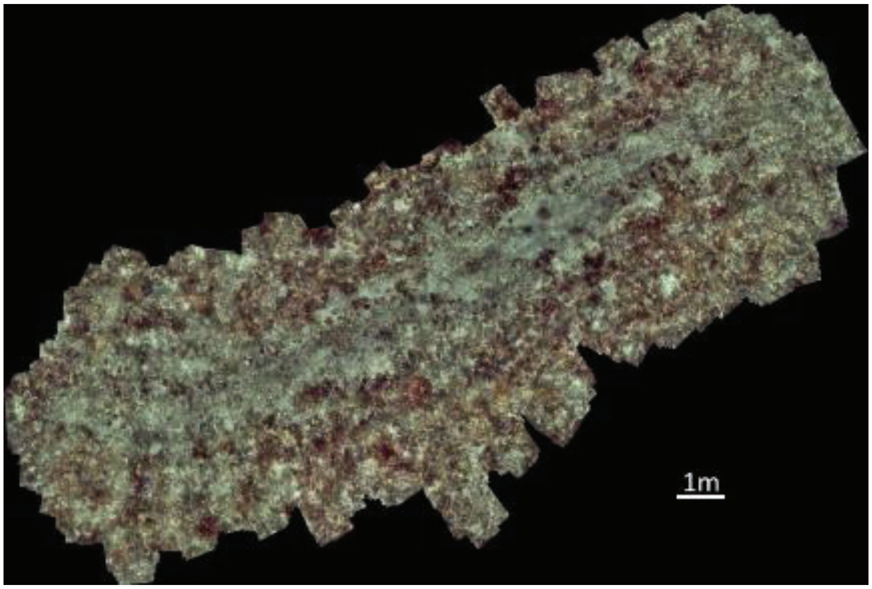
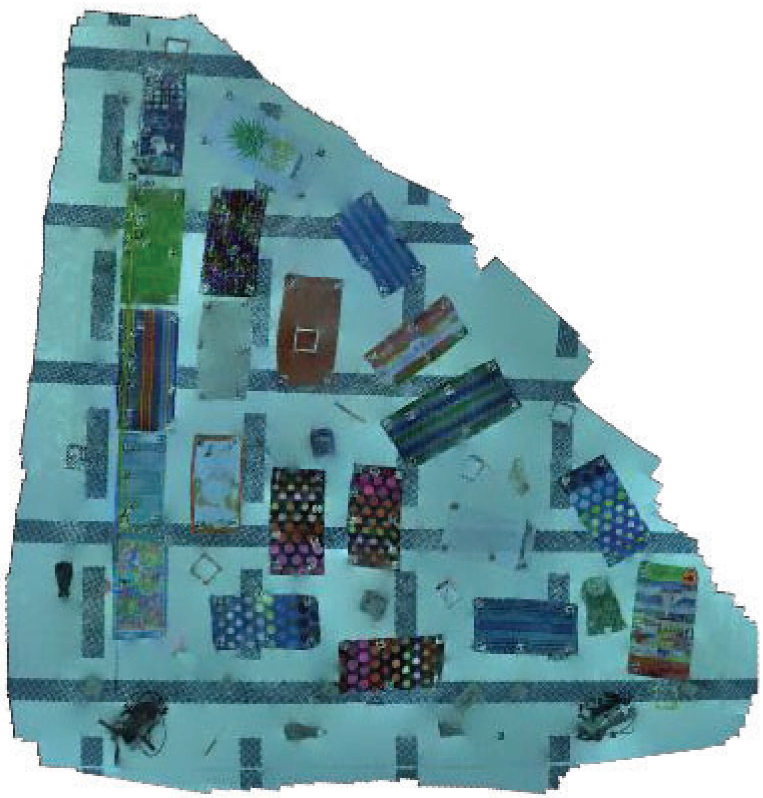


Figure 53. Mosaic of the area of damage of the *Evening Star* ship grounding.

5.6.3.3 Performance Objective 3

The goal of Performance Objective 3 was to measure the accuracy of diver and mosaic linear distances on the scale of 1 to 10 m. Measurements of this scale are important to the accurate delineation of grounding assessments. The University of Miami pool was used as a controlled environment to perform these tests. A total of 45 distances of known length were deployed by marking the ends using tiles and other markers in the UM pool. Distances were then measured by divers in the water, from a snorkeler using a GPS and from a mosaic analyst measuring the distances using scaled pixels. The mosaic image of the pool location where the known distances were deployed is shown in Figure 54. The results of the accuracy comparison are presented in Section 6.3.

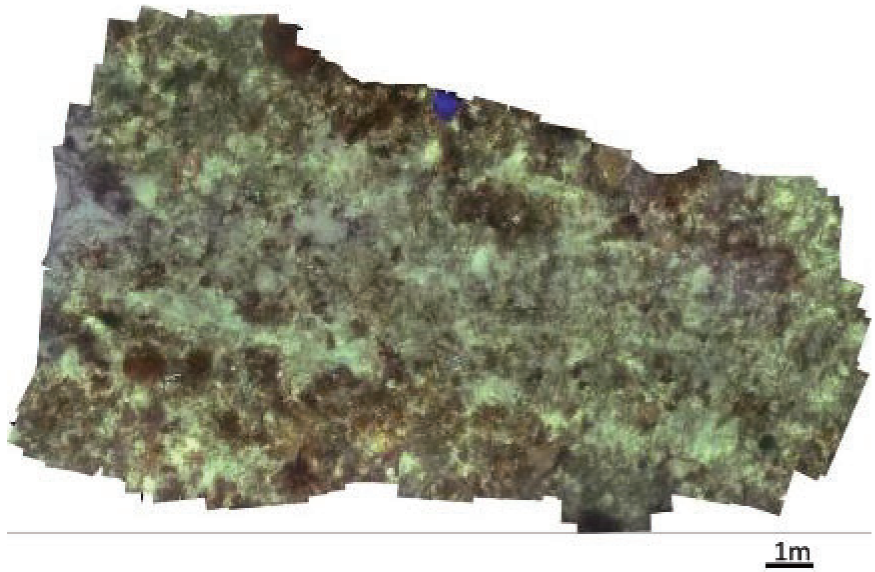


- Divers measured distances between each marker and all other markers in the demo. GPS measurements were taken of each marker were taken from the surface and all measurements were compared to known distances.

Figure 54. Random distances between 1 and 10m were placed along 2 axes in the University of Miami pool.

5.6.3.4 Performance Objective 4

The goal of Performance Objective 4 was to determine if ecological measurements made from mosaics were comparable to diver metrics. Here we determined if the metrics of benthic cover, species richness, coral colony size-frequency, and juvenile density as measured both inside and outside of ship-damaged coral reefs were comparable between diver and mosaic methods. For this performance objective two areas, each roughly 100 m2 in size, were chosen with one inside and the other outside the area of damage. Divers assessed the site using PCQT, LPIM, BT, and juvenile survey methods. Mosaic images were acquired over the site and the same ecological measurements were extracted from the mosaic images. The two test sites chosen for this performance objective are shown in Figure 55 and Figure 56. The results of these comparisons are presented in Section 6.3.



- Ecological metrics of benthic cover, coral species richness, coral size frequency, and juvenile density were assessed by divers and from mosaic images from inside the vessel grounding area.

Figure 55. Mosaic image of the test plot located inside the area of reef damage from the Evening Star vessel grounding.

Figure 56. Mosaic image of the area outside the vessel grounding damage that was used to compare methods of extracting ecological metrics.

5.6.3.5 Performance Objective 5

The goal of Performance Objective 5 was to determine if measurements of live coral cover and coral colony size were comparable between a UM/RSMAS coral reef expert and a Navy ecologist expert. The data for this performance objective were not restricted to that of a vessel grounding. Thus, the data for comparing extractions of live coral cover and the extraction of coral sizes were performed on the data of the first test site established in the long-term monitoring demonstration (Figure 43). Using this mosaic image, both the UM and navy analyst measured the colony sizes of 48 coral colonies. Benthic cover was assessed by placing 400 random points across the image and identifying the benthic composition beneath each point. The results of this investigation are presented in Section 6.3.

5.6.4 Traditional Metrics Demonstration

5.6.4.1 Performance Objective 1

The goal of Performance Objective 1 of the traditional metrics demonstration was to determine if ecological measurements obtained by divers were comparable to the same estimates made directly from mosaic images in a variety of reef environments. Four test sites were identified, two representing shallow reef communities (less than 30 ft) and two representing deeper forereef communities (30 ft or greater). Divers performed traditional transect-based methods for extracting ecological information on reef condition (LPIT, PCQT, BT, and juvenile density) and mosaic analysts applied virtual methods to extract the same information from test sites mosaics. Image mosaics that were used in this performance objective are shown in Figure 57, Figure 58, Figure 59 and Figure 60. The results of the comparisons of ecological measurement methods are detailed in Section 6.4.

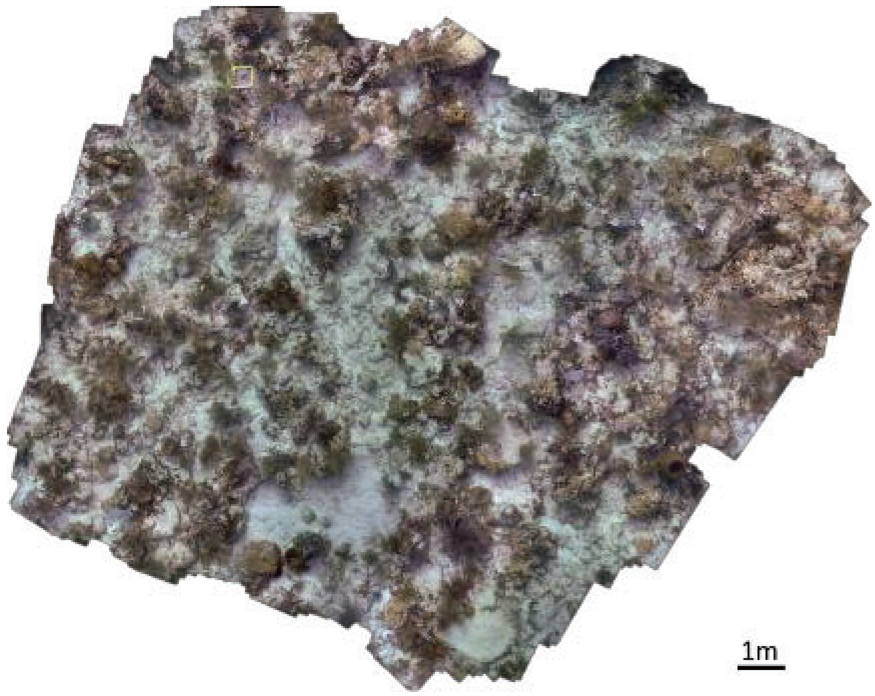


Figure 57. Mosaic image of the Brooke's Reef forereef (>30 ft deep) test site.

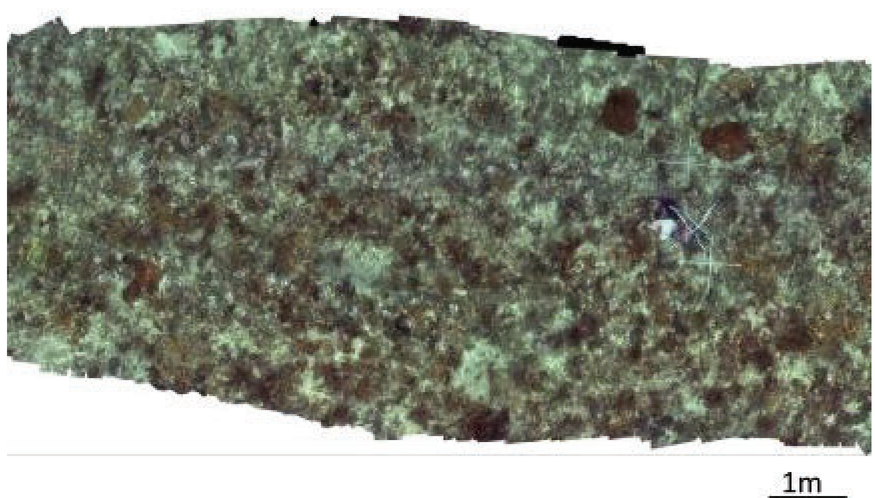


Figure 58. Mosaic image of the Anniversary Reef patch reef (12 ft depth) test site.

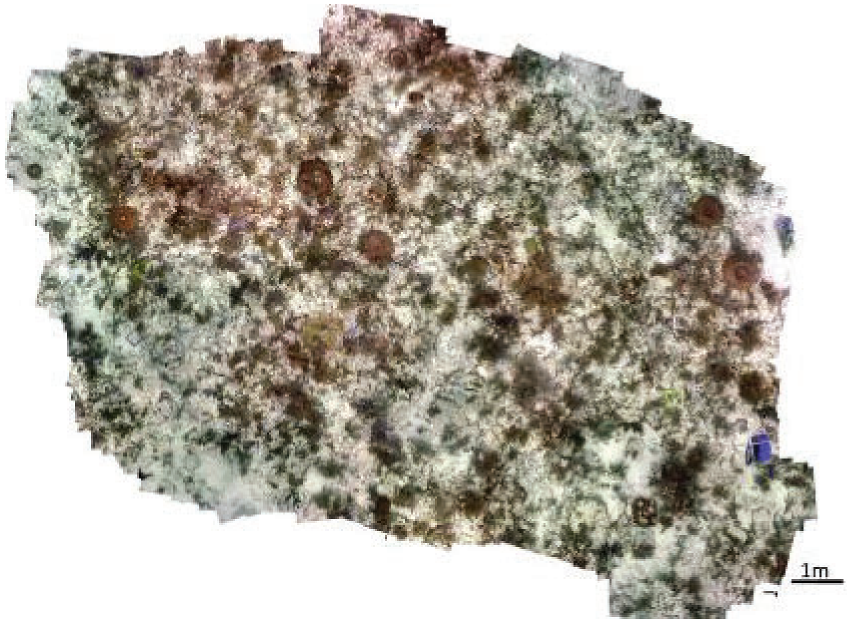


Figure 59. Mosaic image of the Evan's Reef forereef (40 ft depth) test site.

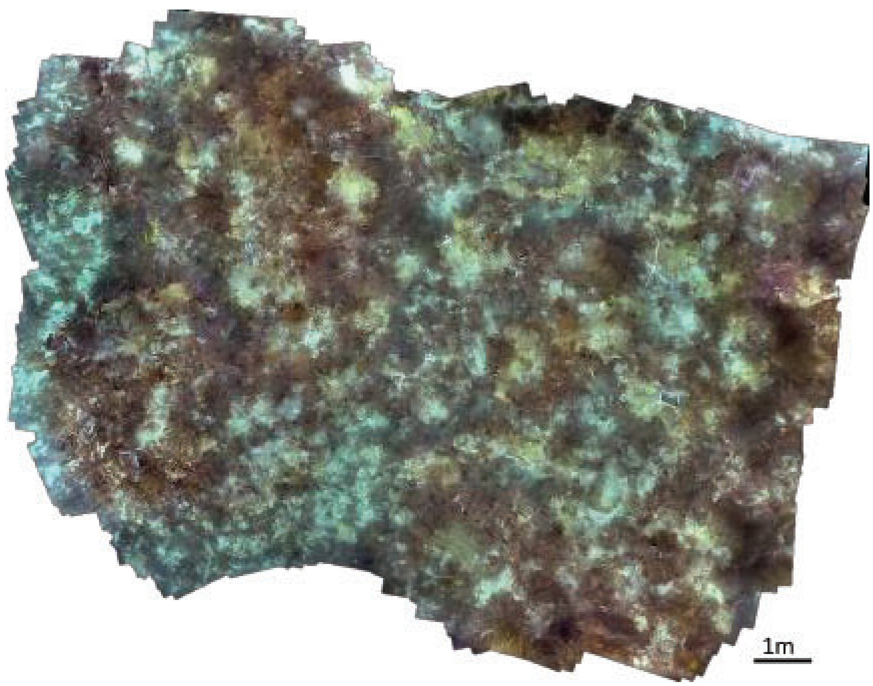


Figure 60. Mosaic image of the Evan's Reef crest (12 ft depth) test site.

5.6.4.2 Performance Objective 2

The goal of Performance Objective 2 was to determine if ecological measurements made by different methods could be extracted from mosaic images. At the four test sites established for PO 1, divers assessed various transects using the PCQT, LPIT, BT, and VT methods. Mosaic analysts then used the images produced in PO 1 to compare ecological metrics to diver based methods. The results of this performance objective are presented in Section 6.4.

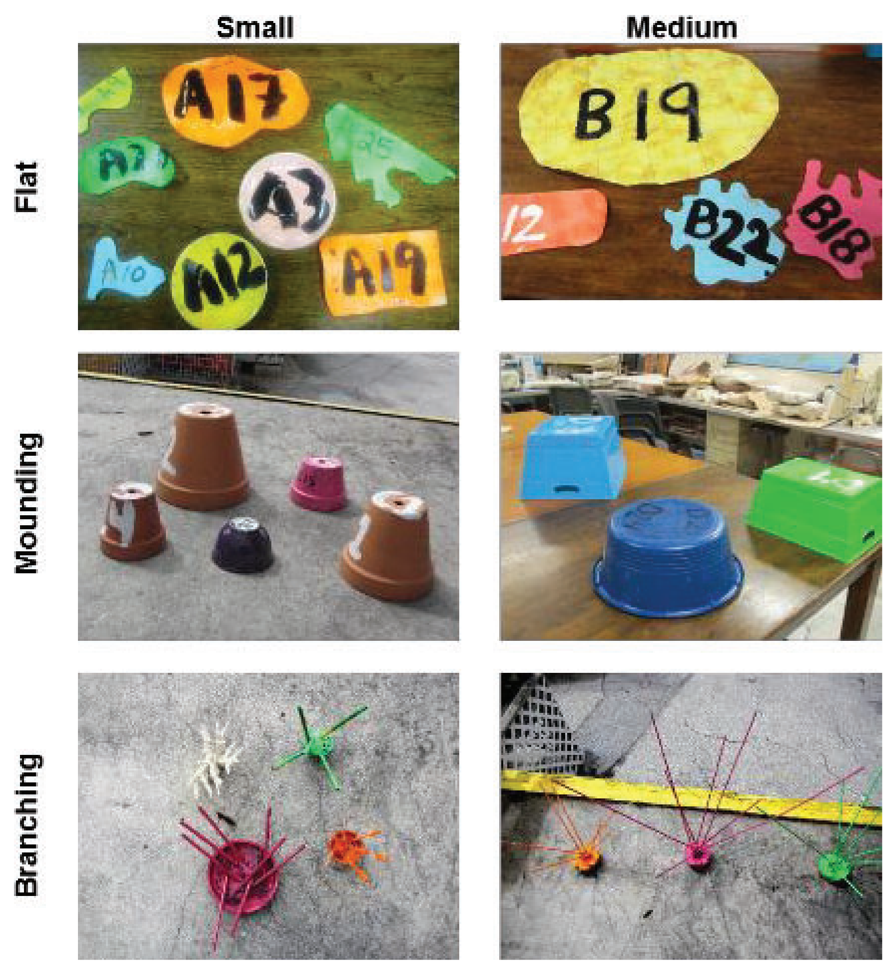
5.6.4.3 Performance Objective 3

The goal of Performance Objective 3 was to determine if novice Navy personnel using a mosaicing guide and minimal training could create mosaic images that were equivalent to those created by experienced RSMAS analysts. The image data used in this demonstration was collected during PO 1 at the Evan's forereef test site. The results of the comparison are provided in Section 6.4.

5.6.5 Absolute Accuracy Demonstration

5.6.5.1 Performance Objective 1

The goal of Performance Objective 1 was to determine the absolute accuracy of mosaic and diver size measurements in a controlled setting. The data for performance objective were based on objects of known size that were measured by both divers in a pool setting and from a mosaic image of the test area with known objects. The targets consisted of three types, flat, mounding, and branching, and two size classes, small (5–25 cm) and medium (25–120 cm). A minimum of 25 objects of each type/size class were created and deployed in the University of Miami pool from which divers and mosaic analysts measured the object sizes. Examples of each of these targets are shown in Figure 61.



- Targets were grouped into three types: flat, mounding, and branching; and two sizes: small (5–25 cm) and medium (25–120 cm).

Figure 61. Examples of the targets of known size used in PO 1 (A & B), PO 2, and PO 3 in the absolute accuracy demonstration.

For PO 1 C & D, the small, flat targets from PO 1 A & B were traced onto planes inclined at a 30-degree angle in order to test the accuracy of divers and mosaics for assessing the projected area of inclined objects. An example of the inclined targets used to answer these questions is shown in Figure 56.

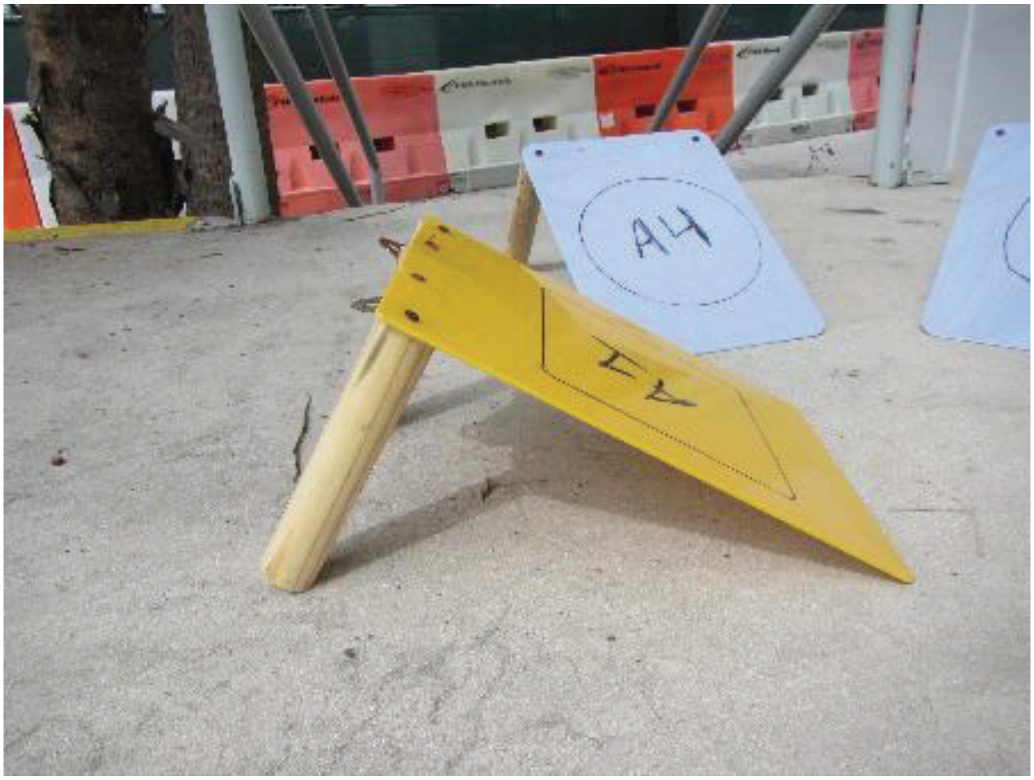


Figure 62. Small flat objects on an inclined plane were used as the targets of known size in PO 1, C and D.

Image mosaics were acquired over both the non-inclined and inclined targets of known size (Figure 63 and Figure 64). Results of the accuracy assessments are provided in Section 6.4.

Figure 63. Image mosaic of known targets from the absolute accuracy demonstration.

Figure 64. Mosaic image of inclined targets used in the absolute accuracy demonstration.

5.6.5.2 Performance Objective 2

The goal of Performance Objective 2 was to determine if measurements made from multiple mosaics were repeatable or if these measurements differed due to the variability from multiple divers.

Image mosaics of the non-inclined and inclined targets were collected by multiple divers in the pool. No new targets or sites were needed for PO 2. The results of these comparisons are presented in Section 6.4.

5.6.5.3 Performance Objective 3

The goal of Performance Objective 3 was to determine if measurements made from multiple analysts were repeatable of if these measurements differed due to the variability from multiple analysts. Size data from a single mosaic were extracted by multiple mosaic analysts. The targets and mosaic images collected in PO 1 and PO 2 were used for the assessment of PO 3. The results of these comparisons are presented in Section 6.4.

5.6.5.4 Performance Objective 4

The goal of Performance Objective 4 was to determine if there was a different bias present from mosaic images acquired in a pool environment or from an oceanic test site. For this performance objective, tiles of known size (10.7 cm on each side) were placed in the pool and in the mosaics made in the field to measure determine if there are differences in measurement accuracy between the pool and the field Figure 65.

- These same tiles were also placed in all of the mosaics taken in the field. For example, they are visible in Figure 48–Figure 50. Note the white, 10.7 x 10.7 cm tiles..

Figure 65. Portion of a mosaic image from the pool, used for the absolute accuracy demonstration.

6. PERFORMANCE ASSESSMENT

6.1 LONG-TERM MONITORING DEMONSTRATION PERFORMANCE ASSESSMENT

Sections 6.1.1, 6.1.2, and 6.1.3 provide the results of Performance Objectives 1, 2, and 3, respectively, for the long-term monitoring demonstration. Results are summarized in Table 15.

Table 15. A summary of the Long-Term Monitoring Demonstration performance assessment.

PO.Metric	Question	Status	Conclusions
PO1.1	1. Are measurements of coral size made by divers significantly different than measurements made by the same diver from mosaic images?	Complete	There was no significant difference in the measurements of coral size as recorded *in situ* by diver A and measurements from the mosaic by analyst A ($p = 0.35$).
PO1.1	2. Is the difference in colony size as measured by a diver in the field and from a mosaic any larger than the difference as measured by two divers?	Complete	The absolute error for large colonies was greater than the absolute error for small colonies ($p = 0.00$) regardless of method used. There was no significant difference in absolute error between measurement methods ($p = 0.38$), or any interaction between size and method ($p = 0.32$).
PO1.1	3. Is the difference in colony size as measured by multiple analysts using the same mosaic any larger than the difference as measured by two divers?	Complete	The absolute error for large colonies was greater than the absolute error for small colonies ($p = 0.00$) regardless of method used. There was no significant difference in absolute error between measurement methods ($p = 0.88$), or any interaction between size and method ($p = 0.78$) when comparing size information taken by two divers or from two mosaic analysts.
PO1.1	4. Is the difference in colony size as measured by one analyst from multiple mosaics any larger than the difference as measured by two divers?	Complete	The absolute error for large colonies was greater than the absolute error for small colonies ($p = 0.00$) for both diver-diver and mosaic-mosaic differences. There was no significant difference in absolute error between measurement methods ($p = 0.14$), or any interaction between size and method ($p = 0.14$) when comparing size information taken by two divers or from a single mosaic analyst across multiple mosaics.

- The main questions of each performance objective are listed and a color code is given to the assessment of each question.
- **Green** color code indicates that all aspects of the test were successful.

Table 15. A summary of the Long-Term Monitoring Demonstration performance assessment. (Continued)

PO.Metric	Question	Status	Conclusions
PO1.1	5. Are measurements made by a particular analyst repeatable?	Complete	Repeat measures of coral colony sizes by the same analyst from the same mosaic are not significantly different from zero ($p = 0.39$ for BG on two mosaics and $p = 0.44$ for KC on two mosaics).
PO1.2	1. What percentage of colonies identified by divers in the field as bleached is also identified by analysts looking at the mosaic as bleached?	Complete	100% of colonies identified as being bleached by both diver observers were also identified as being bleached by mosaic observers. Note: small sample size $N = 17$.
PO1.2	2. What percentage of colonies identified by divers in the field as diseased are also identified by analysts looking at the mosaic as diseased?	Complete	86% of the corals identified with disease by divers in the water were identified with disease by a mosaic observer. Note: small sample size $N = 7$.
PO1.3	1. Is the difference in % coral bleaching as measured by a diver in the field and from a mosaic any larger than the difference as measured by two divers?	Complete	There were an insufficient number of bleached corals present to perform hypothesis testing. Data were combined across multiple demonstrations and are discussed in Section 6.4.1.

- The main questions of each performance objective are listed and a color code is given to the assessment of each question.
- **Green** color code indicates that all aspects of the test were successful.
- **Grey** color indicates that data for this question were combined with data from other demonstrations and discussed in a different section.

Table 15. A summary of the Long-Term Monitoring Demonstration performance assessment. (Continued)

PO.Metric	Question	Status	Conclusions
PO1.4	2. Is the difference in % new mortality as measured by a diver in the field and from a mosaic any larger than the difference as measured by two divers?	Complete	There were an insufficient number of diseased corals present to perform hypothesis testing. Data were combined across multiple demonstrations and are discussed in Section 6.4.1.
PO1.5	3. Is the difference in % old mortality as measured by a diver in the field and from a mosaic any larger than the difference as measured by two divers?	Complete	There were an insufficient number of corals with old mortality present to perform hypothesis testing. Data were combined across multiple demonstrations and are discussed in Section 6.4.1.
PO2.1	1. Are measurements of the size of individual coral colonies made by diver-drawn maps significantly different than measurements of the same colonies made from mosaic images?	Complete	There was no significant difference in the measurements of coral size as recorded on a hand-drawn map by diver A and measurements from mosaic A by analyst A ($p = 0.29$).
PO2.1	2. Is the difference in colony size as measured from a hand-drawn map and from a mosaic any larger than the difference as measured by a diver in the field and from a mosaic or from two hand-drawn maps or by two divers?	Complete	The absolute error for large colonies was greater than the absolute error for small colonies ($p = 0.03$) for both diver-diver and mosaic-mosaic differences. There was no significant difference in absolute error between measurement methods ($p = 0.54$), or any interaction between size and method ($p = 0.08$) when comparing multiple methods of estimating coral size.

- The main questions of each performance objective are listed and a color code is given to the assessment of each question.
- **Green** color code indicates that all aspects of the test were successful.
- **Grey** color indicates that data for this question were combined with data from other demonstrations and discussed in a different section.

Table 15. A summary of the Long-Term Monitoring Demonstration performance assessment. (Continued)

PO.Metric	Question	Status	Conclusions
PO2.1	3. Is the difference in colony size as measured by multiple analysts using the same mosaic any larger than the difference as measured from two hand-drawn maps or by two divers?	Complete	There was no significant difference in the absolute error of coral size measurements based on the method used ($p = 0.73$), the size of the coral colony ($p = 0.06$), or the interaction between size and method ($p = 0.49$) when comparing multiple methods (diver-diver, map-map, and mosaic analyst-mosaic analyst) methods of estimating coral size.
PO2.1	4. Is the difference in colony size as measured by a single analyst using multiple mosaics any larger than the difference as measured from two hand-drawn maps or by two divers?	Complete	The absolute error for large colonies was greater than the absolute error for small colonies ($p = 0.01$) for all methods. There was no significant difference in absolute error between measurement methods ($p = 0.73$), or any interaction between size and method ($p = 0.16$) when comparing multiple methods (diverA-diverB, MapA-MapB, MosaicA-Mosaic B) of estimating coral size.
PO2.1	5. Are measurements made by a particular analyst repeatable?	Complete	Repeat measures of coral colony size made by the same analyst from the same mosaic were not significantly different from 0 ($p = 0.24$).
PO2.2	1 Are measurements of percent coral cover made by diver-drawn maps significantly different than measurements of the same colonies made from mosaic images?	Complete	There was no significant difference in the measurements of coral cover as recorded by a hand-drawn map made by a diver and measurements made by digitizing coral cover from a mosaic ($p = 0.15$).

- The main questions of each performance objective are listed and a color code is given to the assessment of each question.
- **Green** color code indicates that all aspects of the test were successful.

Table 15. A summary of the Long-Term Monitoring Demonstration performance assessment. (Continued)

PO.Metric	Question	Status	Conclusions
PO2.2	2. Is the difference in percent coral cover as measured from a mosaic and from a hand-drawn map any larger than the difference as measured by two divers making hand-drawn maps?	Complete	There was no significant difference in absolute error between two divers performing manual mapping in the field and the percent cover as measured by a diver and mosaic analyst ($p = 1.0$).
PO2.2	3. Is the difference in percent coral cover measured by multiple analysts using the same mosaic any larger than the difference as measured by two divers making hand-drawn maps?	Complete	There was no significant difference in absolute error between two divers performing manual mapping in the field and two mosaic analysts digitizing coral cover from a single mosaic image ($p = 0.26$).
PO2.2	4. Is the difference in percent coral cover as measured by one analyst from multiple mosaics any larger than the difference as measured by two divers making hand-drawn maps?	Complete	There was no significant difference in absolute error between two divers performing manual mapping in the field and a mosaic analyst digitizing coral cover from two different mosaic images ($p = 0.34$).
PO2.2	5. Are measurements made by a particular analyst repeatable?	Complete	The median difference in repeat measures of coral cover made by the same analyst from the same mosaic was not significantly different than 0 ($p = 0.92$).
PO3	1. Can Navy personnel be trained to acquire image mosaic data?	Complete	Following in-water training and two mosaic image acquisition trials, navy personnel were able to acquire mosaic image data that was indistinguishable from expert users.

- The main questions of each performance objective are listed and a color code is given to the assessment of each question.
- **Green** color code indicates that all aspects of the test were successful.

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6.1.1 Performance Objective 1: Provide Colony-Based Metrics of Coral Reef Condition

As a reminder, the overall approach was:

(A) Select a reef plot with high abundance of coral colonies and a wide range of colony sizes and morphologies.
(B) Identify, tag, measure, and assess the health and condition of coral colonies within the plot by divers.
(C) Mosaic the area that was assessed by divers
(D) Extract coral colony sizes from the mosaic.
(E) Extract species identification, bleaching, disease, and mortality metrics from the mosaic.
(F) Compare the size and condition of the colonies in the test plot as derived from diver data with the size and condition of the colonies derived from the mosaic.
(G) Compute the costs of diver and mosaic methods.

Steps A–E were described in Section 5.4.1 along with instructions for setting up the cameras. Step F is described here and Step G in Section 7.1.

Performance was quantified by comparing the coral colony size, number of bleached colonies, number of diseased colonies, and three metrics of coral colony condition extracted from mosaics and diver surveys (Table 16). Accuracy was quantified by the differences between a metric (e.g., coral cover) extracted from the mosaics and from diver-based estimates. The statistical significance of the differences between and among methods were tested with a t-test or ANOVA, as appropriate using a significance level (α) of 5%.

Table 16. Description of test metrics, the method of extraction for both diver and mosaic based surveys and the method of analysis.

Metric	Data Measurement in the field	Data measurement from Mosaic	Analysis
1. Coral colony size	Maximum length (cm), Maximum width (cm)	Using scaled pixels and image analysis programs (such as CPCe) we will measure the length and width of each colony (cm).	(A) Repeated measures t-test (single observer in field and from mosaic) (B) Two-way ANOVA with coral size and method as factors
2. Coral bleaching/Coral Disease	# of bleached colonies # of diseased colonies	# of bleached colonies from mosaic image	% Accuracy = (#obs mosaic/# obs diver)*100
3. Percent Colony Bleaching	Diver estimate of the % of each colony that is bleached	Observer estimate of % of each colony that is bleached	Two-way ANOVA with coral size and method as factors
4. New Coral Mortality	Diver estimate of the % of each colony that is new coral mortality	Observer estimate of % of each colony showing new mortality	Two-way ANOVA with coral size and method as factors
5. Old Coral Mortality	Diver estimate of the % of each colony that is old coral mortality	Observer estimate of % of each colony that is old mortality	Two-way ANOVA with coral size and measurement method as factors

- Metrics 3–5 together refer to the “coral condition.”

6.1.1.1 Metric 1: Coral Colony Size

Colony size was measured directly in the field using measuring tapes by each of 2 divers for N colonies. These colonies were then measured from mosaics in the lab using scaled pixels to determine the same maximum length and width. Five questions were used to determine if there was a difference in the methods of measurement.

Question 1:

Are measurements made by divers in the water significantly different than measurements made by the same diver from mosaic images?

Analysis:

Paired Samples t-test. Diver A (RSMAS) measured N colony sizes in the field, mosaic analyst A (RSMAS) measured the same N colonies using scaled pixels from the mosaics. We then computed N differences. Was the mean difference significantly different than zero?

H_0: There is no significant difference in the measurements of coral size as recorded in situ by diver A and measurements from the mosaic by analyst A.

H_A: There is a significant difference in the measurement of coral size when using the two methods.

Results: A total of N = 87 corals were measured by observer Brooke Gintert both in the field and from mosaic images at the long-term monitoring test sites. The size data were not normally distributed initially, but after a square root transformation both distributions were normally distributed and the paired t-test was employed for significance testing. The distribution of sizes were not significantly different than one another (p = 0.347, Table 117). The mean difference between diver and mosaic measurements was 0.39 cm (Table 17).

Table 17. Results of repeat measures t-test of size measurements.

Measurement	N	Mean Difference (cm)	T-value	P-value
Diver-Mosaic Comparison	87	0.39	-0.94	0.347

- Measurements made by Brooke Gintert in the field and from a mosaic image.

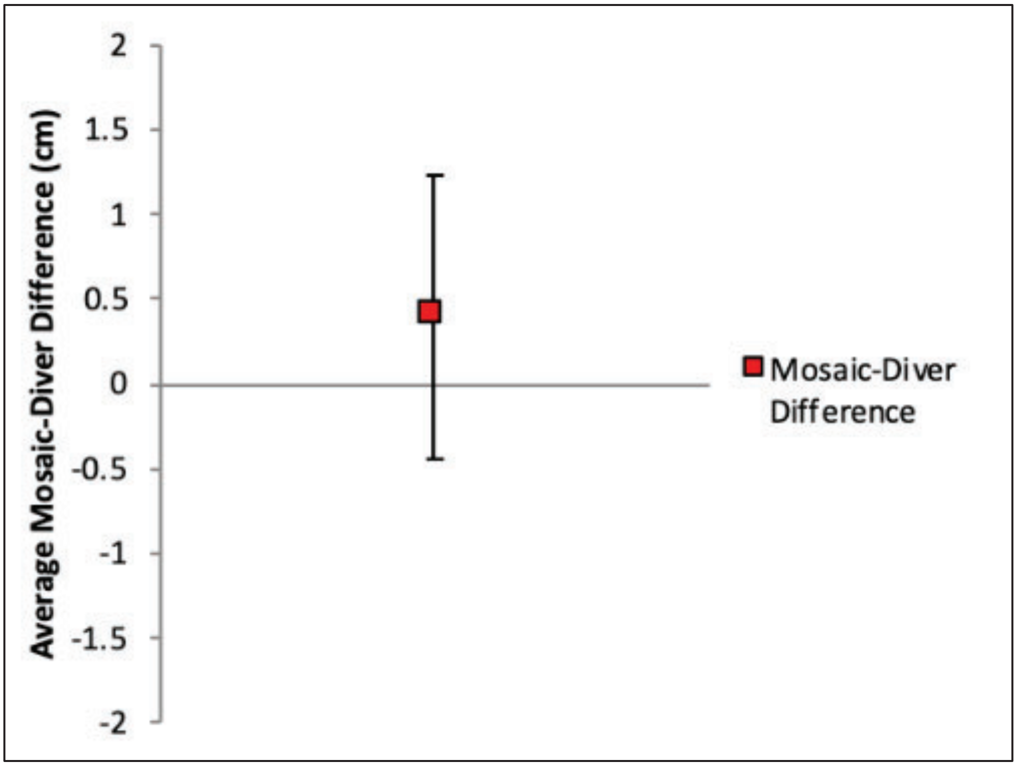


Figure 66. Mean difference and 95% confidence interval (*N* = 87) between diver and mosaic size measurements as made by the same person during the long-term monitoring demonstration.

Conclusion:

There was no significant difference in the measurements of coral size as recorded in-situ by diver A and measurements from the mosaic by analyst A.

Question 2:

Is the difference in colony size as measured by a diver in the field and from a mosaic any larger than the difference as measured by two divers?

Analysis:

Two-factor ANOVA with measurement method and coral colony size class as the independent variables and coral size as the main effect. For this comparison we examined the absolute error of diver-diver measurements as compared with diver to mosaic measurements. Diver A (RSMAS) and Diver B (Navy) both measured N colonies in 2 size classes in situ. The size classes were “small” corals less than 25 cm and “medium to large” corals greater than 25 cm. These size classes corresponded to those used in the absolute accuracy demonstration where targets of known size were constructed to determine the absolute accuracy of diver and mosaic methods for estimating object sizes. Mosaic analyst A (RSMAS) also measured the same colonies from mosaics of each site. For each colony, two measures of the absolute error were computed:

Absolute Error = AE = (|Diver A-Diver B|) and (|Diver A-Mosaic|)

For this design there were 3 null hypotheses and 3 alternative hypotheses:

Ho1: There is no significant difference in absolute error between the measurement methods

HA1: There is a significant difference in absolute error between the measurement methods

Ho2: There is no significant difference in the measurement of colony size based on coral size categories

HA2: There is a significant difference in the measurement of colony size based on coral size categories

Ho1-2: There is no interaction between size and measurement method

HA1-2: There is a significant interaction between coral size category and measurement method

Results:

The absolute error data were not normally distributed (and none of the transformations applied approximated a normal distribution). Therefore, the two-way ANOVA was performed with ranked absolute error data. The two-way ANOVA based on ranks indicated that there was a significant difference in the absolute error, regardless of method, based on the size of the corals ($p = 0.00$). There was no significant treatment effect and no interaction between size and treatment (Table 18). These results are shown graphically in Figure 67, where the mean absolute error of small corals was 1.5 and 1.6 cm respectively for mosaic and diver methods and 3.8 and 5.3 cm respectively for large colonies.

Table 18 shows results of a two-factor ANOVA based on ranks.

Table 18. Results of a two-factor ANOVA based on ranks comparing the absolute error of a mosaic and diver analyst and that of two divers.

Factors	SS	MS	F	P
Size	55257.0	55257.0	33.07	0.00
Method	1275	1275.1	0.76	0.38
Interaction	1694	1693.6	1.01	0.32

- Results occurred when measuring coral sizes of two size classes. Significant results are shown green.

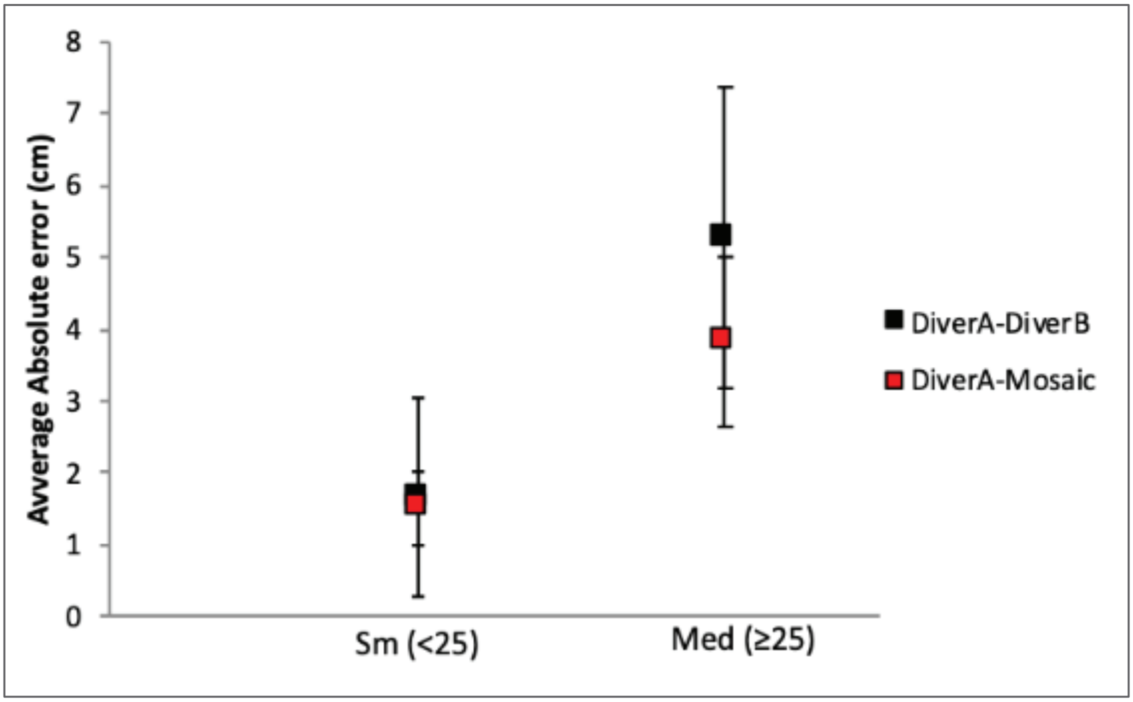


Figure 67. Mean absolute error and 95% confidence intervals for diver and mosaic measurements of small and large corals as measured in the field and from mosaic images.

Despite the fact that there was an increase in measurement error as the size of the coral increased, there was no difference between diver-diver and diver-mosaic sizes in either size class. This suggests that the error was inherent to the measurement and is present regardless of whether or not the object is being measured by a diver in the water or from a mosaic image.

Conclusion:

There was a significant difference in the magnitude of the absolute error between size classes; smaller corals had smaller absolute error than larger corals. In either size class, however, there was no significant difference in absolute error between measurement methods, or any interaction between size and method. These data suggest that measuring small colonies is more accurate for both methods and that the error of the measurement increases with coral size. These data are in agreement with the data from the absolute accuracy demonstration in which the mosaic and diver bias of known targets was less than 2 cm for small objects (less than 25 cm) and less than 5 cm for larger objects (between 25 and 120 cm) (Section 6.5). In this case, the average absolute error was slightly smaller (though not significantly smaller) when being measured from a mosaic then from a diver in the water. This observation was also seen in the absolute accuracy demonstration for larger targets (see Section 6.5).

Question 3:

Is the difference in colony size as measured by multiple analysts using the same mosaic any larger than the difference as measured by two divers?

Analysis: Two-factor ANOVA with measurement method and coral colony size class as the independent variables and coral size as the main effect. For this comparison we examined the absolute error of diver-diver measurements as compared with mosaic-mosaic measurements. Diver A (RSMAS) and Diver B (Navy) both measured N colonies in two size classes in situ. Mosaic analysts

A and B (RSMAS) extracted sizes from mosaic A for the same colonies. For each colony, two measures of the absolute error were computed:

Absolute Error = AE = (|DiverA-DiverB|) and (|AnalystA-AnalystB|)

For this design there were 3 null hypotheses and 3 alternative hypotheses:

H_{o1}: There is no significant difference in absolute error between the measurement methods

HA1: There is a significant difference in absolute error between the measurement methods

Ho2: There is no significant difference in the measurement of colony size based on coral size categories

HA2: There is a significant difference in the measurement of colony size based on coral size categories

Ho1-2: There is no interaction between size and measurement method

HA1-2: There is a significant interaction between coral size category and measurement method

Results:

As in the previous question, the data were not normally distributed even after several attempts at normalization through transformation. Therefore, the two-way ANOVA was performed based on ranked data. The results of the two-factor ANOVA comparing the absolute error of two divers and two mosaic analysts measuring the same coral colonies are shown in Table 19.

Table 19. The results of a two-factor ANOVA based on ranks comparing the absolute error of two mosaic analysts and that of two divers.

Factors	SS	MS	F	P
Size	20311.8	20311.8	40.96	**0.00**
Method	17.4	17.4	0.04	0.85
Interaction	32.9	32.9	0.07	0.78

- Results occurred when measuring coral sizes of two size classes. Significant results are shown green.

The two-way ANOVA based on ranks indicated that there was a significant difference in the magnitude of the absolute error between size classes; smaller corals had smaller absolute error than larger corals. In either size class, however, there was no significant treatment effect and no interaction between size and treatment (Table 19). These results are shown graphically in Figure 68. where the mean absolute error of small corals was 1.3 and 1.6 cm respectively for mosaic and diver methods and 4.6 and 5.3 cm respectively for large colonies.

Conclusion:

There was a significant difference in the magnitude of the absolute error between size classes; smaller corals had smaller absolute error than larger corals. In either size class, however, there was no significant difference in absolute error between measurement methods, or any interaction between size and method. These data suggest that measuring small colonies is more accurate for both methods and that the error of the measurement increases with coral size. This result is consistent with question two of this performance objective. Despite the fact that there was an increase in measurement error as the size of the coral increases there was no difference in treatment at either level. This suggests that the error is inherent to the measurement and is present regardless of whether or not the object is being measured by two divers in the water or from two mosaic analysts. The absolute error of two mosaic analysts was slightly lower than that of two divers (although not significantly) across both size classes.

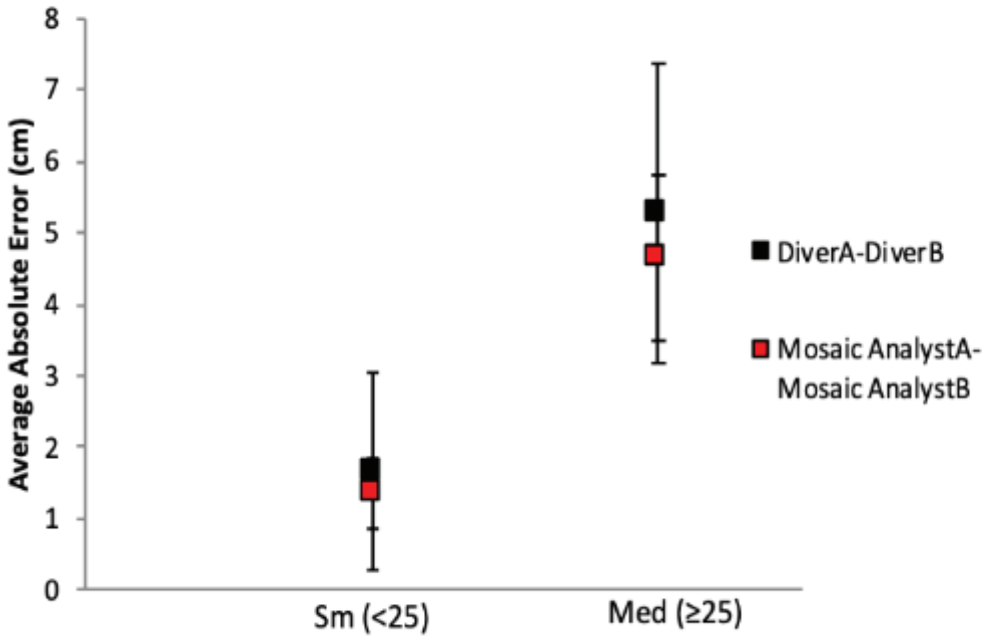


Figure 68. Mean absolute size error and 95% confidence intervals of small and large corals for two divers and two analysts measurements from the same mosaic.

Question 4:

Is the difference in colony size as measured by one analyst from multiple mosaics any larger than the difference as measured by two divers?

Analysis:

Two-factor ANOVA with measurement method and coral colony size class as the independent variables and coral size as the main effect. For this comparison we examined the absolute error of diver-diver measurements as compared with mosaic-mosaic measurements. Diver A (RSMAS) and Diver B (Navy) both measured *N* colonies in 2 size classes *in situ*. Mosaic analyst A (RSMAS) also extracted sizes from mosaics A and B for the same colonies. For each colony, two measures of the absolute error will be computed:

$$\text{Absolute Error} = \text{AE} = (|\text{DiverA-DiverB}|) \text{ and } (|\text{MosaicA-MosaicB}|)$$

For this design there were 3 null hypotheses and 3 alternative hypotheses:

Ho1: There is no significant difference in absolute error between the measurement methods

HA1: There is a significant difference in absolute error between the measurement methods

Ho2: There is no significant difference in the measurement of colony size based on coral size categories

HA2: There is a significant difference in the measurement of colony size based on coral size categories

Ho1-2: There is no interaction between size and measurement method

HA1-2: There is a significant interaction between coral size category and measurement method

Results:

As in the previous questions, the data were not normally distributed even after several attempts at normalization through transformation. Therefore, the two-way ANOVA was performed using ranked data (Table 20).

Table 20. The results of a two-factor ANOVA based on ranks comparing the absolute error of an analyst measuring sizes from two mosaics and that of two divers.

Factors	SS	MS	F	P
Size	52690	52690.3	31.46	**0.00**
Method	3722	3722.1	2.22	0.14
Interaction	3722	3731.9	2.23	0.14

- Results occurred when measuring coral sizes of two size classes. Significant results are shown green.

The two-way ANOVA based on ranks indicates that there was a significant difference in the absolute error estimates between small and large corals (p = 0.00) but that there was no significant treatment effect and no interaction between size and treatment (Table 20; Figure 69). The mean absolute error of small corals was 1.7 and 1.6 cm respectively for an analyst measuring coral sizes from two mosaics and from two divers in the field and 4.0 and 5.3 cm respectively for large colonies.

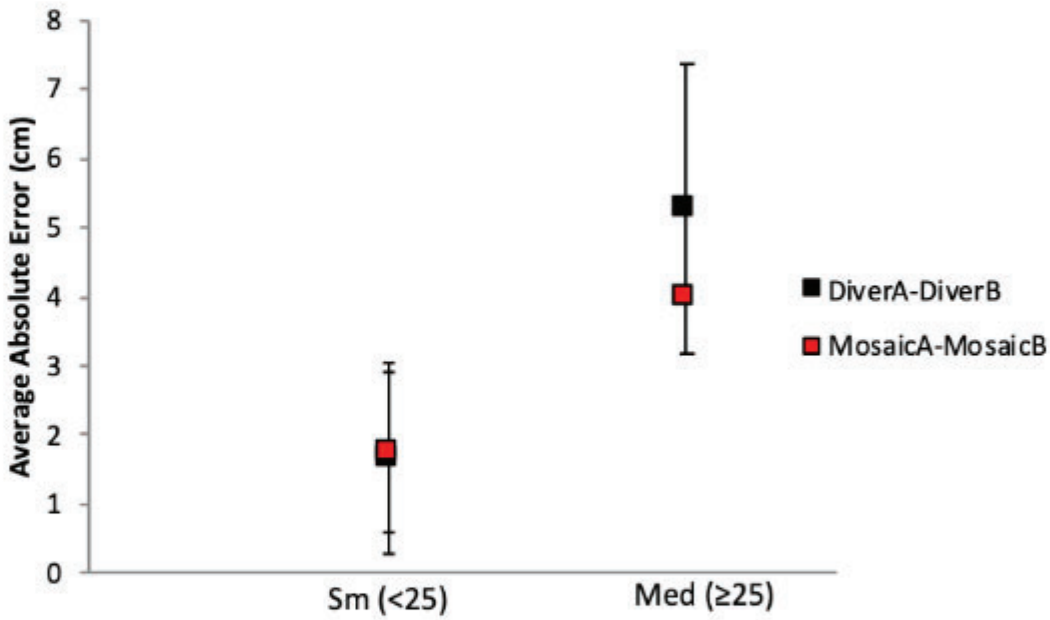


Figure 69. Mean absolute error and 95% confidence intervals of diver-diver differences and the differences from one analyst measuring coral colony sizes from two mosaic images.

Despite the fact that there was an increase in measurement error as the size of the coral increased the measurement error was present in both methodologies. This suggests that the error was inherent to the measurement and would be present regardless of whether or not the object was measured by two divers in the water or from a single analyst across two mosaics.

Conclusion:

There was a significant difference in the absolute error of coral size measurements based on colony size but there is no significant difference in absolute error between measurement methods, or any interaction between size and method when comparing size information taken by two divers or from a single mosaic analyst across multiple mosaics. These data suggest that measuring small colonies is more accurate for both methods and that the error of the measurement increases with coral size. This pattern is consistent with results of questions two and three of this performance objective. The absolute error of the single analyst over two mosaics was slightly lower than that of two divers (although not significantly) for large colonies. These results are in line with results of absolute accuracy of mosaic and diver measurements made during the absolute accuracy demonstration in Section 6.5.

Question 5:

Are measurements made by a particular analyst repeatable?

Analysis: Paired samples t-test. Analyst A measured the sizes of the N marked colonies from mosaic A. Analyst A then measured the sizes of these same colonies again. N differences between the repeat measurements were computed. The test was used to determine if the mean difference was significantly greater than 0. This test was performed twice, once each by two different analysts.

Ho: The mean difference in repeat measures of coral colony size by the same analyst from the same mosaic does not significantly differ ($p > 0.05$) from 0.

H1: The mean difference in repeat measures of coral colony size by the same analyst from the same mosaic does significantly differ ($p < 0.05$) from 0.\

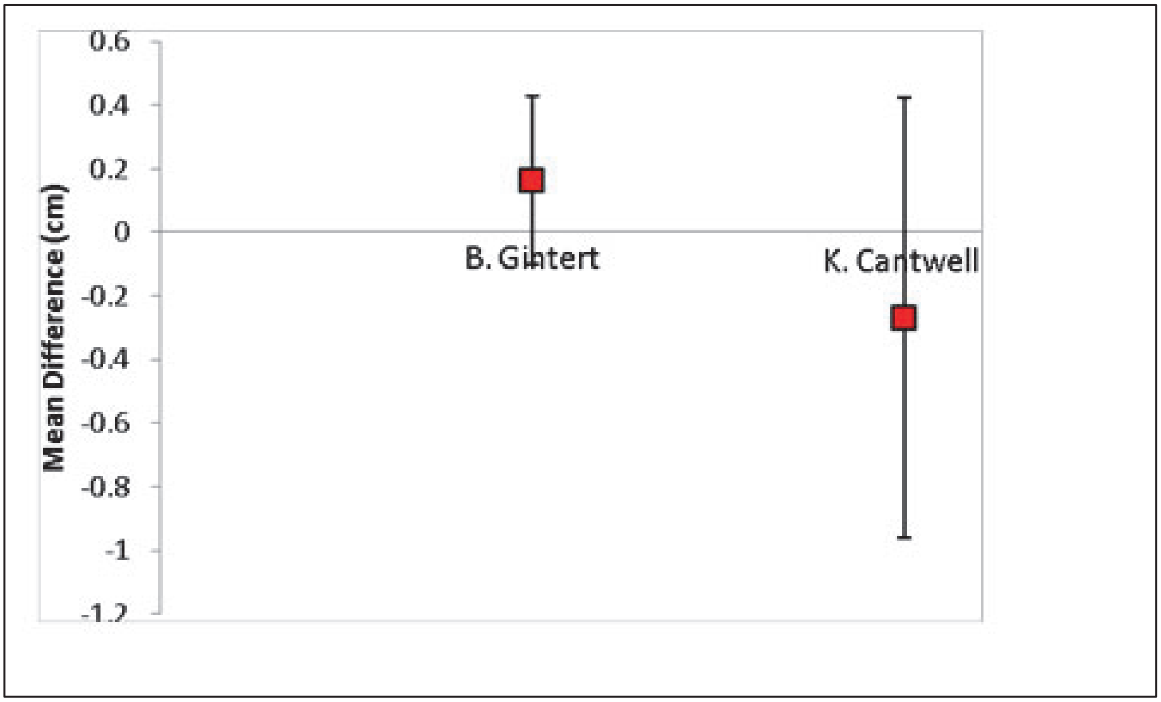
Results:

This test was performed twice using two mosaic analysts, BG and KC. The measurements from BG were normally distributed following a square root transformation. The data from KC were normally distributed without the need for transformation. In each case, a paired t-test was used to determine if the measurements made from a mosaic were repeatable using the same analyst. A total of N = 87 colonies were measured twice by each analyst. The results of the paired t-tests are shown in Table 21.

Table 21. Results of paired *t*-tests comparing the repeatability of mosaic measurements of coral size from a single analyst.

Observer	N	Mean Diff.	*t*-value	P-value
BG	87	0.01	0.87	0.39
KC	87	-0.2	-0.78	0.44

Paired t-test showed that the mean difference in measures of colony size were not significantly different when measured repeatedly by the same observer (Table 21, Figure 70).. The repeatability of the mosaic measurements was shown for two separate analysts, B. Gintert and K. Cantwell. These results demonstrate that mosaic results are repeatable.



- This test was performed for two different mosaic observers (B. Gintert and K. Cantwell).

Figure 70. Mean difference between mosaic measurements made by a single observer twice on the same mosaic image.

Conclusion:

Repeat measures of coral colony size by the same analyst from the same mosaic were not significantly different from zero.

6.1.1.2 Metric 2: Prevalence of Coral Bleaching and Disease

For each of the coral colonies marked and tagged during the demonstration, each diver evaluated the colony for the presence of coral bleaching and for coral disease.

Question 1:

What percentage of colonies identified by divers in the field as bleached were also identified by analysts looking at the mosaic as bleached?

Analysis:

To evaluate the accuracy of mosaic monitoring to detect this indicator of coral condition, traditional percentage accuracy was computed using the number of corals identified as bleached by both divers as the standard.

% Accuracy bleached = # of bleached colonies observed in mosaics / # of bleached colonies observed by both divers × 100

Results:

The prevalence of bleached corals at the Long-Term Monitoring demonstration site was low with only seven colonies being identified as bleached. Due to the small number of colonies the data for this question were combined with those from the Grounding and Traditional Metrics demonstrations. Over all three demonstrations, a total of 17 colonies were identified by diver or by a mosaic analyst as being bleached. Of the 17 colonies observed to be bleached, all the colonies that were identified by both diver observers as being bleached were also identified by the mosaic analyst as being bleached. Therefore the % accuracy for identifying bleached colonies was100% for mosaic observers.

Conclusion:

100% of colonies identified as being bleached by both diver observers were also identified as being bleached by mosaic observers.

Question 2:

What percentage of colonies identified by divers in the field as diseased were also identified by analysts looking at the mosaic as diseased?

Analysis: To evaluate the accuracy of mosaic monitoring to detect this indicator of coral condition, traditional percentage accuracy was computed using the number of corals identified by both divers as diseased as the standard.

% Accuracy diseased = # of diseased colonies observed in mosaics / # of diseased colonies observed by both divers × 100

Results: The prevalence of diseased corals at the Long-Term Monitoring demonstration site was low with only four colonies being identified as diseased. Due to the small number of diseased colonies, the data for this question were combined with the condition information from the Grounding and Traditional Metrics demonstrations. Over the three demonstrations, a total of 7 colonies were identified by diver or mosaic observers as being diseased. Of the 7 colonies observed to be diseased, all but one of the colonies that were identified by both diver observers as being diseased were also identified by the mosaic observer as being diseased. Therefore the % accuracy for identifying diseased colonies is (6/7 × 100 = 86% accuracy) for mosaic observers. The single diseased colony not observed by the mosaic observer as being disease was noted as having less than 5% of the colony infected by disease by both divers. The area may have been on the side of a colony and not visible to the mosaic image or was overlooked by the mosaic observer.

Conclusion: Six of the seven corals identified with disease by divers in the water were identified with disease by a mosaic observer. This suggests that mosaic observation was 86% accurate for identification of coral disease, and we conclude that mosaic analysis is a successful way to identify coral disease.

6.1.1.3 Coral Condition, Metrics 3-5: % Coral Bleaching, % New Mortality and % Old Mortality

The same absolute error approach used to compare coral colony sizes between diver and mosaic methods was used to assess the consistency of metrics of coral colony condition extracted from mosaics and diver surveys.

Question 1:

Is the difference in % coral bleaching as measured by a diver in the field and from a mosaic any larger than the difference as measured by two divers?

Question 2:

Is the difference in % new mortality as measured by a diver in the field and from a mosaic any larger than the difference as measured by two divers?

Question 3:

Is the difference in % old mortality as measured by a diver in the field and from a mosaic any larger than the difference as measured by two divers?

Results (for questions 1–3):

The abundance of corals in each of these categories (bleaching N = 7; diseased N = 4, new mortality N = 1, and old mortality N = 17) was extremely low at the Long-Term Monitoring demonstration site. Therefore, the results of this demonstration were pooled with those of the Grounding and Traditional Metrics demonstrations to increase the sample size for hypothesis testing. To see the results and discussion for these questions please refer to Section 6.4.1.

Conclusion (for questions 1–3):

There were an insufficient number of corals present to perform hypothesis testing. Data were combined across multiple demonstrations and is discussed in Section 6.4.1.

6.1.2 Performance Objective 2: Maintain Continuity with Long-Term, Map-Based Coral Reef Monitoring Data Sets.

As a reminder, the overall approach was:

(A) Select one of the plots for which AUTEC has historical data.
(B) Create hand-drawn maps of subsections of the selected plot and measure the sizes of all coral colonies within the subsection by divers
(C) Extract coral cover and sizes of individual colonies from the hand-drawn map.
(D) Mosaic the entire plot.
(E) Extract coral cover and sizes of individual colonies from the mosaic, using the subsection mapped by divers as a guide.
(F) Compare the sizes and estimates of total coral cover within the test plot as derived from hand-drawn map data with the size and percent coral cover estimated from scaled mosaic images.
(G) Compute the costs of diver and mosaic methods.

Steps A–E were described in Section 5.4.1 along with instructions for setting up the cameras. Step F is described here and Step G in Section 7.1.

Performance was quantified by two metrics as extracted from the mosaics and measured by divers. Metric 1 was coral colony size and metric 2 was % live coral cover. The statistical significance of the differences between and among methods was tested with a t-test or ANOVA, as appropriate.

6.1.2.1 Metric 1: Coral Colony Size

As a reminder, coral colony size was measured in three ways: (1) Diver A (RSMAS) and Diver B (Navy) in the field measuring maximum length and width of each colony, (2) Diver A (RSMAS) and Diver B (Navy) in the field estimating coral size through mapping 2 × 2 m areas by hand, and (3) using scaled pixels from mosaics. Five questions were used to determine if there was a difference in coral colony size due to the methods of measurement.

Question 1:

Are measurements of the size of individual coral colonies made by diver-drawn maps significantly different than measurements of the same colonies made from mosaic images?

Analysis:

Paired-samples t-test. Diver A mapped N colony sizes in the field, mosaic analyst A measured the same N colonies using scaled pixels from mosaic A. We computed N differences. Is the mean difference significantly different than 0?

- H0: There is no significant difference ($p > 0.05$) in the measurements of coral size as recorded on a hand-drawn map by diver A and measurements from mosaic A by analyst A.
- HA: There is a significant difference ($p \leq 0.05$) in the measurement of coral size when using the two methods.

Results:

A total of N = 71 corals were mapped in the field and measured by a mosaic analyst in the lab. The distributions of sizes were each transformed to normal using a square root transformation then tested using a paired t-test. Significance testing showed that there was no significant difference between sizes measured by divers mapping coral colonies in the field and those measured directly from mosaic images in Table 22, and Figure 71). The mean difference was 0.06 cm (Figure 65).

Table 22. Results of a paired *t*-test of coral colony sizes measured from mapped corals by divers and from mosaic analysts.

Test	N	Mean	*t*-value	P-value
Difference	71	0.06	1.06	0.29

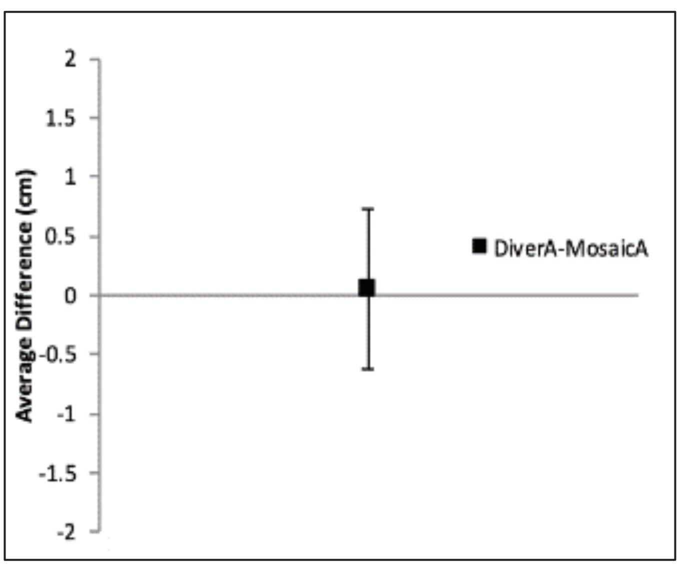


Figure 71. Mean difference and 95% confidence interval of coral sizes measured by divers mapping colonies and from mosaic images.

Question 2: Is the difference in colony size as measured from a hand-drawn map and from a mosaic any larger than the difference as measured by a diver in the field and from a mosaic, or from two hand-drawn maps, or by two divers?

Analysis: Two-factor ANOVA with measurement method and coral colony size class as the independent variables and coral size as the main effect. For each colony, four measures of the absolute error will be computed:

Absolute Error = AE = (|DiverA-DiverB|), (|MapA-MapB|), (|DiverA-Mosaic|), (|MapA-Mosaic)

For this design there are 3 null hypotheses and 3 alternative hypotheses:

Ho1: There is no significant difference ($p > 0.05$) in absolute error among the measurement methods

HA1: There is a significant difference ($p \leq 0.05$) in absolute error among the measurement methods

Ho2: There is no significant difference ($p > 0.05$) in the measurement of colony size based on coral size categories

HA2: There is a significant difference ($p \leq 0.05$) in the measurement of colony size based on coral size categories

Ho1-2: There is no interaction ($p > 0.05$) between size and measurement method

HA1-2: There is a significant interaction ($p \leq 0.05$) between coral size category and measurement method

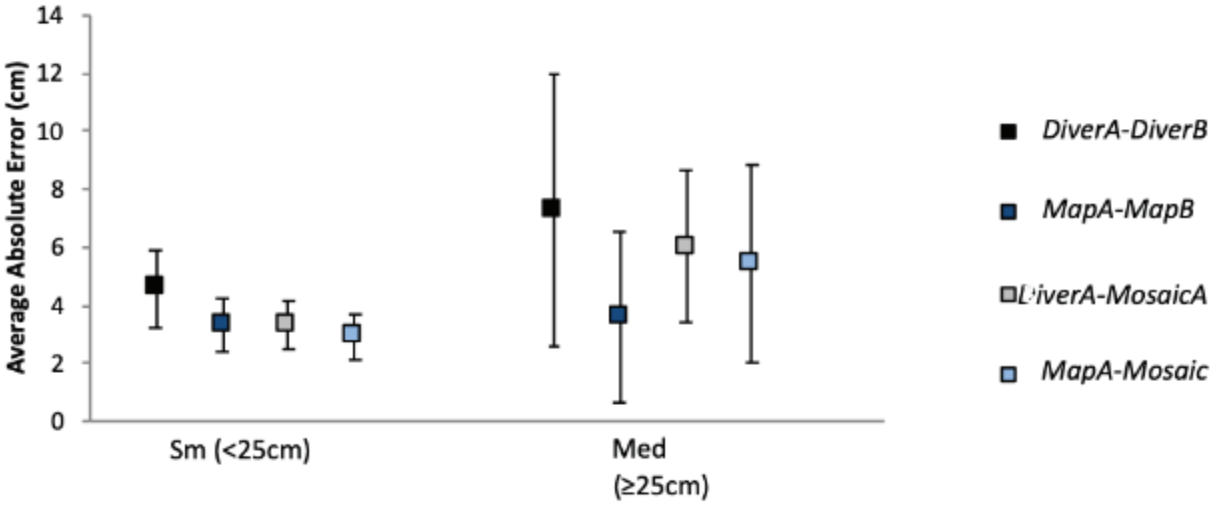
Results: The AE distributions measured for these tests were not normally distributed. In addition, of the 71 corals sampled, only 15 were of the larger size class. Due to these restrictions, a traditional two-way ANOVA was not applicable. A General Linear Model (GLM) ANOVA using ranked data was used to satisfy the nonparametric and unbalanced constraints of the data. The results of the GLM ANOVA are shown in Table 23.

Table 23. Results of GLM ANOVA testing for differences between 4 measurement methods.

Factors	SS	MS	F	P
Size	2018.8	2018.8	5.03	**0.03**
Method	870.3	290.1	0.72	0.54
Interaction	2655.4	888.5	2.21	0.08

- Methods shown include: (diver-diver, map-map, diver-mosaic, and map-mosaic) over two size classes (small, < 25, and medium, ≥ 25).
- Significant results are shown green.

The GLM ANOVA based on ranks indicated a significant difference in the absolute error estimates between small and large corals ($p = 0.03$) but that there was no significant treatment effect and no interaction between size and treatment (Table 23). These results are shown graphically in Figure 72 where the mean absolute error of small corals was significantly lower (~3 – 4.5 cm) than the mean absolute error of medium corals (~3.6 – 7.3 cm) regardless of the methods used (Figure 72).



- Sizes for two size classes are small (< 25cm) and medium (≥ 25cm)

Figure 72. Average absolute error and 95% confidence intervals for Diver-Diver, Map-Map, Diver-Mosaic, and Map-Mosaic differences in coral colony.

Conclusion:

There was a significant difference in the absolute error of coral size measurements based on colony size but there was no significant difference in absolute error between measurement methods, or any interaction between size and method when comparing multiple methods of estimating coral size. These data suggest that measuring small colonies was more accurate for all methods and that the error of the measurement increased with coral size. Despite the fact that there was an increase in measurement error as the size of the coral increased, the measurement error was present in all methodologies. This suggests that the error was inherent to the measurement and would be present regardless of whether or not the object is being measured by divers in the field, from mapping coral colonies, or from mosaics.

Question 3:

Is the difference in colony size as measured by multiple analysts using the same mosaic any larger than the difference as measured from two hand-drawn maps or by two divers?

Analysis: Two-factor ANOVA with measurement method and coral colony size class as the independent variables and coral size as the main effect. For each colony, three measures of the absolute error were computed:

Absolute Error = AE = (|DiverA-DiverB|), (|MapA-MapB|), (|AnalystA-AnalystB|)

For this design there are 3 null hypotheses and 3 alternative hypotheses:

Ho1: There is no significant difference ($p > 0.05$) in absolute error among the measurement methods

HA1: There is a significant difference ($p \leq 0.05$) in absolute error among the measurement methods

Ho2: There is no significant difference ($p > 0.05$) in the measurement of colony size based on coral size categories

HA2: There is a significant difference ($p \leq 0.05$) in the measurement of colony size based on coral size categories

Ho1-2: There is no interaction ($p > 0.05$) between size and measurement method

HA1-2: There is a significant interaction ($p \leq 0.05$) between coral size category and measurement method

Results:

The difference distributions used in this test were not normally distributed. In addition, of the 71 corals sampled, only 15 were of the larger size class. Due to these restrictions a traditional two-way ANOVA was no longer applicable for the proposed comparison. A General Linear Model (GLM) ANOVA using ranked data was used to satisfy the nonparametric and unbalanced constraints of the data. The results of the GLM ANOVA are shown in Table 24.

Table 24. Results of GLM ANOVA testing for differences between 3 measurement methods.

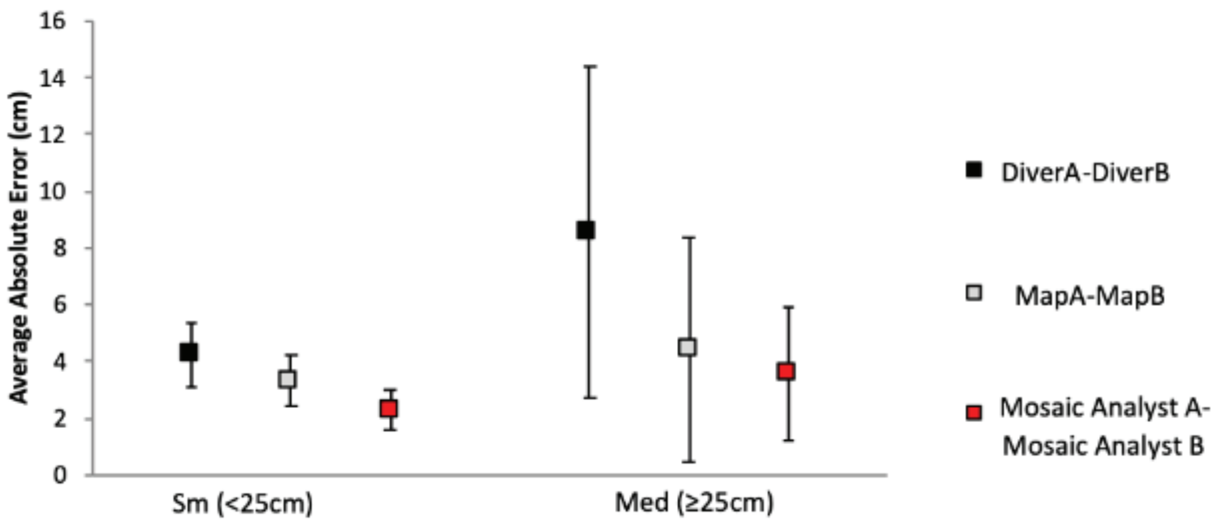
Factors	SS	MS	F	P
Size	1261.9	1261.9	3.59	0.06
Method	218.4	109.2	0.31	0.73
Interaction	499.0	249.5	0.71	0.49

- Methods include: (diverA-diverB, mapA-mapB, and mosaic analyst A-mosaic analyst B) over two size classes (small, < 25 and medium, ≥ 25).

The GLM ANOVA based on ranks indicated that there were no significant differences in the absolute error estimates between small and medium corals ($p = 0.06$) and that there was no significant treatment effect ($p = 0.73$) and no interaction between size and treatment ($p = 0.49$, Table 24). These results are shown graphically in Figure 73 where the mean absolute error of small corals was lower (~ 2.3 – 4.2 cm) than the mean absolute error of medium corals (~ 3.6 – 8.5 cm) regardless of the methods used (Figure 73). However, due to the large variability in coral size measurements, especially in the large size classes, sizes were not a significantly different factor.

Conclusion:

There was no significant difference in the absolute error of coral size measurements based on the method used, the size of the coral colony, or the interaction between size and method when comparing multiple methods (diver-diver, map-map, and mosaic analyst-mosaic analyst) methods of estimating coral size. The difference between this test and the tests performed in the previous question is the addition of multiple mosaic analysts. Multiple mosaic analysts had slightly lower AEs than divers performing traditional measurements or divers mapping colonies for both coral size classes. These results are not significant but it demonstrates that there is no more error in size measures when examined by two mosaic analysts when compared against more traditional methods of measuring coral size.



- Differences in coral colony sizes for two size classes, small (< 25cm) and medium (≥ 25cm).

Figure 73. Average absolute error and 95% confidence intervals for DiverA-DiverB, MapA-MapB, and Mosaic analyst A-Mosaic analyst B

Question 4:

Is the difference in colony size as measured by one analyst from multiple mosaics any larger than the difference as measured from two hand-drawn maps or by two divers?

Analysis:

Two-factor ANOVA with measurement method and coral colony size class as the independent variables and coral size as the main effect. For each colony, three measures of the absolute error were computed:

Absolute Error = AE = (|DiverA-DiverB|), (|MapA-MapB|), (|MosaicA-MosaicB|)

For this design there were 3 null hypotheses and 3 alternative hypotheses:

Ho1: There is no significant difference ($p > 0.05$) in absolute error among the measurement methods

HA1: There is a significant difference ($p \leq 0.05$) in absolute error among the measurement methods

Ho2: There is no significant difference ($p > 0.05$) in the measurement of colony size based on coral size categories

HA2: There is a significant difference ($p \leq 0.05$) in the measurement of colony size based on coral size categories

Ho1-2: There is no interaction ($p > 0.05$) between size and measurement method

HA1-2: There is a significant interaction ($p \leq 0.05$) between coral size category and measurement method

Results:

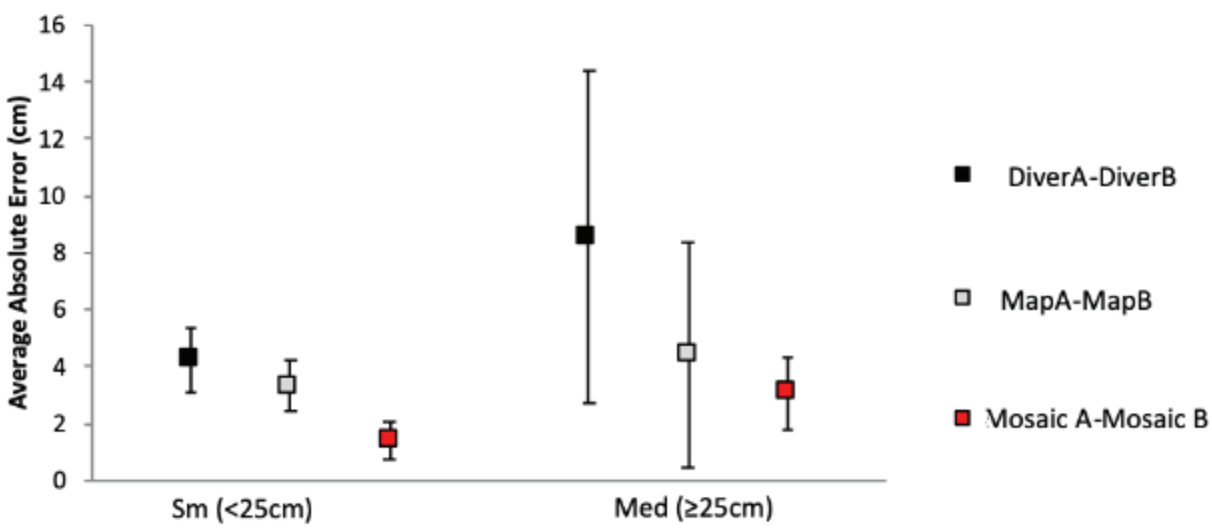
The difference distributions used in this test were not normally distributed. In addition, of the 71 corals sampled, only 15 were of the larger size class. Due to these restrictions, a traditional two-way ANOVA was no longer applicable for the proposed comparison. A General Linear Model (GLM) ANOVA using ranked data was used to satisfy the nonparametric and unbalanced constraints of the data. The results of the GLM ANOVA are shown in Table 23.

Table 25. Results of GLM ANOVA testing for differences between 3 measurement methods.

Factors	SS	MS	F	P
Size	2564.4	2225.7	6.67	**0.01**
Method	54.4	104.9	0.31	0.73
Interaction	1221.0	610.5	1.86	0.16

- Methods include: (diverA-diverB, mapA-mapB, and mosaic A-mosaic B) over two size classes (small, < 25, and medium, ≥).
- Significant results, if present, are shown green.

The GLM ANOVA based on ranks indicated that there was a significant difference in the absolute error estimates between small and medium corals (p=0.01) but that there was no significant treatment effect and no interaction between size and treatment (Table 25). These results are shown graphically in Figure 74 where the mean absolute error of small corals was significantly lower (~1.4 – 4.5 cm) than the mean absolute error of medium corals (~ 3.0 – 8.5 cm) regardless of the methods used (Figure 74).



- Small is defined as (< 25 cm) and medium (≥ 25 cm).

Figure 74. Average absolute error and 95% confidence intervals for DiverA-DiverB, MapA-MapB, and Mosaic A-Mosaic B differences in coral colony sizes for two size classes.

Conclusion: There was a significant difference in the absolute error of coral size measurements based on colony size but there is no significant difference in absolute error between measurement methods, or any interaction between size and method when comparing multiple methods (diverA-diverB, MapA-MapB, MosaicA-MosaicB) of estimating coral size. This suggests that the error was inherent to the measurement and is present regardless of whether or not the object is being measured by divers in the field, from mapping coral colonies, or from mosaics. The absolute error of colony size when measured by multiple mosaics was less than traditional measures of colony size made by divers or by mapping coral colonies in the field. The differences were not significant but it demonstrates that there is no more error in size measures when examined by two mosaics when compared against more traditional methods of measuring coral size. These data suggest that measuring small colonies is more accurate for all methods and that the error of the measurement increases with coral size.

Question 5: Are measurements made by a particular analyst repeatable?

Analysis: Paired samples t-test. Analyst A measured the sizes of N colonies from mosaic A. Analyst A then measured the sizes of these same colonies again. N differences between the repeat measurements were computed. The test for success was to determine if the mean difference was significantly greater than 0.

Ho: The mean difference in repeat measures of coral colony size by the same analyst from the same mosaic does not significantly differ ($p > 0.05$) from 0.

H1: The mean difference in repeat measures of coral colony size by the same analyst from the same mosaic does significantly differ ($p < 0.05$) from 0.

Results: A total of 71 corals mapped in the field were measured twice by the same analyst from the same mosaic. The distribution of the differences in sizes was not normal until transformed using a square root transformation. A paired t-test showed that there was no significant difference between sizes measured by an analyst measuring the same corals from a single mosaic twice (Table 26, Figure 75). The mean difference between measurements was 0.13 cm (Figure 75).

Table 26. Results of a paired *t*-test of coral colony sizes as measured twice by a single analyst from a single mosaic image.

Test	N	Mean	*t*-value	P-value
Difference	71	0.13	1.18	0.24

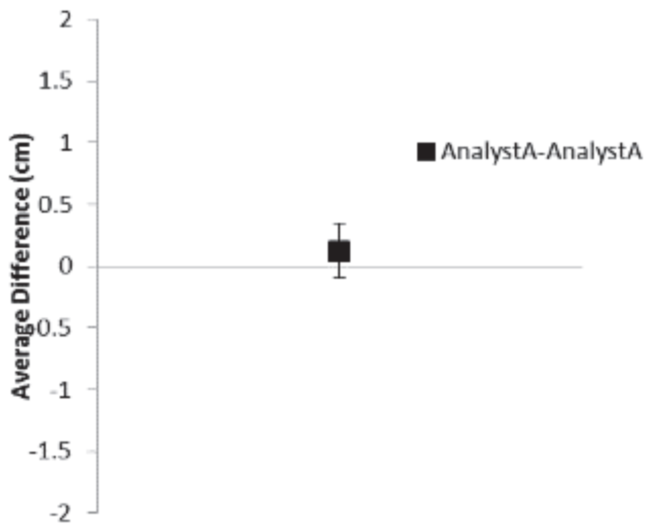


Figure 75. Mean difference and 95% confidence interval of coral sizes measured twice by a single analyst from a single mosaic image.

6.1.2.2 Metric 2: Coral Cover

Total coral cover was measured in two ways: (1) by digitizing the hand drawn maps of the areal extent of 2 × 2 m areas as performed by Diver A (RSMAS) and Diver B (Navy) in the field and (2), by digitizing the total live coral cover of 2 × 2 m area of interest using scaled pixels from mosaic products. To determine if there is a difference in the methods of measurement the following analyses were completed.

Question 1: Are measurements of percent coral cover made by diver-drawn maps significantly different than measurements of the same colonies made from mosaic images?

Analysis: Paired-samples t-test. Diver A mapped N 2 × 2 m quadrats by hand, mosaic analyst A digitized the live coral cover from a mosaic for the same N 2 × 2 m quadrats. We computed N × 4 differences in coral cover for 1 × 1 m subquadrats. Is the mean difference significantly different than zero?

H0: There is no significant difference ($p > 0.05$) in the measurements of coral cover as recorded on a hand-drawn map by diver A and measurements from mosaic A by analyst A.

HA: There is a significant difference ($p \leq 0.05$) in the measurement of coral cover when using the two methods.

Results: Mapping coral cover was extremely time consuming in the field. No single diver mapped more than two 2 × 2 m quadrats over a two-day period. Therefore the initial analysis was adjusted to examine the differences at the 50 × 50 cm scale in order to increase the sample size from N = 8 to N = 32. In addition, all data from the four divers in the field were combined and compared to a single mosaic analyst. A total of 55, 50 × 50 cm subquadrats were mapped by divers in the field and measured by a mosaic analyst in the lab. The distributions of percent cover estimates were tested using a paired t-test. The significance testing showed that there was no significant difference in the percent cover estimates measured in the field by divers performing hand mapping or by an analyst in the lab digitizing corals from a mosaic image. (Table 27, and Figure 76). The mean difference between area measurements was 0.002 m^2 (Figure 76).

Table 27. Results of a paired *t*-test of coral cover as measured by divers in the water performing hand mapping and from an analyst digitizing corals from a mosaic image.

Test	N	Mean	*t*-value	P-value
Difference	55	0.003	-1.47	0.146

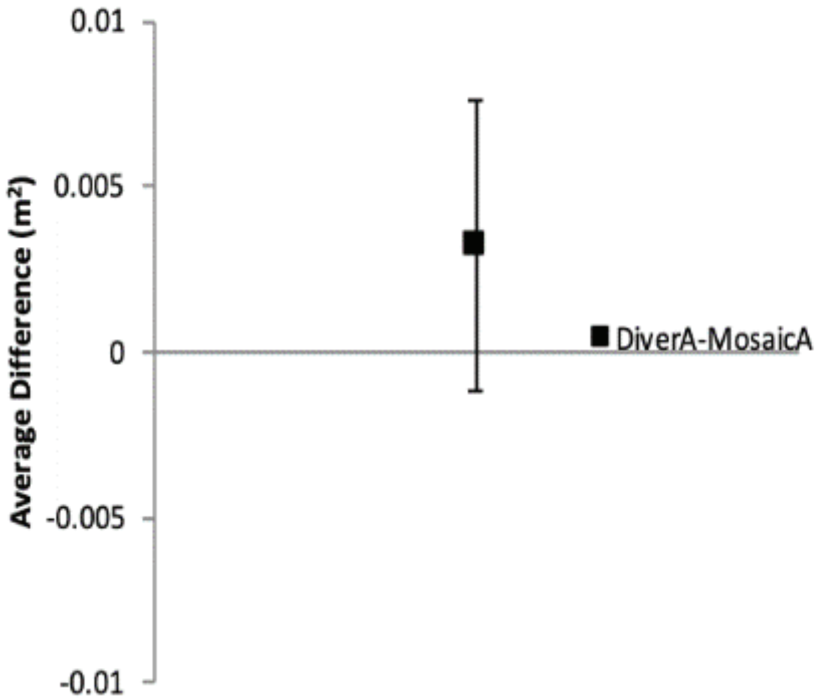


Figure 76. Mean difference and 95% confidence interval of coral cover measured by divers mapping coral colonies by hand in the field and from an analyst digitizing coral cover from a mosaic image.

Conclusion: There was no significant difference in the measurements of coral cover as recorded on a hand-drawn map by diver and measurements from a digitizing coral cover by a mosaic analyst.

Question 2: Is the difference in percent coral cover as measured from a mosaic and from a hand-drawn map any larger than the difference as measured by two divers making hand-drawn maps?

Analysis: ANOVA with measurement method as the independent variable and percent coral cover as the main effect. For each colony, two measures of the absolute error were computed:

Absolute Error = AE = (|Hand-drawn mapA-Hand-drawn map B|) and (|Hand-drawn mapA-MosaicA|)

The null and alternative hypotheses were:

Ho: There is no significant difference ($p > 0.05$) in absolute error between the measurement methods

HA: There is a significant difference ($p \leq 0.05$) in absolute error between the measurement methods

Results: In this test we initially proposed that an ANOVA would be the most appropriate test. However, since only two methods were tested, the results of an ANOVA will be the same as a t-test of independent samples. Using percent cover data from the 55 50×50 cm sub-quadrats, the absolute error distributions were not normally distributed. Thus, a nonparametric Mann-Whitney U test was used in lieu of the t-test.

Since a nonparametric test was used, we found that the median AE values of two divers and that of a mosaic analyst and diver were not significantly different from each other (Table 28). In addition, the mean AE for both methods was 0.009 m^2 (Figure 77). Since both the medians and mean values of each sample are the same we conclude that there are no detectable differences between methods for estimating coral cover.

Table 28. Results of the Mann Whitney U test of medians comparing the absolute error of coral measurements.

Method	N	Median	W	P-value
AE Divers	55	0.005	3052.0	1.00
AE Mosaic	55	0.005		

- Content taken from two divers performing hand mapping and from a mosaic analyst and diver measurements. Significant results, if present, are shown in bold.

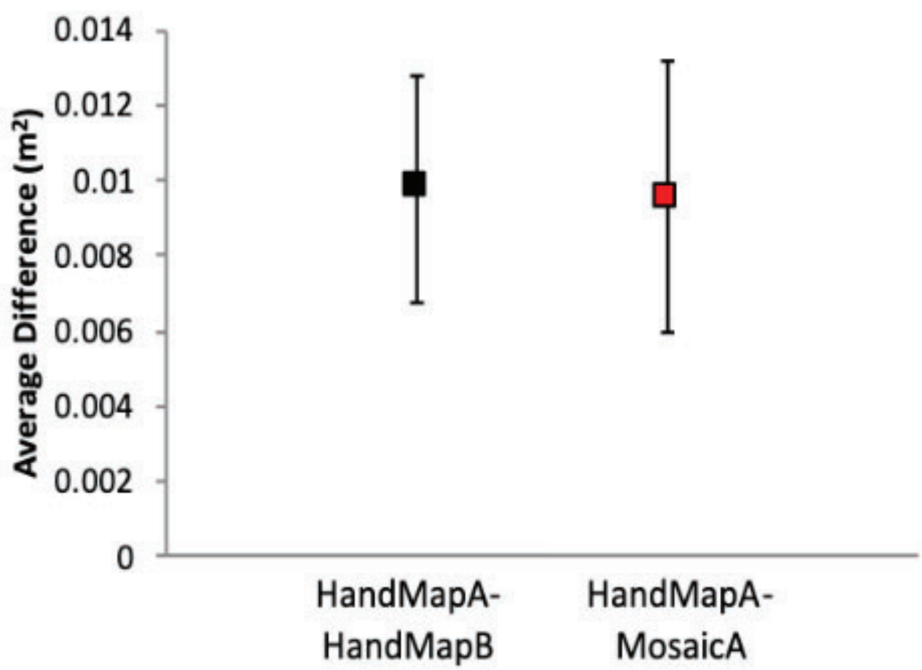


Figure 77. Mean absolute error and 95% confidence intervals of coral cover measured by two divers mapping coral colonies by hand and from a mosaic analyst and diver.

Conclusion: There was no significant difference in absolute error between two divers performing manual mapping in the field and a mosaic and diver analyst estimating percent coral cover.

Question 3: Is the difference in percent coral cover measured by multiple analysts using the same mosaic any larger than the difference as measured by two divers making hand-drawn maps?

Analysis: ANOVA with measurement method as the independent variable and percent coral cover as the main effect. For each colony, two measures of the absolute error were computed:

Absolute Error = AE = (|Hand-drawn mapA-Hand-drawn map B|) and (|AnalystA – Analyst B|)

The null and alternative hypotheses are:

Ho: There is no significant difference ($p > 0.05$) in absolute error between the measurement methods

HA: There is a significant difference ($p \leq 0.05$) in absolute error between the measurement methods

Results: In this test we initially proposed that an ANOVA would be the most appropriate test. However, since only two methods were tested, the results of an ANOVA will be the same as a t-test. Using data from the 55 50×50 cm sub-quadrats, we found that the absolute error distributions of percent cover were not normally distributed. Therefore, a nonparametric Mann Whitney U test was used in lieu of the t-test.

The nonparametric test compared the median AE values of two divers and two mosaic analysts and found they were not significantly different from each other (Table 29). In addition, the mean AE for hand drawn mapping was 0.009 m^2 and from two mosaic analysts was 0.007 m^2 (Figure 78). Since the mean absolute error for two mosaic analysts was slightly less than two divers performing hand mapping we have demonstrated that there was no additional error in percent cover measurements when examined by two mosaic analysts.

Table 29. Results of the Mann Whitney U test of medians comparing the absolute error of coral measurements.

Method	N	Median	W	P-value
AE Maps	55	0.009	3242.0	0.26
AE Mosaics	55	0.007		

- Measurements.were collected from two divers performing hand mapping and from two mosaic analysts digitizing coral cover from a single mosaic image. Significant results, if present, are shown in bold.

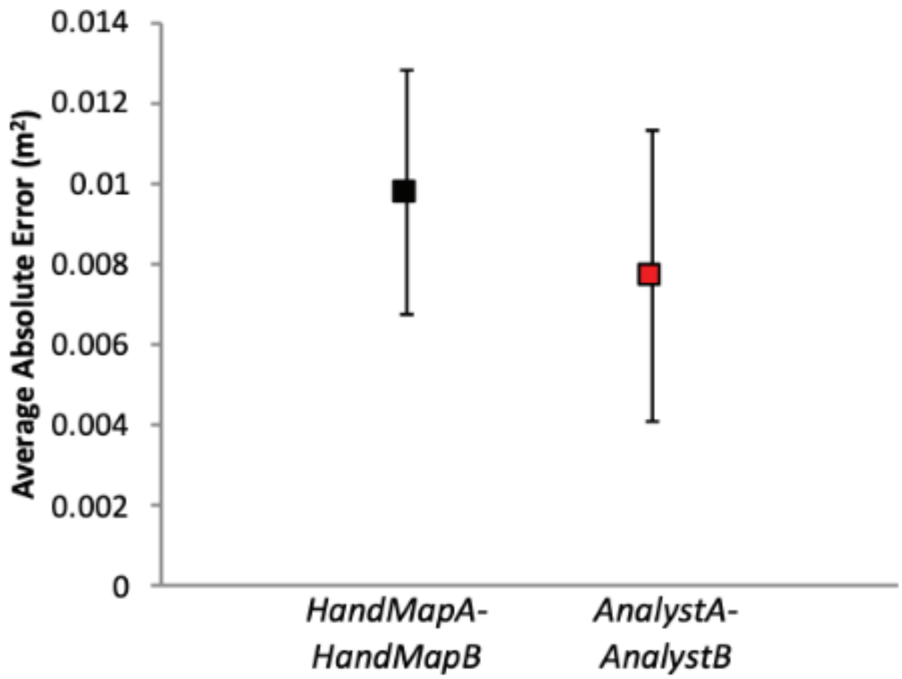


Figure 78. Mean absolute error and 95% confidence intervals of coral cover measured by two divers mapping coral colonies by hand and from two analyst digitizing coral cover from a single mosaic image.

Conclusion: There was no significant difference in absolute error between two divers performing manual mapping in the field and two mosaic analysts digitizing coral cover from a single mosaic image.

Question 4: Is the difference in percent coral cover as measured by one analyst from multiple mosaics any larger than the difference as measured by two divers making hand-drawn maps?

Analysis: ANOVA with measurement method as the independent variable and percent coral cover as the main effect. For each colony, two measures of the absolute error were computed:

Absolute Error = AE = (|Hand-drawn mapA-Hand-drawn map B|) and (MosaicA-MosaicB|)

The null and alternative hypotheses are:

Ho: There is no significant difference ($p > 0.05$) in absolute error between the measurement methods

HA: There is a significant difference ($p \leq 0.05$) in absolute error between the measurement methods

Results: In this test we initially proposed that an ANOVA would be the most appropriate test. However, since only two methods were tested, the results of an ANOVA should be the same as a t-test. Using data from the 55 50 × 50 cm sub-quadrats, we found that the absolute error distributions of percent cover were not normally distributed, thus a nonparametric Mann Whitney U test was used in lieu of the t-test.

The nonparametric test compared the median AE values of two divers and a mosaic analyst measuring percent cover from two mosaics and found that they were not significantly different from each other (Table 30). In addition, the mean AE for hand drawn mapping was 0.009 m^2 and from one mosaic analyst digitizing coral cover from two mosaic images was 0.006 m^2 (Figure 79). Since the mean absolute error for the mosaic analyst digitizing two different mosaic images was slightly less than two divers performing hand mapping we have demonstrated that there was no additional error in percent cover measurements when examined by an analyst across two mosaic images.

Table 30. Results of the Mann Whitney U test of medians comparing the absolute error of coral measurements from two divers performing hand mapping and from one mosaic analyst digitizing coral cover from two mosaic images.

Method	N	Median	W	P-value
AE Maps	55	0.009	3211.0	0.34
AE Mosaics	55	0.006		

- Significant results, if present, are shown in bold.

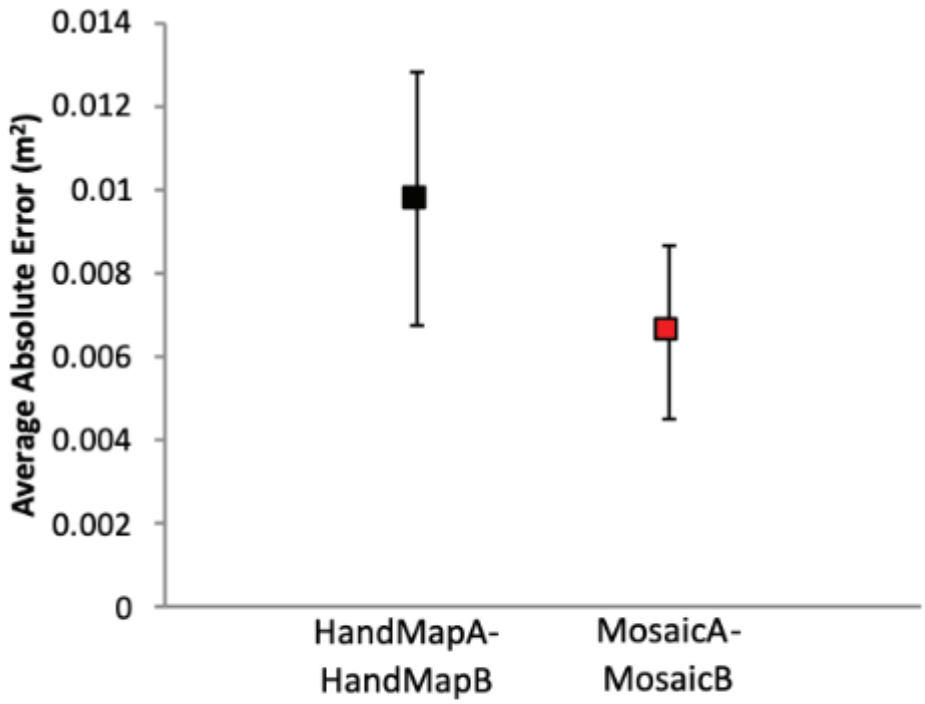


Figure 79. Mean absolute error and 95% confidence intervals of coral cover measured by two divers mapping coral colonies by hand and from a single analyst digitizing coral cover from two mosaic images.

Conclusion: There was no significant difference in absolute error between two divers performing manual mapping in the field and a mosaic analyst digitizing coral cover from two different mosaic images.

Question 5: Are measurements made by a particular analyst repeatable?

Analysis: Paired samples t-test. Analyst A digitized the area of live coral tissue for N quadrats from mosaic A. Analyst A then digitized the area of live coral tissue from these same quadrats again. N differences between the repeat measurements will be computed. The test is to determine if the mean difference is significantly greater than 0.

Ho: The mean difference in repeat measures of coral colony size by the same analyst from the same mosaic does not significantly differ ($p > 0.05$) from 0.

H1: The mean difference in repeat measures of coral colony size by the same analyst from the same mosaic does significantly differ ($p < 0.05$) from 0.

Results: This test was performed using data from mosaic analyst Brooke Gintert. First, the difference data for percent cover measurements were not normally distributed, thus a Wilcoxon Signed Rank test was used in lieu of the proposed t-test. All 55 sub-quadrats drawn by divers in the field were digitized twice by the same mosaic analyst. The results of the Wilcoxon Signed Rank test are shown in Table 31.

Table 31. Results of Wilcoxon Signed Rank test comparing the repeatability of mosaic measurements of coral cover from a single analyst.

Observer	N	Median Diff.	Wilcoxon Stat	P-value
B. Gintert	55	0.00	3036.0	0.92

The Wilcoxon Signed Rank test showed that the median differences in measures of coral cover were not significantly different when measured repeatedly by the same observer (Table 31, Figure 80). These results demonstrate that mosaic methods of digitizing coral cover are repeatable on the same mosaic image. This result is consistent with that of coral sizes shown earlier in this performance objective.

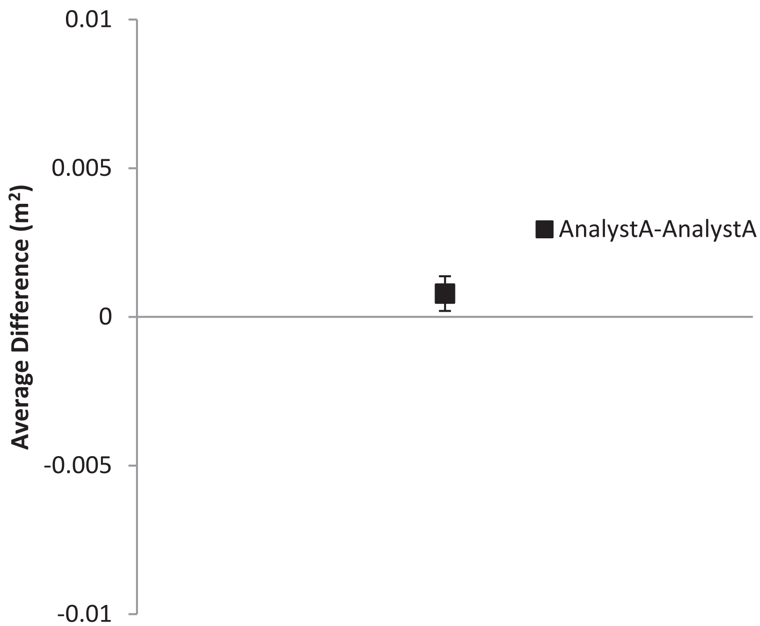


Figure 80. Mean difference between mosaic measurements of coral cover made by a single observer twice on the same mosaic image.

Conclusion: Repeat measures of coral cover made by the same analyst from the same mosaic were not significantly different than 0.

6.1.3 Performance Objective 3: Ease of Use

The question evaluated with PO 3 was whether newly trained divers could acquire images that would be suitable for making mosaics. Performance was assessed by the incorporation percentage metric and the visual quality rating metric. Success was defined by mosaics created with data from newly trained users rated ≥ 4 on average in visual quality and for which the incorporation percentage is ≥ 90% of the value computed for the mosaic created for the same area by an experienced user.

Results: A total of four Navy divers were trained on the use and deployment of the underwater camera system for mosaic acquisition. Following training, each of the four navy divers was asked to acquire mosaic data over the two study sites surveyed in PO 1. Images acquired by Navy divers were processed by the same procedure as described in Section 5.4.1 by a RSMAS mosaic technician. Images were evaluated based on the visual quality and incorporation percentage as described in Section 3.1.3.

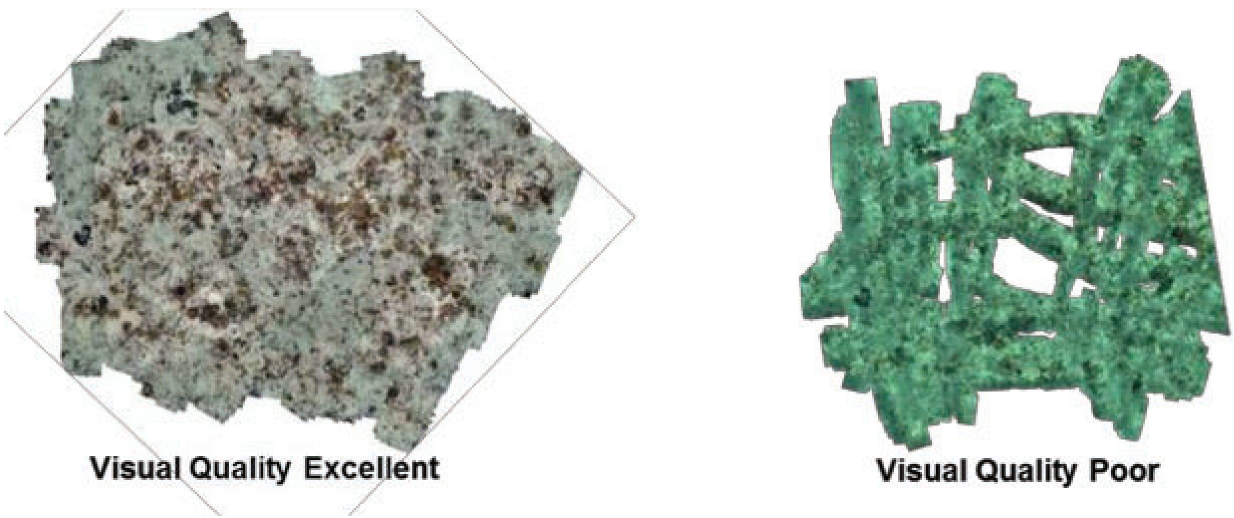
The data revealed that practice with the camera equipment improved data quality rapidly (Table 32). On their first attempt, two of the divers had problems with incorporation percentage, and two had problems with visual quality (Table 32). Following the first set of mosaic acquisitions, users were encouraged to ask questions and make any adjustments recommended by experienced users. In general, the problems encountered had easy fixes. For example, Navy diver 4 scored 0s on survey 1 because the cameras were not powered on, so no data were acquired. After additional familiarity with the equipment, this diver achieved perfect scores on his second attempt. Following the second data acquisition, data from all the newly trained divers were considered to be equal to those of experienced users based on both the incorporation percentage and visual quality (Table 32).

Table 32. The relative incorporation percentage and visual quality rating of Navy personnel mosaic surveys.

Relative Incorporation Percentage			Visual Quality		
Mosaic Survey	Survey 1	Survey 2	Mosaic Survey	Survey 1	Survey 2
Navy Diver 1	82%	100%	Navy Diver 1	5	5
Navy Diver 2	100%	100%	Navy Diver 2	5	5
Navy Diver 3	100%	100%	Navy Diver 3	2	5
Navy Diver 4	0%	100%	Navy Diver 4	0	5

- **Red** indicates areas that failed to meet the success criteria. A successful survey is required to have a 90% or better incorporation percentage and visual quality rating of four or greater.

The results of this test show that it was better for both the incorporation percentage and visual quality of mosaic images to have some access to expert users following the first acquisition of mosaic images (Table 32, Figure 81). However, the fact that all Navy users were able to acquire images that produced mosaics that were visually indistinguishable those of expert users after two in-field surveys demonstrates that this technology can be transitioned with minimal training.



- Two examples are shown: (Visual Quality Excellent, left) and a poor visual quality rating (right).

Figure 81. An example of an excellent visual quality rating.

The ability to train divers without biological / ecological expertise to collect reef mosaic data is a significant advantage over traditional reef methodologies. As Navy ecologists are fewer in number than skilled Navy SCUBA divers, this technology creates an opportunity to leverage the support divers who typically assist Navy ecologists in the field. This may be especially useful when a disturbance of interest (i.e., a grounding or bleaching event) occurs near a Navy installation at a time when an expert Navy ecologist is not available or it is cost prohibitive to fly them to the site of interest. In this situation, a trained Navy diver with the proper equipment could acquire the data in the field and send the information back to the expert coral reef ecologist for ecological analysis. This could result in cost and time savings to the Navy and increase the amount of useful coral reef data that could be acquired in a timely manner.

Conclusion: Following in-water training and two image acquisition trials, Navy personnel were able to acquire mosaic image data that was indistinguishable from expert users.

6.2 ENDANGERED SPECIES DEMO PERFORMANCE ASSESSMENT

Sections 6.2.1, 6.2.2 and 6.2.3 provide the results of Performance Objectives 1, 2, and 3, respectively, from the Endangered Species Act (ESA) demonstration performance. Results are summarized on Table 33.

Table 33. A summary of the Endangered Species Act demonstration performance assessment. The main questions of each performance objective are listed and a color code is given to the assessment of each question.

PO.Metric	Question	Status	Conclusions
PO1.1	1. Do diver and mosaic counts of *A. palmata* colony abundance differ?	**Complete**	The counts of threatened coral colonies made from mosaics agreed with divers at one site but differed by < 10% at two others. These small differences in counts are not likely to have practical implications but failed the test because the divers agreed perfectly.
PO1.2	1. Are the locations of *A. palmata* colonies as measured by divers and mapped from the mosaics significantly different?	**Complete**	There was no significant difference (p = 0.07) in absolute error between the measurement methods.
PO2.1	1. Are measurements of the size of the individual coral colonies made by a diver significantly different than measurements made by the same diver from mosaic images?	**Complete**	There was no significant difference (p = 0.344) in the measurement of coral sizes of threatened species when measured in-situ by diver A and from a mosaic as measured by analyst A.
PO2.1	2. Is the difference in colony size as measured by a diver in the field and from a mosaic any larger than the difference as measured by two divers?	**Complete**	There was no significant difference (p = 0.28) in absolute error between the measurement methods.
PO3.1	1. Are measurements of the % live cover of individual coral colonies made by a diver significantly different than measurements made by the same diver from mosaic images?	**Complete**	There was no significant difference (p = 0.98) in the estimation of % live tissue of threatened coral species when measured in-situ by diver A or from a mosaic.
PO3.1	2. Is the difference in average % live cover as estimated visually by a diver in the field and from a mosaic any larger than the difference of estimations by two divers?	**Complete**	There was no significant difference (p = 0.10) in absolute error between the measurement methods.
PO3.2	1. Do diver and mosaic assessments of *A. palmata* colony type differ?	**Complete**	Diver and mosaic assessments of colony type agreed for all but one colony that the mosaic analyst could not determine whether it was loose or attached to the substrate.

- **Green** color code suggests that all aspects of the test were successful.
- **Yellow** indicates that not all aspects were successful or that inconsistencies were discovered during the analysis of the question, a red color code indicates a failure of that performance objective.

6.2.1 Performance Objective 1: Coral Colony Location and Abundance

As a reminder, the overall approach was:

(A) Map the plot using the procedure defined by Williams *et al.* (2006).
(B) Collect imagery for a mosaic of the plot.
(C) Extract the number and locations of each colony within the plot from the mosaic.
(D) Compare the colony abundance and locations as derived by each method.
(E) Compute the costs of each method.

Steps A–C were described in Section 5.4.2 along with instructions for setting up the cameras. Step D is described here and step E in Section 7.2.

6.2.1.1 Metric 1: Acropora palmata Colony Abundance

Question 1: Do diver and mosaic counts of *Acropora palmata* colony abundance differ?

The number of *A. palmata* colonies were counted by two divers and by one analyst looking at the mosaics. To determine if there was a difference in the total number of colonies estimated by the two methods, the following test based on a threshold comparison was used (Table 5):

> Consider the smaller estimate of abundance by the divers as "min-diver" and the larger estimate of abundance by the divers as "max-diver." Compute Δ-diver = max-diver - min-diver. Use the smaller of Δ-diver or 10% of min-diver as the threshold for success. If the number of colonies counted by the analysts from the mosaic is ≥ min-diver - threshold, the test is considered a success.

Results: Divers independently counted coral colonies within a 7 m radius of a marker pin based on the criteria described in Section 5.5.2. The colony counts from each diver and those of the mosaic analyst are plotted in and the minimum threshold of success and the result of the test are shown in Table 31.

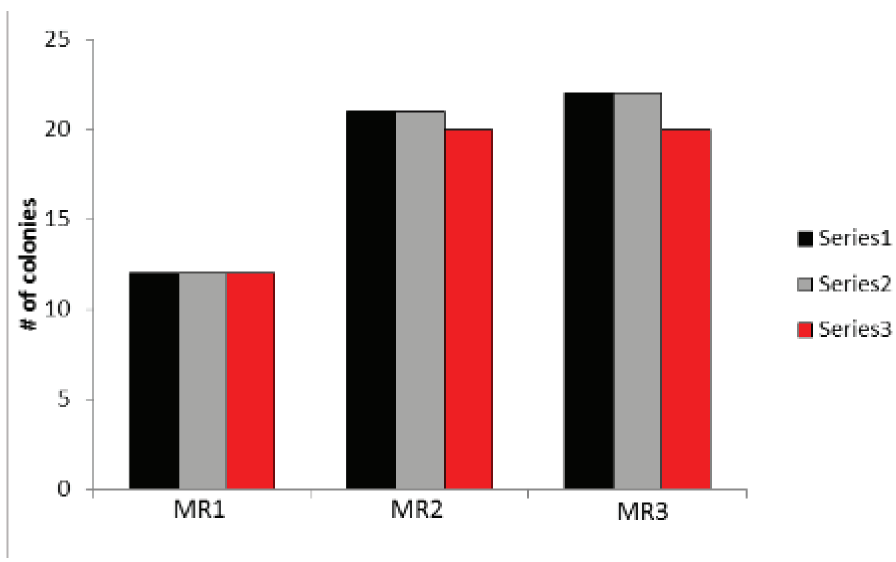
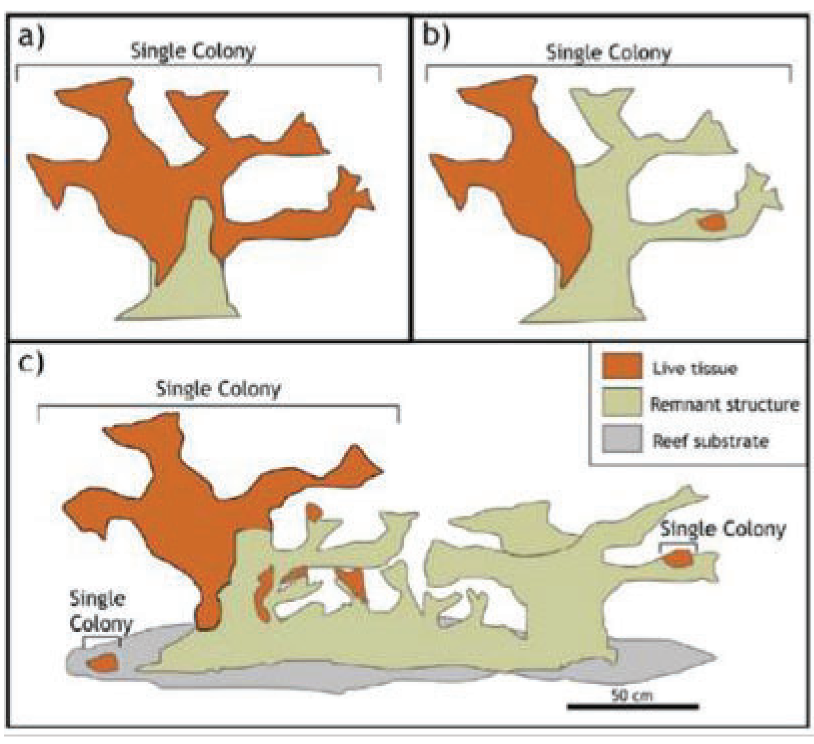


Figure 82. Colony counts of *Acropora palmata* at three test sites (MR1, MR2, and MR3) as recorded by two divers and a mosaic analyst.

Table 34. Colony counts from Diver 1 and Diver 2 and the mosaic analyst, the calculated Δ Diver, and minimum threshold of success, and the determination of a successful test.

Site	Diver1	Diver2	Δ Diver	10% min Diver	Minimum Threshold	Mosaic Analyst	Success
MR1	12	12	0	1	12	12	Y
MR2	21	21	0	2	21	20	N
MR3	22	22	0	2	22	20	N

Counts were perfectly consistent between divers (Table 34 and Figure 82). At site MR1 counts from the mosaic agreed with the divers whereas at sites MR2 and 3 counts from the mosaic were slightly lower than the diver counts. Due to the distinctive color and texture of *A. palmata* tissue, its colonies are usually highly visible. Therefore, the recorded difference between divers and mosaics was likely due to differences in what was considered a single coral colony. Due to severe mortality in this threatened coral species, many colonies have suffered partial mortality, leaving remnants of living tissue on coral skeletons in areas that are distant from the rest of the coral colony (see Figure 83). for an illustrated example). In some cases it was impossible to tell if small patches of living tissue were remnants of a larger, single colony or whether they represented new recruitment to a portion of a partially dead colony. Differentiating between a remnant of an old colony and a newly-recruited individual was determined by the best judgment of the diver at the time of the survey and is subject to interpretation. Differentially interpreting live tissue as new or remnant colonies affects the total number of colonies counted in a given area and thereby leads to variability in colony counts among analysts.



- (taken from Williams *et al.* 2006).

Figure 83. Diagram of general characteristics used to distinguish coral colonies.

Mosaic analyst counts of *A. palmata* abundance were always within 10% of the diver counts, however due to the lack of variability in coral counts between two diver observers in the field, mosaic analyst counts were not always greater than the minimum threshold of success (Table 34)

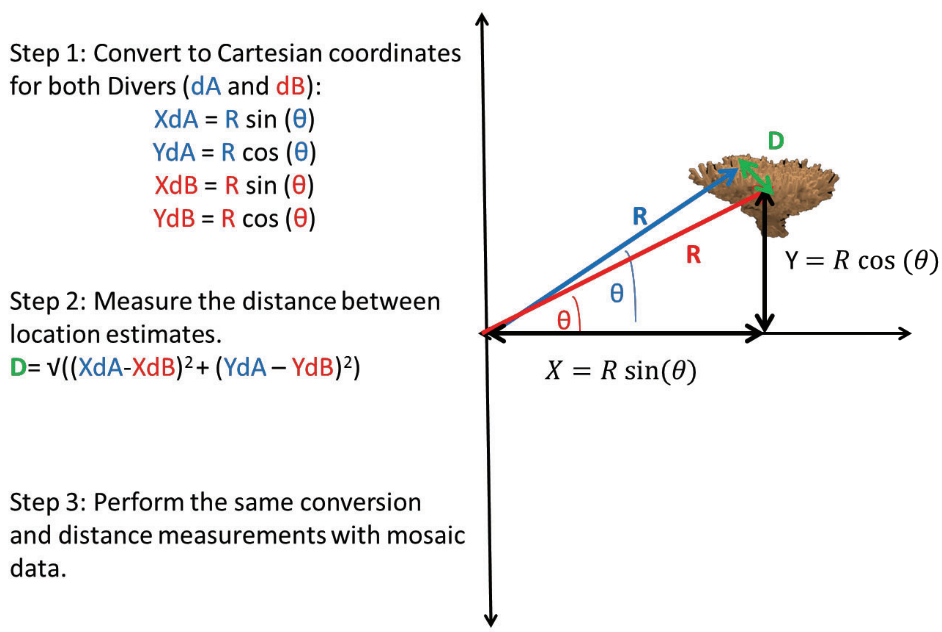
Conclusions: Mosaic analysis only partially passed the designed test for counting threatened coral colonies. At sites where colonies were easily distinguished, the test passed. At sites with patches of live tissue on remnant structure, some colonies identified as multiple by divers were grouped as a single colony by the mosaic analyst.

6.2.1.2 Metric 2: Acropora palmata Colony Locations

Question 1: Are the locations of *Acopora palmata* colonies as measured by divers and mapped from the mosaics significantly different?

The locations of *A. palmata* colonies were mapped by two divers and by the mosaics. To determine if there was a difference in the locations estimated by the two methods, the following test was used:

> Paired-samples *t*-test. For this comparison we examined the absolute error of diver-diver measurements as compared with diver to mosaic measurements. Diver A and Diver B have both measured distance and bearing to at least $N = 30$ colonies. These distance and bearing measurements were converted to Cartesian coordinates using $X = R \sin(\theta)$ and $Y = R \cos(\theta)$, where R is the distance and θ is the bearing to the colony (Figure 84). The absolute error between divers were computed as $D_d = ((X_dA\text{-}X_dB)^2 + (Y_dA\text{-}Y_dB)^2)^{0.5}$ where (X_dA, Y_dA) are the coordinates from diver A and (X_dB, Y_dB) are the coordinates from diver B. Then the absolute error between the divers and mosaic were computed as $D_m = ((X_dA\text{-}X_m)^2 + (Y_dA\text{-}Y_m)^2)^{0.5}$ where (X_m, Y_m) are the coordinates from the mosaic.



- **Blue** items are are line slope labels for XdA
- **Red** items are are line slope labels for XdB
- **Green** shows the relative distance between XdA and XdB top of the line slopes

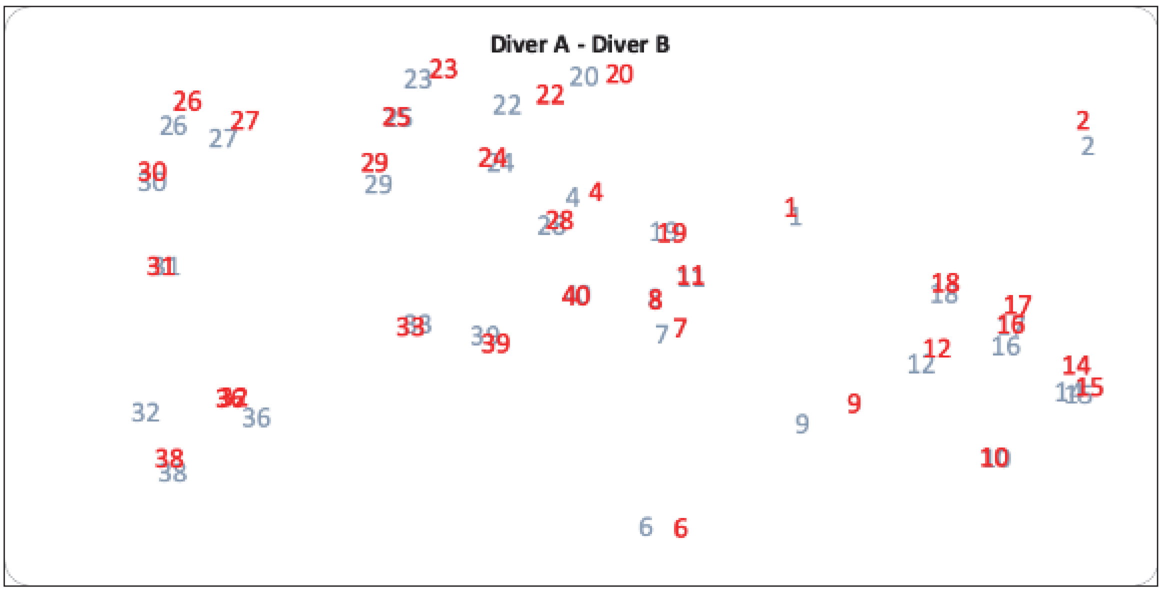
Figure 84. Diagram of how to calculate the distance (D) between two diver estimates of colony location when using distance and angle measurements.

The question asked was if the mean value of D_d was significantly different than the mean value of D_m?

Ho: There is no significant difference ($p > 0.05$) in absolute error between the measurement methods

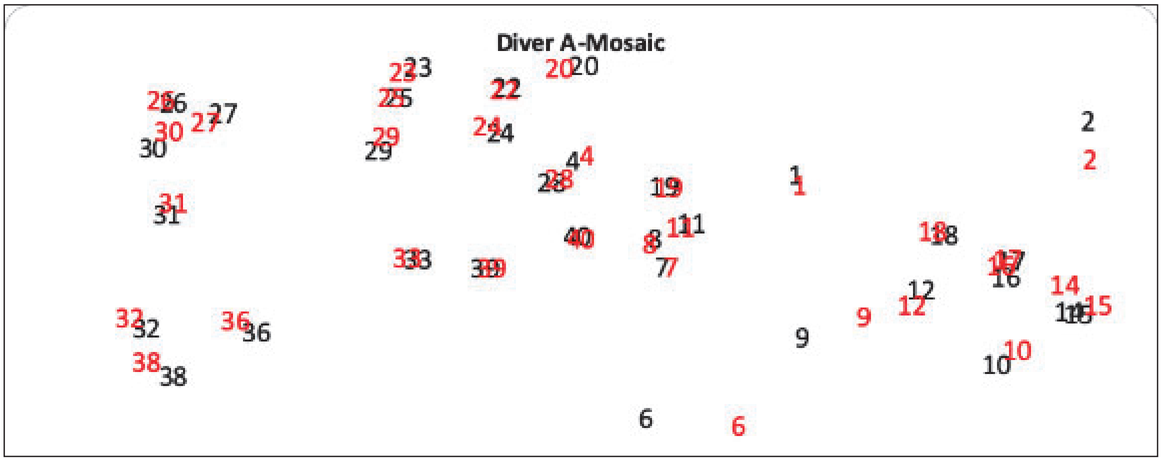
HA: There is a significant difference ($p \leq 0.05$) in absolute error between the measurement methods

Results: A total of 43 colonies of the threatened coral species *Acropora palmata* were mapped by divers in the field and by mosaic analysts using scaled pixels. The mapped positions of the coral colonies as measured by the two divers in the field are shown in Figure 85. The mapped positions as measured by a diver in the field and from a mosaic image are shown in Figure 86.



- Blue gray numbers indicate positions measured by Diver1.
- Red numbers indicate positions measured by Diver 2. The origin is the location of the marker pin at each site. X and Y scale is noted in mm. Coral colonies were combined over three sites for the above location information.

Figure 85. Mapped locations of threatened coral colonies of *Acropora palmata* as measured by two divers in the field.



- **Black** numbers indicate positions measured by Diver1.
- **Red** numbers indicate positions measured by the mosaic analyst. The origin is the location of the marker pin at each site. X and Y scale is noted in mm. Coral colonies were combined over three sites for the above location information.

Figure 86. Mapped locations of threatened coral colonies of *Acropora palmata* as measured by one diver and one mosaic analyst.

The absolute error of two divers measuring locations of threatened corals was not significantly different than the absolute error of a mosaic analyst and diver measuring the locations of threatened corals (P = 0.57, Table 35, Figure 87).

Table 35. Paired *t*-test determining if the absolute error of diver-diver location measurements are significantly different than the absolute error of a diver and mosaic analyst location measurements.

Variable	N	Mean (cm)	Std Dev	*t*-value	P-value
AE Diver1-Diver2	36	32.7	26.5	NA	NA
AE Mosaic1-Diver1	36	28.8	24.8	NA	NA
Difference	36	NA	NA	2.03	0.57

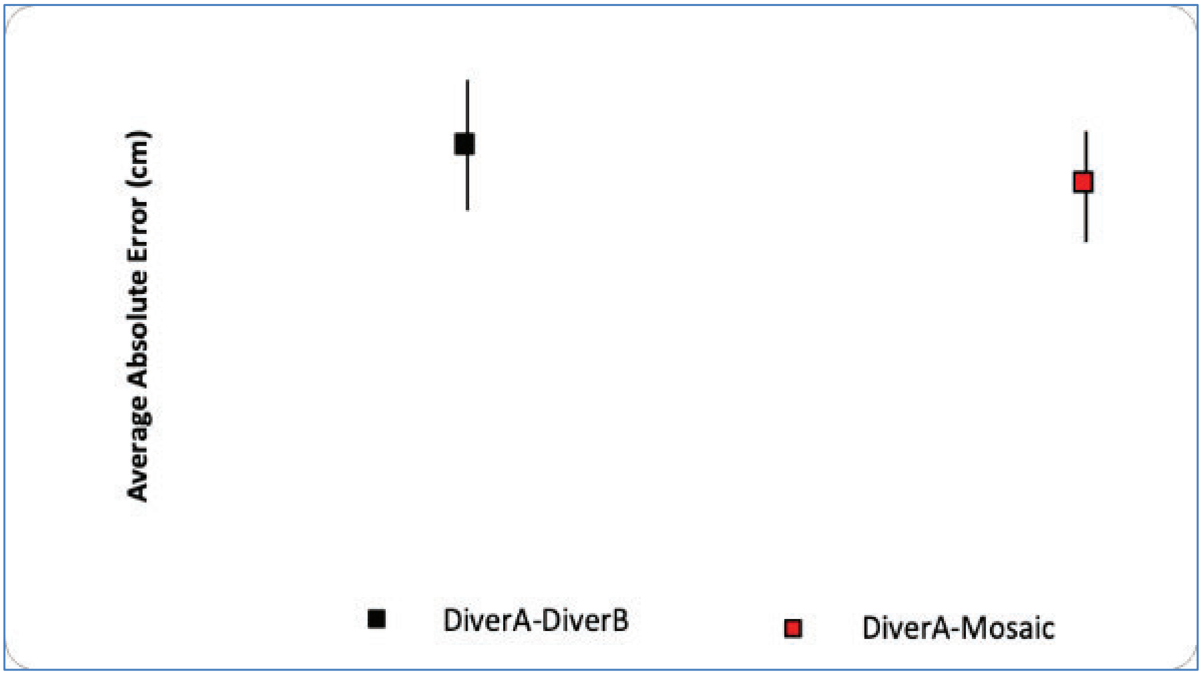


Figure 87. The mean and +/- standard error of colony location estimates as estimated by two divers (divers) and from a mosaic and diver observer (mosaics).

Conclusion: The mean absolute error of two divers measuring coral locations (D_d) was not significantly different than the mean absolute error of a mosaic and diver analyst (D_m).

6.2.2 Performance Objective 2: Coral Colony Size

As a reminder, the overall approach was:

(A) Measure the sizes of each colony in the plot using the procedure defined by Williams *et al.* (2006).
(B) Collect imagery for a mosaic of the plot.
(C) Extract the sizes of each colony within the plot from the mosaic.
(D) Compare the colony sizes as derived by each method.
(E) Compute the costs of each method.

Steps A, B, and C were described in Section 5.4.2 along with instructions for setting up the cameras. Step D is described here and Step E in Section 7.2.

Colony size was measured directly in the field by each of two divers. These colonies were then measured in the lab from the mosaics using scaled pixels to determine the maximum length and width from the mosaics. To determine if there is a difference in the methods of measurement the following analyses were completed.

Question 1: Are measurements of the size of the individual coral colonies made by a diver significantly different than measurements made by the same diver from mosaic images?

Analysis: Paired-samples t-test. Diver A measured N lengths in the field, the mosaic analyst measured the same N lengths using scaled pixels from a mosaic. Is the mean difference between the N lengths significantly different than zero?

H0: There is no significant difference ($p > 0.05$) in measurement of coral sizes of threatened species when measured in-situ by diver A and from a mosaic as measured by analyst A.

HA: There is a significant difference ($p \leq 0.05$) in measurement of coral sizes of threatened species when measured in-situ by diver A and from a mosaic as measured by analyst A.

Results: B. Gintert measured the coral colonies used in this test both as the diver sampling the corals in-situ, and as the mosaic analyst measuring colony size from the mosaic image. The size measurement data were not normally distributed. The size distributions from both methods were transformed using a log transformation and tested for significance using the paired t-test. Means and standard deviations of each distribution and the results of the paired t-test are shown in Table 36.

Conclusion: There was no significant difference ($p = 0.344$) in the measurement of coral sizes of threatened species when measured in-situ by diver A and from a mosaic as measured by analyst A.

Table 36. Distribution information and results of the paired *t*-test.

Variable	N	Mean (cm)	Std Dev	*t*-value	P-value
Diver	43	76.0	67.9	NA	NA
Mosaic	43	74.9	67.5	NA	NA
Difference	43	1.07	5.4	0.96	0.344

- *The t*-test determined if mosaic and diver size measurements of threatened coral species *Acropora palmata* are significantly different from each other.

Question 2: Is the difference in colony size as measured by a diver in the field and from a mosaic any larger than the difference as measured by two divers?

Analysis: Paired-samples t-test. For this comparison we examined the absolute error of diver-diver measurements as compared with diver-mosaic measurements. Diver A and Diver B both measured N = 43 length measurements. The mosaic analyst also extracted sizes from the mosaic of the site for the same colonies. For each distance measurement, two measures of the absolute error were computed:

Absolute Error = AE = (|DiverA-DiverB|) and (|DiverA-MosaicA|)

The question being asked is whether the mean diver - mosaic difference was significantly different than the mean diver - diver difference.

Ho: There is no significant difference ($p > 0.05$) in absolute error between the measurement methods

HA: There is a significant difference ($p \leq 0.05$) in absolute error between the measurement methods

Results: The absolute error data from the measurement of coral sizes from divers in the field and from a mosaic analyst were not normally distributed. The absolute error size distributions were transformed using a log transformation and tested for significance using the paired t-test. Means and standard deviations of each distribution and the results of the paired t-test are shown in Table 37.

Table 37. Distribution information and results of the paired *t*-test.

Variable	N	Mean (cm)	Std Dev	*t*-value	P-value
AE DiverA-DiverB	43	5.53	7.2	NA	NA
AE DiverA-Mosaic	43	3.88	3.87	NA	NA
Difference	43	1.65	9.96	1.08	0.28

- *The t*-test determined if the absolute error of diver and mosaic measurements of threatened coral species *Acropora palmata* are significantly different than each other.

The absolute error between diver-diver size measurements and from a diver and mosaic analyst were not significantly different from one another (P=0.28, Table 37) Although not significantly different, the mean difference in size measurements was larger for two divers in the field (mean = 5.53) than for a mosaic and diver analyst (mean = 3.88cm) (Table 37, Figure 88).

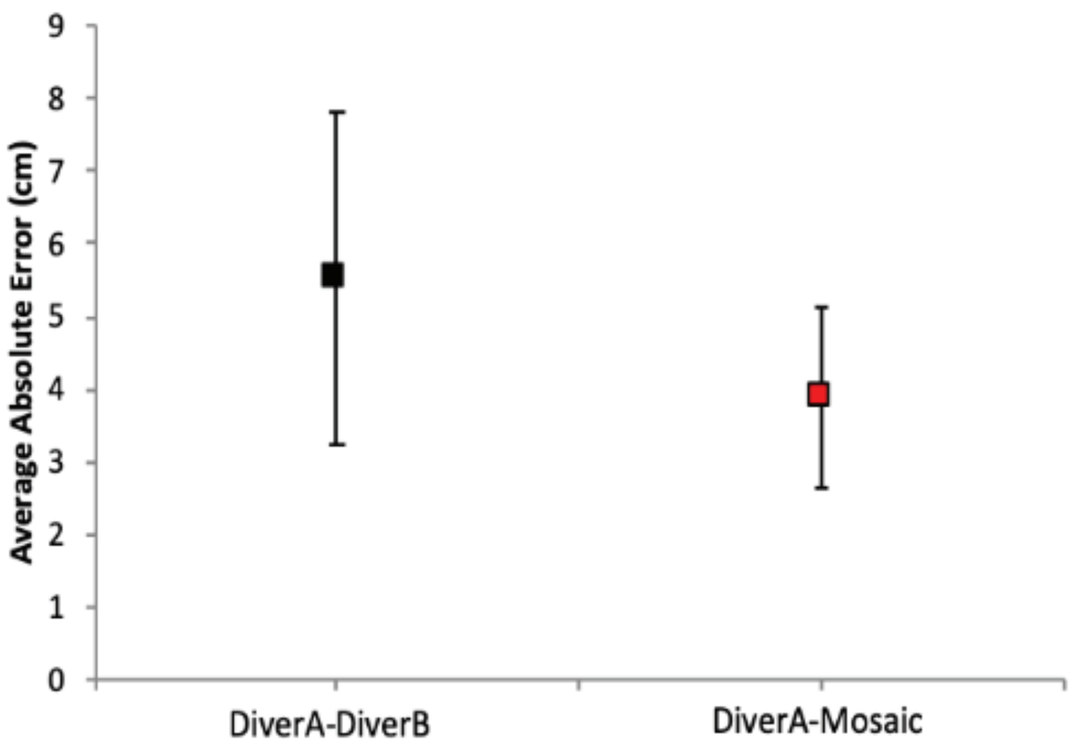


Figure 88. Mean absolute error of size measurements of threatened coral species *Acropora palmata* as measured by two divers in the field and from a mosaic analyst and a diver in the field.

Conclusion: There was no significant difference (p = 0.28) in absolute error between the measurement methods.

6.2.3 Performance Objective 3: Coral Colony Descriptors

(A) Estimate the % live cover and colony type for each colony in the plot using the procedure defined by Williams *et al.* (2006).
(B) Collect imagery for a mosaic of the plot.
(C) Extract the % live cover and colony type for each colony within the plot from the mosaic.
(D) Compare the % live cover and colony type as derived by each method.

Steps A, B, and C were described in Section 5.4.2 along with instructions for setting up the cameras. Step D is described here.

6.2.3.1 Metric 1: % Live Tissue Cover

The percent of each *Acropora palmata* colony that was covered by live tissue was estimated visually by two divers and by one analyst looking at the mosaics. To determine if there was a difference in the average % live cover estimated by the two methods, the following tests were used:

Question 1: Are measurements of the % live cover of individual coral colonies made by a diver significantly different than measurements made by the same diver from mosaic images?

Analysis: Paired-samples t-test. Diver A estimated % live cover for N = 43 colonies in the field, the mosaic analyst estimated % live cover for the same N colonies from a mosaic. Is the mean of the N differences significantly different than zero?

H0: There is no significant difference ($p > 0.05$) in estimated % live cover as recorded in-situ by diver A and measurements from a mosaic by an analyst.

HA: There is a significant difference ($p \leq 0.05$) in estimated % live cover when using the two methods.

Results: B. Gintert estimated the % of live tissue on each of the *A. palmata* colonies, both in the field and from the mosaic images used in this test. The estimates of % live tissue from a diver in the field and from a mosaic image were tested for significance using the paired t-test. The results of the paired t-test are shown in Table 38.

Table 38. Results of the paired *t*-test determining if mosaic and diver estimate of % live tissue of threatened coral species *Acropora palmata* are significantly different than each other.

Variable	N	Mean (%)	Std Dev	*t*-value	P-value
Difference	43	5.87	7.78	2.02	0.98

The estimates of % live tissue made by the same analyst in the field and from a mosaic image were very similar. The mean difference between methods was 5.9% with a standard deviation of less than 10% (Table 38). These results suggest that a single analyst can maintain consistency of estimates of % live tissue when using an in-situ method and from a mosaic image.

Conclusion: There was no significant difference ($p = 0.98$) in the estimation of % live tissue of threatened coral species when measured in-situ by diver A and from a mosaic by analyst A.

Question 2: Is the difference in average % live cover as estimated visually by a diver in the field and from a mosaic any larger than the difference of estimations by two divers?

Analysis: Paired-samples t-test. For this comparison we examined the absolute error of diver-diver estimates as compared with diver to mosaic estimates. Diver A and Diver B both estimated the % live cover for N = 43 colonies. The mosaic analyst has also estimated the % live cover for the same colonies. For each colony, two measures of the absolute error were computed:

Absolute Error = AE = (|DiverA-DiverB|) and (|DiverA-MosaicA|)

The question being asked is whether the mean diver - mosaic difference was significantly different than the mean diver - diver difference.

Ho: There is no significant difference ($p > 0.05$) in absolute error between the measurement methods

HA: There is a significant difference ($p \leq 0.05$) in absolute error between the measurement methods

Results: The absolute error of diver and mosaic estimates of % live tissue were tested for significance using the paired t-test. Means and standard deviations of each distribution and the results of the paired t-test are shown in Table 39.

Table 39. Distribution information and results of the paired *t*-test

Variable	N	Mean (cm)	Std Dev	*t*-value	P-value
AE DiverA-DiverB	43	8.99	8.99	NA	NA
AE DiverA-Mosaic	43	5.88	7.78	NA	NA
Difference	43	2.75	6.50	2.67	0.10

- The *t*-test determined if the absolute error of diver and mosaic estimates of % live tissue of *Acropora palmata* were significantly different than each other.

The absolute error between diver-diver size estimates of % live tissue and from a diver and mosaic analyst were not significantly different from one another (P = 0.10, Table 39). Although not significantly different, the mean difference in estimates of % live tissue was larger for two divers in the field (mean = 8.99%) than for a mosaic and diver analyst (mean = 5.88%) (Table 39, Figure 89).

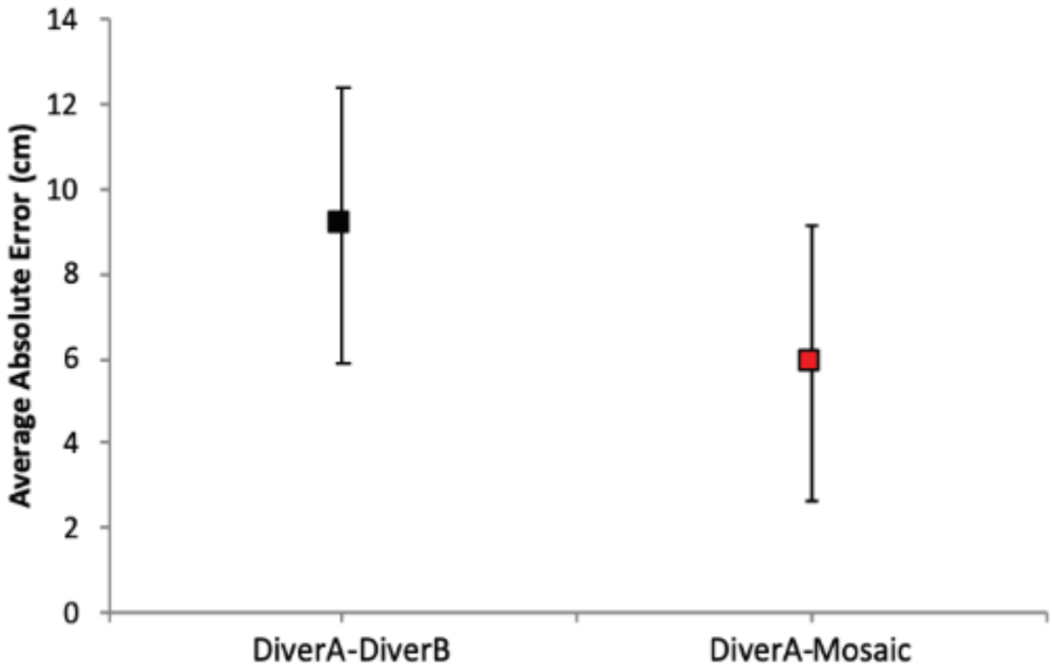


Figure 89. Mean Absolute error of % live tissue estimates of threatened coral species *Acropora palmata* as measured by two divers in the field and from a mosaic analyst and a diver in the field.

Conclusion: There was no significant difference ($p = 0.10$) in absolute error between the measurement methods. The smaller difference in estimates of % live tissue observed between a mosaic and diver analyst was likely due to the fact that the same analyst observed the coral colonies in each case (B. Gintert). Because the data from the two divers are from two separate people the estimates of % live tissue are likely to be less consistent than if observed by a single observer.

6.2.3.2 Metric 2: Acropora palmata Colony Type

Question: Do diver and mosaic assessments of *Acropora palmata* colony type differ?

The number of *A. palmata* colonies of each of the following types were counted by two divers and by one analyst looking at the mosaics: branched colony, remnant colony, attached fragment, stable fragment, loose fragment. To determine if there was a difference in the type determination of colonies estimated by the two methods, the following test based on a threshold comparison was used for each colony type:

Analysis: Consider the smaller count of the number of colonies of a given type by the divers as "min-diver" and the larger count by the divers as "max-diver." Compute Δ-diver = max-diver - min-diver. Use the smaller of Δ-diver or 10% of min-diver as the threshold for success. If the number of colonies of the same type counted from the mosaic is ≥ min-diver - threshold, and ≤ max-diver + threshold, the test is considered a success.

Results: The data for both divers and mosaic analyst identifying the 43 corals by colony type are shown in Table 40. Neither the two divers nor the mosaic analyst identified every colony as the same type every time (Figure 90), but the values counted from the mosaic were always between the "min-diver" and "max-diver" values, so every category was a success.

Table 40. The number of colonies of each type observed by two divers and a mosaic analyst.

Colony Type	Diver1	Diver2	Mosaic	Δ Diver	10% min Diver	Threshold	Mosaic >= thresh
Branching Colony	30	34	33	4	3	27	YES
Remnant Colony	7	5	5	2	1	4	YES
Loose Fragment	11	9	12	3	1	8	YES
Stable Fragment	1	3	2	2	0	1	YES
Attached Fragment	3	1	0	2	0	1	NO
Totals	52	52	52				

- The Δ diver counts and the mosaic-minimum diver count are also shown to show if the mosaic is successful at detecting coral colony types.

Conclusion: Diver and mosaic assessments of *Acropora palmata* colony type were significantly different for the attached fragment category but no others.

The results of this test show that there was some disagreement about what type of colonies were found at a given site both between two divers and when observed from a mosaic (Table 40). None of the categories were the same for both divers, and most of the mosaic evaluations were between the diver counts. The main difficulty in identifying what type of colony was present related to the fact that all observations were made without touching the threatened coral colony. This inability to handle the corals made it difficult to determine with certainty if the colony was an attached fragment or possibly a loose or stable fragment.

Although the categories were found to be subject to interpretation, the fact that the mosaic analyst colony counts (for all types) were within the error of two divers in the field shows that there is no disadvantage for identifying threatened coral colony type from a mosaic as opposed to in situ by a diver for most categories. The attached fragment case was an exception in this demonstration, but we note that it was a class with limited numbers, so small differences in counts made a big difference in test "success." For example, if one of the fragments identified as "loose" on the mosaic had been identified as "attached" then all of the classes would have passed.

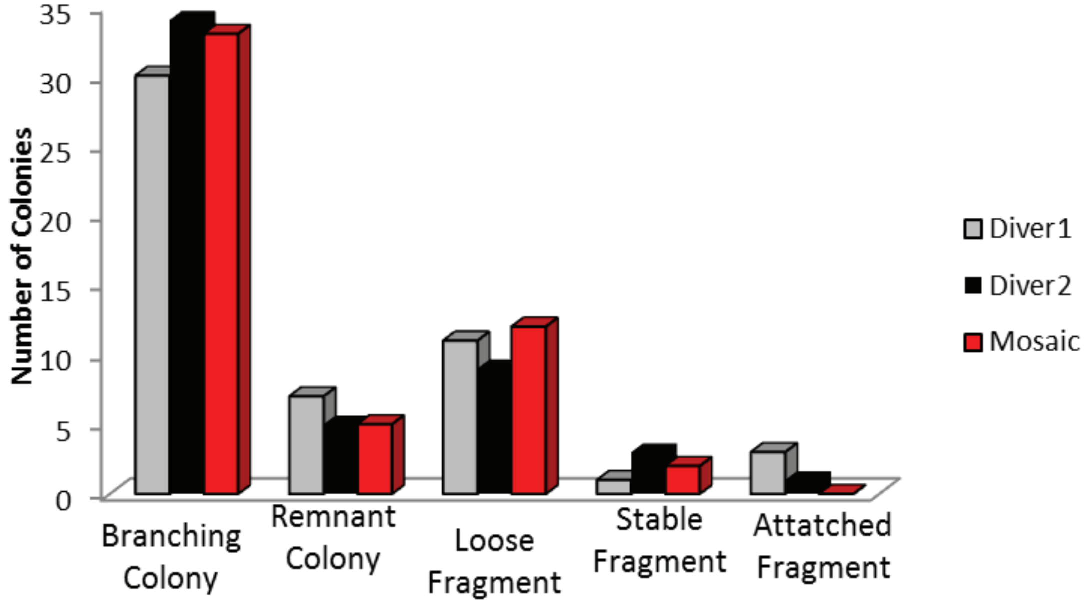


Figure 90. Numbers of colonies identified as various colony types by two diver observers and one mosaic observer.

6.3 GROUNDING DEMONSTRATION PERFORMANCE ASSESSMENT

Sections 6.3.1 to 6.3.5 provide the results of Performance Objectives 1 to 5, respectively, from the Grounding Demonstration. Results are summarized in Table 41.

Table 41. A summary of the grounding demonstration performance assessment.

PO.Metric	Question	Status	Conclusions
PO1.1	1. Are estimates of damaged area significantly different when measured by a diver, GPS, or a mosaic?	**Complete**	The fishbone method estimate of of damaged area was > 10% larger than both the GPS and mosaic methods due to different areas sampled.
PO2.1	1. Is the distribution of diver-mosaic measurements significantly different than zero for long linear distances?	**Complete**	There was no significant difference in distribution of linear measurements of damaged areas recorded in situ by a diver or from a mosaic analyst (p=0.25).
PO2.1	2. Are linear measurements on the scale of a few meters as measured by a diver and from a mosaic any different than the difference measured by two divers?	**Complete**	The differences in linear measurements on the scale of a few m as measured by 2 divers were not significantly different than the differences between a diver and a mosaic (p=0.43).
PO3.1	1. Is the bias in long linear measurements from mosaics, divers, or GPS significantly different than zero?	**Complete**	Mosaic bias was not significantly different than zero (p=0.06), however one set of diver bias was not significantly different than zero (p=0.43) and the other was significantly different (p=0.01). GPS measurements were significantly different than zero (p=0.00). Average mosaic and diver measurements were within 1 cm of truth and are thus considered highly accurate methods for measuring long-linear distances
PO3.1	2. Is the bias in size measurement made from mosaics any different from the size bias for measurements made by divers or GPS?	**Complete**	The GPS measurement bias was significantly different than that of divers or mosaics when measuring long linear distances

- The main questions of each performance objective are listed and a color code is given to the assessment of each question.
- **Green** color code suggests that all aspects of the test were successful.
- **Yellow** indicates that not all aspects were successful or that inconsistencies were discovered during the analysis of the question.
- **Red** color code indicates a failure of that performance objective.

Table 40. A summary of the grounding demonstration performance assessment. (Continued)

PO.Metric	Question	Status	Conclusions
PO4.1	1. Are plot-scale measurements of the % cover for a given class made by a diver significantly different than those made from a mosaic?	**Complete**	Tests comparing LPIT and mosaic estimates of percent cover were not significantly different for corals, sponges, macroalgae, and coralline algae. However, some differences were found between diver estimates of gorgonian and sand cover between divers and mosaics.
PO4.2	1. Are plot-scale estimates of coral species richness made from a mosaic at least as large as those made by a diver?	**Complete**	The mosaic point count method of assessing species richness was not equivalent to information collected by divers in the field, however the mosaic visual inspection method was equivalent to divers for estimating species richneess.
PO4.3	1. Do plot-scale measurements of the size-frequency distribution of coral colonies made by a diver significantly differ from the size-frequency obtained from mosaic images?	**Complete**	There was no significant difference in the estimates of coral colony size frequency as recorded *in situ* by divers and estimated from a mosaic image of the same area (p=0.72)
PO1.4	1. Is the difference in % coral bleaching as measured by a diver in the field and from a mosaic any larger than the difference as measured by two divers?	Complete	There were an insufficient number of bleached corals present to perform hypothesis testing. Data were combined across multiple demonstrations and are discussed in Section6.4.1.
PO1.5	1. Is the difference in % new mortality as measured by a diver in the field and from a mosaic any larger than the difference as measured by two divers?	Complete	There were an insufficient number of diseased corals present to perform hypothesis testing. Data were combined across multiple demonstrations and are discussed in Section6.4.1.
PO1.6	1. Is the difference in % old mortality as measured by a diver in the field and from a mosaic any larger than the difference as measured by two divers?	Complete	There were an insufficient number of corals with old mortality present to perform hypothesis testing. Data were combined across multiple demonstrations and are discussed in Section 6.4.1
PO4.7	1. Does site-averaged juvenile coral colony density as measured by a diver significantly differ from estimates made from mosaics?	**Complete**	There was no significant difference in the mean juvenile coral density as estimated *in situ* by divers and that from a mosaic at the grounding demonstration site (p=0.06 outside the scar and p=0.24 inside the scar).

- The main questions of each performance objective are listed and a color code is given to the assessment of each question.
- **Green** color code suggests that all aspects of the test were successful.
- **Yellow** indicates that not all aspects were successful or that inconsistencies were discovered during the analysis of the question.
- **Red** color code indicates a failure of that performance objective.
- **Grey** color indicates that data for this question were combined with data from other demonstrations and discussed in a different section.

Table 40. A summary of the grounding demonstration performance assessment. (Continued)

PO.Metric	Question	Status	Conclusions
PO5.1	1. Are coral colony size estimates made from a mosaic by a Navy analyst significantly different than those made by a RSMAS analyst?	Complete	There was no significant difference in the estimate of coral colony size as recorded by RSMAS and Navy analysts (p=0.17).
PO5.2	1. Are plot-scale estimates of the % live coral cover made from a mosaic by a navy analyst significantly different from estimates made by a RSMAS analyst?	Complete	The estimates of percent cover obtained by the UM and Navy analyst were not significantly different for the categories of corals, gorgonians, sponges, zoanthids, and macroalgae. However, estimates were significantly different in the category of sand / pavement / rubble.

- The main questions of each performance objective are listed and a color code is given to the assessment of each question.
- **Green** color code suggests that all aspects of the test were successful.
- **Yellow** indicates that not all aspects were successful or that inconsistencies were discovered during the analysis of the question.
- **Red** color code indicates a failure of that performance objective.

6.3.1 Performance Objective 1: Comparison of Area of Damage

The overall approach used to compare the area of damage of a grounding scar using multiple methods was:

(A) Collect a mosaic of the grounding scar including a buffer of unaffected area surrounding the damage.
(B) Collect a GPS track of the boundary between the damaged and undamaged area.
(C) Collect linear measurements of the width of the scar using the “fishbone” technique.
(D) Reacquire mosaic and GPS data over the scar including markers left by the fishbone measurements delineating the edges.
(E) Compute and compare the area of the damage as measured by all three techniques.
(F) Compute the costs of each method.

Steps A-D were described in Section 5.4.3 along with instructions for setting up the cameras. Step E is described here and step F in Section 7.3.

To compute the damaged area from all three methods (mosaic, GPS, and fishbone) data were imported into a GIS-environment, raw measurements were converted into polygons and the area of the polygons were computed as the area of damage.

The mosaics were imported to a GIS as a georeferenced image. Within the GIS, the polygon digitization tool was used to trace the border of the damaged area. The GPS track was imported to a GIS as points. The points defined the vertices of the polygon bounding the damaged area. The fishbone data was first transcribed from the diver datasheets, and then imported to the GIS as points, which then defined the vertices of the polygon bounding the damaged area. The main difference between these methods was that the analyst needed to interpret the mosaic to determine where the border should be placed whereas the decision for where the boundary should be placed was made in the field for the other two methods.

Having defined the bounding polygon for each of the three methods, the area was then reported by the GIS. Since N = 1 for PO 1, there was no statistical test to perform. Instead, we assessed performance by the relative agreement among methods. Specifically, the success criterion for the mosaics was that they measure an area that is within 10% of the area measured by the other methods.

The areas of damage determined by mosaics were not significantly different from GPS measurements of damage. The average area measurement made directly from mosaics (150 m2) was within 6% of the average measurement of the same damage area made by a diver swimming a hand-held GPS (159 m2) (Figure 91). The area measurements made by divers performing a fishbone damage assessment were 19% higher (178 m2) than those made by mosaics and 12% higher than those made by a diver with a hand-held GPS (Figure 92). Using the 10% difference success criteria the fishbone damage assessment method was significantly different than both the GPS and mosaic measurement methods.

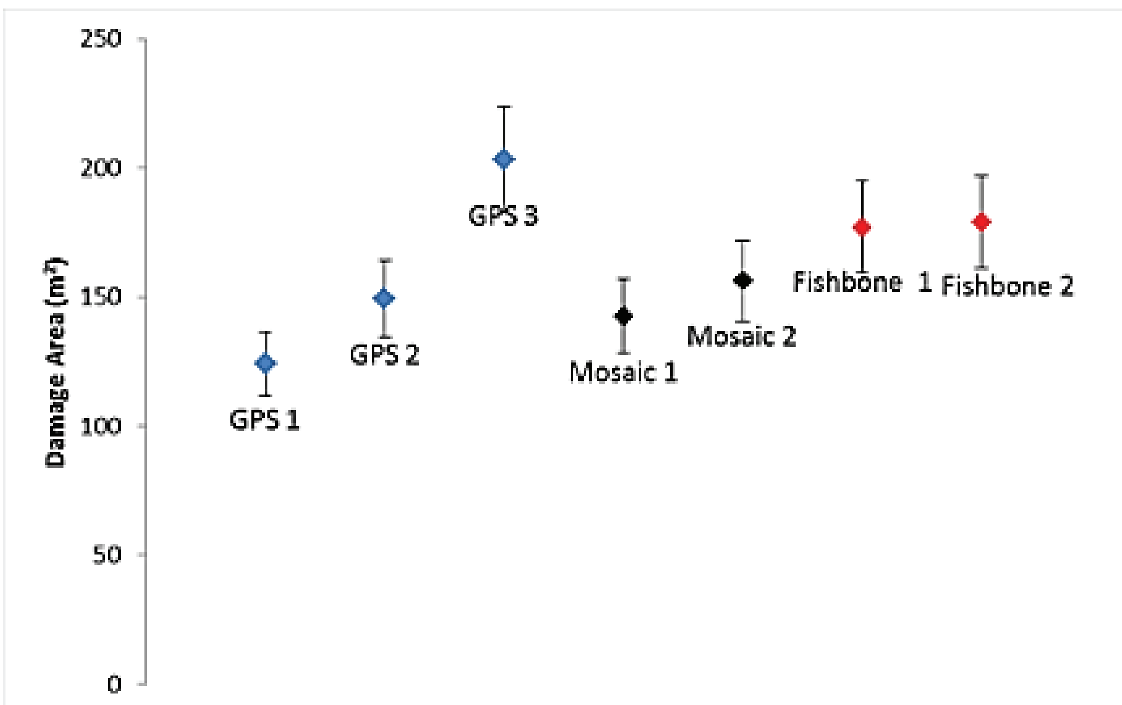


Figure 91. Comparison of individual area damage measurements from various methods including: handheld GPS, mosaic measurements, and diver-based Fishbone measurements.

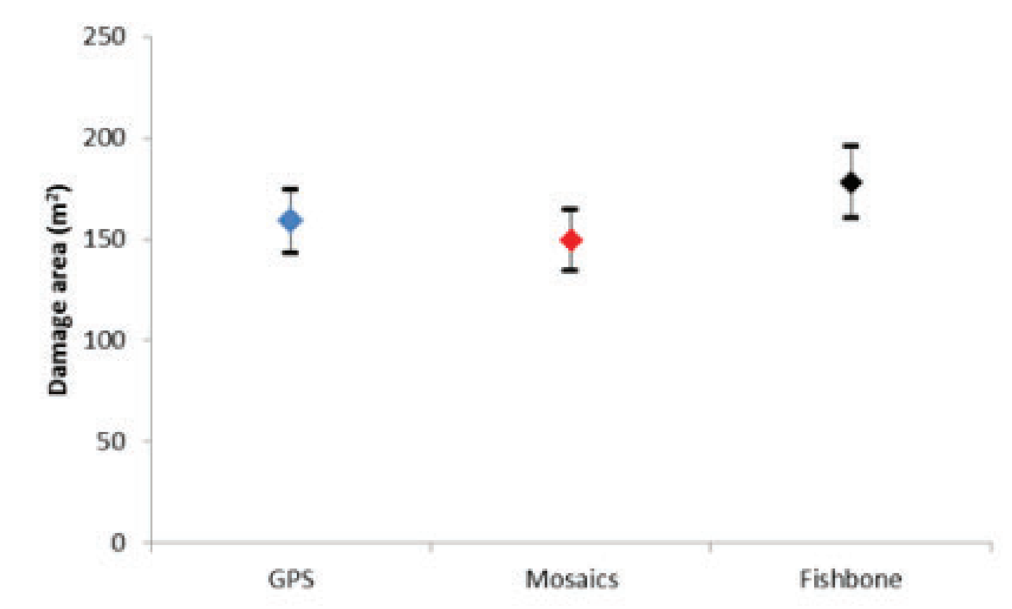
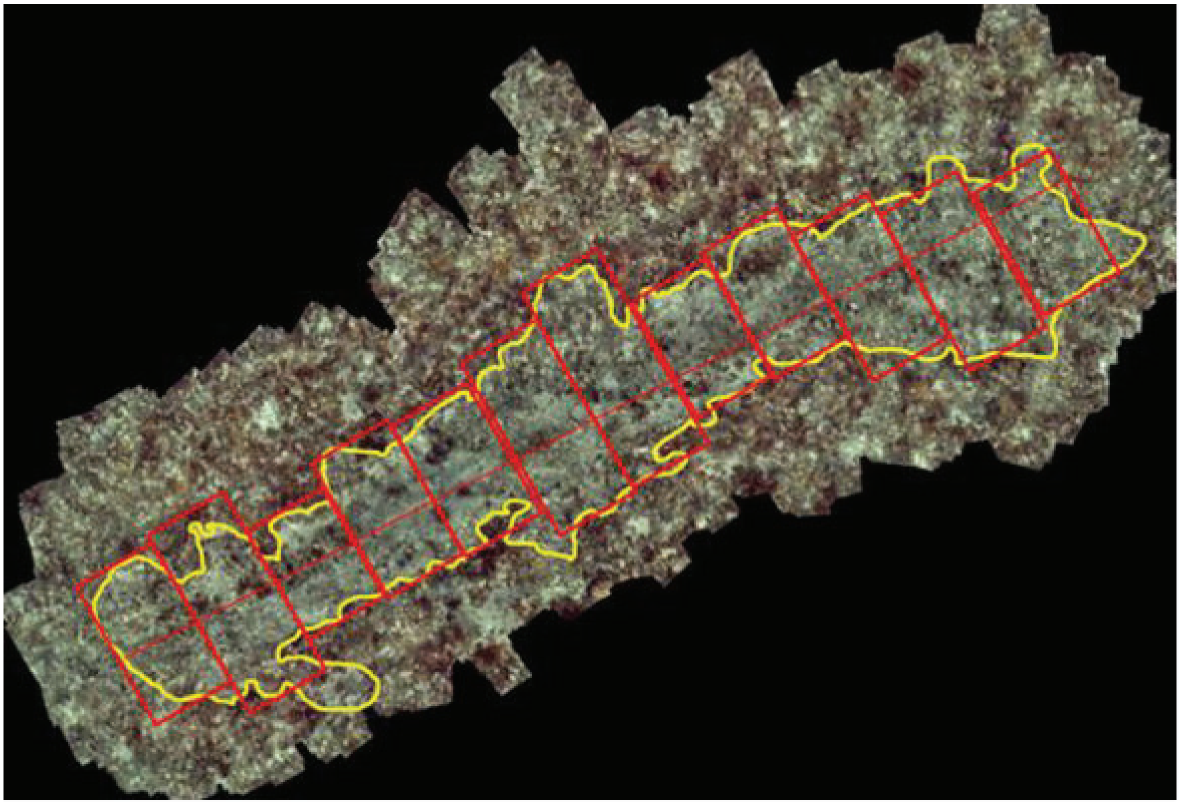


Figure 92. Comparison of average area damage measurement methods ± 10%.

The larger measurement of damaged area obtained by the fishbone method as opposed to the mosaicing and GPS methods may be a reflection of the size and completeness of the area sampled as opposed to method accuracy. Figure 93 shows the difference in scale of mosaic and fishbone estimates of ship grounding damage. The mosaic method allows precise definition of the area of damage (Figure 93, yellow line) whereas the fishbone method makes estimates of the damage area only once per meter along the length of the scar (Figure 93,red boxes).



- Mosaic measurements, shown in yellow can be more precise and define the entire area of the reef damage. Diver-based Fishbone measurements (shown in red) of reef damage are estimated once per meter along the centerline of the damage.

Figure 93. Comparison of damage area measurement methods.

Conclusion: Diver-based fishbone methods of estimating reef damage were significantly higher than both mosaic and GPS methods due to the relative infrequency of the damage estimates along the length of the scar. To determine if the difference in area measurement methods shown above is either a reflection of an inaccuracy of one of the methods or simply a function of the different sampling schemes we also compared the true precision of long-linear measurements between the three measurement methods in Section 6.3.3. Since the mosaic and fishbone measurement methods do not differ significantly in their ability to measure long-linear distances, we conclude that the significant differences shown above are in fact a reflection of area sampled rather than method inaccuracy.

6.3.2 Performance Objective 2: Comparison of Linear Damage Measurements

The overall approach to compare linear damage measurements was:

(A) Collect linear measurements of the width of the scar using the "fishbone" technique.
(B) Acquire mosaic data over the scar including markers left by the fishbone measurements delineating the edges.
(C) Compare the lengths from the baseline to the edge of the scar as measured by the diver and by the mosaic.

Steps A and B were described in Section 5.4.3 along with instructions for setting up the cameras. Step C is described here.

Linear measurements of the dimensions of the scar were measured directly in the field by each of two divers for N = 51 samples. The endpoints of the measurements were marked by the divers with white 10 x 10 cm tiles, which were visible on a mosaic of the area. The same locations were then measured in the lab from the mosaics using scaled pixels. To determine if there is was difference in the methods of measurement the following analyses were performed.

Question 1: Are linear measurements on the scale of a few m made by a diver significantly different than measurements made from mosaic images?

Analysis: t-test. Diver A (RSMAS) measured N = 51 lengths in the field, mosaic analyst A (RSMAS) has measured the same N lengths using scaled pixels from a mosaic. Is the mean of the N differences significantly different than 0?

H0: There is no significant difference ($p > 0.05$) in the linear measurements of damaged area as recorded in-situ by diver A and measurements from a mosaic by analyst A

HA: There is no significant difference ($p > 0.05$) in the linear measurements of damaged area as recorded in-situ by diver A and measurements from a mosaic by analyst A

Results: The mean difference between N = 51 diver fishbone measurements and mosaic analyst measurements of those same locations was 0.01 m. The differences were not normally distributed so a nonparametric Wilcoxon Signed Rank Test was used as an alternative to a one-sample t-test. The median of the sample (0.000) was not significantly different than zero (p=0.245).

Conclusion: There was no significant difference in the linear measurements of damaged area as recorded in-situ by a diver or from a mosaic analyst.

Question 2: Are the differenced between linear measurements on the scale of a few m as measured by a diver in the field and from a mosaic any larger than the difference as measured by two divers?

Analysis: Paired-samples t-test. For this comparison we examined the error of diver-diver measurements as compared with diver to mosaic measurements. Diver A (RSMAS) and Diver B (Navy) both measured N = 51 distances as part of the fishbone technique. Mosaic analyst A (RSMAS) extracted sizes from the mosaic of the site for the same distances. For each distance measurement, two measures of the error were computed:

Error = (DiverA-DiverB) and (DiverA-Mosaic)

The question was whether the mean diver - mosaic difference was significantly different than the mean diver - diver difference.

Ho: There is no significant difference ($p > 0.05$) in error between the measurement methods

HA: There is a significant difference ($p \leq 0.05$) in error between the measurement methods

Result: The mean differences between Diver A-Diver B and Diver A-Mosaic A are shown in

Figure 94. Neither the diver-diver or mosaic-diver samples were normally distributed. A Mann-Whitney U test was used as the nonparametric equivalent of the paired t-test to test whether these distributions were significantly different. For this test $p = 0.4345$, therefore there was no significant difference between methods at the $\alpha = 0.05$ level when comparing diver and mosaic measurements of fishbone measurements.

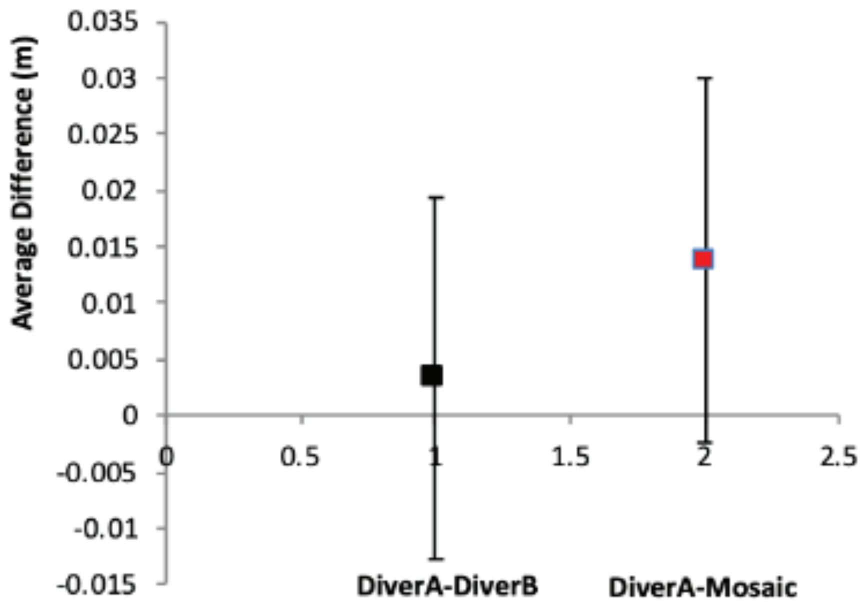


Figure 94. Mean differences +/- one standard error between Diver-Diver and Mosaic-Diver measurements of fishbone measurements.

Conclusion: There was no significant difference in the linear measurements of damaged areas as recorded in-situ by divers or from a mosaic analyst in a lab.

6.3.3 Performance Objective 3: Accuracy of the Measurement of Large Linear Targets

The proposed method for PO 3 involved placing markers on the seabed separated by known, random distances as the basis for this test. In practice, however, the presence of surge at the field site prevented any accurate distances > 1 m from being measured in the field. As an alternative, we used the same approach but in the University of Miami pool to eliminate the complications of environmental factors such as waves and surge. The accuracy of measurement of large linear targets was tested as follows:

(A) Markers were placed on the pool bottom separated by known, random distances ranging from 1 m to 10 m.
(B) Distances were measured between the markers using mosaics, GPS, and diver transects.
(C) Compare the distances as measured by each method to the known values.

Steps A and B were described in Section 5.4.3 along with instructions for setting up the cameras. Step C is described here. The pool setup for measuring long linear targets is shown in Figure 54.

Linear measurements of known dimensions were measured in the pool by divers using tape measures, by snorkelers using GPS, and by analysts in the lab from the mosaics. To assess the accuracy of each method, the following questions were answered.

Question 1: What is the bias in size measurements made from mosaics? What is the bias in size measurements made by divers? What is the bias in size measurements made with GPS?

Analysis: The known size of each target was subtracted from the size measurements. If there is no bias in the size measurements, the mean values of the resulting distributions should not be statistically different from zero. These distributions will be tested for statistical differences from a mean of zero with a one-sample t-test for differences.

H01: There is no significant bias ($p > 0.05$) in the estimate of linear measurements on the scale of a few m as measured from mosaics.

HA1: There is a significant bias ($p \leq 0.05$) in the estimate of linear measurements on the scale of a few m as measured from mosaics.

Results: The bias of each measurement method when applied to measuring long linear distances is shown in Figure 95. The GPS data were found to have much larger variability than either diver or mosaic measurements so the same data points are also shown in Figure 96 using an expanded scale.

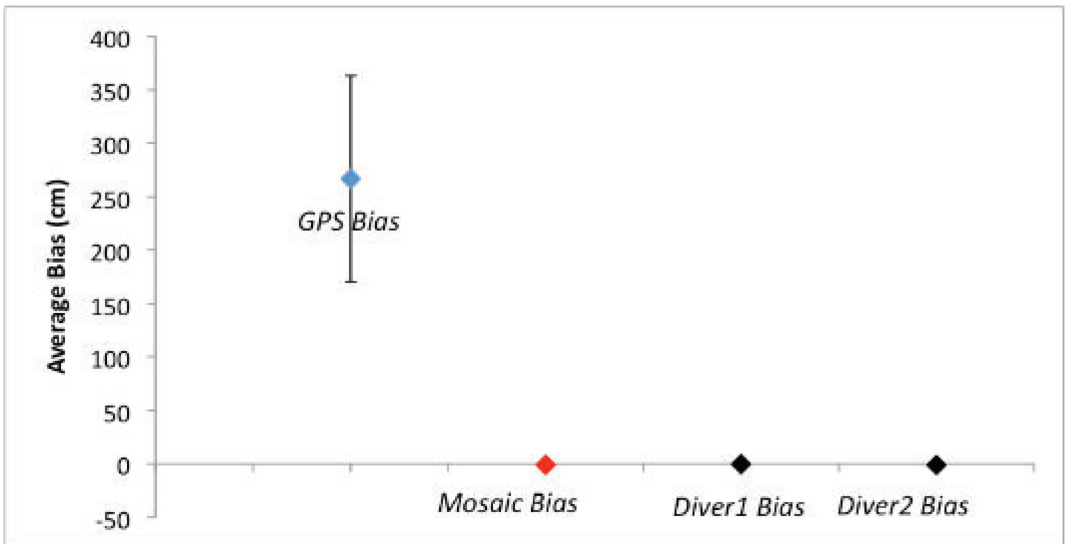


Figure 95. Biases and 95% confidence intervals of GPS, mosaics, and divers when making long linear measurements in a controlled environment.

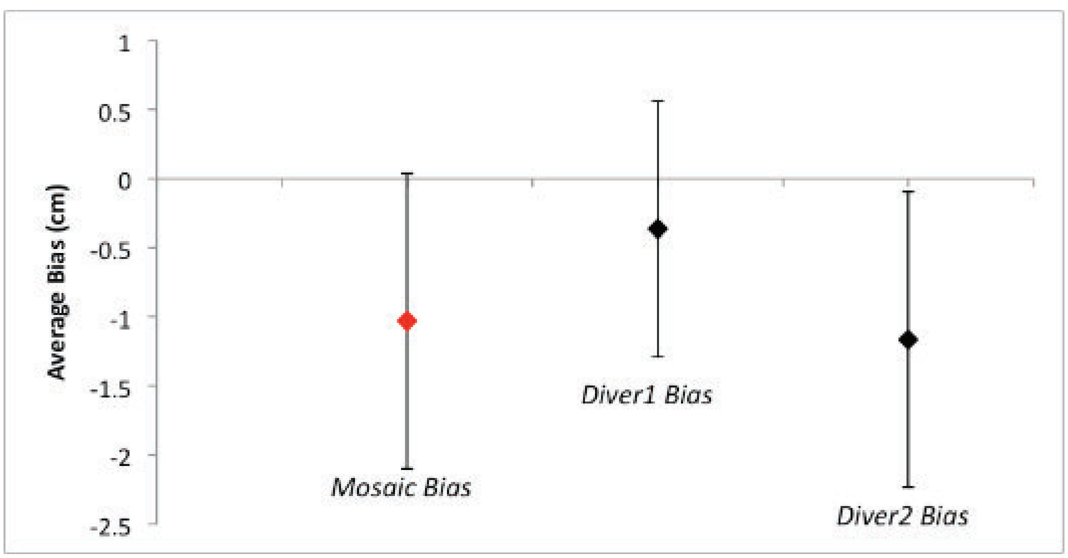


Figure 96. Bias and 95% confidence intervals of mosaics and divers when measuring long linear distances.

The GPS, mosaic, and diver1 distributions were normally distributed thus a t-test was performed to determine if the bias, or average difference from the known measurement, was significantly different than 0. The diver 2 distribution was not normally distributed so a Wilcoxon signed rank test was used as a non-parametric alternative. The GPS and diver 2 biases were found to be significantly different than zero.

The average GPS bias was over 250 times greater than the mosaic or diver bias (Figure 95, Table 42). The average bias of mosaics and diver measurements were between -1 and 0 cm (Figure 96, Table 42). The significantly different result obtained by the Diver 2 data using the Wilcoxon Signed Rank test (Table 43) may be a function of the test itself that compares the median value to zero as opposed to the mean as was computed for the normally distributed data. Regardless, the scale of the bias was small enough that we consider both the diver and mosaic methods to be highly accurate measurement methods for long linear distances.

Table 42. Results of *t*-test for the significance of measurement bias being different than zero for long-linear target measurements.

Variable	N	Mean (cm)	Std Dev	*t*-value	P-value
GPS Bias	45	267.0	320.7	5.59	0.000
Mosaic Bias	45	-1.03	3.583	-1.93	0.06
Diver1 Bias	45	-0.364	3.079	-0.79	0.431

Table 43. Wilcoxon Signed Rank Test determining if the median measurement bias of the long-linear targets is significantly different than zero.

Variable	N	Median	Wilcoxon Stat	P-value
Diver2 Bias	45	-1.004	268.5	**0.014**

Conclusion: The bias in mosaic measurements of long linear distances was not significantly different than zero. Statistically, the diver measurement bias was contradictory, but in practice the scale of diver measurement bias was small enough (1 cm or < 1%) that we conclude that diver measurements are also highly accurate methods for measuring long linear distances. GPS measurement bias was significantly different from zero.

Question 2: Is the bias in size measurements made from mosaics any different from the bias in size measurements made by divers or made by GPS?

Analysis: The same data were used for this test. In this case, however, rather than testing separately whether the mosaic bias, diver bias, or GPS bias was different from zero, we instead tested whether the three biases differed from each other. The distributions of mosaic minus known, diver minus known, and GPS minus known were tested for statistical difference using a one-factor ANOVA.

H0: The bias in the estimate of linear measurements on the scale of a few m as measured from the mosaic is not significantly ($p > 0.05$) greater than the bias as measured by divers or snorkelers using GPS.

HA: The bias in the estimate of linear measurements on the scale of a few m as measured from the mosaic is significantly ($p \leq 0.05$) greater than the bias as measured by divers or snorkelers using GPS.

Result: The one-way ANOVA was used to determine if there was a difference in measurement method between GPS, divers and mosaics when measuring long-linear distances. The methods were found to be significant at p=0.000. Tukey's comparisons showed that the GPS method produced significantly different results than Divers or Mosaics (Table 44). These results are consistent with those from question 1, above. The GPS method was less precise than mosaic or diver-based methods for measuring long linear distances.

Table 44. Grouping information using Tukey Method. Means that do not share a letter are significantly different.

Method	N	Mean	Grouping
GPS	45	267.0	A
Diver1	45	-1.03	B
Mosaic	45	-0.364	B

Conclusion: The GPS measurement bias was significantly different than that of divers or mosaics when measuring long linear distances.

6.3.4 Performance Objective 4: Extract Ecological Measurements From Mosaics that are Comparable with Diver-Based Metrics

As a reminder, the steps for comparing diver and mosaic methods for extracting benthic ecological measurements were:

(A) Sites were selected to have a visually homogenous bottom cover over the scale of 10 × 10 m.
(B) Four 10 m transects were laid out within the site, and assessed using PCQT, and BT diver methods.
(C) The assessed area was mosaiced by divers
(D) Metrics were extracted from the mosaic.
(E) Diver and mosaic metrics were compared.
(F) Compute the costs of diver and mosaic methods.

Steps A-D were described in Section 5.4.3 along with instructions for setting up the cameras. Step E is described here and step F is described in Section 7.3.

Seven metrics were used to quantify this performance objective: benthic cover, coral species richness, coral colony size-frequency distributions, % live tissue that was bleached, % old mortality observed, % new mortality observed, and juvenile density. The three metrics of coral colony condition (% bleached, % old and % new mortality) have been combined among all demonstrations due to low sample sizes and are presented with the results of the Traditional Metrics Demonstration in Section 6.4. For the other metrics, described here, accuracy was quantified by the differences between values extracted from diver-based estimates and those derived from the mosaics. The statistical significance of the differences between and among methods was tested with a binomial test, t-test, or ANOVA, as appropriate using a significance level (α) of 5%.

6.3.4.1 Metric 1: Benthic Cover

Question: Are plot-scale measurements of the % cover for a given benthic class made by a diver significantly different than measurements of % cover for that class made from mosaic images?

Benthic cover was measured in the field by divers using the line point intercept transect (LPIT) method as a component of the point centered quarter transect (PCQT) surveys. Benthic cover was measured in the lab using random point counts of the mosaics. To determine if there was a difference in the methods of measurement, a binomial test was used for each cover class: live coral, turf algae, macroalgae, crustose coralline algae, milleporans, gorgonians, zoanthids, and sponges.

Analysis: Binomial test. Divers measured the benthic cover at N = 400 points in the field, using the LPIT method. An analyst has measured N = 400 random points placed on a mosaic covering the area of the diver transects. Do the estimated proportions of cover for each class significantly differ depending on which method was used to make the estimate?

H0: There is no significant difference ($p > 0.05$) in the estimate of percent cover as recorded in-situ by divers and estimated from a mosaic.

HA: There is a significant difference ($p \leq 0.05$) in the estimate of percent cover when using the two methods

Results: The Fisher's Exact Test was substituted for the Binomial Test due to its accuracy across a range of sample sizes. Tests comparing LPIT and mosaic estimates of percent cover were not significantly different for corals, sponges, macroalgae, and coralline algae (Table 45). For one of the sampled transects the two methods produced a significantly different result for gorgonians and in another transect produced a significantly different estimate of percent cover of sand / pavement / rubble.

Table 45. Results of Fisher's Exact Test comparing diver-based LPIT and mosaic methods of estimating percent benthic cover.

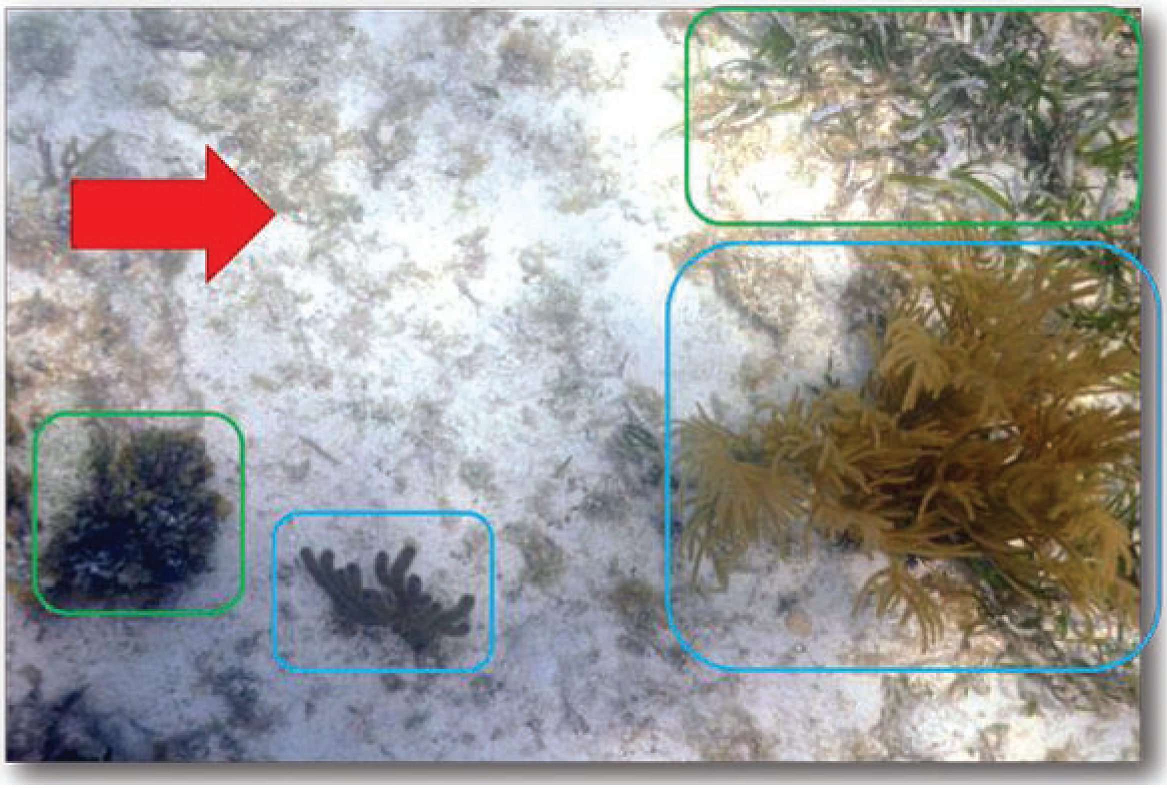
LIT vs. Mosaic	Anniversary Patch (12 ft)				Anniversary Patch Damaged (12 ft)				# Failed	% Success
Major Category	**T1**	**T2**	**T3**	**T4**	**T1**	**T2**	**T3**	**T4**		
Coral	1.00	1.00	0.81	1.00	1.00	0.68	1.00	0.68	0.00	100.00
Gorgonians	1.00	0.17	0.01	1.00	1.00	1.00	n/a	0.80	1.00	88.00
Sponges	1.00	0.10	0.25	1.00	n/a	1.00	1.00	1.00	0.00	100.00
Zoanthids	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.00	100.00
Macroalgae	0.67	0.45	0.09	0.29	1.00	0.89	0.57	0.06	0.00	100.00
Other Live	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Dead Coral With Algae	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Coralline Algae	n/a	n/a	1.00	n/a	0.12	n/a	0.25	n/a	0.00	100.00
Diseased Corals	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Sand, Pavement, Rubble	0.21	0.32	1.00	0.13	0.69	1.00	0.25	0.04	1	88.00

- Each cell contains the p-value of the test. Tests that were significantly different between methods are in bold. Note that the diver who measured LPIT on T2 at each site was the mosaic analyst, and no significant differences were found on either Transect #2.

Conclusion: Tests comparing LPIT and mosaic estimates of percent cover were not significantly different for corals, sponges, macroalgae, and coralline algae. However, some differences between divers and mosaics were observed for estimates of gorgonian and sand cover.

The difference in gorgonian cover between methods may be due to the different sampling heights of the two methods. Mosaics sample above the gorgonian canopy, thus a larger proportion of the benthos will appear to be occupied by the gorgonian than if sampled below the canopy where divers typically record their measurements. This is a common problem among all image-based techniques, however if the sampling method is consistent there is no reason to suspect that the estimates are inaccurate.

The significantly different result found when comparing two estimates of sand, pavement and rubble is most likely due to different classification of benthic bottom types. Often sandy reef substrates can be covered with fine filamentous algae called "turf" (Figure 97). These algae bind together sediments but are usually too small for identification to a genus level as is common in macroalgae identification. This combination substrate type is often called "sand" by one observer and "turf", which is grouped as a type of macroalgae, by a second observer. When the same observer recorded the benthic data as a diver and as a mosaic analyst (T2 for both sites in Table 45) no significant differences in sand, pavement, substrates were found. Therefore we propose that the significantly different result in benthic bottom types is related to a difference in observer terminology between the diver in the field and from the mosaic analyst. We also note that neither the diver or mosaic analyst are wrong but that greater consistency training maybe necessary in the future to avoid inconsistencies among naming bottom types. These issues are discussed in more detail in Section 6.4 where a larger sample size of percent cover comparisons is presented.



- Large discrete benthic organisms such as large stands of macroalgae or seagrass (shown in green boxes), or gorgonians (shown in blue boxes) are easily discriminated by divers.
- However, the rest of the image is covered with a fine layer of sand and turf algae (shown by the red arrow) that can easily be categorized as either sand or as an algal turf depending on the observer making the measurement or the vantage point of the observer.
- This substrate type is not easily reconciled between observers without a concentrated effort at training to arrive on a common definition.

Figure 97. Example image showing a common reef substrate consisting of both sand and algal components.

6.3.4.2 Metric 2: Coral Species Richness

Question: Are plot-scale estimates of coral species richness made from a mosaic at least as large as those made by a diver?

Coral species richness was measured in the field by divers using the BT. Coral species richness was measured in the lab using random point counts and visual inspection of the mosaics. To determine if there was a difference in species richness estimated by the two methods, the following test was used:

Analysis: Consider the smaller number of coral species identified by the divers as “min-diver” and the larger number of coral species identified by the divers as “max-diver.” Compute Δ diver = max-diver - min-diver. Use the smaller of Δ diver or 10% of min-diver as the threshold for success. If the number of colonies counted by the analysts from the mosaic is ≥ min-diver - threshold, the test is considered a success.

Results: Two methods of assessing species richness from a mosaic were tested against diver information (Table 46). The first method of estimating species richness from mosaics, which used point counts, failed to match the diver data. The second method, which used visual inspection of the mosaic, matched the diver data 100% of the time.

Table 46. Species Richness values of divers were used to calculate the minimum species necessary for success. Entries shown in bold did not meet the criteria for a success for detecting species richness.

	Diver1				Diver2				Min # Sp. for Success				Visual Mosaic inspection				Mosaic Pt Counts			
Test Sites	T1	T2	T3	T4	T1	T2	T3	T4	T1	T2	T3	T4	M1	M2	M3	M4	T1	T2	T3	T4
Brookes Reef	13	11	6	5	11	13	5	6	10	10	4	4	10	10	8	7	**2**	**1**	**1**	**0**
Broadkey Forereef	9	9	7	7	9	8	7	4	9	7	7	4	11	10	11	9	**4**	**2**	**2**	**1**
Anniversary Reef	11	9	9	8	10	8	8	6	9	7	7	5	10	10	8	8	**5**	**4**	**4**	**4**
Evans Reef Crest	12	11	11	9	12	10	9	9	12	9	8	9	13	12	12	11	**6**	**5**	**4**	**4**
													100% Success				0% Success			

Conclusion: The mosaic point count method of assessing species richness was not equivalent to information collected by divers in the field, however the mosaic visual inspection method was successful at estimating species richness. The poor success of the point-counting method was likely due to the sampling area. Divers in the field searched a 10 × 1 m area per transect looking for coral species whereas a point count transect only sampled 100 individual points anywhere in the mosaic area. The visual inspection method in which a mosaic analyst visually inspects the entire 10×1 m area where divers also sampled the species richness was found to be successful at detecting species richness 100% of the time. The visual inspection method is therefore the preferred mosaic method for sampling species richness since it was comparable to divers in the water.

6.3.4.3 Metric 3: Coral Colony Size Frequency Distribution

Question: Do plot-scale measurements of the size-frequency distribution of coral colonies made by a diver significantly differ from the size-frequency distribution made from mosaic images?

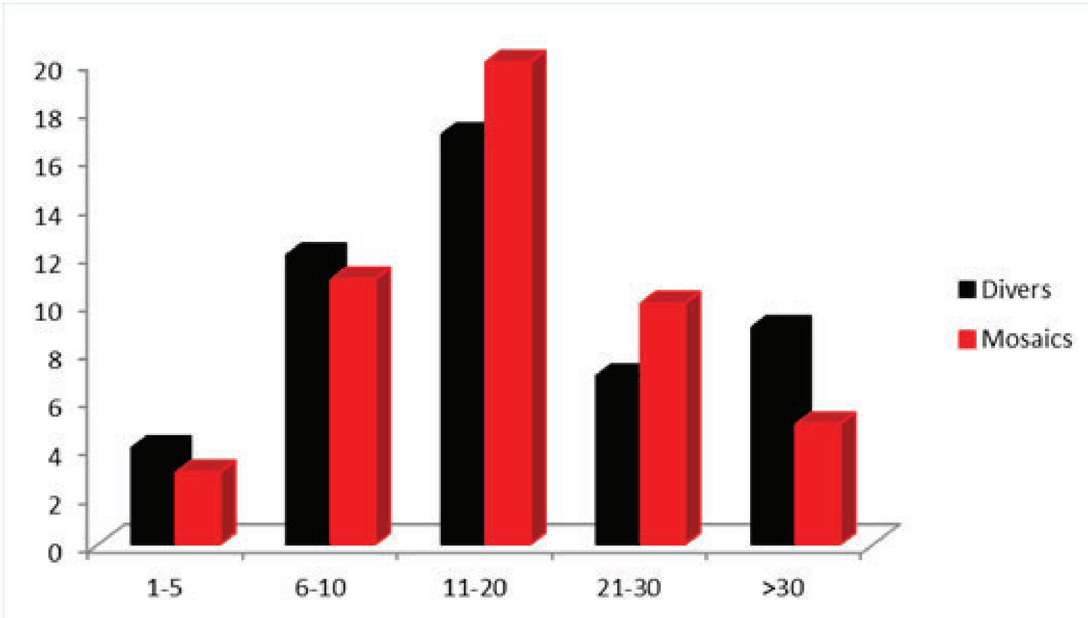
The dimensions of coral colonies with maximum dimension > 4 cm were measured in the field by divers using PCQT. The dimensions of coral colonies > 4 cm were also measured in the lab using visual inspection of the mosaics. A chi-squared goodness-of-fit test was used to determine if there was a difference in the resulting histograms of coral colony sizes.

Analysis: The measurements of coral colonies with maximum dimension > 4 cm were counted within certain size classes (i.e., “binned”) to create a size-frequency distribution for both the diver transect measurements as well as the mosaic measurements. The target bins were 4 -10 cm, 10-20 cm, 20-30 cm, 30-40 cm, 40-50 cm, 50-75 cm, 75-100 cm, 100-150 cm, 150-200 cm, and > 200 cm There is no general consensus on how many corals need to be measured in each bin. Both Zar (1984) and Daniel (1995) suggest following the rule of thumb proposed by Cochran (1977), which is that no more than 20% of the bins should have fewer than 5 observations. Ideally, all of the bins will have more than 5 corals, but since we could not control this ahead of time, it was necessary to combine bins or adjust their divisions to ensure a minimal number in each bin. These distributions were tested for statistical differences with a chi-squared goodness-of-fit test.

H0: There is no significant difference ($p > 0.05$) in the estimates of coral colony size frequency distribution as recorded in-situ by divers and estimated from a mosaic.

HA: There is a significant difference ($p \leq 0.05$) in the estimates of coral colony size frequency distribution when using the two methods.

Results: The size frequency distributions measured by divers using the PCQT method and from mosaics using visual inspection is shown in ???. Due to a lack of large colonies, the bin sizes specified in the demonstration plan were modified to fit the site-specific size distribution sampled in order to ensure at least 5 samples in each bin. Chi-squared analysis of the two distributions found no significant differences between the two-distributions (p = 0.717).



- The histogram in red represents the mosaic size measurements and those in black are the diver size measurements. Total number of colonies measured was N= 49.

Figure 98. Size frequency distribution of coral colonies measured at Anniversary Reef from by divers using the PCQT method and from mosaics.

Conclusion: There was no significant difference in the estimates of coral colony size frequency as recorded in-situ by divers and estimated from a mosaic image of the same area.

6.3.4.4 Metrics 4-6: Coral Condition

Three metrics of “coral condition” were evaluated as part of this demonstration: % live tissue that had been bleached, % of the colony that was old dead skeleton, and % of the colony that was newly dead. Due to low sample sizes, data from the Grounding demonstration for these three metrics were pooled with other similar data from the Long-Term Monitoring and Traditional Metrics demonstrations. The results are discussed in Section 6.4.1.

6.3.4.5 Metric 7: Juvenile Coral Density

Question: Does site-averaged juvenile coral colony density as measured by a diver significantly differ from estimates made from mosaics?

Divers counted juvenile corals in ten, 0.25 m^2 quadrats along each of the four PCQT transects. Analysts examined forty, 0.25 m^2 quadrats randomly subsampled from the mosaic for the site. For both diver and mosaic estimates, the average and standard deviation of the number of juvenile corals per 0.25 m^2 were computed.

Analysis: t-test for differences in mean juvenile coral density.

H0: There is no significant difference ($p > 0.05$) in the mean juvenile coral density as estimated in-situ by divers and from a mosaic.

HA: There is a significant difference ($p \leq 0.05$) in the mean juvenile coral density as estimated in-situ by divers and from a mosaic.

Results: A t-test found no significant difference between diver and mosaic estimates of juvenile density per 0.25 m2 area either in the healthy portion of Anniversary reef or in the disturbed area of the Anniversary Reef grounding test site (Table 47). We conclude that there was no statistical difference between mosaic-based methods of sampling juvenile corals both in a healthy-reef scenario and within a vessel-grounding scar.

Table 47. Mean densities of juveniles per 50×50 cm samples at both the healthy Anniversary Reef.

	Mosaics		Divers		
Reef Site	Mean	95% CI	Mean	95% CI	P-value
Anniversary Reef	0.65	0.2855	1.05	0.3315	0.068
Anniversary Reef (Damage)	1.32	1.85	0.925	0.415	0.237

- Measurments were taken within the affected area of the grounding site using both Diver sampling and Mosaic sampling methods. P-values of a *t*-test comparing densities from both sampling methods are provided.

Conclusion: There was no significant difference in the mean juvenile coral density as estimated in situ by divers and from a mosaic at the grounding demonstration site.

6.3.5 Performance Objective 5: Ease of Use

For PO 5, Navy personnel performed extractions from the same mosaics as a University of Miami analyst for comparison. Two variables were compared, coral colony size and live coral cover.

6.3.5.1 Metric 1: Coral Colony Size

Question: Are coral colony size estimates made from a mosaic by a Navy analyst significantly different from estimates made by a RSMAS analyst?

Analysis: Paired sample t-test. A RSMAS analyst and Navy analyst measured the maximum length and width of coral colonies from the same mosaic image. A total of $N = 48$ colonies were measured by both US Navy ecologist Don Marx and UM ecologist Brooke Gintert. We asked the question: Do the estimated sizes significantly differ depending on which analyst was used to make the estimate?

H0: There is no significant difference ($p > 0.05$) in the estimate of coral colony size as recorded by RSMAS and Navy analysts.

HA: There is a significant difference ($p \leq 0.05$) in the estimate of coral colony size as recorded by RSMAS and Navy analysts.

Result: The paired t-test of coral colony sizes measured by D. Marx and B. Gintert were not significantly different than one another ($p = 0.17$, Table 48).

Table 48. Size measurement data from B. Gintert, and D. Marx and results of the paired *t*-test comparing the results of two observers.

Observer	N	Mean	Std Dev	*t*-value	P-value
B. Gintert	48	24.8	14.31	NA	NA
D. Marx	48	26.5	15.52	NA	NA
Difference	48	-1.7	8.42	-13.9	0.17

Conclusion: There was no significant difference in the estimate of coral colony size as recorded by RSMAS and Navy analysts. This suggests that a few days of training on the software for extracting coral sizes was sufficient to enable a newly trained analyst to extract size data which was not significantly different from data taken from the same mosaic by an experienced user of the software. Other questions of observer differences for measuring object sizes were addressed in the pool demo in Section 6.5.

6.3.5.2 Metric 2: Live Coral Cover

Question: Are plot-scale measurements of the % live coral cover made from a mosaic by a Navy analyst significantly different from estimates made by a RSMAS analyst?

Analysis: Binomial test. A RSMAS analyst measured random points placed on a mosaic covering the area of the diver transects for PO 4. A Navy analyst did the same for random points. Do the estimated proportions of live coral cover significantly differ depending on which analyst was used to make the estimate?

H0: There is no significant difference ($p > 0.05$) in the estimate of live coral cover as recorded by RSMAS and Navy analysts.

HA: There is no significant difference ($p <= 0.05$) in the estimate of live coral cover as recorded by RSMAS and Navy analysts.

Results: Due to its greater reliability in cases of small sample sizes, the Fishers Exact Test was used in lieu of the Binomial test. The estimates of percent cover obtained by the UM and Navy analyst were not significantly different for the categories of corals, gorgonians, sponges, zoanthids, and macroalgae (Table 49). The category of sand, pavement, and rubble was found to be significantly different between analysts (Table 49).

Table 49. Comparison of percent cover estimates derived from a UM analyst using 400 random point counts and a Navy analyst using 400 points counts.

Major Category	UM Percent Cover	Navy Percent Cover	P value
Coral (C)	9	8	0.858
Gorgonians (G)	2	5.5	0.112
Sponges (S)	7.5	6.5	0.845
Zoanthids (Z)	0	0	n/a
Macroalgae (MA)	78	70	0.087
Other Live (OL)	0	0	n/a
Dead Coral with Algae (DCA)	0	0	n/a
Coralline Algae (CA)	0	0	n/a
Diseased Corals (DC)	0	0	n/a
Sand, Pavement, Rubble (SPR)	3.5	10	**0.015**
Unknowns (U)	0	0	n/a
Tape, Wand, Shadow (TWS)	0	0	n/a
Total Transect Points	**400**	**400**	

- Results of a Fishers Exact Test comparing the relative proportions of each category are provided. Significant results are in bold.

Conclusion: The estimates of percent cover obtained by the UM and Navy analyst were not significantly different for the categories of corals, gorgonians, sponges, zoanthids, and macroalgae. Estimates were significantly different in the category of sand, pavement, and rubble. As discussed previously, the sand, pavement, and rubble category is easily confused among observers due to the presence of tiny algae within the sand that could lead an observer to categorize the same area as either sand or algae. Since the methods did not differ with any of the larger and more distinct categories we still conclude that there are no significant differences in sampling method between observers but that more consistency training is necessary to obtain the same responses for categories that are less distinct than individual organisms.

6.4 TRADITIONAL METRICS DEMO PERFORMANCE ASSESSMENT

Sections 6.4.1, 6.4.2 and 6.4.3 provide the results of Performance Objectives 1, 2, and 3, respectively, from the Traditional Metrics Demonstration. Results are summarized in Table 50.

Table 50. A summary of the Traditional Metrics Demonstration performance assessment.

PO.Metric	Question	Status	Conclusions
PO1.1	1. Are plot-scale measurements of the % cover for a given class made by a diver significantly different than measurements of % cover for that class made from mosaic images	**Complete**	Site-level comparisons of benthic cover from divers and mosaics differed for most categories. At the transect level benthic cover was found to be as accurate as diver estimates for all benthic categories.
PO1.2	1. Are plot-scale estimates of coral species richness made from a mosaic at least as large as those made by a diver?	**Complete**	The visual mosaic inspection method produced equivalent metrics of species richness when compared to divers in the field. The mosaic point counts method did not replicate belt transect data.
PO1.3	1. Do plot-scale measurements of the size-frequency distribution of coral colonies made by a diver significantly differ from the size-frequency distribution made from mosaic images?	**Complete**	There was no significant difference in the estimates of coral colony size frequency distribution as recorded in-situ by divers and estimated from a mosaic.
PO1.4	1. Do visual estimates of % area affected by coral disease made by a diver significantly differ from estimates of % area affected by coral disease made from mosaic images?	**Complete**	There was no significant difference in the absolute error of diver or mosaic methods of estimating the percentage of disease infecting a coral colony ($p=0.74$).
PO1.5	1. Do visual estimates of % area affected by coral bleaching made by a diver significantly differ from estimates of % area affected by bleaching made from mosaic images?	**Complete**	There was no significant difference between diver and mosaic methods of estimating the % bleached condition metric ($p=0.68$).
PO1.6	1. Do visual estimates of % area affected by new mortality made by a diver significantly differ from estimates of % area affected by new mortality made from mosaic images?	**Complete**	There was no significant difference between diver and mosaic methods of estimating the % new mortality condition metric ($p=0.92$).
PO1.7	1. Do visual estimates of % area affected by old mortality made by a diver significantly differ from estimates of % area affected by old mortality made from mosaic images?	**Complete**	There was no significant difference in the absolute error of the % old mortality metric when comparing the measurement methods ($p=0.32$), coral size categories ($p=0.31$), or between the coral size category and measurement method ($p=0.65$).

- The main questions of each performance objective are listed and a color code is given to the assessment of each question.
- **Green** suggests that all aspects of the test were successful
- Yellow indicates that not all aspects were successful or that inconsistencies were discovered during the analysis of the question
- Red indicates a failure of that performance objective.

Table 50. A summary of the Traditional Metrics Demonstration performance assessment. (Continued)

PO.Metric	Question	Status	Conclusions
PO1.8	1. Does site-averaged juvenile coral colony density as measured by a diver significantly differ from estimates made from mosaics?	**Complete**	Corals smaller than 4cm were visible from mosaic images and diver and mosaic methods produced similar average density estimates of juvenile corals at three of the four test sites.
PO2.1	1. Are transect-scale measurements of the % cover for a given class made by a diver significantly different than measurements of % cover for that class made from mosaic images?	**Complete**	Mosaic methods of estimating benthic cover were as good as divers performing linear intercept transects or video transects. The category of gorgonian cover was found to be highly variable across all tests and there may be a significant difference between mosaic and video transect estimates gorgonian cover in some cases.
PO2.2	1. Are transect-scale estimates of coral species richness made from a mosaic at least as large as those made by a diver?	**Complete**	Visual inspection of 10x1m areas from mosaic images was found to be as accurate as diver surveys for estimating coral species diversity. Visual inspection of video transects and mosaic point counts did not accurately replicate species diversity information obtained by divers.
PO3	1. Are mosaics created by a Navy analyst of the same quality as those made by an expert mosaic analyst?	**Complete**	Navy analysts with a few days training and the use of a mosaic creation manual were able to produce mosaic images that were indistinguishable from expert operators in terms of area, content, incorporation percentage, and visual quality.

- The main questions of each performance objective are listed and a color code is given to the assessment of each question.
- **Green** suggests that all aspects of the test were successful
- Yellow indicates that not all aspects were successful or that inconsistencies were discovered during the analysis of the question
- Red indicates a failure of that performance objective.

6.4.1 Performance Objective 1: Extract Ecological Measurements from Mosaics that are Comparable with Diver-Based Metrics

As a reminder, the overall approach was:

(A) Select a site with visually homogenous bottom cover over the scale of 10×10 m.
(B) Lay out four 10 m transects within the site, assess each transect using PCQT / LPIT, BT, and juvenile survey diver methods.
(C) Mosaic the area that was assessed by divers
(D) Extract metrics from the mosaic.
(E) Compare the metrics derived from diver data with those derived from the mosaic.
(F) Compute the costs of diver and mosaic methods.

Steps A-D were described in Section 5.4.4 along with instructions for setting up the cameras. Step E is described here. Step F is described in Section 7.4.

Performance was quantified by comparing the benthic cover, coral species richness, coral colony size-frequency distribution, four metrics of coral colony condition, and juvenile coral density extracted from mosaics and diver surveys (Table 51). Accuracy was quantified by the differences between a metric (e.g., coral cover) extracted from diver-based estimates and that derived from the mosaics. The statistical significance of the differences between and among methods were tested with a binomial test, t-test, or ANOVA, as appropriate using a significance level (α) of 5%.

Table 51. Description of test metrics, the method of extraction for both diver and mosaic-based surveys and the method of analysis.

Metric	Data Measurement in the Field	Data Measurement from Mosaic	Analysis
1. Benthic cover	% cover measured by divers using LPIT	% cover measured from mosaics using random point counts	Binomial test for each cover class.
2. Coral species richness	# of coral species as counted by divers using BT.	# of coral species using random point counts and image inspection	Compare the # of species observed with each method.
3. Coral colony size frequency distribution	Sizes of corals measured by divers using PCQT.	Sizes of corals measured from mosaics using scaled pixels	Chi-squared goodness of fit test.
4. % diseased of coral colonies	Diver estimate of the % of each colony that is diseased	Observer estimate of % of each colony that is diseased	One-way ANOVA
5. % bleached of coral colonies	Diver estimate of the % of each colony that is bleached	Observer estimate of % of each colony that is bleached	One-way ANOVA
6. New Coral Mortality	Diver estimate of the % of each colony that is new coral mortality	Observer estimate of % of each colony showing new mortality	One-way ANOVA
7. Old Coral Mortality	Diver estimate of the % of each colony that is old coral mortality	Observer estimate of % of each colony that is old mortality	One-way ANOVA
8. Juvenile coral density	# of juvenile corals (< 4 cm maximum length) as counted by divers using quadrats.	# of juvenile corals (< 4 cm maximum length) as counted from mosaics using inspection of random subquadrats.	*t*-test

6.4.1.1 Metric 1: Benthic Cover

Question: Are plot-scale measurements of the % cover for a given class made by a diver significantly different than measurements of % cover for that class made from mosaic images?

Benthic cover was measured in the field by divers using the PCQT method, which incorporated a LPIT. Benthic cover was measured in the lab using random point counts of the mosaics. To determine if there was a difference in the methods of measurement a binomial test was used for each cover class: live coral, macroalgae, crustose coralline alga, gorgonians, zoanthids, sponges, and sand pavement and rubble.

Analysis: Binomial test. Divers measured the benthic cover at N = 400 points in the field, using the LPIT method. An analyst measured N = 400 random points placed on a mosaic covering the area of the diver transects. Do the estimated proportions of cover for each class significantly differ depending on which method was used to make the estimate?

H0: There is no significant difference ($p > 0.05$) in the estimate of percent cover as recorded in-situ by divers and estimated from a mosaic.

HA: There is a significant difference ($p \leq 0.05$) in the estimate of percent cover when using the two methods

Results: Due to low percent cover, and therefore small sample sizes, for some benthic cover categories, a Fishers exact test was used in lieu of the Binomial test. Percent cover data from all four divers in the field was combined to create a single estimate of percent benthic cover for each category at each of the four sampled sites (Brookes Reef, Anniversary Reef, Evans Reef crest, and Evans Reef forereef). The result of the combined data was a sample of 400 points at each site. In the lab, four trials of 100 random point counts were performed on the mosaic of the test site to create a total sample of N = 400 points. A Fishers exact test was performed for each category at each site to compare diver and mosaic estimates of benthic cover for each category. The resulting p-values of each test are shown in Table 52.

Table 52. P-values of Fishers exact test comparing site-level estimates of percent cover from mosaics to those obtained by divers in the field.

Major Category (occurring in transect)	Brookes Reef (deep)	Anniversary Reef (shallow)	Evans Fore Reef (deep)	Evans Reef Crest (shallow)
Coral (C)	**0.00**	0.62	0.66	0.85
Gorgonians (G)	0.08	**0.00**	0.05	**0.03**
Sponges (S)	0.78	0.14	0.08	0.05
Zoanthids (Z)	0.09	n/a	n/a	0.27
Macroalgae (MA)	**0.00**	0.58	0.71	0.13
Other Live (OL)	n/a	n/a	n/a	0.37
Dead Coral with Algae (DCA)	n/a	n/a	n/a	n/a
Coralline Algae (CA)	n/a	n/a	n/a	0.72
Diseased Corals (DC)	n/a	n/a	n/a	n/a
Sand, Rubble, Pavement (SPR)	**0.00**	**0.00**	0.80	0.05
Unknowns (U)	n/a	n/a	n/a	n/a

- Tests that were significantly different than diver measurements are shown in gray boxes with bold text.

Only the benthic cover estimates of sponges, and zoanthids were not significantly different among methods across all test sites. Estimates of coral, gorgonian, macroalgae, and sand cover were significantly different between sampling methods (divers vs. mosaics) at least one test site. Of the 24 Fishers exact tests that were performed, six were significantly different among methods.

The significant differences found between diver transects and random point counts from mosaics may be related to differences in sampling area as opposed to inaccuracies in the mosaic methodology. When the test comparing benthic categories was proposed, an assumption was made that benthic cover category would be relatively homogenous over the test sites. However, when examining the field data it was obvious that instances of spatial autocorrelation (i.e. the clumping of like categories) were influencing the number of organisms in a given category on a transect basis (Figure 99). For example, at the Brooke's Reef test site, of the 100 points sampled on each LPIT, the four divers noted 2, 10, 11, and 2 points per line that fell directly on living coral. The transects in which 10 and 11 points of living coral were noted were each influenced by the presence of a large coral colony directly under the transect line. In one case, the single colony accounted for 7 of the 10 living coral points and in the other transect the large colony accounted for 8 of the 11 living coral points. The presence of these large colonies suggests that benthic categories are spatially autocorrelated and that methods such as the LPIT that sample at regular intervals (every 10 cm) may produce different results than methods that sample randomly across the test site (i.e. random points counts from mosaics).

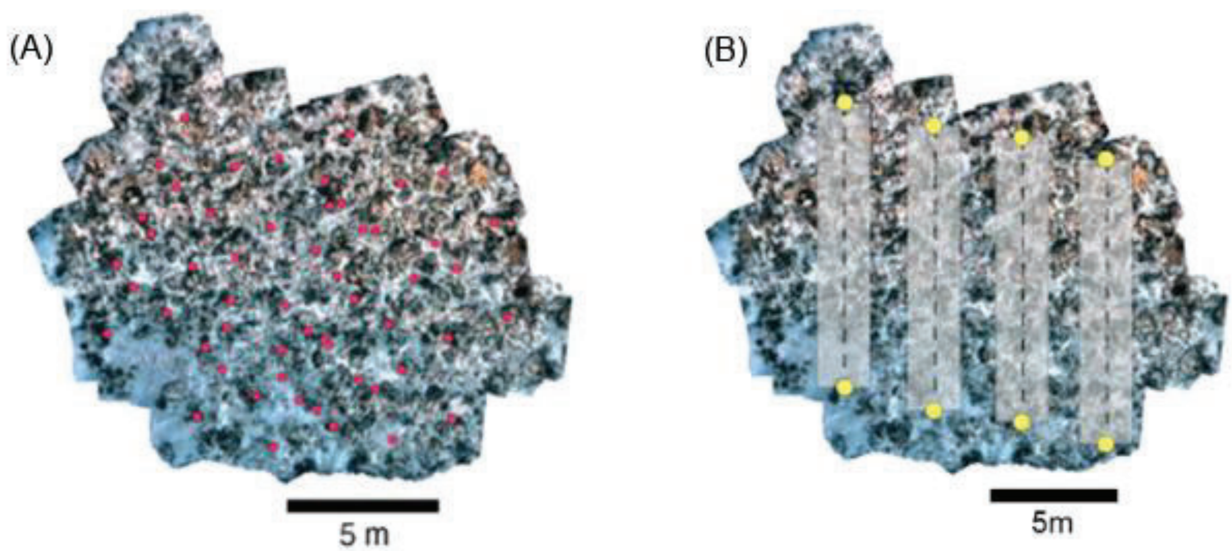


Figure 99. Difference in sampling area from random point counts from a mosaic analyst (A) and from divers sampling 10 m line intercept transects (B).

To determine if sampling area had an effect on the estimates of percent benthic cover obtained from a mosaic, a second test comparing the percent benthic cover of each LPIT to a virtual LPIT of the same line from a mosaic was performed. In this test, mosaic images in which the 10 m line of the diver was left in place was visually inspected and the 100 points sampled from divers in the field was visually inspected by a mosaic analyst. A Fishers exact test was applied to diver and mosaic estimates of benthic cover for each major benthic category and for each transect at the test site. The categories tested and the results of the Fisher's Exact tests of each sampled transect are shown in Table 53.

By changing the area sampled from a site-based design to examination of individual transects, the categories of coral, sponge, zoanthid, and coralline algae cover were not significantly different between mosaic and diver methods. In the previous example of spatial autocorrelation at the Brooke's Reef site where coral cover was significantly different between methods when comparing the four diver transects and the 4 trails of mosaic point counts ($p = 0.00$, Table 53); when comparing the percent cover of diver transects to the visual inspection of the same transect lines, no significant differences in coral cover were noted (Table 53). Significant differences still existed for certain transects for the categories of gorgonians, macroalgae and sand.

Table 53. Fishers Exact Test of each category and transect comparing diver and mosaic methods of estimating percent benthic cover.

LIT vs. Mosaic	Brooke's Reef (30-40 ft)				Evans forereef (30-40ft)				Anniversary Patch (12 ft)				Evans Reef Crest (15-20 ft)					
MAJOR CATEGORY	**T1**	**T2**	**T3**	**T4**	**T1**	**T2**	**T3**	**T4**	**T1**	**T2**	**T3**	**T4**	**T1**	**T2**	**T3**	**T4**	**# Failed**	**% Success**
CORAL (C)	1.00	0.81	0.81	1.00	1.00	0.75	1.00	0.42	1.00	1.00	0.81	1.00	0.68	0.84	1.00	0.84	0	100
GORGONIANS (G)	0.78	0.77	1.00	0.13	0.05	0.15	0.13	**0.03**	1.00	0.17	**0.01**	1.00	0.27	0.33	0.87	0.51	2	88
SPONGES (S)	1.00	0.31	0.36	0.41	0.53	1.00	0.45	0.54	1.00	0.10	0.25	1.00	1.00	0.43	0.50	1.00	0	100
ZOANTHIDS (Z)	1.00	0.52	0.69	1.00	0.21	0.72	n/a	n/a	n/a	n/a	n/a	n/a	1.00	0.11	1.00	1.00	0	100
MACROALGAE (MA)	0.31	**0.04**	**0.00**	0.62	**0.00**	0.78	**0.00**	0.12	0.67	0.45	0.09	0.29	0.14	0.28	0.14	0.88	4	75
OTHER LIVE (OL)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.12	n/a	n/a	n/a	n/a	n/a
DEAD CORAL WITH ALGAE (DCA)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
CORALLINE ALGAE (CA)	n/a	1.00	0.06	n/a	1.00	1.00	1.00	n/a	n/a	n/a	1.00	n/a	1.00	0.12	0.72	0.25	0	100
DISEASED CORALS (DC)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
SAND, PAVEMENT, RUBBLE (SPR)	0.29	0.87	**0.00**	0.57	**0.00**	0.80	**0.00**	0.25	0.21	0.32	1.00	0.13	1.00	0.10	0.06	0.25	3	81

- Categories that were significantly different between methods are shown in bold. A total of 10 tests were found to be significantly different.

Since the true value of benthic cover per category was unknown at each test site, a measure of success needed to be established to determine if there was a significant difference between diver and mosaic methods of estimating this metric. In the demonstration plan we set an arbitrary measure of success to be 90% success across all transects. In this case, mosaics would not be comparable to divers for estimating benthic cover of gorgonians, macroalgae, and sand, pavement, and rubble (Table 54). However, since we had two sets of diver measurements at each transects we decided to determine if these categories were just variable between diver and mosaic measurements or if there was also significant differences between two divers sampling the same transect line.

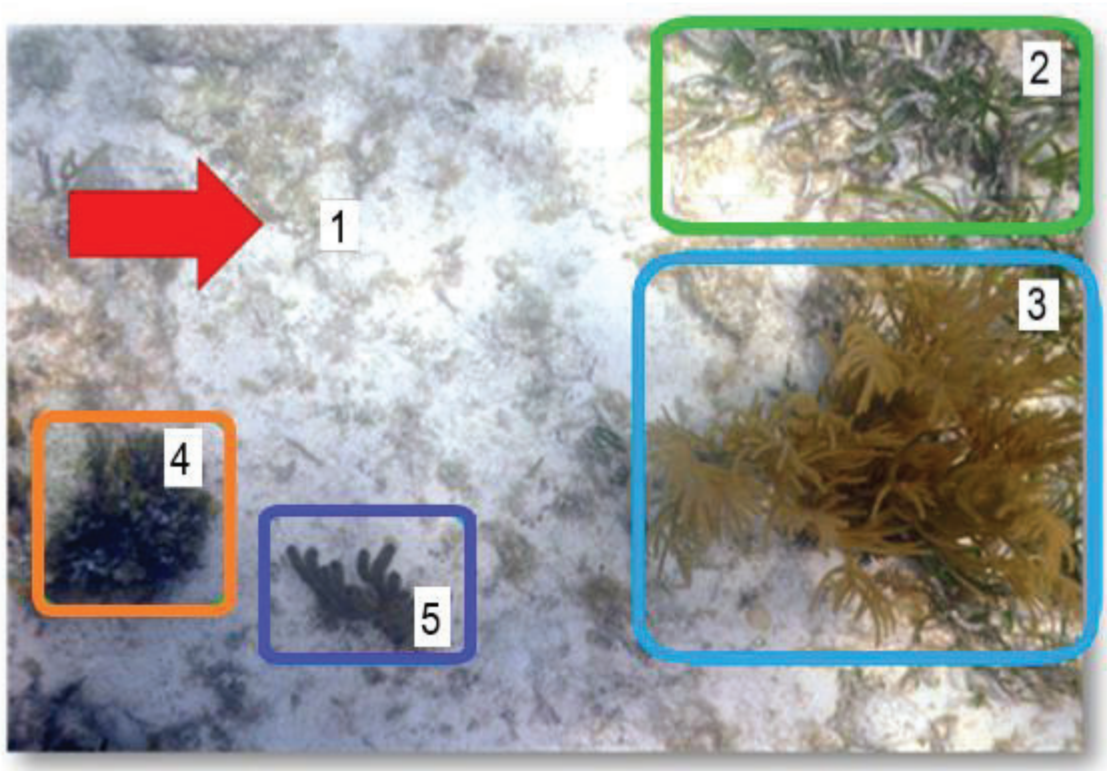
Replicate sets of diver information were available at 3 of the 4 test sites. Estimates of benthic cover per category were computed for each diver, and significance was tested using the Fisher's Exact Test for each of the 4 transects at these 3 sites. The number of failed tests/category was calculated for diver-diver comparisons and compared to the values obtained from a diver and a mosaic analyst sampling each benthic transect at the same three test sites. The results of both the diver-diver comparisons and mosaic-diver comparisons are shown in Table 54.

Table 54. Fishers Exact Test comparing multiple diver estimates at each test site (top of table) and comparing transect-based sampling from divers and from mosaics for each benthic category (bottom of table).

Diver vs. Diver	Evans forereef (30-40ft)				Anniversary Patch (12 ft)				Evans Reef Crest (15-20 ft)					
MAJOR CATEGORY	T1	T2	T3	T4	T1	T2	T3	T4	T1	T2	T3	T4	# Failed	% Success
CORAL (C)	1.00	1.00	1.00	1.00	0.68	0.20	0.46	1.00	1.00	1.00	1.00	0.68	0	100
GORGONIANS (G)	0.11	1.00	**0.00**	0.70	0.80	0.33	**0.00**	0.38	1.00	0.06	0.36	0.09	2	83
SPONGES (S)	0.84	1.00	0.69	0.25	1.00	0.33	0.04	1.00	0.50	0.41	0.50	0.75	0	100
ZOANTHIDS (Z)	0.62	0.45	1.00	n/a	n/a	n/a	n/a	n/a	0.28	0.05	0.53	0.58	0	100
MACROALGAE (MA)	0.15	0.20	**0.00**	0.48	0.06	0.17	0.88	0.08	0.18	**0.00**	**0.02**	0.37	3	75
OTHER LIVE (OL)	0.50	n/a	n/a	n/a	n/a	n/a	n/a	n/a	1.00	n/a	n/a	n/a	n/a	n/a
DEAD CORAL WITH ALGAE (DCA)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
CORALLINE ALGAE (CA)	0.50	0.12	1.00	0.25	n/a	1.00	1.00	n/a	0.06	0.57	0.62	1.00	0	100
DISEASED CORALS (DC)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
SAND, PAVEMENT, RUBBLE (SPR)	**0.00**	**0.01**	**0.02**	0.86	**0.04**	0.16	**0.02**	**0.01**	n/a	1.00	0.19	n/a	6	50
LIT vs. Mosaic	Evans forereef (30-40ft)				Anniversary Patch (12 ft)				Evans Reef Crest (15-20 ft)					
MAJOR CATEGORY	T1	T2	T3	T4	T1	T2	T3	T4	T1	T2	T3	T4	# Failed	% Success
CORAL (C)	1.00	0.75	1.00	0.42	1.00	1.00	0.81	1.00	0.68	0.84	1.00	0.84	0	100
GORGONIANS (G)	0.05	0.15	0.13	**0.03**	1.00	0.17	**0.01**	1.00	0.27	0.33	0.87	0.51	2	83
SPONGES (S)	0.53	1.00	0.45	0.54	1.00	0.10	0.25	1.00	1.00	0.43	0.50	1.00	0	100
ZOANTHIDS (Z)	0.21	0.72	n/a	n/a	n/a	n/a	n/a	n/a	1.00	0.11	1.00	1.00	0	100
MACROALGAE (MA)	**0.00**	0.78	**0.00**	0.12	0.67	0.45	0.09	0.29	0.14	0.28	0.14	0.88	2	83
OTHER LIVE (OL)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.12	n/a	n/a	n/a	n/a	n/a
DEAD CORAL WITH ALGAE (DCA)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
CORALLINE ALGAE (CA)	1.00	1.00	1.00	n/a	n/a	n/a	1.00	n/a	1.00	0.12	0.72	0.25	0	100
DISEASED CORALS (DC)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
SAND, PAVEMENT, RUBBLE (SPR)	**0.00**	0.80	**0.00**	0.25	0.21	0.32	1.00	0.13	1.00	0.10	0.06	0.25	2	83

- Tests that were significantly different between divers or between methods are highlighted in bold.
- A total of 11 tests between two divers were found to be significantly different and a total of 6 tests were significantly different when comparing diver and mosaic categories.

The results of the diver-diver comparison revealed that the categories of gorgonians, macroalgae, and sand, pavement, and rubble were variable enough at the point-intercept level that two divers sampling the same transect line would produce significantly different results for some transects. For gorgonians, divers often differ in their interpretation of benthic categories because points landing on the top of a gorgonian canopy can either be recorded as a gorgonian or the category directly beneath the gorgonian canopy (Figure 100). The categories of sand and macroalgae are often interspersed in the field and can be termed as either sand or macroalgae at any given point depending on the exact field of view of the observer (Figure 100).



- The image as a whole is covered with a fine layer of sand and turf algae shown, by the red arrow (1) that was categorized as sand or as an algal turf depending on the observer making the measurement or the vantage point of the observer. This substrate type was not easily reconciled between observers.
- Large discrete benthic organisms such as large stands of macroalgae or seagrass (**shown in green** (2) and orange boxes (4), the macroalgae and seagrass were easily discriminated by divers.
- if a line-intercept transect lands on a large gorgonian, such as shown in the **blue boxes** (3 &5), the benthic cover at that point could be identified as a gorgonian or the substrate lying beneath the canopy depending on the vantage point of the diver.

Figure 100. Example image showing a common reef substrate consisting of both sand and algal components.

From the diver-diver comparisons, we established a new set of success criteria. Instead of using the arbitrary 90% benchmark proposed in the demonstration plan, we determined that mosaic and diver methods of estimating percent benthic cover would be considered successful if the % success of those comparisons was equal to or greater than that calculated from two divers sampling the same transect. The % success of a given category was calculated as: # of transects sampled - # of transects in which the methods were found to be significantly different /# number of transects sampled*100.

For the categories of coral, sponges, zoanthids, other live, and coralline algae both the mosaic–diver comparisons and diver-diver comparisons were successful across all transects (i.e. 100% success) (Table 54). Thus, mosaic methods and diver methods are considered equally accurate. When sampling gorgonians, the diver-diver success rate was equal to that of the mosaic-diver success rate (83%, Table 54) and thus the methods were considered equally accurate for gorgonians also. In the case of macroalgae, the diver-diver success rate was lower (75%) than the mosaic-diver success rate (83%) and thus the mosaic method is considered at least as accurate as diver estimates of estimating macroalgae cover. Finally, the diver-diver success rate was lower (50%) than the mosaic-diver success rate (83%, Table 54) for the sand, pavement and rubble cover class, so we also conclude that the mosaic method of estimating sand, pavement and rubble cover can be considered at least as accurate as the diver method of estimation. The variability of these categories when comparing two divers suggests that these categories can vary considerably at the point level (i.e., sand and macroalgae, Figure 100) or that greater diver-diver consistency training would have been necessary to remove inconsistency (i.e. gorgonians).

Conclusion: Site-level comparisons of benthic cover were only successful for sponges and zoanthids at all sites, most likely due to different sampling areas between methods. Comparison of transect-level estimates between divers and from divers and mosaics indicates that mosaic estimates of benthic cover are as accurate as diver estimates for all benthic categories.

6.4.1.2 Metric 2: Coral Species Richness

Question: Are plot-scale estimates of coral species richness made from a mosaic at least as large as those made by a diver?

Coral species richness was measured in the field by divers using the BT. Coral species richness was measured in the lab using random point counts and visual inspection of the mosaics. To determine if there is a difference in species richness estimated by the two methods, the following test was used:

Analysis: Consider the smaller number of coral species identified by the divers as "min-diver" and the larger number of coral species identified by the divers as "max-diver." Compute Δ-diver = max-diver - min-diver. Use the larger of Δ-diver or 10% of min-diver as the threshold for success. If the number of colonies counted by the analysts from the mosaic is ≥ min-diver - threshold, the test was considered a success.

Results: For each transect at each of the four test sites a minimum # of species was calculated as described above as the threshold for test success (Table 55). For the visual mosaic inspection method, the mosaic analyst imposed a virtual 10x1m transect along the mosaic image that covered the area of the belt transect that divers in the field sampled for their species richness counts. Because the areas sampled were equivalent, the success criteria was calculated on a per transect basis (Table 55). For the random point count method, where each sample consisted of a 100 random points over the entire site (as opposed to the exact 10 × 1 m transect that was sampled by divers in the water), the minimum number of species calculated among all four diver transects at a given test site was used as the minimum number of species for success number for all mosaic point count samples.

Table 55. Results of species richness test between divers and visual mosaic inspection and mosaic point counts. Unsuccessful comparisons are shown in bold.

Test Sites	Diver1				Diver2				Min # Sp. for Success				Visual Mosaic inspection				Mosaic Pt Counts			
	T1	T2	T3	T4	T1	T2	T3	T4	T1	T2	T3	T4	M1	M2	M3	M4	T1	T2	T3	T4
Brookes Reef	13	11	6	5	11	13	5	6	10	10	4	4	10	10	8	7	**2**	**1**	**1**	**0**
Broadkey Forereef	9	9	7	7	9	8	7	4	9	7	7	4	11	10	11	9	**4**	**2**	**2**	**1**
Anniversary Reef	11	9	9	8	10	8	8	6	9	7	7	5	10	10	8	8	**5**	**4**	**4**	**4**
Evans Reef Crest	12	11	11	9	12	10	9	9	12	9	8	9	13	12	12	11	**6**	**5**	**4**	**4**
													100% Success				0% Success			

When comparing the species richness of divers in the field to the visual mosaic inspection method, all samples at all test sites were successful using the criteria stated above. In contrast, the mosaic point count method of sampling species richness was not successful at any of the sites. We conclude that the mosaic point count method is not a reliable method to replicate species richness results of belt transects performed in the field by divers but that the visual inspection of mosaics can give adequate species richness metrics.

The differences observed between diver belt transects and mosaic point counts were most likely a function of the test-area sampled. Divers in the field measured species richness from10 × 1 m areas whereas mosaic point counts merely sampled 100 random points across the entire test site. Since coral cover was low at all test sites (i.e. less than 10%), less than 10 points per transect were likely to be scleractinian corals and it is highly unlikely that rare species would be sampled at all with this method. Therefore, the difference in sampling methods explains the much lower estimates of species richness obtained by the mosaic point count method than either the diver belt transect or the visual mosaic inspection methods (Figure 99).

These results show that when comparing the same sampling areas there were no differences in diver and mosaic estimates of species richness. However, when testing methods that sample different areas, (i.e., random mosaic point counts and diver belt transects) significant differences between methods were found. It is important to note that this test was not designed to determine if random point counts were a valid method of estimating species richness, instead this test merely shows that you do not obtain the same results as diver belt transects when using random mosaic point counts. Since we found no significant differences between diver and mosaic sampling methods when the same areas are sampled we conclude that the species richness values obtained from point counts are probably valid but due to small total area sampled they will produce different values than belt transect methods.

6.4.1.3 Metric 3: Coral Colony Size Frequency Distribution

Question: Do plot-scale measurements of the size-frequency distribution of coral colonies made by a diver significantly differ from the size-frequency distribution made from mosaic images?

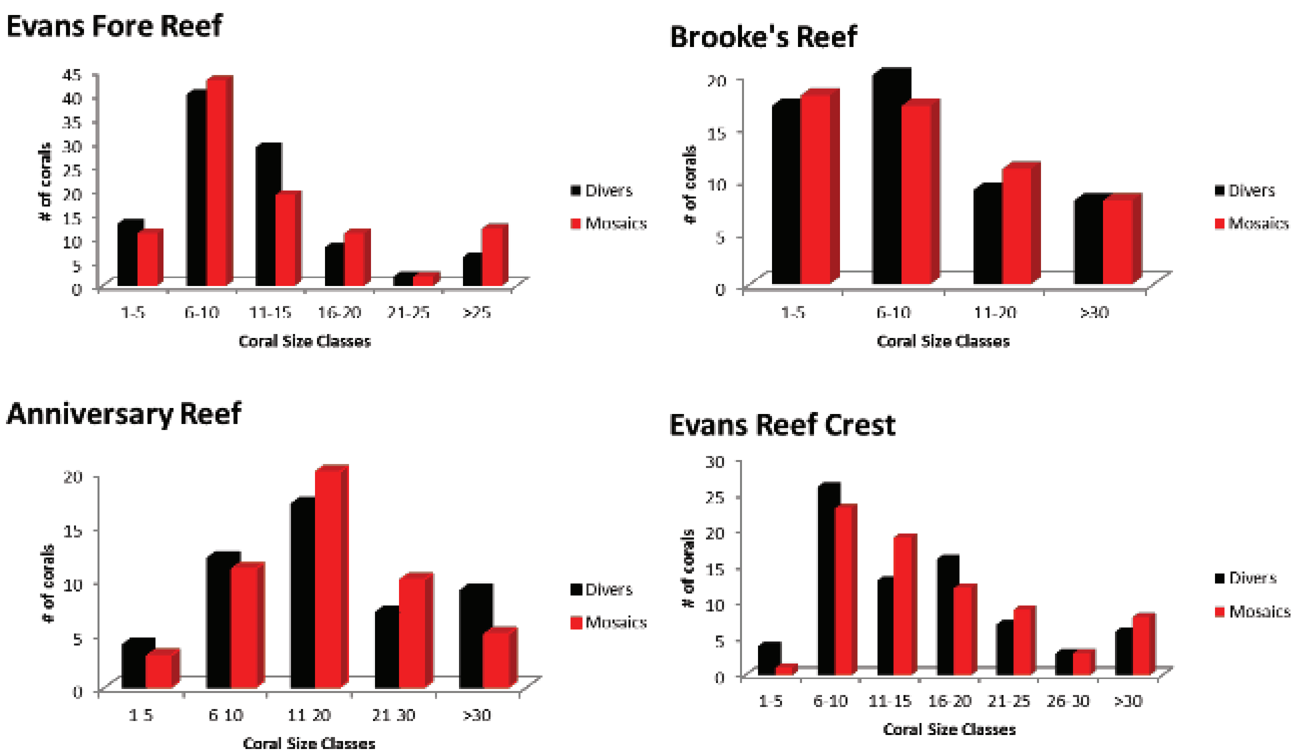
The dimensions of coral colonies with maximum dimension > 4 cm were measured in the field by divers using PCQT. The dimensions of coral colonies > 4 cm were also be measured in the lab using visual inspection of mosaics. A chi-squared goodness-of-fit test was used to determine if there was a difference in the resulting histograms of coral colony sizes.

Analysis: The measurements of coral colonies with maximum dimension > 4 cm were counted within certain size classes (i.e., “binned”) to create a size-frequency distribution for both the diver transect measurements as well as the mosaic measurements. The target bins from the demonstration plan were: 4–10 cm, 10–20 cm, 20–30 cm, 30–40 cm, 40–50 cm, 50–75 cm, 75–100 cm, 100–150 cm, 150–200 cm, and > 200 cm. There is no general consensus on how many corals need to be measured in each bin. Both Zar (1984) and Daniel (1995) suggest following the rule of thumb proposed by Cochran (1977), which is that no more than 20% of the bins should have fewer than five observations. Ideally, all of the bins will have more than five corals, but since we could not control this ahead of time, it was necessary to combine bins or adjust their divisions to ensure a minimal number in each bin.

H0: There is no significant difference ($p > 0.05$) in the estimates of coral colony size frequency distribution as recorded in-situ by divers and estimated from a mosaic.

HA: There is a significant difference ($p \leq 0.05$) in the estimates of coral colony size frequency distribution when using the two methods.

Results: The size distributions of coral colonies at each of the test sites were not previously sampled and thus the ranges of sizes at each site were unknown prior to being surveyed. As a result, the size distributions sampled were of a smaller range than initially assumed and therefore appropriate bin sizes were chosen on a site-by-site basis. We followed the rule above by Cochran to avoid classes with fewer than five observations if possible. he comparison of diver and mosaic-based size frequency distributions at each of the four test sites is shown in Figure 101.



- The size measurements in red depict the mosaic measurements and those in black were assessed by divers. Evans Forereef, Brooke's Reef, Anniversary Reef and Evans Reef Crest) by divers using the PCQT method and from mosaics.

Figure 101. Size frequency distribution of coral colonies measured at the four test sites.

The size-distributions were compared using a chi-squared test as described above. None of the four size frequency distributions were significantly different between methods (Brooke's Reef $p = 0.437$; Evans Forereef $p = 0.437$; Anniversary Reef $p = 0.717$; Evans Reef Crest $p = 0.647$) indicating that there was no significant difference in estimating the population size frequency between diver and mosaic-based methods. These results agree with the tests of absolute accuracy of coral colony size measurements demonstrated in Section 6.5.

Conclusion: There was no significant difference in the estimates of coral colony size frequency distribution as recorded in-situ by divers and estimated from a mosaic.

6.4.1.4 Metric 4: % Coral Diseased

Question: Do visual estimates of coral disease made by a diver significantly differ from estimates of coral disease made from mosaic images?

Coral disease was assessed by the divers as they performed the PCQT. All the corals identified by the divers had been marked with tiles, so the ones with disease were positively identified on the mosaic. For each colony, two measures of the absolute error were computed for each metric:

Absolute Error = AE = (|DiverA-DiverB|) and (|DiverA-Mosaic|)

Analysis: Two-way ANOVA was completed in which the independent variables were condition assessment method (diver or mosaic) and coral colony size class. The main effect was the % affected area. Diver A (RSMAS) and Diver B (Navy) both evaluated 477 corals in the Long-Term Monitoring, Grounding, and Traditional Metrics demonstrations combined. Diver A (used as the standard of measurements) also assessed mosaic measurements for the same 477 colonies. The replicate measurements by RSMAS and Navy divers were used as a check for consistency. Only those corals that the RSMAS and Navy diver assessments agreed were diseased were used in the comparison with the mosaic.

For this design there were three null hypotheses and three alternative hypotheses:

Ho1: There is no significant difference ($p > 0.05$) in the absolute error of % coral diseased between the measurement methods

HA1: There is a significant difference ($p \leq 0.05$) in the absolute error of % coral diseased between the measurement methods

Ho2: There is no significant difference ($p > 0.05$) in the absolute error of % coral diseased based on coral size categories

HA2: There is a significant difference ($p \leq 0.05$) in the absolute error of % coral diseased based on coral size categories

Ho1-2: There is no interaction ($p > 0.05$) between coral size category and measurement method

HA1-2: There is a significant interaction ($p \leq 0.05$) between coral size category and measurement method

Results: Of the 477 coral colonies that were examined for their condition across three of the four field demonstrations (Long-Term Monitoring, Grounding, and Traditional Metrics) the prevalence of coral disease was very low, with only N = 7 coral colonies being identified as diseased from either a diver or mosaic observer. The mean absolute error estimated by divers and from mosaics for the 7 diseased colonies is shown in Figure 102.

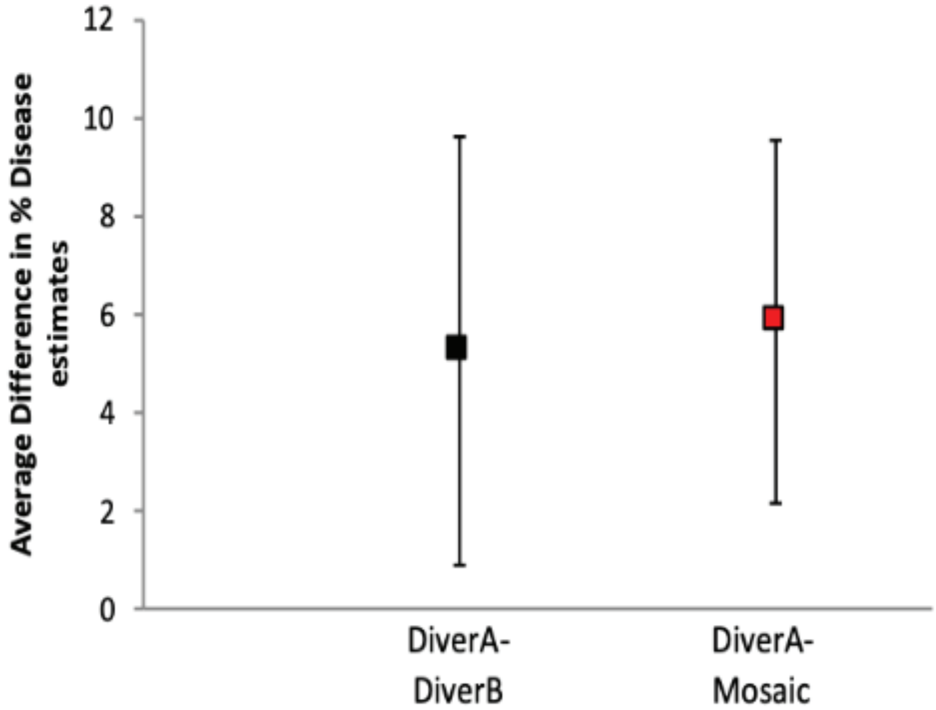


Figure 102. Absolute error and 95% confidence intervals of the absolute error of diver and mosaic estimates of the % diseased condition metric.

Due to the naturally low sample size, the proposed hypothesis testing in which samples were compared based on method and colony size was not possible. Furthermore, the AE data were not normally distributed. Therefore, a Mann-Whitney U Test was used to compare the absolute error of diver and mosaic estimates of % disease by testing the following null and alternative hypotheses:

Ho1: There is no significant difference ($p > 0.05$) in the absolute error of the % disease metric between the measurement methods

HA1: There is a significant difference ($p \leq 0.05$) in the absolute error of the % disease metric between the measurement methods

The Mann Whitney U test indicated that no significant difference existed between the absolute error of diver and mosaic estimates of the percent of a coral colony infected by disease (p=0.736). Overall, the fact that the average absolute error between divers and mosaics was ~5% in both samples suggests that there was a high degree of accuracy in an observers' ability to estimate the percent of a coral infected with disease. This sample size was small, but based on the natural sample encountered there was no statistical evidence that measures of % diseased differed between the mosiacs and divers.

Conclusion: There was no significant difference in the absolute error of diver or mosaic methods of estimating the percentage of disease infecting a coral colony.

6.4.1.5 Metric 5: % Coral Bleached

Question: Do visual estimates of % area affected by coral bleaching made by a diver significantly differ from estimates of % area affected by bleaching made from mosaic images?

Coral bleaching was assessed by the divers as they performed the PCQT. All the corals identified by the divers had been marked with tiles, so the ones with bleached tissue were positively identified on the mosaic. For each colony, two measures of the absolute error were computed for each metric:

Absolute Error = AE = (|DiverA-DiverB|) and (|DiverA-Mosaic|)

Analysis: Two-way ANOVA was completed in which the independent variables were condition assessment method (diver or mosaic) and coral colony size class. The main effect was the % affected area. Diver A (RSMAS) and Diver B (Navy) both evaluated 477 corals in the Long-Term Monitoring, Grounding, and Traditional Metrics demonstrations combined. Diver A (used as the standard of measurements) also assessed mosaic measurements for the same 477 colonies. The replicate measurements by RSMAS and Navy divers were used as a check for consistency. Only those corals that the RSMAS and Navy diver assessments agreed were bleached were used in the comparison with the mosaic.

For this design there were three null hypotheses and three alternative hypotheses:

Ho1: There is no significant difference ($p > 0.05$) in the absolute error of % coral bleached between the measurement methods

HA1: There is a significant difference ($p \leq 0.05$) in the absolute error of % coral bleached between the measurement methods

Ho2: There is no significant difference ($p > 0.05$) in the absolute error of % coral bleached based on coral size categories

HA2: There is a significant difference ($p \leq 0.05$) in the absolute error of % coral bleached based on coral size categories

Ho1-2: There is no interaction ($p > 0.05$) between coral size category and measurement method

HA1-2: There is a significant interaction ($p \leq 0.05$) between coral size category and measurement method

Results: Of the 477 colonies sampled, only N = 18 were identified as being bleached by diver or mosaic analysts. Of the 18 bleached colonies identified, only one colony was larger than 25 cm. Due to the naturally low sample size of the larger size class, the proposed hypothesis testing in which samples were compared based on method and colony size was not possible. As such, all samples were combined and an alternative test was performed to compare the estimates of % coral colonies that were bleached from diver and mosaic observers. Furthermore, the AE data were not normally distributed, so a Mann-Whitney U Test was used to compare the absolute error of diver and mosaic estimates of % bleached by testing the following null and alternative hypotheses:

Ho1: There is no significant difference ($p > 0.05$) in the absolute error of the % bleached metric between the measurement methods

HA1: There is a significant difference ($p \leq 0.05$) in the absolute error of the % bleached metric between the measurement methods

The Mann-Whitney U test of the absolute error of divers and mosaics of the % bleached condition metric indicated that there was no significant difference between methods ($p = 0.684$). The average absolute error of diver and mosaic observers was within one percent of each other (Figure 103), suggesting that there was no difference between estimation methods.

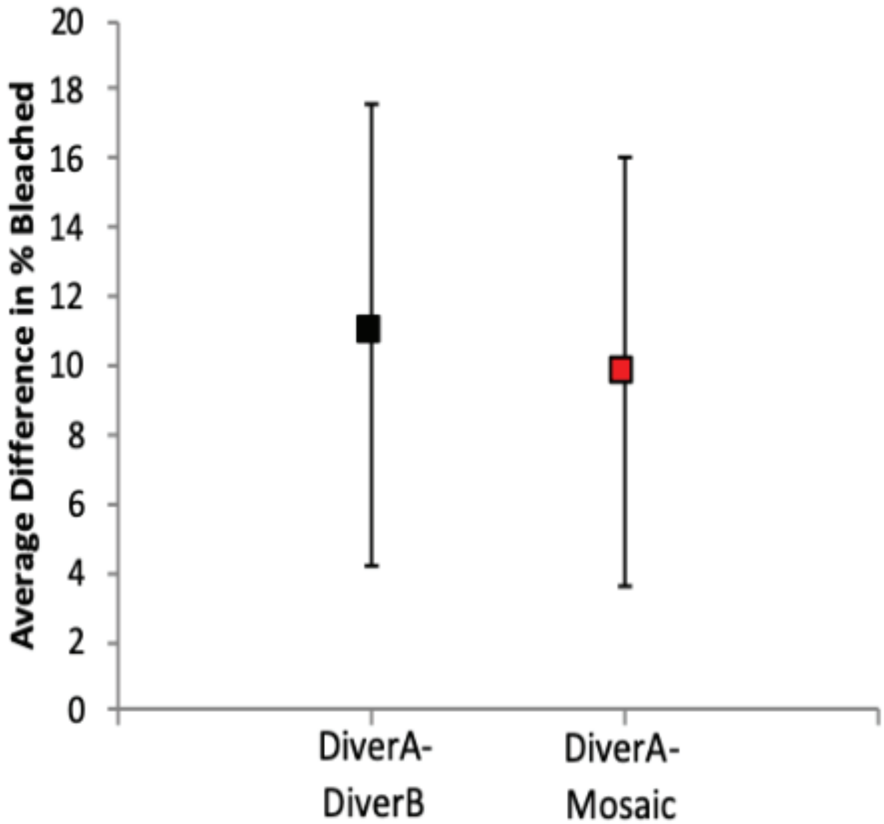


Figure 103. Absolute error and 95% confidence intervals of the absolute error of diver and mosaic estimates of the % bleached condition metric.

Conclusion: There was no significant difference between diver and mosaic methods of estimating the % bleached condition metric. Although the absolute error between methods was higher for estimating % of colonies bleached (~10%) than for estimating the % of colonies diseased (~5%) we considered these variances to be reasonable for methods of measurement based on visual estimation.

6.4.1.6 Metric 6: % New Mortality

Question: Do visual estimates of % area affected by new mortality made by a diver significantly differ from estimates of % area affected by new mortality made from mosaic images?

Coral mortality was assessed by the divers as they performed the PCQT. For each colony, two measures of the absolute error were computed for each metric:

Absolute Error = AE = (|DiverA-DiverB|) and (|DiverA-Mosaic|)

Analysis: Two-way ANOVA was completed in which the independent variables were condition assessment method (diver or mosaic) and coral colony size class. The main effect was the % of the coral skeleton affected by new mortality. Diver A (RSMAS) and Diver B (Navy) both evaluated 477 corals in the Long-Term Monitoring, Grounding, and Traditional Metrics demonstrations combined.

Diver A (used as the standard of measurements) also assessed mosaic measurements for the same 477 colonies. The replicate measurements by RSMAS and Navy divers were used as a check for consistency. Only those corals that the RSMAS and Navy diver assessments agreed contained newly dead skeleton were used in the comparison with the mosaic.

For this design there were three null hypotheses and three alternative hypotheses:

Ho1: There is no significant difference ($p > 0.05$) in the absolute error of % new mortality between the measurement methods

HA1: There is a significant difference ($p \leq 0.05$) in the absolute error of % new mortality between the measurement methods

Ho2: There is no significant difference ($p > 0.05$) in the absolute error of % new mortality based on coral size categories

HA2: There is a significant difference ($p \leq 0.05$) in the absolute error of % new mortality based on coral size categories

Ho1-2: There is no interaction ($p > 0.05$) between coral size category and measurement method

HA1-2: There is a significant interaction ($p \leq 0.05$) between coral size category and measurement method

Results: Of the 477 colonies examined for condition indices, only N = 35 were noted to have new mortality either by divers in the field or from mosaic analysts. Of the 35 colonies showing new mortality, 26 colonies were less than 25 cm, and 9 were greater than 25 cm in maximum diameter. Due to the low sample size of large colonies, all 35 individuals showing new mortality were grouped together for hypothesis testing. The data were not normally distributed, so a Mann-Whitney U Test was used to compare the absolute error of diver and mosaic estimates of % new mortality by testing the following null and alternative hypotheses:

Ho1: There is no significant difference ($p > 0.05$) in the absolute error of the % new mortality metric between the measurement methods

HA1: There is a significant difference ($p \leq 0.05$) in the absolute error of the % new mortality metric between the measurement methods

The average absolute error of estimates of % new mortality from divers in the field and from mosaics is shown in Figure 104. The Mann Whitney U test revealed no significant differences between measurement method when comparing the absolute error of estimates of % new mortality ($p = 0.9235$).

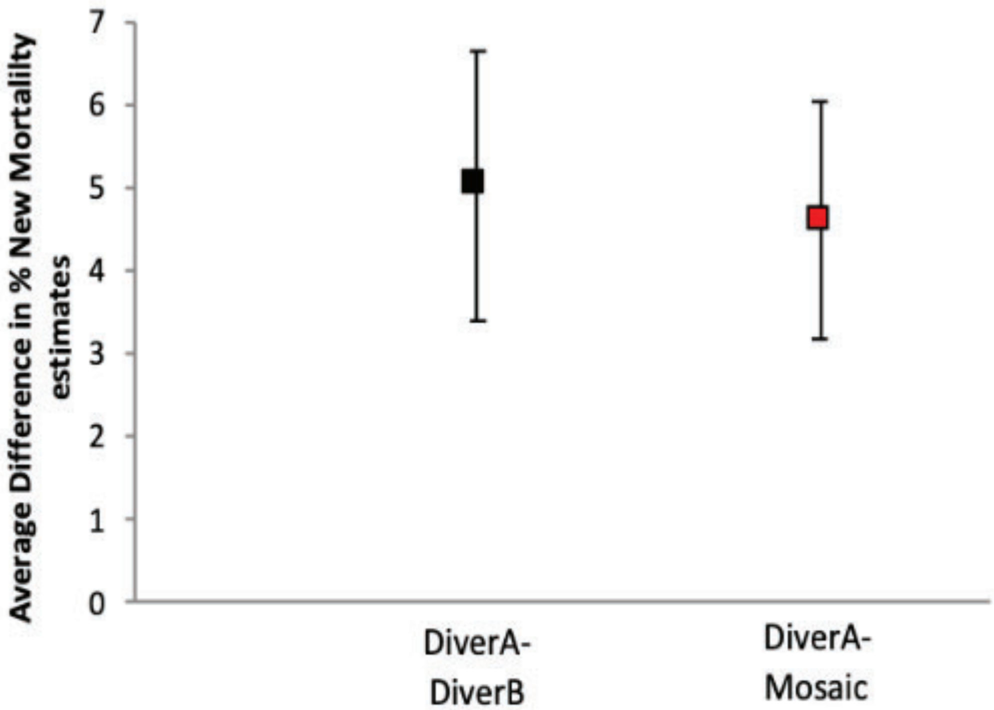


Figure 104. Average absolute error estimates from divers and mosaics when estimating the % new mortality of a coral colony.

Conclusion: There was no significant difference between diver and mosaic methods of estimating the % new mortality condition metric. The average absolute error of % new mortality estimates (~5%) were similar to those obtained when comparing estimates of % coral colonies infected with disease and are considered to be an acceptable variance for a measurement based on visual estimation. The lower absolute error of % new mortality and % diseased estimates when compared to % bleaching estimates suggests that both new mortality and coral disease are more distinctive and defined than the bleaching condition metric and therefore the consistency between observers is higher.

6.4.1.7 Metric 7: % Old Mortality

Question: Do visual estimates of % area affected by old mortality made by a diver significantly differ from estimates of % area affected by old mortality made from mosaic images?

Coral mortality was assessed by the divers as they performed the PCQT. For each colony, two measures of the absolute error were computed for each metric:

Absolute Error = AE = (|DiverA-DiverB|) and (|DiverA-Mosaic|)

Analysis: Two-way ANOVA was completed in which the independent variables were condition assessment method (diver or mosaic) and coral colony size class. The main effect was the % of the coral skeleton affected by old mortality. Diver A (RSMAS) and Diver B (Navy) both evaluated 477 corals in the Long-Term Monitoring, Grounding, and Traditional Metrics demonstrations combined. Diver A (used as the standard of measurements) also assessed mosaic measurements for the same 477 colonies. The replicate measurements by RSMAS and Navy divers were used as a check for consistency. Only those corals that the RSMAS and Navy diver assessments agreed contained old dead skeleton were used in the comparison with the mosaic.

For this design there were three null hypotheses and three alternative hypotheses:

Ho1: There is no significant difference ($p > 0.05$) in the absolute error of % old mortality between the measurement methods

HA1: There is a significant difference ($p \leq 0.05$) in the absolute error of % old mortality between the measurement methods

Ho2: There is no significant difference ($p > 0.05$) in the absolute error of % old mortality based on coral size categories

HA2: There is a significant difference ($p \leq 0.05$) in the absolute error of % old mortality based on coral size categories

Ho1-2: There is no interaction ($p > 0.05$) between coral size category and measurement method

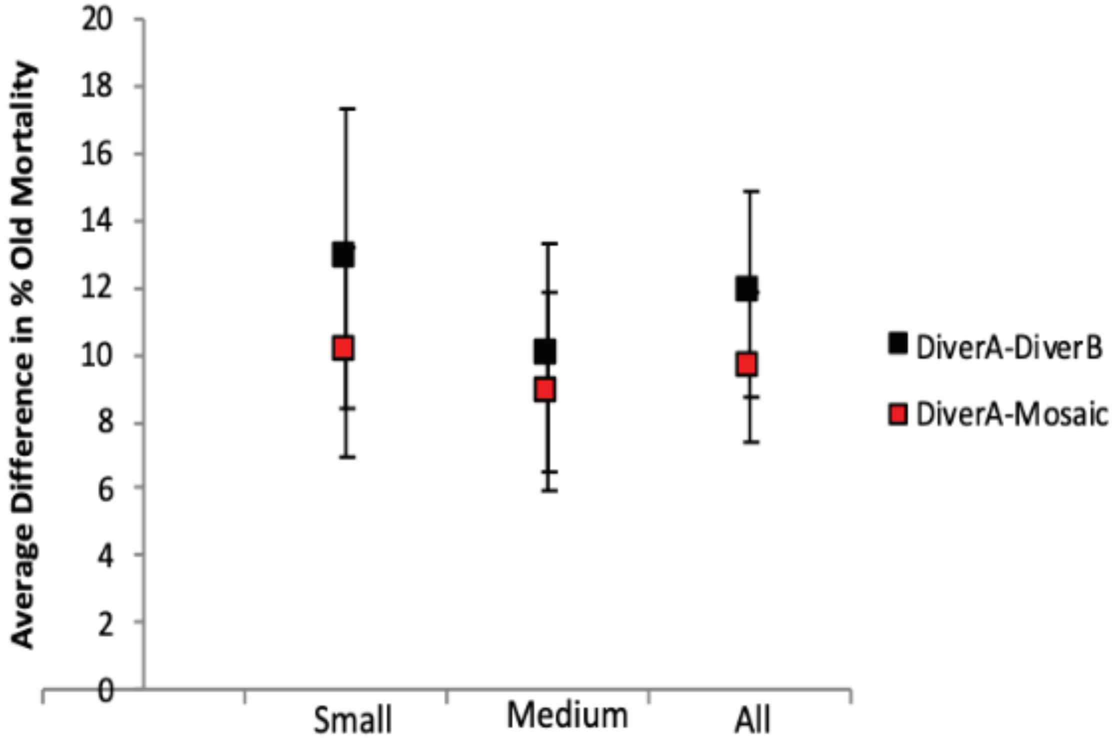
HA1-2: There is a significant interaction ($p \leq 0.05$) between coral size category and measurement method

Results: Of the 477 colonies evaluated for coral condition, N = 69 were evaluated by divers or mosaic analysts as having old mortality. Of the 69 colonies that experienced old mortality, 44 were categorized as small (< 25cm) and 25 were categorized as large (> 25cm). Unlike the two-way ANOVA originally proposed, the general linear model (GLM) ANOVA is capable of handling unbalanced designs. As such, the GLM ANOVA was substituted for the two-way ANOVA to examine the measurement methods of % old mortality. Using the GLM we evaluated the measurement method, size, and interaction between measurement method and size as factors. The results of the GLM ANOVA are shown in Table 56.

Table 56. Results of the general linear model ANOVA in which measurement method, colony size, and the interaction of size and measurement method were assessed as factors.

Category	F	P
Size	1.08	0.301
Method	0.97	0.326
Size*Method Interaction	0.21	0.648

None of the factors (size, method, or the interaction term) were significantly different when comparing the absolute error of diver and mosaic estimates of % old mortality. The average absolute error of mosaics and divers were comparable for both small and large colonies and when all measurements were combined (Figure 105). The largest differences in absolute error were observed for small colonies. Intuitively this makes sense because in small corals a small change in the total area affected can result in a large difference in the percentage of area affected (e.g. if a coral of 10 cm total area has 2 cm of old mortality this is equal to 20% of the total colony but 4 cm, an increase in only 2 cm, represents 40% of the total area). Despite this inherent challenge, there were no significant differences observed between diver and mosaic measurements of % old mortality at either size category and the mean absolute errors of both methods were consistent with other condition categories that were estimated visually (i.e. % bleaching).



- The total figure range top to bottom shows the compared measurement methods.
- **Black**: signifies the absolute error of divers.
- **Red**: signifies the absolute error of mosaics.
- Small coral sized categories were (< 25cm) and medium (> 25cm).

Figure 105. The average absolute error of divers and mosaics when comparing measurement methods and when measurements are broken into small coral size categories

Conclusion: There was no significant difference in the absolute error of the % old mortality metric when comparing the measurement methods, coral size categories, or between the coral size category and measurement method.

6.4.1.8 Metric 8: Juvenile Coral Density

Question: Does site-averaged juvenile coral colony density as measured by a diver significantly differ from estimates made from mosaics?

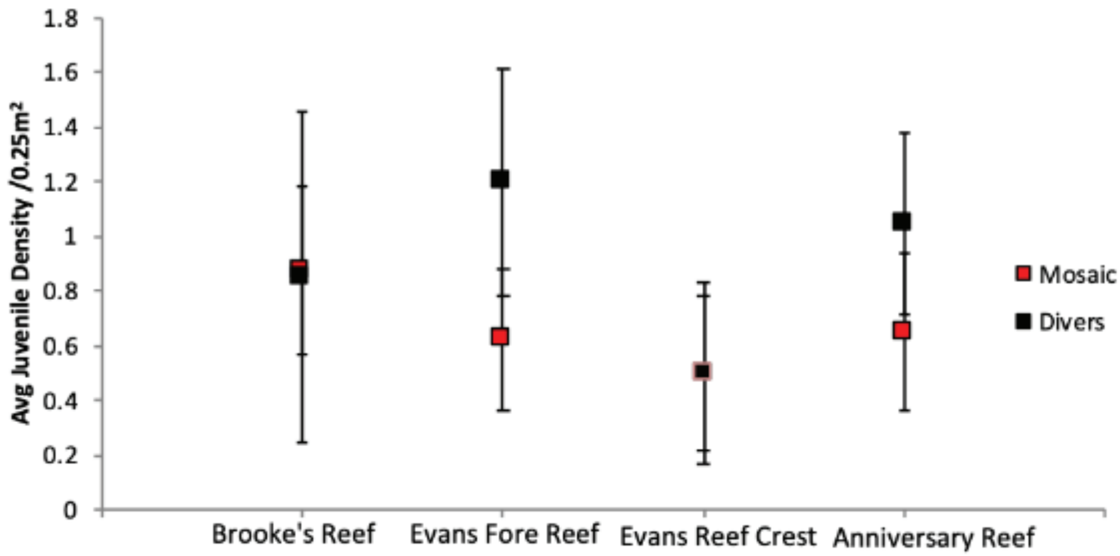
Divers counted juvenile corals in ten, 0.25 m^2 quadrats along each of the four PCQT transects. Analysts examined forty, 0.25 m^2 quadrats randomly subsampled from the mosaic of the site. Methods of assessing juvenile density were be compared using a t-test as proposed below.

Analysis: t-test for differences in mean juvenile coral density.

H0: There is no significant difference ($p > 0.05$) in the mean juvenile coral density as estimated in-situ by divers and from a mosaic.

HA: There is a significant difference ($p \leq 0.05$) in the mean juvenile coral density as estimated in-situ by divers and from a mosaic.

Results: The estimates of juvenile coral density were not normally distributed therefore the nonparametric Mann-Whitney U test of medians was substituted in the above analysis for the proposed t-test. The average estimates of juvenile density from divers in the field and from a mosaic analyst of the four test sites is shown in Figure 106. The comparison of methods of estimating juvenile density revealed that diver and mosaic methods were not significantly different at the Evan's Reef Crest or Anniversary reef sites (Table 57). Methods of estimating juvenile density were significantly different at the Brooke's Reef and Evan's Forereef site.



- Black: from all divers in the field
- From visual inspection of mosaics (**Red**) at all four test sites.

Figure 106. Comparison of juvenile density estimates and the 95% confidence intervals of each mean from divers in the field.

Table 57. Results of Mann-Whitney U Test of juvenile density between divers and from visual inspection of mosaics. Significant results are shown in bold.

Site	N	Median	W	P
Brooke's (mos)	40	1.00	1824.0	**0.03**
Brooke's (div)	40	0.00		
Evans Reef Crest (mos)	40	0.00	1625.0	0.96
Evans Reef Crest (div)	40	0.00		

Table 57. Results of Mann-Whitney U Test of juvenile density between divers and from visual inspection of mosaics. Significant results are shown in bold. (Continued)

Site	N	Median	W	P
Evans Forereef (mos)	40	0.00	1425.0	**0.04**
Evans Forereef (div)	40	1.00		
Anniversary Reef (mos)	40	1.00	1806.0	0.06
Anniversary Reef (div)	40	0.00		

The significantly different results of diver and mosaic estimates of juvenile density at Brooke's Reef and Evan's Forereef are inconclusive with respect to understanding if mosaic methods can replicate diver estimates of juvenile density. At Brooke's reef the Mann Whitney U test showed a significantly different result between methods when comparing median values of each sample (Table 57). However, when we examine the mean juvenile density using both sampling methods we obtain nearly identical results (diver mean = 0.85, mosaic mean = 0.87, Figure 106). However, because the medians of each sample were different the nonparametric significance test indicated a difference between methods. We conclude that this significant result at the Brooke's reef site is a reflection of the difference in parameters measured when performing parametric and non-parametric tests.

The significantly different result of juvenile density estimation methods at Evan's Forereef may either indicate a difference in estimation method or a difference in sampling area of the two methods. The quadrat sampling of the divers in the field was performed once every meter along the 10m linear transects from which the LPIT, BT, and PCQT surveys were performed. The virtual 50 × 50 cm quadrats analyzed by mosaic observers were placed randomly on the mosaic of each test site (Figure 107).

Differences in sampling area have already been shown to be important in comparing estimates of percent cover between divers and from mosaics (Section 6.4.1.1). In that example, several categories of benthic cover were found to be significantly different between divers and from mosaics when comparing randomly placed points (mosaics) and points along a 10m linear transect (divers). In the percent cover example, since all the 10 m linear transects that were sampled by divers were left in place during the mosaic surveys, it was possible to return to the mosaic image and sample the exact same areas as divers in the field for a more in-depth analysis.

In the case of the juvenile surveys, even though we know that the quadrats were placed along the 10 m transect lines once per meter, since the quadrats were not marked in the mosaic image, it is impossible to directly replicate the diver surveys. Thus, a direct comparison between juvenile and mosaic methods of estimating juvenile density is not possible using this field methodology. Thus the differences in juvenile density obtained in the statistical analysis may reflect natural differences in the number of juveniles on different areas on the reef and not necessarily indicate differences in sampling methods.

So, although this test is inconclusive at the Evan's forereef site, the performance objective did showed that corals smaller than 4 cm can be directly detected from mosaic images, and that the estimates of juvenile density agreed with diver estimates at three of the four test sites. A test in which both divers and mosaic analysts sample the same 50 × 50 m quadrats would be needed to rule out spatial autocorrelation as the driver of the observed differences in juvenile density at the Evans fore reef test site.

Conclusion: Corals smaller than 4 cm were visible from mosaic images and diver and mosaic methods produced similar average density estimates of juvenile corals at three of the four test sites.

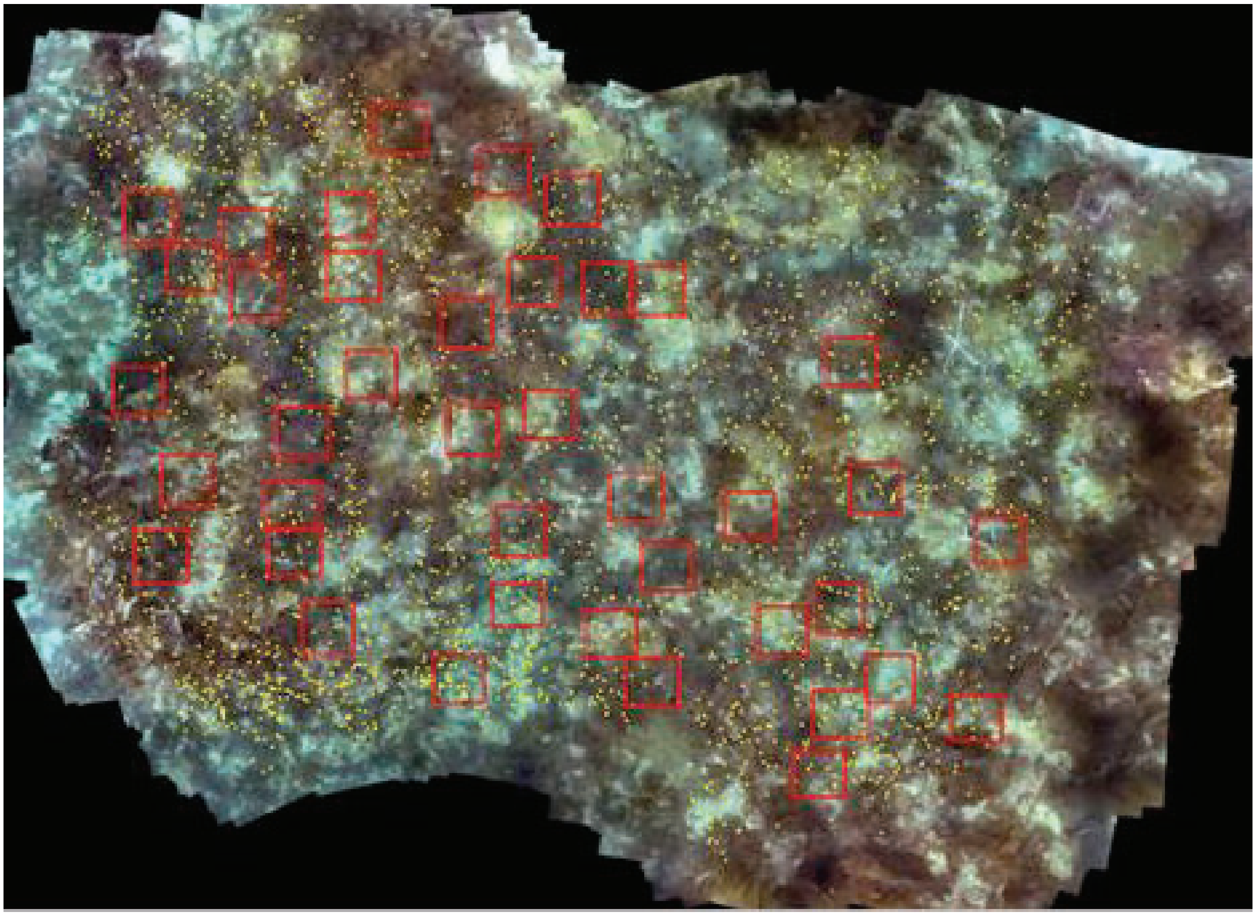


Figure 107. A mosaic image of the Evan's Reef Crest test site with 40 random 50×50 cm quadrats (shown in red) overlaid on the image to estimate juvenile density. The yellow dots show locations where high-resolution stills are present for coral health and identification information.

6.4.2 Performance Objective 2: Extract Ecological Measurements from Mosaics using Multiple Methods

As a reminder, the overall approach was:

(A) Select a site with visually homogenous bottom cover over the scale of 10 × 10 m.
(B) Lay out four 10 m transects within the site, assess each transect using PCQT, LPIT, BT and VT diver methods.
(C) Mosaic the area that was assessed by divers
(D) Extract metrics from the VT data.
(E) Extract metrics from the mosaic.
(F) Compare the metrics derived from diver data with those derived from the mosaic.
(G) Compute the costs of diver and mosaic methods.

Steps A-E were described in Section 5.4.4 along with instructions for setting up the cameras. Step F is described here. Step G is described in Section 7.4.

Performance was quantified by comparing benthic cover and species richness metrics extracted from mosaics and diver surveys. For each type of transect, accuracy was quantified by the differences in each of these two metrics as extracted from the mosaics and as measured by divers. The statistical significance of the differences in percent cover between methods was tested with a binomial test. The diver measurement of species richness was used as a minimum performance value for the mosaic.

6.4.2.1 Metric 1: Benthic Cover

Question: Are transect-scale measurements of the % cover for a given class made by a diver significantly different than measurements of % cover for that class made from mosaic images?

Benthic cover was measured in the field by divers using the LPIT and VT methods. Benthic cover was measured in the lab using simulated LPIT and VT. To determine if there was a difference in the methods of measurement a binomial test was used for each cover class: live coral, turf algae, macroalgae, crustose coralline algae, milleporans, gorgonians, zoanthids, and sponges.

Analysis: For each transect a binomial test was conducted. Divers have measured the benthic cover at N points in the field, using the LPIT and VT methods. An analyst has measured N points from lines placed on a mosaic replicating as closely as possible the area of the diver transects. Do the estimated proportions of cover for each class significantly differ depending on which method was used to make the estimate? Success was achieved if there is no significant difference for 90% or more of the transects.

H0: There is no significant difference ($p > 0.05$) in the estimate of percent cover as recorded in-situ by divers using the LPIT and estimated from a mosaic using a virtual LPIT.

HA: There is a significant difference ($p \leq 0.05$) in the estimate of percent cover when using the two methods

H0: There is no significant difference ($p > 0.05$) in the estimate of percent cover as recorded in-situ by divers using the VT and estimated from a mosaic using a virtual VT.

HA: There is a significant difference ($p \leq 0.05$) in the estimate of percent cover when using the two methods

Results: Due to small sample sizes for some categories, the Fisher's Exact Test was substituted for the binomial test for all comparisons. For the linear point intercept transects (LPIT), the categories of coral, sponges, zoanthids, other live, and coralline algae were not significantly different when estimated by a diver in the field or from a visual inspection of a mosaic (Table 58). Only the categories of gorgonians, macroalgae and sand, pavement, and rubble had a few cases where the estimates were significantly different based on the sampling method used. As discussed in Section 6.4.1.1, these three categories were difficult to calibrate among divers (e.g., sampling above or below a gorgonian canopy) or they varied considerably on a cm scale (sand vs. turf macroalgae). Originally, we proposed that only categories that had a 90% success rate, in terms of not being significantly different from diver methods, would be considered a successful test. However, after examining the agreement observed between two divers sampling the same transect, we propose that a successful test is one in which the % success of the diver and mosaic comparisons are as good or better than the % success of two divers sampling the same transect.

Table 58. Diver-based line-intercept and video transect methods were compared to mosaic estimates of benthic cover on a transect-by-transect basis at four reef test sites.

LIT vs. Mosaic	Brooke's Reef (30-40 ft)				Evans forereef (30-40ft)				Anniversary Patch (12 ft)				Evans Reef Crest (15-20 ft)						Diver-Diver
MAJOR CATEGORY	T1	T2	T3	T4	T1	T2	T3	T4	T1	T2	T3	T4	T1	T2	T3	T4	# Failed	% Success	% Success
CORAL	1.00	0.81	0.81	1.00	1.00	0.75	1.00	0.42	1.00	1.00	0.81	1.00	0.68	0.84	1.00	0.84	0	100	100
GORGONIANS	0.78	0.77	1.00	0.13	0.05	0.15	0.13	**0.03**	1.00	0.17	**0.01**	1.00	0.27	0.33	0.87	0.51	2	88	83
SPONGES	1.00	0.31	0.36	0.41	0.53	1.00	0.45	0.54	1.00	0.10	0.25	1.00	1.00	0.43	0.50	1.00	0	100	100
ZOANTHIDS	1.00	0.52	0.69	1.00	0.21	0.72	n/a	n/a	n/a	n/a	n/a	n/a	1.00	0.11	1.00	1.00	0	100	100
MACROALGAE	0.31	**0.04**	**0.00**	0.62	**0.00**	0.78	**0.00**	0.12	0.67	0.45	0.09	0.29	0.14	0.28	0.14	0.88	4	75	75
OTHER LIVE	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.12	n/a	n/a	n/a	n/a	n/a	n/a
DEAD CORAL WITH ALGAE	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
CORALLINE ALGAE	n/a	1.00	0.06	n/a	1.00	1.00	1.00	n/a	n/a	n/a	1.00	n/a	1.00	0.12	0.72	0.25	0	100	100
DISEASED CORALS	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
SAND, PAVEMENT, RUBBLE	0.29	0.87	**0.00**	0.57	**0.00**	0.80	**0.00**	0.25	0.21	0.32	1.00	0.13	1.00	0.10	0.06	0.25	3	81	50
Video Transect vs. Mosaic	Brooke's Reef (30-40 ft)				Evans forereef (30-40ft)				Anniversary Patch (12 ft)				Evans Reef Crest (15-20 ft)						Diver-Diver
MAJOR CATEGORY	T1	T2	T3	T4	T1	T2	T3	T4	T1	T2	T3	T4	T1	T2	T3	T4	# Failed	% Success	% Success
CORAL (C)	1.00	0.80	0.57	1.00	1.00	0.77	0.72	0.20	0.72	0.33	0.23	0.72	1.00	0.84	0.40	1.00	0	100	100
GORGONIANS (G)	1.00	0.08	1.00	0.31	0.40	0.06	0.07	0.11	0.44	0.33	**0.01**	**0.00**	0.74	0.13	**0.00**	**0.00**	4	75	83
SPONGES (S)	0.15	0.78	1.00	0.40	0.82	1.00	1.00	0.75	0.68	0.50	n/a	**0.03**	0.25	0.12	0.25	0.21	1	94	100
ZOANTHIDS (Z)	**0.03**	1.00	0.43	0.33	0.45	0.25	n/a	0.50	n/a	n/a	n/a	n/a	0.41	1.00	0.11	0.73	1	94	100
MACROALGAE (MA)	0.39	1.00	0.77	**0.01**	1.00	0.57	**0.03**	0.10	0.89	0.77	0.06	0.56	1.00	1.00	**0.04**	**0.00**	4	75	75
OTHER LIVE (OL)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
DEAD CORAL WITH ALGAE (	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
CORALLINE ALGAE (CA)	1.00	1.00	0.06	n/a	0.25	0.25	1.00	n/a	n/a	n/a	1.00	n/a	**0.00**	1.00	0.06	0.25	1	94	100
DISEASED CORALS (DC)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
SAND, PAVEMENT, RUBBLE	0.43	0.21	0.77	**0.00**	0.24	0.77	0.51	**0.01**	0.50	0.44	0.08	0.08	0.62	0.10	n/a	0.32	2	88	50

- Category estimates were compared between methods using the Fishers Exact test and significant differences are shown in bold.
- Results of a diver-diver comparison of line-intercept results are shown in the column at the far right as the measure of success. Benthic classes for which the % success was greater than or equal to the diver-diver % success were considered successful tests.

In the case presented above, the LPIT and mosaic comparison was as successful as two divers comparing the same transect line in all categories. The only categories that showed significant results between methods (i.e. gorgonians, macroalgae, and sand, pavement and rubble) were the same metrics that had significant differences between two divers.

Tests of the virtual VT were similar to those for the virutal LPIT. We compared the benthic cover estimates obtained by a video transect performed 50cm from the benthos over the line intercept transects with benthic cover estimated by inspecting the mosaics at 100 points along the line intercept transect. The results of the comparisons were also shown in Table 58. In this comparison, the methods agreed 100% of the time for the category of % coral cover. For the categories of gorgonians, sponges, zoanthids, macroalgae, coralline algae and sand, pavement, and rubble there was at least one instance where the methods produced significantly different estimates of percent cover (Table 58).

As with the virtual LPIT, we compared the % success of each category, not with the 90% benchmark established previously, but with the % success of two divers sampling the same linear intercept transect. Using this benchmark, the categories of sponge, zoanthid, and coralline algae cover were different between methods. In each of these cases one transect had a significantly different result between methods resulting in a 94% overall success rate, whereas two divers had 100% success at estimating these categories. We consider the failure of one transect out of 16 to be a successful error rate and propose that the observed differences are most likely perpetuated by the different areas sampled between the methods. A 10 m video transect performed at 50 cm above the benthos has a sampled area of at least 10 m×50 cm of benthos, whereas the visual assessment performed from the mosaic of each transect was performed directly along the 10m line without any regard to the surrounding area. Thus, the random points applied to the video transect sampled a larger area than that of the mosaics which could potentially drive the small differences in benthic categories that were documented during this test.

Considering the overall ability of mosaics to estimate benthic cover when compared with video transects we concluded that the mosaic method performs as well as the video transect method for all categories with the possible exception of gorgonian cover that had a lower % success rate (75%) than two divers sampling the same exact area (83%). The high variability of this category of cover across methods suggests that it is highly spatially variable and that greater interpretation training would be needed to control the observer variability.

Conclusion: Mosaic methods of estimating benthic cover were as good as divers performing linear intercept transects or video transects. The category of gorgonian cover was found to be highly variable across all tests and there may be a significant difference between mosaic and video transect estimates of gorgonian cover in some cases.

6.4.2.2 Metric 2: Coral Species Richness

Question2: Are transect-scale estimates of coral species richness made from a mosaic at least as large as those made by a diver?

Coral species richness was measured in the field by divers using the BT and VT methods. Coral species richness was measured in the lab using virtual BT and VT methods. To determine if there was a difference in species richness estimated by the diver or mosaic methods, the following test was used:

Analysis: Consider the smaller number of coral species identified by the divers as "min-diver" and the larger number of coral species identified by the divers as "max-diver." Compute Δ-diver = max-diver - min-diver. Use the larger of Δ-diver or 10% of min-diver as the threshold for success. If the number of colonies counted by the analysts from the mosaic is ≥ min-diver - threshold, the test was considered a success for the transect. The overall metric was considered a success if 90% or more of the transects individually were successful.

Results: Species diversity was assessed by divers in the field, using visual inspection of 10x1m transects from mosaics (visual mosaic inspection), using random point counts of the surveyed area directly from a mosaic image (mosaic pt counts), and from visual inspection of video transects (visual inspection of video transects). The success of a test between methods was established by calculating a minimum # of species for success. Using the diver data at the same transect, the max diver-min diver = Δdiver. The smaller of min diver-Δdiver or 90% of min diver was established as the minimum species for success for each transect (Table 59). The total species observed using the alternate methods was then recorded. If the number of species observed by the alternative method was equal to or greater than the minimum number of species established for success the test was successful. Unsuccessful tests are shown in bold in Table 59.

Table 59. Species diversity information from divers in the field.

	Diver1				Diver2				Min # Sp. for Success				Visual Mosaic inspection				Mosaic Pt Counts				Visual Inspection Video Transect			
Test Sites	T1	T2	T3	T4	T1	T2	T3	T4	T1	T2	T3	T4	M1	M2	M3	M4	T1	T2	T3	T4	VT1	VT2	VT3	VT4
Brookes Reef	13	11	6	5	11	13	5	6	10	10	4	4	10	10	8	7	2	1	1	0	9	7	5	3
Broadkey Forereef	9	9	7	7	9	8	7	4	9	7	7	4	11	10	11	9	4	2	2	1	8	7	6	5
Anniversary Reef	11	9	9	8	10	8	8	6	9	7	7	5	10	10	8	8	5	4	4	4	6	6	6	5
Evans Reef Crest	12	11	11	9	12	10	9	9	12	9	8	9	13	12	12	11	6	5	4	4	9	8	6	4
													100% Success				0% Success				18.7% Success			

- Includes visual mosaic inspection, mosaic point counts, and visual video transects are shown.
- A minimum number of species was calculated to evaluate the success or failure of each method to estimate species diversity.
- T1 to T4 are test sites 1 to 4.
- M1 to M4 are mosaics of Test Sites 1 to 4.
- VT1 tp VT4 are video transects of test Sites 1 to 4.

The number of coral species found within a given area varied depending on the interpretation of the divers in the field with respect to species identity, and the exact area sampled, and the visibility of coral species. In our field tests, a diver sampled 10 × 1 m areas along a transect and tallied the number of corals within each area. A second diver sampled the same transect to obtain the diver variability at each transect location. The greatest difference between two divers sampling the same transect was three species, whereas most differed by one or two species.

Using the diver-diver data to establish the minimum # species for success, the visual inspection of the 10 × 1 m areas from a mosaic was successful in estimating the species richness 100% of the time, making it a valid alternative to diver-based transects of species richness (Table 59).

Visual inspection of video transects proved less accurate in terms of replicating data extracted from diver surveys with respect to species richness. Visual inspection of video transects was only successful 18.75% of the time, far lower than the established success criterion of 90%. The difference between diver estimates of percent cover and those from video transects is most likely due to a combination of resolution and areas sampled between methods. Divers sampled a 10 × 1 m transect for species richness whereas the video transect method only samples about a 10 × 0.5 m swath over the same area. Any rare species or small colonies that fell outside the video transect area would not be sampled. The resolution of a video transect was also not as high as those of most image mosaics so it is also possible that some small species may have been missed due to resolution. A direct comparison of the same surveyed area would be needed to establish the efficacy of using video transects to estimate species richness when compared with diver estimates.

Finally, the mosaic point count test was performed in which four sets of 100 random points were placed on the mosaic of each test site and the points were evaluated for the benthic categories beneath the random points. The total species observed during this test was recorded per 100 random points. The mosaic point count method was not successful at replicating the diver data (Table 59). Once again, the difference in sampled area was believed to be the cause of the observed method differences. Since most of the sites sampled had relatively low coral cover (less than 10–15%), we would expect that only 10–15 of the random points would fall on corals. Of the corals that were sampled, it was unlikely that rare or small colonies would be included in this method. Therefore it was not a comparable method for sampling species richness when compared to 10 × 1 m belt transects performed by divers. However, since it was previously established in this performance objective that visual inspection of mosaics was successful 100% of the time we can conclude that the differences observed when comparing mosaic point counts and diver belt transects were not due to the technology but the different areas being sampled.

Conclusion: Visual inspection of 10 × 1 m areas from mosaic images was found to be as accurate as diver surveys for estimating coral species diversity. Visual inspection of video transects and mosaic point counts did not accurately replicate species diversity information obtained by divers.

6.4.3 Performance Objective 3: Ease of Use

The mosaics used for analysis under PO 1 and PO 2 were created by a RSMAS analyst. For PO 3, mosaics were created from the same raw data but with Navy personnel operating the software. The performance of the Navy analysts in creating the mosaics was assessed by the incorporation percentage metric and the visual quality rating metric. Success was achieved if the newly trained users were able on average to create a mosaic rated ≥ 4 in visual quality and for which the incorporation percentage was ≥ 90% of the value computed for the mosaic created for the same area by an experienced user.

Question: Are mosaics created by a Navy analyst of the same quality as those made by an expert mosaic analyst?

Results: Training for this performance objective involved a demonstration phase and the use of written materials with detailed instructions on mosaic creation. Two Navy analysts met with RSMAS mosaic technicians with several years of expertise in creating image mosaics. As part 1 of the mosaic creation training, each Navy analyst was provided with a copy of the mosaic creation manual (see Appendix B) from which to follow along and write personal notes and observations. Then, as a second step, the RSMAS mosaic technician walked the group through mosaic creation step-by-step using real-world data collected from PO 1 to create a mosaic. Since several steps of this process take many hours to process, this tutorial was completed over the course of 3 days. Navy participants were encouraged to ask questions and follow each step of the process in their manual. As the third part of the training, Navy analysts were provided with a real-world dataset and asked to follow the steps of the mosaic manual to create their own mosaic. RSMAS technicians were available if a step was unclear or to answer questions, but Navy participants were required to read the manual and the step-by-step instructions in order to create the mosaic. The result of this exercise was that both Navy analysts were able to create a mosaic from raw images using the software and the mosaic creation manual (Figure 108).

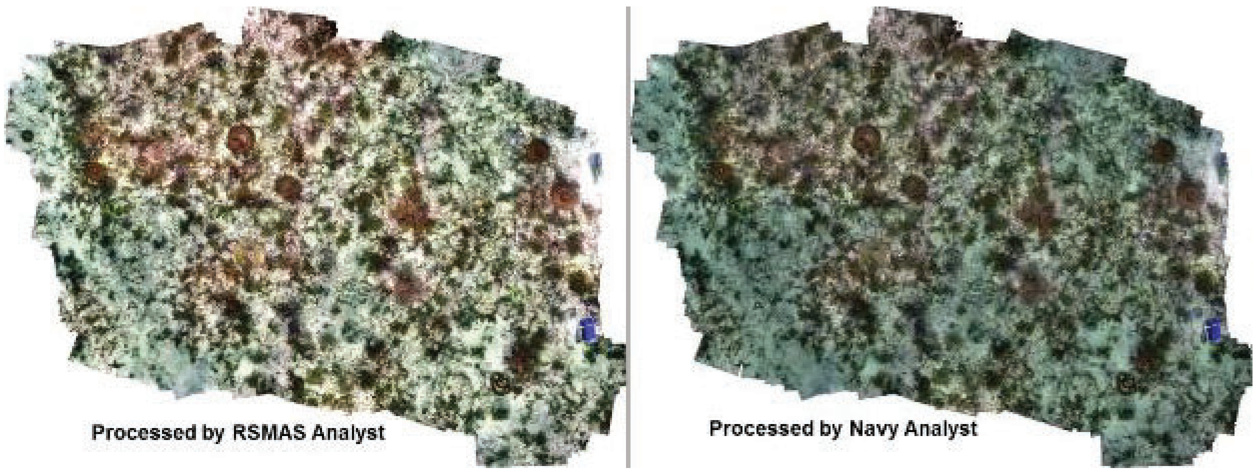


Figure 108. Image of Evan's Fore Reef Site created by a UM mosaic analyst with several years' experience (left) and by a Navy analyst (right) following the directions of the mosaic creation manual.

Both Navy analysts were able to make mosaics of the same size and content of those made by an experienced mosaic analyst (Table 61). No holes were produced in Navy-derived mosaics. The only discernible differences between Navy and RSMAS-produced mosaics were in the color and contrast corrections applied to the dataset. These corrections were subjective based on what an analyst decides "looks" better and have no effect on the quality of the image data.

Table 60. Incorporation percentage and visual quality rating of mosaic images produced by Navy analysts using the mosaic creation manual.

Analyst		Incorporation Percentage	Visual Quality Rating (1-5)
Navy Analyst 1	100%	5	5
Navy Analyst 2	100%	5	5

Although the mosaic images themselves were of the same quality, there was a discernible difference in the amount of time needed to prepare each dataset when comparing a beginner mosaic analyst and an expert. A beginner mosaic creation technician must read every word of the manual prior to each step in the mosaic processing, as opposed to an expert analyst who is familiar with each processing step and rarely consults the manual. Therefore operator time for processing will decrease with experience.

Conclusion: Navy analysts with a few days training and the use of a mosaic creation manual were able to produce mosaic images that were indistinguishable from expert operators in terms of area, content, incorporation percentage, and visual quality.

6.5 ABSOLUTE ACCURACY DEMO PERFORMANCE ASSESSMENT

Sections 6.5.1 to 6.5.4 provide the results of Performance Objectives 1 to 4, respectively, from the Absolute Accuracy Demonstration. Results are summarized in Table 61.

Table 61. A summary of the Absolute Accuracy demonstration performance assessment.

PO	Question	Status	Conclusions
PO1	1. What is the bias in size measurements made from mosaics? What is the bias in size measurements made by divers?	Complete	The mean bias of all objects/sizes was within 1 cm of the true value for both mosaics and divers. There was no significant bias in estimating object size from three divers or from two mosaics. One mosaic had median bias significantly different than zero. When examining different groupings of object types and sizes, the average bias from multiple mosaics and multiple divers was no greater than 4cm from the true value.
PO1	2. Is the bias in size measurements made from mosaics any larger than the size bias for measurements made by divers?	Complete	Mosaic and diver methods of estimating object size were not significantly different from one another when grouping all targets (p=0.56). Mosaic and diver methods of estimating target size were not significantly different when measuring small objects (of any type) or for large branching objects. Mosaic bias was larger than diver bias for large flat objects, but the mosaic bias was less than 2 cm. Mosaic bias was less than diver bias for large mounding objects.
PO1	3. What is the bias in size measurements of inclined targets made from mosaics? What is the bias in size measurements of inclined targets made by divers?	Complete	The bias in the estimate of inclined coral colony size was significantly different than zero as measured from mosaics and divers ($p = 0.05$ for mosaics and $p = 0.00$ for divers). However, the average bias was within 1 cm of the true value for both methods.
PO1	4. Is the bias in size measurements made from mosaics any greater than the size bias for measurements made by divers for inclined objects?	Complete	The bias in the estimate of inclined objects as measured from mosaic was not significantly greater than as measured by divers ($p = 0.31$).

- The main questions of each performance objective are listed and a color code is given as a result of the assessment of each question.
- Yellow indicates that not all aspects were successful or that inconsistencies were discovered during the analysis of the question
- **Green** suggests that all aspects of the test were successful, yellow indicates that not all aspects were successful or that inconsistencies were discovered during the analysis of the question.
- Red if present indicates a failure of that performance objective.

Table 61. A summary of the Absolute Accuracy demonstration performance assessment. (Continued)

PO	Question	Status	Conclusions
PO2	1. Do repeat estimates from a single observer over multiple mosaics produce the same average bias in size measurements?	Complete	There was no significant difference in the size bias as estimated from a single observer over 3 replicate mosaics (p = 0.28).
PO2	2. Is the variance around the bias in size measurements made from a single observer over multiple mosaics any greater than the variance around the bias for sizes measured by divers?	Complete	The variance in size measurement bias as measured from multiple mosaics was significantly less than the bias measured by multiple divers.
PO3	1. Do repeat estimates made by multiple analysts from a single mosaic produce the same average bias in size measurements?	Complete	There was no significant difference in the size bias of known targets as estimated by multiple analysts (p = 0.32).
PO3	2. Is the variance of the bias in size measurements made from multiple mosaic analysts any greater than the variance in size bias for measurements made by divers?	Complete	The variance of the bias as measured from multiple mosaics was not significantly greater than the bias measured by multiple divers (p = 0.79).
PO4	1. Is the bias in size measurements of known targets made from mosaics created in a pool setting any different from the size bias for measurements made from mosaics taken in the field?	Complete	The bias of the size measurements for objects measured in the pool mosaics was not significantly greater than for objects measured from field mosaics (p = 0.22).

- The main questions of each performance objective are listed and a color code is given as a result of the assessment of each question.
- **Green** suggests that all aspects of the test were successful, yellow indicates that not all aspects were successful or that inconsistencies were discovered during the analysis of the question.
- Red if present indicates a failure of that performance objective.

6.5.1 Performance Objective 1: Absolute Accuracy of Mosaic and Diver Size Measurements

This performance objective addressed four questions related to the accuracy of size measurements made from mosaics. Question 1 tested whether the bias, defined as the average difference between the measured and known size (i.e. the average error), was significantly different from 0 for both diver and mosaic measurements. Question 2 compared the absolute values of the mosaic and diver biases. Questions 3 and 4 were the same as questions 1 and 2 but for inclined objects, rather than those that were flat on the bottom.

Question 1: What is the bias in size measurements made from mosaics? What is the bias in size measurements made by divers? Are either significantly different from 0.

Analysis: For this performance objective, a total of 150 objects of three morphologies and two sizes were measured each by three divers and by one analyst from three mosaic images. The known size of each target was subtracted from the size measurements to compute the error. The bias was computed as the average error. If there were no bias in the size measurements, the mean values of the resulting distributions would not be statistically different from zero. These distributions were tested for statistical differences from a mean of zero with a one-sample t-test for differences. The tests were done in two ways, first by pooling objects of all sizes and shapes, then separately on each shape / size category.

Question 1 tested the following hypotheses:

H01: There is no significant bias ($p > 0.05$) in the estimate of coral colony size as measured from mosaics.

HA1: There is a significant bias ($p \leq 0.05$) in the estimate of coral colony size as measured from mosaics.

H02: There is no significant bias ($p > 0.05$) in the estimate of coral colony size as recorded in-situ by divers.

HA2: There is a significant bias ($p \leq 0.05$) in the estimate of coral colony size as recorded in-situ by divers.

Results: When pooled over morphology and size classes, neither the mosaic nor diver error distributions were normally distributed, therefore a nonparametric Wilcoxon Signed Rank Test was used in lieu of the one-sample t-test (Table 62). All six sample distributions had biases within 1 cm of the true value. Only the median from mosaic 3 was significantly different from zero (Table 62). This significant result is contrary to expectations given that the mean bias from this sample was the closest to zero of the six methods examined (Figure 109). Since we used a nonparametric test to examine if the measurements are significantly different than zero, the test actually examined the median as opposed to the mean measurement. Therefore, the median of the sample can be significantly different than zero while the mean of the same sample can be very close to zero, as was the case with the mosaic 3 data.

Table 62. Mean measurement bias (cm), median bias, and Wilcoxon Signed Rank p-value for each measurement.

Measurement Method	Mean bias (cm)	Median bias (cm)	P-value
Mosaic 1	0.19	-0.03	0.71
Mosaic 2	0.50	0.20	0.11
Mosaic 3	0.06	-0.50	**0.02**
DIVER 1	-0.51	-0.30	0.44
DIVER 2	-0.41	-0.50	0.09
DIVER 3	-0.68	-0.10	0.64

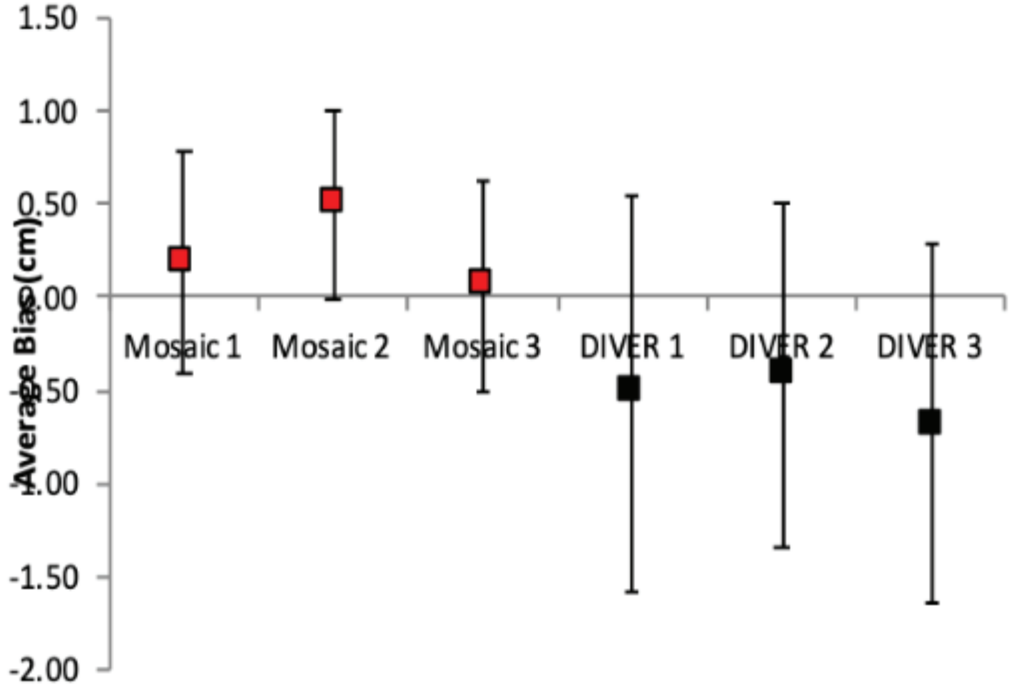


Figure 109. The average bias and 95% CI of different mosaic and diver measurements.

The same test of absolute accuracy was performed when targets were grouped into each of three different morphologies (flat, mounding, and branching) and two different size classes (small = 5-25 cm; medium= 25-120 cm). Either a t-test (parametric) or Wilcoxon Signed Rank test (nonparametric) was used to determine if the bias of object types of various sizes were significantly different than zero when measured by divers or mosaics (Table 63).

Table 63. Results of either a *t*-test or Wilcoxon Signed Rank test comparing the mean, for normally distributed errors, or median, for non-normally distributed errors, bias of object size measurements.

Small Flat vs. Truth					Medium Flat vs. Truth				
Methods	**Mean**	**Median**	**Test**	**P-value**	**Methods**	**Mean**	**Median**	**Test**	**P-value**
Mosaic 1	-0.48	-0.63	T-test	**0.02**	**Mosaic 1**	-1.92	-1.50	T-test	**0.00**
Mosaic 2	-0.21	0.00	T-test	0.40	**Mosaic 2**	-0.64	-0.65	T-test	0.06
Mosaic 3	-0.58	-0.71	Wilcoxon	**0.00**	**Mosaic 3**	-1.32	-1.55	T-test	**0.00**
Diver1	-0.19	-0.50	Wilcoxon	**0.03**	**Diver1**	-4.02	-1.10	Wilcoxon	**0.00**
Diver2	-0.53	-0.60	Wilcoxon	**0.00**	**Diver2**	-0.29	-0.30	T-test	0.36
Diver3	0.13	0.10	Wilcoxon	0.83	**Diver3**	-1.31	-0.40	Wilcoxon	0.08
Small Round vs. Truth					**Medium Round vs. Truth**				
Methods	**Mean**	**Median**	**Test**	**P-value**	**Methods**	**Mean**	**Median**	**Test**	**P-value**
Mosaic 1	0.79	0.80	T-test	0.08	**Mosaic 1**	-0.28	0.00	T-test	0.74
Mosaic 2	0.84	0.50	Wilcoxon	**0.01**	**Mosaic 2**	-0.37	-0.10	T-test	0.30
Mosaic 3	0.10	-0.39	Wilcoxon	0.11	**Mosaic 3**	0.82	-0.33	Wilcoxon	0.93
Diver1	-1.04	-0.75	Wilcoxon	**0.00**	**Diver1**	0.95	0.50	Wilcoxon	0.29
Diver2	-0.69	-0.70	T-test	**0.03**	**Diver2**	-3.06	-3.50	T-test	**0.00**
Diver3	-0.18	-0.30	T-test	0.62	**Diver3**	-4.03	-3.90	T-test	**0.00**
Small Branching vs. Truth					**Medium Branching vs. Truth**				
Methods	**Mean**	**Median**	**Test**	**P-value**	**Methods**	**Mean**	**Median**	**Test**	**P-value**
Mosaic 1	0.75	0.65	T-test	**0.02**	**Mosaic 1**	1.65	3.20	Wilcoxon	**0.07**
Mosaic 2	1.20	0.75	Wilcoxon	**0.00**	**Mosaic 2**	1.42	2.40	T-test	0.47
Mosaic 3	-0.44	-0.20	Wilcoxon	0.29	**Mosaic 3**	2.76	3.45	T-test	**0.03**
Diver1	0.63	0.70	T-test	**0.04**	**Diver1**	1.30	1.40	Wilcoxon	0.07
Diver2	1.04	0.90	T-test	**0.01**	**Diver2**	-0.74	0.55	Wilcoxon	0.65
Diver3	0.88	0.80	Wilcoxon	**0.02**	**Diver3**	0.04	2.00	Wilcoxon	0.23

- This test was performed for measurements from one mosaic analyst using three different mosaics and again for data from each of three divers. Significant differences from zero are shown in bold.

Unlike the pooled data in which the measurement bias was, for the most part, not significantly different than zero, the individual tests of the bias of various colony types and sizes measurements were significantly different than zero in 19 of the 36 tests (Table 63). Nine tests were significantly different using mosaic measurement methods and ten tests were significantly different using diver measurement methods (Table 63).

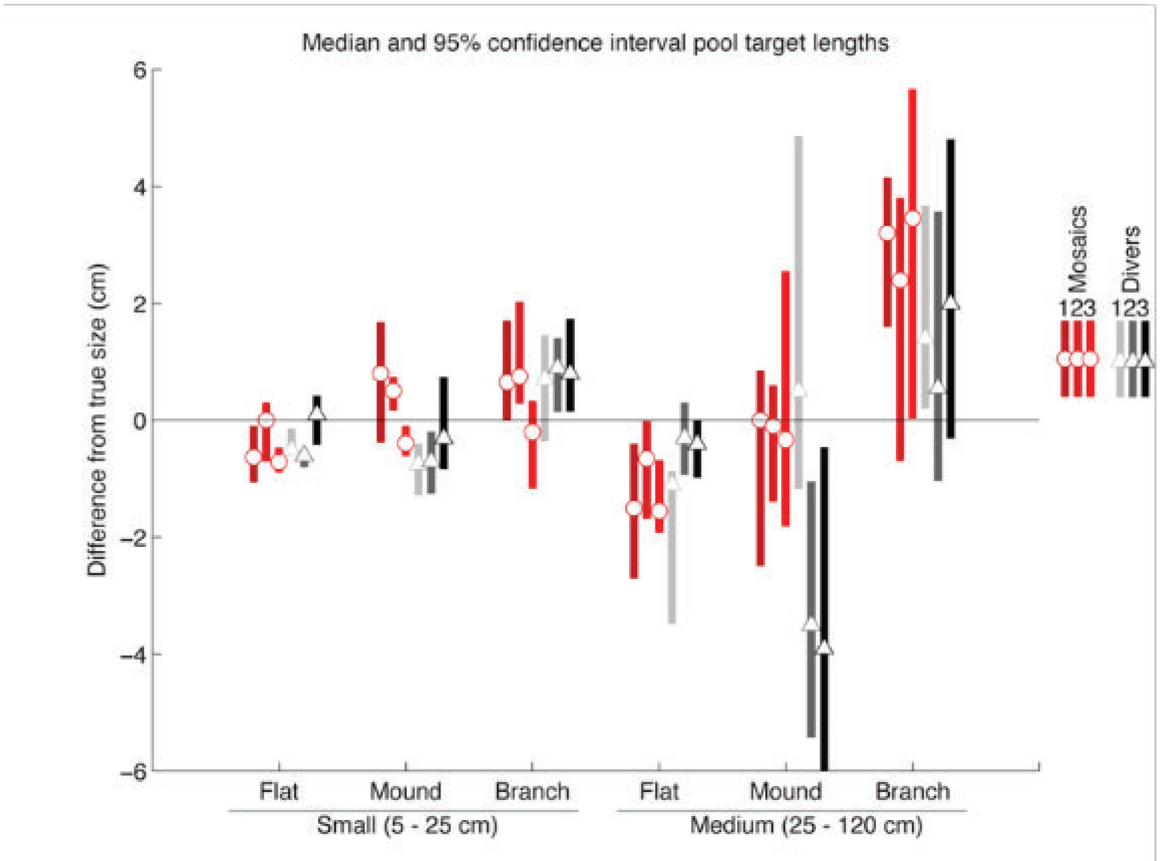


Figure 110. The median bias and 95% confidence interval of pool target lengths when measured by mosaics (Red) and divers (Black).

The bias of medium targets (25–120 cm) across all types was larger for both diver and mosaic measurements than the biases for smaller objects. The bias for medium objects ranged from -4.02 to 2.76 cm across all mosaics and divers tested (Table 63, Figure 110). That the measurement bias should scale with object size was not surprising for both mosaic and diver measurements. To measure large objects without the help of an additional diver, an observer in the water must hold the measuring tape steady and strain to hold the other end to the other edge of the colony while viewing the measurement on the tape without moving either end. Often this proves difficult, and the measurement ends up being either larger or smaller than the true value.

Conclusion: Some of the bias estimates statistically differed from 0, but on the whole they were small, on the order of cm. The mosaic and diver measurement biases were within 1 cm of the true value when all targets were pooled together. When divided into size / shape categories, the biases of small objects ranged from -1.04 to 1.20 cm and of large objects from -4.02 to 2.76 cm across all divers and mosaics. These small biases suggest that regardless of whether the bias was significantly different than zero, the mosaic method of estimating object size and diver methods of estimating object size are both highly accurate when compared to the true value (Table 63, Figure 110). Larger objects were found to have a larger average error than small objects.

Question 2: Is the bias in size measurements made from mosaics any larger than the size bias for measurements made by divers?

Analysis: The same data from question 1 were used for this test. In this case, however, rather than testing separately whether the mosaic bias or diver bias was different from zero, we instead tested whether the mosaic bias was any greater than the diver bias. The distributions of diver minus known and mosaic minus known were tested for statistical difference using a one-tailed two-sample t-test. As in question 1, the analysis was performed both for pooled data and separately on each morphology / size category.

Question 2 tested the following hypotheses:

H0: The bias as measured from the mosaic is not significantly ($p > 0.05$) greater than the bias in the estimate of coral colony size as measured by divers.

HA: The bias as measured from the mosaic is significantly ($p \leq 0.05$) greater than the bias in the estimate of coral colony size as measured by divers.

Results: The absolute difference between the measurement and truth was used in all comparisons for this performance objective. When all data from the 3 divers and from the 3 mosaics were combined, none of the distributions were normally distributed, thus the Mann Whitney U nonparametric significance test was used to compare mosaic and diver sample distributions during this performance objective.

When all targets were grouped together, the bias, as quantified by the median error, was not significantly different between divers and mosaic methods of estimating target size (Table 64, Figure 117).

Table 64. Results of the Mann Whitney U significance test of mosaic and diver methods of measuring target size.

Test	Mean	Median	W	P-value
Mosaic	2.18	1.20	178080.00	0.56
Divers	2.78	1.10		

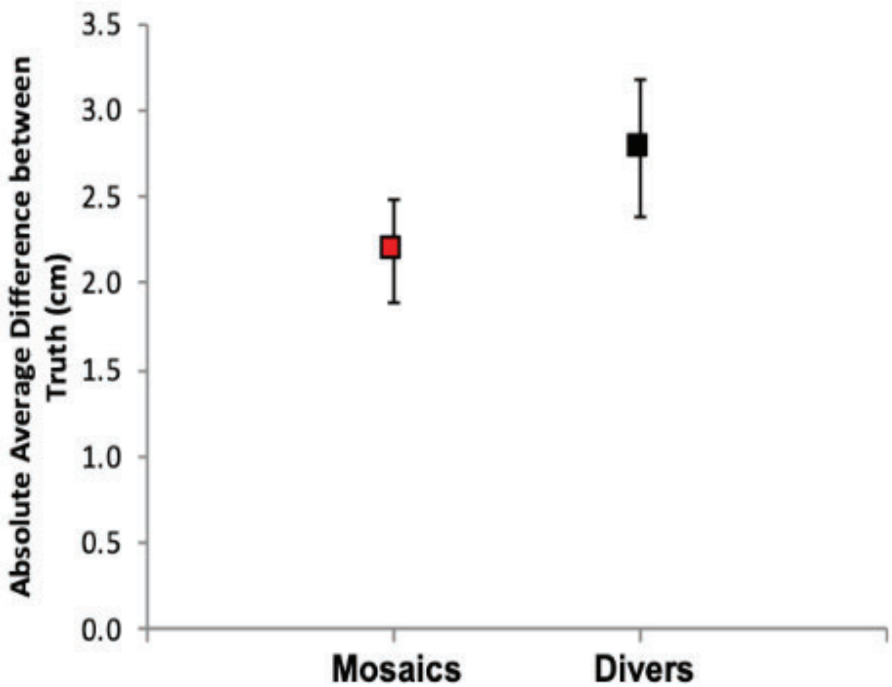


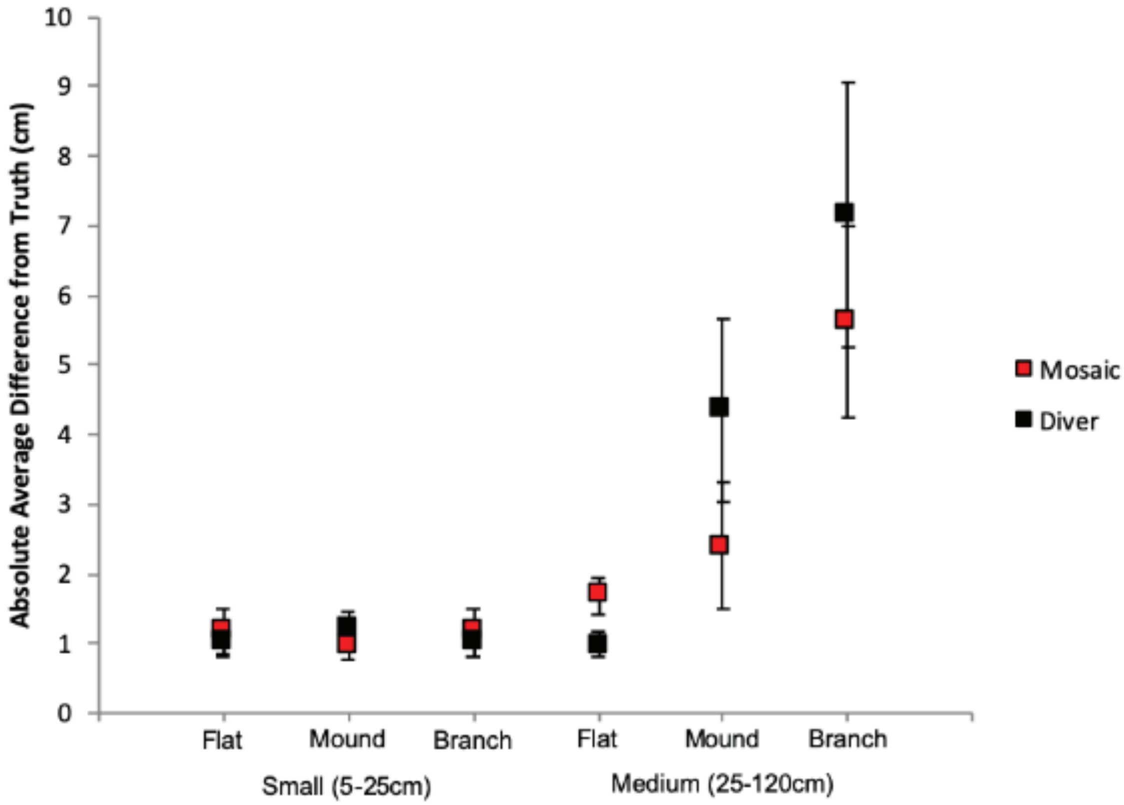
Figure 111. Absolute average error of mosaic and diver methods of measuring target size and the 95% confidence intervals of the mean.

When the three sets of mosaic and three sets of diver data were tested separately using the Mann Whitney U significance test, differences between mosaics and divers were only apparent in the large-flat and large-mounding categories (Table 65; Figure 106).

Table 65. Results of the Mann Whitney U significance test of mosaic and diver methods of measuring target sizes.

Small Targets (5-25cm)				
Test	**Mean**	**Median**	**W**	**P-value**
Flat (Mosaic)	1.18	0.60	6944.50	0.25
Flat (Diver)	1.02	0.78		
Mounding (Mosaic)	0.99	0.70	3962.50	0.13
Mounding (Diver)	1.20	0.90		
Branching (Mosaic)	1.17	0.60	69445.50	0.25
Branching (Diver)	1.02	0.78		
Medium Targets (25-120cm)				
Test	**Mean**	**Median**	**W**	**P-value**
Flat (Mosaic)	1.68	1.50	5470.00	**0.01**
Flat (Diver)	0.98	0.78		
Mounding (Mosaic)	2.40	1.40	2069.50	**0.00**
Mounding (Diver)	4.35	3.50		
Branching (Mosaic)	5.61	4.00	5528.50	0.86
Branching (Diver)	7.15	4.00		

- Targets are broken into three types (flat, mounding, branching) and two size classes (small 5–25 cm; medium 25–120 cm). Significant results are highlighted in bold.



- Parameters for the figure include: (flat, mounding, branching) and both size categories (small 5-25 cm; medium 25-120 cm)

Figure 112. Absolute average bias of mosaic and diver methods of measuring target size and the 95% confidence intervals of the mean for all three target types.

Mosaic and diver methods of estimating target size were not significantly different for any of the small targets regardless of shape (Table 65). Only the large flat objects and large mounding objects were found to have a significantly different median bias when comparing mosaic and diver methods ($p = 0.01$ for large flat objects and $p = 0.00$ for large mounding objects). For the large flat objects the mean mosaic bias was 1.68 cm whereas the diver bias in that test was 0.68 cm. For the large mounding objects, the mean bias of mosaic measurements was significantly less than for divers ($p = 0.00$, 2.4 cm for mosaics vs. 4.35 cm for divers, Table 65). Mosaics were more accurate at estimating the sizes of large mounding objects.

Conclusion: The magnitude of the bias in size measurements by mosaic and diver methods were not significantly different from one another when all targets were grouped together. Furthermore, the magnitude of the bias in size measurements by mosaic and diver methods were not significantly different when measuring small objects (of any type) or for medium-sized branching objects. The mosaic bias was larger than the diver bias for medium-sized flat objects, but it was smaller than the diver bias for medium-sized mounding objects.

Breaking the target data into groups based on morphology and size category revealed that measuring small objects of any type was very accurate using both mosaic and diver methods (Figure 112). For larger objects, the accuracy of both mosaic measurements and diver measurements declined. For the medium-sized objects, as the complexity of the object increased so did the bias of the measurement method (Figure 112). The reason for this increase in bias is due to the increased difficulty in estimating the boundaries of complex large objects for both diver and mosaic analysts.

Large, complex structures, such as the large branching objects, (Figure 112) have irregular outlines that make identifying the longest dimensions of the object difficult.

For most shape/size categories, mosaics were more accurate, or no worse than, divers at measuring their sizes. The medium, flat objects which were the exception to this observation may be explained by the nature of the test objects used. Most of the medium, flat objects were vinyl cut-outs that were essentially perfectly flat. For these objects, divers could lay the tape directly on their surface, potentially increasing accuracy relative to the other objects for which the tape measure needed to be held at least slightly above the object.

Question 3: What is the bias in size measurements of inclined targets made from mosaics? What is the bias in size measurements of inclined targets made by divers? Are either significantly different from 0?

Analysis: Divers and mosaic analysts measured the projected longest length of small flat objects on an inclined plane. The known size of each target was subtracted from the size measurements made from mosaics as well as from the size measurements made by divers. If there were no bias in the size measurements, the mean values of the resulting distributions should not be statistically different from zero. These distributions were tested for statistical differences from a mean of zero with a one-sample t-test for differences.

Question 3 tested the following hypotheses:

- H01: There is no significant bias ($p > 0.05$) in the estimate of inclined coral colony size as measured from mosaics.
- HA1: There is a significant bias ($p \leq 0.05$) in the estimate of inclined coral colony size as measured from mosaics.
- H02: There is no significant bias ($p > 0.05$) in the estimate of inclined coral colony size as recorded in-situ by divers.
- HA2: There is a significant bias ($p \leq 0.05$) in the estimate of inclined coral colony size as recorded in-situ by divers.

Results: Both the diver and mosaic measurement bias were normally distributed. Data from all divers and from multiple mosaics were pooled for this test. Mean error of mosaic bias was 0.28 cm vs. the mean error of diver bias 0.85 cm. Diver measurement bias was significantly different than zero at the $p \leq 0.05$ level and mosaic measurement bias was not (Table 66, Figure 113). The mean error of both samples was less than 1 cm different from truth. These results suggest that both divers and mosaics are very accurate methods of estimating the longest linear dimension of an inclined object.

Table 66. Results of t-test test to determine whether or not of the mean error of diver and mosaic methods of measuring inclined targets were significantly different than zero.

Method	Mean	t-value	P
Divers	0.85	5.49	**0.00**
Mosaics	0.28	1.91	0.06

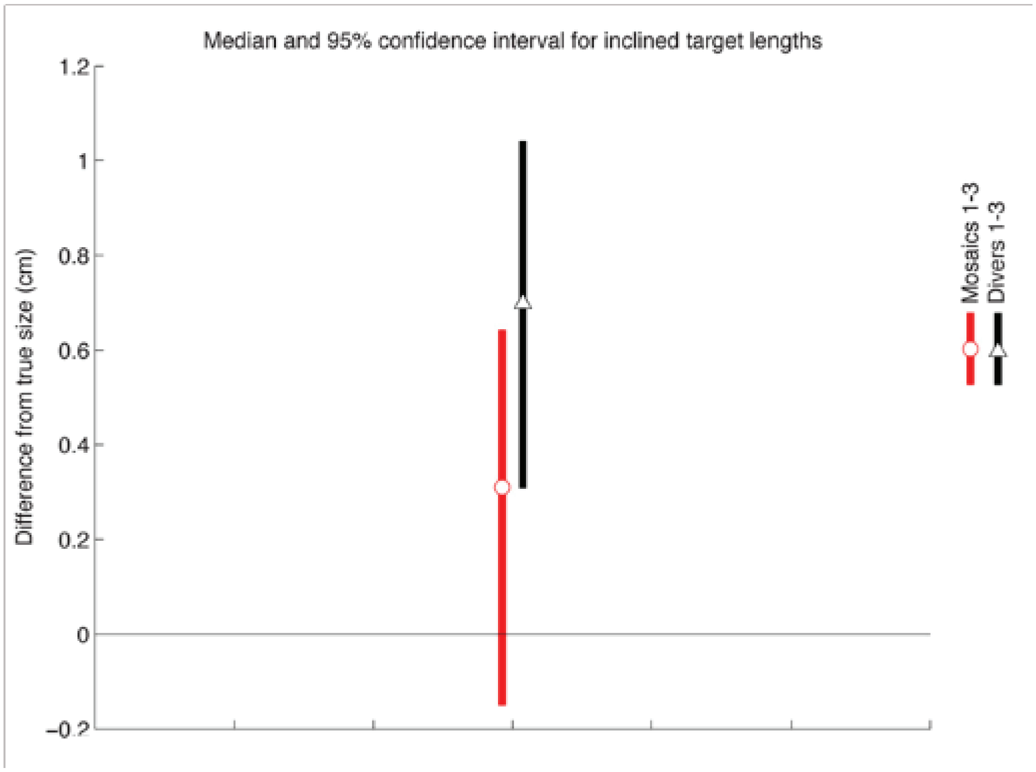


Figure 113. The median and 95% confidence intervals of the median for diver and mosaic measurements of the projected linear length of an inclined object.

Conclusion: The bias in the estimate of inclined coral colony size was significantly different than zero as measured by divers but not by mosaics. However, the average bias of both samples was within 1 cm of the true value (Table 66), thus both methods were considered accurate measurement methods of projected longest length.

Question 4: Is the bias in size measurements of inclined objects made from mosaics any greater than the size bias for measurements made by divers?

Analysis: The same data from question 3 were used for this test. In this case, however, rather than testing separately whether the mosaic bias or diver bias is different from zero, we instead tested whether the mosaic bias was greater than the diver bias. The distributions of diver minus known and mosaic minus known were tested for statistical difference using a one-tailed two-sample t-test.

Question 4 tested the following hypotheses:

H0: The bias of inclined objects as measured from the mosaic is not significantly ($p > 0.05$) greater than the bias in the estimate of coral colony size as measured by divers.

HA: The bias of inclined objects as measured from the mosaic is significantly ($p \leq 0.05$) greater than the bias in the estimate of coral colony size as measured by divers.

Results: The absolute biases of diver and mosaic measurements were used to determine if diver and mosaic measurements of incline targets were significantly different from one another. The absolute biases of diver and mosaic measurements were not normally distributed and thus a nonparametric Mann-Whitney U Test was used in lieu of the two-sample t-test previously proposed. Results of the Mann-Whitney U test are shown Table 67 and Figure 116. Mosaic and diver methods of measuring the projected longest length of inclined targets were not significantly different than one another ($p = 0.31$, Table 67).

Table 67. Results of the Mann-Whitney U test to determine whether or not of the absolute bias of diver and mosaic methods of measuring inclined targets are significantly different than each other.

Method	Mean	Median	Mann-Whitney	p value
Divers	1.32	0.97	7262.0	0.31
Mosaics	0.81	0.64		

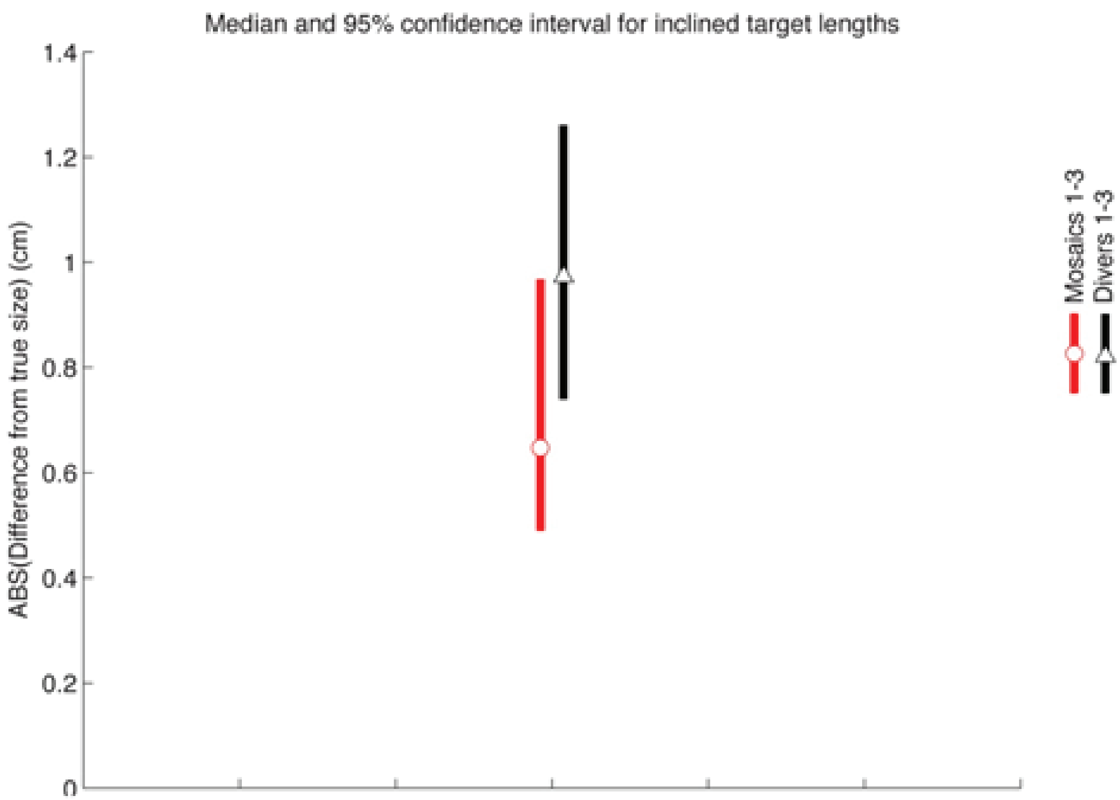


Figure 114. Median and 95% confidence intervals for absolute bias measurements of projecting longest linear dimension of inclined targets from mosaics and using divers in the water.

Conclusion: The bias of inclined objects as measured from mosaic was not significantly greater than the bias in the estimate of coral colony size as measured by divers. The fact that both methods were able to estimate the projected length of inclined objects within 1.5 cm of truth shows that both methods can accurately measure the projected maximum lengths of inclined objects.

6.5.2 Performance Objective 2: Precision of Multiple Mosaic and Diver Measurements

The goal of performance objective two was to determine if measurements made from multiple mosaics were repeatable (PO 2A) and if these measurements differed from the variability from multiple divers (PO 2B).

Question A: Do repeat estimates of object size measured from one analyst over multiple mosaics produce the same average bias?

Analysis: The goal of PO 2 (A) was related to the consistency, or repeatability, of size estimates made from mosaics. PO 2 (A) tested the repeatability of a single analyst measuring sizes from three replicate mosaics. In each case, the data were three distributions of size measurements, which were converted to three average biases by subtracting the known sizes of the objects. If the technique produced repeatable results, the average biases should not have been statistically different from one another. The distributions were tested for statistical differences using a single-factor ANOVA.

H01: There is no significant difference ($p > 0.05$) in the size bias as estimated from multiple mosaics.

HA1: There is a significant difference ($p \leq 0.05$) in the size bias as estimated from multiple mosaics.

Results: The bias of size measurements of known targets was measured by a single analyst, Brooke Gintert, from mosaics acquired by three different divers (Art Gleason, Brooke Gintert, and Kasey Cantwell). The targets measured in this test were the same as from PO 1, but data were combined across colony types and size classes. None of the three distributions of mosaic bias were normally distributed. A Kruskal-Wallis nonparametric one-way analysis of variance was used in lieu of the single-factor ANOVA. Results of the Kruskal-Wallis ANOVA are shown in Table 68.

Table 68. Results of the Kruskal-Wallis nonparametric test of one mosaic analyst measuring object sizes from three mosaics.

Mosaic	Mean	Median	Average Rank	Z	P
A. Gleason	2.11	0.79	108.9	-0.42	0.284
K. Cantwell	2.29	1.28	120.9	1.54	
B. Gintert	1.56	0.900	104.7	-1.11	

The average bias of known targets as measured by a single analyst (Brooke Gintert) over three different mosaics was not significantly different amongst mosaic samples (Table 68, Figure 115). The average bias of the different mosaics ranged from 1.56 to 2.29 cm, a difference of less than 1 cm. These results show that the accuracy of mosaic measurements is repeatable across multiple mosaic images.

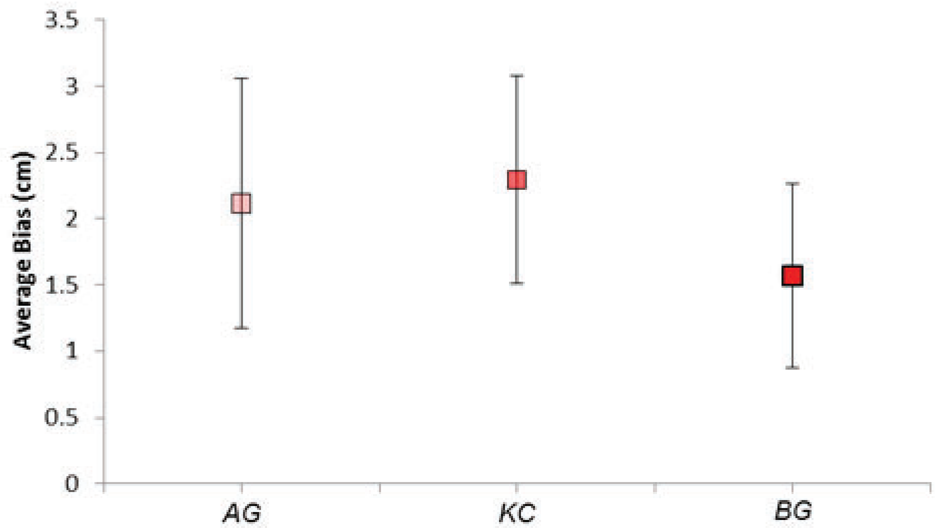


Figure 115. Average mosaic bias and 95% confidence intervals of known targets as measured by a single observer from mosaics acquired by three different divers. The mosaics are denoted by the initials of the divers who acquired the data.

Conclusion: There was no significant difference in the size bias as estimated from multiple mosaics.

Question B: Is the variance in the bias in size measurements made from a single observer across multiple mosaics any different from the variance in size bias for measurements made by divers?

Analysis: The goal of PO 2 (B) related to the variability, or precision, of size estimates made from mosaics. PO 2 (B) tested the precision of a single analyst measuring sizes from three replicate mosaics. In this case, the data were distributions of size measurements, which were converted to three distributions of biases by subtracting the known sizes of the objects. The distributions were tested for statistical differences in variance using an F-test.

H01: The variance in bias as measured from multiple mosaics is not significantly ($p > 0.05$) greater than the bias in the estimate of coral colony size as measured by multiple divers.

HA1: The variance in bias as measured from multiple mosaics is significantly ($p \leq 0.05$) greater than the bias in the estimate of coral colony size as measured by multiple divers.

Results: The data for this test were the bias measurements as measured by a single analyst across three mosaics and the size bias as measured by three divers. This data was already presented in PO 1 question 1 of this demonstration. The average bias and 95% confidence interval of each measurement method is reproduced here (Figure 116). In this test we examined the variance in mosaic measurements made by one analyst over multiple mosaics as compared to the variance of three divers. In this case all sizes were estimated by a single observer (Brooke Gintert) from mosaics acquired from three different divers (Art Gleason, Kasey Cantwell, and Brooke Gintert). Data from the three mosaics and three diver measurements were pooled and the mean and variance of the measurement methods are shown in Figure 116.

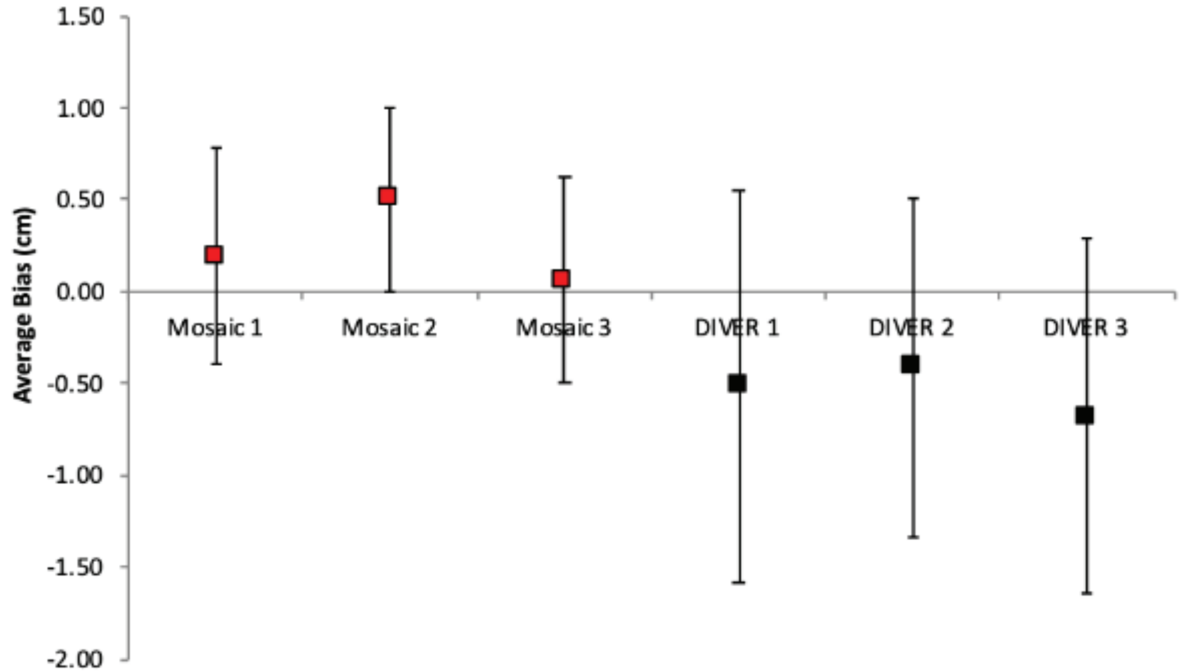
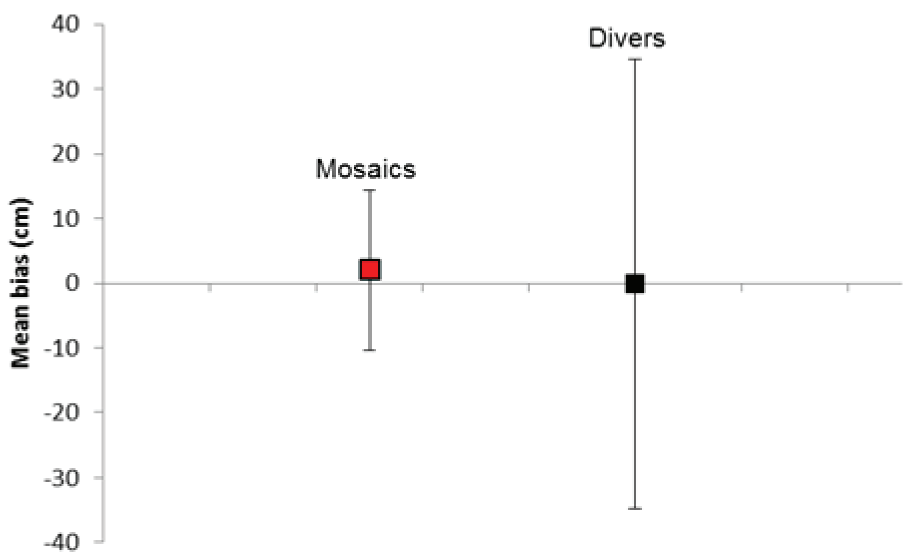


Figure 116. Average bias and 95% confidence intervals of one analyst measuring target sizes from three mosaics (denoted by their initials, AG, KC, and BG) and from three divers in the water.



- The sample of mosaic measurements was combined for one analyst measuring target sizes over three mosaic images and the diver measurements were combined from three diver measurements.

Figure 117. Mean bias and variance for mosaic and diver measurements.

Conclusion: The variance in bias as measured from multiple mosaics was significantly less than the bias in the estimate of coral colony size as measured by multiple divers.

6.5.3 Performance Objective 3: Precision of Multiple Mosaic Analyst and Diver Size Measurements

The goal of performance objective three was to determine if measurements made from multiple analysts were repeatable (PO 3A) and if these measurements differed from the variability from multiple divers (PO 3B).

Question A: Do repeat estimates from different mosaic analysts produce the same average bias in size measurements made from mosaics?

Analysis: In this test we examined the repeatability of multiple analysts measuring sizes from a single mosaic. In this case, the data were three distributions of size measurements, which were converted to three average biases by subtracting the known sizes of the objects. If the technique produced repeatable results, the average biases should not have been statistically different from one another. The distributions were tested for statistical differences using a single-factor ANOVA.

H01: There is no significant difference ($p > 0.05$) in the size bias as estimated by multiple analysts.

HA1: There is a significant difference ($p \leq 0.05$) in the size bias as estimated by multiple analysts.

Results: The data for this test was performed on a single mosaic acquired by the diver Kasey Cantwell. Each of three mosaic analysts (Brooke Gintert, Kasey Cantwell, and Jesse Alpert) measured the known targets directly from the mosaic image. The analyst measurements were subtracted from the known value of target size and the mean and 95% confidence interval of each analyst measurements are shown in Figure 118.

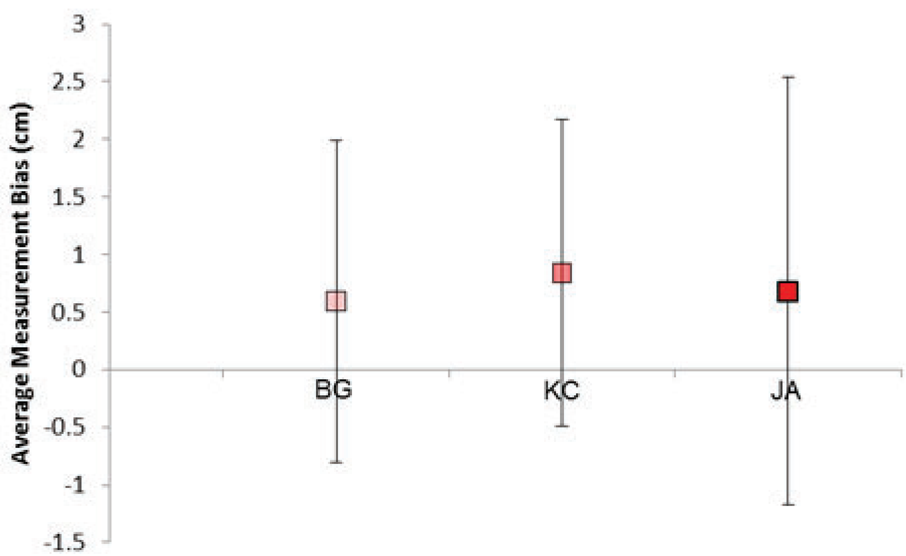


Figure 118. The mean and 95% confidence intervals of three mosaic analysts measuring targets of known size from a single mosaic image.

The analyst bias measurements were not normally distributed and due to this fact the nonparametric Kruskal-Wallis test was used in lieu of the proposed ANOVA. The results of the Kruskal-Wallis test are shown in Table 69. The mean bias among analysts was not significantly different (p = 0.318, Table 69). This test shows that the size information available from mosaic images is consistent among multiple analysts.

Table 69. Results of Kruskal-Wallis Test of medians for three analysts measuring known targets from a single mosaic image.

Mosaic Analyst	Mean	Median	Z	p-value	
BG	0.59		-0.05	116.9	0.318
KC	0.84		0.38	133.2	
JA	0.68		0.1	129.3	

Conclusion: There was no significant difference in the size bias of known targets as estimated by multiple analysts.

Question B: Is the variance in the bias in size measurements made from multiple mosaic analysts any different from the variance in size bias for measurements made by multiple divers?

Analysis: The goal of this test related to the variability, or precision, of size estimates made from mosaics. In this test we examined the precision of multiple analysts measuring sizes from a single mosaic. In each case, the data were distributions of size measurements, which were converted to three distributions of biases by subtracting the known sizes of the objects. The distributions were tested for statistical differences in variance using an F-test.

H01: The variance in bias as measured from multiple mosaics is not significantly ($p > 0.05$) greater than the bias in the estimate of coral colony size as measured by multiple divers.

HA1: The variance in bias as measured from multiple mosaics is significantly ($p \leq 0.05$) greater than the bias in the estimate of coral colony size as measured by multiple divers.

Results: In this test we were determining if the variance in target measurements between three divers from a single mosaic was significantly different than three divers in the field. Three mosaic analysts (Brooke Gintert, Kasey Cantwell, and Jesse Alpert) were tasked with measuring the pool targets from a single mosaic acquired in the pool by Kasey Cantwell. The data from the three divers were the same in this test as in PO 3 question1 and the diver data is also the same as that presented in PO 2 question 1. The measurement information was pooled among the three mosaic analysts and the three divers in the pool. The average absolute bias of each method (mosaic analysts and divers) and the variance are presented in Figure 119.

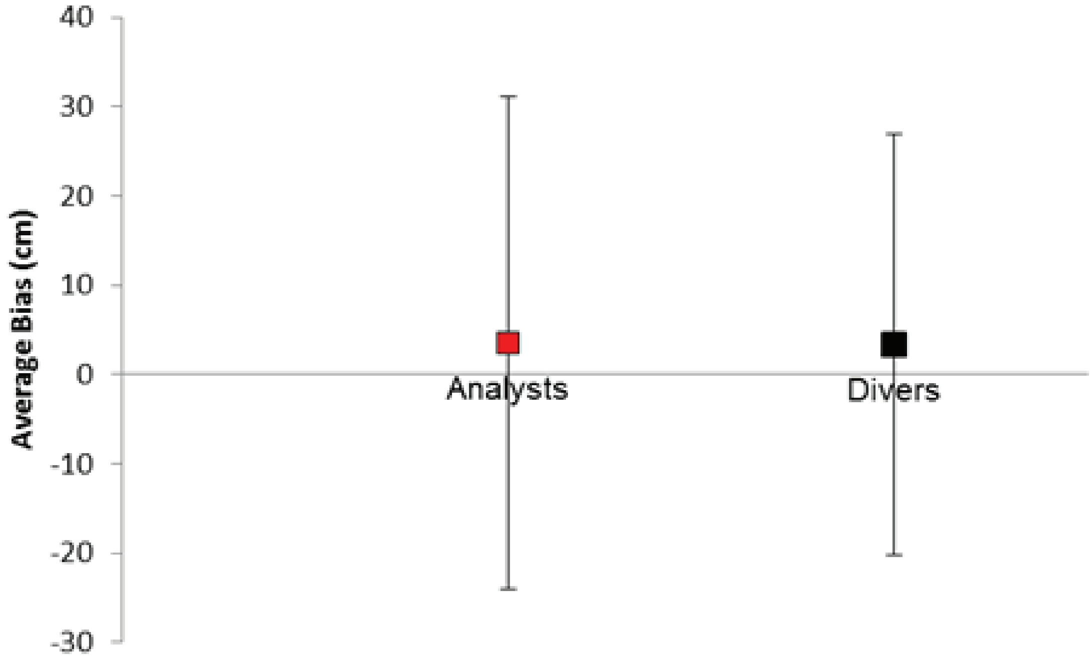


Figure 119. Average absolute bias and variance of three mosaic analysts (Brooke Gintert, Kasey Cantwell, and Jesse Alpert) measuring target sizes from a single mosaic and from three divers.

Neither the analyst or diver measurement bias was normally distributed. Due to the nonparametric nature of the data, the Levene's test was used in lieu of the F-test. The variance of target measurements of the three mosaic analysts was not significantly different than the variance of the three divers (Levene's test statistic = 0.07, p = 0.794). From this test we concluded that the variance of measuring the size of known targets between three analysts was not significantly different than that variance of three divers.

The other result of this test was that the variance of the three analysts (this test) was actually larger than a single analyst over multiple mosaics (PO 2 question B, Figure 117. This suggests that just as with diver-based data we need to recognize that data analyzed by a single analyst is more consistent than data analyzed by multiple people.

Conclusion: The variance in bias as measured from multiple mosaics was not significantly different than the bias in the estimate of coral colony size as measured by multiple divers.

6.5.4 Performance Objective 4: Comparison of Mosaic Bias in the Pool vs. in the Field

Question 1: Is the bias in size measurements of known targets made from mosaics created in a pool setting any different from the size bias for measurements made from mosaics taken in the field?

Analysis: We tested whether the bias of measuring known objects in the pool from a mosaic is different than the bias of measuring known objects in the field. The distributions of pool minus known and field mosaic minus known were tested for statistical difference using a two-tailed two-sample t-test.

H0: The bias of objects as measured from the pool mosaic is not significantly ($p > 0.05$) greater than the bias in the estimate of known objects from field mosaics.

HA: The bias of objects as measured from the pool is significantly ($p \leq 0.05$) greater than the bias in the estimate of known objects from field mosaics.

Results: For this test, ceramic tiles of known size (10.7cm on each side) had been placed in the field and in pool to determine if the measures of accuracy and precision from pool mosaics were equivalent to those acquired in the field. A total of 25 tiles each were measured directly from one of the pool mosaics and one of the field mosaics.

Both the pool and field bias were normally distributed, so the two-sample t-test was applied to the bias data. The average biases of measurements from both pool and field mosaics were within 0.3 cm of the true value (Figure 120). Furthermore, the average bias of known targets measured from pool mosaics was not significantly different than the average bias of targets measured from mosaics acquired in the field ($p = 0.216$; Table 70).

These results suggest that both pool and field mosaics were highly accurate for measuring known targets, which supports the assumptions made at the beginning of this demonstration that measurements acquired from images taken in the pool would be equivalent to those performed in the field. The pool was chosen as the site of the majority of this demonstration due to the fact that there were fewer confounding factors, such as waves or surge that can prevent data acquisition in the field. Even though the mean bias between pool and field measurements the confounding factors discussed above may be the reason for the larger spread of the 95% confidence interval observed for field measurements (Figure 120).

Table 70. Results of two-sample *t*-test comparing measurement bias of targets of known size as measured in the pool and in the field.

Location	Mean	T-value	p-value
Pool	0.27	1.26	0.216
Field	0.07		

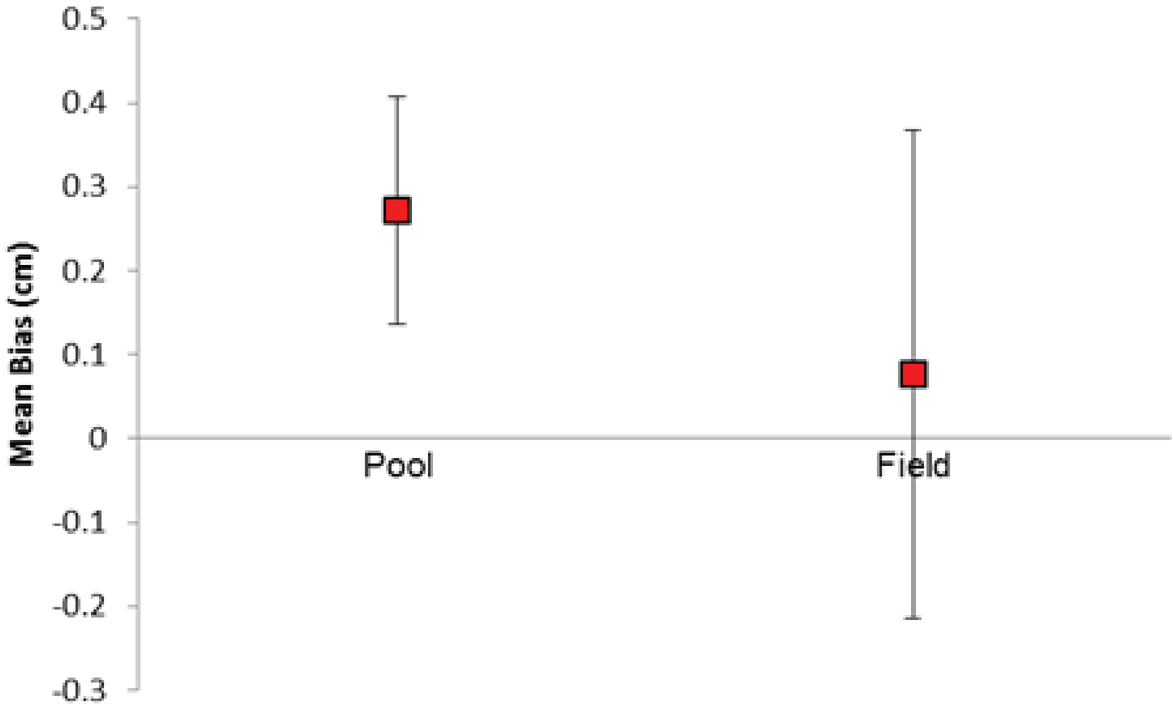


Figure 120. Average bias and 95% confidence intervals of standard tile measurements from mosaics acquired in the pool and mosaics acquired over coral reefs.

Conclusion: The biases of objects as measured from pool mosaics were not significantly different than the bias in the estimate of known objects from field mosaics.

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7. COST ASSESSMENT

The performance objectives of the various demonstrations were chosen, in part, to extract cost information for different applications of the mosaicing technology. Cost assessments are therefore provided for each performance objective separately. The cost drivers for the technology were assessed based on the results of the suite of cost models.

The cost of implementing the mosaic technology was broken down into fixed costs of equipment that can be amortized over many surveys (Table 71) and variable labor costs for data acquisition and processing that scaled with the number of sites surveyed (Table 72). Costs that did not vary between the mosaic method and the diver-based standard, such as travel to/from a home office and field site, were also tracked (Table 73).

Table 71. Fixed equipment costs of implementing the mosaic technology.

Cost element	Data tracked during demonstration
Computer hardware	Actual costs tracked
Software	Actual costs tracked
Cameras	Actual costs tracked

Table 72. Variable, or per-site, costs of implementing the mosaic or diver-based technology.

Cost element	Data tracked during demonstration
Consumables	Actual costs tracked
Travel, lodging, boat rental	Actual costs tracked
Diver salary	Actual costs tracked
Dive Time	Actual time tracked
Transcribe diver data	Time required to convert from paper datasheets to computer
Mosaic processing	Time required to convert raw data to a mosaic
Mosaic analysis	Time required to extract measurements from mosaic

Table 73. Costs that did not differ between mosaic and diver technologies.

Cost element	Data tracked during demonstration
Personal dive gear	Estimate from actual gear used
Travel to/from site	Actual costs tracked

The three fixed costs were computer hardware, software, and cameras (including underwater housings). The actual costs of these items as used during the project were computed. With the exception of consumables, travel, lodging, and boat time, which were computed based on actual costs during the project, the per-survey costs are all a function of time. We recorded the times required for these various activities and then projected a range of potential costs based on the salaries of divers and analysts who participated in the project.

7.1 LONG-TERM MONITORING DEMONSTRATION

Costs were tracked and modeled for performance objectives 1 and 2 during the Long-Term Monitoring demonstration. Performance objective 3 for the long-term monitoring demo was a training exercise and verification that divers who were newly trained on the mosaicing equipment could successfully acquire data. Therefore, no cost model was considered for this performance objective.

7.1.1 Cost Model, Long-Term Monitoring Performance Objective 1

For the long-term monitoring demonstration, PO 1, we asked the question "what is the cost per colony to do size and condition assessment?" Specifically, we wanted to compare the cost per colony as computed for the diver-based technique vs. the cost per colony as computed for the mosaic-based technique. Thus, we needed two cost models.

DIVER MODEL:

The number of colonies that can be mapped per diver, per hour of dive time is N_h. The number of colonies that can be mapped per field day is N_f, which is a function of N_h, the number of divers performing the mapping, N_d, and the number of dives possible per day, N_D, which itself is based primarily on depth. The cost per day of field time is C_f, which equals the total cost of the trip, C_T (Equation 1), divided by the number of field days, N_F.

$$
\begin{aligned}
C_T = {} & \text{travel cost to site (\textit{e.g.} flights)} \times N_d \\
& + \text{diver daily salary} \times N_d \times N_F \\
& + \text{per diem} \times N_d \times N_F \\
& + \text{boat rental} \\
& + \text{fuel} \times N_F \\
& + \text{lodging} \times N_d \times N_F
\end{aligned} \qquad (1)
$$

Assumptions in (1) are that the boat driver is included in boat rental cost, and that other travel expenses such as parking, taxi, scuba tank fills etc., are negligible. The cost per colony due to field expenses is therefore $C_{cf} = C_f / N_f$.

Lab processing costs for the diver data are primarily due to transcription (copying the data from the data sheets into a computer). The cost of post processing per colony is $C_{cp} = C_h \times T_e / N_T$, where C_h is the cost per hour of the person entering the data, T_e is the number of person-hours spent entering the data, and N_T is the total number of colonies measured.

The total cost per colony for the diver method is $C_c = C_{cf} + C_{cp}$.

MOSAIC MODEL:

The field component of the cost per colony model for the mosaic method is the same as for the diver method, although some of the variables are parameterized differently, as discussed below in Section 7.1.2.The lab portion of the mosaic model is different, however. Lab work for the mosaics has two components, processing, which is creation of the mosaics from the raw data, and analysis, which is the extraction of ecological information from the mosaics. A complete accounting includes the costs of the equipment needed for mosaicing.

Processing for the mosaics included downloading the data from the cameras, entering the parameters into the mosaicing software, assessing output, and adjusting parameters as necessary. The cost per mosaic of processing $C_{mp} = C_h \times T_p$, where C_h is the cost per hour of the person processing the data, T_p is the number of person-hours spent processing the data. The cost per colony of processing C_{cp} should ideally be computed as C_{mp} divided by the total number of coral colonies in the area covered by the mosaic, but we used $C_{cp} = C_{mp} / N_T$, which was a conservative estimate since $N_T <$ the total number of coral colonies in the area covered by the mosaic.

Extracting data from the mosaics involved measuring the sizes and health of some or all of the colonies visible in each mosaic. The cost per colony of data extraction is $C_{ce} = C_h \times T_x / N_T$ where T_x is the number of person-hours spent extracting the data.

The cost per mosaic of equipment C_{mq} equals the cost of the cameras, computers, and software divided by the number of mosaics that could be expected to be made by each in their useful lifetime. As in the case of C_{cp}, the cost per colony of equipment C_{cq} should ideally be computed as C_{mq} divided by the total number of coral colonies in the area covered by the mosaic, but we used $C_{cq} = C_{mq} / N_T$, which was a conservative estimate since $N_T <$ the total number of coral colonies in the area covered by the mosaic.

7.1.2 Cost Analysis and Comparison, Long-Term Monitoring PO 1

PARAMETER ESTIMATION FOR THE DIVER MODEL:

We used the actual costs incurred for the long-term monitoring demo as a starting point to estimate the parameters for the diver and mosaic models described above.

As part of PO 1 we tagged, measured, and assessed 87 colonies. In addition, we performed an exercise where a different set of divers (i.e. not the ones who had tagged the colonies originally) relocated all the tags. These activities were timed, so we could compute the average time for each (Table 74).

Table 74. Average time to tag, measure and assess, and relocate each colony while diving, and the average time to transcribe the data for each coral from underwater paper to computer spreadsheet.

Activity	Average Time of Completion (min)
Tag Colony (min/colony)	1.4
Measure & Health/colony	2
Re-find tags (min/tag)	1.1
Data Entry/coral	0.76

- Food, lodging, and boat expenses were the same in each scenario ($4860). The differences among scenarios are due to travel costs to/from the AUTEC base and salary.

Using the data from Table 74, we found the average time to tag and measure a colony was 3.4 minutes and the average time to relocate and measure a colony was 3.1 minutes. Thus the number of colonies that can be assessed by 1 diver in 1 hour was in the range N_h = 17.6 – 19.3 corals per hour.

Both of the sites used for PO 1 in the long-term monitoring demo were less than 30 feet deep, so we made some assumptions about the number of corals that could be mapped in a day, N_f. Assume 2 divers were doing the work and were each able to spend 6 hours underwater per day, then $N_f = 6 \times N_h \times 2$ = 211.2 – 231.6 corals per day.

Some of the trip costs were constant for all participants. For example food was $15 per person per day, lodging $30 per person per day, and total boat costs including fuel and driver were $4,500. The number of field days was N_F = 4. Travel and salary, on the other hand, varied among the participants. For the purpose of illustrating the range of possible costs consider situations of three of the divers from our trip. The two RSMAS divers needed round trip airfare from West Palm Beach to the Navy's AUTEC base on Andros Island, Bahamas for $306.00. One of the Navy divers traveled from Virginia for total airfare of $957.30. The RSMAS divers' daily salary, including fringe benefits and overhead were $335 / day (diver 1) and $532 / day (diver 2). The Navy divers salary for the entire trip was $11,284. In addition, the Navy team was supported by three additional divers for a total of $15,000 for the entire trip including all of their expenses. Using these numbers, we computed a range of values for the trip cost, C_T (Table 76). From the trip cost, we computed cost per field day then divided by the number of corals measured in a day to get C_{cf} (Table 75).

Table 75. Total trip cost C_T using values derived from three different divers who participated in the long-term monitoring demo.

Data from	C_T	C_{cf} (minimum – maximum)
RSMAS diver 1	$8,152	$8.80 – 9.65
RSMAS diver 2	$9,728	$10.50 – 11.52
Navy diver 1	$44,343	$47.87 – 52.49

- Food, lodging, and boat expenses were the same in each scenario ($4860). The differences among scenarios are due to travel costs to/from the AUTEC base and salary.

The cost to transcribe field data into computer format is also sensitive to the salary of the person doing the transcription. Again, for illustrative purposes we used two values corresponding to people who actually worked with the data in this project. One value came from a RSMAS post-doctoral scientist, whose daily salary including fringe benefits and overhead was $335 or $41.88 / hour. A second value came from SSC Note 7600 (SPAWARSYSCEN PAC, 2012) which was $117.00 / hour. Using these values and the time for data entry per coral from Table 75, C_{ce} ranged from $0.53 to $1.48.

PARAMETER ESTIMATION FOR THE MOSAIC MODEL:

The number of colonies that can be mapped per diver, per hour of dive time using mosaics is, at minimum, the number of colonies tagged at each site divided by the time taken to mosaic the site. This number is a minimum value because there were additional colonies at each site that were not tagged. At site S1_10 we tagged 50 colonies, at site S1_15 we tagged 37 colonies. The average mosaic acquisition time at site S1_10 was 36.4 min and at S1_15 was 37.3 min, resulting in a range of N_h = 59.4 - 82.4 colonies per dive team per hour.

Using the same assumptions for depth and time spent underwater that were used for the diver model, above, the number of corals that could be mapped per day is in the range $N_d = 6 \times N_h = 357$ - 495 corals per day, assuming the team has only one camera system.

Estimates of C_T were the same for the mosaic model as for the diver model.

Average user time required for processing the mosaics was 240 minutes (Table 76). As for the diver model, we assumed a range of labor rates ranging from $41.88 / hour to $117.00 / hour resulting in an estimate for C_{mp} in the range $223.36 - $468.

Table 76. Average times for processing and analyzing mosaics for the AUTEC PO1 demo.

Activity	Average Time of Completion (min)
Measure/assess colony using CPCE	1.3
Mosaic Processing (Operator)	240

Average analyst time required to extract coral colony size and condition assessments from the mosaics was 1.3 minutes per colony (Table 77). As for the diver model, we assumed a range of labor rates ranging from $41.88 / hour to $117.00 / hour resulting in an estimate for C_{me} in the range $0.91 - $2.53.

Substantially more equipment is required for surveying with mosaics than with the traditional diver method. For a full accounting, these costs should be incorporated as an additional cost per mosaic. Like the labor costs above, however, estimates of the equipment costs per mosaic are quite situation-specific. Prices for cameras, computers, and particularly software are highly variable depending on exact components, vendors, and discounts (e.g. commercial, government, and academic prices can vary widely). Furthermore, the useful lifetime of this equipment, as measured by the number of mosaics that can be made before replacement, is difficult to estimate. Nevertheless, some estimates were made using equipment purchased for this project, for SERDP RC-1333, and for other projects using mosaics.

Four computers currently being used for making mosaics illustrate the potential range of computing hardware costs (Table 77). Based on this experience, we estimated the computer cost = $8,000 and the lifetime of a computer at 1,000 mosaics, resulting in an estimate of $C_{m\text{-}computer}$ = $8.

Table 77. Costs of computers used for mosaic creation.

Year	Purchaser	Model	Specifications	Cost ($)
2007	RSMAS	Dell Precision 690	Xeon E5345 2.33GHz (8 cores) 8 GB DDR2 ECC SDRAM	4,700
2009	RSMAS	Custom built	AMD Opteron 2358SE 2.4GHz (8 cores) 16 GB DDR2 SDRAM	1,800
2011	RSMAS	Custom built	AMD Opteron 6168 1.9GHz (24 cores) 116 GB DDR2 SDRAM	6,700
2013	Navy	HP Z820	Xeon E5-2667 2.90GHz (12 cores) 48 GB DDR3 RAM	9,600

- All four of these computers are currently (July 2016) still being used to create mosaics on a regular basis.

The cameras purchased for this project were a Nikon D7000 with Ikelite housing and Canon VIXIA HF S20 with Equinox housing costing $7,500 including accessories like memory cards and extra batteries. The Navy recently purchased a set of cameras including a Nikon D7000 with Aquatica housing and Canon HF G10 with Equinox housing for $9,500. The main difference was the Aquatica housing, which is potentially more rugged than the Ikelite because it is made from aluminum rather than polycarbonate. Using these data, we estimate the camera cost for a suitable mosaicking system at $8,000. We have not had a set of cameras fail, so determining the lifetime of the cameras is imprecise. One approach is to note that the RSMAS cameras have been used for more than 200 mosaics thus far and are still in operational use. If we assume the lifetime of cameras is 300 mosaics then the $C_{m\text{-}cameras} \approx \$25$.

Software is the most variable equipment cost. The Navy recently purchased Matlab for $4,100, and Adobe premiere for $800 to enable mosaic processing. The Navy also purchases regular upgrades for the Windows operating system at several hundreds of dollars each. The University of Miami purchases site licenses for Matlab and Microsoft products, so from the users' point of view, these software are "free." On the other hand, commecial users would have to purchase all of these products at likely even greater prices than the government users. Since the prices are so variable, we took a conservative approach and assumed the software cost was $8,000 and the lifetime of software was the same as the lifetime of the computer hardware, namely 1,000 mosaics, leadin to an estimate of $C_{m\text{-}software} = \$8$.

Total cost of equipment per mosaic was estimated as $C_{mq} = C_{m\text{-}computer} + C_{m\text{-}cameras} + C_{m\text{-}software} = \$41$.

Results for the long-term monitoring demo PO 1:

Using the models and parameter estimates described above, the cost per colony for the PO 1 measurements in the long-term monitoring demonstration were as follows. For the diver method, using the range of values in Table 77 and for data transcription and the formula $C_c = C_{cf} + C_{cp}$, the cost per coral ranged from $9.33 to $53.97. For the mosaic method, $C_c = C_{cf} + C_{cp} + C_{ce} + C_{cq}$, so the cost per coral ranged from $9.20 to $47.34.

Given the assumptions used above, the actual costs for the AUTEC trip, and the nature of the sites sampled at AUTEC, the cost per coral to get size measurements was essentially the same using the diver method and the mosaic method. Given that the performance of the two methods was also about the same, as evidenced by the fact that the diver-diver size measurements did not statistically differ from the diver-mosaic size measurements (Section6.1.1), we need to ask whether there was advantage to the mosaic approach? The answer is yes, for three reasons:

One advantage the mosaics have relative to the divers in the situation modeled for long-term monitoring PO 1, even though the cost per coral appears to be the same, is that the total number of corals that would be measured using the assumptions above is approximately double for the mosaic method as for the diver method. The situation modeled above was for a trip with $N_F = 4$ field days. If the value of N_F is constant for both methods, approximately twice as many corals will be measured using the mosaic method as would be measured using the diver method. Thus, for the same field effort, the sample size from the mosaic would be double that from the divers. Alternatively, to collect the same sample size, the field effort would need to be about double for the divers as it would be for the mosaics. Thus, when considering the total cost for the project, as opposed to the cost per coral, a comparison giving equal sample sizes would cost about twice as much to obtain with divers as it would with mosaics.

A second advantage the mosaics have relative to the divers in the situation modeled for long-term monitoring PO 1, even though the cost per coral appears to be the same, is that the field costs for this trip were relatively low. In fact, one reason AUTEC was chosen as a demonstration site for this project was specifically because field costs were relatively low. For example, the model above used \$15/person/day for food and \$30/person/day for lodging, which are quite low. The model above used \$4,500 for four days for boat rental, including two boats, two captains, and fuel or \$575/day for a boat. For a UM scientist to take a UM boat on a local trip in Miami is about the same rate (\$300 / day plus fuel at ~\$5.00 / gallon), but to charter a small boat from a commercial operator could easily cost \$1,000 /day plus fuel. Finally, note that AUTEC is easy to get to because they operate their own charter flights from West Palm Beach. Field costs would be even greater for trips that required plane tickets and shipping or chartering live-aboard vessels to remote destinations. These points are relevant because any factor that drives up the cost of field time will increase the cost per coral of using the diver-based method relative to the mosaic-based method.

A third advantage the mosaics have relative to the divers in the situation modeled for long-term monitoring PO 1, even though the cost per coral appears to be the same, is that the model assumes that only coral sizes and condition were measured. If any other variable besides coral sizes and condition were of interest, say for example percent live coral cover, then less field time would be available for the divers to measure sizes. Therefore the number of corals measured per day would go down, and the cost per coral would go up. With mosaics, on the other hand, the field time does not increase for measuring additional variables. Whether coral cover, coral sizes, coral condition, or all three are extracted from a mosaic affects only the lab time (C_{ce}) not the field time (C_{cf}). Therefore, the advantage for multiple variables is the same as the first point above. To obtain equal sample sizes, field time for the divers will have to be longer therefore the total cost will increase.

7.1.3 Cost Model, Long-Term Monitoring Performance Objective 2

For the long-term monitoring demo, PO 2, we asked the question "what is the cost per m^2 to create digitized maps of the seabed and extract coral sizes and percent live cover from them?" Specifically, we wanted to compare the cost per m^2 as computed for the diver-based technique vs. the cost per m^2 as computed for the mosaic-based technique. Thus, we needed two cost models.

DIVER MODEL:

The area that can be mapped per diver, per hour of dive time is A_h. The area that can be mapped per field day is A_f, which is a function of A_h, the number of divers performing the mapping, N_d, and the number of dives possible per day, N_D, which itself is based primarily on depth. The cost per m^2 due to field expenses is therefore $C_{af} = C_T / A_T$, where C_T, the total cost of the trip was defined above (Equation 1), and $A_T = A_f \times N_F$ is the total area mapped.

Lab processing costs for the diver data are due to scanning and then digitizing the paper maps drawn by divers. The cost of processing diver data per m^2 is $C_{ap} = C_h \times T_e / A_T$, where C_h is the cost per hour of the person entering the data, T_e is the number of person-hours spent entering the data.

The total cost per m^2 for the diver method is $C_a = C_{af} + C_{ap}$.

MOSAIC MODEL:

The field component of the cost per area model for the mosaic method was the same as for the diver method, although some of the variables were parameterized differently, as discussed below (Section ???). The lab portion of the mosaic model was different, however. Lab work for the mosaics has two components, processing, which is creation of the mosaics from the raw data, and analysis, which is the extraction of ecological information from the mosaics. Furthermore, a complete accounting includes the costs of the equipment needed for mosaicing.

Processing for the mosaics included downloading the data from the cameras, entering the parameters into the mosaicing software, assessing output, and adjusting parameters as necessary. The cost per mosaic of processing $C_{mp} = C_h \times T_p$, did not differ from PO 1. The cost per area of processing $C_{ap} = C_{mp} / A_m$, where A_m is the area covered by a given mosaic.

Extracting data from the mosaics involved digitizing the perimeter of and assessing the health of some or all of the colonies visible in each mosaic. The cost per unit area of data extraction was $C_{ae} = C_h \times T_x$, where T_x is the number of person-hours spent extracting the data.

The cost per mosaic of equipment C_{mq} equals the cost of the cameras, computers, and software divided by the number of mosaics that could be expected to be made by each in their useful lifetime. The cost per area of equipment $C_{aq} = C_{mq} / A_m$.

The total cost per m^2 for the mosaic method was $C_a = C_{af} + C_{ap} + C_{ae} + C_{aq}$.

7.1.4 Cost Analysis and Comparison, Long-Term Monitoring PO 2

PARAMETER ESTIMATION FOR THE DIVER MODEL:

We used the actual costs incurred for the long-term monitoring demonstration as a starting point to estimate the parameters for the diver and mosaic models described above.

As part of PO 2, divers created hand-drawn maps of the seabed using gridded quadrats to guide their estimates of the sizes of objects and locations of the boundaries between objects. These activities were timed, so we could compute the average time for each (Table 78).

Table 78. Average time to draw, scan, and digitize maps of portions of a patch reef. Times have been scaled to 10×10 m areas.

Activity	Average Time of Completion (min)
Hand Mapping (10×10 m)	4,601
Data entry and QA/QC (10×10)	2,360
Digitizing into Arc (10×10)	4,450

Using the times from ???. we found that $A_h = 1.3$ m^2, the area that can be mapped per diver, per hour of dive time. The site used for PO 2 in the long-term monitoring demonstration was less than 30 feet deep, so we made some assumptions about the area that could be mapped in a day, A_f. Assume two divers were doing the work and were each able to spend six hours underwater per day, then $A_f = 6 \times A_h \times 2 = 15.6$ m^2 per day. The total area that could have been mapped using this strategy for the entire AUTEC trip is $A_T = 62.4$ m^2 over a four day period. The total trip cost was the same as for PO 1 (Table 75, Table 79), so the cost per m^2 due to field expenses, C_{af}, therefore ranged from \$131 to \$711 per m^2 (Table 80).

Table 79. Total trip cost C_T (taken from Table 75) and the field cost per meter squared to acquire mapped data of the reef by divers and with mosaics.

Data from	C_T	Diver C_{af} ($/m^2)	Mosaic C_{af} ($/m^2)
RSMAS diver 1	$8,152	$131	$2.14
RSMAS diver 2	$9,728	$155	$2.55
Navy diver 1	$44,343	$711	$11.62

The cost to transcribe field data into computer format is also sensitive to the salary of the person doing the transcription. Again, for illustrative purposes we used two values corresponding to people who actually worked with the data in this project. One value comes from a RSMAS post-doctoral scientist, who's daily salary including fringe benefits and overhead is $335 or $41.88 / hour. A second value comes from SSC Note 7600 (SPAWARSYSCEN PAC, 2012), which is $117.00 / hour. Using these values and the sum of the time for data entry and digitizing per m^2 from Table 78. C_{ap} ranges from $47.53 to $132.79 per m^2.

PARAMETER ESTIMATION FOR THE MOSAIC MODEL:

The area that can be mapped per diver, per hour of dive time was computed from the average times to acquire and areas covered by the mosaics acquired in this demo. Using the measured values we found an average A_h = 159 m^2. The site used for PO 2 in the long-term monitoring demonstration was less than 30 feet deep, so we made some assumptions about the area that could be mapped in a day, A_f, Assume 2 divers were doing the work with one operating the cameras and the other serving as dive buddy and that they were each able to spend 6 hours underwater per day, then $A_f = 6 \times A_h$ = 954 m^2 per day. The total area that could have been mapped using this strategy for the entire AUTEC trip was A_T = 3,816 m^2 over a four day period The total trip cost was the same as for PO 1 (Table 75, and Table 79), so the cost per m^2 due to field expenses, C_{af} , therefore ranged from $2.14 to $11.62 per m^2 (Table 79).

Average user time required for processing the mosaics was 240 minutes (Table 76). As for the diver model, we assumed a range of labor rates ranging from $41.88 / hour to $117.00 / hour resulting in an estimate for C_{mp} in the range $223.36 – $468. For an average mosaic size of 100 m^2, C_{ap} = $2.23 to $4.68.

Average user time required for digitizing the mosaics was 44.5 min m^{-2}. As for the diver model, we assumed a range of labor rates ranging from C_h = $41.88 / hour to $117.00 / hour resulting in an estimate for is C_{ae} = $31.06 to $86.78 per m^2.

The total cost of equipment per mosaic was estimated as C_{mq} = $41 (see calculations in Section 7.1.1. For an average mosaic size of 100 m^2, C_{aq} = $0.41.

Results for the long-term monitoring demo PO 2:

Using the models and parameter estimates described above, the cost per m^2 for the PO 2 measurements in the long-term monitoring demonstration were as follows. For the diver method, $C_a = C_{af} + C_{ap}$, so the cost per coral ranged from $178 to $853 per m^2. For the mosaic method, $C_a = C_{af} + C_{ap} + C_{ae} + C_{aq}$, so the cost per m^2 ranged from $36 to $110 per m^2.

Given the assumptions used above, the actual costs for the AUTEC trip, and the nature of the sites sampled at AUTEC, the actual cost per m^2 to use mosaics to map coral shapes, sizes, and cover was between 13 - 20% of the cost to use the diver method. Given that the performance of the two methods was also about the same, as evidenced by the fact that the diver-diver size measurements did not statistically differ from the diver-mosaic size measurements, the mosaic method was clearly superior for this performance objective.

In addition, it should be noted that the total area covered in a given time was much greater for the mosaic method than the diver method. In the $N_F = 4$ days assumption used for these calculations, the mosaic method could map ~3,800 m^2 whereas the diver method could be used to map only 62 m^2. In order to map comparable areas with the diver method would require additional divers or ~50 times as long (200 days) in the field for two divers. Thus, the mosaic method may be the only practical approach when field time is limited.

7.2 ENDANGERED SPECIES DEMONSTRATION

7.2.1 Cost Model, ESA Demonstration

DIVER MODEL:

The number of colonies that can be mapped and assessed per hour by a diver using the Williams *et al.* (2006) protocol is N_h. The number of colonies that can be mapped per field day is N_f, which is a function of N_h and the number of dives possible per day, N_D, which itself is based primarily on depth. The cost per colony due to field expenses was therefore $C_{cf} = C_T / N_T$, where C_T, the total cost of the trip was defined above (Equation 1), and $N_T = N_f \times N_F$ is the total number of colonies mapped.

Lab processing costs for the diver data were due to transcribing data sheets and importing to a GIS system. The cost of processing per colony was $C_{cp} = C_h \times T_e / A_T$, where C_h is the cost per hour of the person entering the data, T_e is the number of person-hours spent entering the data.

The total cost per m^2 for the diver-based implementation of the Williams *et al.* (2006) method was $C_c = C_{cf} + C_{cp}$.

MOSAIC MODEL:

The field component of the cost model for the mosaic method was the same as for the diver method, although some of the variables are parameterized differently, as discussed below. The lab portion of the mosaic model was different, however. Lab work for the mosaics has two components, processing, which is creation of the mosaics from the raw data, and analysis, which is the extraction of ecological information from the mosaics. Furthermore, a complete accounting includes the costs of the equipment needed for mosaicing.

Processing for the mosaics included downloading the data from the cameras, entering the parameters into the mosaicing software, assessing output, and adjusting parameters as necessary. The cost per mosaic of processing was $C_{mp} = C_h \times T_p$, where C_h is the cost per hour of the person processing the mosaic, and T_p is the number of person-hours spent processing. The cost per colony of processing $C_{cp} = C_{mp} / N_T$.

Extracting data from the mosaics involved measuring the locations of colonies (PO 1) their sizes (PO 2), their live coral cover (PO 3) and identifying their type (also PO 3). The cost per colony of data extraction was $C_{ce} = C_h \times T_x / N_T$ where T_x is the number of person-hours spent extracting the data.

The cost per mosaic of equipment C_{mq} equals the cost of the cameras, computers, and software divided by the number of mosaics that could be expected to be made by each in their useful lifetime. The cost of equipment per colony $C_{cq} = C_{mq} / N_T$,.

The total costs for extracting perimeters using the mosaic method is:

$$C_c = C_{cf} + C_{cp} + C_{ce} + C_{cq} \text{ (in \$ per colony)}$$

7.2.2 Cost Analysis and Comparison, ESA Demonstration

We used the actual costs incurred for the ESA demonstration as a starting point to estimate the parameters for the diver and mosaic models described above.

PARAMETER ESTIMATION FOR THE DIVER MODEL:

During the ESA demonstration, divers mapped, measured, and assessed 62 colonies at three sites using the Williams *et al.* (2006) method. Diver time for measurements and setup was 298 minutes, resulting in an estimate of N_h = 12.5 colonies / h.

We estimated that about four underwater-hours per day could be spent actually mapping using the Williams *et al.* (2006) method. This estimate was based primarily on experience with the logistics of implementing the method rather than diving no-decompression limits. *Acropora palmata* grows in shallow water, most commonly shallower than 10 m depth. Thus, depth limits are not the main constraint on the daily total number of colonies that can be mapped. During the ESA demonstration we found that each 7-m radius site required approximately 2 hours to locate, setup, map, and assess. This is consistent with NOAA's experience using the method for the past 7 years (Dana Williams personal communication). Two sites per day is a reasonable average, assuming 1 hour to travel from the dock to the first site and from the last site back to the dock, plus at least a 1 hour surface interval following each site due to moving the boat and giving the divers a short rest after a 2 hour dive. Therefore, N_f = 50, and N_T = 150 because N_F = 3 for the ESA demo.

Field costs for the ESA demo differed from the other demonstrations because Navy personnel participated in the ESA demo as observers and snorkelers, but not as divers. Therefore, actual costs are available only for the RSMAS divers (Table 81). RSMAS diver 1 drove a car to Key Largo, incurring mileage expenses, whereas RSMAS diver 2 drove the boat there, incurring no additional travel expense over boat rental. The RSMAS team stayed in a private residence to reduce field costs (Table 80). At AUTEC, the Navy diver's cost was 5.4 times RSMAS diver 1 (Table 76) and for the traditional metrics and the grounding demonstrations, the Navy diver's cost was 6.4 times RSMAS diver 1 (Table 85). For the purposes of illustrating the range of costs for the ESA demonstration, we have assumed that the Navy diver's cost would have been 5.9 times the cost of RSMAS diver 1, or $19,199.

Table 80. Total trip cost C_T using values was derived from two RSMAS divers who participated in the ESA demo.

Expense	RSMAS diver 1	RSMAS diver 2
Travel	$41	$-
Salary	$1,340	$2,128
Per diem	$200	$200
Boat Rental	$1,200	$1,200
Fuel	$473	$473
Lodging	$-	$-
C_T	**$3,254**	**$4,001**

- Actual costs for the Navy were not available for this trip, but an estimated cost, based on the ratio of costs for the long-term monitoring, traditional metrics, and grounding demonstrations, is C_T = $19,199 for the Navy diver 1.

The cost to transcribe the diver data was a function the salary of the person doing the transcription and the time required. As for the other demonstrations, we assumed a range of labor rates ranging from $41.88 / hour to $117.00 / hour. Using these values and the time recorded during the demonstration for data transcription (112 min), the cost of processing the diver data ranged from $1.26 to $3.52 per coral colony, depending on the hourly wage of the analyst.

PARAMETER ESTIMATION FOR THE MOSAIC MODEL:

Mosaic acquisition for this demonstration took 92 minutes total for all three sites, so N_h = 40.4 colonies / h. Using the same assumptions of 4 diving hours per day, N_f = 162 colonies per day, and N_T = 486 colonies for the entire trip.

Estimates for CT were the same for the mosaic model as for the diver model (Table 80 above).

Average user time required for processing the mosaics was 240 minutes (Table 76). As for the GPS and fishbone models, we assumed a range of labor rates ranging from $41.88 / hour to $117.00 / hour resulting in an estimate for C_{mp} in the range $167.52 - $468 per mosaic or C_{ap} in the range $2.70–$7.55 per colony.

Analyst time to compute the damaged area from the completed mosaic was 81 minutes. Using the same labor rates gave a range of C_{ae} from $0.91 - $2.55 per colony.

The total cost of equipment per mosaic was estimated as C_{mq} = $41 (see calculations in Section 7.1.1. For an average of 21 colonies at a site, C_{aq} = $1.95 per colony.

RESULTS FOR THE ESA DEMONSTRATION:

Using the models and parameter estimates described above, the costs to measure each variable were derived (Table 81). The mosaic method was less-expensive per coral colony than the diver-based method.

Table 81. Total cost per coral colony to map, measure, type, and estimate live coral cover for *Acropora palmata* colonies.

Diver			Mosaics	
C_c (low)	C_c (high)	C_c (low)	C_c (high)	Units
\$22.96	\$131.52	\$12.26	\$51.56	(\$/coral colony)

- Derived using the diver-based Williams *et al.* (2006) method and the mosaic-based method.

7.3 GROUNDING DEMONSTRATION

In the grounding demonstration, performance objectives 1 and 2 tested different aspects of the same types of surveys. Thus, the same cost question was relevant to both PO 1 and 2, namely "what is the cost per m^2 to compute the size of an area damaged by ship grounding?" Specifically, we wanted to compare the cost as computed for the snorkeler-based GPS technique, the diver-based fishbone technique, and the mosaic technique. Thus we needed three cost models.

Grounding PO 3 was identical to the traditional metrics demonstration PO 1. The data collected during the grounding demonstration for PO 3 were pooled with the traditional metrics data for analysis and cost assessment. See Section 7.4.1 and 7.4.2 for cost assessment of the grounding demo PO 3.

Grounding PO4 was performed under controlled conditions in a pool. Like the experiments performed during the absolute accuracy demonstration, grounding demo PO4 was a one-time test of the absolute accuracy and precision of the size measurements made from underwater landscape mosaics. Since this was a one-time event set up under artificial, controlled conditions no cost model was considered for PO4.

Grounding PO5 was a training exercise and verification that an analyst who was newly trained on the mosaicing software could successfully extract ecological data from mosaics. As in the case of the long-term monitoring PO 3 and traditional metrics PO 3, there is no cost model for PO5.

7.3.1 Cost Model, Grounding Performance Objectives 1 and 2

GPS MODEL:

The area that can be delimited by a diver or snorkeler per hour of dive time is A_{gh}. The area that can be delimited per field day is A_{gf}, which is a function of A_{gh}, the number of divers performing the mapping, N_d, and the number of dives possible per day, N_D, which itself is based primarily on depth (or unlimited for a snorkeler). The cost per m^2 of delimiting a damaged area due to field expenses is therefore $C_{gf} = C_T / A_T$, where C_T, the total cost of the trip was defined above (Equation 1), and $A_T = A_{gf} \times N_F$ is the total area mapped.

Lab processing costs for the GPS data were due to downloading track lines and importing to a GIS system. The cost of processing per m^2 was $C_{gp} = C_h \times T_e / A_T$, where C_h is the cost per hour of the person entering the data, T_e is the number of person-hours spent entering the data.

The total cost per m^2 for the GPS method was $C_g = C_{gf} + C_{gp}$.

FISHBONE MODEL:

The area that can be delimited by a diver using the fishbone method per hour of dive time is A_{fh}. The area that can be delimited per field day is A_{ff}, which is a function of A_{fh}, the number of divers performing the mapping, N_d, and the number of dives possible per day, N_D, which itself is based primarily on depth. The cost per m^2 of delimiting a damaged area due to field expenses was therefore $C_{ff} = C_T / A_T$, where C_T, the total cost of the trip was defined above (Equation 1), and $A_T = A_{ff} \times N_F$ is the total area mapped.

Lab processing costs for the fishbone data were due to transcribing data sheets and importing to a GIS system. The cost of processing per m^2 was $C_{fp} = C_h \times T_e / A_T$, where C_h is the cost per hour of the person entering the data, T_e is the number of person-hours spent entering the data.

The total cost per m^2 for the fishbone method was $C_f = C_{ff} + C_{fp}$.

MOSAIC MODEL:

The field component of the cost model for the mosaic method was the same as for the diver method, although some of the variables were parameterized differently, as discussed below. The lab portion of the mosaic model was different, however. Lab work for the mosaics had two components, processing, which is creation of the mosaics from the raw data, and analysis, which is the extraction of ecological information from the mosaics. Furthermore, a complete accounting includes the costs of the equipment needed for mosaicing.

Processing for the mosaics included downloading the data from the cameras, entering the parameters into the mosaicing software, assessing output, and adjusting parameters as necessary. The cost per mosaic of processing was $C_{mp} = C_h \times T_p$, where C_h is the cost per hour of the person processing the mosaic, and T_p is the number of person-hours spent processing. The cost per m^2 of processing was $C_{ap} = C_{mp} / A_m$, where A_m is the area covered by a given mosaic.

The cost of extracting the perimeter of the damaged area from a mosaic was modeled as $C_{ae} = C_h \times T_x$, where T_x is the number of person-hours spent extracting the data.

The cost per mosaic of equipment C_{mq} equals the cost of the cameras, computers, and software divided by the number of mosaics that could be expected to be made by each in their useful lifetime. The cost of equipment per area $C_{aq} = C_{mq} / A_m$.

The total costs for extracting perimeters using the mosaic method was:

$$C_a = C_{qf} + C_{ap} + C_{ae} + C_{aq} \text{ (in \$ per m}^2\text{)}$$

7.3.2 Cost Analysis and Comparison, Grounding PO 1 and 2

We used the actual costs incurred for the grounding demo as a starting point to estimate the parameters for the diver and mosaic models described above.

PARAMETER ESTIMATION FOR THE GPS MODEL:

As part of PO 1, snorkelers swam around the perimeter of the damaged area three times. This activity was timed, resulting in estimates of $A_{gh} = 392 \text{ m}^2 / \text{h}$, when using three replicate measurements, or $A_{gh} = 1{,}176 \text{ m}^2 / \text{h}$, if only a single pass around the perimeter was used.

The Anniversary Reef site used for this demo was in shallow (~2 m) water, and, although there are exceptions (e.g., Gleason *et al.* 2011), it's a reasonable assumption that most grounding sites will be found in depths shallow enough to snorkel or at least not be limited by bottom time constraints. Therefore, we assumed 6 hours of mapping were possible each day in order to estimate the totals that could be mapped in a day. Assuming 1 GPS unit were available and three replicate measurements were made, $A_{gf} = 6 \times A_{gh} = 2{,}350 \text{ m}^2$ per day. The total area that could have been mapped using this strategy for the entire grounding trip was $A_T = 9{,}410 \text{ m}^2$ over a four day period.

Trip costs were essentially identical to the traditional metrics trip. Navy diver costs were within 1.5% and RSMAS diver costs were within 1% of the traditional metrics trip. Therefore, we used the same range of values for the trip cost, C_T computed using equation 1 and the data in Table 84. The number of field days was $N_F = 4$. From the trip cost, C_T, we divided by the total area that could have been surveyed to compute C_{gf} = \$0.49, \$0.62, and \$3.17 m^{-2} for the two RSMAS divers and the Navy diver respectively.

The cost to download the GPS data and convert to a GIS polygon format is a function the salary of the person doing the transcription and the time required. For illustrative purposes we used two values corresponding to people who actually worked with the data in this project. One value came from a RSMAS post-doctoral scientist, whose daily salary including fringe benefits and overhead was \$335 or \$41.88 / hour. A second value came from SSC Note 7600, which was \$117.00 / hour. Using these values and the time recorded during the demonstration for downloading GPS data (20 min), the cost of processing the diver data ranged from \$13.96 to \$39.00 per polygon, depending on the hourly wage of the analyst. The area of the polygon measured in this demo was 159 m^2, so C_{gp} was in the rage \$0.09 to \$0.25 m^{-2}.

PARAMETER ESTIMATION FOR THE FISHBONE MODEL:

As part of PO 1 and 2, divers measured the damaged area using the fishbone method (Hudson and Goodwin 2001). Diver time for measurements and setup was 133 minutes, and the average measured area of the scar was 178 m^2, resulting in an estimate of A_{fh}. = 80.3 m^2 / h. Note, this was using 1 m spacing of measurements along the centerline transect.

Using the same assumptions regarding depth, dive time, and trip costs detailed above for the GPS model, A_{ff} = 482 m^2 per day. The total area that could have been mapped using this strategy for the entire grounding trip was A_T = 1928 m^2. Using C_T, from Table 84, the field cost of the fishbone method was C_{ff} = \$2.41, \$3.02, and \$15.46 m^{-2} for the two RSMAS divers and the Navy diver respectively.

The cost to transcribe the fishbone data is a function the salary of the person doing the transcription and the time required. As for the GPS model, we assumed a range of labor rates ranging from \$41.88 / hour to \$117.00 / hour. Using these values and the time recorded during the demonstration for data transcription (41 min), the cost of processing the diver data ranged from \$0.16 to \$0.45 m^{-2}, depending on the hourly wage of the analyst. Note, these costs included only data input, not conversion to a GIS format or any other format necessary for subsequent analysis.

PARAMETER ESTIMATION FOR THE MOSAIC MODEL:

Mosaic acquisition for this demonstration took 61 minutes to cover an area of 250 m^2, so A_{mh} = 245 m^2 / h. Using the same assumptions regarding depth, dive time, and trip costs detailed above for the GPS model, A_{mf} = 1,470 m^2 per day. The total area that could have been mapped using this strategy for the entire grounding trip was A_T = 5,880 m^2, over four days. Using C_T, from Table 84, the field cost of the mosaic method was C_{mf} = \$0.79, \$0.99, and \$5.07 m^{-2} for the two RSMAS divers and the Navy diver respectively.

Average user time required for processing the mosaics was 240 minutes (Table 76). As for the GPS and fishbone models, we assumed a range of labor rates ranging from \$41.88 / hour to \$117.00 / hour resulting in an estimate for C_{mp} in the range \$167.52 - \$468 per mosaic or C_{ap} in the range \$0.67 – \$1.87 m^{-2}.

Analyst time to compute the damaged area from the completed mosaic was 6 minutes. Using the same labor rates gave a range of C_{ae} from \$0.02 – \$0.05 m^{-2}.

The total cost of equipment per mosaic was estimated as C_{mq} = \$41 (see calculations under Section 7.1.2. For a minimum mosaic size of 100 m^2, C_{aq} = \$0.41.

RESULTS FOR THE GROUNDING DEMO PO 1 AND 2:

Using the models and parameter estimates described above, the costs to measure each variable were derived (Table 83). The GPS method was least-expensive, the fishbone method most expensive, and the mosaic method in-between. One factor to consider is that the cost of the fishbone method could be adjusted by using a different spacing for the measurements. In this case, the recommendation of Hudson and Goodwin (2001), to space the measurements by 1 m, was used. If transects were farther apart, however, the cost would decrease. Conversely if transects were closer together costs would increase.

Table 82. Total cost per m^2 to measure damaged area from a ship grounding for each survey methodology.

GPS		Fishbone		Mosaics		
C_g (low)	C_g (high)	C_f (low)	C_f (high)	C_a (low)	C_a (high)	Units
\$0.58	\$3.42	\$2.57	\$15.91	\$1.89	\$7.40	(\$/m^2)

A second factor to consider with these costs is that the mosaic data can also be used for ecological data extraction, whereas with the fishbone or GPS methods additional field time would be required to collect data for community assessment. The effect of this would be the same as discussed under PO 1 for the Traditional Metrics demonstration (Section 7.4.2), the more variables that need to be extracted, the more cost-effective the mosaics become because the same source data (the images) can be used for all measurements.

7.4 TRADITIONAL METRICS DEMONSTRATION

Performance objective 1 of the traditional metrics demonstration evaluated multiple parameters: benthic cover, coral species richness, coral colony size frequency distribution, coral colony condition as evaluated by disease, bleaching, and mortality, and juvenile coral colony density. The total cost model needed to be divided into four sub-models, based on the different parameters measured.

(1) Benthic cover was assessed at a discrete number of points using LPIM by divers, and image-based point counting, from mosaics. Therefore, the relevant cost question was “what is the cost of assessing benthic cover per point?”

(2) Coral species richness was assessed by divers using 1×10 m belt transects and from the mosaics by visual inspection of 1×10 m “virtual transects.” The relevant cost question was therefore “what is the cost per m^2 to assess species richness?”

(3) Coral sizes and condition, including assessment of bleaching, disease, and mortality, were measured by divers using the PCQT method and from the mosaics using random point counts and image inspection. The relevant cost question was “what is the cost per colony to assess coral sizes and condition?”

(4) Finally, juvenile density was assessed by divers using quadrats and from the mosaics by visual inspection of “virtual quadrats.” Thus, the cost question was “what is the cost per m^2 to estimate juvenile coral density?”

The purpose of traditional metrics PO 2 was to illustrate the value of underwater landscape mosaics as data archives. The mosaics are valuable archives because they store raw data that can be reanalyzed in the future. The same cost model computed for PO 1 can illustrate the efficacy of mosaics as a data archive, so we did not compute a separate cost model for PO 2. To illustrate the point, consider the following two situations in which reanalysis of mosaics would prove valuable.

One situation in which reanalysis of mosaics would prove valuable is to extract another variable that was not desired at the time of the original survey. For example, many corals in the Florida Keys bleached and or died following the passage of a strong cold front in 2010. Monitoring programs that were set up to track corals captured this event in their data. Cantwell (2013), using underwater landscape mosaics documented this event for corals, but was also able to go back to old mosaics of the site to quantify mortality of gorgonians and sponges that had also been affected. At a minimum, this sort of archival drives the cost effectiveness of mosaics toward mutli-variable surveys (Table 90) as opposed to single-variable surveys (Table 91). In fact, however, the ability to measure variables later without having to plan for them ahead of time is even more valuable because it is impossible to go back in time and measure something with a diver transect that was not captured during the original survey.

A second situation in which reanalysis of mosaics would prove valuable is to enable a single variable to be extracted in different ways. For example, there are numerous ways to get the percent cover of different benthic organisms either with diver transects or from the mosaics. The “standard method” that we propose for the mosaics is point counting: namely to place N points randomly across the mosaic and identify what is underneath each one of them. Alternate methods include simulated line point intercept transects, tracing the outlines of benthic organisms, or automated image analysis. Furthermore, even using the standard approach of point counting, one has the choice of how many points to use; more points leads to greater precision but higher labor cost. It is possible, using the mosaics, to perform the same analysis using any or all of these methods given a single data acquisition. With diver transects, on the other hand, each type of analysis would require a different data collection, thereby increasing field costs. This nature of archival quality of the mosaics also implies that the cost is more like multi-variable surveys (Table 91) as opposed to single-variable surveys (Table 90).

Performance Objective 3 for the Traditional Metrics demonstration was a training exercise and verification that divers who were newly trained on the mosaicing software could successfully use it to convert raw images into mosaics. Therefore no cost model was considered for this performance objective.

7.4.1 Cost Model, Traditional Metrics Performance Objective 1

DIVER MODEL FOR BENTHIC COVER:

The number of points that can be assessed with LPIM per diver, per hour of dive time is N_{ph}. The number of points that can be assessed with LPIM per field day is N_{pf}, which is a function of N_{ph}, the number of divers performing the mapping, N_d, and the number of dives possible per day, N_D, which itself is based primarily on depth. The cost per day of field time is C_f, which equals the total cost of the trip, C_T (Equation 1), divided by the number of field days, N_F. The cost per point for field expenses is therefore $C_{pf} = C_f / N_{pf}$.

Lab processing costs for the diver data were due to transcribing the field data sheets. The cost of processing diver data per point is $C_{pp} = C_h \times T_e / N_{pf}$, where C_h is the cost per hour of the person entering the data, T_e is the number of person-hours spent entering the data.

The total cost per point for the diver method was $C_p = C_{pf} + C_{pp}$.

DIVER MODEL FOR SPECIES RICHNESS:

The area that can be mapped with belt transects per diver, per hour of dive time is A_{bh}. The area that can be mapped with belt transects per field day is A_{bf}, which is a function of A_{bh}, the number of divers performing the mapping, N_d, and the number of dives possible per day, N_D, which itself is based primarily on depth. The cost per m^2 of assessing species richness with belt transects due to field expenses is therefore $C_{bf} = C_T / A_{bT}$, where C_T, the total cost of the trip was defined above (Equation 1), and $A_{bT} = A_{bf} * N_F$ is the total area mapped.

Lab processing costs for the belt transect data were due to transcribing field data sheets. The cost of processing diver data per m^2 was $C_{bp} = C_h \times T_e / A_{bT}$, where C_h is the cost per hour of the person entering the data, T_e is the number of person-hours spent entering the data.

The total cost per m^2 for the diver method was $C_b = C_{bf} + C_{bp}$.

DIVER MODEL FOR CORAL SIZE AND CONDITION:

The number of coral colonies that can be assessed with PCQT per diver, per hour of dive time is N_{qh}. The number of colonies that can be assessed with PCQT per field day is N_{qf}, which is a function of N_{qh}, the number of divers performing the mapping, N_d, and the number of dives possible per day, N_D, which itself is based primarily on depth. The cost per day of field time is C_f, which equals the total cost of the trip, C_T (Equation 1), divided by the number of field days, N_F. The cost per colony for field expenses was therefore $C_{qf} = C_f / N_{qf}$.

Lab processing costs for the diver data were due to transcribing the field data sheets. The cost of processing diver data per colony is $C_{qp} = C_h \times T_e / N_{qf}$, where C_h is the cost per hour of the person entering the data, T_e is the number of person-hours spent entering the data.

The total cost per point for the diver method was $C_q = C_{qf} + C_{qp}$.

DIVER MODEL FOR JUVENILE DENSITY:

The area that can be inspected for juvenile corals per diver, per hour of dive time is A_{jh}. The area that can be assessed per field day is A_{jf}, which is a function of A_{jh}, the number of divers performing the mapping, N_d, and the number of dives possible per day, N_D, which itself is based primarily on depth. The cost per m^2 of assessing juvenile density due to field expenses is therefore $C_{jf} = C_T / A_{qT}$, where C_T, the total cost of the trip was defined above (Equation 1), and $A_T = A_{bf} \times N_F$ is the total area mapped.

Lab processing costs for the juvenile density data were due to transcribing field data sheets. The cost of processing diver data per m^2 is $C_{jp} = C_h \times T_e / A_{qT}$, where C_h is the cost per hour of the person entering the data, T_e is the number of person-hours spent entering the data.

The total cost per m^2 for the diver method is $C_j = C_{jf} + C_{jp}$.

MOSAIC MODEL:

The field component of the cost model for the mosaic method was the same as for the diver method, although some of the variables were parameterized differently, as discussed below. The lab portion of the mosaic model was different, however. Lab work for the mosaics had two components, processing, which is creation of the mosaics from the raw data, and analysis, which is the extraction of ecological information from the mosaics. Furthermore, a complete accounting includes the costs of the equipment needed for mosaicing.

Processing for the mosaics included downloading the data from the cameras, entering the parameters into the mosaicing software, assessing output, and adjusting parameters as necessary. The cost per mosaic of processing is $C_{mp} = C_h \times T_p$, where C_h is the cost per hour of the person processing the mosaic, and T_p is the number of person-hours spent processing. The cost per point for benthic cover due to processing is $C_{pp} = C_{mp} / N_{Tp}$, where is N_{Tp} is the number of points used to estimate benthic cover. The cost per area of processing, which is used for the species richness and juvenile density cost estimates, is $C_{bp} = C_{jp} = C_{mp} / A_m$, where A_m is the area covered by a given mosaic. The cost per colony of processing C_{qp}, which is used for the coral size and condition cost estimate, should ideally be computed as C_{mp} divided by the total number of coral colonies in the area covered by the mosaic, but we use $C_{qp} = C_{mp} / N_{Tq}$, where is N_{Tq} is the number of colonies actually counted in the demo using the PCQT method, which will be a conservative estimate since N_{Tq} < the total number of coral colonies in the area covered by the mosaic.

Extracting data from the mosaics involved different methods for the different metrics, but the costs of each was modeled as $C_e = C_h \times T_x$, where T_x is the number of person-hours spent extracting the data. Having measured T_x for each of the metrics extracted, the model contained four estimates of C_e: C_{pe} for benthic cover, C_{be} for species richness, C_{qe} for colony size and condition, and C_{je} for juvenile density.

The cost per mosaic of equipment C_{mq} equald the cost of the cameras, computers, and software divided by the number of mosaics that could be expected to be made by each in their useful lifetime. The cost of equipment per area $C_{aq} = C_{mq} / A_m$, and the cost of equipment per point, C_{pq}, or colony, C_{qq}, equald C_{mq} divided by N_{Tp} or N_{Tq}, respectively.

The total costs for extracting individual variables using the mosaic method were:

$C_p = C_{pf} + C_{pp} + C_{pe} + C_{pq}$ for benthic cover in \$ per point counted
$C_b = C_{bf} + C_{bp} + C_{be} + C_{aq}$ for species richness in \$ per m^2
$C_q = C_{qf} + C_{qp} + C_{qe} + C_{qq}$ for coral colony size and condition in \$ per colony
$C_j = C_{jf} + C_{jp} + C_{je} + C_{aq}$ for juvenile density in \$ per m^2

It is important to note that the costs of acquisition, C_{xf}, processing , C_{xp}, and of equipment, C_{xq}, where x = p, f, q, or j, are shared when multiple variables are extracted from a given mosaic.

When extracting all four types of variables, which we called the "combined scenario", the total costs for the individual variables using the mosaic method were:

$C_p = C_{pe} + (C_{pf} + C_{pp} + C_{pq}) / 4$ for benthic cover in \$ per point counted
$C_b = C_{be} + (C_{bf} + C_{bp} + C_{aq}) / 4$ for species richness in \$ per m^2
$C_q = C_{qe} + (C_{qf} + C_{qp} + C_{qq}) / 4$ for coral colony size and condition in \$ per colony
$C_j = C_{je} + (C_{jf} + C_{jp} + C_{aq}) / 4$ for juvenile density in \$ per m^2

7.4.2 Cost Analysis and Comparison, Traditional Metrics PO 1

We used the actual costs incurred for the traditional metrics demo as a starting point to estimate the parameters for the diver and mosaic models described above.

PARAMETER ESTIMATION FOR THE DIVER MODEL:

As part of PO 1, divers performed LPIM, BT, PCQT, and juvenile surveys at four sites. These activities were timed, so we could compute the average time for each (Table 83).

Table 83. Average time to perform each of the four types of diver surveys.

Activity	Average Time of Completion (min)
LPIM (10 m, 100 points)	8.5
BT (1×10 m)	3.75
PCQT (40 colonies)	40.0
Juvenile assessment (2.5 m^2)	6.5

Using the times from Table 83, we found that N_{ph} = 705 points / h, A_{bh} = 160 m^2 / h, N_{qh} = 54 colonies / h, A_{jh} = 23 m^2 / h. Two of the sites used for PO 1 in the traditional metrics demo were less than 30 feet deep, two were between 30-40 feet deep. Using those depths as guides, we assumed a dive profile of one 40-foot dive for 60 minutes followed by two 30-foot dives for 60 minutes each per day in order to estimate the totals that could be mapped in a day. Further, assuming two divers were doing the work and each was able to measure at the rates specified in Table 83. Under these assumptions, $N_{pf} = 3 \times N_{ph} \times 2$ = 4235 points / day, $A_{bf} = 3 \times A_{bh} \times 2$ = 960 m^2 per day, $N_{qf} = 3 \times N_{qh} \times 2$ = 324 colonies / day, $A_{jf} = 3 \times A_{jh} \times 2$ = 138 m^2 per day. The total areas that could have been mapped using this strategy for the entire traditional metrics trip were A_{bT} = 3,840 m^2 and A_{qT} = 554 m^2.

Note that the above calculations assume that a given transect type is the only measurement being performed. For example, N_{ph} = 705 colonies / h if both divers perform only LPIM surveys and not any of the other types of transects. This is a valid approach for cost estimation if benthic cover is the only type of measurement desired, but sometimes it may be desired to measure all of the parameters using a combination of the transects. In this case, we note that it takes 1 hr to perform one each of the four types of transects in Table 83.Thus, under the "combined scenario" the numbers above became: N_{ph} = 100 colonies / h, A_{bh} = 10 m^2 / h, N_{qh} = 36 colonies / h, A_{jh} = 2.5 m^2 / h, $N_{pf} = 3 \times N_{ph} \times 2$ = 600 points / day, $A_{bf} = 3 \times A_{bh} \times 2$ = 60 m^2 per day, $N_{qf} = 3 \times N_{qh} \times 2$ = 216 colonies / day, $A_{jf} = 3 \times A_{jh} \times 2$ = 15 m^2 per day, A_{bT} = 240 m^2 and A_{qT} = 60 m^2.

Trip costs were computed using equation 1 and the data in Table 84. The number of field days was N_F = 4. For the purpose of illustrating the range of possible costs consider situations of three of the divers from our trip. The two RSMAS divers drove from Miami for the cost of mileage reimbursement ($41). The Navy diver flew from Virginia for total costs of $1138. The RSMAS divers' daily salary, including fringe benefits and overhead were $335 / day (diver 1) and $532 / day (diver 2). The Navy diver's salary for the entire trip was $11,284. In addition, the Navy team was supported by four additional divers for a total of $15,000 for the entire trip including all of their expenses. Using these numbers, we computed a range of values for the trip cost, C_T (Table 84).

Table 84. Total trip cost C_T using values derived from three different divers who participated in the Key West demo.

Expense	RSMAS diver 1	RSMAS diver 2	Navy diver 1
Travel	$41	$41	$1,368
Salary	$2,010	$3,192	$11,284
Per diem	$300	$300	$759
Boat Rental	$1,500	$1,500	Incl. w/ support divers
Fuel	$625	$625	Incl. w/ support divers
Lodging	$167	$167	$1,395
Support Divers	$-	$-	$15,000
CT	$4,642	$5,824	$29,806

- Navy boat rental was included in cost of the support divers.

From the trip cost, C_T, we computed cost per field day then divided as appropriate by the number or area for each transect type to compute field expenses considering both situations, i.e., those in which a single type of measurement would be made (Table 85) as well as the combined scenario in which all four transect types were performed (Table 86).

Table 85. Cost per measurement due to field expenses for the four transect types assuming only one type of transect were performed.

Transect type	RSMAS diver 1	RSMAS diver 2	Navy diver 1	Units
LPIM: C_{pf}	$0.27	$0.34	$1.76	($/point)
BT: C_{bf}	$1.21	$1.52	$7.76	($/m^2)
PCQT: C_{qf}	$3.58	$4.49	$23.00	($/colony)
JUV: C_{jf}	$8.41	$10.55	$54.00	($/m^2)

Table 86. Cost per measurement due to field expenses for the four transect types under the combined scenario

Transect type	RSMAS diver 1	RSMAS diver 2	Navy diver 1	Units
LPIM: C_{pf}	$1.93	$2.43	$12.42	($/point)
BT: C_{bf}	$19.34	$24.27	$124.19	($/m^2)
PCQT: C_{qf}	$5.37	$6.74	$34.50	($/colony)
JUV: C_{jf}	$77.37	$97.07	$496.77	($/m^2)

- This assumes all four types of transect were performed in the same proportions per dive as used during the demo.

The cost to transcribe field data into computer format is also sensitive to the salary of the person doing the transcription. For illustrative purposes we used two values corresponding to people who actually worked with the data in this project. One value came from a RSMAS post-doctoral scientist, whose daily salary including fringe benefits and overhead was $335 or $41.88 / hour. A second value came from SSC Note 7600, which was $117.00 / hour. Using these values and the time recorded during the demonstration for transcribing data sheets, the cost of processing the diver data ranged from $0.08 per point to $4.68 per m^2, depending on the variable and hourly wage of the analyst (Table 87).

Table 87. Cost per unit due to processing diver data.

	T_e / N_{xf} or A_{xT}	Units	C_{xp} RSMAS	C_{xp} Navy	Units
LPIM: x = p	0.1075	(min/point)	$0.08	$0.21	($/point)
BT: x = b	0.9	(min/m^2)	$0.63	$1.76	($/m^2)
PCQT: x = q	1.5	(min/colony)	$1.05	$2.93	($/colony)
JUV: x = j	2.4	(min/m^2)	$1.68	$4.68	($/m^2)

- The variable x in N_{xf}, A_{xT}, and C_{xp} takes on different values depending on the transect, as noted in the left column.

PARAMETER ESTIMATION FOR THE MOSAIC MODEL:

The average time to acquire the mosaics for this demonstration was 40.5 minutes, and the minimum area covered was 100 m^2. The assumed diver profile used above was one 40-foot dive for 60 minutes followed by two 30-foot dives for 60 minutes each per day in order to estimate the totals that could be mapped in a day. 60 minutes was required per dive to make the suite of measurements tested under this demo when using diver transects. To make the same measurements using mosaics required only ~40 minutes to capture the necessary data. Therefore, four dives, each for 45 minutes with maximum depth ≤ 40 feet, could be made per day using the mosaic method with the same total bottom time as three hour-long dives using the diver method. Under this dive profile and using the actual numbers or areas of measurements made during the demonstration we found that that N_{pf} = 1600 points / day, A_{bf} = 400 m^2 per day, N_{qf} = 144 colonies / day, A_{jf} = 400 m^2 per day. The total areas that could have been mapped using this strategy for the entire traditional metrics trip are A_{bT} = A_{qT} = 1600 m^2. Note that the above calculations were the same regardless of whether a given transect type was the only measurement being performed or whether some combination of variables were going to be extracted from the mosaics.

Using the estimates of C_T derived above, which were the same for the mosaic model as for the diver model (Table 84), the cost per measurement due to acquisition was calculated (Table 89).

Table 88. Cost per measurement due to field expenses using mosaics, assuming measurements were performed in the same numbers per site as used during the demo.

Expense	RSMAS diver 1	RSMAS diver 2	Navy diver 1	Units
LPIM: Cpf	$0.73	$0.91	$4.66	($/point)
BT: Cbf	$2.90	$3.64	$18.63	($/m2)
PCQT: Cqf	$8.06	$10.11	$51.75	($/colony)
JUV: Cjf	$2.90	$3.64	$18.63	($/m2)

Average user time required for processing the mosaics was 240 minutes (Table 76). As for the diver model, we assumed a range of labor rates ranging from \$41.88 / hour to \$117.00 / hour resulting in an estimate for C_{mp} in the range \$223.36 - \$468. Therefore, C_{pp} ranged from \$0.56 to \$1.17 per point, C_{bp} and C_{jp} ranged from \$2.23 to \$4.68 per m^2, and C_{qp} ranged from \$6.20 to \$13.00 per colony.

Average analyst time required for point counting and estimating species richness, which were performed simultaneously, was 76 minutes. Average analyst time required to measure colony size and assess health from the mosaics was 1.3 min / colony. Average analyst time required to inspect the mosaics for juvenile corals was 5.35 min / m^2. As for the diver model, we assumed a range of labor rates ranging from C_h = \$41.88 / hour to \$117.00 / hour resulting cost estimates for the extractions (Table 89).

Table 89. Cost per unit due to extracting data from the mosaics.

	T_e / N_{xf} or A_{xT}	Units	C_{xp} RSMAS	C_{xp} Navy	Units
LPIM: x = p	0.19	(min/point)	\$0.13	\$0.37	(\$/point)
BT: x = b	0.76	(min/m2)	\$0.53	\$1.48	(\$/m^2)
PCQT: x = q	1.32	(min/colony)	\$0.92	\$2.57	(\$/colony)
JUV: x = j	5.35	(min/m2)	\$3.73	\$10.43	(\$/m^2)

- The variable *x* in N_{xf}, A_{xT}, and C_{xp} takes on different values depending on the variable being extracted, as noted in the left column.

The total cost of equipment per mosaic was estimated as C_{mq} = \$41 (see calculations under Section 7.1.1). For a minimum mosaic size of 100 m^2, $C_{bq} = C_{jq}$ = \$0.41. Using N_{Tp} = 400 points and N_{Tq} = 36 colonies, as done in this demo, C_{pq} = \$0.10 and C_{qq} = \$1.14.

Results for the traditional metrics demo PO 1:

Using the models and parameter estimates described above, the costs to measure each variable were derived both for single-variable surveys (Table 90) and for surveys acquiring all four variables (Table 91). For most of the transect types, it was less expensive to use the traditional diver-based transect than to use mosaics if only one variable (i.e. one type of transect) were desired (Table 90). On the other hand, if multiple types of information were required (i.e. if the survey demanded all four types of transects) then the mosaics became more cost-effective than using the diver transects (Table 91).

Table 90. Total cost per unit for each transect type for surveys that consist of only one transect type.

	Diver transects		Mosaics		
	C_x (low)	C_x (high)	C_x (low)	C_x (high)	Units
LPIM: x = p	\$0.35	\$1.97	\$1.52	\$6.30	(\$/point)
BT: x = b	\$1.84	\$9.52	\$6.08	\$25.20	(\$/m^2)
PCQT: x = q	\$4.63	\$25.92	\$16.33	\$68.46	(\$/colony)
JUV: x = j	\$10.08	\$58.68	\$9.28	\$34.15	(\$/m^2)

- The variable *x* in C_x takes on different values depending on the transect type, as noted in the left column. Note that, except for juvenile surveys, the traditional diver transects are less expensive per unit measured than the mosaics when only one transect type is desired.

Table 91. Total cost per unit for each transect type for surveys that consist of all four types of transects.

	Diver transects		Mosaics		
	C_x (low)	C_x (high)	C_x (low)	C_x (high)	Units
LPIM: x = p	$2.01	$12.63	$0.48	$1.85	($/point)
BT: x = b	$19.97	$125.95	$1.92	$7.41	($/m^2)
PCQT: x = q	$6.42	$37.42	$4.77	$19.05	($/colony)
JUV: x = j	$79.04	$501.45	$5.12	$16.36	($/m^2)

- The variable *x* in C_x takes on different values depending on the transect type, as noted in the left column. Note that when measuring multiple variables, the traditional diver transects are more expensive per unit measured than the mosaics.

Note that diver transects get more expensive per unit measured when more variables are added to the overall survey. The reason for this is that more field time is required, or, for the same amount of field time fewer measurements can be made. In contrast, making more types of measurements from the mosaics requires more lab time, but no more field time than measuring a single variable.

7.5 SPATIAL ACCURACY DEMONSTRATION

The spatial accuracy demonstration was a one-time test of the absolute accuracy and precision of the size measurements made from underwater landscape mosaics. Since this was a one-time event set up under artificial, controlled conditions in a swimming pool there is no cost model for any of the performance objectives related to this demonstration.

7.6 COST DRIVERS

The cost analysis of Sections 7.1 – 7.4 (summarized in Table 92) revealed three main cost drivers of the mosaic technology relative to existing alternatives. The most important cost driver was the type of measurement being made. Costs for different types of measurements varied over at least two orders of magnitude, which was much greater than the range of costs associated with different methods or different divers performing the same type of measurement. Measurements with common cost units had widely varying costs because the actual measurements made depended on the specific application. For example, costs for both the long-term monitoring demonstration PO 2, in which we created digitized maps of benthic organisms, and the grounding demonstration PO 1 and 2, in which we created a digitized map of the outline of a grounding scar, were estimated in $ / m^2. The long term monitoring costs were 1-2 orders of magnitude greater than the grounding costs, however, because in the long term monitoring exercise we digitized the outlines of every benthic organism (i.e., many hundreds of polygons) whereas for the grounding we digitized only the overall outline of the damaged area (i.e., just a single polygon). Perhaps the most important conclusion from a cost standpoint is that cost depends not just on technology but also on application. It makes no sense to ask "what is the cost of the mosaic technology?" The correct question is "what is the cost of the mosaic technology to do X?" The same observation holds true for divers, of course, or any other technology.

Table 92. Summary of costs by performance objective. R1 refers to costs derived for RSMAS diver 1.

Demo / PO	Variable(s)	Cost Units	Diver method		Mosaic method		Diver/mosaic cost ratio	
			R1	Navy	R1	Navy	R1	Navy
1. LTM PO 1	size & condition	$ / colony	$9.33	$53.97	$9.20	$47.34	1.0	1.1
2. LTM PO 2	digitize maps of benthos	$ / m^2	$178.00	$853.00	$36.00	$110.00	4.9	7.8
3. Traditional PO 1	LPIM (individual)	$ / point	$0.35	$1.97	$1.52	$6.30	0.2	0.3
4. Traditional PO 1	BT (individual)	$ / m^2	$1.84	$9.52	$6.08	$25.20	0.3	0.4
5. Traditional PO 1	PCQT (individual)	$ / colony	$4.63	$25.92	$16.33	$68.46	0.3	0.4
6. Traditional PO 1	JUV (individual)	$ / m^2	$10.08	$58.68	$9.28	$34.15	1.1	1.7
7. Traditional PO 1	LPIM (all 4)	$ / point	$2.01	$12.63	$0.48	$1.85	4.2	6.8
8. Traditional PO 1	BT (all 4)	$ / m^2	$19.97	$125.95	$1.92	$7.41	10.4	17.0
9. Traditional PO 1	PCQT (all 4)	$ / colony	$6.42	$37.42	$4.77	$19.05	1.3	2.0
10. Traditional PO 1	JUV (all 4)	$ / m^2	$79.04	$501.45	$5.12	$16.36	15.4	30.6
11. Grounding PO 1, 2	area of damage	$ / m^2	$2.57	$15.91	$1.89	$7.40	1.4	2.2
12 ESA PO 1-3	size, condition, type	$ / colony	$22.96	$131.52	$12.26	$51.56	1.9	2.6

- Navy refers to costs derived for the Navy diver.

The second most important cost driver was the number of variables that need to be measured. In short, the more variables that one needs to measure, the more cost-effective the mosaic technique becomes. This point was most vividly illustrated in the traditional metrics demonstration. For example, it was shown that if one only wanted to measure percent cover using the line point intercept method, then it was 3–5 times more cost effective to use divers than to use mosaics (see the diver/mosaic cost ratio columns of the LPIM (individual) line 3 in Table 92.On the other hand, if one needed to measure not just percent cover, but also species richness with the belt transects, coral sizes and condition with the PCQT, and juvenile density, then it became 4–7 times more cost effective to use mosaics rather than divers to get the LPIM data, and up to 30 times more cost-effective to get the juvenile data (compare lines 3-6 with 7-10 of Table 92.

The third most important cost driver was the relative cost of lab vs. field time. Mosaics shift effort from the field to the lab. Therefore, the larger the differential in cost between field time and lab time the more cost-effective mosaics become. Notice that the diver/mosaic cost ratio was larger in all cases for the Navy diver than the RSMAS diver (Table 92). This is because field costs were greater for the Navy diver than for the RSMAS diver. The Navy diver traveled farther requiring extra airfare, stayed in hotels for some demonstrations when the RSMAS diver stayed at home, had higher per-diem rates, and also paid for four extra support divers not required for the RSMAS diver. The reason to point out these differences in field costs is not to critique one party or the other. These differences were all legitimate and realistic for projecting future costs. Rather, the reason to point out differences in cost between dive teams is to prove the point that the greater the field costs the more cost effective the mosaic technique will be. Here we illustrated this fact by using two divers with different costs to do the same work, but it will also be true for any given dive team working in a logistically benign location vs. a logistically expensive location. The locations of the demonstrations for this project were chosen in large part to minimize field costs. For example, the RSMAS divers had virtually no travel costs for the three demonstrations conducted in Florida. All of the costs Table 92 would increase if these demonstrations had been conducted with more expensive field costs, in, say, Guam or from a live-aboard dive ship as two hypothetical examples. The important point is that the mosaic costs would increase less when compared to the diver-based survey costs as field costs increase. Since field costs were very low for these demonstrations, one could therefore, view the diver/mosaic cost ratio in Table 92as minimum values.

In conclusion, the key points related to costs are as follows. Cost depends not just on technology but also on the specific application of the technology. The more one needs to do with the data, the more cost effective mosaics become. Conversely, with a mosaic, one can do more with the same dataset, which is why they are so effective for archival purposes. Finally, the more expensive the field work, the more cost effective mosaics become.

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8. IMPLEMENTATION ISSUES

8.1 POTENTIAL REGULATIONS THAT MAY APPLY TO THE USE OF THE TECHNOLOGY OR METHODOLOGY

8.1.1 Site-Specific Regulations

Any in-water field work done on a DoD facility or its submerged lands needs to have a NEPA analysis for compliance done on it (See Appendix D). Specific requirements will change based on what site you are at, but the minimum required would be a Categorical Exclusion (CATEX), usually *CATEx #(18): Studies, data, and information-gathering that involve no permanent physical change to the environment (e.g., topographic surveys, wetlands mapping, surveys for evaluating environmental damage, and engineering efforts to support environmental analyses* (SECNAVINST 5090.6A). It is best to contact the local environmental director of the area or facility you are working in and find out which NEPA compliance documents are requires and what specific permits or outside regulatory consultations are needed. For our project, compliance with OPNAVINST 5090.1C, SECNAVINST 5090.6A and CNO's Supplemental Environmental Planning Policy (SER N45/N4U732460), which are the basis of Navy NEPA compliance, were followed and specific during this project and a National Marine Sanctuary permit were acquired for our work done in the Florida Keys National Marine Sanctuary (Appendix C).

8.1.2 DoD Software Use Regulations

DADMS is the Department of the Navy (DON) Application & Database Management System. DADMS is the list of approved software for use on Navy networks. If the software you want to use is not listed, you must go through the proper IT/EIT procedure to get it added. Next, if your command is not listed as an "approved user" of said software, than you must follow the proper procedure to be added as an "approved user" before you can buy the software. See Appendix E for further regulations.

8.2 END-USER CONCERNS

The technology has not been certified nor demonstrated for night diving usage. Further studies need to be conducted to see how artificial light (stoplights or strobes) will affect the video and photo acquisition process, in addition to analyzing its effect on color and matching during the processing phase of mosaic creation.

The technology has not been certified nor demonstrated for use in the analysis of vertical surface, like pier/quay walls. Further studies need to be conducted to see if this technology can be mounted on an underwater autonomous vehicle in order to swim the required lawnmower pattern across the face of a pier wall and obtain a crisp mosaic. Automation of this technology would also be helpful to assess corals in areas that are of human health and safety concern to assess, like corals growing on unexploded ordinance or other buried mentions constituents.

The technology has not been certified nor demonstrated to work with Diver Propulsion Vehicles (DPVs). Further studies need to be conducted to see how the increased speed caused by the DPVs affects the image acquisition and post-video processing in order to make a non-blurry mosaic.

While the in-water component of acquiring the images is very easy to train, the processing component is not and requires many in-lab training hours and experience to master. Training in MATLAB® is highly suggested, and even though the technology transition staffs assigned to this project were not given that training nor afford the chance to take that level of training during this project, it is something that funding should be programmed for in future efforts.

8.3 RELEVANT PROCUREMENT ISSUES

8.3.1 Purchasing Concerns

Depending on how your organization regulates purchasing, several purchases using several different venues/processes may be required in order to procure the equipment. Within SSC PAC, it took ten credit card purchases ($3K max per purchase; for computer accessories/back-up laptop, camera accessories, software), one Simplified Acquisition (for the MATLAB® software), one Sole Source (major camera gear and accessories), and two NMCI FAST Track purchases (computer/monitors) to obtain all the components for both the field gear and the processing capability. All of these different processes/venues of purchase have associated fees that differ on an organization-by-organization basis, but the excess of time it takes to complete processes such as Sole Source and Simplified Acquisitions also needs to be factored in.

8.3.2 Network/IT Concerns

Even after you are approved to purchase software etc., each different DoD network has their own specific standards/qualifications/certifications that need to be obtained before the computer can be "plugged in" to the network (see Appendix E). It is best to contact the local IT or Computer Service Group lead at your facility to see what requirements need to be met, as the SSC PAC list if quite extensive (see Appendix E).

8.3.3 Camera Frame Concerns

The frame which holds together the SLR and video camera is a custom-made piece and requires a skilled machinist to design and fabricate the frame. It has to be custom-made and updated every time a different underwater housing is chosen. There is no one template or design that will work with every type of underwater housing available. Additional costing for the frame will vary accordingly.

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APPENDIX A
POINTS OF CONTACT

Table A-1. Points of contact.

Point Of Contact Name	Organization Name Address	Phone Fax E-mail	Role in Project
Mr. Bill Wild	SSC PACIFIC SPAWARSYSCEN PACIFIC 71751 53475 STROTHE RD RM 268 SAN DIEGO CA	(619) 553-2781 (619) 553-5404 bill.wild@navy.mil	Principal Investigator, Project Lead, Project Manager
Mrs. Cheryl Cooke	SSC PACIFIC SPAWARSYSCEN PACIFIC 71750 53475 STROTHE RD RM 268 SAN DIEGO CA	(619) 553-5313 (619) 553-5404 cheryl.kurtz@navy.mil	Contracts, Logistics, Reports
Dr. Pamela Reid	Rosenstiel School of Marine and Atmospheric Science University of Miami N260 Grosvenor North Miami, FL	(305) 421-4606 preid@rsmas.miami.edu	Project coordination at UM, expert in seafloor mapping and carbonate sedimentology
Dr. Arthur Gleason	Rosenstiel School of Marine and Atmospheric Science University of Miami N260 Grosvenor North Miami, FL	(305) 421-4810 art.gleason@miami.edu	Expert in remote sensing and sea floor mapping; software and field support, cost benefit analysis
Dr. Diego Lirman	Rosenstiel School of Marine and Atmospheric Science University of Miami Room 107 Glassell Building 4600 Rickenbacker Causeway	(305) 421-4168 d.lirman@umiami.edu	Expert in coral reef ecology- field work and technical reports
Dr. Brooke Gintert	Marine Geology and Geophysics Rosenstiel School of Marine and Atmospheric Science University of Miami N260 Grosvenor North Miami, FL	(305) 421-4812 ext #2 b.gintert@umiami.edu	Expert in coral reef ecology- field work, technical reports and software support.

Table A-1. Points of contact. (Continued)

Point Of Contact Name	Organization Name Address	Phone Fax E-mail	Role in Project
Dr. Nuno Gracias	University of Girona POLITÈCNICA 4 Campus Montilivi 17071 GIRONA GIRONA, SPAIN	ngracias@isr.ist.utl.pt	Expert in computer vision technology and underwater video mosaicing-software support, incorporate feedback from demonstrations, reports.
Meghan Gonzalez	Marine Geology and Geophysics Rosenstiel School of Marine and Atmospheric Science University of Miami N260 Grosvenor North Miami, FL	(305) 421-4664 mgonzalez@rsmas.miami.edu	Mosaic processing, coral reef field work and software support.
Mr. Don Marx Jr.	NAVFAC ESC SDS 2073 Tartar Avenue, Suite 110 Virginia Beach, VA 23461-1944	(757) 492-6882 donald.marx@navy.mil	Navy Diver/Marine Ecologist, SDS Transition Agent
Dr. Eric Hochberg	Bermuda Institute of Ocean Sciences 17 Biological Station St. George's GE 01 Bermuda	eric.hochberg@nova.edu	Coral Reef Biologist
Mr. Marc Ciminello	Naval Undersea Warfare Center Detachment AUTEC 801 Clematis Street West Palm Beach, FL	(561) 832-8566 mmarc.ciminello@autec.navy.mil	AUTEC liason
Mr. Thomas Szlyk	Naval Undersea Warfare Center Detachment AUTEC 801 Clematis Street West Palm Beach, FL	(561) 832-8566, Ext. 7249 mthomas.szlyk@autec.navy.mil	AUTEC liason
Dr. Dana Williams	NOAA Southeast Fisheries Science Center 75 Virginia Beach Dr. Miami, FL 33149	(305) 361-4200 Dana.Williams@noaa.gov	ESA liasion

APPENDIX B
MOSAICING CREATION MANUAL

The manual can be downloaded from https://www.serdp-estcp.org/content/download/9091/109015/file/RC-1333-FR.pdf.

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APPENDIX C
PERMITS REQUIRED FOR THE DEMONSTRATION SITES

Permits are shown on page C-2 to C-10.

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL OCEAN SERVICE

Florida Keys National Marine Sanctuary
33 East Quay Road
Key West, FL 33040

FLORIDA KEYS NATIONAL MARINE SANCTUARY
RESEARCH PERMIT

Permittee:
Dr. Dana Williams
University of Miami / RSMAS
75 Virginia Beach Drive
Miami, FL 33149

Permit Number: FKNMS-2010-130
Effective Date: December 1, 2010
Expiration Date: November 30, 2015

Project Title: Demographic Monitoring of *Acropora* species

This permit is issued for activities in accordance with the National Marine Sanctuaries Act (NMSA), 16 USC §1431 *et seq.*, and regulations thereunder (15 CFR Part 922). All activities must be conducted in accordance with those regulations and law. No activity prohibited in 15 CFR Part 922 is allowed except as specified in the activity description below.

Subject to the terms and conditions of this permit, the National Oceanic and Atmospheric Administration (NOAA), Office of National Marine Sanctuaries (ONMS) hereby authorizes the permittee listed above to conduct research activities within Florida Keys National Marine Sanctuary (FKNMS or sanctuary). All activities are to be conducted in accordance with this permit and the permit application received October 17, 2010. The permit application is incorporated into this permit and made a part hereof; provided, however, that if there are any conflicts between the permit application and the terms and conditions of this permit, the terms and conditions of this permit shall be controlling.

Permitted Activity Description:
The following activities are authorized by this permit:

1. Deployment of marker stakes, aluminum marker tags, nails, epoxy, light/temperature meters, and other materials on the sea floor in areas of non-living bottom substrate.

2. Temporary deployment of scientific equipment on the sea floor, including transect lines, weighted markers, and other materials.

3. Incidental touching and contact with elkhorn coral colonies, *Acropora palmata*, for the purposes of collecting measurements or monitoring data.

No further violation of sanctuary regulations is allowed.

3. All materials and markers deployed on the sea floor must be removed upon permit expiration by the permittee.

4. The permittee must provide daily advance notification to Florida Fish and Wildlife Conservation Commission (FWC) Law Enforcement Dispatch and the Upper Region FKNMS office for all permitted activities occurring within any SPA. The permit number, contact person, vessel type, vessel registration number, and location of the day's activities must be reported prior to conducting activities as follows:
   A. Notify FWC Dispatch in Marathon at (305) 289-2320 or 888-404-3922;
   B. Notify John Halas at (305) 852-7717 x34.

5. A NOAA research flag must be flown from all vessels operating under this permit while conducting permitted activities in any SPA. Contact Scott Donahue at (305) 809-4700 x239 or Scott.Donahue@noaa.gov for flag issuance. The flag must be returned when the permit expires.

6. The permittee must submit the following reports in the time frames given:
   A. Interim Report, due June 1, 2013.
   B. Final Report, due 30 days after the permit expires (or 30 days prior if a renewal is desired).

   Each report shall consist of a 1-2 page summary of activities conducted under this permit that follows the attached permit report guidelines. These reports shall be submitted to Scott Donahue (Scott.Donahue@noaa.gov), FKNMS Associate Science Coordinator, and Joanne Delaney (Joanne.Delaney@noaa.gov), FKNMS Permit Coordinator.

7. Any scientific publications and/or reports resulting from activities conducted under the authority of this permit must include the notation that the activity was conducted under permit number FKNMS-2010-130. Additionally, the permittee and her respective institution(s) are required to acknowledge during any media coverage (press releases, video/photo, or other means) that research activities occurred within the FKNMS and under permit. Boilerplate language on the sanctuary is available by request; contact Karrie Carnes at Karrie.Carnes@noaa.gov.

8. Prior to *Acropora palmata* monitoring activities, the permittee shall contact Dr. David Palandro of Florida Fish and Wildlife Conservation Commission (FWC) at (727) 896-8626, ext. 3056 for information on assisting the FWC with benthic habitat characterization data in terms of dominant cover at a particular location (i.e., live stony coral, submerged aquatic, covered hardbottom, bare hardbottom, unconsolidated sediment).

General Terms and Conditions:

1. Within 30 (thirty) days of the date of issuance, the permittee must sign and date this permit for it to be considered valid. Once signed, the permittee must send copies, via mail or email, to the following individuals:

10. Any publications and/or reports resulting from activities conducted under the authority of this permit must include the notation that the activity was conducted under National Marine Sanctuary Permit FKNMS-2010-130 and be sent to the ONMS officials listed in general condition number 1.

11. This permit does not relieve the permittee of responsibility to comply with all other federal, state and local laws and regulations, and this permit is not valid until all other necessary permits, authorizations, and approvals are obtained. Particularly, this permit does not allow disturbance of marine mammals or seabirds protected under provisions of the Endangered Species Act, Marine Mammal Protection Act, or Migratory Bird Treaty Act. Authorization for incidental or direct harassment of species protected by these acts must be secured from the U.S. Fish and Wildlife Service and/or NOAA Fisheries, depending upon the species affected.

12. The permittee shall indemnify and hold harmless the Office of National Marine Sanctuaries, NOAA, the Department of Commerce and the United States for and against any claims arising from the conduct of any permitted activities.

13. Any question of interpretation of any term or condition of this permit will be resolved by NOAA.

Your signature below, as permittee, indicates that you accept and agree to comply with all terms and conditions of this permit. This permit becomes valid when you, the permittee, countersign and date below. Please note that the expiration date on this permit is already set and will not be extended by a delay in your signing.

11/23/2010

Dr. Dana Williams
University of Miami / RSMAS

Date

November 16, 2010

Sean Morton
Superintendent
Florida Keys National Marine Sanctuary

Date

1 document attached.

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL OCEAN SERVICE

Florida Keys National Marine Sanctuary
33 East Quay Road
Key West, FL 33040

November 4, 2011

Mr. William Wild
Space and Naval Warfare Systems Center Pacific
53475 Strothe Rd.
Code 71751, Bldg. 111, Bayside
San Diego, CA 92152-6310

Dear Mr. Wild:

The National Oceanic and Atmospheric Administration, Office of National Marine Sanctuaries (ONMS) has approved the issuance of permit number FKNMS-2011-131 to conduct activities within Florida Keys National Marine Sanctuary (sanctuary) for research purposes. Activities are to be conducted in accordance with the permit application and all supporting materials submitted to the sanctuary, and the terms and conditions of permit number FKNMS-2011-131 (enclosed).

This permit is not valid until signed and returned to the ONMS. Retain one signed copy and carry it with you while conducting the permitted activities. Additional copies must be signed and returned, by either mail or email, to the following individuals within 30 days of issuance and before commencing any activity authorized by this permit:

Scott Donahue
Associate Science Coordinator
Florida Keys National Marine Sanctuary
33 East Quay Road
Key West, FL 33040
Scott.Donahue@noaa.gov

National Permit Coordinator
NOAA Office of National Marine Sanctuaries
1305 East-West Highway (N/ORM6)
SSMC4, 11th Floor
Silver Spring, MD 20910
nmspermits@noaa.gov

Your permit contains specific terms, conditions and reporting requirements. Review them closely and fully comply with them while undertaking permitted activities.

If you have any questions, please contact Joanne Delaney at Joanne.Delaney@noaa.gov. Thank you for your continued cooperation with the ONMS.

Sincerely,

Sean Morton
Superintendent

Enclosure

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL OCEAN SERVICE
Florida Keys National Marine Sanctuary
33 East Quay Road
Key West, FL 33040

FLORIDA KEYS NATIONAL MARINE SANCTUARY RESEARCH PERMIT

Permittee:
Mr. William Wild
Space and Naval Warfare Systems Center Pacific
53475 Strothe Rd.
Code 71751, Bldg. 111, Bayside
San Diego, CA 92152-6310

Permit Number: FKNMS-2011-131
Effective Date: November 4, 2011
Expiration Date: November 3, 2012

Project Title: High Resolution Landscape (2-D) Mosaics for Improved Coral Reef Monitoring Capability

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This permit is issued for activities in accordance with the National Marine Sanctuaries Act (NMSA), 16 USC §1431 *et seq.*, and regulations thereunder (15 CFR Part 922). All activities must be conducted in accordance with those regulations and law. No activity prohibited in 15 CFR Part 922 is allowed except as specified in the activity description below.

Subject to the terms and conditions of this permit, the National Oceanic and Atmospheric Administration (NOAA), Office of National Marine Sanctuaries (ONMS) hereby authorizes the permittee listed above to conduct research activities within Florida Keys National Marine Sanctuary (FKNMS or sanctuary). All activities are to be conducted in accordance with this permit and the permit application received September 27, 2011. The permit application is incorporated into this permit and made a part hereof; provided, however, that if there are any conflicts between the permit application and the terms and conditions of this permit, the terms and conditions of this permit shall be controlling.

Permitted Activity Description:
The following activities are authorized by this permit:

1. Temporary deployment of scientific monitoring equipment on the sea floor, including transects, quadrats, meter sticks, tiles, markers, and other materials.

2. Incidental contact with coral colonies while undertaking measurements and monitoring.

No further violation of sanctuary regulations is allowed.

Permitted Activity Location:
The permitted activity is allowed only in the following locations:

Truman Harbor (Key West), Hawk Channel patch reefs southwest of Key West, and along the offshore reef tract between Eastern Dry Rocks and Western Sambo reefs.

Special Terms and Conditions:

1. No activities are allowed in any Sanctuary Preservation Area, Special Use (Research Only) Area, or Ecological Reserve.

2. All materials deployed on the sea floor must be removed upon the conclusion of each monitoring event.

3. The permittee must submit a final report of activities thirty (30) days after the permit expires or (30) days prior if a renewal is desired. The report shall consist of a 1-2 page summary of activities conducted under this permit that follows the attached permit report guidelines. The report shall be submitted to: Scott Donahue (Scott.Donahue@noaa.gov), FKNMS Associate Science Coordinator, and Joanne Delaney (Joanne.Delaney@noaa.gov), FKNMS Permit Coordinator.

4. Any scientific publications and/or reports resulting from activities conducted under the authority of this permit must include the notation that the activity was conducted under permit number FKNMS-2011-131. Additionally, the permittee and his respective institution(s) are required to acknowledge during any media coverage (press releases, video/photo, or other means) that research activities occurred within the FKNMS and under permit. Boilerplate language on the sanctuary is available by request; contact Karrie Carnes at Karrie.Carnes@noaa.gov.

General Terms and Conditions:

1. Within 30 (thirty) days of the date of issuance, the permittee must sign and date this permit for it to be considered valid. Once signed, the permittee must send copies, via mail or email, to the following individuals:

Scott Donahue
Associate Science Coordinator
Florida Keys National Marine Sanctuary
33 East Quay Road
Key West, FL 33040
Scott.Donahue@noaa.gov

National Permit Coordinator
NOAA Office of National Marine Sanctuaries
1305 East-West Highway (N/ORM6)
SSMC4, 11th Floor
Silver Spring, MD 20910
nmspermits@noaa.gov

2. It is a violation of this permit to conduct any activity authorized by this permit prior to the ONMS having received a copy signed by the permittee.

3. This permit may only be amended by the ONMS. The permittee may not change or amend any part of this permit at any time. The terms of the permit must be accepted in full, without revision; otherwise, the permittee must return the permit to the sanctuary office unsigned with a written explanation for its rejection. Amendments to this permit must be requested in the same manner the original request was made.

4. All persons participating in the permitted activity must be under the supervision of the permittee, and the permittee is responsible for any violation of this permit, the NMSA, and sanctuary regulations for activities conducted under, or in junction with, this permit. The permittee must assure that all persons performing activities under this permit are fully aware of the conditions herein.

5. This permit is non-transferable and must be carried by the permittee at all times while engaging in any activity authorized by this permit.

6. This permit may be suspended, revoked, or modified for violation of the terms and conditions of this permit, the regulations at 15 CFR Part 922, the NMSA, or for other good cause. Such action will be communicated in writing to the applicant or permittee, and will set forth the reason(s) for the action taken.

7. This permit may be suspended, revoked or modified if requirements from previous ONMS permits or authorizations issued to the permittee are not fulfilled by their due date.

8. Permit applications for any future activities in the sanctuary or any other sanctuary in the system by the permittee might not be considered until all requirements from this permit are fulfilled.

9. This permit does not authorize the conduct of any activity prohibited by 15 CFR § 922, other than those specifically described in the "Permitted Activity Description" section of this permit. If the permittee or any person acting under the permittee's supervision conducts, or causes to be conducted, any activity in the sanctuary not in accordance with the terms and conditions set forth in this permit, or who otherwise violates such terms and conditions, the permittee may be subject to civil penalties, forfeiture, costs, and all other remedies under the NMSA and its implementing regulations at 15 CFR Part 922.

10. Any publications and/or reports resulting from activities conducted under the authority of this permit must include the notation that the activity was conducted under National Marine Sanctuary Permit FKNMS-2011-131 and be sent to the ONMS officials listed in general condition number 1.

11. This permit does not relieve the permittee of responsibility to comply with all other federal, state and local laws and regulations, and this permit is not valid until all other necessary permits, authorizations, and approvals are obtained. Particularly, this permit does not allow disturbance of marine mammals or seabirds protected under provisions of the Endangered Species Act, Marine Mammal Protection Act, or Migratory Bird Treaty Act. Authorization for incidental or direct harassment of species protected by these acts must be secured from the U.S. Fish and Wildlife Service and/or NOAA Fisheries, depending upon the species affected.

12. The permittee shall indemnify and hold harmless the Office of National Marine Sanctuaries, NOAA, the Department of Commerce and the United States for and against any claims arising from the conduct of any permitted activities.

13. Any question of interpretation of any term or condition of this permit will be resolved by NOAA.

Your signature below, as permittee, indicates that you accept and agree to comply with all terms and conditions of this permit. This permit becomes valid when you, the permittee, countersign and date below. Please note that the expiration date on this permit is already set and will not be extended by a delay in your signing.

William Wild 11/4/11

Mr. William Wild
Space and Naval Warfare Systems Center Pacific

Date

November 4, 2011

Sean Morton
Superintendent
Florida Keys National Marine Sanctuary

Date

1 document attached.

FLORIDA KEYS NATIONAL MARINE SANCTUARY
RESEARCH & EDUCATION PERMITS

GUIDELINES FOR SUBMITTING PERMIT REPORTS
Interim Report & Final Report

Please submit all the requested information electronically (MS Word, rich text format, or PDF) to Scott Donahue (Scott.Donahue@noaa.gov) and Joanne Delaney (Joanne.Delaney@noaa.gov).

Permit number:
Date:
Permittee name and contact information (affiliation, address, phone, fax, e-mail):

Type of report: (contents are the same)
☐ Interim report
☐ Final report

Please provide a 1-2 page (max.) project summary, which includes topics listed below. Please indicate if any of the information contained in your project summary **should not be made available to the public** in Sanctuary research summaries or other literature.

- Goal(s) of project
- Significance of project and connection to Sanctuary management issues
- Hypotheses (if applicable) & methods (brief description)
- Results/findings to date
- Table, graph, photos as appropriate
- List of publications resulting from permitted activities

Additionally, if permitted activities included collection of organisms, provide the following information (list, table or chart is acceptable):

For stony coral and/or sea fan collections:	For non-coral species collections (fish, regulated invertebrates, algae, etc.):
• Dates of collection • Species • Quantity • Size(s) • Method of collection • Location of collection (GPS coordinates) • Fate of all specimens collected • Mitigation completed, if any	• Dates of collection • Location of collections (GPS coordinates) • Names of organisms and approximate quantity collected

Please briefly describe any other permitted activities conducted (date and description of activity performed) that were not mentioned above (list, table or chart).

Please briefly describe any deviations from permitted activities.

APPENDIX D
ABBREVIATED LIST OF ENVIRONMENTAL LAWS/REGULATIONS CONCERNING DOD ACTIONS

This section lists examples of the types of laws/regulations that have to be address for projects occurring within the Navy concerning impacts of Navy actions on coral reefs and the monitoring of these reefs. Table D-1 shows laws and policies, responsible agency, and compliance guidelines.

Table D-1. Table showing laws and policies, responsible agency, and compliance guidelines.

Laws and Policies (as applicable)	Responsible Agency	What is Needed/Compliance Status (as applicable)
National Environmental Policy Act (NEPA) (42 USC § 4321 et seq.) DoN Procedures for Implementing NEPA (32 CFR 775)	U.S. Navy	Analysis and documentation prepared in accordance with regulations and U.S. Navy procedures (including OPNAVINST 5090.1C & SSCPACINST 5090.2).
Clean Water Act (§§ 401-402 and 404, 33 USC § 1251 et seq.)	U.S. EPA/ U.S. Army Corps of Engineers (ACOE)	Water quality certification application. Coordinated through respective Navy Region; signature by installation. Concurrence by state agency.
Rivers and Harbors Act (33 USC §403)	U.S. ACOE	In-water construction and associated issues; permit application. Coordinated through respective Navy Region; signed by installation. Permit by USACE.
Endangered Species Act (ESA) (16 USC §1531 et seq.)	U.S. Navy, U.S. Fish and Wildlife Service (U.S. FWS), National Marine Fisheries Service (NMFS)	Determination of effect and informal/formal consultation as appropriate through OPNAV N45/respective Region. Obtain concurrence on findings from USFWS/NMFS.
Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA) (16 USC §§1801-1802)	NMFS	Determination of effect on and informal/formal consultation as appropriate through OPNAV N45/respective Region. Obtain concurrence on findings from NMFS.
The Sikes Act Improvement Act (16 USC 670 et. seq.)	Secretary of Defense, in cooperation with the U.S. FWS and State fish and wildlife agencies	Requires the preparation of Integrated Natural Resource Management Plans (INRMPs) to guide natural resource management on DoD installations with significant protected environmental resources.

Table D-2. Table showing laws and policies, responsible agency, and compliance guidelines. (Continued)

Laws and Policies (as applicable)	Responsible Agency	What is Needed/Compliance Status (as applicable)
DoD instruction 4715.3	Secretary of Defense, in cooperation with the U.S. FWS and State fish and wildlife agencies	Requires an ecosystem-based approach to natural resources management. In addition to the Sikes Act, DoD must comply with the Endangered Species Act (ESA; 7 USC § 136, 16 USC § 1531 et seq.) which requires that agency actions not jeopardize the continued existence of species listed under the ESA and directs agencies to use their authority to conserve those species.
Coral Reef Conservation Act	National Oceanic and Atmospheric Administration (NOAA)	Aims to preserve and coral reef ecosystems, to effectively manage those ecosystems with the aid of scientific research, and to fund programs consistent with those goals.
EO 13158 Marine Protected Areas (65 Federal Register 34909)	U.S. Navy	Determination of effect. Coordination/permit from respective management agency through respective Navy Region. {This has not been determined yet if Navy use areas are included.}
National Marine Sanctuaries Act (NMSA) (16 USC §1431 et seq.)	NOAA	Determination of effect. Coordination/permit from respective management agency through respective Navy Region. Ocean dumping of dredged material addressed by USACE permit process.
EO 11990 Protection of Wetlands (42 Federal Register 26961)	U.S. Navy	Determination of effect. Wetlands fill addressed by USACE permit process.
EO 13089 Coral Reef Protection (63 Federal Register 32701)	U.S. Navy	Determination of effect.
E.O. 13547 Stewardship of the Ocean, our Coasts, and the Great Lakes, require assessment of aquatic resources in proximity to project sites; and	U.S. Navy	Determination of effect.
E.O. 12114 Environmental Effects Abroad of Major Federal Actions	U.S. Navy	Determination of effect.

APPENDIX E
ABBREVIATED LIST OF
DOD/DON/SSC PAC IT STANDARDS

Computers used to process the mosaics and transfer any data acquired from the mosaics must be kept in compliance with all DoD, DoN, SSC and NAVFAC government standards, including, but not limited to:

DOD-LEVEL DIRECTIVES/POLICIES:

- DODD 8000.1 MANAGEMENT OF DOD INFORMATION RESOURCES AND IT
- DODD 8100.02 USE OF COMMERCIAL WIRELESS DEVICES, SERVICES, AND TECHNOLOGIES IN THE DEPARTMENT OF DEFENSE GLOBAL INFORMATION GRID
- DODD 8500.01E IA
- DOD O-8530.1 COMPUTER NETWORK DEFENSE
- DODD 8570.01 INFORMATION ASSURANCE TRAINING, CERTIFICATION, AND WORKFORCE MANAGEMENT
- DODI 5200.40 DOD INFORMATION TECHNOLOGY SECURITY CERTIFICATION AND ACCREDITATION (C&A) PROCESS (DITSCAP)
- DODI 8500.2 INFORMATION ASSURANCE IMPLEMENTATION
- DODI 8510.01 DOD INFORMATION ASSURANCE CERTIFICATION AND ACCREDITATION PROCESS (DIACAP)
- DODI O-8530.2 SUPPORT TO COMPUTER NETWORK DEFENSE
- DODI 8551.1 PORTS, PROTOCOLS, AND SERVICES (PPSM)
- DODI 8552.01 USE OF MOBILE CODE TECHNOLOGIES IN DOD INFORMATION SYSTEMS
- DOD 5200.1-R INFORMATION SECURITY PROGRAM
- DOD 5220.22-M- NATIONAL INDUSTRIAL SECURITY PROGRAM OPERATING MANUAL
- DOD 8510.1-M DOD INFORMATION TECHNOLOGY SECURITY CERTIFICATION AND ACCREDITATION PROCESS (DITSCAP) APPLICATION MANUAL
- DOD 8570.01-M INFORMATION ASSURANCE WORKFORCE IMPROVEMENT PROGRAM

DON-LEVEL DIRECTIVES/POLICIES (CONTINUED):

- SECNAV 2075.1 DON USE OF COMMERCIAL WIRELESS LOCAL AREA NETWORK (WLAN) DEVICES, SERVICES, AND TECHNOLOGIES
- SECNAV 5239.1 DEPARTMENT OF THE NAVY INFORMATION ASSURANCE MANUAL
- SECNAV 5239.3A DEPARTMENT OF THE NAVY INFORMATION ASSURANCE POLICY
- SECNAV 5510.36A DON INFORMATION SECURITY PROGRAM INSTRUCTION
- OPNAV 2201.2 NAVY AND MARINE CORPS COMPUTER NETWORK INCIDENT RESPONSE
- OPNAV 3501.1A DEPARTMENT OF THE NAVY CRITICAL INFRASTRUCTURE PROTECTION (CIP)
- OPNAV 5239.1B NAVY INFORMATION ASSURANCE PROGRAM
- CTO 07-12: DEPLOYMENT OF THE HOST BASED SECURITY SYSTEM (HBSS)
- CTO 10-25B: PROTECTION OF CLASSIFIED INFORMATION ON DON INFORMATION SYSTEMS
- NTD 03-11: DISPOSAL OF NAVY COMPUTER HARD DRIVES
- NTD 04-07: USE OF REMOVABLE STORAGE MEDIA
- NTD 06-10: PASSWORD REQUIREMENTS
- NTD 09-11: FILE TRANSFER BETWEEN SECURITY DOMAINS
- NTD 11-11: FY-12 ANNUAL IA TRAINING
- NTD 12-08: DISPOSITION OF NAVY COMPUTER HARD DRIVES
- 031648Z- ACCEPTABLE USE POLICY FOR DEPARTMENT OF THE NAVY (DON) INFORMAT ION TECHNOLOGY (IT)-OCT 11
- NETWARCOM LTR 5239 SER N64/110 OF 18 NOV 02- NMCI S&T USER AGREEMENT SCIENCE AND TECHNOLOGY USERS
- SSC-LEVEL DIRECTIVES/POLICIES:
- SSCPACIA SOP-12 (V.1.0)- NON-SSC OWNED COMPUTER SYSTEMS REQUEST (EXTERNAL)
- SSCPACIA SOP-20 (V.1.0)- INFORMATION-SYSTEM AND MEDIA PROTECTION (EXTERNAL)
- SSCPACIA SOP-22 (V.1.0)- USB STORAGE DEVICES (EXTERNAL)
- SSC PACIFIC IA MANUAL V.2.2 (DTD 25 JULY 2011).

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6. AUTHORS

Cheryl Ann Cooke
Wild, William
NIWC Pacific

R. Pamela Reid
University of Miami

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

NIWC Pacific
53560 Hull Street
San Diego, CA 92152–5001

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14. ABSTRACT

The overall objective of ESTCP project RC-201021 was to demonstrate the utility of underwater image mosaics for coral reef monitoring. The report includes solutions that were part of the tests team plan to overcome the problem of efficiently mapping and monitoring coral reef resources.This report is relevant to the Department of Defence (DoD) for several reasons. First, at least 46 US military facilities have adjacent coral reef sites. Second, federal policy mandates that DoD characterize, assess, and monitor underwater benthic communities at these sites to ensure that DoD operations do not lead to natural resource degradation. Third, coral reef ecosystems worldwide are presently threatened by increasing levels of both human and natural disturbance. Thus, monitoring efforts that can efficiently provide data that will help distinguish between reef degradation that can be directly attributed to DoD activities versus those that that are correlated with region-wide decline are of primary concern.

15. SUBJECT TERMS

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