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Appendix J
Supplemental Aircraft Carrier Marine Surveys

1. Assessment of Stony Corals Between Orote Point and Sumay Cove Apra Harbor, Guam. April 2006

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ASSESSMENT OF STONY CORALS BETWEEN

OROTE POINT AND SUMAY COVE

APRA HARBOR, GUAM

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EXECUTIVE SUMMARY

Kilo Wharf is a 400-foot (122 meters [m]) long ammunition pier located along the Orote Peninsula in Apra Harbor, Guam. The wharf is part of the Apra Harbor Naval Complex (Figure 1). In order to accommodate a new class of supply vessel, the wharf must be expanded. An EIS is being prepared to address the potential environmental concerns. This report is intended to provide supplemental information in support of the EIS process.

Guam is located in the tropical western Pacific and is the southern most and largest island in the Marianas Archipelago. Guam falls within the marine biogeographic region known as the Indo-Pacific. This region is widely recognized as supporting the world's most diverse assemblage of corals, fishes and other associated coral reef organisms.

In 2004 detailed quantitative studies of the marine community around Kilo Wharf were completed and the area was divided into ten distinct habitats (Figure 2). The present study was performed to provide comparable detail for the remaining portions of the peninsula fronting Apra Harbor.

Our findings are very briefly summarized below:

- Reef building stony corals are the dominant benthic organisms in the 3 to 100 foot (1 – 31 m) depth zone between Orote Point and the Sumay Cove Entrance Channel.
- *Porites rus* is the dominant coral species within this entire area, although its dominance is less pronounced at the eastern and western ends of the study area and at depths greater than 70 feet (22 m).
- The reef between Orote Point and the Sumay Cove Entrance Channel is biologically significant based on six global standards: 1) the percentage of the sea floor covered by live coral, 2 – 4) the size frequency distribution, growth forms and apparent health of the corals, 5 – 6) the physical complexity and rugosity of the reef.
- The fringing reef and fringing reef slope areas adjacent to Kilo Wharf are not substantially different than the fringing reef and fringing reef slope along the other portions of the peninsula facing Apra Harbor.
- Two species of sea turtles have been sighted within the study area, the Endangered Hawksbill turtle and the Threatened Green sea turtle.
- One listed marine fish Species of Concern, the Napoleon (Humphead) wrasse (*Cheilinus undulatus*) was observed.
- All of Apra Harbor has been designated Essential Fish Habitat (EFH); however, none of Orote Peninsula has been designated as EFH Habitat Area of Particular Concern (HAPC). There are four criteria for designation of HAPC, only one of the criteria needs to be met for designation. Most of the peninsula meets two of the four criteria for designation as HAPC.

The marine environment within the 3 to 100 foot (1 – 31 m) depth range, between Orote Point and the Sumay Cove entrance channel shows a high degree of uniformity. There are no substantive differences in the ecological values provided by the coral reef areas adjacent to Kilo Wharf and the ecological values provided by the remainder of the peninsula. All of these locations are significant from the perspective of corals, coral reefs and associated organisms.

I. Introduction

This document is presented in six sections: Introduction, Objectives, Methods, Results, Discussion and Summary. The Introduction is subdivided into three components: Project Background, Biological Setting and Recent Navy Surveys.

A. Project Background

Kilo Wharf is a 400-foot (122 meters [m]) long ammunition pier located along the Orote Peninsula in Apra Harbor, Guam (Figure 1). The wharf is operated by the U.S. Navy and is part of the Apra Harbor Naval Complex. The present wharf was originally completed in 1989. In order to accommodate a new class of supply vessel, the wharf must be expanded to a total length of 800-feet (244 m). An EIS is being prepared to address the potential environmental concerns of this project. This report is intended to provide supplemental information in support of the EIS process.

B. General Biological Setting

Guam is located in the tropical western Pacific and is the southern most and largest island in the Marianas Archipelago. Guam falls within the marine biogeographic region known as the Indo-Pacific. This region is widely recognized as supporting the world's most diverse assemblage of corals, fishes and other associated coral reef organisms. Guam's marine flora and fauna is less diverse than some other Indo-Pacific areas, such as Indonesia, Malaysia and Diego Garcia; however, Guam is more diverse than any areas in the Caribbean or Hawaii.

Apra Harbor is located mid-way along Guam's western coast (Figure 1). It is the only deep lagoon in the Mariana Archipelago. Although the harbor has been dramatically altered since the liberation of Guam during WWII, it "…holds a vibrant and thriving marine community, including well-developed reefs with some of the highest coral cover on Guam, and a diverse biota of algae, invertebrates and fish. In this regard the harbor is unlike most other major ports, which tend to become greatly degraded for marine life." (Paulay et al. 1997).

All corals belong to the Phylum Cnidaria (Coelenterata). In addition to corals, this phylum includes many other organisms, such as jellyfish and hydroids. The physical framework of coral reefs is comprised of many different coral taxa, as well as many non-coral groups such as algae, foraminifera, sponges and mollusks.

The primary coral groups are: **Class Hydrozoa** (Orders Milleporina [fire corals], Stylasterina [lace corals]), **Class Anthozoa** (**Sub Class Zooantharia**, Orders Scleractinia [reef and non-reef building stony corals], Antipatharia [black corals], **Sub Class Octocorallia**, Orders Coenothecalia [blue coral], Alcyonacea [soft corals] and Gorgonacea [sea fans]). Members of each of these groups are present along the Orote

Peninsula; however, the reef building forms of the Order Scleractinia are overwhelmingly dominant, followed by soft corals of the Order Alcyonacea. The term dominance, as used here, is based upon the frequency of occurrence and area of the sea floor occupied.

Paulay et al. (1997) conducted studies on the biodiversity of Apra Harbor. He divided the northern side of the Orote Peninsula into two components, the first extending from Orote Point to San Luis Point, and the second from San Luis Point to the mouth of Inner Apra Harbor. Pauley et al. (1997) characterized these two components as follows:

> (First) "*This area has a well developed fringing reef and fringing reef slope that changes in character from mid-lagoonal to oceanic, westward. Much of the slope is dominated by Porites rus, the dominant scleractinian coral in the harbor, but a diversity of other corals, sponges, soft corals, and other taxa are also common. The fringing reefs and reef slopes harbor diverse marine communities, but no species are known only from this zone on Guam.*"

> (Second) "*Artificial shores, created as landfill during harbor construction line this area of the harbor. After a narrow shelf at 2 – 3 m depth, the reef slopes quickly, giving way to a silty Halimeda sand slope with isolated coral patches below 10-20 m. Although, there is abundant debris in this area, the reef community is diverse and thriving. The reef slope is dominated by Porites rus, but also has numerous other corals….*"

In the Marine Research Consultants (MRC) report of 2005(a), the shoreline between Orote Point and Gabgab Beach is characterized as consisting of four zones (back-reef flat, reef crest, fore-reef terrace and fore-reef slope). The back-reef flat extends from the shoreline seaward to the reef crest. The back-reef flat is often referred to as the fossilized reef platform by other authors; it is generally less than 3 feet (1 m) deep along the Orote Peninsula and is routinely subject to strong wave and surge activity. The reef crest is at the outer edge of the back-reef flat and generally ranges from 2 to 5 feet (.7 – 1.5 m) deep and is followed by the fore-reef terrace (ranging from about 3 to 15 feet (1– 5 m). The fore-reef terrace supports diverse and extensive coral growth. The fore-reef slope generally starts at a depth of about 13 feet (4 m), and plunges at a 45 to 90^o angle to a depth of 65 to 80 feet (20 – 25 m).

Smith (2004a) characterized Paulay's fringing reef and fringing reef slopes and MRC's fore-reef terrace and fore-reef slope as being an extremely complex reef, with a very high rugosity factor and coral cover reaching 100% for extensive stretches of the peninsula. Along most of the peninsula coral cover below 70 feet (22 m) diminishes quickly and the reef slope / fore-reef slope terminates around 80 feet (25 m) in a gently sloping plane of unconsolidated sediment that extends to depths of up to 160 feet (50 m).

C. Recent Navy Surveys

During November 2003 an initial reconnaissance level marine ecological field survey was performed by the senior author. This survey confirmed that significant coral reefs and associated marine natural resources were present in close proximity to Kilo Wharf. As a result of these initial observations a number of additional studies have been conducted by the Navy, to more precisely identify and delineate marine resources and conditions in and adjacent to the proposed project area. The studies performed include the following:

- *March 2004 Ecological Assessment of the Marine Community in the Vicinity of Kilo Wharf, Apra Harbor, Guam* by Stephen H. Smith June 2004a (Nomenclature Revised September 2005)
- *Field Report of Supplemental Reconnaissance Level Observations in the Vicinity of Kilo Wharf, Apra Harbor, Guam November 3rd and 4th, 2004* by Stephen H. Smith November 30, 2004b
- *Reconnaissance Survey of the Marine Environment Outer Apra Harbor, Guam Characterization of Benthic Habitat* by Marine Research Consultants, September, 2005a
- *Reconnaissance Surveys of the Marine Environment Outer Apra Harbor, Guam Baseline Assessment of Water Chemistry* by Marine Research Consultants, September 2005b
- *Current Measurement and Numerical Circulation Model Study for Kilo Wharf Improvements Apra Harbor, Guam* by Sea Engineering April, 2005 (Draft).

In addition to these studies, the Navy facilitated a survey by the USFWS, NOAA Fisheries and Guam Department of Aquatic and Wildlife Resources in January 2006. The results of that survey will be presented in the form of a habitat equivalency analysis. At the time of this writing, that report was not available.

II. Objectives

Quantitative and qualitative surveys completed by Smith (2004a, 2004b) and MRC (2005a) show that coral reefs, with up to 100% live coral cover occupy much of the sea floor in the 20 to 70 foot (6 – 22 m) depth range between Orote Point and Gabgab Beach. These scleractinian (stony coral) reefs determine, more than any other group, the ecological functions and values of this coastal area. During the first 2004 survey quantitative data was obtained on corals for the area extending 800 feet (244 m) to the western and eastern sides of Kilo Wharf and 800 feet (244 m) directly offshore. This data was used to delineate 10 habitat types or Zones (Figure 2).

The objective of the present study was to quantitatively assess the fringing reef and fringing reef slope for the remaining portions of the peninsula between Orote Point and the eastern side of the Sumay Cove entrance channel. This additional quantitative data could then be used to compare the reefs adjacent to Kilo Wharf, with those along the remainder of the peninsula.

The data from this investigation is intended to help clarify the relative ecological value of the Zones adjacent to Kilo Wharf with the remainder of the peninsula between Orote Point and Sumay Cove. In addition, qualitative observations were made relative to sea turtles, sea turtle forage, sea turtle resting habitat, fish species of concern, and Essential Fish Habitat (EFH) Habitat Areas of Particular Concern (HAPC).

III. Methods

A. Diving

Open circuit, compressed air scuba dives were utilized to obtain qualitative and quantitative data on corals and the other marine natural resources addressed in this project. Two Navy marine ecologists (the authors) conducted the underwater surveys; one or both of the marine ecologists participated in every dive. During the October 2005 surveys Explosive Ordnance Disposal Detachment Marianas under the command of LT Ken Kleinschnittger provided support. The February 2006 surveys were supported by the COMNAVMARIANAS Dive Locker under the command of Master Diver BMCS (MDV/DSW/SW) Daniel A. Horvath. The other divers, participating in the two surveys were: BMC(EOD/DSW/SW/AW) John Hatcher, IT2(EOD/SW/AW) Krishna Hayden, BMC(EOD/SW/AW) Jed Ray Anderson, HMC(DSW/FMF/IDC) William F. Montfort, ENC(DSW/SW) Kevin T. Credle, QM1(SW/DV) Geoffery Ives, HM1(DSW/FMF) Shawn J. Kern, MM2(DSW) Jad Graves, HT2(DV) Joshua E. Amberger, EN3(DV) Patrick A. Senecal, QM2(DV) Steven G. Lubitz and EN2(DV) Andrew J. Strause.

B. Coral Survey Methods

Surveys were conducted using the Point Centered Quarter Transect (PCQT) method, the method used during the 2003 and 2004 Apra Harbor coral surveys (Paulay et al., 2003; Smith, 2004a). This technique has been successfully used for decades to study randomly clumped organisms (Cottam and Curtis, 1956; Dix, 1961; Penfound, 1963; Risser and Zedler, 1968; Smith et al. 1978; Randall et al. 1988; and many others). The PCQT method was used in this survey as the basis for quantitatively estimating the distribution, abundance and size frequency of stony corals within the surveyed area.

Specific procedures used were as follows:

a) A base point for each transect was randomly selected within the sea floor zone for which data was needed. The location of the point was recorded using GPS and range finders.
b) A transect line was established beginning at the base point and extended for 228 feet (70 m) along a predetermined depth contour. In some cases the transect length was less due to bottom time restrictions.
c) Additional points were established at 33 foot (10 m) intervals along the transect line. At the base point, and at each 33 foot (10 m) point, the transect line was bisected at a 90 degree angle, thus creating four quarters around each point.
d) The distance from the point to the edge of the closest stony coral colony was then measured and recorded.
e) The closest stony coral colony was placed into one of the following categories: *Porites rus, Porites sp., Faviidae* and All Other Species (of stony corals). These four categories were used because of the overwhelming dominance of *Porites rus* on

nearly all the transects. Coral identification was based upon Paulay et al. (2003), Randall (2003), Veron (1997) and Veron (2000).
f) The greatest dimension of the colony, parallel to the substrate, was recorded.
g) This procedure was repeated until 35 transects were completed. The combined total linear distance covered by all the transects was 7,215 linear feet (2,220 m) and measurements were taken in 1,008 quarters.

Most of the coral colonies measured had a roughly circular ‘footprint’ on the sea floor. The greatest dimension, measured parallel to the sea floor, was considered to be a diameter measurement and the area of the sea floor covered by the colony was therefore determined by calculating the area of a circle. The actual area for colonies not having a circular footprint was either over or underestimated, depending on the shape of the colony. It should be noted, that for colonies with substantial growth in a vertical direction, resulting in a skyscraper type effect versus a flat encrusting growth form, the total surface area of the colony could be many times greater than the area of the footprint.

The apparent health of coral colonies was also noted. Colonies exhibiting bleaching, algal overgrowth, disease (e.g. black band disease) or predation by the Crown of Thorns Starfish (*Acanthaster planci*) were recorded. Notes were also made of other coral species, which were present, but outside the transect.

Based upon qualitative observations of the entire Orote Peninsula by the senior author, as well as the MRC survey, the area for the present study was divided into three segments (Figure 1). Segment 1 extended from the western limit of the March 2004 quantitative survey (800 feet [246 m] west of the western edge of the wharf) to Channel Marker Buoy G-1 near Orote Point (3150 feet [969 m]). Segment 2 extended from the eastern limit of the 2004 survey (800 feet [246 m] east of the eastern edge of the wharf) to the western end of Saint Louis Beach. Segment 3 extended from the western end of Saint Louis Beach to the eastern side of the Sumay Cove Entrance Channel.

In addition to dividing the peninsula into segments, three distinct depth ranges (10 – 20, 30 – 40 and 60 – 70 feet [3-6, 9-12, 18-22 m]) were surveyed, as described in Table 1.

Table 1
General Point Center Quarter Transect Locations

	Pauley Equivalent Nomenclature	MRC Equivalent Nomenclature
Segment 1		
30-40 ft	(Upper) Fringing-Reef Slope	(Upper) Fore-Reef Slope
60-70 ft	(Lower) Fringing-Reef Slope	(Lower) Fore-Reef Slope
Segment 2		
10-20 ft	Fringing-Reef	Fore-Reef Terrace to Fore-Reef Slope
30-40 ft	Upper) Fringing-Reef Slope	(Upper) Fore-Reef Slope
60-70 ft	(Lower) Fringing-Reef Slope	(Lower) Fore-Reef Slope
Segment 3		
10-20 ft	Fringing-Reef	Fore-Reef Terrace to Fore-Reef Slope
30-40 ft	Upper) Fringing-Reef Slope	(Upper) Fore-Reef Slope
60-70 ft	(Lower) Fringing-Reef Slope	(Lower) Fore-Reef Slope

For the remainder of this report, the terms fringing reef and fringing reef slope will be used to describe these portions of the reef.

B. Sea Turtle Observations

The threatened green sea turtle (*Chelonia mydas*) is frequently sighted in Apra Harbor. Two sightings of the endangered hawksbill sea turtle (*Eretmochelys imbricata*) were made during dives conducted in November 2003 near Kilo Wharf and one was made in October 2004.

All sea turtles species are cosmopolitan in the tropics, except for Kemp's ridley and flatback sea turtles (NMFS & USFWS, 1998a); therefore, occasional transits by other species, such as the olive ridley (*Lepidochelys olivacea*), leatherback (*Dermochelys coriacea*) or loggerhead (*Caretta caretta*) are possible.

Sea turtle species are all quite distinctive in appearance and obtaining a positive identification underwater is not difficult. All divers were briefed upon the identifying characteristics. Turtle sightings from the boat and underwater were recorded. The following information was noted whenever possible:

1. species
2. carapace length (recorded as less than 1.5, >1.5 < 3.0, and > 3.0 feet [1 m])
3. sex (if the carapace length was > 2.5 feet [0.75 m] the turtle was presumed to be sexually mature)
4. distinguishing features/apparent health (such as scars, barnacles or tumors)
5. activity when first sighted (swimming, resting, foraging).

Observations were also made on preferred sea turtle forage and resting habitat.

None of the sea turtles sighted during this survey had clearly identifiable markings. Therefore, it was not possible to know if the same individual was sighted repeatedly, or if different individuals of the same species, size and sex were sighted.

C. Species of Concern

Effective April 15, 2004 the National Oceanic and Atmospheric Administration (NOAA) Fisheries issued new guidance under the Endangered Species Act, relating to species of concern. Species of concern are defined as organisms, which based upon demographic and genetic factors, as well as abundance, productivity, distribution and life history are judged to be vulnerable to continued decline.

Two species of marine fish recorded from Guam are listed as species of concern. These species are the Humphead wrasse, also known as the Napoleon wrasse (*Cheilinus undulatus*), and the Humphead parrotfish, also known as the Bumphead parrotfish (*Bolbometopon muricatum*). The Napoleon wrasse is one of the largest of all reef fish, attaining a length of over six feet (two meters) and weights of over 400 pounds (181.4 kilograms [kg]); the Humphead parrotfish is the largest member of the parrotfish family and attains a length of three feet (0.9 m) and weights of 100 pounds (45.4 kg) (Myers, 1991). Note, there are reliable, but unpublished reports of Humphead parrotfish having been weighed in at over 300 pounds.

Special attention was given to these fishes during the surveys. Both of these species were common prior to the mid 1970's, but are currently extremely rare, due primarily to over fishing (Myers, 1991).

D. Essential Fish Habitat

All of Apra Harbor has been designated as Essential Fish Habitat (EFH). Within EFH, areas of special concern are further designated as Habitat Areas of Particular Concern (HAPC). No HAPC have been designated along the Orote Peninsula.

The survey area was subjectively evaluated using the four criteria for HAPC: (1) the ecological function provided by the habitat is important; (2) the habitat is sensitive to human-induced environmental degradation; (3) development activities are, or will be, stressing the habitat type; and (4) the habitat is rare.

IV. Results

A. Diving

During the October 2005 surveys 21 dives (75 person dives) were completed; during the February 2006 surveys 21 dives (70 person dives) were completed. Some of the February dives were in support of another investigation and were not performed along the peninsula. The maximum dive depth during October and February was 100 feet (31 m). During 2004, 41 dives (86 person dives) were completed; observations to 150 feet (46 m) were made during those surveys. There were no accidents or injuries during any of these diving operations.

B. Corals

Table 2 illustrates the linear distance of PCQTs completed at each depth zone as well as the number of quarters completed and those quarters which contained coral. As previously noted, the Orote Peninsula supports extensive coral reefs. Table 2 shows that within all the areas surveyed, the frequency of occurrence of coral, within the transects, ranged from a low of 92% up to 100%, with four of the eight segments/depth zones having frequencies of occurrence at 100%.

Table 2
PCQT Distances and Quarters With Coral

	Linear Distance Of Transects (in Feet/Meters)	Quarters Completed	Quarters W/ Coral	Percentage Of Quarters W/Coral
Segment 1				
30-40 ft	422 / 130	60	60	100%
60-70 ft	845 / 260	120	118	98%
Segment 2				
10-20 ft	617 / 190	88	88	100%
30-40 ft	1268 / 390	180	180	100%
60-70 ft	422 / 130	60	60	100%
Segment 3				
10-20 ft	683 /210	96	96	100%
30-40 ft	1398 /430	192	191	99%
60-70 ft	1560 / 480	212	195	92%

MRC (2005a), Paulay et al. (2003), and Smith (2004a, 2004b) have clearly shown that *Porites rus* (Order Scleractinia – stony coral) is the dominant coral on the Orote Peninsula, based upon both the frequency of occurrence and total area occupied by this species (see Table 3 and Plates 1, 2 & 6). This dominance is most pronounced in Segment 2 where the fringing reef slope has nearly mono-specific coverage by *Porites rus*. It is important to note, however, that one or more representatives of all the major families of scleractinian corals known from Guam were observed in each of the Segments. These include the following families: Pocilloporidae, Acroporidae, Agariciidae, Poritidae, Faviidae, Oculinidae, Merulinidae, Mussidae, and Pectiniida. The Scleractinian family Fungiidae is not considered a reef builder, like the other families just listed; however, specimens of Fungiidae were common in Segments 1, 2 and 3.

Hydrozoan corals (Milleporidae [fire coral] and Stylasteridae [lace corals]) were present but not common in any of the Segments. The Octocorallia were best represented by soft corals from the Order Alcyonacea (Plate 3). Several genera were abundant at scattered locations within Segment 1 and 2. These genera were *Sinularia*, *Sarcophyton* and *Lobophyton*.

Table 3 provides additional data on coral distribution within the study area.

Table 3
Distribution of Selected Stony Corals By Segment and Depth

Coral Taxa & Segment	Frequency of Occurrence in Quarters with Coral	Mean Colony Size (cm^2)	Size Range in Diameter (cm)
Porites rus (Segment 1, 30-40' Zone)	**41.7%**	**1670**	**8 - 280**
Porites rus (Segment 1, 60-70' Zone)	**41.5%**	**2449**	**3 - 186**
Porites rus (Segment 2, 10-20'Zone)	**95.5%**	**2496**	**2 - 310**
Porites rus (Segment 2, 30-40'Zone)	**93.9%**	**2996**	**3 - 255**
Porites rus (Segment 2, 60-70'Zone)	**48.3%**	**855**	**6 - 190**
Porites rus (Segment 3, 10-20'Zone)	**73.4%**	**2305**	**2 - 490**
Porites rus (Segment 3, 30-40'Zone)	**67.0%**	**3588**	**4 - 1470**
Porites rus (Segment 3, 60-70'Zone)	**36.9%**	**699**	**2 - 500**
Porites spp. (Segment 1, 30-40'Zone)	**15.0%**	**3430**	**16 - 120**
Porites spp. (Segment 1, 60-70'Zone)	**15.3%**	**218**	**2 - 56**
Porites spp. (Segment 2, 10-20'Zone)	**3.3%**	**491**	**20 - 30**
Porites spp. (Segment 2, 30-40'Zone)	**4.4%**	**5542**	**1 - 230**
Porites spp. (Segment 2, 60-70'Zone)	**41.7%**	**1780**	**4 - 210**
Porites spp. (Segment 3, 10-20'Zone)	**16.8%**	**1061**	**2 - 230**
Porites spp. (Segment 3, 30-40'Zone)	**9.4%**	**113**	**2 - 42**
Porites spp. (Segment 3, 60-70'Zone)	**30.3%**	**306**	**3 - 63**
Faviidae (Segment 1, 30-40' Zone)	**26.7%**	**3530**	**5 - 160**
Faviidae (Segment 1, 60-70' Zone)	**23.7%**	**568**	**6 - 40**
Faviidae (Segment 2, 10-20' Zone)	**0%**	**0**	**0**
Faviidae (Segment 2, 30-40' Zone)	**0.6%**	**940**	**1 - 70**
Faviidae (Segment 2, 60-70' Zone)	**1.7%**	**314**	**20**
Faviidae (Segment 3, 10-20' Zone)	**7.0%**	**5411**	**8 - 150**
Faviidae (Segment 3, 30-40' Zone)	**17.3%**	**269**	**3 - 109**
Faviidae (Segment 3, 60-70' Zone)	**16.9%**	**115**	**3 - 56**
All Others (Segment 1, 30-40' Zone)	**16.7%**	**137**	**3 - 40**
All Others (Segment 1, 60-70' Zone)	**19.5%**	**277**	**2 - 72**
All Others (Segment 2, 10-20' Zone)	**7.1%**	**214**	**10 - 23**
All Others (Segment 2, 30-40' Zone)	**1.1%**	**20**	**3 - 7**
All Others (Segment 2, 60-70' Zone)	**8.3%**	**3078**	**50 - 470**
All Others (Segment 3, 10-20' Zone)	**2.8%**	**154**	**5 - 30**
All Others (Segment 3, 30-40' Zone)	**6.3%**	**140**	**1 - 35**
All Others (Segment 3, 60-70' Zone)	**15.9%**	**167**	**2 - 56**

Six species from the family Poritidae were lumped into the *Porites sp.* category. These species were *Porites cylindrica*, *Porites lichen*, *Porites annae* and three predominately head/lobate forming species *Porites lobata*, *Porites australiensis* and *Porites lutea.* This was done because the frequency of occurrence for each of these individual species was never more than 1%.

The family Faviidae is represented by 13 genera in Guam (Pauley et al. 2003). Members of at least seven genera were observed. These corals were most frequently sighted in the western most portions of Segment 1 and eastern portion of Segment 3. Species tentatively identified in the field included: *Favia stelligera*, *Favia pallida*, *Goniastrea edwardsi*, *Goniastrea retiformis*, *Cyphastrea seralia*, *Cyphastrea microphthalma*, and *Diploastrea heliopora.* Some very large specimens (over 3 m in diameter) of *Diploastrea heliopora* were observed in Segment 1.

Corals in the “All Others” category included species from at least 10 additional families of stony corals. The most commonly occurring families were: Acroporidae, Agariciidae, Fungiidae, Mussidae, and Pocilloporidae.

Highlights listed in Table 3 that merit further emphasis, as well as several additional points, are as follows:

- *Porites rus* is the dominant species in each of the eight Segment/depth categories, based upon frequency of occurrence and percent cover.
- There is little variability in the growth forms of *Porites rus*; nearly all consist of wide laminar plates with tall thin spires or columns extending above the plates towards the surface. The result is a physically very complex reef whose actual surface area far exceeds the coral footprint on the sea floor.
- The size of *Porites rus* colonies in all Segments ranged from very young specimens (2 cm in diameter) to very old specimens over 500 cm in diameter.
- *Porites rus* becomes less dominant as one moves to the east and west away from Kilo Wharf and to depths below 60 feet (18 m).
- The greatest diversity based upon frequency of occurrence and percentage of the sea floor covered by various coral groups is found near Orote Point. Paulay et al.’s (2003) studies showed similar results.
- Very large specimens of *Porites sp.* were only recorded within PCQTs in Segment 2, although large specimens of *Porites sp.* were sighted outside the transects in all Segments and at all depths.
- Specimens of Faviidae were most abundant in Segments 1 and 3, with fewer being sighted or measured in Segment 2. Large specimens (over 100 cm) were measured within the PCQTs and even larger specimens were sighted in the vicinity of the transects.
- Based upon the coral species measured and recorded growth rates from other locations, many of the coral colonies from all the coral families present within the study area are in excess of 50 years old; some may be more than 150 years old.
- Based primarily upon qualitative observations, the fossilized reef platform near the juncture of Gabgab and Saint Louis Beaches appears to support the greatest diversity of, and sea floor cover by, soft and stony corals and macro algae.

The fringing reef and fringing reef slope between Orote Point and the eastern side of the Sumay Cove Entrance Channel can be characterized as supporting generally dense to very dense coral cover between depths of 10 and 70 feet. The reef was physically complex, had a very high rugosity factor, and although dominated by *Porites rus*, also supported representatives of all the major stony coral families on Guam. Corals from every family represented, ranged from one or two year old specimens, to very old, mature colonies (based upon their size). The corals appeared to be very healthy, with virtually no bleaching or disease and very little algal overgrowth. There were sections along the peninsula where moderate numbers of *Porites rus* appeared to be infested with an unidentified black sponge. These sponges were most common in Segment 2.   In addition to stony corals, there was a diversity of other species including, but not limited to: foliose algae, encrusting calcareous algae, foliose calcareous algae, sponges, soft corals, mollusks and fin fish. The foliose calcareous alga (Halimeda sp.) was observed to be over-growing several colonies of the finger coral *Porites cylindrica.* This phenomenon was most noticeable in Segment 3.

Additional characteristics of the three Segments and depth zones within those Segments are presented below.

<u>Segment 1</u>

This Segment is the most exposed of the three and has the strongest oceanic influence. The area is routinely subject to large ocean waves and generally unprotected from typhoon influence.

The fossilized reef platform at the western end of the study area was typical of high energy environments and supported only sparse coral development. The surge in this area was too strong to allow the team to conduct any PCQTs, and only very limited qualitative observations were made above 30 feet (9 m). The corals which were present were all small, very robust specimens, predominately *Pocillopora meandrina, Pocillopora sp., Acropora sp.,* and some small (10 cm diameter) heads of *Astreopora myriophthalma.* The most obvious macro algae present was *Turbinaria sp.* As one proceeds in an easterly direction, towards Kilo Wharf, coral and algal cover on the fossilized reef platform increased; the Brown alga *Padina sp.* became the dominant cover at the eastern edge of Segment 1.

The fringing reef was not as distinct here, as it was along most of the rest of the peninsula. Likewise, the reef slope profile was somewhat different. The most obvious difference between the reef slope in Segment 1 and the other study areas was the presence of more dome or head forming species, such as *Porites lobata, Diploastrea heliopora, Cyphastrea serailia* and *Montastrea curta.* In addition, the percent coral cover and percent cover contributed by *Porites rus* were both reduced (Table 5). These differences were most pronounced at the western most edge of the study area.

The reef profile at our western most study site (3,150 feet [969 m]) west of Kilo Wharf was as follows: 150 to 130 feet (46-40 m) sand; 130 to 100 feet (31 m) large rocks and boulders with approximately 10% stony coral cover, 25% *Halimeda sp.* (foliose calcareous algae) cover and 50% cover by other algae; 100 to 75 feet (31-23 m) 40^o slope of boulders and solid rock outcrops, stony coral cover 10 – 15%, *Halimeda sp.* cover 50%; by 75 feet (23 m) stony coral cover was 50% increasing to over 75% cover by 55 feet (17 m), slope had also increased to approximately 65^o; below 65 feet (20 m) *Porites lobata* was dominant, from 65 to 28 feet (20-9 m) *Porites rus* was very dominant. At 28 feet (9 m) the reef slope diminished to less than 30^o and the coral cover dropped dramatically and coral specimens were primarily small head forming species, until the shelf break was reached at the fossilized reef platform, approximately 18 feet (6 m). (Note: the percentages listed in this paragraph, are subjective estimates for a single location. They are not equal to the quantitative values generated by the PCQTs and the PCQTs for Segment 1 were conducted to the east of this profile site.)

In November 2004, this area was under attack by the Crown of Thorns Starfish (*Acanthaster planci*) (Smith, 2004b). This coral eating starfish was also observed during dives made in Segment 1 during February 2006. None of these starfish were observed in any of the other Segments. No estimates were made of the number of *Acanthaster planci;* however, these starfish were observed feeding on several different genera of Faviidae, such as Goniastrea and Favia. In addition, moderate numbers of dead 20 to 40 cm diameter head forming corals were observed at this location. Species identification was not possible due to their deteriorated condition. On no occasion were *Acanthaster planci* observed to be feeding on *Porites rus* and no *Porites rus* colonies showed any evidence of having been attacked by the starfish.

<u>Segment 2</u>

Segment 2 was the least diverse of the three Segments. The dominance of *Porites rus* was the strongest here; in the 10 – 20 foot and 30 – 40 foot (3-6, 9-12 m) depth zones, the frequencies of occurrence were 96% and 94% and the percentages of total coral cover contributed (by this species) were over 90%. Large specimens of *Porites rus* were even present on the mid to outer portions of the fossilized reef platform, resulting in a more distinct fringing reef. In spite of the dominance of *Porites rus,* large colonies of *Porites lichen, Porites lutea,* and *Porites lobata,* were present, as well as thickets of the finger coral *Porites cylindrica.* Large specimens of many other scleractinian species were also present. Sea floor cover by soft corals was qualitatively estimated to be the highest in this Segment, with *Sinularia sp.* appearing to be the most common.

Commercial sport diving boats utilize Segment 2 on a regular basis. Although their diving is concentrated off Gabgab Beach, most if not all of Segment 2 is utilized. Anchor and chain damage to the reef was obvious. There were four sites where very fresh anchor and chain damage had destroyed the reef for distances of up to 60 feet (18 m) by 15 feet (5 m). At another location, a permanent mooring had dragged and destroyed an even larger reef segment.

For much of Segment 2, the reef slope was between 75^o and 90^o. Large and small grottos were present at many locations within Segment 2. These grottos would normally be expected to provide excellent habitat for a variety of fish species, as well as resting habitat for green sea turtles. Few fish were observed in any of these grottos, and no sea turtles were ever observed utilizing them.

Between the eastern end of Gabgab Beach and Saint Louis Beach, the fossilized reef platform reaches its maximum width, for the entire Orote Peninsula. Much of this area is less than 6 feet (2 m) deep. Sea conditions only permitted a limited assessment of the outer edges of this section of the fossilized reef platform. In the areas less than 10 feet (3 m) deep, algal, coral and fish diversity (subjectively) appeared to be higher than at other locations along the peninsula. At depths greater than 10 feet (3 m) *Porites rus* reasserted its dominant position.

Segment 3

Much of the shoreline in Segment 3 has, or appears to have been altered by the placement of rock revetment, sheet piles and so on (Plate 4). The fossilized reef platform was narrow and generally only 3 to 8 feet (1 to 2.5 m) deep. The fringing reef was not as well developed; however, coral cover on the reef slope was still high, 68% in the 30 – 40 foot depth range and 35% in the 60 – 70 foot range.

Segment 3 has supported much more shore infrastructure and been subject to more disturbance than any other portion of the study area. This includes pipelines, piers, a former sea plane facility (Clipper Landing), and so on. WWII debris and wreckage was also present, as well as at the remnants of at least two barges (Plate 5).

Wide swaths through the coral on the reef slope were plainly visible, where barges sunk and slid down to the floor of the harbor (Plate 5). Other disturbed areas were visible from broken pipe lines and dragged anchors. Although the events described above all took place over 15 years ago, in some cases over 60 years ago, coral recruitment to the disturbed areas, and the metallic debris was very limited (Plates 4 & 5).

The frequency of occurrence of corals in the "All Others" category was 15.9%, in the 60 - 70 foot (18 to 22 m) zone. However, most of these specimens were small; the size range was 2 to 56 cm, with a mean colony size of only 167 cm^2. Genera and species encountered included: *Acropora sp., Leptoseris mycetoseroides, Pavona varians, Favia sp., Lobophyllia hemrichii, Lobophyllia corybosa, Acanthastrea echinata* and *Pocillopora damicornis.*

Another very noticeable difference between Segment 3 and the other portions of the study area was the presence of large numbers of elephant ear sponges (*Ianthella basta*) in the 60 to 100 foot zone (18 to 31 m). A thorough quantitative assessment of these sponges was not made; however, one count was completed covering an area of 6 X 975 feet (2 X 300 m) at a depth of 80 feet (25 m). Sixty three specimens were counted, one of which measured 8.5 feet (260 cm) in diameter.

C. Threatened and Endangered Species and Species of Concern

There was one sighting of an endangered Hawksbill sea turtle (*Eretmochelys imbricata*). The specimen was sighted on October 18, 2005; it was swimming along a vertical wall at a depth of approximately 20 feet (6 m). The location was offshore St. Louis Beach (Segment 2). The carapace length (shell length) was approximately 1.5 feet (0.5 m). The turtle appeared to be healthy; it had no visible tumors, bite marks, barnacles or algae. Sex was not determined.

Adult Hawksbill sea turtles are believed to feed primarily on sponges (NMFS & USFWS, 1998a). A moderate number and diversity of sponges were present in Segments 1, 2 and

3. Little quantitative data was not taken on sponges; however, the greatest number and largest biomass of sponges appeared to be located in Segment 3. The elephant ear sponge (*Ianthella basta*) was the primary contributor to this biomass. No bite marks were observed in any of the sponges sighted, although hawksbill sea turtles may be utilizing these sponges as a food source.

Sightings of the threatened green sea turtle (*Chelonia mydas)* were not as common during the October 2005 and February 2006 survey periods as they had been during March 2004. During the March 2004 surveys there were a total of 16 green sea turtle sightings underwater, and six from the boat. During the October and February surveys there were five green sea turtle sightings from the boat and six underwater, all underwater sightings were within Segment 2. The turtles sighted underwater were swimming and had no visible tumors, bite marks, barnacles, algae or abnormalities. Four of the green sea turtle sightings underwater were of juvenile specimens with a carapace length of less than 1.5 feet (0.5 m). The fifth sighting was of a specimen estimated to have a carapace length of 1.5 feet and the last sighting was of an adult female with a carapace length of 3 feet (1 m). All sightings were adjacent to reef areas supporting over 90% live coral cover and along nearly vertical walls (Segment 2). The surface sightings of green sea turtles occurred in all three Segments.

Green sea turtles that are large enough (one foot [30 – 35 cm]) to reside in the near shore environment are exclusively herbivorous (NMFS & USFWS, 1998b). Preferred forage includes sea grass and algae of the genera *Codium, Amansia, Ptercladia, Ulva, Gelidium, Acanthophera,* and *Hypnea* (NMFS & USFWS, 1998). These genera were either missing, or relatively sparse within the survey area. That is, no substantial quantities of preferred green sea turtle forage were present within the areas surveyed. However, only very limited observations were made on the portions of the fossilized reef platform less than 10 feet deep (3 m), and some of the preferred forage species are often found in waters less than 10 feet deep. Sea conditions were the limiting factor in making very shallow observations. Based upon subjective observations, Segment 2 appears to support the most diverse and dense population of foliose macro-algae.

Green sea turtles are known to prefer resting under ledges and within shallow grottos. There are a substantial number of (apparently suitable) grottos within the 20 to 60 foot depth (6-18 m) range within Segments 1, 2 and 3.

As noted, two listed fish species of concern are known to be present in Guam; the Napoleon (Humphead) wrasse and the Humphead (Bumphead) parrotfish. Segments 1 and 2 meet the preferred habitat criteria for both these species; the preferred food of both species was also abundant. Napoleon wrasse prefer steep reef slopes leading to deep channels and are believed to have home caves, on the reef slopes (Randall, 1982). In addition, they prey heavily on mollusks. Gastropod mollusks were particularly abundant on the western side of Kilo Wharf. The species present included high numbers of the common turban shell (*Tectus sp.*), believed to be a prey item of the Napoleon wrasse. The Humphead parrotfish prefers outer lagoon and seaward reefs at depths of three to 100 feet (1 – 31 m) and feeds heavily on live stony coral (Myers, 1991). No Humphead parrotfish were sighted. However, a single Napoleon wrasse was observed at a depth of 80 feet (25 m) in the vicinity of Orote Point (Segment 1). The specimen was estimated to be approximately two feet (.8 m) in total length. Another Napoleon wrasse sighting was made in November 2004; that specimen was one foot long (31 cm).

D. Essential Fish Habitat

NOAA Fisheries and the Western Pacific Regional Fishery Management Council have included all of Apra Harbor within the designated EFH zone for Guam. However, none of the study area has been designated as HAPC.

As noted above, there are four criteria utilized for designating HAPC. Only one of the four criteria must be met. Segments 1, 2 and 3 could qualify as HAPC; each meets two criteria required for designation. That is, (1) the ecological function provided by the habitat is important; (2) the habitat is sensitive to human-induced environmental degradation. Segments 1, 2 and 3 all contain extensive coral reef areas with over 85% live coral cover, complex physical formations, high rugosity, large individual coral colonies, and predominately fragile growth forms (plate and spire type formations).

Coral reefs are universally acknowledged as being important habitats (Spalding et.al. 2001; DoD, 2000). The coral reefs along most of the Orote Peninsula supported an extraordinarily high percentage of live coral cover, appeared to be disease free, showed virtually no bleaching and were highly complex topographically. Therefore, the first criterion is met. Due to the predominant growth forms of the corals, plate and spire formations, this zone is also vulnerable to disturbance from potential construction activities, and even human activity in general, such as fishing or diving. Hence, the second criterion is also met.

Micronesian Reef Fishes Myers (1991) lists 103 families of fishes; *The Guide to the Coastal Resources of Guam: Vol.1 The Fishes* (Amesbury and Meyers,1982) lists 59 families of fishes; *Marine Biodiversity Resource Survey and Baseline Reef Monitoring Survey of the Southern Orote Peninsula and North Agat Bay Area, COMNAVMARIANAS* (Paulay et. al. 2003) records 54 families of fish.

No fish surveys were conducted during the October 2005 and February 2006 field work. During the March 2004 survey, relatively little effort was spent on surveying fish, and no specific fish transects were conducted; however, one or more species, from 38 bony fish families were recorded during the 2004 surveys. If small and cryptic species had been investigated, the number of families would certainly have been larger. No sharks or rays were sighted. Although the Orote Peninsula can reasonably be said to support a diverse fish community, the total number of fishes was very low and the size of fishes was small.

As noted in the 2004 surveys, the representatives of most of the intermediate sized reef fish families, such as grunts, emperors, goatfishes, wrasses, parrotfishes and surgeonfishes were also predominately small/young fishes. The only intermediate sized fish family well represented by mature sized adults was Holocentridae (soldierfishes and squirrelfishes), such as *Myripristis sp.*, *Neoniphon sp.* and *Sargocentron sp.* The entire Orote Peninsula appears to be suffering from severe over fishing.

V. Discussion

This section is presented in four parts: corals and coral reefs, sea turtles, species of concern and Essential Fish Habitat. The reader may wish to review the previously cited project documents to obtain a more complete perspective on the issues as they relate to the proposed expansion of Kilo Wharf.

A. Corals and Coral Reefs

Corals in this area have been very thoroughly assessed; the authors have completed over 10,900 linear feet (3,364 m) of PCQTs. Scleractinian (stony) corals are the dominant macro-scopic benthic organisms on the Orote Peninsula between Orote Point and Sumay Cove, within the depth range of 3 to 100 feet (1 – 31 m). They are dominant in terms of their frequency of occurrence, percentage of the sea floor that they cover, and the degree to which they affect what other invertebrate and vertebrate species are present. Scleractinian corals determine, more than any other group within the study area, what the ecological functions and values are and how they inter-relate. It is for these reasons that the emphasis of the current study was on assessing corals and coral reefs, versus other groups of marine organisms.

As previously noted, the coastal area between Orote Point and Sumay Cove was subdivided into three Segments for this study. The area adjacent to Kilo Wharf was divided into eight Zones during the Navy's March 2004 study. Figure 2 illustrates the various Zones demarcated during the 2004 study. A comparison of the three Segments and some of the Zones is presented in Tables 4 and 5.

Only modest differences exist between the different study areas, except for the Zones impacted by the construction of Kilo Wharf where dramatic differences are obvious. However, the authors believe that between 10 and 80 feet (3 – 25 m), relative to stony corals, the similarities in species composition, size frequency distribution, percentage of the sea floor covered by coral, colony growth forms and apparent colony health far outweigh the differences (Plates 1 & 2). Although quantitative data was not gathered on algae or sponges, our subjective assessment is that there are very strong similarities between all the study areas, relative to these organisms, as well. Zones 1, 2 and 3 were directly impacted during the original construction of Kilo Wharf. As discussed, the flora and fauna in these areas is dramatically different than the other portions of the Orote Peninsula. Coral cover, for example, is less than 1% in Zones 1 and 3, and less than 5% in Zone 2. Zone 2 is the artificially created dredge wall on the western side of Kilo Wharf that extends vertically from a depth of 4 feet to 45 feet (1 – 14 m). Immediately adjacent to Zones 1, 2 and 3 are Zones 4, 6 and 7. Although not dredged, these areas appear to

Table 4
A Comparison of the Orote Point to Sumay Cove Study Sites Based Upon the Present Data and the March 2004 Survey

Location (Depths In Feet)	NOAA Habitat Type	Common Name	% Coral Cover PCQT	Dominant Coral By % Cover	Apparent Coral Health
Segment 1 <10	Colonized Hardbottom	Fossilized Reef Platform	Not Avail.	Not Avail.	Excellent
10-20	Coral Reef	Fringing Reef	Not Avail.	Porites rus	Excellent
30-40/60-70	Coral Reef	Reef Slope	27/14%	Porites rus	Excellent
Kilo West <10	Colonized Hardbottom	Fossilized Reef Platform	1%	Pocillopora damicornis	Excellent
W Zone 8[2] 10-20	Coral Reef	Fringing Reef	100%	Porites rus	Excellent
W Zone 8[2] 30-40/60-70	Coral Reef	Reef Slope	100%	Porites rus	Excellent
Kilo Wharf	Artificial	Wharf Face	Not Avail.	Pocillopora sp.	Excellent
Zone 1[2] 40-50	Scattered Rock/ Coral in Unconsol-dated Sediment	Dredged Platform	0.3%	Faviidae	Excellent
Zone 2[2] 50-90	Uncolonized rock/ Rubble/Boulder Slope	Reef Slope	1%	Faviidae	Excellent
Kilo East <10	Colonized Hardbottom	Fossilized Reef Platform	1%	Pocillopora damicornis	Excellent
E Zone 8[2] 10-20	Coral Reef	Fringing Reef	100%	Porites rus	Excellent
E Zone 8[2] 30-40/6070	Coral Reef	Reef Slope	100%	Porites rus	Excellent
Segment 2 <10	Colonized Hardbottom	Fossilized Reef Platform	Not Avail.	Not Avail.	Excellent
10-20	Coral Reef	Fringing Reef	100%	Porites rus	Excellent
30-40/60-70	Coral Reef	Reef Slope	100%	Porites rus	Excellent
Segment 3 <10	Colonized Hardbottom	Fossilized Reef Platform	Not Avail.	Not Avail.	Excellent
10-20	Coral Reef	Fringing Reef	88%	Porites rus	Excellent
30-40/60-70	Coral Reef	Reef Slope	68/35%	Porites rus	Excellent

Note 1: If the value for the 30 – 40 foot and 60 to 70 foot zones are different, both are listed.
Note 2: Zone 8 is the Coral Reef >90% cover zone; Zones 1 and 2 are the Altered by Construction Zones described in Smith 2004a.

have sustained impacts from the adjacent dredging and construction activities, and may also be affected by prop-wash from ships and tug boats berthing and departing from Kilo Wharf. In any case, these areas are also distinctly different than the remainder of the peninsula. Smith (2004a) considers these zones to be 'transitional', between the undisturbed portions of the peninsula and the disturbed portions. An additional unique Zone was described by Smith (2004a), Zone 5. It is a 45^{o} unconsolidated sediment slope composed predominately of *Halimeda* sand. Widely scattered boulder and rock outcrops are present, but they appear to be natural and not related to the construction activities.

Table 5
Coral Distribution Data Along the Orote Peninsula

Location	Percentage of the Sea floor Covered by Coral of all Species	Frequency of Occurrence of Porites rus in Quarters with coral	Average Area of Porites rus colonies in cm^2
Seg. 1 30-40'	27%	42%	1670
Seg. 1 60-70'	14%	42%	2449
Kilo Zone 8 W	100%	72%	1075
Kilo Zone 8 E	100%	92%	3215
Seg. 2 10-20'	100%	96%	2496
Seg. 2 30-40'	100%	94%	2996
Seg. 2 60-70'	100%	48%	855
Seg.3 10-20'	88%	73%	2305
Seg.3 30-40	68%	67%	3588
Seg.3 60-70	35%	37%	699

The previously dredged areas at Kilo Wharf appear to have similarities with some disturbed areas investigated in Segment 3 and other portions of Apra Harbor. For example, a barge sunk near the Sumay Cove entrance channel during Typhoon Pamela in 1976 and subsequently slid down the reef slope. The sinking barge crushed a swath through the *Porites rus* dominated reef, resulting in a large area of unstable rubble substrate and scattered boulders (Plate 5). This unstable substrate is similar to the construction/dredge area (Zone 1 in Figure 2) offshore Kilo Wharf. Neither of these disturbed areas have returned to their pre-disturbance condition; that is, to an area dominated by scleractinian corals. Instead, corals are sparse and small, even on the areas with solid substrate. At the Sumay Cove site, both the unstable rubble and the exposed stable hardbottom/bedrock are predominately covered by the Brown algae *Padina sp.* Algal cover in Zone 1, however, is sparse. At other sites within Apra Harbor, where anchor chains destroyed sections of reef more than 30 years ago algae has replaced the coral as the dominant bottom cover.

Permanent, or long term (more than 35 years) shifts from live coral to macro-algal dominance have been shown to occur after various events, including flooding, discharging of toxic volcanic water, dredging and ship groundings (Endean, 1976; Hatcher, 1984). The replacement of coral with algae at various sites in Apra Harbor may be due to two factors: first, the crushed and broken coral is unstable and less favorable for successful coral recruitment; second, due to the depressed fish stocks, and low numbers of herbivorous fishes, algae are able to quickly monopolize the available substrate and thereby prevent the slower growing stony corals from re-establishing themselves.

The authors suggest that the situation in Zone 1 at Kilo Wharf may be due to the fact that substrate in the areas is unstable (primarily rubble and sand) and that the area is routinely subject to very strong prop wash from ships and tugs berthing and departing. The unstable substrate is physically moved and the rubble rolled about, preventing successful recruitment by either corals or macro-algae. This thesis was investigated by MRC (2005c), although the results were not definitive.

These observations may provide clues on the extent to which corals and coral reefs in Apra Harbor will be able to re-establish, after they are disturbed or destroyed. The depressed fish population in Apra Harbor probably means that the likelihood and/or rate of recovery for Apra Harbor coral reefs (after they are disturbed) is less than it would be if healthy fish stocks were present. The potential for altered steady state environments should be considered a distinct possibility for areas subject to disturbance. Studies from other geographic areas support this concept (for example, Deslarzes et.al. 2005, Smith 1988, Hatcher 1984, Endean 1976).

B. Sea Turtles

The endangered Hawksbill sea turtle (*Eretmochelys imbricata*) is present within Apra Harbor and sightings were made along the Orote Peninsula. However, during the course of over 210 dives made during the Navy's biological surveys of this area between March 2004 and February 2006, only three Hawksbill sightings were made. The authors believe it is accurate to characterize this species as rare in Apra Harbor.

Green sea turtles (*Chelonia mydas*) are listed as threatened; they are frequently sighted from boats and often sighted underwater along Orote Peninsula and throughout Apra Harbor. Adult green sea turtles forage on a variety of algal genera; however, the three dominant genera of macro-algae along the Orote Peninsula appear to be *Halimeda*, *Padina*, and *Turbinaria* (Smith, 2004a and MRC, 2005a), none of which are listed as preferred forage by the NMFS or USFWS (1998b). It should also be noted, that the abundance and diversity of macro-algae is highest in the central and eastern portions of Segment 2, and not in the vicinity of Kilo Wharf or Segment 1. Likewise, Segment 2 contains the largest number of potential green sea turtle resting habitat sites.

C. Species of Concern

As previously noted, and documented by other investigators, the fish stocks in Apra Harbor are depressed. However, the Orote Peninsula, as well as many of the shoal/pinnacle areas in the harbor offer potentially good habitat for the two marine fish species presently listed. If efforts to restore Guam's fish stocks are successful, one could expect to find both of these species here in the future.

D. Essential Fish Habitat – Habitat Areas of Particular Concern (HAPC)

No HAPC have been designated on the Orote Peninsula. Segments 1, 2 and 3 meet the criteria for HAPC designation as do Zone 8 West and Zone 8 East. Based upon the authors' quantitative and qualitative observations of corals and fishes along the Orote Peninsula we would rank these five areas, from best to worst as follows: **i**) Segment 1, **ii**) Zone 8 West, **iii**) Segment 2, **iv**) Zone 8 East and **v**) Segment 3.

VI. SUMMARY

The proposed project involves a wide range of complex environmental and natural resource issues. A thorough review of all existing project documents is recommended to facilitate a better understanding of the physical, chemical and biological parameters.

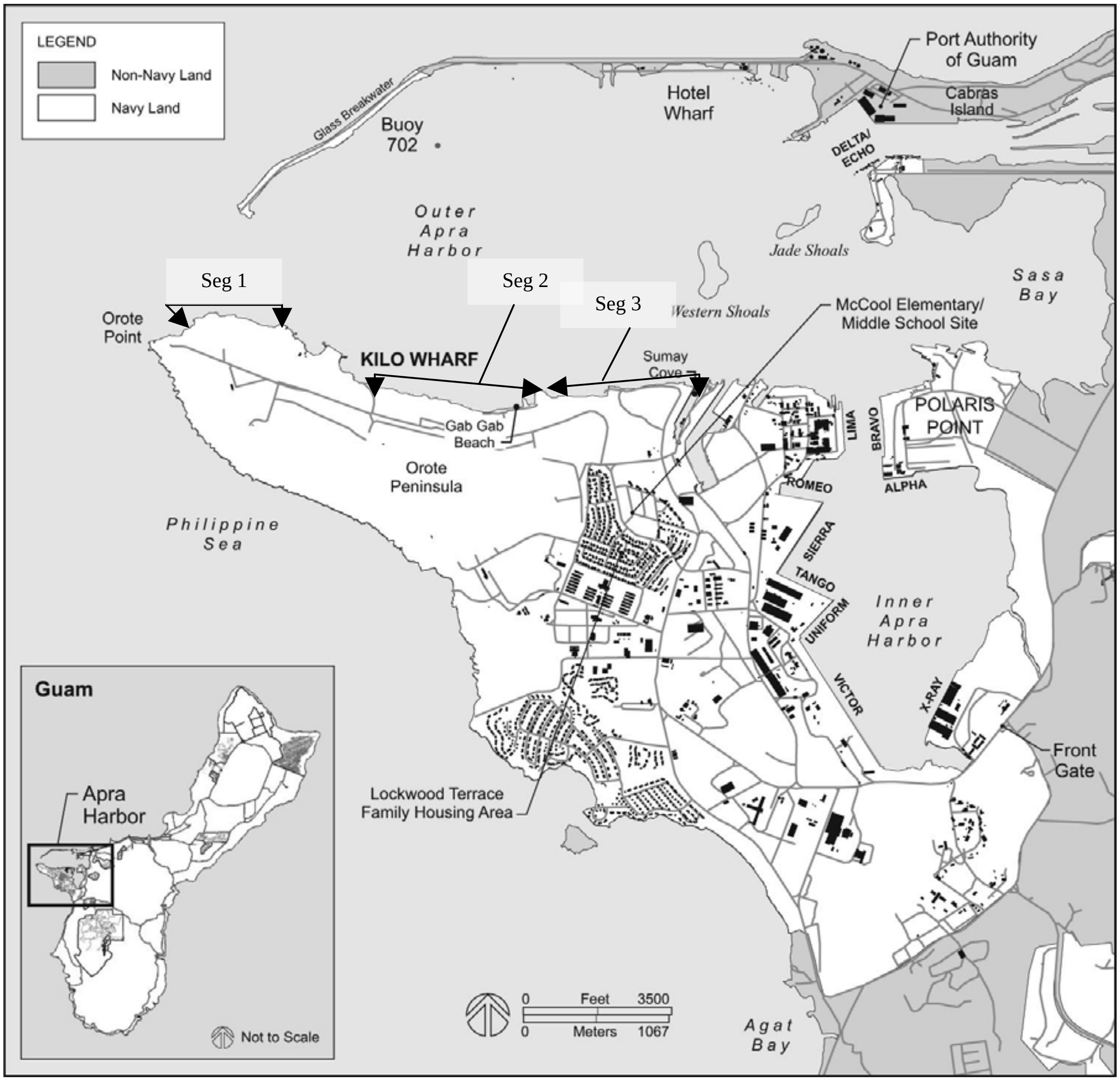
The present investigation focused on corals and coral reefs, with some additional data being gathered on sea turtles, marine fish species of concern and Essential Fish Habitat/Habitat Areas of Particular Concern (EFH/HAPC). The findings are summarized below.

- Reef building Scleractinian stony corals are the dominant benthic organisms in the 3 to 100 foot (1 – 31 m) depth zone between Orote Point and the Sumay Cove Entrance Channel.
- *Porites rus* is the dominant coral species within this entire area, although its dominance is less pronounced at the eastern and western ends of the study area and at depths greater than 70 feet (22 m). This dominance is based upon the percentage of the sea floor covered by this species, the percentage of all coral cover contributed by this species, its frequency of occurrence and size frequency distribution.
- The reef between Orote Point and the Sumay Cove Entrance Channel is biologically significant based on six factors: 1) the percentage of the sea floor covered by live coral, 2 – 4) the size frequency distribution, growth forms and apparent health of the corals, 5 – 6) the physical complexity and rugosity of the reef.
- The fringing reef and fringing reef slope area (Zone 8 in Figure 2) adjacent to Kilo Wharf are not substantially different than the fringing reef and fringing reef slope along the other portions of Orote Peninsula facing Apra Harbor.
- Fish populations in Guam are depressed, primarily as a result of over-fishing. The depressed fish stocks increase the likelihood of permanent or long term shifts from live coral to macro-algal dominance, if coral areas are disturbed or destroyed.
- Two species of sea turtles have been sighted within the study area. The Endangered Hawksbill sea turtle (*Eretmochelys imbricata*) is considered uncommon, based on the number of sightings. The Threatened Green sea turtle (*Chelonia mydas*) is often sighted from boats and underwater; it is considered common within Apra Harbor and the study area.

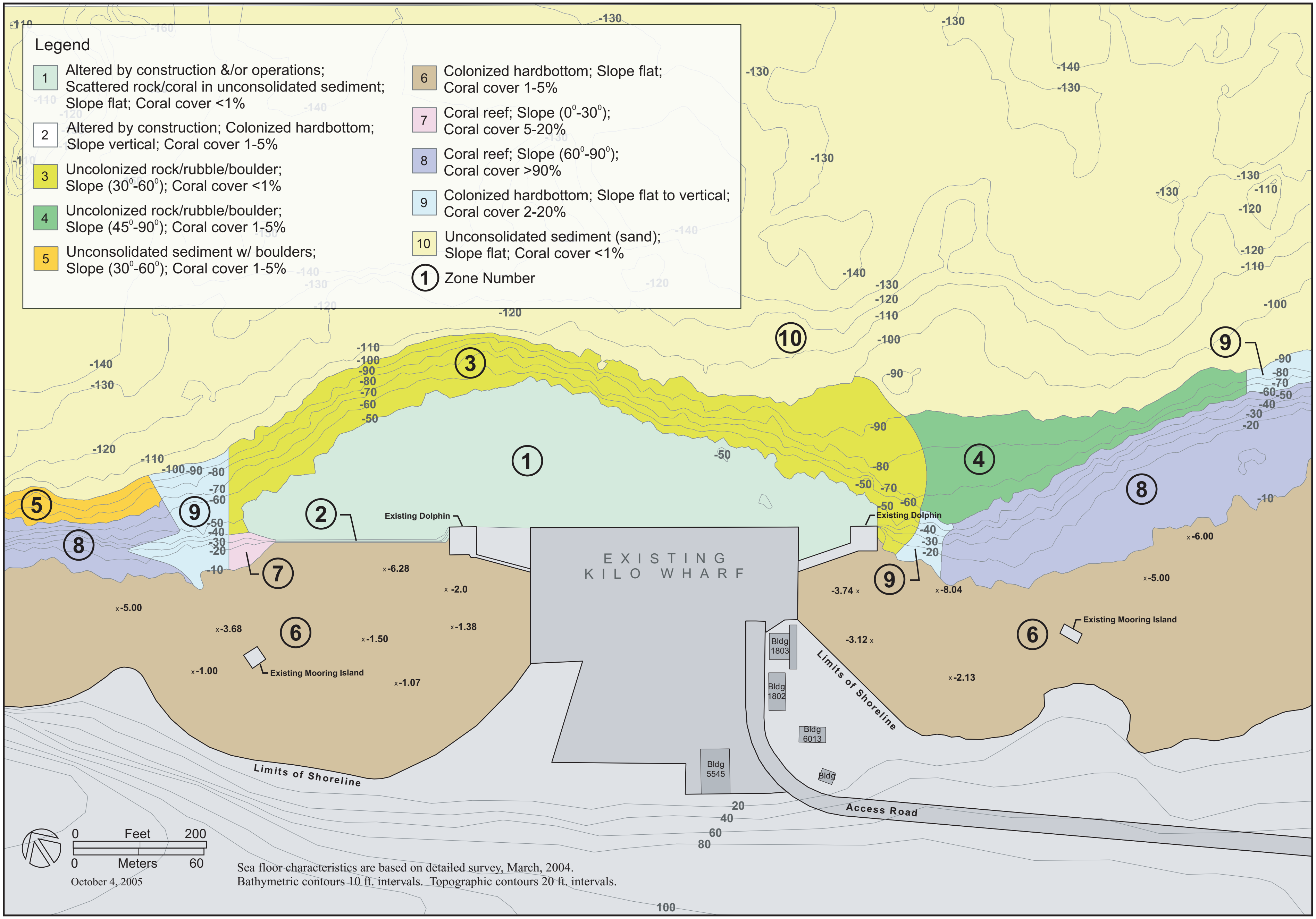
- Two marine fish species of concern have been reported from Guam. One sighting of a Napoleon wrasse also known as the Humphead wrasse (*Cheilinus undulatus*) was made during this study. No sightings were made of the second species, the Humphead parrotfish, also known as the Bumphead parrotfish (*Bolbometopon muricatum*).
- The entire study area has been designated EFH; however, none of Orote Peninsula has been designated as HAPC. There are four criteria for designation of HAPC, only one of the criteria needs to be met for designation. Segments 1, 2 and 3 of the study area and Zone 8 (Figure 2) meet two of the four criteria for designation as HAPC.

The marine environment within the 3 to 100 foot (1 – 31 m) depth range, between Orote Point and the Sumay Cove entrance channel shows a high degree of uniformity. There are no substantive differences in the ecological values provided by the coral reef areas adjacent to Kilo Wharf (Zone 8 East and Zone 8 West) and the ecological values of Segments 1, 2 and 3 investigated during this study. All these locations are significant from the perspective of corals, coral reefs and associated organisms.

FIGURE 1



LEGEND
Non-Navy Land
Navy Land
Glass Breakwater
Buoy
702
Hotel
Wharf
Port Authority
of Guam
Cabras
Island
DELTA/
ECHO
Outer
Apra
Harbor
Jade Shoals
Sasa
Bay
Seg 1
Seg 2
Seg 3
Western Shoals
McCool Elementary/
Middle School Site
Orote
Point
KILO WHARF
Sumay
Cove
Gab Gab
Beach
Orote
Peninsula
POLARIS
POINT
LIMA
BRAVO
ROMEO
ALPHA
SIERRA
TANGO
UNIFORM
Philippine
Sea
Inner
Apra
Harbor
VICTOR
X-RAY
Front
Gate
Guam
Apra
Harbor
Lockwood Terrace
Family Housing Area
0
Feet
3500
0
Meters
1067
Not to Scale
Agat
Bay



Kilo Wharf Sea Floor Characteristics

Figure 2

Kilo Wharf Extension (MILCON P-502)
Apra Harbor Naval Complex, Guam

PLATE 1

Fringing reef slope in Segment 1, 2 & 3. Note dominance of *Porites rus*

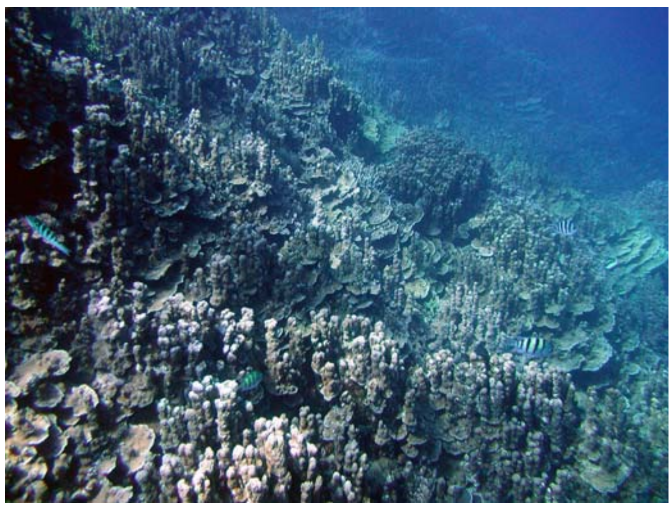


PLATE 2
Fringing reef slope Zone 8 near Kilo Wharf. Note, *Porites lichen* in bottom photo.

PLATE 3

Representative non-scleractinian corals from top to bottom: golden fire coral (*Millepora platyphylla*); soft coral (*Sinularia sp.*) with the scleractinian *Porites annae* in foreground; *Sinularia sp.* in front of scleractinian coral head *Porites lobata*

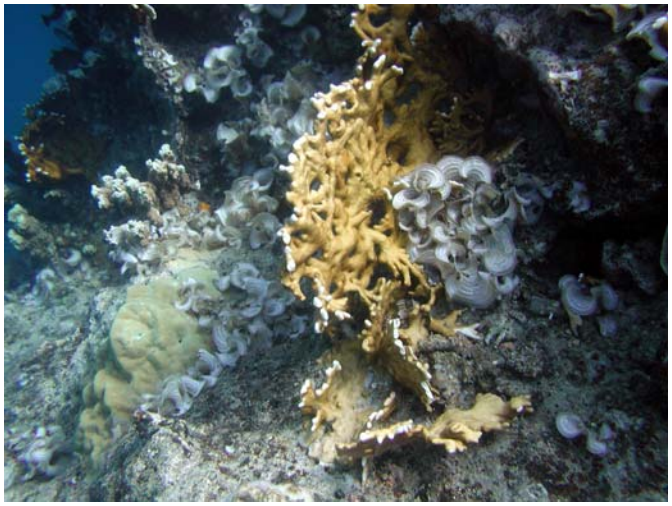
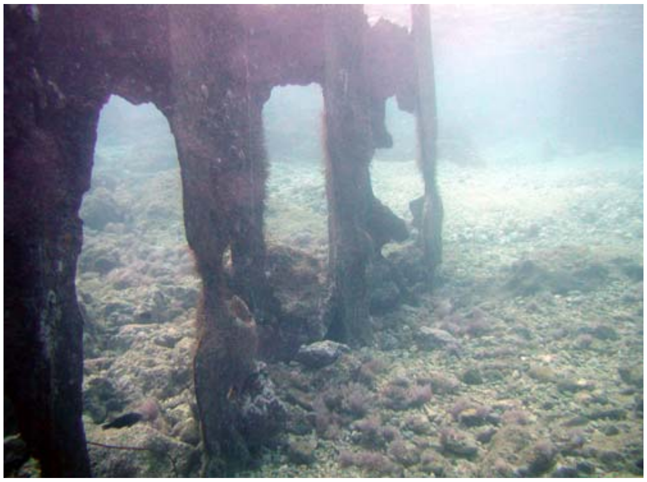


PLATE 4

Fossilized reef platform with sheet piles, debris and chain at eastern end of Segment 3. Note, the Brown algae *Padina sp.* in the two bottom photos.



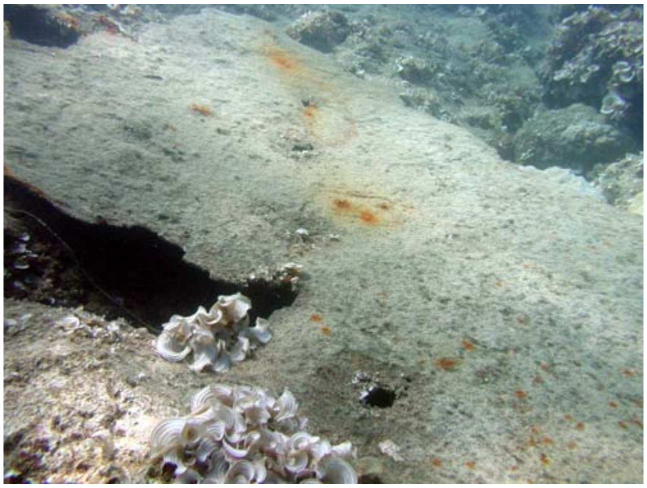
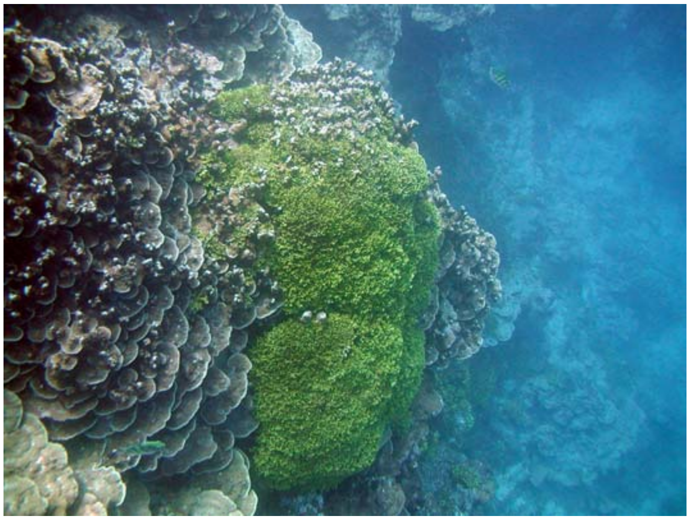


PLATE 5

Reef slope of *Portes rus* ,adjacent swath where barge sunk and slid down to the harbor floor (1976). Note, the replacement of coral by algae and the remnants of the barge. The location is Segment 3.

PLATE 6

Reef slope scenes: *Porites lutea* (tent) surrounded by *Porites rus* at 45'; large Faviidae *Diploastrea heliopora* at 70'; wall of *Porites rus* at 60' with a large green clump of foliose calcareous algae *Halimeda sp.*



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Appendix J
Supplemental Aircraft Carrier Marine Surveys

2. Marine Biological Survey of Oscar and Papa Wharves, Inner Apra Harbor Guam. Review Draft 2008

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MARINE BIOLOGICAL SURVEY OF OSCAR AND PAPA WHARVES, INNER APRA HARBOR, GUAM

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Review Draft

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We are most grateful for the support and assistance provided by several organizations and individuals. We extend our thanks to Mr. Kenneth Foote, Director, Port Operations (NB31) Naval Base Guam, and his staff for providing access and coordinating our movements to and from the various study sites in Apra Harbor. We thank Ms. Gretchen R. Grimm, Environmental Protection Specialist, Naval Facilities Marianas, Ms. Vanessa Pepi, Naval Facilities Pacific, and Mr. Matthews Pothen, President and Chief Executive Officer of Guam Shipyard, for assisting our personnel in obtaining base passes or facilitating access to the Inner Harbor.

Marine Technicians Chris Bassler and Jason Miller piloted the boats and served as diving safety officials. They also maintained communications with Port Operations during our field work.

Finally, we are especially grateful for the guidance provided by Dr. Mark Moese of AECOM for acting as our liaison and project coordinator. Once again, his assistance and patience have made this project possible.

INTRODUCTION

This report describes marine natural resources surveyed at Oscar and Papa Wharves, Inner Apra Harbor, Guam during March, 2010. This report compliments previous surveys conducted at other wharves, as well as patch reefs and the harbor bottom within the Inner Apra Harbor (Smith et al., 2008).

Inner Apra Harbor is a natural embayment formed by tectonic activity along the Cabras Fault, separating the volcanic Tenjo Block in central Guam from the limestone Orote Block immediately to the west (see Tracey et al., 1964 for structural details). Rotation of the Orote Block resulted in subsidence of the eastern portion of the block adjacent to the Cabras Fault line. Accompanying rotation, the sea flooded into the slumped areas, forming Apra Harbor, a deep-water lagoon bounded on the north by Cabras Island and the long, curving Glass Breakwater. Two rivers—the Apalacha and Atantano—drain the volcanic mountain land to the east of Apra Harbor and empty into the inner harbor (Randall and Holloman, 1974).

Although naturally formed, Inner Apra Harbor has been extensively modified by dredging, construction, and landfills by the U.S. Navy since 1945 (Paulay et al., 2001a). The inner harbor was dredged, changing the southernmost part of the original lagoon from a reef-choked, silty embayment into a harbor with a nearly uniform depth and mud bottom. Fill projects created the Dry Dock Peninsula, Polaris Point, and manmade shorelines along the northeastern and southeastern boundaries of the harbor. These and other developments in the outer harbor (e.g., construction of Glass Breakwater) reduced water exchange between the harbor and the Philippine Sea, creating a gradient of increasing turbidity, abundance of plankton and benthic suspension feeders, and finer sediments from the entrance to the outer harbor to the inner harbor environment. The only portion of the inner harbor remaining unchanged is the mangrove area at the mouth of the Atantano River.

Randall and Holloman (1974) reported living *Pocillopora* and *Porites* corals on the wharf and dock structures in the inner harbor. Paulay et al. (2001a) found that artificial surfaces in the inner harbor supported diverse fouling communities, including both indigenous and introduced species. They noted the presence of *Porites convexa*, known in Guam from only a few locations. In a more recent survey,8 et al. (2009) found both *Pocillopora* and *Porites* corals to be relatively abundant on wharf faces, as well, with *Pocillopora damicornis* and *Porites lutea* being especially common among the 13 species observed on wharf face transects. With the inclusion of non-scleractinian anthozoans, they found 28 species of corals and related organisms from 11 families and 13 genera on or adjacent to transects (including patch reefs on the harbor bottom and on miscellaneous scrap found there.

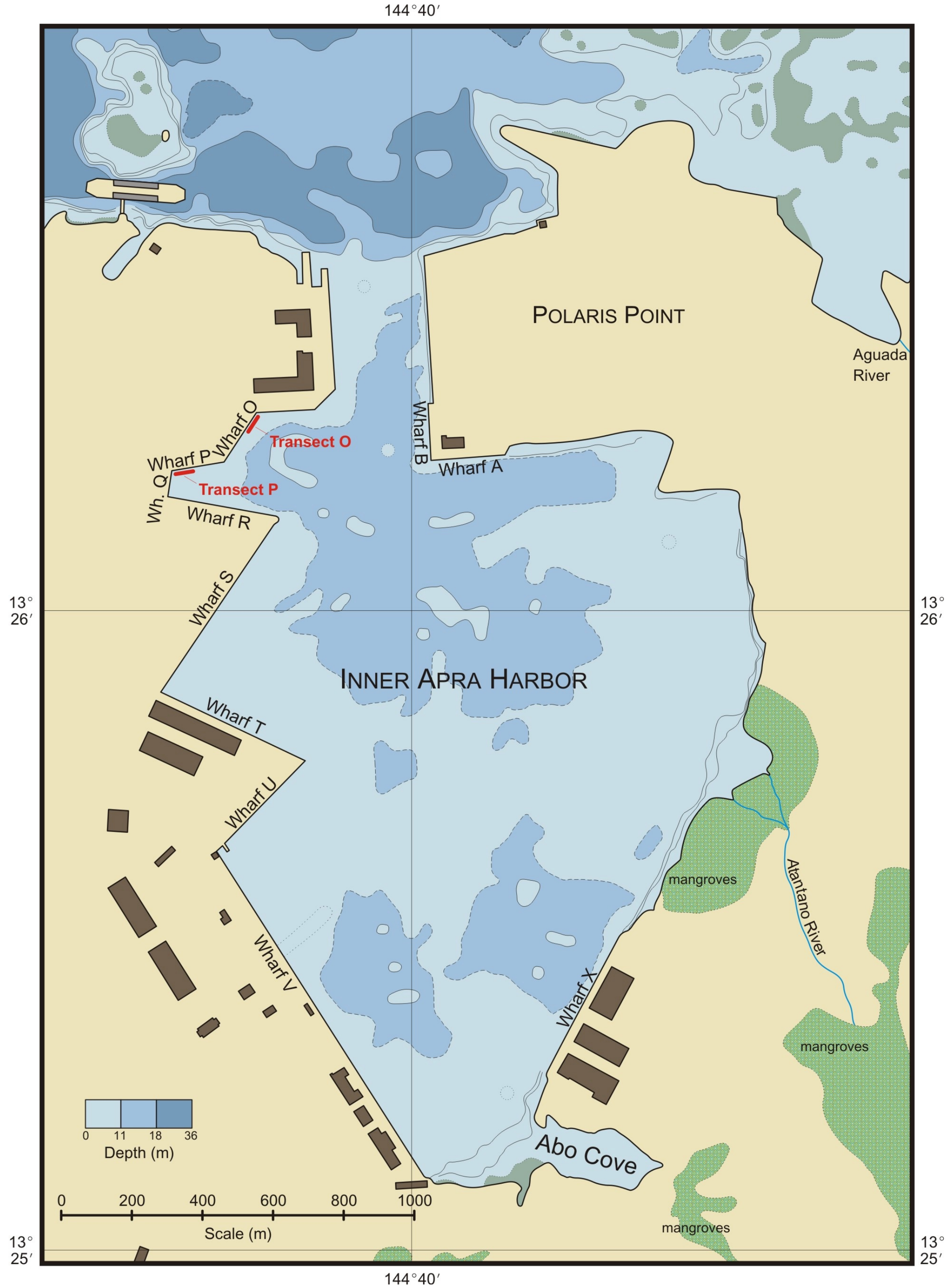

Figure 1. Map of Inner Apra Harbor showing geographic locations of transect sites at Oscar and Papa Wharves.

Randall and Holloman (1974) also remarked about the abundance of the hammer oyster *Malleus decurtatus* on wharf faces in Inner Apra Harbor. Smith et al. (2008) found this species to be very common, especially on Victor Wharf, as well.

Wharves and adjacent structures, including silt or fine sediment substrates at the base of wharves, support small assemblages of fishes (Smith et al., 2008). Juvenile fishes, especially damselfishes (Pomacentridae), such as *Chromis viridis* and *Pomacentrus pavo*, cardinalfishes (Apogonidae), and diminutive gobies (Gobiidae), seek shelter amongst corals, benthic algae, and man-made structures along wharf faces. Burrowing gobies may be common in the sediments at the base of these faces. Free-ranging fishes, such as the surgeonfish *Acanthurus blochii* (Acanthuridae), the snapper *Lutjanus fulvus* (Lutjanidae), and the trevallys *Caranx melampygus* and *C. sexfasciatus*, (Carangidae) were observed swimming near wharf faces and adjacent jetsam and debris. Three invasive fish species were found along some wharf faces, as well (Smith et al., 2008). These include two damselfishes, *Amblyglyphididon ternatensis* and *Neopomacentrus violescens*, and a cardinalfish, *Rhabdamia cypselerus*.

Relocation of elements of the Marine Expeditionary Force (MEF) from Okinawa to Guam by the Marine Corps will require renovation of existing port facilities to accommodate MEF embarkation, as well as construction of various new operations facilities in support of the MEF mission. Furthermore, new training areas and associated facilities are proposed for selected areas on Guam. These developments require extensive surveys that locate, identify, and assesses the natural resources of Guam, and also identify and assess invasive species that might expand their ranges within Guam's waters.

Data from these surveys are expected to serve as a guide for decisions affecting land and coastal use for proposed construction and renovation of facilities and training sites on Department of Defense and contractor-controlled lands in the Inner Apra Harbor of Guam.

<u>Scope of Work</u>

1. Conduct field surveys for fish, corals, macroinvertebrates, and macrophytes of harbor bottom and sheet piling wharf faces at Oscar and Papa Wharves in Inner Apra Harbor.

2. Prepare a technical report on fishes, corals, macroinvertebrates, macrophytes, essential fish habitat evaluation, and assessment of endangered species.

3. Attend project team meetings/conferences calls.

METHODS

Survey Site Selection

Both Oscar and Papa Wharves (Figure 1) are obstructed by large shipyard facilities that limited access to wharf faces. During the survey period, two large crane barges were moored at Oscar Wharf while a large dry dock occupies virtually all of Papa Wharf's main face. Therefore, transect lengths were limited to a 50-m stretch of wharf face at Oscar Wharf and a 50-m stretch of wharf face at the back of Papa Wharf where this wharf s with Romeo Wharf. GPS coordinates were recorded for transect locations at each wharf.

Benthic Cover

Benthic cover was surveyed along 50-m transects established at a depth of 6 m for coral, invertebrate, and fish surveys at Oscar and Papa Wharves. Marine plant communities and substrate types in each zone were quantified by a modified point-quadrat method (Tsuda, 1972). This method consists of identifying and recording substrate types and organisms under the points of intersection of strings stretched across a 0.25-m^2 (50 cm x 50 cm) quadrat. Four strings stretched from each side of the quadrat provide 16 points (intersections). The quadrat was placed randomly at 5-m intervals along the length of the transect. The quadrat was deployed a total of 10 times, providing 160 data points on a 50-m transect. Percent cover was calculated from these points. Limited visibility in the inner harbor precluded documentation of benthic flora and fauna with photoquadrat records. Species within the study area, but not encountered along the transect line, were also recorded.

Corals

Coral communities were quantified along the transects by an observer using the point-quarter method of Cottam et al. (1953). Points were assigned at 5-m intervals along each transect. Each point served as a focus of four equal-sized quadrants arrayed around the point. Within each quadrant, the coral closest to the central point was located. This coral's identity, distance from the point, length, and width were recorded. If no corals lay within 1 m of the point, that quadrant was recorded as having no corals. From the recorded data, community and species-specific population density of colonies, percent coverage, and frequency of occurrence were then computed with the following equations from Cottam et al. (1953):

Total Density Of All Colonies = Unit Area / (Average Point-To-Colony Distance)^2
Relative Density Of A Species = 100 * Number Of Colonies Of The Species / Number Of All Colonies
Absolute Density Of A Species = Percent Density * Total Density / 100
Total Percent Coverage Of All Species = Total Density * Average Coverage Of All Species
Relative Coverage Of A Species = Species Density * Average Coverage of the Species

Population data for each species were also calculated, including the number of colonies, average colony size, standard deviation of colony size, and minimum and maximum colony size. To record the less common species not recorded by the quantitative survey, a list of species was also assembled by swimming along the entire transects and recording all species seen within 2 m of the line.

Macroinvertebrates

All conspicuous solitary epibenthic macroinvertebrates occurring within 1 m of either side of the transect lines were identified and enumerated by an observer swimming along the transect line. For this study, conspicuous is defined as being larger than 50 mm in size and as being clearly visible to an observer without need of overturning rocks or digging into the substrate. Cryptic, microscopic, nocturnal, and highly motile species that avoid humans (e.g., crabs and shrimps) were not included within the scope of this study. Species diversity and abundance were recorded in 10-m intervals along the transect line. Therefore, for statistical purposes, each belt transect consisted of five 20-m^2 replicate plots, except where noted.

Similarities in structure of macroinvertebrate assemblages on the two transects were calculated by the Bray-Curtis similarity method with PRIMER ver. 6 (Clarke and Gorley, 2006). Species of macroinvertebrates observed in the study area, but not encountered along the transect line, were also recorded but not included in the similarity analyses.

Fishes

Fishes were surveyed visually along transect lines. Observations were constrained by poor visibility and all species had to be counted on a single pass along the transect line. Along both wharf faces, three transects were run (where possible), respective of depth, just below the surface(subsurface), at mid-depth (the principal transect line), and at the bottom of the wharf wall. All fishes observed 0.5m above or below the line, were counted on subsurface and mid-depth transects; at the bottom, all fishes observed 1 m to the seaward side (away from the wharf face) of the line were counted. These methods provided estimates of density (no. individuals/m^2) for each species. Fishes were identified to species. Identifications followed Myers (1999) and Myers and Donaldson (2003), except where more recent taxonomic studies were relevant. Reference photographs were taken with an underwater digital camera but image quality tended to be extremely poor because of turbid conditions. For estimates of species diversity, standard measures of species richness, species diversity, and similarity were calculated and compared between stations with PRIMER vers. 6; DIVERSE PROCEDURE; Clarke and Gorley, 2006). Multidimensional scaling (PRIMER vers. 6; MDS procedure) was used to examine similarities between stations based upon Bray-Curtis coefficients calculated for each. This test indicates relative distances between samples based upon their similarities in assemblage structure. Points found close together represent samples that were very similar in species composition while those far away represented different assemblage structures (Clarke and Gorley, 2006). Analysis of Similarities (PRIMER, ver. 6; ANOSIM procedure, square root transformed) was used to test the null hypothesis that there were no differences in assemblage structure between groups of observations (depth of transect) at the stations (wharves).

Essential Fish Habitat

Qualitative measures of habitat utilization by fishes were limited to observations of association between species and habitat and microhabitat types. Major habitat types were the vertical surfaces of both Oscar and Papa Wharves (= wharf) and the harbor floor (= soft bottom). Microhabitats included corals, mollusc shells (mainly *Malleus decurtatus* and *Spondylus squamosus*), debris (hanging and deposited on the bottom), silt, and the water column).

RESULTS AND DISCUSSION

Because of the length of the transects (50m) at each wharf, no attempt was made to determine the starting and ending coordinates of each transect. GPS coordinates describing the general location of each 50 m transect were N 13.43824, E 144.66241 for Oscar Wharf and N 13.43658, E 144.66032 for Papa Wharf.

Benthic Cover

Mean surface coverage of the vertical substrate along the transects at Oscar and Papa Wharves is presented in Figure 2. The harbor floor not sampled. Substrate coverage was divided into seven abiotic and biotic features at the sites. The mean biotic coverage in ten quadrat samples was 20.63 % at Oscar Wharf and 55.63 % at Papa Wharf. Sponges were the predominant biotic cover organisms at Oscar Wharf, ranging from 0–18.75 percent cover; macroalgae were predominant at Papa Wharf, ranging from 12.5–62.5 percent cover. Bray-Curtis similarity analysis (fourth root transform, cluster mode: group average) indicated 83.91% resemblance of the benthic cover data at the two wharves. A list of marine plants observed at the two sites is given in Table 1.

Corals

Size-frequency distributions of the six species of scleractinian corals encountered on transects at Oscar and Papa Wharves, Inner Apra Harbor are presented in Table 2. An additional 13 species of scleractinian corals were observed on wharf faces adjacent to the transects (Table 3). One species of non-scleractinian anthozoan and one species of hydrozoan were also recorded. Therefore, a cumulative total of 21 species of corals and related organisms, representing 13 families and 16 genera, was observed at the study site.

Species richness was highest at Oscar Wharf, where six species occurred on the transect; only three species occurred on the transects at Papa Wharf. *Leptastrea purpurea*, *Pocillopora damicornis* and *Porites lobata* were the most frequently observed species. Three species, *Dendrophyllia* sp., *Psammocora haimeana, and Porites rus* occurred on the transect only at Oscar Wharf.

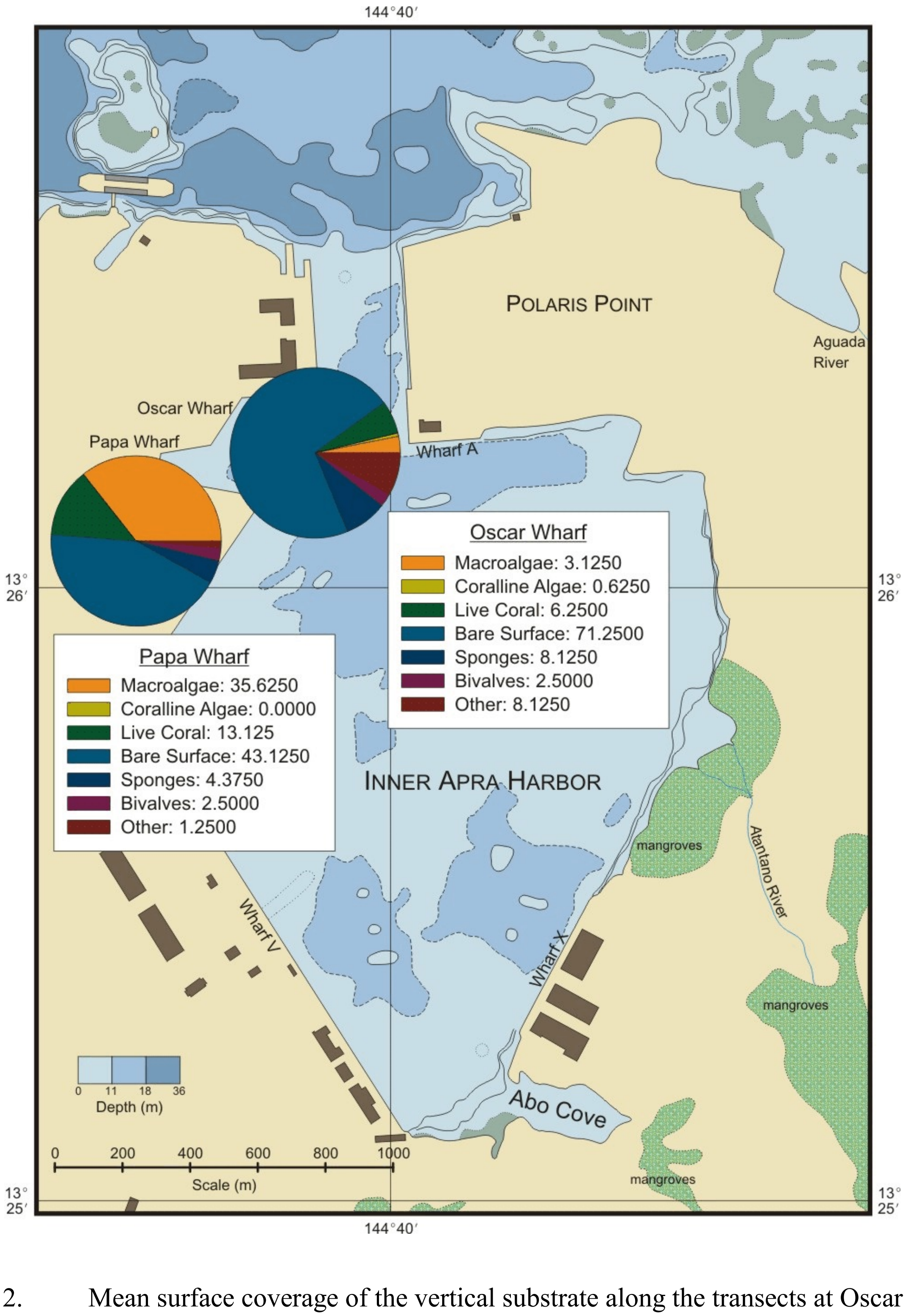

Figure 2. Mean surface coverage of the vertical substrate along the transects at Oscar and Papa Wharves

Table 1. Taxonomic list of marine plants observed at depths of 0–6 m on the faces of Oscar and Papa Wharves. Phylogenetic arrangement follows Lobban and Tsuda (2003).

	Oscar Wharf	Papa Wharf
Cyanophyta:Cyanophyceae		
cf. *Lyngbya aestuarii*	●	○
Rhodophyta:Rhodophyceae		
Galaxaura filamentosa	●	○
Peyssonnelia rubra		●
Heterokontophyta:Phaeophyceae		
Dictyota bartayersiana	●	●
Padina boryana	●	●
Chlorophyta:Chlorophyceae		
Enteromorpha clathrata	●	○
Bryopsis sp.	●	○

Table 2. Size-frequency distributions of coral species recorded on transects Oscar and Papa Wharves, Inner Apra Harbor. N_i = number of colonies. Mean, SD (standard deviation), and Range refer to colony size in cm^2.

Location	Species	N_i	Mean	SD	Range
Oscar Wharf	*Leptastrea purpurea*	15	7.36	9.355	1.18–29.45
	Pocillopora damicornis	7	24.15	20.627	4.71–65.97
	Porites lobata	7	4.82	5.038	0.79–14.14
	Dendrophyllia sp.	2	3.63	1.805	2.36–4.91
	Porites rus	1	–	–	8.25
	Psammocora haimeana	1	–	–	1.18
Papa Wharf	*Pocillopora damicornis*	21	346.67	364.357	0.79–1,154.54
	Leptastrea purpurea	17	13.32	14.513	1.57–44.18
	Porites lobata	2	214.71	296.701	4.91–424.51

Table 3. Species of scleractinian and hydrozoan corals observed at Oscar and Papa Wharves. A filled circle (●) indicates presence of a species, and an open circle (○) indicates that the species was not recorded at that site. Phylogenetic arrangement follows Randall (2003).

	Oscar Wharf	Papa Wharf
Hydrozoa:Milleporidae		
Millepora tuberosa	●	○
Anthozoa:Pocilloporidae		
Pocillopora damicornis	●	●
Anthozoa:Acroporidae		
Astreopora myriophthalma	●	●
Astreopora randalli	○	●
Anthozoa:Agariciidaea		
Leptoseris mycetoseroides	●	○
Anthozoa:Siderastreidae		
Psammocora haimeana	●	●
Anthozoa:Fungiidae		
Herpolitha weberi	●	○
Anthozoa:Poritidae		
Porites compressa	○	●
Porites lichen	●	○
Porites lobata	●	●
Porites rus	●	●
Anthozoa:Faviidae		
Diploastrea heliopora	○	●
Leptastrea purpurea	●	●
Oulophyllia levis	○	●
Anthozoa:Rhizangiidae		
Culicia rubeola	●	○
Anthozoa:Mussidae		
Lobophyllia corymbosa	●	○
Lobophyllia hemprichii	○	●

Table 3, continued.

	Oscar Wharf	Papa Wharf
Anthozoa:Pectiniidae		
Pectinia paeonia	○	●
Anthozoa:Dendrophylliidae		
Dendrophyllia sp.	●	●
Turbinaria reniformis	○	●

Quantitative analysis of the coral species encountered on each transect is presented in Table 4. *Pocillopora damicornis* was predominant in coverage and averaged 71.5% relative coverage between the two transects. *Leptastrea purpurea* had the second highest relative coverage (18.2%) between the two transects. A Bray-Curtis Similarity Index value calculated from 4th- root transformed relative coverage data indicated a similarity of 68.6% between coral assemblages at the two wharves. The data set was too small, however, to compare assemblage structures by non-metric multidimensional scaling (NMDS) analysis.

Macroinvertebrates

Mean densities of conspicuous, solitary invertebrates at Oscar and Papa Wharves are given in Table 5. Seventeen species of solitary macroinvertebrates were encountered on the transect at Papa Wharf, and 12 species were recorded on the transect at Oscar Wharf. As noted at other sites in Inner Apra Harbor (Smith et al., 2008), 100 percent of the macroinvertebrates encountered on the transects were suspension feeders. Bivalve molluscs (7 species) and solitary ascidians (8 species) dominated the macroinvertebrate fauna at both wharves, and mean densities were generally greater at Papa Wharf. The bivalves *Malleus decurtatus* and *Spondylus squamosus* were remarkably more abundant at Papa Wharf, as was the ascidian *Rhopalaea circula*. Mean densities ranged from <1.0 individual/20 m^2 (several species) to 55.0 individuals/20 m^2 (*Spondylus squamosus* at Papa Wharf). Spondylid bivalves occurred at the greatest density encountered at both sites, with a cumulative density of 70.0 ± 30.9 individuals/20 m^2. Mean density of all species at Oscar Wharf was 45.4 ± 43.71 solitary invertebrates/20 m^2, and 207.6 ± 199.47 solitary invertebrates/20 m^2 at Papa Wharf. Bray-Curtis similarity analysis (fourth root transform, cluster mode: group average) indicated 71.2% resemblance of the solitary invertebrate densities in the two communities.

α-level diversity of conspicuous epibenthic invertebrates, including both solitary and colonial forms, at Oscar and Papa Wharves is given in Table 6. A total of 36 species was observed during the survey, 28 species at Oscar Wharf and 33 species at Papa Wharf. The two wharves share 75% of the total recorded fauna. As noted above for invertebrate densities on transects, α-diversity was dominated by bivalve molluscs (12 species) and ascidians (10 species). Bray-Curtis similarity analysis (fourth root transform, cluster mode: group average) indicated 80.0% resemblance of the α-diversity in the two invertebrate communities.

Suspension-feeding invertebrates were predominant, making up some 86% of the fauna at the two sites. Grazing herbivorous gastropods were observed just above the water-line on the faces of both wharves, as was a browsing herbivorous grapsid crab. The deposit-feeding sea cucumber *Synapta maculata* was observed on the face of Papa Wharf. No predatory invertebrates were observed at either wharf.

Two noteworthy species of macroinvertebrates were observed at Oscar and Papa Wharves. The ahermatypic coral *Dendrophyllia* sp. was recorded on vertical wharf faces of both transects.

Table 4. Population density, frequency, and coverage of coral species recorded on transects at Oscar and Papa Wharves, Inner Apra Harbor, Guam.

Location	Species	N_i	Relative Density	Absolute Density	Frequency	Absolute Coverage	Relative Coverage
Oscar Wharf	*Leptastrea purpurea*	15	0.375	2.285	0.70	0.0021	0.3345
	Pocillopora damicornis	7	0.175	1.066	0.40	0.0033	0.5125
	Porites lobata	7	0.175	1.066	0.50	0.0007	0.1024
	No coral	7	0.175	1.066	0.40	0.0000	0.0000
	Dendrophyllia sp.	2	0.050	0.305	0.20	0.0001	0.0220
	Psammocora haimeana	1	0.025	0.152	0.10	0.0000	0.0036
	Porites rus	1	0.025	0.152	0.10	0.0002	0.0250
Papa Wharf	*Pocillopora damicornis*	21	0.525	10.088	1.00	0.4453	0.9173
	Leptastrea purpurea	17	0.425	8.167	1.00	0.0139	0.0285
	Porites lobata	2	0.050	0.961	0.20	0.0263	0.0541

Table 5. Mean densities of conspicuous, solitary invertebrates at Oscar and Papa Wharves. Data given are means ± standard deviations of counts in five 10-m^2 quadrats. Phylogenetic arrangement follows Paulay (2003) for bivalves and Lambert (2003) for ascidians.

	Oscar Wharf	Papa Wharf
Cnidaria:Anthozoa		
Dendrophyllia sp.	1.40 ± 1.14	0.20 ± 0.45
Annelida:Polychaeta		
Sabellastarte spectabilis	0.20 ± 0.45	0.60 ± 0.89
Mollusca:Bivalvia		
Malleus decurtatus	2.00 ± 1.58	36.00 ± 23.69
Spondylus multimuricatus	4.00 ± 5.10	10.80 ± 2.77
Spondylus squamosus	13.00 ± 11.07	55.00 ± 23.98
Spondylus spp.	2.40 ± 2.61	11.20 ± 4.15
Ostreidae sp.	---	0.20 ± 0.45
Chama lazarus	6.20 ± 3.56	15.20 ± 7.05
Chama spp.	1.40 ± 1.34	1.20 ± 1.10
Chordata:Ascidiacea		
Ascidia ornata	---	0.40 ± 0.89
Phallusia julinea	0.20 ± 0.45	2.80 ± 1.30
Phallusia niger	---	1.20 ± 2.17
Rhopalaea circula	8.00 ± 8.57	50.60 ± 40.34
Rhopalaea crassa	---	1.00 ± 1.00
Rhopalaea sp. A	6.20 ± 7.29	10.80 ± 6.72
Polycarpa cryptocarpa	0.40 ± 0.55	7.40 ± 1.82
Polycarpa spp.	---	3.00 ± 0.71

Table 6. Species of conspicuous epibenthic invertebrates observed at Oscar and Papa Wharves. A filled circle (●) indicates presence of a species, and an open circle (○) indicates that the species was not recorded at that site. Phylogenetic arrangement follows Kelly et al. (2003) for sponges, Smith (2003) for gastropods, Paulay (2003) for bivalves, and Lambert (2003) for ascidians.

	Oscar Wharf	Papa Wharf
Porifera:Demospongiae		
Dysidea sp.	●	●
Hyrtios sp.	●	●
Haliclona sp.	●	●
Clathria sp. (orange)	●	○
Clathria sp. (pink)	●	●
Clathria sp. (red)	●	●
Cnidaria:Hydrozoa		
Leptolida spp.	●	●
Cnidaria:Anthozoa		
Dendrophyllia sp.	●	●
Carijoa sp.	○	●
Annelida:Polychaeta		
Sabellastarte spectabilis	●	●
Mollusca:Gastropoda		
Littoraria pintado	●	○
Littoraria scabra	●	●
Siphonaria guamensis	●	●
Mollusca:Bivalvia		
Brachidontes sp.	○	●
Pinctada sp.	○	●
Malleus decurtatus	●	●
Spondylus multimuricatus	●	●
Spondylus squamosus	●	●
Spondylus spp.	●	●
Chama lazarus	●	●
Chama spp.	●	●
Alectryonella plicatula	●	●
Saccostrea mordax	●	●
Saccostrea cucullata	○	●

Table 6, continued.

	Oscar Wharf	Papa Wharf
Mollusca:Bivalvia		
Ostreidae spp.	●	●
Arthropoda:Crustacea		
Metapograpsus latifrons	●	●
Echinodermata:Holothuroidea		
Synapta maculata	○	●
Chordata:Ascideacea		
Lissoclinum fragile	○	●
Ascidia ornata	○	●
Phallusia julinea	●	●
Phallusia niger	●	●
Rhopalaea circula	●	●
Rhopalaea crassa	○	●
Rhopalaea sp. A.	●	●
Polycarpa cryptocarpa	●	●
Polycarpa spp.	●	●

Ahermatypic corals tolerate dim light conditions like those of the turbid waters of the inner harbor, as well as caves and deeper waters. *Dendrophyllia* spp. are considered rare in shallow waters in Guam (Richard H. Randall, personal communication, 26 March 2010); however, they are more common in deeper, darker waters offshore.

The observation of the octocoral *Carijoa* sp. is just the third record of this species in Guam. Paulay et al. (2003) previously reported *Carijoa* sp. from mooring buoys in Outer Apra Harbor and from a submarine cave near the Shark's Pit at Orote Peninsula. Although there is no indication of proliferation of *Carijoa* sp. in Guam, the presence of the species is noteworthy because of the situation in Hawaii. *Carijoa riisei*, a native of the tropical Western Atlantic, has invaded mesophotic coral reefs in Hawaii and devastated black coral communities that have been sustainably harvested for the jewelry industry for more than 40 years (Grigg, 2003, 2004; Kahng and Grigg, 2005)

Fishes

A checklist of species and their relative abundance (as percent) at each station is given in Table 7. Thirty-five species of fishes were observed on transects surveyed at both wharves. As with other sites within the Inner Apra Harbor surveyed previously (Smith et al., 2008), this low level of species richness represents an impoverished fish fauna (there are ca. 1,000 species of reef and nearshore fishes reported from the Mariana Islands; Myers and Donaldson, 2003; unpublished data). Components of this fauna, however, are indicative of protected, turbid lagoons or bays of Guam, of which there are relatively few compared to clear water reefs (unpublished data), and thus constitute a relatively unique assemblage of fishes.

Two invasive species were observed at both wharves. One, *Neopomacentrus violescens* (Pomacentridae, damselfishes), has been reported previously (Myers, 1999; Myers and Donaldson, 2003). This species was found more recently on Tango, Uniform and X-ray Wharves (Smith et al., 2008). The second species, *Amblygliphididon ternatensis* (Pomacentridae) was reported from Sierra, Tango, Uniform and Victor Wharves, while a third, *Rhamdia cypselurus* (Apogonidae, cardinalfishes), was reported previously from Sierra, Tango, Uniform and X-ray Wharves (Smith et al., 2008). The latter species was not observed at Oscar or Papa Wharves. The two damselfishes occur elsewhere in the western Indo-Pacific region in natural habitats somewhat similar to those found in Inner Apra Harbor (Myers, 1999).

Data on species richness, diversity, and abundance for each transect are given in Table 8. Species richness (the number of species observed) ranged from 15 (n = 57 individuals) at Oscar Wharf to 29 (n = 1347 individuals) at Papa Wharf Generally, species richness was greater on or adjacent to mid-wall and top-wall transects at both wharves, where corals, hanging debris, and oyster shells provided shelter for various species, but especially damselfishes, cardinalfishes and juvenile butterflyfishes. Bottom-transects at both wharves had the lowest number of species and individuals. These included burrowing gobies (mainly *Oplopomus oplopomus*) or transient snappers (*Lutjanus fulvus*).

Table 7. Fishes observed on transects at Oscar and Papa Wharves, Inner Apra Harbor. M = mid-transect, B = bottom transect, T = top transect, IS = invasive species.

	Oscar Wharf					Papa Wharf				
Species	IS	M	B	T	Total	M	B	T	Total	Grand total
Family Apogonidae										
Apogon lateralis		0	0	10	10	0	0	3	3	13
Apogon leptacanthus		0	0	0	0	0	0	1	1	1
Archamia fucata		0	0	0	0	1	0	6	7	7
Cheilodipterus quinquelineatus		1	1	0	2	0	0	9	9	11
Sphaeramia orbicularis		0	0	1	1	0	0	0	0	1
Family Carangidae										
Caranx melampygus		0	0	0	0	2	0	0	2	2
Caranx sexfasciatus		0	0	0	0	13	0	0	13	13
Family Lutjanidae										
Lutjanus fulvus		0	1	0	1	2	8	0	10	11
Family Mullidae										
Parupeneus ciliatus		0	0	0	0	1	0	0	1	1
Family Chaetodontidae										
Chaetondon bennetti		0	0	0	0	0	0	10	10	10
Chaetodon ephippium		2	0	0	2	2	0	0	2	4
Chaetodon ulietensis		0	2	0	2	0	0	0	0	2
Chaetodon unimaculatus		0	0	0	0	0	0	1	1	1
Chaetodon vagabundus		1	0	0	1	0	0	0	0	1
Family Pomacentridae										
Abudefduf sexfasciatus		0	0	2	2	0	0	0	0	2
Amblyglyphididon curacao		1	0	0	1	0	0	0	0	1
Amblyglyphididon ternatensis	1	1	0	0	1	50	0	47	97	98
Chromis viridis		0	0	12	12	98	0	1015	1113	1125
Dascyllus aruanus		0	0	0	0	0	0	14	14	14
Neoglyphididon violescens	1	0	0	0	0	0	0	1	1	1
Pomacentrus amboinensis		3	0	10	13	2	2	4	8	21
Pomacentrus pavo		2	0	4	6	0	1	6	7	13
Family Labridae										
Halichoeres trimaculatus		0	0	0	0	0	0	3	3	3
Family Labridae: Scarinae										
Chlorurus sordidus juv		0	0	0	0	0	0	4	4	4
Leptoscarus vaigiensis juv		0	0	0	0	0	0	6	6	6
Family Callionymidae										
Dactylopus dactylopus		0	0	0	0	0	1	0	1	1
Family Gobiidae										
Amblygobius phaelena		0	0	0	0	0	0	0	0	0
Asterropteryx semipunctatus		0	0	0	0	0	0	1	1	1

Table 7. Continued.

Species	Oscar Wharf					Papa Wharf				
	IS	M	B	T	Total	M	B	T	Total	Grand total
Eviota punctulata		0	0	0	0	2	0	0	2	2
Eviota sp.		0	0	0	0	3	0	8	11	11
Exyrias bellissmus		0	0	0	0	0	1	0	1	1
Oplopomus oplopomus		0	0	0	0	0	6	0	6	6
Family Acanthuridae										
Acanthurus blochii		0	0	3	3	0	2	7	9	12
Zebrasoma veliferum		0	0	0	0	0	0	1	1	1
Family Tetraodontidae										
Canthigaster solandri		0	0	0	0	0	1	2	3	3
Total individuals		11	4	42	57	176	22	1149	1347	1404

Table 8. Species richness (S), diversity (H'), and abundance (N) of fishes at Oscar (O) and Papa (P) Wharves, Inner Apra Harbor. M = mid-transect, B = bottom-transect, and T = top-transect.

Transect	S	H'	N
OM	7	1.85	11
OB	3	1.04	4
OT	7	1.69	42
PM	11	1.26	176
PB	8	1.72	22
PT	20	0.63	1149

Shannon's H', a measure of species diversity that adjusts species richness to consider also the influence of abundance (Magurran, 1988), was highest on the mid-transect at Oscar Wharf. Here, low abundance of fishes (n = 11) but relatively high species richness (7 species) accounted for high diversity. The top-transect at Papa Wharf, on the other hand, had high abundance (n = 1149) and also the greatest overall species richness (S = 20), but the most individuals were of a single species, *Chromis viridis* (Table 7). At both wharves, corals, soft corals, and molluscs (mainly oysters) were present and appeared to be protected from ship or barge damage by fenders, thus making them available to fishes for shelter.

At Oscar Wharf, relative abundance, the percentage of a single individual out of the total number of individuals observed (Table 9), was greatest for the juvenile butterflyfish, *Chaetodon ulietensis* (50% on the top-transect), followed by the damselfish *Pomacentrus amboinensis* (27.3 % on the mid-transect) and the cardinalfish *Cheilodipterus quinquelineatus* (25% on the bottom transect). At Papa Wharf, relative abundance was greatest for the damselfish *Chromis viridis* (88.4 % on the top-transect), followed by the snapper *Lutjanus fulvus* (37% on the bottom-transect) and the invasive damselfish *Amblyglyphididon ternatensis* (28.4% on the mid-transect).

Densities of fish species (number of individuals/m^2) at each wharf are given in Table (10). The damselfish *Pomacentrus amboinensis* had the greatest density at Oscar Wharf, followed by another damselfish, *Chromis viridis* and a cardinalfish, *Apogon lateralis*. Most of the damselfishes, particularly *C. viridis*, were juveniles or sub-adults. At Papa Wharf, *C. viridis* had, by far, the greatest density, followed by two water-column dwelling species, the trevally *Caranx sexfasciatus* and the snapper *Lutjanus fulvus*. A previous survey of other wharves within the Inner Apra Harbor (Smith et al., 2008) found that the small, structure-associated cardinalfish *Apogon lateralis* had the highest densities, followed by another cardinalfish, the apparently invasive *Rhabdamia cypselerus,* and the invasive damselfish, *Amblyglyphididon ternatensis*.

The similarity of species composition between stations and transect depths was examined with group cluster analysis (Figure 3) and multiple dimension scaling analysis (Figure 4). The fish assemblages revealed the following pattern: Oscar bottom-transect had a similarity of 20% with all other transects; Papa bottom and Oscar mid- and top transects had a 30% similarity with one another; Papa mid- and top transects had a similarity of 35%; Oscar top and Papa bottom transects were the most similar (40%) because of the presence of the surgeonfish *Acanthurus blochii* on both transects (Table 7). A stress level of 0.00 indicated a high degree of confidence in the MDA results (Clarke and Gorley, 2001).

Analysis of similarity (ANOSIM) between fish assemblage structure of both wharves in relation to depth of transect indicated that there were only minor differences between them (Global R = 0.167) and these were not significant. Thus, the fish faunas of each tended to share many of the same species typical of protected and turbid waters, while differences can be

Table 9. Relative abundance (RA, %) of fishes on transects at Oscar and Papa Wharves, Inner Apra Harbor, Guam. M = mid-transect, B = bottom transect, and T = top transect.

	Oscar Wharf Transect			Papa Wharf Transect		
Family and Species	M	B	T	M	B	T
Family Apogonidae						
Apogon lateralis	0.0	0.0	23.8	0.0	0.0	0.3
Apogon leptacanthus	0.0	0.0	0.0	0.0	0.0	0.1
Archamia fucata	0.0	0.0	0.0	0.5	0.0	0.5
Cheilodipterus quinquelineatus	9.1	25.0	0.0	0.0	0.0	0.8
Sphaeramia orbicularis	0.0	0.0	2.4	0.0	0.0	0.0
Family Carangidae						
Caranx melampygus	0.0	0.0	0.0	1.1	0.0	0.0
Caranx sexfasciatus	0.0	0.0	0.0	7.1	0.0	0.0
Family Lutjanidae						
Lutjanus fulvus	0.0	25.0	0.0	1.1	53.3	0.0
Family Mullidae						
Parupeneus ciliatus	0.0	0.0	0.0	0.5	0.0	0.0
Family Chaetodontidae						
Chaetondon bennetti	0.0	0.0	0.0	0.0	0.0	0.9
Chaetodon ephippium	18.2	0.0	0.0	1.1	0.0	0.0
Chaetodon ulietensis	0.0	50.0	0.0	0.0	0.0	0.0
Chaetodon unimaculatus	0.0	0.0	0.0	0.0	0.0	0.1
Chaetodon vagabundus	9.1	0.0	0.0	0.0	0.0	0.0
Family Pomacentridae						
Abudefduf sexfasciatus	0.0	0.0	4.8	0.0	0.0	0.0
Amblyglyphididon curacao	9.1	0.0	0.0	0.0	0.0	0.0
Amblyglyphididon ternatensis	9.1	0.0	0.0	27.3	0.0	4.1
Chromis viridis	0.0	0.0	28.6	53.6	0.0	88.3
Dascyllus aruanus	0.0	0.0	0.0	0.0	0.0	1.2
Neoglyphididon violescens	0.0	0.0	0.0	0.0	0.0	0.1
Pomacentrus amboinensis	27.3	0.0	23.8	1.1	13.3	0.3
Pomacentrus pavo	18.2	0.0	9.5	0.0	6.7	0.5
Family Labridae						
Halichoeres trimaculatus	0.0	0.0	0.0	0.0	0.0	0.3
Family Labridae: Scarinae						
Chlorurus sordidus juv	0.0	0.0	0.0	0.0	0.0	0.3
Leptoscarus vaigiensis juv	0.0	0.0	0.0	0.0	0.0	0.5
Family Callionymidae						
Dactylopus dactylopus	0.0	0.0	0.0	0.0	6.7	0.0
Family Gobiidae						
Amblygobius phaelena	0.0	0.0	0.0	0.0	0.0	0.0
Asterropteryx semipunctatus	0.0	0.0	0.0	0.0	0.0	0.1
Eviota punctulata	0.0	0.0	0.0	1.1	0.0	0.0
Eviota sp.	0.0	0.0	0.0	1.6	0.0	0.7
Exyrias bellissmus	0.0	0.0	0.0	0.5	0.0	0.0
Oplopomus oplopomus	0.0	0.0	0.0	3.3	0.0	0.0

Table 9. Continued.

Family and Species	Oscar Wharf Transect			Papa Wharf Transect		
	M	B	T	M	B	T
Family Acanthuridae						
Acanthurus blochii	0.0	0.0	7.1	0.0	13.3	0.6
Zebrasoma veliferum	0.0	0.0	0.0	0.0	0.0	0.1
Family Tetraodontidae						
Canthigaster solandri	0.0	0.0	0.0	0.0	6.7	0.2
Total number of individuals	11	4	42	183	15	1149

Table 10. Density (no. /sq m) of fishes observed on transects at Oscar and Papa Wharves, Inner Apra Harbor, Guam. IS = invasive species, M = mid-transect, B = bottom transect, T = top transect.

	Oscar Wharf Transect				Papa Wharf Transect			
Family and Species	M	B	T		M	B	T	
Family Apogonidae								
Apogon lateralis	0	0	0.1	0.1	0	0	0.03	0.03
Apogon leptacanthus	0	0	0	0	0	0	0.01	0.01
Archamia fucata	0	0	0	0	0.01	0	0.06	0.07
Cheilodipterus quinquelineatus	0.01	0.01	0	0.02	0	0	0.09	0.09
Sphaeramia orbicularis	0	0	0.01	0.01	0	0	0	0
Family Carangidae								
Caranx melampygus	0	0	0	0	0.02	0	0	0.02
Caranx sexfasciatus	0	0	0	0	0.13	0	0	0.13
Family Lutjanidae								
Lutjanus fulvus	0	0.01	0	0.01	0.02	0.08	0	0.1
Family Mullidae								
Parupeneus ciliatus	0	0	0	0	0.01	0	0	0.01
Family Chaetodontidae								
Chaetondon bennetti	0	0	0	0	0	0	0.1	0.1
Chaetodon ephippium	0.02	0	0	0.02	0.02	0	0	0.02
Chaetodon ulietensis	0	0.02	0	0.02	0	0	0	0
Chaetodon unimaculatus	0	0	0	0	0	0	0.01	0.01
Chaetodon vagabundus	0.01	0	0	0.01	0	0	0	0
Family Pomacentridae								
Abudefduf sexfasciatus	0	0	0.02	0.02	0	0	0	0
Amblyglyphididon curacao	0.01	0	0	0.01	0	0	0	0
Amblyglyphididon ternatensis	0.01	0	0	0.01	0.5	0	0.47	0.97
Chromis viridis	0	0	0.12	0.12	0.98	0	10.15	11.13
Dascyllus aruanus	0	0	0	0	0	0	0.14	0.14
Neoglyphididon violescens	0	0	0	0	0	0	0.01	0.01
Pomacentrus amboinensis	0.03	0	0.1	0.13	0.02	0.02	0.04	0.08
Pomacentrus pavo	0.02	0	0.04	0.06	0	0.01	0.06	0.07
Family Labridae								
Halichoeres trimaculatus	0	0	0	0	0	0	0.03	0.03
Family Labridae: Scarinae								
Chlorurus sordidus juv	0	0	0	0	0	0	0.04	0.04
Leptoscarus vaigiensis juv	0	0	0	0	0	0	0.06	0.06
Family Callionymidae								
Dactylopus dactylopus	0	0	0	0	0	0.01	0	0.01
Family Gobiidae								
Amblygobius phaelena	0	0	0	0	0	0	0	0
Asterropteryx semipunctatus	0	0	0	0	0	0	0.01	0.01
Eviota punctulata	0	0	0	0	0.02	0	0	0.02
Eviota sp.	0	0	0	0	0.03	0	0.08	0.11
Exyrias bellissmus	0	0	0	0	0.01	0	0	0.01
Oplopomus oplopomus	0	0	0	0	0.06	0	0	0.06

Table 10. Continued.

	Oscar Wharf Transect				Papa Wharf Transect			
Family and Species	M	B	T		M	B	T	
Family Acanthuridae								
Acanthurus blochii	0	0	0.03	0.03	0	0.02	0.07	0.09
Zebrasoma veliferum	0	0	0	0	0	0	0.01	0.01
Family Tetraodontidae								
Canthigaster solandri	0	0	0	0	0	0.01	0.02	0.03
Total density of all fishes	0.11	0.04	0.42	0.57	1.83	0.15	11.49	13.47

attributed to the presence of seemingly unusual species (i.e., butterflyfishes normally seen in clear or less-turbid reef systems) associated with structure on some transects or the simple absence of most species, other than some burrowing gobies, on others (i.e., bottom transects).

Essential Fish Habitat

Overall, both wharf faces provided some considerable habitat for most species of fishes observed compared to the harbor floor offshore from the wharves (Table 11). Microhabitats associated with wharves included coral, debris, and shells that were attached to a wharf, the wharf wall and associated structures (pilings, fenders, pipes, zinc electrodes, etc.), debris, and silt at the base of the wharf wall, and the water column directly adjacent to the wharf. Most species were associated with one or more of these microhabitats. Benthic species such as cardinalfishes (Apogonidae), damselfishes (Pomacentridae), and gobies (Gobiidae) favored corals, debris, shells, and the wharf wall and pilings. Species that were active swimmers, such as butterflyfishes (Chaetodontidae), a snapper (Lutjanidae), a surgeonfish (Acanthuridae), trevallys and jacks (Carangidae), etc., were found in the water column directly adjacent to the wharves. Burrowing gobies and a dragonet (Callionymidae) were found on the silt bottom.

Threatened and Endangered Species

High turbidity levels at Oscar and Papa Wharves, as with elsewhere within Inner Apra Harbor (Smith et al., 2008), limited visibility (<5 m) prevented the detection of highly motile species, especially vertebrate organisms. No threatened or endangered species were observed at either of these survey sites.

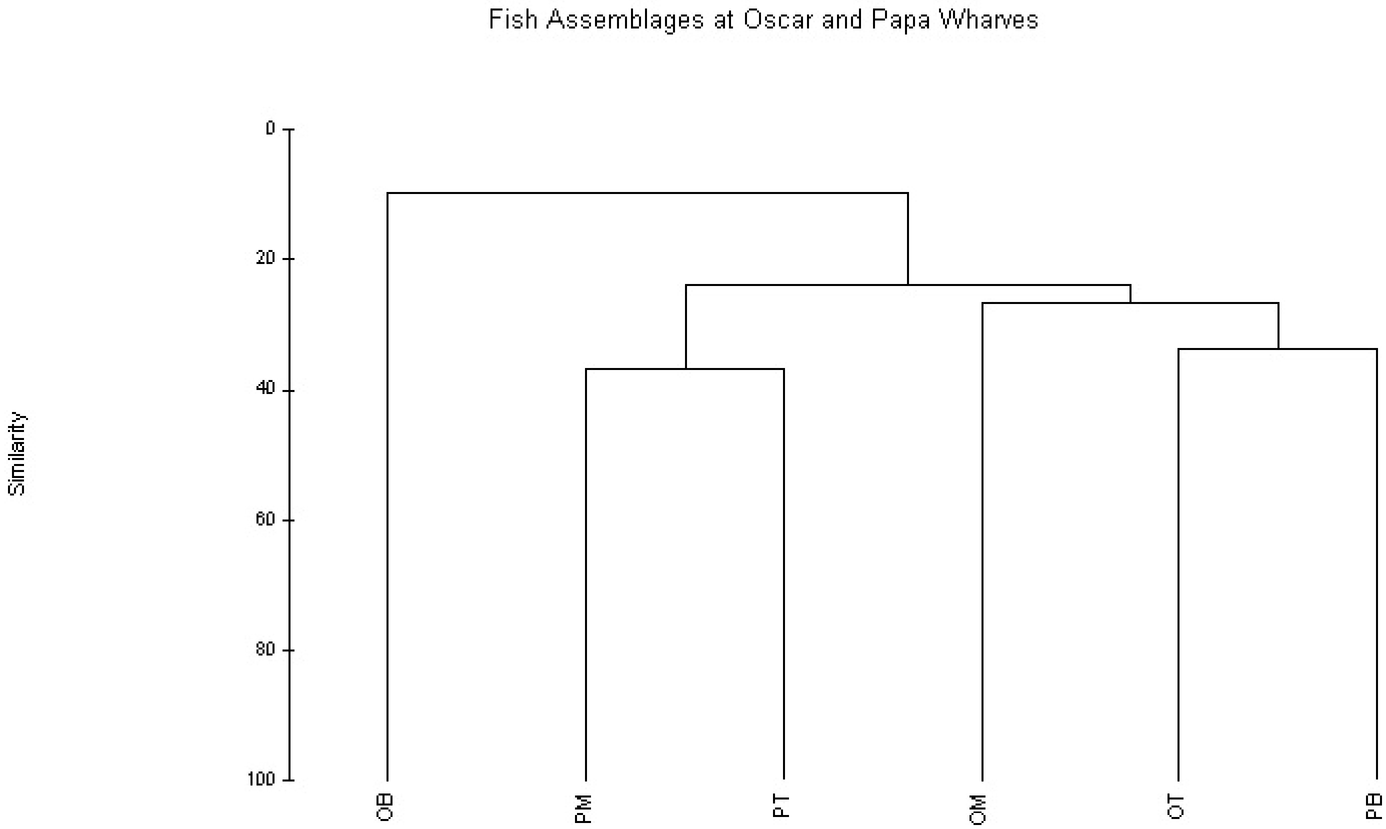

Figure 3. Cluster analysis of similarity between fish assemblages on transects at Oscar and Papa Wharves. See Table 7 for station definitions.

Fish Assemblages at Oscar and Papa Wharves

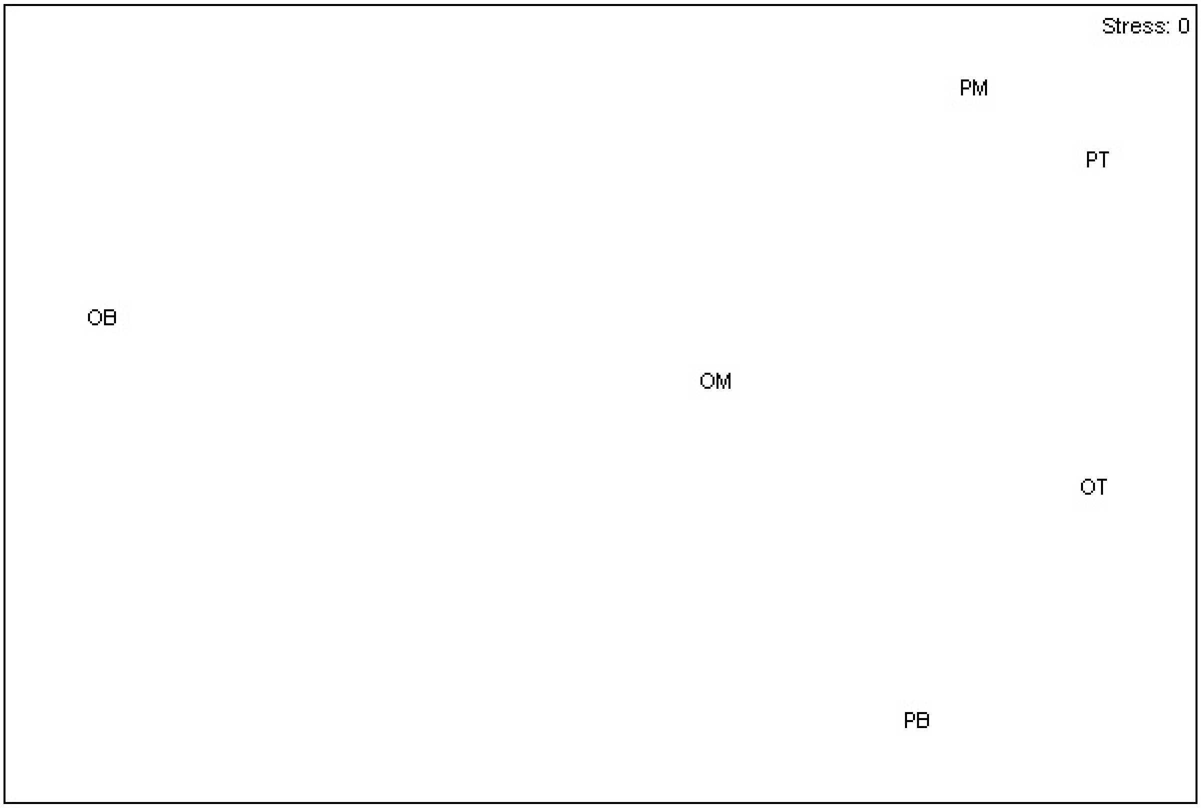

Figure 4. Multiple dimensional scaling (MDS) analysis of fish assemblages observed on transects at Oscar and Papa Wharves. See Table 7 for station definitions.

Table 11. Habitat and microhabitat associations of fishes observed at Oscar and Papa Wharves, Inner, Apra Harbor, Guam. Station codes are defined in Table . Habitat codes are W = wharf, B = soft , bottom. Microhabitat codes are c = coral, sh = shell, d = debris, st = silt, and wc = water column.

	Oscar Wharf Transect			Papa Wharf Transect			
Family and Species	M	B	T	M	B	T	
Family Apogonidae							
Apogon lateralis	0	0	Wc	0	0	Wc	
Apogon leptacanthus	0	0	0	0	0	Wc	
Archamia fucata	0	0	0	Wc	0	Wc	
Cheilodipterus quinquelineatus	1	1	0	0	0	Wc	d
Sphaeramia orbicularis	0	0	1	0	0	0	
Family Carangidae							
Caranx melampygus	0	0	0	Wwc	0	0	
Caranx sexfasciatus	0	0	0	Wwc	0	0	
Family Lutjanidae							
Lutjanus fulvus	0	1	0	Wwc	Wwc	0	
Family Mullidae							
Parupeneus ciliatus	0	0	0	Wc	0	0	
Family Chaetodontidae							
Chaetondon bennetti	0	0	0	0	0	Wc	
Chaetodon ephippium	Wwc	0	0	Wwc	0	0	
Chaetodon ulietensis	0	Wwc	0	0	0	0	
Chaetodon unimaculatus	0	0	0	0	0	Wwc	
Chaetodon vagabundus	Wwc	0	0	0	0	0	
Family Pomacentridae							
Abudefduf sexfasciatus	0	0	Wc	0	0	0	
Amblyglyphididon curacao	Wc	0	0	0	0	0	
Amblyglyphididon ternatensis	Wc	0	0	Wc	0	Wc	d
Chromis viridis	0	0	Wc	d	98	0	Wcd
Dascyllus aruanus	0	0	0	0	0	Wc	sh
Neoglyphididon violescens	0	0	0	0	0	Wsh	
Pomacentrus amboinensis	Wc	sh	0	Wc	2	Wd	Wsh
Pomacentrus pavo	Wc	0	Wc	0	Wd	Wc	
Family Labridae							
Halichoeres trimaculatus	0	0	0	0	0	Wd	
Family Labridae: Scarinae							
Chlorurus sordidus juv	0	0	0	0	0	Wd	
Leptoscarus vaigiensis juv	0	0	0	0	0	Wd	
Family Callionymidae							
Dactylopus dactylopus	0	0	0	0	Bst	0	
Family Gobiidae							
Amblygobius phaelena	0	0	0	0	0	0	
Asterropteryx semipunctatus	0	0	0	0	0	Wc	
Eviota punctulata	0	0	0	Wc	0	0	
Eviota sp.	0	0	0	Wc	sh	0	Wc
Exyrias bellissmus	0	0	0	0	Bst	0	
Oplopomus oplopomus	0	0	0	0	Bst	0	

Table 11. Continued.

Family and Species	Oscar Wharf Transect M	B	T	Papa Wharf Transect M	B	T
Family Acanthuridae						
Acanthurus blochii	0	0	Wwc	0	Wwc	Wwc
Zebrasoma veliferum	0	0	0	0	0	Wwc
Family Tetraodontidae						
Canthigaster solandri	0	0	0	0	Wc	Wc

Habitat Areas of Particular Concern (HAPC)

None of the three areas of Apra Harbor recognized by Paulay et al. (2001a) for their species richness and unique biota are encompassed by Oscar or Papa Wharves within the Inner Apra Harbor. These authors described the inner harbor as the most altered area with Apra Harbor, while remarking on the presence of uncommon species, such as *Porites convexa*, and the abundance of the hammer oyster *Malleus decurtatus* on wharf faces. Inner Apra Harbor lies at the extreme end of the gradient of increasing turbidity, abundance of plankton and benthic suspension feeders, and finer sediments. The harbor continues to support thriving marine communities, despite the extensive dredging and filling operations that significantly altered the area after World War II.

SUMMARY

As shown in a previous study (Smith et al., 2008), the artificial and most anthropogenically-impacted habitats, wharves, might contribute most to the biotic richness and diversity of the inner harbor. The synoptic account of the benthic invertebrates is indicative of unique benthic fauna, especially so for the sponges. Hence, more extensive taxonomic surveys are warranted to assess the biological value of the inner harbor, as well as its potential as an area for potential establishment of invasive species.

The coral fauna of the study area consisted of 19 species of scleractinian corals, and an additional two taxa including a stony hydrozoan and an octocoral. The predominant corals were *Pocillopora damicornis, Porites lobata,* and *Leptastrea purpurea.* The coral assemblage in Inner Apra Harbor is characteristic of environments with high levels of sedimentation and turbidity, with the most common species, in order of tolerance to these conditions, being *Porites lutea*, *Pocillopora damicornis*, and *Leptastrea purpurea* (Amesbury et al., 1977). Coral species richness is highest on relatively sediment-free, hard substrates on vertical faces of wharves (Smith et al., 2008; this report).

Macroinvertebrates communities on the vertical surfaces of Oscar and Papa Wharves were only moderately diverse, with species observed on or near transects. This pattern is consistent with that reported for similar localities within the inner harbor (Smith et al., 2008). For corals, availability of sediment-free hard substrate for sessile and sedentary macroinvertebrates is a limiting factor on horizontal surfaces. Macroinvertebrate assemblages on both wharves were dominated by suspension feeding species, which comprised 100% of the species occurring on transects and 90% of all species observed.

The species richness and diversity of the fish faunas of Oscar and Papa Wharves, like elsewhere in the inner harbor (Smith et al., 2008), are relatively low compared to habitats elsewhere on Guam (Donaldson, unpublished data). These faunas are highly adapted and representative of protected and turbid habitats usually associated with mangroves, estuaries, and back reefs, with some exceptions. A considerable amount of habitat is provided by artificial shelter in the form of wharves and jetsam and debris (pilings, frames, storage units, etc.), and the microhabitats found on or adjacent to these were utilized by many species of fishes. Larval fishes of these species could have settled and recruited to these habitats and microhabitats, either through natural stochastic processes or by transport (i.e., bilge water), and became established at each of the wharves. Many of the individuals of these species were juveniles or subadults. Alternatively, some species, particularly those that swim actively in the water column, may have colonized these habitats as adults after swimming to them from outside of the inner harbor.

RECOMMENDATIONS

During the planning phase for construction and renovation of facilities at Oscar and Papa Wharves, the following recommendations should be given consideration.

1. Floating turbidity curtains, extending from the surface to the lagoon floor, should be placed completely around all dredge and fill sites, and turbidity curtains should be routinely monitored and maintained to contain silt produced by construction.

Dredge and fill operations produce large quantities of fine silt particles suspended in the water column. Turbidity and sedimentation are significant problems for coral reefs surrounding high islands or in coastal areas of continents. Sediments may have an energetic cost to the coral that must cleanse its surface, resulting in slower growth rates and in less energy available for reproduction (Tomascik and Sander, 1987; Wolanski et al., 2003). Sediments can also interfere with larval recruitment on coral reefs by interfering with the chemosensory ability of coral larvae seeking the appropriate chemical signals from preferred settlement substrates, such as coralline algae (Richmond, 1997). Turbidity curtains can be effective in confining suspended sediments when properly deployed and maintained. Removal of the turbidity barriers and the related components is vital once the project activities are complete. Failure to do so can cause the barrier to come loose from its anchors and entangle benthic and other marine organisms (PBS&J, 2008).

2. All dredge and fill operations should be suspended during the period of the annual coral spawning event in Guam waters.

Some 85% of reef-building corals are spawners, i.e., reproduction occurs after the release of gametes into the water, where fertilization takes place (Richmond, 1997). Multispecies mass-spawning events occur during limited periods each year. To maximize reproductive success, most spawning species release their gametes over a 5–8-day period that is related to the lunar cycle. Studies in Guam revealed that peak spawning occurs 7–10 days after the full moon in July (Richmond and Hunter, 1990). Because suspended sediments may interfere with egg-sperm interactions in the fertilization process (Richmond, 1997; Wolanski et al., 2003), dredge and fill operations can affect coral reproduction on reefs far down current of the actual construction activities.

Construction windows are a management tool to map out the times of year during which coastal construction may be limited due to the presence of threatened or endangered species or other sensitive marine life (PBS&J, 2008). Construction windows may consider wildlife activity such as coral spawning and coral bleaching. U.S. Army Corps of Engineers permits for maintenance dredging of the Naval Base require that dredging operations cease during annual coral spawning periods in Guam (M.E. Guarin, P.E., Construction Management Engineer, NAVFAC OICC Marianas, personal communication, April 27, 2004).

3. Marine biological communities should be monitored during and after dredge and fill operations at Oscar and Papa Wharves.

Monitoring studies on small, tropical islands have shown that precautions for environmental protection can limit the effects of dredge and fill operations on nearby marine communities. Amesbury et al. (1982) identified few measurable effects related to construction of the airport runway extension at Weno Island, Chuuk [= Moen Island, Truk]. However, these authors reported that fluctuations in species richness, percent cover, and population density of several taxa occurred during the construction period. Where siltation was heaviest, the decline in coral coverage was significant, and no evidence of new coral recruitment was found one year after the completion of runway construction. Marine plants, macroinvertebrates, and reef fishes also declined at those monitoring stations that were inundated with sediments.

Biological monitoring should be required for any project that is proposed for construction in Oscar and Papa Wharves, so that any damage to coral communities along vertical surfaces caused by sedimentation can be identified promptly and so that necessary measures can be taken to minimize any damage. Monitoring is necessary to determine any direct or indirect biological impacts to the ecosystem caused by physical and/or chemical changes to the environment as a result of the project.

4. Invasive species should be monitored.

Because invasive species have been detected on both wharves, and on others surveyed previously (Smith et al., 2008), monitoring studies should emphasize early detection and eradication/management of invasive species and the possible expansion of their ranges locally.

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Appendix J
Supplemental Aircraft Carrier Marine Surveys

3. Ecological Assessment of Stony Corals and Associated Organisms in the Eastern Portions of Apra Harbor, Guam. August 2007.

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Ecological Assessment of Stony Corals and Associated Organisms in the Eastern Portions of Apra Harbor, Guam

AUGUST 2007

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EXECUTIVE SUMMARY

Apra Harbor is located mid-way along Guam's western coast and is the Mariana Archipelago's only deep lagoon. The harbor was substantially altered during WWII and has experienced additional development since the war. Apra Harbor supports a variety of commercial, military and recreational activities and installations and is also home to the Apra Harbor Naval Complex (AHNC).

In consideration of potential future projects at the AHNC the Navy completed a series of biological and oceanographic surveys in the central and western portions of the harbor; these surveys were conducted between 2003 and 2006. The present study was intended to provide comparable data on corals and associated organisms in the eastern portions of Apra Harbor.

Field surveys were conducted during July 2006 and May 2007; 152 person dives were completed. The dives were supported by the Naval Base Guam Dive Locker and there were no accidents or injuries. Ecological reconnaissance swims and Point Centered Quarter Transects were used to obtain data; corals in 1,908 quarters were measured.

Corals are present throughout the eastern portions of Apra Harbor; however, not all of eastern Apra Harbor is a functioning coral reef ecosystem. Some areas support only sparse, scattered corals or small patch reefs.

Most of the sea floor within the Turning Basin and Fairway, as designated on Nautical Chart 81054, consists of unconsolidated soft sediment.

The southwestern portion of Western Shoals (Big Blue Reef West) is a well developed, complex coral reef and is of comparable ecological value to any other reefs within Apra Harbor.

The second most ecologically important reef investigated in this study was located at Dry Dock Island. The present condition of this reef indicates that the corals of Apra Harbor may be more resilient and hardy than previously thought.

The coral reef in the Polaris Point/Bay segment is of marginal quality and showed the greatest signs of stress. The coral reefs in the remainder of the study area were of marginal to modest ecological value, based upon standard criteria for evaluating reefs. The coastal segment between Sumay Cove and the western side of the mouth of the Inner Apra Harbor Entrance Channel had only 2/10th of one percent sea floor cover by coral; it was not functioning as a coral reef.

No Endangered hawksbill sea turtles were observed during this study. Only nine underwater sightings of the Threatened green sea turtle were made; five of those sightings were at Big Blue Reef West. Three additional sightings were made from the boat. Sea turtles appeared to be significantly less numerous in the eastern portion of Apra Harbor than in the western portion.

I. Introduction

Guam is located in the tropical western Pacific and is the southern most and largest island in the Mariana Archipelago. Apra Harbor is located mid-way along Guam's western coast and is the archipelago's only deep lagoon (see Figure 1). Although the harbor has been dramatically altered since the liberation of Guam during WWII, it "…holds a vibrant and thriving marine community, including well-developed reefs with some of the highest coral cover on Guam, and a diverse biota of algae, invertebrates and fish. In this regard, the harbor is unlike most other major ports, which tend to become greatly degraded for marine life" (Paulay et al. 1997). Plates 1 – 6 provide aerial views of Apra Harbor during the 1940's and at present.

Apra Harbor supports a variety of commercial, military and recreational activities and includes both municipal and federal installations. A large portion of the harbor is home to the Apra Harbor Naval Complex (AHNC). Several projects are presently being considered to expand and improve the capabilities of the AHNC. As part of its long-range planning process, the Navy completed a series of biological and oceanographic surveys within the harbor. These surveys were conducted between 2003 and 2006 (see Appendix 1).

Results of these studies confirmed the 1997 conclusions of Paulay et al. that in spite of severe disruption during WWII and extensive development during and after the war, Apra Harbor continues to support well developed coral reefs and complex marine communities.

Figure 2 depicts general benthic habitats within Apra Harbor, as delineated by the National Oceanic and Atmospheric Administration (NOAA), and based primarily upon remote sensing technologies. The recent investigations conducted by the Navy, including this survey, provide increased detail on the distribution of corals and coral reefs.

FIGURE 1
Location Maps

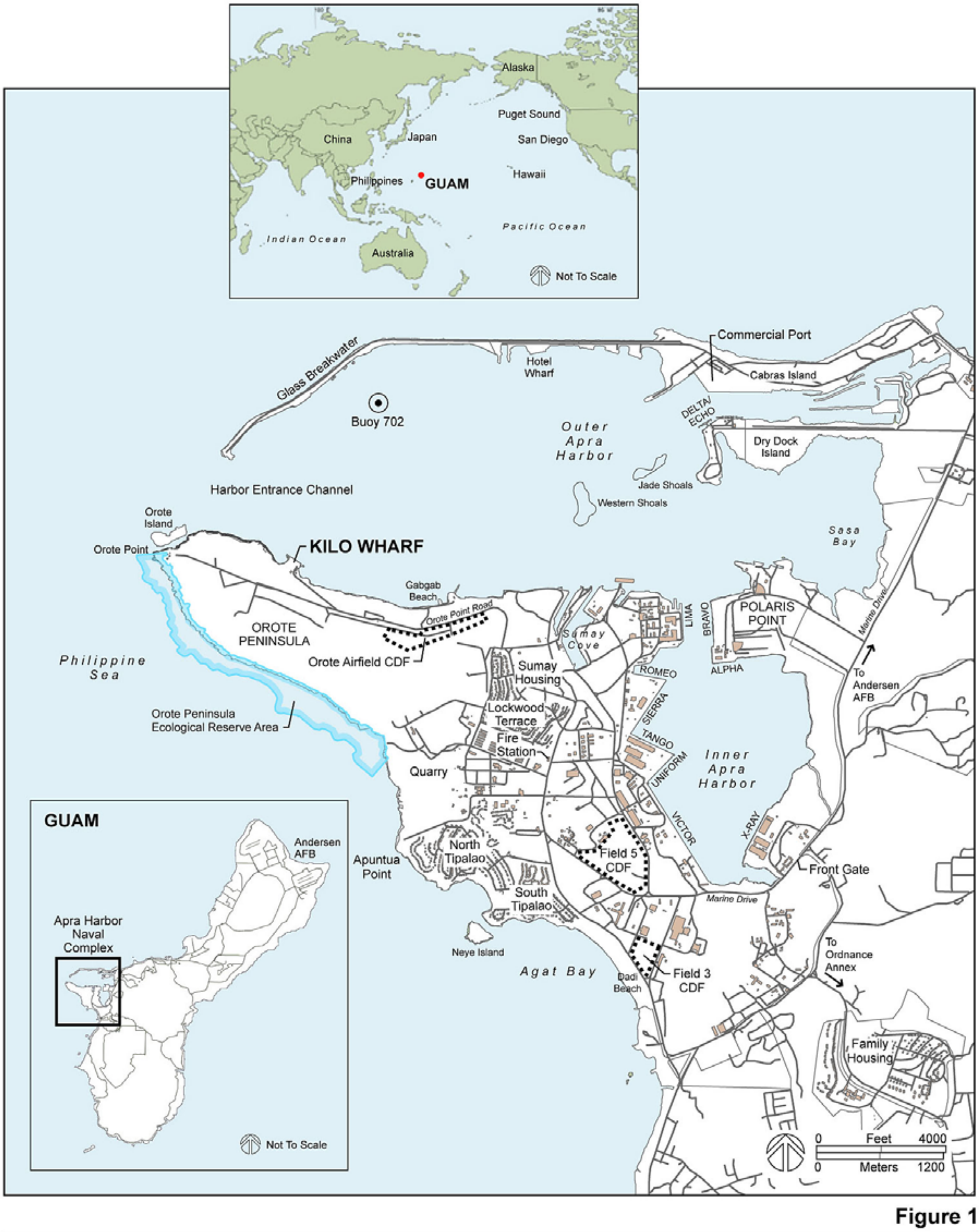


FIGURE 2
Apra Harbor with General Locations of NOAA Benthic Cover Types

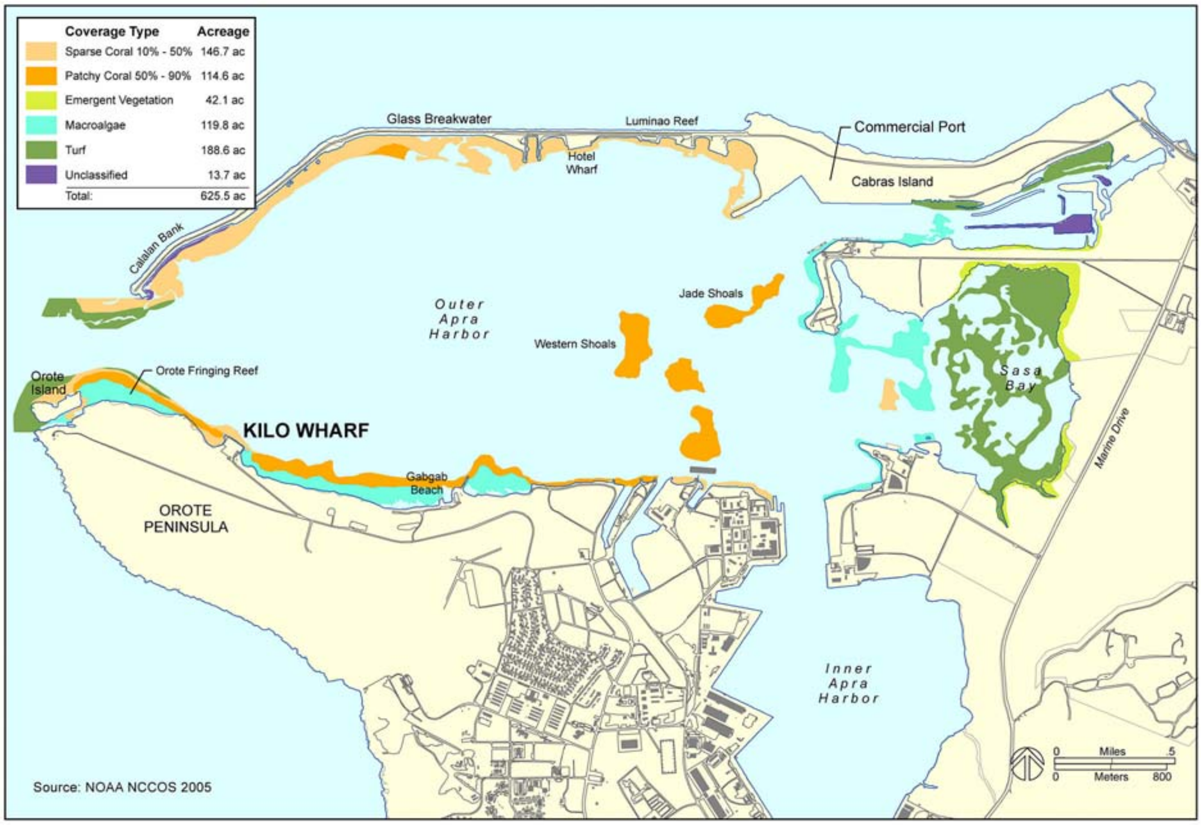


Figure 2

II. Objectives

A. Geographic Scope and General Objective

The quantitative investigations completed by the Navy between 2003 and 2006 were geographically focused on the area between Orote Point and Sumay Cove (see Figure 1). The present investigation was designed to assess and rank eight distinct areas to the east and north of the previous study areas. Corals and coral reefs served as the primary factor to rank each of these eight areas.

Figures 3 and 4 illustrate the portions of the harbor covered in this study. Table 1 provides commonly used names for these segments.

Table 1
General Study Locations

Commonly Referred To As:	Hereafter Referred To In This Report As:
Mouth of Sumay Cove (E edge) to Mouth of Inner Apra Harbor Entrance Channel (W edge)	Sumay-Inner Apra
SE Component of Western Shoals Complex	Big Blue Reef E and Big Blue Reef W
Polaris Point and Polaris Bay	Polaris Point/Bay
Turning Basin (N of Inner Apra Harbor Entrance Channel; East of Big Blue Reef E; South of Dry Dock Island)	Turning Basin
Fairway (Fairway to Inner Apra Harbor as denoted on Nautical Chart 81054 Jan. 28, 2003)	Fairway Shoals
Dry Dock Island (excluding the eastern side)	Dry Dock Is.
Delta Wharf and Echo Wharf (as denoted on Nautical Chart 81054 Jan. 28, 2003) located on Dry Dock Point and Dry Dock Island	Delta-Echo Wharves

Appendix 2 provides the coordinates for all of the shoal sites within the Fairway and Turning Basin, designated by the prefixes FWLW and TB, respectively.

B. Ecological Scope

The primary ecological objective of the surveys was to quantitatively assess the distribution and abundance of Scleractinian (stony) corals within the eight selected portions of Apra Harbor listed in Table 1 and shown in Figures 3 and 4. Information was also gathered on other coral taxa; however, Scleractinian corals were emphasized because of their dominant role in Apra Harbor in determining which other benthic invertebrates and fishes are present (Paulay et al. 1997; and Smith and Marx, 2006).

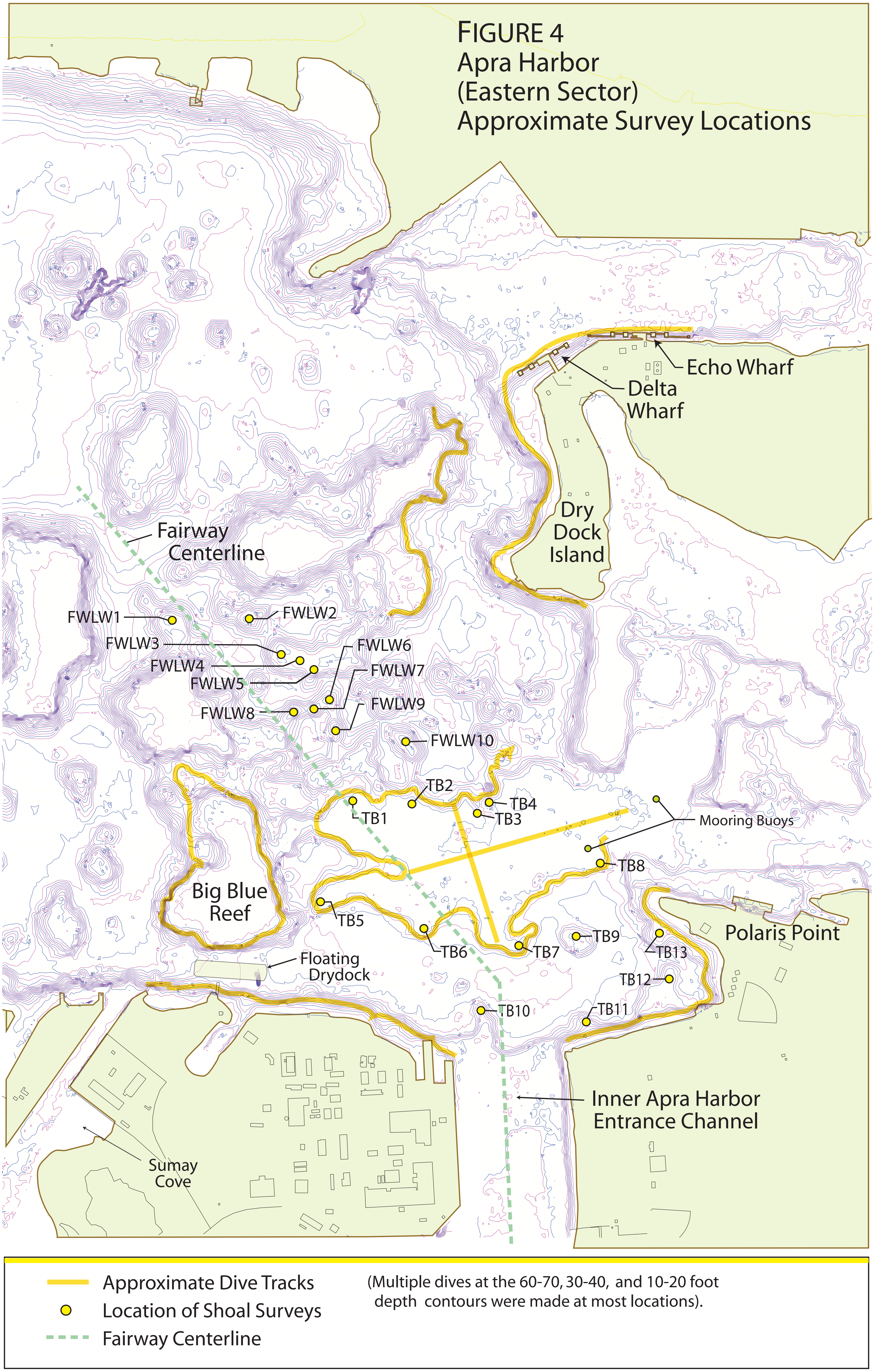
Specifically, data were obtained on the major Scleractinian coral taxa present at each location, their frequency of occurrence within transects, relative densities, size distribution, percentage of the sea floor covered by coral, and apparent health. It was not within the scope of this project to compile a list of species present; exhaustive species lists have already been developed and published for Guam (Micronesica Vol. 35 – 36, June 2003).

Qualitative and semi-quantitative data was also gathered on:

- Selected species of macro-algae and macro-benthic invertebrates
- Fin fish, Essential Fish Habitat (EFH) and potential Habitat Areas of Particular Concern (HAPC)
- Fish Species of Concern
- Threatened and Endangered sea turtles.

Figure 3
Bathymetric Chart of Apra Harbor

Approximate Dive Tracks	(Multiple dives at the 60-70, 30-40, and 10-20 foot depth contours were made at most locations).
Location of Shoal Surveys	
Fairway Centerline	



Approximate Dive Tracks
Location of Shoal Surveys
Fairway Centerline

(Multiple dives at the 60-70, 30-40, and 10-20 foot depth contours were made at most locations).

III. Methods

A. Diving

Open circuit, compressed air scuba dives were utilized to obtain quantitative and qualitative data. Two Navy marine ecologists (Donald E. Marx Jr. and the author) conducted the underwater surveys; one or both of the marine ecologists participated in every dive. The surveys were conducted during July 2006 and May 2007; 152 person dives were completed with maximum dive depths of 100 feet and maximum dive durations of 85 minutes. There were no accidents or injuries. Naval Base Guam Dive Locker under the command of Master Diver NDCS(MDV/DSW/SW) Daniel A. Horvath provided dive support. The other divers participating in the surveys included: HMC(DSW/FMF/IDC) William F. Montfort, ND1(DSW/SW) Christian D. Echeverry, ND1(SW/DV) Kevin T. Credle, ND1(SW/DV) Geoffery Ives, ND1(DSW/FMF) Shawn J. Kern, ND1(DSW/SW) Brian P. Odonnell, ND2(DSW) Jad Graves, ND2(DSW) Joshua E. Amberger, ND2(DV) Patrick A. Senecal, ND3 Jason L. Peters and ND2 Michael Fuzy IV.

B. Biological Survey Methods

General Procedures

The field study procedure consisted of two primary components: 1) ecological reconnaissance swims and 2) Point Centered Quarter Transects (PCQT). As applied to the study of corals in Guam the general PCQT procedures have been described by Randall et al.1988; Paulay et al. 2003; Smith 2004; and Smith and Marx 2006.

Reconnaissance Swims

Reconnaissance swims, often utilizing diver propulsion vehicles (DPVs), were completed covering the complete length of each coastal segment and the perimeter of all shoal areas. Figures 3 and 4 show the approximate dive tracks of the reconnaissance swims and the limits within which the PCQTs were performed. These swims were conducted along as many different depth contours as needed to ensure that the entire area from approximately 4 feet deep, or the crest of the shoal, to the harbor floor was observed. Shoal areas were located based upon a detailed hydrographic survey performed for the Navy in October 2005 (Sea Engineering, 2005). Previous observations, made during surveys completed in 2003, 2004, 2005 and 2006 (see Appendix 1), were also considered in selecting the locations to be investigated during this study.

Point Centered Quarter Transects

Based upon observations from previous surveys and reconnaissance swims made during this study it was apparent that there was a high degree of uniformity within each of the eight study areas. PCQT base points were randomly selected within the coastal sections. Range finders and GPS were used to locate base points where 60 and 70 m long PCQTs were completed, generally at the following depth contours: 60–70 feet, 30– 40 feet and 10-20 feet. Depths are reported in feet; all other measures in this document are metric.

On the shoals within the Turning Basin and Fairway, base points were selected by using the GPS center point of each charted shoal. A 60 and a 70 m PCQT were then conducted, each using a randomly selected compass heading. Nearly all the measurements within the Turning Basin and Fairway Shoals were within the 45-55 foot depth range due to sea floor topography.

At Big Blue Reef, PCQTs were conducted following the 30–40 and 10–20 foot depth contours. These transects were completed on both the eastern and western sides of the shoal.

For all the PCQTs the “0” m point and every subsequent 10 m point along the transect line was bisected at a 90^{o} angle, thus creating four quarters. The distance from the intersection point to the closest coral colony was then measured and recorded. The maximum dimension of the colony, parallel to the substrate was measured and the coral was placed into one of eight taxonomic categories, see Table 2. Colony heights were not measured.

Table 2
Taxonomic Categories Used in the PCQ Transects

Category 1 *Porites rus*	**Category 4 *Pocillopora damicornis***	**Category 8 All other taxa (includes: other major Scleractinian families; plus Milleporidae (fire corals) Stylasteridae (lace corals) Antipathidae (black & wire corals) Alcyoniidae (soft corals) Helioporacea (blue corals)**
Category 2 *Porites cylindrica*	**Category 5 *Acropora spp.***	
Category 3 *Porites spp.* (includes: *P. australiensis* *P. lobata, P. lutea* *P. annae, P. lichen* *P. horizontalata*)	**Category 6 Faviidae** **Category 7 Mussidae**	

These categories were used because of the overwhelming dominance of *Porites rus* on most of the transects; so few representatives of other species were present in most quarters that they had to be pooled to provide statistically meaningful results. The circumstances requiring pooling of taxa to produce meaningful results have been discussed and demonstrated by Cottam and Curtis (1956), Risser and Zedler (1968) and others. Coral identification was based upon Paulay et al. (2003), Randall (2003), and Veron (2000). Unequivocal identification of many coral species can only be done using a microscope; however, because no samples were taken in this study, identifications should be treated as ‘field identifications’only.

These data were utilized to determine a number of values, including: 1) general taxonomic/species composition, 2) frequency of occurrence within transects, 3) relative density, 4) size frequency and 5) the percentage of the sea floor covered by corals. It should be noted that, by taking a single measurement and treating it as a diameter, the size of coral colonies which are not round is actually over estimated. Also, Cottam and Curtis (1956), Smith et al. (2006) and others have demonstrated that the PCQT method generally gives a slightly higher estimate of percent cover than other commonly used methods such as quadrats, nearest neighbor, etc. It was the author's intent to obtain data in a manner which would err on the side of overestimating coral abundance versus under estimating it.

Other Observations of Corals and Macro-Benthos

In addition to the data acquisition described above, the following items were recorded both within and outside the PCQTs: 1) Scleractinian and non-scleractinian corals, to the lowest possible taxa, 2) Scleractinian specimens larger than 100 cm in their greatest dimension parallel to the substrate, 3) apparent health of all corals (bleached, diseased, overgrown with algae or sponge, copious secretion of mucous, predation by Crown of Thorns starfish), 4) associated benthos (e.g., macro algae, sponges and lobsters), 5) qualitative appraisal of reef complexity and rugosity, 6) evidence of anthropogenic impacts, such as anchor/chain damage, fish traps, etc.

Presence/absence data were recorded on select invertebrates. The animals noted were: *Octopus sp.* (octopus), *Trochus niloticus* (top shell), *Lambis sp.* (spider conch), *Panulirus penicillatus* (double spined rock lobster), and *Zosimus aeneus* (Xanthid reef crab). Porter et al. (2005) listed these species among Guam's most important harvested invertebrates.

Fin Fish, Essential Fish Habitat (EFH) and Habitat Area of Particular Concern (HAPC)

Semi-quantitative estimates of major fin fish families were made. Three abundance categories were used; abundant (> 50 individuals within a family sighted per dive), common (10-50) and occasional (<10). These estimates were for all members of each family recorded, regardless of their distance relative to the transect or the diver. Fish identification was based upon Amesbury and Myers (1982) and Myers (1991).

None of the study areas has been designated as HAPC. However, each location was subjectively evaluated relative to the four criteria used to designate HAPC. The four criteria are: 1) the ecological function provided by the habitat is important; 2) the habitat is sensitive to human induced environmental degradation; 3) development activities are or will be stressing the habitat and 4) the habitat is rare. Any one of these criteria may serve to provide the legal basis for designating HAPC.

Threatened and Endangered Species and Species of Concern

Four species listed under the Endangered Species Act are known to occur within the study area: Threatened green sea turtle (*Chelonia mydas*), Endangered hawksbill turtle (*Eretmochelys imbricata*) and two Species of Concern, Napoleon/humphead wrasse (*Cheilinus undulatus*) and humphead/bumphead parrotfish (*Bolbometopon muricatum*). The presence of these species was noted, as well as preferred habitat and/or forage. In the case of sea turtles an effort was made to obtain the following data: carapace length (<0.5 m, >0.5 < 1.0 m and > 1.0 m), sex, apparent health, distinguishing features (scars, barnacles, tumors) and the turtles activity when first sighted. If multiple turtle sightings were made on any single dive and if it could not be positively differentiated from the other sighting, the observation was simply recorded as two sightings. If the specimens sighted could be positively differentiated, the observation was recorded as two (or more) individual specimens.

IV. Results

A. Corals and coral reefs

Corals and/or coral reefs were present in all the locations investigated. Coral development varied dramatically between sites and at different depths, with some locations supporting well developed complex coral reefs and others supporting only small patch reefs or sparse scattered corals. Plates 7 – 13 illustrate some of these differences.

General species composition

Three Scleractinian coral families (Poritidae, Faviidae and Fungiidae) had representatives at every study location. Three others (Acroporidae, Pocilloporidae and Mussidae) had representatives at all but one of the study sites. Table 3 lists the major coral families observed at each location. It is important to note that apparent discrepancies between Table 3 and Tables 5 through 7 reflect the fact that all families seen on both transect dives and reconnaissance dives are listed in Table 3, while the taxa listed in Tables 5 through 7 represent only the coral taxa measured within a particular quarter. In most cases many colonies were present within each quarter, but per the PCQT method only the closest colony was measured.

Quantitatively assessing species diversity was not within the scope of this project; however, it was clearly higher on Big Blue Reef W than at any of the other study sites. All 17 coral families assessed were sighted at that location, and for many of those families more species were represented within each family than were observed at any of the other locations. This was particularly obvious for Pocilloporids, Acroporids, Agariciids, and Faviids. The Sumay-Inner Apra segment ranked second in the number of families sighted (13), followed by Dry Dock Is. (12). The lowest number of families sighted (5) was on Big Blue Reef E. Based upon the percentage of sea floor covered, Dry Dock Is. had the highest percentage of sea floor cover by “other taxa.” Much of that consisted of *Pavona cactus* (Agariciidae) and *Lobophyllia hemprichii* (Mussidae). *Leptoseris gardineri* (Agariciidae), which resembles *Pavona cactus*, and was also present.

Antipathidae (black and wire corals) were represented by small wire corals on the wharves and sunken causeways off Dry Dock Is. and by both small wire corals and black corals at Big Blue Reef W. A number of black coral “trees” were observed at Big Blue Reef W; the largest was approximately 60 cm in its greatest dimension. The latter location also supported the only Helioporidae (blue coral) and the largest number and variety of Alcyoniidae (soft corals), although some soft corals were present at every location. The most abundant genera were: *Sinularia*, *Lobophytum* and *Sacrophyton.*

The taxonomy of the horny corals/sea fans (Order Gorgonacea) is not well settled. Paulay et al. (2003) listed nine families within this group in Guam and CNMI. Representatives of these nine families were not recorded due to the author's lack of familiarity with this group. However, representatives of this Order were definitely present at Big Blue W, and tentatively at Dry Dock Is., Polaris Point/Bay and on the Fairway Shoals.

Table 3
Major Coral Taxa By Study Location Class Hydrozoa (red); Class Anthozoa Sub Class Hexacorallia Order Scleractinia [stony corals] (green); Order Antipatharia (black); Sub Class Octocorallia (blue)

FAMILIES	Delta & Echo Wharves	Dry Dock Island	Polaris Point	Turning Basin	Fairway Shoals	Big Blue Reef E.	Big Blue Reef W.	Sumay-Inner Apra
Milleporidae	x	x	x	o	o	o	x	x
Stylasteridae	x	o	o	o	o	o	x	x
Pocilloporidae	x	x	x	x	o	x	x	x
Acroporidae	x	x	x	x	x	o	x	x
Agariciidae	o	x	x	x	x	o	x	x
Siderastreidae	o	o	o	x	x	o	x	o
Fungiidae	x	x	x	x	x	x	x	x
Poritidae	x	x	x	x	x	x	x	x
Faviidae	x	x	x	x	x	x	x	x
Oculinidae	o	o	o	o	o	o	x	x
Merulinidae	o	x	x	o	o	o	x	o
Mussidae	x	x	x	x	x	o	x	x
Pectiniidae	o	o	o	o	o	o	x	x
Euphyllidae*	o	x	x	o	o	o	x	x
Antipathidae	o	x	o	o	o	o	x	o
Helioporidae	o	o	o	o	o	o	x	o
Alcyoniidae	x	x	x	x	x	x	x	x
TOTAL # OF FAMILIES	9	12	11	9	8	5	17	13

* Euphyllidae is considered a Family, by Veron and a Sub Family by Randall.

Frequency of occurrence within transects

Table 4 summarizes the number of PCQT quarters taken at each location and depth, the number of quarters which contained coral (from all taxa), the number of quarters with *Porites rus* and, lastly, the percentage of quarters in which any coral was present. Measurements were taken in 1,908 quarters; 1,325 (69%) of these contained coral; 49% of all corals measured were *Porites rus*.

At every study location and depth (except for the 60-70 ft. contour in Polaris Point/Bay and the 30– 40 contour in Sumay–Inner Apra) the percentage of quarters with coral was at least 58%, with the range being 58 to 98%. The percentages of quarters with coral was lowest in Polaris Point/Bay's 60-70 ft. zone (8%), followed by the 30-40 ft. zone in Sumay– Inner Apra (32%). Frequency of occurrence is not equal to percentage of the sea floor covered by coral and is not as meaningful a parameter; however, it does provide a clear indication of the fact that substantial numbers of corals, if not functioning coral reefs, were present at every study location.

Table 4
Frequency of Occurrence of Corals Within PCQ Transect Quarters

Location	Depth Contour	Total Quarters	Quarters w/Coral	Quarters w/ *Porites rus*	% of Quarters w/ Corals of all taxa
Sumay-Inner Apra	**10–20**	**84**	**54**	**7**	**64%**
Sumay-Inner Apra	**30-40**	**56**	**18**	**0**	**32%**
Big Blue E	**10-20**	**92**	**71**	**10**	**77%**
Big Blue E	**30-40**	**152**	**91**	**35**	**60%**
Big Blue W	**10-20**	**92**	**77**	**29**	**84%**
Big Blue W	**30-40**	**60**	**60**	**51**	**100%**
Polaris Pt./Bay	**10-20**	**156**	**91**	**37**	**58%**
Polaris Pt./Bay	**30-40**	**212**	**124**	**52**	**59%**
Polaris Pt./Bay	**60-70**	**120**	**10**	**2**	**8%**
Turning Basin	**45-55**	**228**	**161**	**91**	**71%**
Fairway Shoals	**45-60**	**116**	**90**	**40**	**78%**
Dry Dock Is.	**10-20**	**120**	**116**	**76**	**97%**
Dry Dock Is.	**30-40**	**120**	**116**	**100**	**97%**
Dry Dock Is.	**60-70**	**120**	**109**	**78**	**91%**
Delta Echo	**10-20**	**120**	**78**	**20**	**65%**
Delta Echo	**30-40**	**60**	**59**	**22**	**98%**
TOTALS		**1908**	**1325**	**650**	

Relative Density

The relative density for each taxa or taxonomic grouping is determined as follows:

number of quarters of taxa "x" / total number of quarters of all taxa.

Values for relative density are presented in Tables 5 through 7. Note, percentages are rounded to the nearest whole number, so the totals do not always equal 100; 0% was entered for groups with values of <0.5%.

Table 5
Relative Densities Sumay Cove – Inner Apra,
Polaris Point/Bay, Turning Basin and Fairway Shoals

Coral Taxa	Sumay	Sumay	Polaris	Polaris	Polaris	Turning Basin	Fairway Shoals
	10-20'	**30-40'**	**10-20'**	**30-40'**	**60-70'**	**45-55**	**45-60**
Porites rus	**13%**	**0%**	**41%**	**42%**	**20%**	**57%**	**44%**
Porites cylindrica	**0%**	**0%**	**1%**	**26%**	**0%**	**3%**	**1%**
Porites spp.	**59%**	**50%**	**43%**	**9%**	**40%**	**27%**	**24%**
Pocillopora damicornis	**0%**	**0%**	**9%**	**3%**	**0%**	**1%**	**2%**
Acropora spp.	**0%**	**0%**	**0%**	**2%**	**0%**	**1%**	**0%**
Faviidae	**20%**	**33%**	**0%**	**2%**	**2%**	**1%**	**0%**
Mussidae	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**
All other coral taxa	**7%**	**17%**	**7%**	**15%**	**40%**	**12%**	**28%**

Table 6
Relative Densities Big Blue Reef East and West

Coral Taxa	Big Blue East 10-20'	Big Blue East 30-40'	Big Blue West 10-20'	Big Blue West 30-40'
Porites rus	**14%**	**39%**	**38%**	**85%**
Porites cylindrica	**0%**	**2%**	**4%**	**2%**
Porites spp.	**39%**	**32%**	**23%**	**3%**
Pocillopora damicornis	**16%**	**2%**	**5%**	**0%**
Acropora spp.	**0%**	**0%**	**4%**	**0%**
Faviidae	**7%**	**3%**	**5%**	**7%**
Mussidae	**0%**	**0%**	**0%**	**0%**
All other coral taxa	**24%**	**22%**	**21%**	**3%**

Table 7
Relative Densities Dry Dock Island, Delta Wharf and Echo Wharf

Coral Taxa	Dry Dock Is. 10-20'	Dry Dock Is. 30-40'	Dry Dock Is. 60-70'	Delta Echo 10-20'	Delta Echo 30-40'
Porites rus	**66%**	**86%**	**72%**	**26%**	**37%**
Porites cylindrica	**7%**	**0%**	**0%**	**8%**	**3%**
Porites spp.	**8%**	**1%**	**6%**	**38%**	**42%**
Pocillopora damicornis	**0%**	**0%**	**0%**	**0%**	**0%**
Acropora spp.	**1%**	**6%**	**5%**	**5%**	**2%**
Faviidae	**0%**	**2%**	**2%**	**0%**	**0%**
Mussidae	**0%**	**0%**	**2%**	**0%**	**0%**
All other coral taxa	**19%**	**5%**	**15%**	**23%**	**15%**

Size Frequency

Substantial differences in the size frequency distribution of individual coral colonies were observed. Measurements within the PCQT quarters ranged from 2 cm to 295 cm. The 295 cm specimen was a *Diploastrea heliopora* located off Dry Dock Is.

Individual stony coral specimens over 100 cm in size were observed at every location. Big Blue Reef W supported the largest total number of specimens over 100 cm, and the greatest number of species with specimens over 100 cm in size.

The mean sizes (maximum measurement parallel to the sea floor) of all colonies, from all depth contours, ranged from 11 cm to 30 cm. There was a large standard deviation of these measurements and a large range in the number of quarters with coral (see Table 4). With these limitations in mind, the mean values are presented in Table 8, with additional comments on size frequency following.

Table 8
Mean Size Values for Corals of All Taxa

Location	Size	Location	Size	Location	Size	Location	Size
Sumay-Inner Apra 10-20	**13 cm**	**Big Blue W 10-20**	**24 cm**	**Polaris 60-70**	**30 cm**	**Dry Dock Is. 30-40**	**22 cm**
Sumay-Inner Apra 30-40	**11 cm**	**Big Blue W 30-40**	**23 cm**	**Turning Basin**	**22 cm**	**Dry Dock Is. 60-70**	**13 cm**
Big Blue E 10-20	**12 cm**	**Polaris 10-20**	**27 cm**	**Fairway Shoals**	**21 cm**	**Delta Echo 10-20**	**16 cm**
Big Blue E 30-40	**21 cm**	**Polaris 30-40**	**16 cm**	**Dry Dock Is. 10-20**	**27 cm**	**Delta Echo 30-40**	**16 cm**

The highest percentage of colonies less than 11 cm in their greatest dimension (parallel to the sea floor) in the 10 – 20 foot depth zone was at Big Blue Reef E (63%) followed by Polaris Point/Bay (41%). The lowest percentages of colonies (< 11 cm), in those depth zones, were at Dry Dock Is. (29%) and Big Blue Reef W (36%).

For colonies more than 26 cm in their greatest dimension within the 30– 40 foot depth zone the highest percentage was at Big Blue Reef W (38%). The lowest percentage for colonies over 26 cm was at Polaris Point/Bay (19%).

Percentage of sea floor covered by coral

The author believes that the most meaningful measure of the ecological importance of various coral taxa is the percentage of the sea floor they occupy. Percentages of sea floor cover for different coral taxa, or taxonomic groupings are shown in Figure 5. Figure 6 depicts combined sea floor coral cover of all Scleractinian corals by study area. The Sumay Cove – Inner Apra segment is not included in Figures 5 or 6 because even the percentage of sea floor cover of all taxa combined was only 0.22% and 0.18% at the 10-20 and 30-40 foot contours. At most study sites, *Porites rus* contributed the highest percentage of sea floor cover of any single species.

Porites cylindrica surpassed *Porites rus* at three survey locations: 12.7% to 3.1% in the Turning Basin, 17.8% to 3.8% at the Big Blue Reef W 30– 40 foot contour, and 21.8% to 11.7% at the Dry Dock Is. 10 – 20 foot contour. Extensive thickets with large individual colonies of *Porites cylindrica* were present at Big Blue Reef W and at Dry Dock Is. The colonies in the Turning Basin, however, were generally small and less well developed.

The multi-species group of *Porites spp.* (*P. australiensis, P. lobata, P. lutea, P. annae, P. lichen, P. horizontalata.*) surpassed *P. rus and P. cylindrica* 28.9% to 3.8% and 17.8% respectively at Big Blue Reef W in the 30 – 40 depth zone. The next highest value for the *Porites spp.* group was at Dry Dock Is., but was only 3.2%. The nearly ten fold increase in diversity of Poritids at Big Blue Reef W was an important factor in making it the most diverse of all the study sites. Although corals of all taxa were sparse in the Sumay-Inner

Apra segment, the *Porites spp.* group ranked first in both percentage of sea floor cover and frequency of occurrence.

The 'All other taxa' category data are illustrated in Figure 5. The highest percentage of sea floor cover for this group was recorded at Dry Dock Is. with 47.5% and 37.9% at the 10-20 and 30-40 foot contours. Of the Scleractinian (stony) corals included in the 'All other taxa' group, *Pavona cactus* (Agariciidae) and *Lobophyllia hemprichii* (Mussidae) were the most abundant at Dry Dock Is., followed by *Astreopora myriophthalma,* and *Astreopora sp.* (Acroporidae). Alcyoniid soft corals, including *Sinularia sp.* and *Lobophytum sp.*, were also present at this location.

Unlike any of the other study areas, the Turning Basin had several monospecific patch reefs/thickets of *Acropora formosa.* These monospecific patch reefs were located in the vicinity of station TB 6; the largest was approximately 300 m^2 in size.

Figure 5
Percentage of the Sea Floor Covered by Selected Coral Taxa

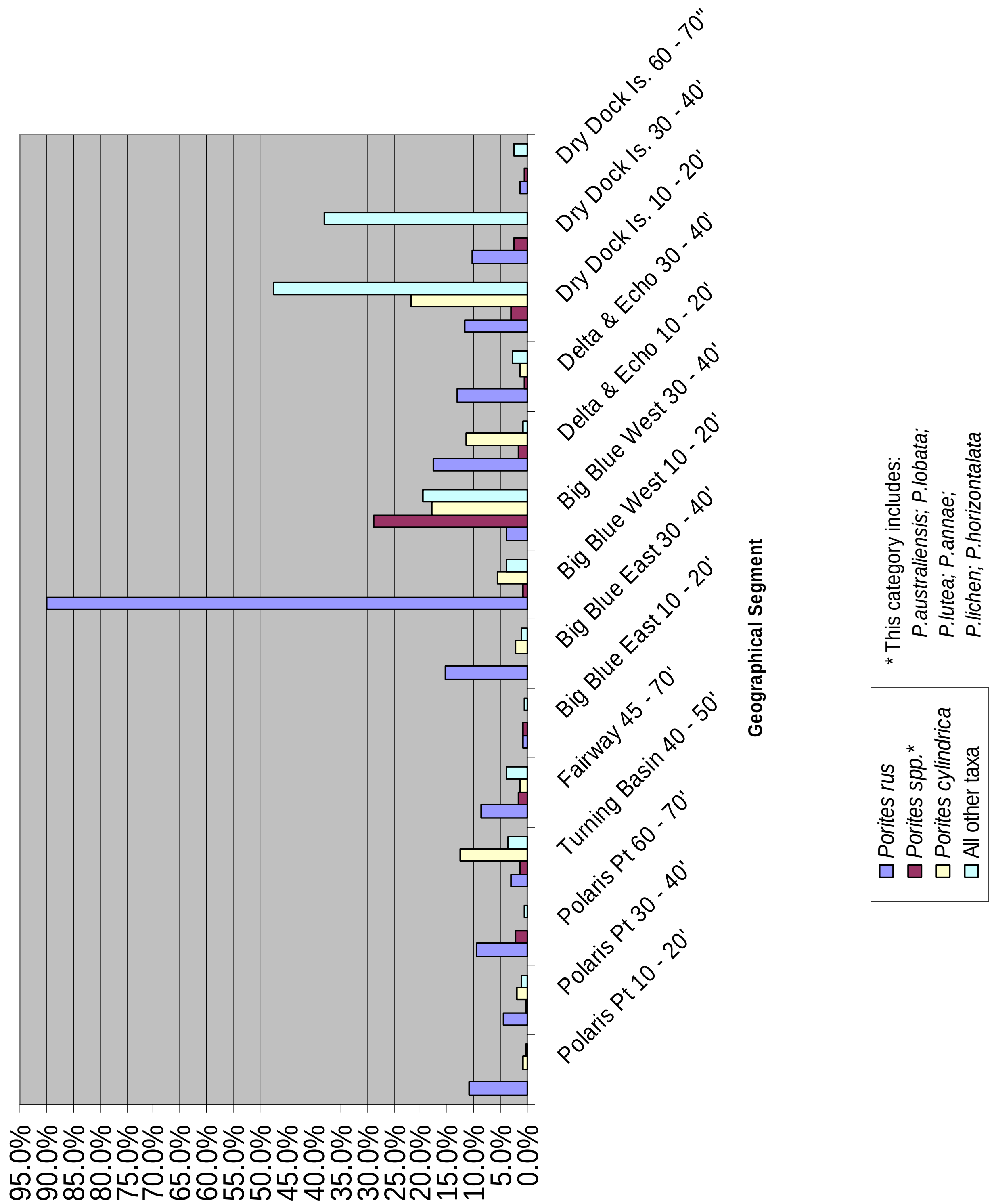
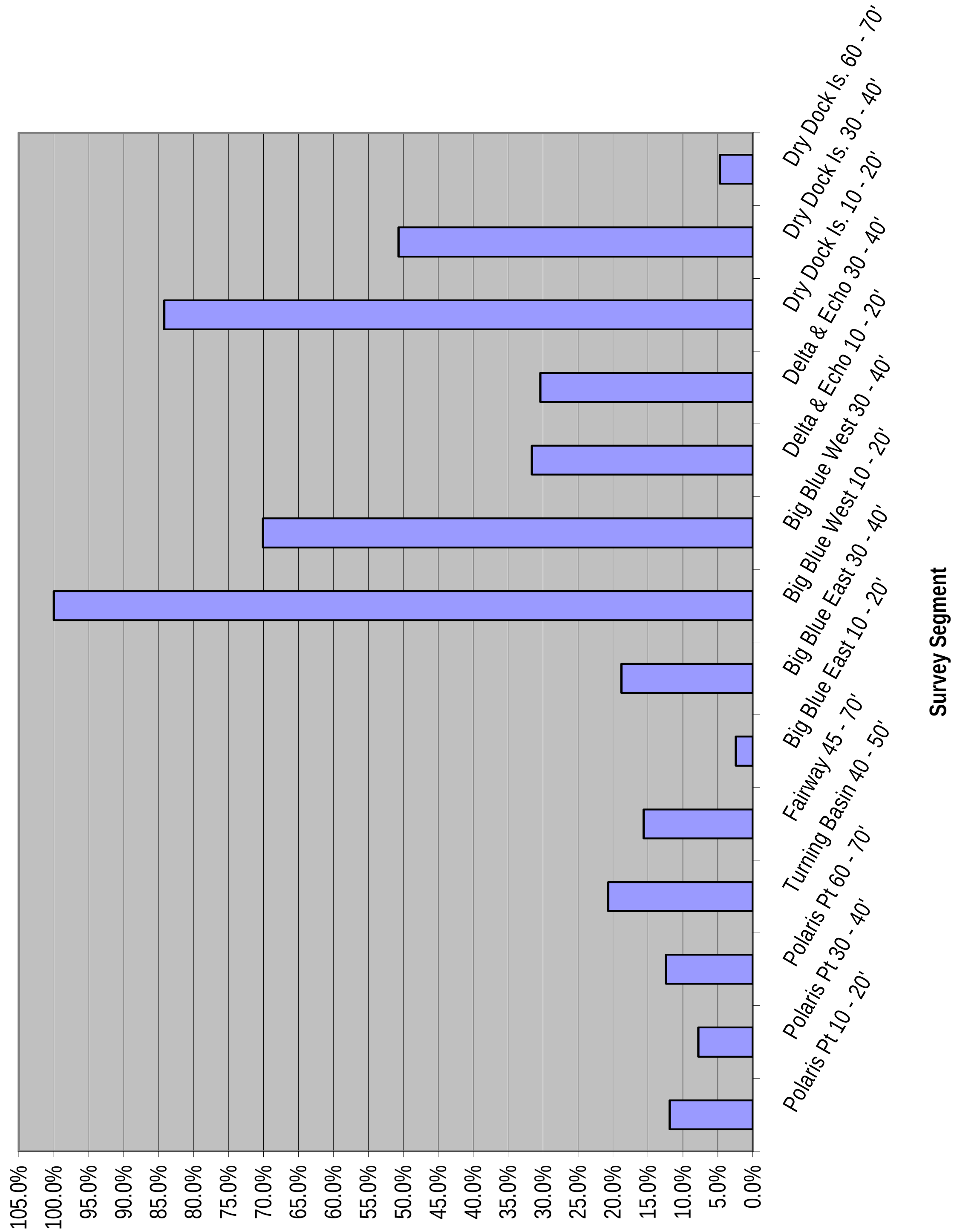


Figure 6
Percentage of the Sea Floor Covered by Corals of All Taxa



Coral Health

Based upon a qualitative visual inspection, coral health appeared to vary considerably between the different study sites. Partially bleached coral colonies were observed at every location, but they were few in number and were generally small specimens, less than 20 cm across. None of the areas were experiencing what would be considered a bleaching event. Filamentous algae was growing on the bleached portions of most of the affected colonies, but was not observed to be overgrowing any non-bleached colonies. No examples of black-band disease, white-band disease, or white plague were observed. Head forming species, such as *Porites lobata,* in the Polaris Point/Bay, Turning Basin and Fairway Shoals were observed to have copious secretions of mucous. Telesnicki and Goldberg (1995) have shown that corals increase mucus secretion to remove fine particles when turbidity levels are high. These three areas are routinely subject to high levels of total suspended solids (TSS); therefore, this response to turbidity is not surprising, but may indicate these corals are stressed. No Crown-of-Thorns starfish (*Acanthaster planci*)were seen at any of the study sites and there was no visual evidence of recent predation by this species.

Other Macro-Benthos

Comments on macro-algae are presented with the sea turtle discussion. Very few specimens of the harvested invertebrates, identified by Porter et al. (2005) as the most important, were observed. *Octopus sp.* (octopus), *Trochus niloticus* (top shell), *Lambis sp.* (spider conch), *Panulirus penicillatus* (double spined rock lobster), and *Zosimus aeneus* (Xanthid reef crab) were all sighted at Big Blue Reef W; however, none of these species were observed at any of the other study sites except for top shells and octopus at Dry Dock Is. and top shells and Xanthid reef crabs in the Sumay-Inner Apra segment. Sea cucumbers were present at every study site and were abundant in the Turning Basin and Fairway Shoals.

Anthropogenic Factors

There was evidence of anchor damage at every location. Some of the anchor damage appeared to have occurred more than 10 years ago, based upon the re-growth of corals, sponges, etc. The only significant recent anchor damage was in the Sumay–Inner Apra, and Big Blue Reef E segments. The anchor chains used to secure the floating dry dock continue to move due to tidal changes, raising and lowering the dry dock and, of course, during inclement weather conditions. Movement of these chains is much more pronounced on the south/shore side of the dry dock. Most of the substrate in this area is coarse, unstable rubble. The unstable rubble conditions are not conducive to successful coral recruitment and undoubtedly are the reason coral is sparse in this area. It is interesting to note that the chains at the north west end of the dry dock do not appear to have moved for an extended period of time; large coral colonies have overgrown long sections of the chain, indicating they have been stable for many years.

Substantial quantities of concrete and metallic debris and scrap are found throughout Apra Harbor. Polaris Point/Bay had the largest quantities of such material of any of the study sites; followed by the south western portion of Dry Dock Is. Some of the debris supported substantial coral growth, other items were nearly bare. Oysters (*Spondylus sp.*) up to 18 cm in diameter were observed on many of the debris items. Increased numbers of fish were associated with most of the large, more complex items, particularly three sunken causeways off Dry Dock Is. These causeways measured approximately 30 m x 3 m x 2 m.

Fishing line and sinkers were sighted at every study location except Fairway Shoals. Spear gun shafts were observed at Big Blue Reef W and Polaris Point/Bay. Net fragments were observed at Big Blue Reef W and Dry Dock Is. No fish traps were sighted.

B. Fin Fish and Essential Fish Habitat (EFH)

Although, rigorous population estimates of fin fishes were not included in the scope of this project, estimates of abundance are summarized in Tables 9 through 13. It is noteworthy, that not a single shark or ray was sighted on any of the dives.

Table 9
Fin Fish Families Sighted at: Sumay Cove-Inner Apra and Turning Basin

Abundant (> 50 individuals sighted/dive)	Common (10-50 individuals sighted/dive)	Occasional (< 10 individuals sighted/dive)	Occasional (< 10 individuals sighted/dive)
Pomacentridae (Damselfishes)	Labridae (Wrasses)	Acanthuridae (Surgeonfishes & Unicornfishes)	Synodontidae (Lizardfishes)
	Chaetodontidae (Butterflyfishes)	Lutjanidae (Snappers)	Scorpaenidae (Scorpionfishes)
	Clupeidae (Herrings, Sardines)	Caesionidae (Fusiliers)	Malacanthidae (Tilefishes)
	Holocentridae* (Soldier & Squirrelfishes)	Mullidae (Goatfishes)	Carangidae (Jacks & Trevallies)
	Kyphosidae (Chubs & Rudderfishes)	Lutjanidae (Snappers)	Haemulidae (Sweetlips, Grunts)
	Mugilidae (Mullets)	Scaridae (Parrotfishes)	Zanclidae (Moorish Idol)
		Blenniidae (Blennies)	Balistidae (Triggerfishes)
1 family	6 families	14 families	TOTAL = 21 FAMILIES

*Holocentrids were abundant in the *Acropora formosa* thickets.

The abundance estimates of families composed of many cryptic species, such as Blenniidae (Blennies) are probably too low, because no effort was made to search for those fishes. Likewise, under estimates were probably made for fishes which tend to remain in caves and under ledges during the day (Holocentridae – Soldierfishes and Squirrelfishes). Pempheridae (Sweepers) were not included in the estimates; only one small group was sighted under a large ledge at Big Blue Reef W.

Table 10
Fin Fish Families Sighted at Big Blue Reef West

Abundant (> 50 individuals sighted/dive)	Common (10- 50 individuals sighted/dive)	Occasional (< 10 individuals sighted/dive)	Occasional (< 10 individuals sighted/dive)
Pomacentridae (Damselfishes)	Clupeidae (Herrings, Sardines)	Muraenidae (Moray eels)	Scombridae (Tunas, Mackerels)
Labridae (Wrasses)	Priacanthidae (Bigeyes)	Synodontidae (Lizardfishes)	Balistidae (Triggerfishes)
Acanthuridae (Surgeonfishes & Unicornfishes)	Carangidae (Jacks & Trevallies)	Aulostomidae (Trumpetfishes)	Monocanthidae (Filefishes)
Holocentridae (Soldier & Squirrelfishes)	Haemulidae (Sweetlips, Grunts)	Fistularidae (Coronetfishes)	Ostraciidae (Trunkfishes)
Serranidae (Fairy Basslets, Groupers)	Lethrinidae (Emperors)	Scorpaenidae (Scorpionfishes)	Tetraodontidae (Puffers)
Lutjanidae (Snappers)	Apogonidae (Cardinalfishes)	Cirrhitidae (Hawkfishes)	Diodontidae (Porcupinefishes)
Caesionidae (Fusiliers)	Pomocanthidae (Angelfishes)	Malacanthidae (Tilefishes)	
Mullidae (Goatfishes)	Zanclidae (Moorish Idol)	Nemipteridae (Breams, Spinecheeks)	
Chaetodontidae (Butterflyfishes)	Belonidae (Needlefishes)	Pempheridae (Sweepers)	
Scaridae (Parrotfishes)	Mugilidae (Mullets)	Kyphosidae (Chubs, Rudderfishes)	
Holocentridae (Soldier & Squirrelfishes)	Blenniidae (Blennies)	Sphyraenidae (Barracudas)	
	Gobiidae (Gobies)	Siganidae (Rabbitfishes)	
11 families	**12 families**	**18 families**	**TOTAL = 41 FAMILIES**

Table 11
Fin Fish Families Sighted at Big Blue Reef East and Fairway Shoals

Abundant (> 50 individuals sighted/dive)	Common (10- 50 individuals sighted/dive)	Occasional (< 10 individuals sighted/dive)	Occasional (< 10 individuals sighted/dive)
	Pomacentridae (Damselfishes)	Clupeidae (Herrings, Sardines)	Carangidae (Jacks & Trevallies)
	Labridae (Wrasses)	Serranidae (Fairy Basslets, Groupers)	Lethrinidae (Emperors)
	Acanthuridae (Surgeonfishes & Unicornfishes)	Lutjanidae (Snappers)	Pomocanthidae (Angelfishes)
	Holocentridae (Soldier & Squirrelfishes)	Blenniidae (Blennies)	Zanclidae (Moorish Idol)
	Caesionidae (Fusiliers)	Gobiidae (Gobies)	Balistidae (Triggerfishes)
	Mullidae (Goatfishes)	Synodontidae (Lizardfishes)	Ostraciidae (Trunkfishes)
	Chaetodontidae (Butterflyfishes)	Priacanthidae (Bigeyes)	Tetraodontidae (Puffers)
	Scaridae (Parrotfishes)	Belonidae (Needlefishes)	Siganidae (Rabbitfishes)
0 families	**8 families**	**16 families**	**TOTAL = 24 FAMILIES**

Table 12
Fin Fish Families Sighted at Polaris Point and Polaris Bay

Abundant (> 50 individuals sighted/dive)	Common (10- 50 individuals sighted/dive)	Occasional (< 10 individuals Sighted/dive)	Occasional (< 10 individuals sighted/dive)
Pomacentridae (Damselfishes)	Labridae (Wrasses)	Lutjanidae (Snappers)	Apogonidae (Cardinalfishes)
	Acanthuridae (Surgeonfishes & Unicornfishes)	Caesionidae (Fusiliers)	Carangidae (Jacks & Trevallies)
	Holocentridae (Soldier & Squirrelfishes)	Mullidae (Goatfishes)	Pomocanthidae (Angelfishes)
	Mugilidae (Mullet)	Scaridae (Parrotfishes)	Sphyraenidae (Barracudas)
		Blenniidae (Blennies)	Zanclidae (Moorish Idol)
		Gobiidae (Gobies)	Tetraodontidae (Puffers)
		Synodontidae (Lizardfishes)	Diodontidae (Porcupinefishes)
1 family	4 families	14 families	TOTAL = 19 FAMILIES

Table 13
Fin Fish Families Sighted at Dry Dock Island, Delta and Echo Wharves

Abundant (> 50 individuals sighted/dive)	Common (10- 50 individuals sighted/dive)	Common (> 10 < 50 individuals sighted/dive)	Occasional (< 10 individuals sighted/dive)	Occasional (< 10 individuals sighted/dive)
Pomacentridae (Damselfishes)	Labridae (Wrasses)	Holocentridae (Soldier & Squirrelfishes)	Muraenidae (Moray eels)	Scombridae (Tunas, Mackerels)
Acanthuridae (Surgeonfishes & Unicornfishes)	Holocentridae (Soldier & Squirrelfishes)	Clupeidae (Herrings, Sardines)	Synodontidae (Lizardfishes)	Balistidae (Triggerfishes)
Scaridae (Parrotfishes)	Serranidae (Fairy Basslets, Groupers)	Carangidae (Jacks & Trevallies)	Cirrhitidae (Hawkfishes)	Ostraciidae (Trunkfishes)
	Lutjanidae (Snappers)	Haemulidae (Sweetlips, Grunts)	Nemipteridae (Breams, Spinecheeks)	Tetraodontidae (Puffers)
	Caesionidae (Fusiliers)	Lethrinidae (Emperors)	Kyphosidae (Chubs, Rudderfishes)	Diodontidae (Porcupinefishes)
	Mullidae (Goatfishes)	Apogonidae (Cardinalfishes)	Siganidae (Rabbitfishes)	Belonidae (Needlefishes)
	Chaetodontidae (Butterflyfishes)	Pomocanthidae (Angelfishes)		
	Blenniidae (Blennies)	Zanclidae (Moorish Idol)		
	Gobiidae (Gobies)	Mugilidae (Mullet)		
3 families		18 families	12 families	TOTAL = 33 FAMILIES

Tables 9 through 13 show substantial differences in both total numbers of fin fish and the number of families (and species). Polaris Point/Bay had the lowest estimated number of fishes and fish families(19 families); Big Blue Reef W had the highest estimated number of fishes and fish families (41 families). It should be noted, that those numbers were undoubtedly affected by generally turbid water at the first site and clear water at the second. Visual fish counts or estimates in turbid water are of limited value. The area supporting the second highest estimated number of both fishes and fish families was Dry Dock Is./Delta-Echo Wharves. There was a well developed reef at the northern end of Dry Dock Is. At the time of the survey, that reef wrapped around the island and continued between Delta Wharf and the shore. Most fish sightings around the wharves included fishes that appeared to be moving between the wharves and the shallow reef east of the wharves. The Dry Dock Is. reef terminates prior to the eastern end of Echo Wharf and there was a corresponding drop in the number of fish sightings as one moved in an easterly direction.

At all locations, the number of fish sightings dropped dramatically when the substrate changed from coral or coral and rubble to fine unconsolidated sediment.

All of the nearshore waters of Guam including Apra Harbor have been designated as EFH (WPRFMC, 2001). None of the study sites have been designated Habitat Areas of Particular Concern (HAPC). Jade Shoals (the first shoal area directly west of Dry Dock Is.) has been designated as an HAPC; reconnaissance surveys were made on the eastern side of Jade Shoals for comparative purposes.

C. Threatened and Endangered Species and Species of Concern

Two species of sea turtles, listed pursuant to the Endangered Species Act, are relatively common in Apra Harbor: the Endangered hawksbill sea turtle (*Eretmochelys imbricata*) and the Threatened green sea turtle (*Chelonia mydas*). During previous surveys, the author has observed both of these species within Apra Harbor. Within the areas studied, the green sea turtle is typically more common than the hawksbill sea turtle; however none of the latter were sighted during this project. Table 14 summarizes the sightings of green sea turtles by area.

Table 14
Green Sea Turtle Sightings Underwater

Location	Sighting	Location	Sighting	Location	Sighting	Location	Sighting
Sumay-Inner Apra 10-20	0	Big Blue W 10-20	2	Polaris 60-70	0	Dry Dock Is. 30-40	1
Sumay-Inner Apra 30-40	0	Big Blue W 30-40	3	Turning Basin	0	Dry Dock Is. 60-70	0
Big Blue E 10-20	1	Polaris 10-20	0	Fairway Shoals	1	Delta Echo 10-20	0
Big Blue E 30-40	0	Polaris 30-40	0	Dry Dock Is. 10-20	1	Delta Echo 30-40	0

All the green sea turtles sighted were swimming, none were resting or feeding. The estimated carapace length of all of the individuals was between 40 and 60 cm. At that size, the turtles were probably not sexually mature; sex was not determined for any of the specimens. All of the turtles observed appeared to be healthy; none had any visible fibro-papilloma tumors, bite marks or other apparent injuries. Because the turtles did not have any obvious distinguishing characteristics and were all approximately the same size, it was not possible to determine if multiple sightings represented the same turtle seen more than once, or different individual turtles. Three additional green sea turtle sightings were made from the dive boat at Big Blue Reef W and one sighting was made off Dry Dock Is.

Big Blue Reef W had more potential turtle resting habitat and more potential algal forage than the other locations. Balaz (1987) listed ten genera of algae which he considered to be ‘preferred forage’ for green sea turtles in Hawaii. Although algal surveys were not conducted, it appeared that more of the preferred genera were present on Big Blue Reef W and on the Fairway Shoals than in any of the other locations. Preferred forage genera observed included: Chlorophyta (green algae) *Dictyospheria* and *Ulva*; Phaeophyta (brown algae) *Sargassum*; and Rhodophyta (red algae) *Gracillaria, Jania, Hypnea, Acanthophera* and *Laurencia.* Green sea turtles are probably opportunistic feeders; however, within preferred food items listed above three specific species (*Dictyospheria versluysii, Sargassum obtusifolium* and *Acanthophera specifera*) have been reported from Guam (Loban and Tsuda, 2003) and were tentatively field identified on Big Blue Reef West and the Fairway Shoals. During the observation periods, none of the algae listed above were abundant at any of the study sites.

Adult hawksbill sea turtles are believed to feed primarily on sponges (NMFS and USFWS, 1998). Sponges were most abundant and diverse at Big Blue Reef W, followed by Dry Dock Is. Sponges were not abundant at the other study locations, but were present at all locations. At depths below 80 feet, on the unconsolidated soft sediment portions of the harbor floor large specimens of elephant ear sponges (*Ianthella basta*) were sighted on every dive; most specimens ranged in diameter from 1 to 2 m. It is not known if hawksbill sea turtles feed on these sponges or not, but no bite marks were observed.

Two species of marine fish recorded from Guam are listed as Species of Concern. These species are the humphead wrasse, also known as the Napoleon wrasse (*Cheilinus undulatus*) and the humphead parrotfish, also known as the bumphead parrotfish (*Bolbometopon muricatum*). No specimens of either of these species were sighted on any of the dives and none of the study sites would qualify as preferred habitat for the Napoleon wrasse or the bumphead parrotfish.

IV. Discussion

A. Corals and Coral Reefs

The distribution of corals within the eastern portions of Apra Harbor is generally in keeping with the findings of both site specific studies performed in Guam and broader treatments of corals worldwide. For example, *Psammocora obtusangula* (Family Siderastreidae) is often only weakly attached to the substrate and found in rubble environments (Veron, 2000). Those were the conditions/habitats in which that species was sighted.

Scleractinian stony corals were present at all study sites, with *Porites rus* being dominant at most locations based upon frequency of occurrence, relative dominance and the percentage of the sea floor covered. Other coral taxa (Milleporidae – fire corals, Stylasteridea – lace corals, Antipathidae – black and wire corals, Alcyoniidae – soft corals, Helioporidae – blue corals and members of the Order Gorgonacea – horny corals and sea fans) were all represented at Big Blue Reef W, but were poorly represented or absent at all the other study locations.

Although corals were present at all study sites, not all study sites had what could be regarded as functioning coral reefs. The percentage of sea floor covered by coral in the Sumay Cove–Inner Apra segment was so low (2/10th of one percent) that the corals played only a relatively minor ecological role at that location. The Sumay-Inner Apra segment was not functioning as a coral reef.

In the Polaris Point/Bay area, sea floor cover by coral ranged from a low of approximately 7% in the 30-40 foot depth contour to a maximum of approximately 13% at the 60-70 foot contour. A substantial percentage of the coral at all depth contours was growing on metallic and/or concrete debris. It is arguable whether or not the Polaris Point/Bay community should be considered a coral reef. What is clear, however, is that more of the corals within the Polaris Point/Bay segment had copious mucous secretions and more algal overgrowth than at any other location in Apra Harbor evaluated during the current study or other recent Navy studies. These conditions were obvious during the author's 2004 observations at this location and during all subsequent observations (2005, 2006 and 2007). They are indicative of stress. As previously noted, Telesnicki and Goldberg (1995) have shown that corals increase mucus secretion to remove fine particles when turbidity levels are high. Many other investigators (e.g., Spalding et al. 2001, Ghiold and Smith, 1990) have shown that stressed corals are more vulnerable to algal overgrowth. While TSS levels are high in much of Apra Harbor, the Polaris Point/Bay area appears to be subject to increased TSS levels due to the movement of highly turbid water out of Inner Apra Harbor on falling tides. If the proximity to Inner Apra Harbor is a contributing factor to diminished coral health at Polaris Point/Bay, the current dredging activities, which will remove substantial quantities of the fine unconsolidated sediment, may result in future reductions in turbidity and long term benefits to the Polaris Point/Bay corals.

Ranking coral reefs is a somewhat arbitrary undertaking, with different investigators placing their emphasis on different parameters. The author and many other investigators (e.g. Dubinsky et al. 1990; Spalding et al. 2001; and Veron, 2000) believe that the following factors are generally the most significant: 1) percentage of the sea floor covered by coral, 2) reef complexity and rugosity, 3) species diversity, to include not only the number of species present, but the number of major coral taxa represented, 4) coral health, 5) size frequency distribution of coral colonies, 6) diversity and abundance of sessile macro-benthos other than corals (e.g. sponges), 7) diversity and abundance of mobile macro-invertebrates and 8) the diversity and abundance of fin fishes.

Based upon these eight factors the coral reefs and habitats in the study areas for this project were ranked, from highest ecological value to lowest, as follows:

Table 15
Ranking of Coral Reefs and Habitats Based On Overall Ecological Value

1. Big Blue Reef W	**2. Dry Dock Is.**
3. Delta – Echo Wharves	**4. Turning Basin**
5. Big Blue Reef E	**6. Fairway Shoals**
7. Polaris Point/Bay	**8. Sumay-Inner Apra (NOT a coral reef)**

Big Blue Reef W was first in all eight categories. Relative to other coral reef areas the author has studied within Apra Harbor, and utilizing the eight criteria presented above, this location should be regarded as biologically equal to or superior to any other location within Apra Harbor (see Plates 7 - 8). Big Blue Reef W was also the only study area in which five of the economically most important invertebrates (octopus, lobster, top shell, spider conch, lobster and Xanthid reef crab) were sighted.

In *Status of Coral Reef Ecosystems of Guam* Porter et al. (2005) placed Guam's reefs into nine categories, based upon their condition. The categories were: 1) Best, 2) Good, 3) Mixed, 4) Recovering, 5) Fair, 6) Impacted, 7) Poor, 8) Heavily Impacted and 9) Unknown. The area between Orote Point and Sumay Cove was rated 'Good'. Smith and Marx (2006) completed detailed coral surveys in the Orote Point – Sumay Cove area and it is the author's opinion that Big Blue Reef W is biologically comparable or superior to that coastal segment. The areas designated Big Blue Reef W and E were not categorized in Porter et al. 2005.

The reef at Dry Dock Is. and the western portion of Delta Wharf had a more diverse coral fauna than most of the coral reefs within Apra Harbor. Although not as highly ranked as Big Blue Reef W, it still ranks relatively high in each of the categories used here to rate coral reef quality or value. Porter et al. (2005) characterized Dry Dock Island as "Recovering' and Delta Wharf as 'Impacted'. While the terms 'Recovering' and 'Impacted' could certainly be applied to these two locations, the present study clearly demonstrates that complex coral reef communities are present in the 10-20 and 30-40 foot depth zones (see Plate 13). The author believes that a rating of 'Good' is appropriate. Plates 1 - 5 show that the present area of Dry Dock Island was severely disturbed during and shortly after WWII. The presence of some large individual coral specimens, such as the 295 cm *Diploastrea heliopora*, shows that some of the corals survived the construction during WWII. A *Diploastrea heliopora* colony of this size would almost certainly be much more than 62 years old. In addition to the large, old specimens, other corals have also become well established. Approximately, 84% of the sea floor and 50% of the sea floor are covered by coral in the 10-20, and 30-40 foot zones, respectively.

Dry Dock Is. and Polaris Point were artificially created during and shortly after WWII. The fact that such well developed, complex coral reefs were observed at Dry Dock Is.

during this investigation was not expected. It appears that these two locations were "created" at approximately the same time, yet the coral communities at the two locations are dramatically different. A possible explanation for the differences is that the Polaris Point/Bay area is subject to higher levels of turbidity than Dry Dock Isl. Also, Dry Dock Is. is believed to be subject to better water circulation and greater turbulence; both of those physical factors would favor greater coral development.

The eastern portion of Delta Wharf, all of Echo Wharf, the Turning Basin, Big Blue Reef E, the Fairway Shoals and Polaris Point/Bay are considered to be only marginally functional as coral reefs. Based upon sea floor cover, most of the Turning Basin, Big Blue Reef E and Fairway Shoals consisted of unconsolidated sediment in the medium to fine sand grain size range. Sea floor cover at eastern Delta Wharf, Echo Wharf and Polaris Point/Bay was primarily unconsolidated rubble in the shallow areas and became increasingly fine unconsolidated sediment as one approached the harbor floor. All of these sites were of substantially less ecological value/importance than Big Blue Reef W, Dry Dock Is., or the Orote Peninsula between Orote Point and Sumay Cove and most other coral reef areas within Apra Harbor. Porter et al. (2005) categorized Polaris Point/Bay as 'Fair'; the Turning Basin, Fairway Shoals, Echo Wharf and Big Blue Reef E were not categorized.

The Sumay–Inner Apra segment clearly should not be considered a coral reef based upon the fact that it supported less than $2/10^{th}$ of one percent sea floor cover by corals of all taxa. This segment consisted primarily of coarse unconsolidated rubble grading into sand near the harbor floor.

B. Fin Fishes, Essential Fish Habitat and Habitat Areas of Particular Concern

Fish family diversity was highest at Big Blue Reef W; representatives of 41 families were sighted. Fish diversity, total numbers of fish and total fish biomass have been shown to be closely correlated with the percentage of the sea floor covered by coral, reef complexity and rugosity (Bell and Galzin, 1984; Luckhurst and Luckhurst, 1978 and others). The relationship between fish diversity and total numbers of fishes appears to follow this relationship at the sites investigated during this study, although no attempt was made to correlate these parameters statistically. No sharks, large barracuda, jacks or other high-level predators were sighted on any dive.

Most fishes at all the study sites and from all taxa, even those not normally sought after by fishermen, were small or medium sized. As previously noted, targeted invertebrates, such as octopus, lobster and crab, were very rarely seen and the specimens were small. These observations support the conclusions of Porter et al. (2005) and many others that over fishing is a significant problem in Guam and that the fin fish and harvested invertebrate stocks are biologically depressed.

HAPC designation is based upon four independent criteria, any one of which may be used to justify designation. Relative to the other study areas assessed during this project, as well as other portions of Apra Harbor previously evaluated, the ecological function of Big Blue Reef W is important. It is also sensitive to human induced environmental degradation. Big Blue Reef W, therefore, meets two of the four criteria for HAPC designation.

The Sumay Cove-Inner Apra, Polaris Point/Bay, Turning Basin, Big Blue Reef E, Fairway Shoals and Delta-Echo Wharves study sites do not meet the criteria for HAPC, in the author's opinion. The suitability for designating Dry Dock Is. as an HAPC is debatable; additional studies should be undertaken prior to making such a decision.

C. Threatened and Endangered Species and Species of Concern

No Endangered hawksbill sea turtles were sighted from the boat or during any of the dives. This species would be more likely to occur at Big Blue Reef W than at the other sites because of the increased quantities of preferred forage (sponges) and increased number of potential resting sites (small grottos, undercut ledges and caves).

A total of five underwater sightings and three surface sightings of Threatened green sea turtles were made at Big Blue Reef W. Only four underwater and one surface sighting were made at all the other sites combined. The greater number of green sea turtle sightings at Big Blue Reef W, relative to the other study sites, is believed to be due to three factors: 1) increase quantities of potential forage, 2) greater number of potential resting sites, and 3) proximity to other forage and resting sites along Orote Peninsula and outer harbor shoal areas.

None of the sites investigated during this study provide preferred habitat for either of the two fish species of concern, the Napoleon wrasse and the bumphead parrotfish. Although members of either of these two species could swim through the study areas, it is unlikely that either species would reside at or even frequent any of the eight study sites.

V. Summary

There are eight key findings that the author would like to emphasize.

- Corals are present throughout the eastern portions of Apra Harbor; however, not all of eastern Apra Harbor is a functioning coral reef ecosystem. Some areas support only sparse, scattered corals or small patch reefs.

- Most of the sea floor within the Turning Basin and Fairway consists of unconsolidated soft sediment.

- Big Blue Reef W is a well developed, complex coral reef and is of comparable ecological value to any other reefs within Apra Harbor. It meets the criteria for designation as an EFH HAPC. Based upon current information, none of the other sites qualify for HAPC designation.

- The second most ecologically important reef investigated in this study was located at Dry Dock Island. This reef should be considered 'Good,' based upon the criteria used in *Status of the Coral Reef Ecosystems of Guam* (2005). Dry Dock Island was created in the mid to late 1940s. The present condition of this reef indicates that the corals of Apra Harbor may be more resilient and hardy than previously thought.

- The coral reefs at Big Blue Reef E, Fairway Shoals, Turning Basin, Eastern Delta Wharf and Echo Wharf are of marginal to modest ecological value, based upon the eight criteria discussed in Section IV A.

- The coral reef in the Polaris Point/Bay segment is of marginal quality and showed the greatest signs of stress. This stress appeared to be due in part to high levels of TSS coming from Inner Apra Harbor. Dredging activities within Inner Apra Harbor will remove substantial volumes of fine unconsolidated sediment. This has the potential to benefit the corals in Polaris Point/Bay.

- The Sumay Cove – Inner Apra segment supports only $2/10^{th}$ of one percent sea floor cover by coral and should not be considered a functioning coral reef.

- No Endangered hawksbill sea turtles were observed during this study. Only nine underwater sightings of the Threatened green sea turtle were made during the 152 person-dives. Five of those sightings were at Big Blue Reef West. Three additional sightings were made from the boat. Sea turtles appeared to be significantly less numerous in the eastern portion of Apra Harbor than in the western portion.

Acknowledgements

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APPENDIX 1
Recent Navy Surveys Conducted in Apra Harbor in Chronological Order

1. Paulay, Gustav et al. 2003. *Marine Biodiversity Resource Survey and Baseline Reef Monitoring Survey of the Southern Orote Peninsula and North Agat Bay Area.* 37pp.
2. Smith, Stephen H. 2004. *March 2004 Ecological Assessment of the Marine Community in the Vicinity of Kilo Wharf, Apra Harbor, Guam.* 35pp.
3. Smith, Stephen H. 2004. *Field Report of Supplemental Reconnaissance Level Observations in the Vicinity of Kilo Wharf, Apra Harbor, Guam November 3rd and 4th , 2004.* 9pp.
4. Marine Research Consultants. 2005. *Reconnaissance Surveys of the Marine Environment, Outer Apra Harbor, Guam, Baseline Assessment of Water Chemistry.* 20pp.
5. Marine Research Consultants. 2005. *Reconnaissance Surveys of the Marine Environment, Outer Apra Harbor, Guam, Characterization of Benthic Habitats.* 19pp.
6. Sea Engineering Inc. 2005. *Multi-Beam Bathymetric Survey Approaches to Inner Apra Harbor Guam October 2005.*
7. Sea Engineering Inc. 2005. *Current Measurement and Numerical Circulation Model Study for Kilo Wharf Extension Apra Harbor, Guam.* 195pp.
8. Smith, Stephen H. & Donald E. Marx. 2006. *Assessment of Stony Corals Between Orote Point and Sumay Cove Apra Harbor, Guam.* 31pp.
9. Smith, Stephen H. 2006. *Marine Ecological Reconnaissance of Selected Shoal Areas Within Apra Harbor, Guam.* 19pp.

APPENDIX 2
Coordinates for Fairway (FWLW) and Turning Basin (TB) Shoal Areas Less than 50 Feet Deep
Surveys Were Completed at Each of these Locations

SiteName	Latitude	Longitude	Site Name	Latitude	Longitude
FWLW 1	13^O 27'07.78"	144^{O}39'29.57"	TB 1	13^{O}26'53.28"	144^{O}39'44.31"
FWLW 2	13^O 27' 07.47"	144^{O}39'35.31"	TB 2	13^{O}26'53.01"	144^{O}39'48.53"
FWLW 3	13^O 27' 04.22"	144^{O}39'38.33"	TB 3	13^{O}26'51.68"	144^{O}39'53.77"
FWLW 4	13^O 27' 04.07"	144^{O}39'39.47"	TB 4	13^{O}26'52.97"	144^{O}39'54.79"
FWLW 5	13^O 27' 03.27"	144^{O}39'40.49"	TB 5	13^{O}26'44.68"	144^{O}39'41.47"
FWLW 6	13^O 27' 01.01"	144^{O}39'41.85"	TB 6	13^{O}26'42.92"	144^{O}39'49.89"
FWLW 7	13^O 27' 00.21"	144^{O}39'40.75"	TB 7	13^{O}26'41.35"	144^{O}39'57.47"
FWLW 8	13^O 26'59.96"	144^{O}39'39.08"	TB 8	13^{O}26'48.40"	144^{O}40'03.39"
FWLW 9	13^O 26'58.69"	144^{O}39'42.39"	TB 9	13^{O}26'42.32"	144^{O}40'02.47"
FWLW 10	13^O 26'57.87"	144^{O}39'47.97"	TB 10	13^{O}26'35.56"	144^{O}40'54.76"
			TB 11	13^{O}26'35.58"	144^{O}40'02.69"
			TB 12	13^{O}26'38.60"	144^{O}40'09.33"
			TB 13	13^{O}26'42.48"	144^{O}40'08.77"

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PLATES

The photographs for Plates 1 through 6 were provided by Mr. Robert Wescom of Naval Facilities Engineering Command Marianas

The photographs for Plates 7 through 13 were taken by the author.

Plate 1

Apra Harbor Prior to 1945


Plate 2
Apra Harbor Circa 1945
With Future Locations of
Polaris Point and
Dry Dock island
Location of
Polaris Point
Present Location of
Dry Dock Island

Plate 3

Eastern Portion of Apra Harbor Near Present Day Dry Dock Island Circa 1945

Plate 4

Vicinity of Present Day Dry Dock Island Circa 1945


Plate 5
Apra Harbor Circa 1948
Dry Dock Island
Polaris Point

Plate 6

Apra Harbor Current

Plate 7
Big Blue Reef West. Note dense coral cover including *Acropora austera (tentative)* (foreground in top photo) and *Porites rus.*

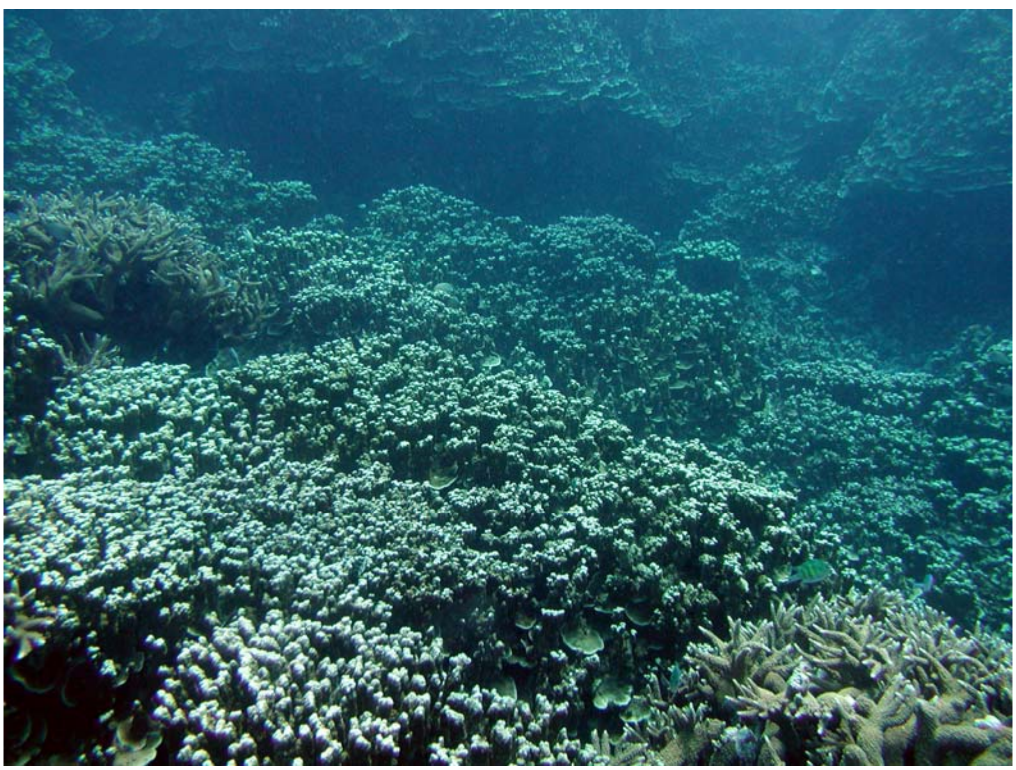
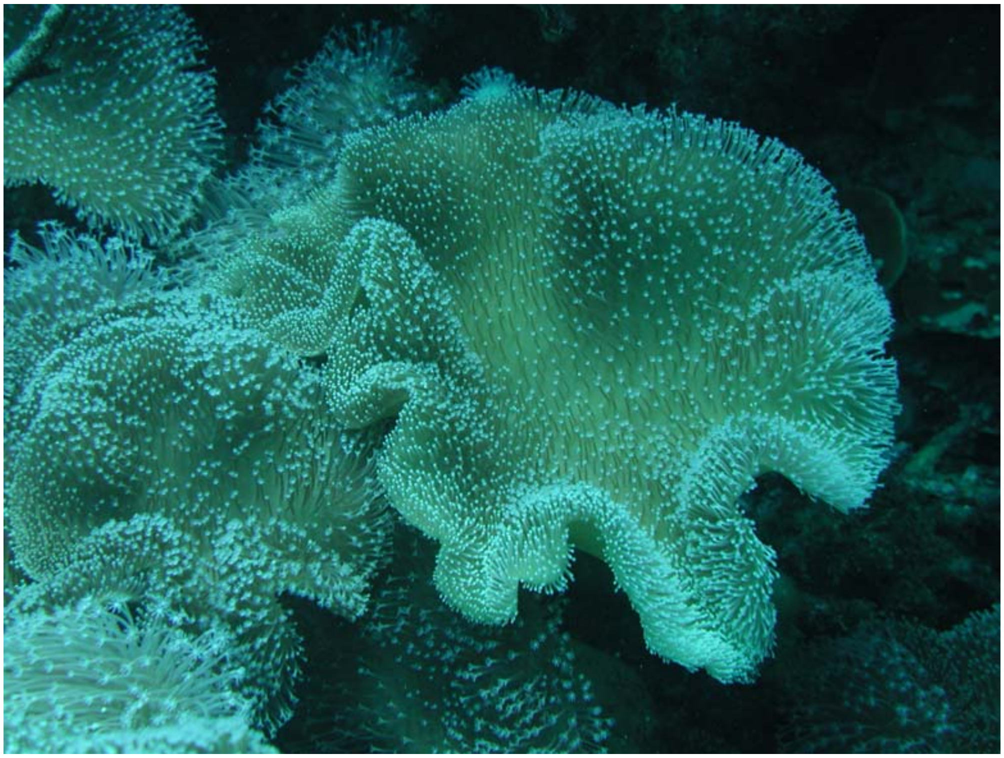


Plate 8

Big Blue Reef West. Soft coral (Family Alcyoniidae) *Sacrophytum glaucum* (top). Bottom photo shows anchor chains from the floating dry dock overgrown with *Porites rus* and other organisms.



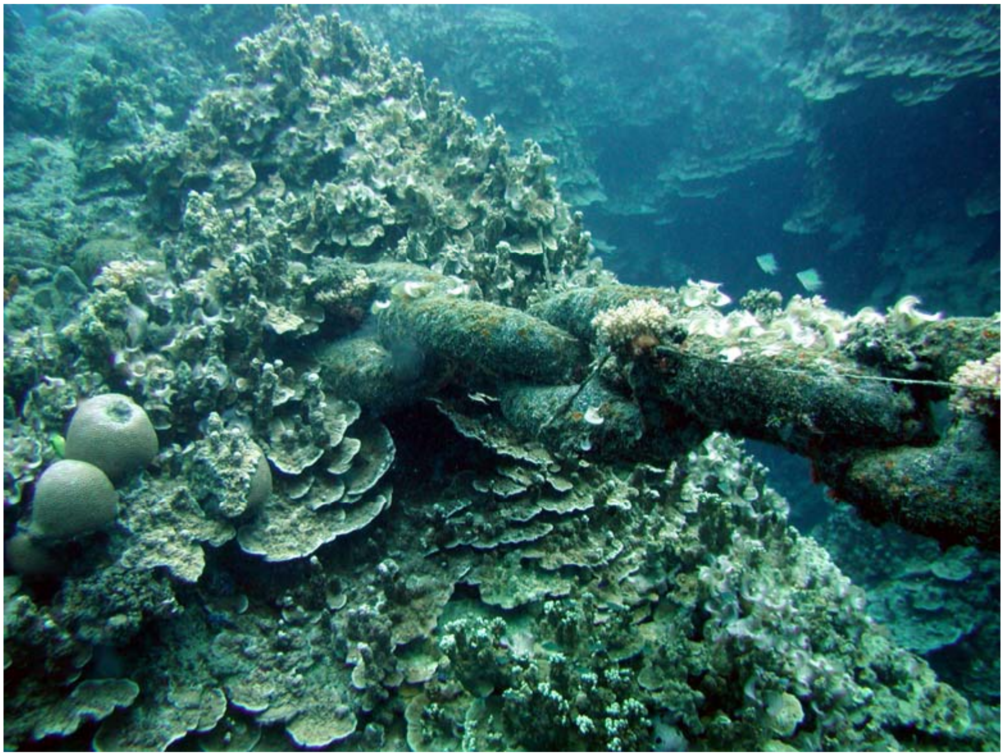
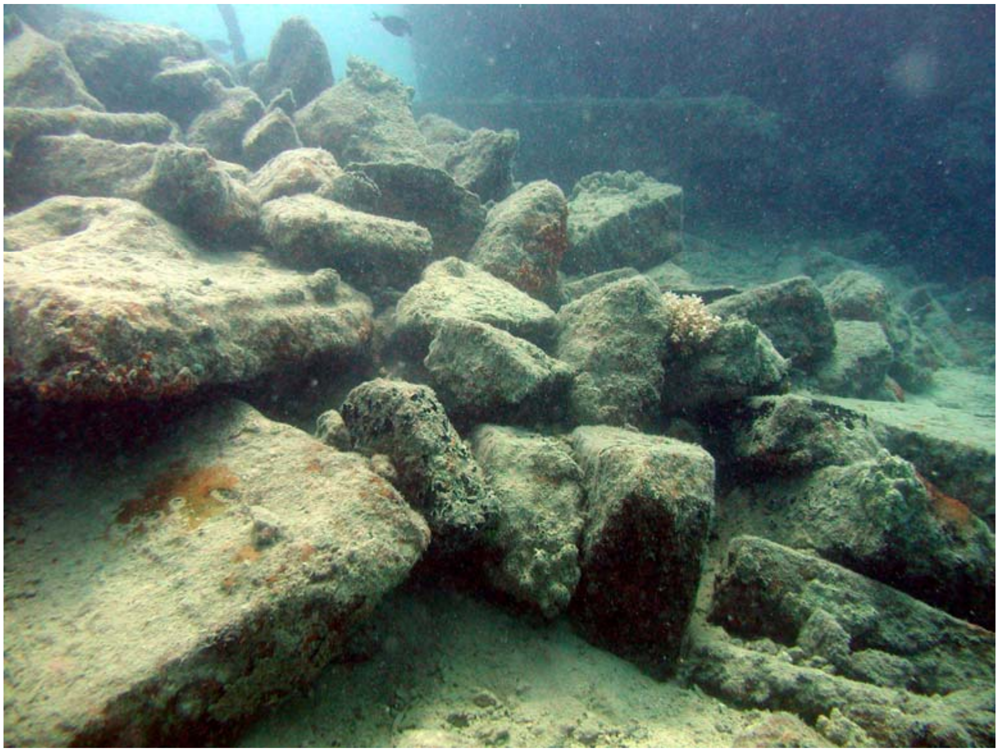


Plate 9
Polaris Point/Bay. Top photo, typical concrete debris, note small colony of *Pocillopora damicornis* growing on concrete. Bottom photo, typical metallic debris items .



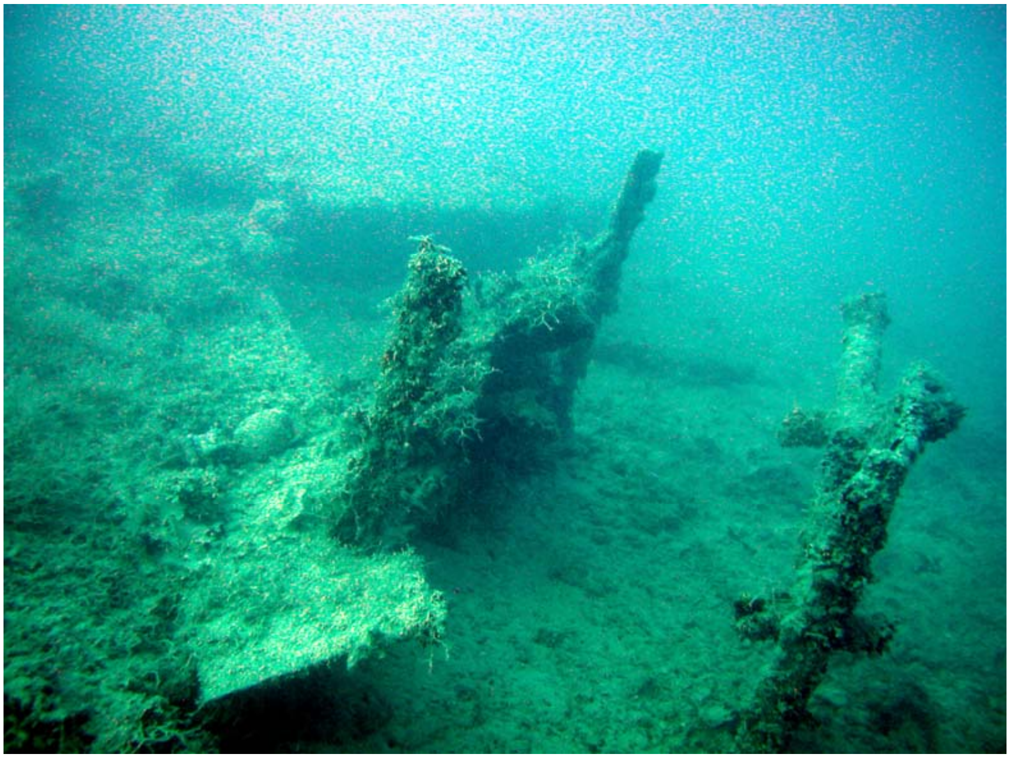


Plate 10.
Top-Big Blue Reef East. Thick patches of the calcareous green algae *Halimeda spp.* were common at depths less than 20 ft. Bottom-Fairway Shoals large sea cucumbers, such as this *Thelenota annas* were common.

Plate 11
Top-Fire corals (Family Milleporidae) were sighted in five of the eight study areas. This specimen was near Delta Wharf . Bottom-tabular specimens of Acroporidae were only sighted at Big Blue Reef West; this specimen is *Acropora azurea.*

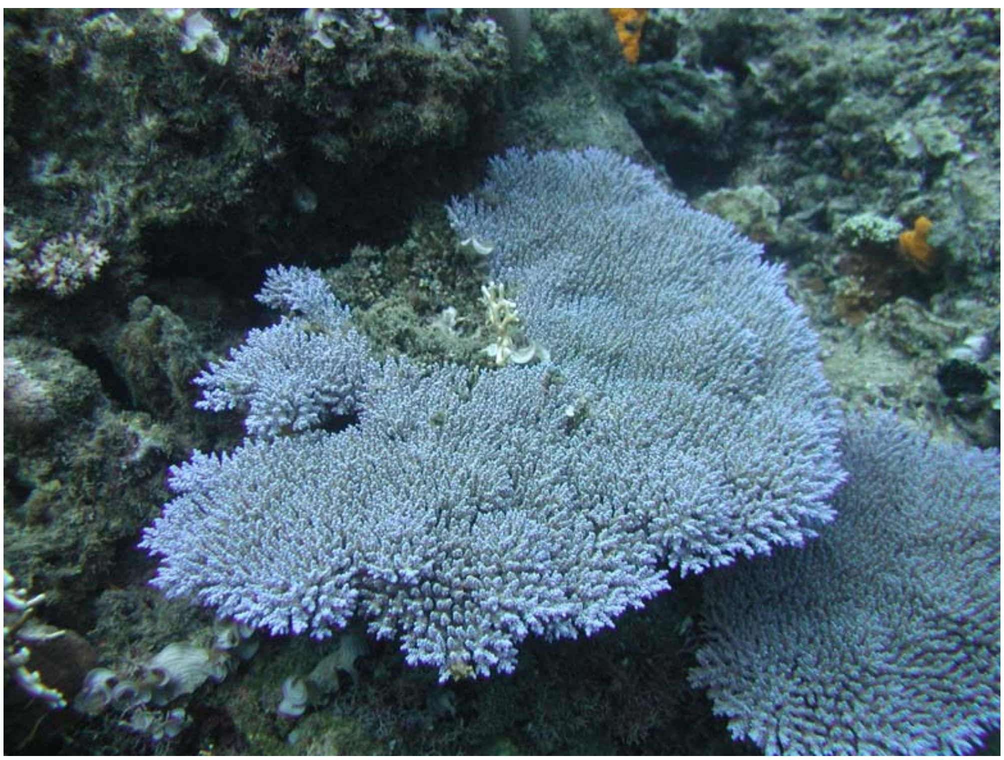
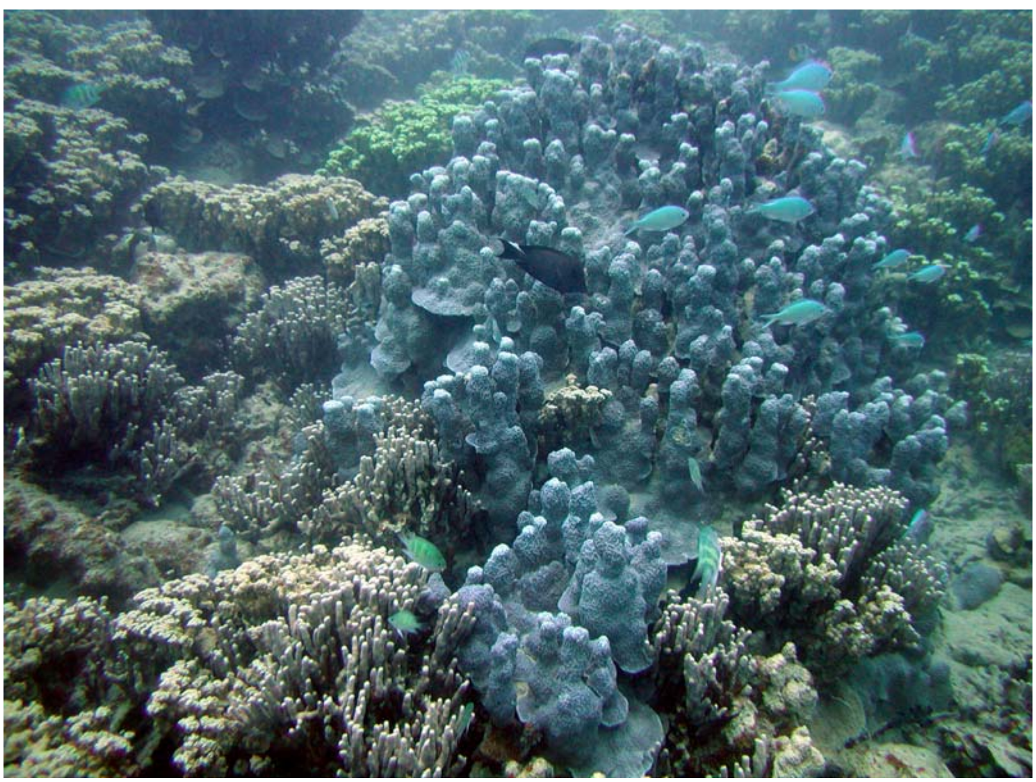


Plate 12

Fairway Shoals. The crest of many of the shoals were rubble and sand with dense brown algae *Padina sp.* Elephant ear sponges (*Ianthella basta*) were common on the slopes, as well as oval shaped free living corals (Family Fungiidae). Fungiidae were common at every study site.

Plate 13
Dry Dock Is. Note dense cover of stony corals and the presence of soft coral and large sponges. Bottom-*Porites cylindrica* in foreground with relatively rare bluish color morph of *Porites rus*



Appendix J
Supplemental Aircraft Carrier Marine Surveys

4. On Coral Size and Problems with Unlocking the Inherent Information. April 2010.

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On Coral Size and Problems with Unlocking the Inherent Information

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April 2010

Executive Summary

The purpose of this paper is to provide an overall viewpoint of the theoretical and practical considerations of the use of measures of size-frequencies of coral populations as a more suitable method to assess the function and structure of reef ecosystems than methods employing measure of benthic (coral) cover. While measures of size-frequency provides a important aspect of population dynamics, care must be taken not to confuse population dynamics with ecosystem functioning. While organism size, by encoding age and reproductive stage, does indeed determine the role played by the organisms in the population, this has nothing *a priori* to do with its role in the ecosystem (defined here as the ensemble of all living and interacting organisms plus their environmental determinants. While the size of an organism may determines its role in the ecosystem, a mere description of the size-frequency can never lead to understanding of the functioning of the entire ecosystem, since it only measures a single parameter of a part of the living component. Size-frequency provides no information about all the other factors determining trophic (energy-flow, etc.) and sociological (competition, predation, etc.) dynamics, nor of the environmental determinants. Thus, size-frequency analysis can be considered as one of many critical tools to understand the functioning of individual populations, but must not be overstated as a key to understanding ecosystem functioning. Size-distributions are mostly a key tool of demographics, i.e., population ecology. Since it remains to be demonstrated exactly how size-frequency distributions better facilitate assessment of ecosystem functioning than living cover of corals, it can hardly be considered a superior metric than measures of cover of all of the components of entire habitats.

Coral reefs are complex marine ecosystems distributed throughout the world's tropical ocean that comprise approximately 5–15% of the shallow sea areas within 0–30 m depth. Quantification of benthic community structure is central to understanding coral reef ecosystem function. Given the proper historical and geomorphological context, quantifying the area coverage of community-types at a point in time allows a researcher to identify the current phase of the reef, and thus assess reef status. Quantifying community-type cover over time enables identification of phase shifts, and thus changing reef status.

Knowledge of area distributions of reef community-types further allows straightforward estimates of functional rates of reef productivity, community metabolism and biogeochemical cycles. Thus, important aspects of reef system function which can interpret reef status are reducible to the quantitative measure of area coverage of basic reef community-types.

Regardless of the methodology, there are constraints on the utility of *in situ* coral reef surveys. Even when surveying a single reef, cost and logistical considerations dictate a statistical sampling approach. Observations are made at discrete (either random or nonrandom) locations on the reef, while large areas of the reef remain unobserved. Such sampling provides estimates of various statistics, generally the mean and variance of the observed parameters. However, reef communities exhibit a great deal of patchiness, and even the most intensive surveys may not adequately capture community distributions. When extending surveys beyond a single reef, *in situ* methods become intractable.

However, remote sensing has become a proven tool for quantifying reef community structure and distribution at large scales. This technology has been demonstrated to be the most cost-effective means for acquiring synoptic data on reef community structure, and it is the only available tool that can produce globally uniform data. It is important to note that virtually all remote sensing studies rely on some kind of estimate of benthic cover. The use of counting methods, such as size-frequency, provide only statistical samples of coral populations that are not amenable to applications of remote sensing, eliminating the potential for gaining synoptically uniform data.

The major point of argument of this paper has been concerned with the scientific justification of whether measures of size-frequency provide a better estimate of "ecosystem function" than measures of percent benthic cover. However, regardless of the scientific merits of either side of this argument, it is imperative that the actual field and analytical methods employed to generate these data provide a valid and unequivocal representation of the reef ecosystems under study.

Specifically, the two methods in question are: 1) Measurement of the size of discrete coral colonies using a one-dimensional measurement performed entirely *in-situ*, which provides a size-frequency distribution of corals of each species population, and 2) Measurement of coral community structure in terms of percentage of total bottom cover using a two-dimensional photographic method for collection of digital data *in-situ*, and subsequent analysis in the laboratory. The size-frequency method has been proposed by Federal Resource Agencies as the preferred method of assessment; the photographic percent coral cover method was employed by the Navy to conduct the resource assessment during fieldwork performed in April-May 2009.

Studies using size-frequency methods reported in the scientific literature typical employ multi-dimensional measurements (usually height, width, length) to arrive at an estimate of colony surface area or volume. A single dimension, in the absence of the others, will not provide sufficient information to construct a valid assessment of colony size, nor population structure. The size-frequency method involves data collection by a single investigator entirely *in-situ*, which no record of the data source. As a result, the size-frequency method contains no opportunity for replication, nor is there any possibility for evaluation of bias or error. On the other hand, the photographic cover method produces a permanent record of the data source which can be analyzed repeatedly in an identical manner to arrive at reliable and repeatable estimates with elimination of bias.

There are two main criteria for valid and successful size-frequency analyses are 1) colonies sizes small with respect to the sampling unit, and 2) discrete colony growth forms that are measurable. In the case of Apra Harbor, neither of these criteria is met. As many corals are much larger than the sampling unit, “rules” have to be applied to determine which colonies are included or rejected in counts, which adds a degree of subjectivity to the data. In addition, growth forms that do no consist of discrete colonies, such as branching corals that occur in interconnected mats that may cover hundreds of square meters of reef add another level of subjectivity to discrete measures. Fragmentation and formation of amalgamated multi-generational “supracolonies” clouds the distinction of separation of true colonies which equivocates the data as meaningful, particularly in terms of functionality. None of these subjective issues are a factor in methods using benthic cover.

In summary, quantifying area cover of benthic habitats and component communities is central to understanding coral reef ecosystem status and function. A myriad of theoretical considerations indicate that measurement of populations structure in terms of size-frequency is not the most effective method for evaluating reef ecosystem structure and function. In addition, the field method suggested to determine population structure in Apra Harbor has a variety of problems that negate this metric as providing a valid, non-subjective data set. These methodological short-comings do not exist for measures of benthic cover. For all of these reasons, use of traditional measures of area cover provide a more practicable and scientifically defensible tool for assessing coral reef ecosystem structure and function.

Theoretical Aspects of Measures of Size-Frequency Distributions on Coral Reefs

What Are Size-Frequency Distributions?

The most obvious signal of life-history is an organism's size. It encodes its fitness, survival through preceding life-stages, and assigns it a function within the population according to life-stage, in the simplest case whether reproductively active or not. Size is often key to an organism's role in the ecosystem and has important evolutionary implications (Damuth 1981; Calder 1984; LaBarbera 1989). In sessile organisms (plants, corals, etc.), the sum of all size-information is the proportion of substratum covered by the ensemble of all differently-sized individual organisms and is generally referred-to as "living cover." The sum of all individuals per life stage, if the stages are determined by sizes, leads to a size-frequency distribution. The following shall concern itself with the different types of information contained in cover and size-frequency measures.

One can often estimate the size of individual organisms and their distribution over different classes, the latter a powerful tool with long tradition in assessment of population dynamics in particular in entomology and fisheries (van Sickle 1977; Southwood 1978; Barry and Tegner 1988). At any time, size-distributions encode much of a population's history and are regularly used for making predictions about a population's future trajectory or to evaluate the effects that certain mortality levels and agents (exploitation by fisheries, control by pesticides, etc.) may have (Varley et al. 1973; Pauly 1984). In reef studies, size-frequencies have been used to make inferences about past and future coral population dynamics (Bak and Meesters 1998, 1999; Meesters et al. 2001; Zvuloni et al. 2008; McClanahan et al. 2008). Population viability analysis, an important tool in conservation biology, relies in many instances on size-frequency-type information (Morris et al.,1999). Therefore, it is appropriate to critically examine the usefulness of size-frequency studies for environmental impact statements in coral reef environments.

The size distribution of organisms can vary (Huston and DeAngelis 1987) and is determined by differences in

- settlement,
- initial size,
- different growth rates due to genetic or environmental effects, and
- mortality.

These variables in turn are influenced by a host of biotic and abiotic factors such as predation, disturbances, competition, currents, settlement rates, temperature stress, and many more. These factors can act either systematically or randomly. Different combinations of these factors might produce similar distributions, as might interactions with various other biological or abiotic mechanisms. For example a reduction in birth rate (stage 1), may have the same effect on the number of juvenile corals (stage 2) as a constant birth rate but increased mortality of juveniles. If juveniles (stage 2) are the first life-stage that can be cencussed with certainty, the two above-mentioned mechanisms may be impossible to tell apart. Such complications make inferences about the mechanisms generating size-distributions difficult, but many theoretical studies have made important contributions to our understanding (van Sickle 1977; Southwood 1980; Huston and De Angelis 1987; Barry and Tegner 1988; Botsford et al. 1994; Bak and Meesters 1998, 1999; Caswell et al. 1998; Caswell 2001). Models have been developed that attempt harnessing the shape of size-frequency distributions to make inferences about growth and mortality.

Besides live cover, size-frequency is a straightforward means to measure characters of coral (plant or any animal) populations. How much information can be wrested from such size distributions, with special references to corals, shall be discussed underneath.

Size-frequency Varies and May Not Stabilize

Individuals move through age- or size-classes as they grow older. Unless new recruits enter the smallest size-class, all individuals will move toward the bigger size-classes, and the size-frequency curve will move from strongly right-skewed (toward the small size-classes) to strongly left-skewed (toward the big size-classes). The shape of the curve will change every year. If there are no extraneous influences (predation, disease, etc.), this year-to-year change will be strictly deterministic (Figure 1). Given that extraneous influences are ubiquitous on coral reefs, it is highly unlikely that changes will be strictly deterministic.

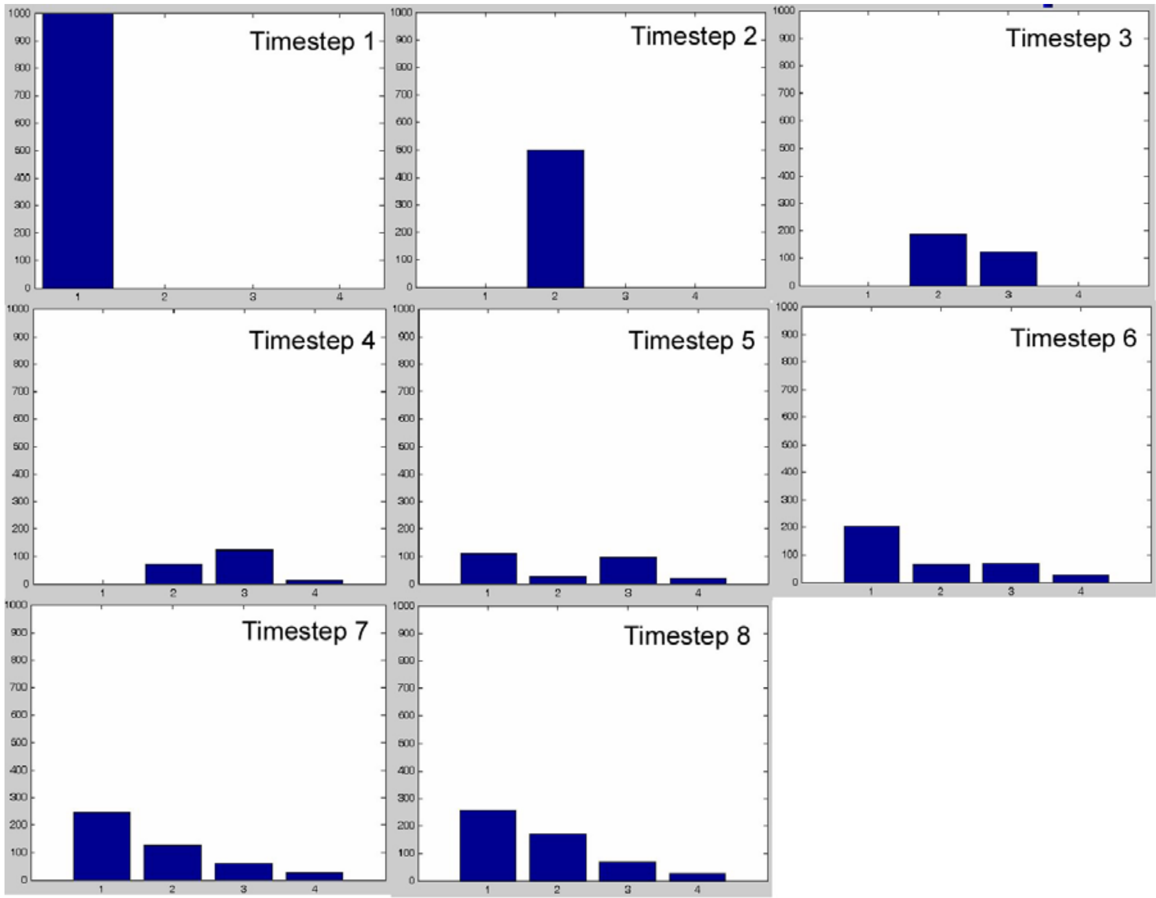

Figure 1. An illustration of an animal population with a starting population of 1,000 individuals stepping through four size-classes. No extraneous mortality or predation are included, as they would complicate the progress through the size-classes. It is obvious that, unless stable stage (age, size) structure is reached, size-frequency distribution will differ at every time-step.

Many animal populations can reach a stable age distribution, at least theoretically (Caswell 2001). Stable age (or stage, or size) distribution refers to a state in which the number of individuals in each different stage (size, age) changes in equal proportion to each other. Thus, while the overall population grows, there always remains a constant ratio of big to small individuals. Stable stage (age, size) distribution is a hallmark of demographically closed populations (see below). Since demographic closure has not been unequivocally proven for coral populations, it is unclear whether coral populations will ever reach a stable stage distribution.

Where and Why Size-Frequency Analysis is Routinely Used

Fisheries management largely concerns itself with the determination of permissible levels of exploitation of fish stocks (Pauly 1984). This refers essentially to the study of maximum levels of mortality that can be sustained by a fish stock without depressing its reproduction to a level that can no longer replenish stocks. Similar questions are being asked by, for example, game management (Owen-Smith 2008) forestry, entomology or theoretical studies concerning predator/prey or other competition phenomena (May

1975; Case 2001). The question concerning the minimum levels of reproduction in a population automatically leads to a question of size distribution, since recruits are usually the smallest size-class in a population, and, in most organisms, the biggest size-class is the most reproductively active (post-reproductive large size classes occur rarely, for example in whales, great apes and humans; Caswell 2001). This, and the fact that different gear catches different size classes (e.g., net mesh size, hook size, etc.), leads to detailed models of population functioning arriving almost invariably as size-, age- or stage-based. The evaluation of size-frequency distributions then becomes a key tool in assessing the population's functioning and being able to predict or hindcast trajectories.

Knowledge of reproductive capability and fate of reproductive elements is critical for the assumption that size-based information is useful to express the dynamics of a population. In short, it is necessary to know how many offspring are produced per adult, and where these offspring go. Ideally, a population is demographically "closed," i.e., its recruits stay within the population and can therefore be accounted for (Figure 2, Top). A fish population in a lake would be a good example, where all larvae produced by adult fish remain in the lake and therefore replenish the local population.

Problems arise when populations are demographically "open," i.e., their recruits seed other, independent populations, and they in turn receive their recruits from other, independent populations (Figure 2, Bottom). In such a case, the reproductive success of the focal population depends on the reproductive output of a connected population. If the focal population exports all its recruits and receives them from elsewhere, then an evaluation of its inherent fecundity due to large, fertile organism is meaningless for its trajectory. Size-information of the focal population in such a case only helps to estimate the amount of larvae that are being exported, but does not allow estimation of population replenishment in the focal population. Its value thus becomes questionable.

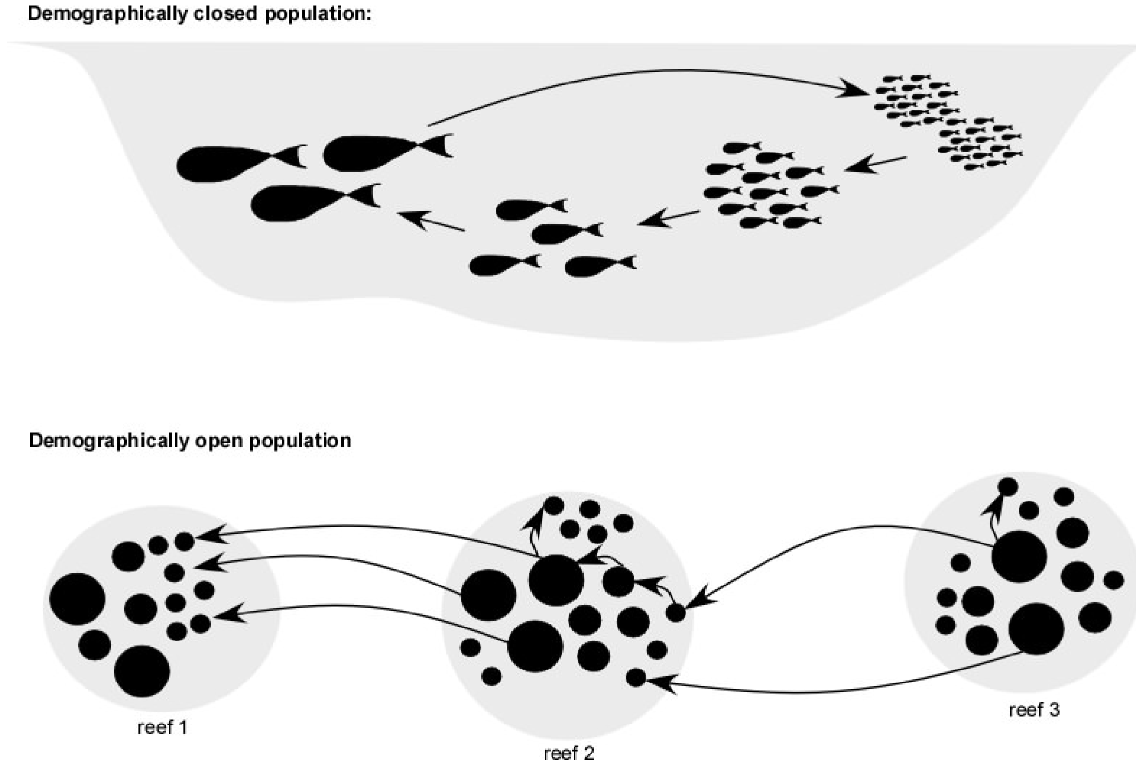

Figure 2. (Top) The fish population of a lake as an example of a demographically closed population that recruits into itself. Due to this dynamic, the number of future offspring can be estimated by the standing stock of fertile adults. Size-frequency distributions in the population can be understood as the deterministic flow of organisms across size classes. The number of young (smallest size-class) is determined by the number of adult (largest size-class) in the population and can be calculated with relative ease. (Bottom) In an open population, such as this example of three coral populations on three distinct but demographically connected reefs, each sub-population receives recruits from outside, and some from within. Thus, there is no fixed relationship between adult organsisms and the numbers in the smallest size-class within each sub-population. Size-frequency cannot be understood in terms of the simple deterministic flow that exists in the closed population. The evaluation of each sub-population's size-frequency does not yield unequivocal (if any) information about population functioning.

Problem: Coral Reefs Tend to Be Demographically Open

Size-frequency information is best harnessed for insights into a population's history in demographically closed populations (the fishes of a lake, the salmon population in the Bering sea, the birch trees in a forest patch), since that allows tallying recruit survival and mortality in relation to fecundity of the large size-classes. However, many benthic marine invertebrate populations are demographically open (Caley et al. 1996), and coral reefs are certainly among them (Hughes et al. 2000). Recruitment may be patchy and unpredictable in space and in time (Sammarco and Andrews 1988; Sammarco and Heron 1994). It can reliably be assumed that, somewhere on each reef, some coral species will likely recruit—or not recruit—in any given year. While instances of within-reef larval retention have been demonstrated (Jones et al. 2009), strong connectivity among reefs, or at least different reef zones, seems to be the norm. This makes interpretation of local size-frequencies difficult, since it introduces uncertainty of how the smaller (younger) size-classes relate to the bigger (older) ones.

What Good Are Size-Frequencies?

Much has been made in the preceding text about the importance of size-frequency analysis for understanding population dynamics. Care must be taken not to confuse population dynamics with ecosystem functioning. While organism size, by encoding age and reproductive stage, does indeed determine the role played by the organisms in the population, this has nothing *a priori* to do with its role in the ecosystem (defined here as the ensemble of all living and interacting organisms plus their environmental determinants, i.e., in the original sense of Tansley 1935). While an organism's size often also determines its role in the ecosystem, a mere description of the size-frequency can never lead to understanding of the functioning of the entire ecosystem, since it only measures a single parameter of a part of the living component. Size-frequency provides no information about all the other factors determining trophic (energy-flow, etc.) and sociological (competition, predation, etc.) dynamics, nor of the environmental determinants. Thus, size-frequency analysis must be understood as one of many critical tools to understand the functioning of individual populations, but must not be overstated as a key to understanding ecosystem functioning. Size-distributions are a mostly key tool of demographics, i.e., population ecology.

Is Size Even the Right Variable to Measure?

While size is the generally easiest to observe (as long as individuals occur as discrete colonies), and the most obvious state variable of most organisms, it may not necessarily be the most meaningful to measure. Age or developmental stage (an insect example: several larval instars – nymph – pupa – imago) may provide more meaningful characterization of the population. Size is also an elusive variable, since it can be characterized by radius, diameter, length, width, volume, or any other more or less arbitrary measure. The decision of which variable to measure is usually taken by employing statistical tests, for example searching which of a multitude of measured variables correlates most strongly to the target variable that defines the population trajectory – more often than not this is fertility. Other methods would be log-linear models (Caswell 2001) that are maximum likelihood methods for a probability model in which fate categories (e.g., death) are not the same as the state categories (e.g., size or age). Known fate transition probabilities for different states, or combinations of state, can then be tested. This allows for detection of the state variable with the highest correlation to fate, i.e., the best predictor of population trajectory and thus the ideal target variable for measuring. Any frequency analysis of state variables (size-frequency, age-frequency, etc.) that does not justify the reason for selection, should be treated with caution since, in the worst case, it may be measuring a meaningless variable or one that poorly correlates to the target fate!

Measuring coral sizes and size-distributions – problems and pitfalls

The problem of measuring coral size has a long history in literature (Pichon 1978), and, given that it is not clear what exactly coral size is, continues to fill the pages of journals. These problems relate to the frequently very uneven to highly contorted growth forms of many coral species that can create challenges on exactly what to measure (greatest length, diameter, radius, heights, etc). This problem can be overcome through the above-mentioned log-linear or other analyses, but the process of finding the most meaningful measure can be tedious and time-consuming. It is within the realm of the feasible, but it requires large amounts of data, if done correctly.

A more insidious problem is related to the fact that many coral species have a propensity toward asexual reproduction (Tunnicliffe 1981; Highsmith 1982). Many corals can break and from the fragments, new colonies (so-called ramets) can form. Many ramets (asexually produced colonies) then form a single genet (a genetically identical individual spread over separate clones). It is possible that wide areas of reef are made up by single genets, although they are covered by many outwardly independent corals (Stoddard 1984). This has important implications for population dynamics. Since many corals have barriers to avoid "selfing" (i.e., self-fertilization), such apparent "populations" could indeed be sterile, even if they should be hermaphrodites with both male and female gonads available at the same time. Thus any population dynamics based on genetically distinctive size-frequencies would be incorrectly estimated. This statement, however, depends on whether the corals are treated as a demographically closed population, in which case they would be infertile if inbreeding barriers exist, or demographically open, in which case all ramets flow into a pelagic pool of gonadal products and fertilization with other, imported material is possible. Only genetic analysis can identify whether a population is clonal or consists of genetically independent individuals. The problem is that specific markers exist only for a minority of species.

If we choose to ignore such genetic problems, and assume that every encountered coral should be counted as a potentially reproductively active individual whose size should be measured, problems of counting remain. We have to avoid bias in order to arrive at a true representation of the sizes (the following is specific to sizes, not ages, stages, etc.). Bias is introduced into the counting process by the mere fact that detection of an individual is proportional to its size. The larger a coral is, the more likely it will be seen, and the more likely a random point (if, for example image analysis is used) would fall onto it. In order to avoid under-representation of size-classes, certain correction factors have to be introduced (Zvuloni et al., 2008). These should be specified in the methodology, and any size-frequency dataset that is non-specific about bias avoidance should be treated with caution.

Do Corals of Different Size Have Different Value?

Usually, size-frequency information is collected in order to populate a model, or evaluate the size-frequencies with a model. We may, however, decide to just measure some size-specific property (such as fertility) and thus assign a certain value to specimens of a certain size. We could then simply use the observed size-frequency to measure the "value" of a given population. For example, if the number of larvae produced per individual is a measure of value, then large corals would rank higher than small corals (note: while coral fertility among individual polyps is variable, the fact that the number of polyps contained in larger corals increases exponentially also makes their gonadal production increase exponentially). Thus, a population of large corals could be assigned a higher “value” than a population of small corals.

The problem with such an approach can be seen in the lack of process information provided if a momentarily observed size-frequency distribution is used to assign value. While large individuals will certainly produce more larvae (and therefore might indeed be more valuable for the population), the vagaries of recruitment might well negate any success to the entirety of this cohort, if they are transported to a patch unsuitable for settlement (or eaten, etc.). One might conceive of a situation where the single lucky larva of a small individual is the only one to settle. Thus, the assignment of anything but highly subjective “values” to certain size-classes in preference to others may prove futile. There is likely little value in preferential consideration of certain size-classes; rather, the population should be considered as a whole. Even if large individuals may be highly desirable due to their important reproductive output (or serving as habitat to other, associated species, etc.), they would not exist had they not been small individuals at an earlier stage of their lives. Which is more valuable: today’s large specimen that tomorrow might be at end of its life-span, or today’s small specimen that tomorrow might become a large specimen?

How Do Given Size-Frequency Distributions Enhance Understanding of Population Functioning?

Since it is difficult to assign differential values to individuals of differing size, one might ask what purpose size distributions serve at all. Given that individuals of all sizes are needed to maintain a population, one could surmise that it might be more appropriate to ignore the subtleties of size-frequency distributions and simply provide a basic statistic that encompasses the entire population. That is the essence of “total living cover.”

A good understanding of size-distributions does allow us to investigate population dynamics. Several relevant questions might include

- How many larvae were available at the beginning to create the population observed today?
- How many larvae are needed every year to maintain a population as it is seen today?
- What would be the impact on the population if the mortality rate in a specific size-class changes?

To answer any of these questions, a quanticum of mathematics is needed. This is the world of theoretical ecology. Size-frequency analysis is often combined with models of growth rates of individuals. This is because both growth rate and mortality affect the shape of the distribution. The interdependence of growth and mortality allows deduction of the one parameter if the other is known. The following is an example of the usefulness of such an approach.

Many organisms are characterized by von Bertallanffy growth, which is exponential growth decaying with time:

$$S_t = S_\infty \left(1 - be^{-K(t-t_0)}\right),$$

where St is the size of an individual at time t after the moment of recruitment t0, S∞ is maximum size, b a scaling factor to account for size greater than zero at recruitment (b = 1 for recruitment at size 0), and K is the Brody growth coefficient, which determines the shape of the growth function. The meaning is that organisms grow fastest when young, and growth slows as they get older until they eventually reach an upper size limit. Many fish follow such a growth pattern, and individual coral polyps and solitary corals do, as well. Most coral colonies do not follow this type of growth: they can be approximated as ever-expanding spheres. Therefore the mathematical solution described below is not applicable to coral colonies.

Barry and Tegner (1989) developed a simple model to evaluate the shape of the size-frequency distribution to gain insight into mortality/growth payoffs. Using a simple exponential model of change in abundance per cohort combined with the von Bertalanffy growth model (hence referred to as VBGM), Barry and Tegner (1990) solved for the conditions necessary for zero-slope, i.e., the existence of modes or troughs:

$$\frac{dN}{dS} = \left(\frac{Z}{K} - 1\right)\frac{-N_0}{KS_\infty^2}\left(1 - \frac{S_T}{S_\infty}\right)$$

From this equation, stability conditions can be derived. These are

- N0 = 0: trivial
- ST = S: trivial
- S∞ = ∞: trivial
- Z = K: growth balanced by mortality

Dynamics of the model and the resultant size-frequency distribution patterns depend largely on the dynamics within the first bracketed expression on the right-hand side of the equation. If Z exceeds K, a negative slope results; otherwise a positive slope results. Depending on whether mortality (Z) is considered constant or variable, different size-frequency patterns can be derived (Figure 3). Z and K are parameters that have relevance for growth and mortality estimations in our other models and simulations, and it is from the Barry-Tegner model as applied to observed size-frequency distributions that we derive their relative sizes.

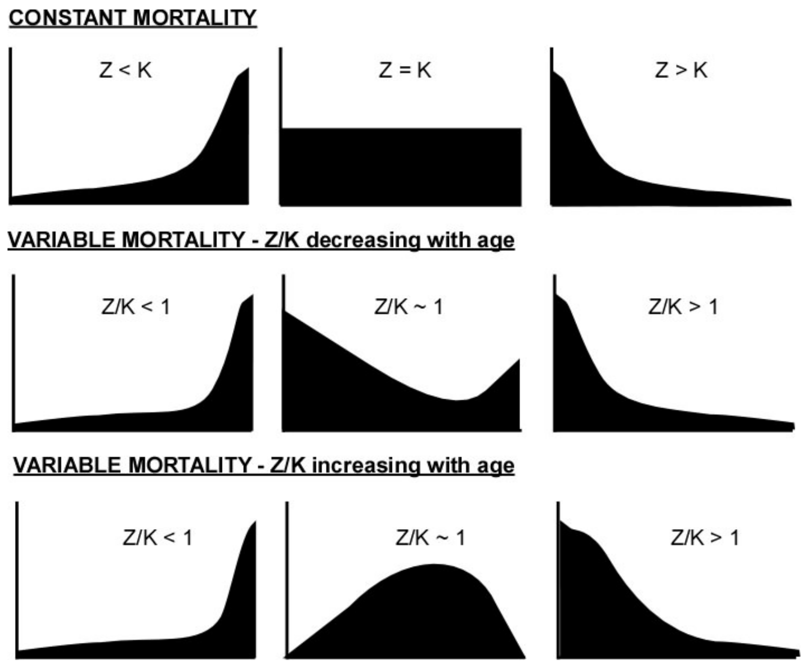

Figure 3. Solutions of the Barry-Tegner model, which is applicable to all organisms with von Bertalanffy growth – thus excluding most corals. The shape of the size-frequency relationship gives convenient information about the interplay between growth (K) and mortality (Z).

Is this meaningful for corals? Corals grow essentially as expanding disks (when seen from above, e.g., tabular Acropora, encrusting corals) of more or less irregular shape or as hemispheres (most massive genera). While growth is theoretically indeterminate, physiological and mechanical considerations set an upper bound (Sebens 1982), and many coral species reduce growth rate with age or obtain an upper modal size that is only exceeded by exceptional specimens. While the growth of some scleractinian corals can be described using the von Bertalanffy growth model (Chadwick-Furman et al. 2000; Goffredo and Lasker 2008), and its adequacy is certainly suggested by its derivation from first principles, it appears that many other corals indeed grow indeterminately. Thus, this elegant and simple model is not applicable to corals. Using the same path for an explicit solution provides us with a formula that is difficult to read, and not straightforward to interpret. We therefore need to reject it as a model that does not further our understanding of coral population dynamics.

The Value of Size-Frequencies for Population Fore- and Hind-Casting

An even simpler mathematical expression would be the use of size-frequency information for the derivation of a matrix model (Caswell 2001). In such a model, transitions among size classes are assumed to follow equations that are linear with respect to the variables that are collected in a vector of size-class information (the size-frequency distribution). Transition rules encode survivabilities and fertilities collected in a matrix that pre-multiplies that vector. Such models have been frequently applied to corals (Hughes 1984; Caswell 2001), and their use has been previously suggested for coral monitoring (Smith et al. 2005). Thus we may expect immediate applicability here.

Since many benthic marine populations are open (Caley et al. 1996), causing uncertainty about how much of the local population recruits back into itself, two different types of models are required.

The projection in a population that recruits into itself is expressed as

$$n(t+1) = \mathbf{A}n(t).$$

In the case of an open population, the expression is

$$n(t+1) = \mathbf{A}n(t) + v.$$

In these equations, n(t + 1) is the solution vector resulting from multiplying the size transition matrix A (which contains all the survival and fertility information) by a vector of a size-frequency distribution at time zero, to which is added a vector with a value in position 1. This value represents recruitment, and can be varied at will. Thus, recruitment can be treated as from within the local population, expressed as An(t), or from outside the local population if vector v is added. It is therefore possible to explore mixtures of only local recruitment, local and imported recruitment, and only imported recruitment.

When provided with size-frequency data from any given reef, it is necessary to ask for the origin of a given distribution. We may ask what the original population looked like before it began to grow to reach the present distribution. This would allow forecasting of population trajectories, since we would possess knowledge of the transition rules and the start-up population. The above formulae suggest a deceptively simple solution to this posit: suppose we have a size-frequency distribution and we express it as a vector. If the transition rules causing individuals to move among size-classes are encoded in a matrix (i.e., pre-multiplied to a vector), then certainly an inversion of the formula would allow us to obtain the starting vector:

$$\mathbf{A}n(t) = n(t+1) \quad \rightarrow \quad n(t) = \frac{n(t+1)}{\mathbf{A}}.$$

However, matrices do not commute, therefore the above solution is incorrect. Instead, we must resort to an optimization method, such as quadratic programming. Using such a routine, it is possible to find an inverse solution to the matrix from which the measured population vectors originated. However, multiple size-frequency distributions are required, since optimization is not possible based a single distribution.

What does this show us? Even though size-frequency distributions do contain valuable information, it is difficult to interpret the exact meaning of that information. If one assumes a lack of extraneous influences (mortality events due to inclement weather or an unusually strong predation event), then one can, at least theoretically, arrive at the matrix that determines these size-distributions. The utility of such analysis in the context of an EIS or HEA remains to be demonstrated.

Can Species and Their Size-Frequencies Be Ignored, Instead Concentrating on Cover?

It has been hypothesized (Hubbell 1997, 2001) that dynamics in coral communities is neutral, i.e., that species are roughly equivalent to each other and that dominance and replacement happens within a zero-sum game with Markovian properties. This translates to replacements taking place largely due to "ecological drift," rather than due to niche separation along axes of optimal resource usage. Dornelas et al. (2007) provide evidence that Pacific coral communities are neither neutral nor niche-accommodated, but apparently driven by stochastic processes, such as disturbances. Thus, no clear consensus yet exists, and there is a possibility that some subsets of coral communities may indeed be neutral, others clearly niche accommodated, and others determined by stochastic processes. In a neutral world, community dynamics is largely independent of species-specific characters, since these are interchangeable and the eventual dominance of species is determined by drift, not competition. Species-specific differences in regeneration ability (recruitment, healing at the colony level) may well drive the dynamics of communities subjected to stochastic disturbance regimes. However, the demonstrated stochasticity of recruitment processes (Sammarco and Andrews 1988; Sammarco and Heron 1994), if superimposed on stochastic disturbances, may negate many adaptive advantages. In the absence of a demonstrated importance of species-specific information, it appears permissible to characterize a coral community by a denominator common to all species and all life stages. The logical choice would be the living cover achieved by the sum of all corals in a community. This is a simple and intuitive metric that integrates across all other dynamics.

Overall, we observe that size-frequency distributions are a valuable tool for population assessment and, potentially, for impact assessment if population trajectories need to be demonstrated. Obtaining the latter is neither straightforward nor easy. Much temporal information is required, as is justification for the parameter to be measured (size may be an unsatisfactory descriptor). It is difficult to envisage raw size-frequency distributions as encoding ecosystem function, since the ecosystem is the sum of all living and environmental factors, and size-frequencies measure only a small fraction of those. Since it remains to be demonstrated exactly how size-frequency distributions better facilitate assessment of ecosystem functioning than living cover of corals, it can hardly be considered a superior metric.

On the Importance of Quantifying Coral Reef Habitat Structure

Definition of "Coral Reef"

"Coral reefs are shallow-water, tropical or subtropical marine ecosystems that contain one or more communities dominated by corals and other framework-building organisms such as crustose coralline algae. Communities of framework-building organisms have persisted or recurred over a sufficiently long period to have built a three-dimensional structure on top of the underlying (non-reef) substrata."

Buddemeier and Smith (1999)

Background on Coral Reef Benthic Ecosystems

Coral reefs are complex marine ecosystems distributed throughout the world's tropical ocean. Reefs directly occupy an estimated area of 250,000–600,000 km2 (Kleypas 1997; Smith 1978; Spalding and Grenfell 1997). These values correspond approximately to 0.05–0.15% of the global ocean area, respectively, and about 5–15% of the shallow sea areas within 0–30 m depth. Differences between area estimates reflect the use of different estimation methodologies, as well as variations in reef definition (Buddemeier and Smith 1999). In all, coral reefs exist in the territorial waters of 100 out of 160 member states of the United Nations (as of 1992; Salvat 1992).

Modern reefs initiated growth on antecedent platforms between 9,000 and 6,000 years ago, at the end of the Wisconsin glacial maximum (Veron 1995). Through the Holocene, reefs have grown in parallel with sea level change (Camoin et al. 1997; Grigg 1998). Over that time, today's extant reefs have maintained net accretion rates sufficient to keep up with, or to catch up to, changes in sea level. Reefs with lower net accretion rates either were unable to keep up with the Holocene sea level rise and have drowned, or are currently at the lower limit of reef growth, very slowly accreting toward present sea level (Grigg and Epp 1989).

Coral reefs have existed over millennia as geologic features, but their construction is biogenic, composed of the skeletons of hermatypic (reef-building) organisms (Achituv and Dubinsky 1990). The most conspicuous organisms in reef formation are scleractinian corals, which have high calcification rates and produce most of the calcium carbonate (aragonite) that makes up the reef framework. Other important reef calcifiers are various calcareous algae: crustose red coralline algae cement the softer, more porous coral skeletons, creating a more wave-resistant structure, and the calcareous green alga Halimeda can account for large fractions (up to 80%) of reef sand deposits (Berner 1990). The association of these organisms produces a living structure that grows and maintains itself near sea level.

Coral reef benthic ecosystems are collections of distinctive communities, which are distinguished by their characteristic assemblages of organisms and substrates (Stoddart 1969). Because coral and algae are responsible for reef construction and maintenance, their environmental limits determine the distribution of reefs (Kleypas et al. 1999). The abiotic parameters most affecting the distributions of coral and algae are temperature, light, salinity, nutrients, carbonate saturation state and water motion (Smith and Buddemeier 1992), while the most important biotic parameter is grazing (Berner 1990). The specific influences of these parameters on reef-building organisms are interconnected and complex, and they are a major focus of ongoing reef research.

Major coral reef ecosystem processes are those linking the physical environment to the reef community (Hatcher 1997). Reefs are noted for their high rates of ecosystem gross primary production and respiration (Odum and Odum 1955), probably their most basic and important ecosystem functions. At the ecosystem spatial scale and at seasonal time scales, respiration generally equals production so that ecosystem net production is near zero (Kinsey 1985). The same is not necessarily true for shorter time periods (days to weeks), smaller sub-reef areas (Falter et al. 2001), or even some entire reef systems. Importantly, no matter the temporal or spatial scale, four basic classes—fleshy algae, non-fleshy algae, hermatypic coral and sediment—apparently dominate reef biogeochemistry (Kinsey 1985).

In addition to the reef-building organisms, coral reefs host a diversity of life that rivals that of tropical rain forests, with the number of species potentially reaching the millions (Small et al. 1998; Bellwood and Hughes 2001). This biodiversity and the general abundance of life on reefs provide a vital resource for human populations around the world, supporting, among other activities, artisanal, commercial and sport fisheries and ecotourism. It has been estimated that direct and indirect use of reefs contributes more than US$1 billion annually to the economy of the Philippines (White et al. 2000), and nearly US$7 billion annually to the economy of four southeastern Florida counties (Johns et al. 2001). While the accuracies of these dollar amounts are debatable, it is certain that coral reefs are important to the cultural and economic lives of millions of people around the world.

Assessing the Status of Coral Reef Benthic Ecosystems

Specifically, quantification of benthic community structure is central to understanding coral reef ecosystem function:

1. Given the proper historical and geomorphological context, quantifying the area coverage of community-types at a point in time allows a researcher to identify the current phase of the reef, and thus assess reef status. Quantifying community-type cover over time enables identification of phase shifts, and thus changing reef status (Done 1992,1995; Connell 1997; Connell et al. 1997; Hoegh-Guldberg et al. 2007).

2. Knowledge of reef community-type area distributions further allows straightforward estimates of rates for reef productivity, community metabolism and biogeochemical cycles (Atkinson and Grigg 1984; Kinsey 1985; Andréfouët and Payri 2000; Brock et al. 2006b; Hochberg and Atkinson 2008).

3. Different reef habitat types are important in life history strategies of different reef-dwelling organisms, e.g., as recruitment sites for coral larvae (Miller et al. 2000) and juvenile fish (Light and Jones 1997), and as habitat for adult fish (Chabanet et al. 1997; Purkis et al. 2008).

4. Community structure identifies habitats and resources for general reef monitoring and management (Bour et al. 1986; Price et al. 1987).

Thus, important aspects of reef system function and, more crucially, reef status are reducible to the quantitative measure of area coverage of basic reef community-types.

"Basic" reef community-types are those that have a fundamental, general role in reef ecosystem processes. Coral reefs are largely mosaics of coral, various algae and sand (Kinsey 1985), and, as previously mentioned, knowledge of their distributions is fundamental to assessment of reef status. The importance of coral has been stated above. Algae can also play a pivotal role in reef structure and function, and include three basic forms: turf algae, crustose coralline algae, and fleshy macroalgae (Berner 1990). Crustose coralline algae are important reef calcifiers (Kinsey 1985), cementing the products of disintegration of various other calcifying reef organisms, thus creating a harder skin for the reef (Berner 1990). Turf algae and fleshy macroalgae are a major source of fixed carbon to reef primary consumers (Klumpp and McKinnon 1989). The different fleshy macroalgae taxa—mainly Chlorophytes, Phaeophytes and Rhodophytes—are preferred forage material for different reef consumers (Glynn 1990) and are therefore important to understanding energy flow through the reef system. Soft corals and gorgonian corals can occupy substantial reef areas and may compete with scleractinian corals for space (Ben-Yosef and Benayahu 1999; Bastidas et al. 2001). Seagrass is important as essential habitat in the life histories of many reef species, and it can also be spatially important on and near some reefs (Enríquez et al. 2002). Finally, the spread and deposition of terrigenous sediments can be deleterious to reefs near high islands (Watanabe et al. 1993). Quantifying the relative cover and spatial distribution for each of these reef constituents is the foundation for reef ecosystem studies.

There are three common methods for determining benthic cover on coral reefs: (1) 1–10 m scale quadrats, (2) 10–100 m scale line transects, and (3) 100+ m scale manta-tows, which entail towing a diver on a sled behind a boat, with the diver pausing periodically to record estimates of reef benthic cover. Quadrats and transects resolve reef elements at the scale of tens of centimeters, providing detailed and statistically rigorous estimates of reef community structure (Bouchon, 1981). Manta-tows are less rigorous because they are conducted at a much larger spatial scale without spatial reference cues, which has two main drawbacks: a decrease in resolving power and a lack of repeatability (Bainbridge and Reichelt, 1988; Miller and Müller, 1999). Nevertheless, the manta-tow is the accepted standard for the Global Coral Reef Monitoring Network (UNESCO, 1991).

Coral Reef Remote Sensing

Regardless of the methodology, there are constraints on the utility of *in situ* coral reef surveys. Even when surveying a single reef, cost and logistical considerations dictate a statistical sampling approach. Observations are made at discrete (either random or nonrandom) locations on the reef, while large areas of the reef remain unobserved. Such sampling provides estimates of various statistics, generally the mean and variance of the observed parameters. However, reef communities exhibit a great deal of patchiness, and even the most intensive surveys may not adequately capture community distributions. Extending surveys beyond a single reef, *in situ* methods become intractable. Remote sensing is one tool that has potential for quantifying reef community structure and distribution at large scales (Mumby et al. 2001). This technology has been demonstrated to be the most cost-effective means for acquiring synoptic data on reef community structure (Mumby et al. 1999), and it is the only available tool that can acquire globally uniform data. It is important to note that virtually all remote sensing studies described below rely on estimates of benthic cover, which can be extrapolated from small scales to large with equal consideration using remote sensing techniques. The use of counting methods, such as size-frequency, do not provide the capability for such extrapolation to large areas, and data products inherently do not cover entire areas of study with equal intensity.

Kuchler et al. (1988), Green et al. (1996), Mumby et al. (2004), and Andréfouët et al. (2005) provide thorough reviews of the history of coral reef remote sensing. By far, the predominant applications of remote sensing to coral reefs are to delineate reef geomorphology and to determine distributions of benthic communities. There have been numerous demonstrations of the utility of remote sensing data to other areas of reef science. Andréfouët et al. (2004b) used IKONOS imagery to estimate percent cover of an invasive algae on Tahitian reefs, then used an empirical relationship to scale the percent cover estimates to biomass. Harborne et al. (2006) evaluated beta-diversity for nearly the entire reefscape of St. John, U.S.V.I., based on a map of benthic community structure derived from airborne multispectral imagery. Ortiz and Tissot (2008) manually digitized habitat maps of marine protected areas on the Big Island if Hawaii using aerial photographs and lidar data. They found that in all areas surveyed, yellow tang recruits preferred coral-rich areas, while the distribution and abundance of adults varied greatly between sites. Brock et al. (2006) used rugosity values derived from high-spatial-resolution lidar data to locate clusters of massive coral colonies growing among seagrass beds in the Florida Keys. Kuffner et al. (2007) found that fish species richness and abundance in Biscayne Bay, Florida were correlated with reef rugosity values derived from airborne lidar data. Purkis et al. (2008) found a similar correlation of reef fish diversity and abundance with rugosity derived from IKONOS imagery for Diego Garcia (Chagos Archipelago). Palandro et al. (2008) processed a time-series of 28 Landsat scenes to detect changes in the coral reefs of the Florida Keys. Their results mirror the habitat decline observed by long-term in situ monitoring. Phinney et al. (2001) re-traced the Caribbean-wide mortality of *Diadema antillarum* during 1983–1984 using satellite ocean color data and changes in reef habitats detected in Landsat imagery. Finally, remote sensing appears particularly suited to large-scale determination of reef biogeochemical rates. Atkinson and Grigg (1984) initially demonstrated the use of remote sensing imagery to scale modal rates of reef productivity and calcification (Kinsey 1985). This approach has since been repeated by other researchers using various image sources (Andréfouët and Payri 2000; Brock et al. 2006b; Moses et al. 2009).

Remote sensing has also entered the realm of purely applied reef science. The U.S. Coral Reef Task Force stated a national need for comprehensive coral reef maps that create accurate baselines for long-term monitoring; illustrate important community-scale trends in coral reef health over time; characterize habitats for place-based conservation measures such as MPAs; and enable scientific understanding of the large-scale oceanographic and ecological processes affecting reef health (U.S. Coral Reef Task Force 1999). To meet these needs, the National Oceanic and Atmospheric Administration initiated numerous regional mapping projects extensively utilizing IKONOS imagery. With funding from the National Aeronautics and Space Administration, the Millennium Coral Reef Mapping Project mapped the locations, extents and geomorphologies of all the coral reefs in the world, based on Landsat imagery. These projects employed the most basic of image analysis methods: they relied almost exclusively on manual digitization to generate map products, essentially applying the same techniques that had been in use prior to the advent of digital remote sensing. However, these large-scale mapping efforts clearly demonstrate the utility of remote sensing data for coral reef study.

In sum, quantifying area cover of benthic habitats and component communities is central to understanding coral reef ecosystem status and function. In situ counting techniques however, provide only statistical samples of reef benthic communities, that is not amenable to applications of remote sensing, eliminating the potential for gaining synoptically uniform data.

On Applicability of Methods for Coral Reef Survey in Apra Harbor, Guam

The purpose of this section is to provide a summary of pertinent issues regarding the application of two alternative scientific field methods to acquire the most informative, and most defensible, assessment of reef coral communities in the region of Apra Harbor, Guam that will be affected by proposed dredging activities required for safe passage of nuclear aircraft carriers (CVN). The major point of argument of this paper has been concerned with the scientific justification of whether measures of size-frequency provide a better estimate of “ecosystem function” than measures of percent benthic cover. However, regardless of the scientific merits of either side of this argument, it is imperative that the actual field and analytical methods employed to generate these data provide a valid and unequivocal representation of the reef ecosystems under study.

Specifically, the two methods in question are: 1) Measurement of the size of discrete coral colonies using a one-dimensional measurement performed entirely *in-situ*, which provides a size-frequency distribution of corals of each species population, and 2) Measurement of coral community structure in terms of percentage of bottom cover using a two-dimensional photographic method for collection of digital data *in-situ*, and subsequent analysis in the laboratory. The size-frequency method has been proposed by Federal Resource Agencies as the preferred method of assessment; the photographic percent coral cover method was employed by the Navy to conduct the resource assessment during fieldwork performed in April-May 2009.

Considering the size-frequency method, the actual process of data collection consists of a single measure made with a ruler subjectively deemed to be the "longest dimension" of each colony within a 1 × 10 m belt transect. Only colonies with "centers" within the belt are counted, although no information has been provided on the criteria for determining what constitutes the center of irregular shaped colonies or mats of branching or leafy species. Classification of growth form is noted for each coral. Data is collected and recorded exclusively underwater by a single individual, with no independent or permanent record of the data source, and no post-analysis.

Field methods for the percent cover method entail recording digital photographs of the interior of the same belt transect using a camera mounted on a rigid frame that ensures identical dimensions of all photos. Subsequent to fieldwork, photos are analyzed in the laboratory using off-the-shelf software (CPCe) to provide an estimate of community structure (coral as well as other types of bottom cover) within a two-dimensional planar format. Photographs are typically analyzed separately by multiple investigators to ensure repeatability.

As discussed above, review of the scientific literature reveals that analysis of coral colony size-frequency distributions can show important characteristics of populations, particularly with regard to how a variety of environmental stressors affect population structure across space and time (e.g., Bak and Meesters 1998, 1999; Meesters et al. 2001; Lirman and Fong 2007; McClanahan et al. 2008). These studies typical rely on field methods using multi-dimensional (usually height, width, length) measurement to arrive at an estimate of colony surface area or volume (Figure 4). Any one of these measures, in the absence of the others, will not provide sufficient information to construct a valid assessment of colony population structure. One study that did primarily employ a single measurement of diameter was conducted in an area where corals were primarily symmetrical (Lewis 1997). To address the concern that a single measurement would not adequately reflect the size of irregularly shaped colonies Lewis (1997) determined the size of these colonies as the means of lengths and widths intersecting at the middle of the longest dimension. However, the proposed size-frequency method classifies coral size solely by the single longest "dimension" of a colony. This single measurement is taken unsystematically in three-dimensional space (unsystematically in that measurements are not constrained to any one dimension of height, width or depth). Such a one-dimensional size-frequency measure actually produces less information than the planar two-dimensional products of the Navy photographic methods.

Another liability of the one-dimensional size-frequency method is that corals of distinctly different growth forms fall into the same size class. While a note is made on the structure of each colony measured, this information is not explicitly contained within the size-class data. Thus, a coral one meter tall and one centimeter wide will be classed as identical to another coral one centimeter tall and one meter wide. As coral morphology may be as important a factor in functional processes as colony size, the lack of differentiation between colony morphology within the method appears to nullify any usefulness of these measures for the supposed purpose. While an acknowledged flaw in the photographic method is the inability to account for the three dimensionality of reef structure, the measure of percent cover provides a consistent metric (planar area) throughout the data set.

Zvuloni et al. (2008) present a detailed derivation of mathematical corrections to mitigate the biases of count-based measures, including size-frequency, owing to edge effects of the sampling unit (i.e., boundaries of quadrats). These authors provide a set of corrections for both Type 1(any coral that intersects an edge is excluded from the sample) and Type 2 (any coral that intersects an edge is included in the sample), as well as a method that provides a compromise to the bias by only including corals which have “centers” lying within the sampling unit. They also point out that measures of percent cover do not raise any such sampling problems, as only the part of the colony lying within the sampling unit is taken into account.

Zvuloni et al. (2008) also point out the weakness of a count-based approach (e.g., size-frequency) when colonies are large compared to the size of the sampling unit. In cases where large colonies occur, use of either the Type I bias correction or center rule approach could mean that large corals that are partially within the sampling area would not be counted at all. They also point out that in practice, determining whether the center of a coral is located within a quadrat “is a decision that can be greatly influenced by a sampler’s subjectivity.”

Perhaps the most critical factor associated with the field measurement of size-frequency of coral colonies is the determination of what constitutes a “colony.” In discussing the objection to using methods based on defining individual coral colonies cited by Stoddart and Johannes (1978), Bak and Meesters (1998) point out that these problems can generally be overcome, at least in non-branching colonies. This statement implies that there are problems with determination of discrete colonies with branching species. Thus, when communities are dominated by interconnected mats of branching, leafy or foliose species, a method that depends on accurate and unequivocal determination of discrete colonies may not be considered the best investigative technique.

From a zoological standpoint, Pichon (1978) defines a colony as “the formation originating from a single planula.” In terms of differentiating between colonies, this definition can be problematic as planulae may settle on the dead part of colonies of the same species. Growth of the new colony can fuse with the old colony, and if such a process happens repeatedly over generations, can form amalgamations or "supracolonies." These structures, made up of fused individual elements can extend continuously over large areas of reef, but cannot strictly be labeled as a single colony owing to the amalgamation of colonies originating from a single planula. *Porites rus*, which is the primary reef component in Apra Harbor, occurs in a variety of growth forms, including merged "supercolonies." As these growth forms may be essentially indistinguishable in terms of individual colonies, any attempt at such differentiation is subjective at best. In addition, as noted above, fragmentation of colonies into genetically identical ramets, all of which originated from a single planula do not technically qualify as true colonies.,

Thus, the two main criteria for valid and successful size-frequency analyses are 1) colonies sizes small with respect to the sampling unit, and 2) discrete colony growth forms. In the case of Apra Harbor, neither of these criteria is met: many of the dominant coral species occur in growth forms that are not discrete colonies, and they are often larger than the sampling unit. The community is composed largely of amalgamated "supercolony" complexes, or expansive fields of interconnected fine branches or fronds. Figure 4 shows several examples of such coral communities within the study area of Apra Harbor where corals clearly do not occur as discrete colonies. Hence measuring discrete individual corals within these survey areas of Apra Harbor is subjective at best. Such subjectivity will further limit reliability and repeatability, which is a critical factor for scientific legitimacy. In addition, there is no reason to expect that the functional processes of these communities would differ at all regardless of how they are subjectively divided into separate "colonies." For example, would the function processes of any of the coral communities shown in Figure 4 differ if they were labeled one large colony versus ten smaller colonies? These limitations should put into serious question, the applicability of the size-frequency method in the target environment.

In addition, the data produced by any field method is only acceptable if it provides for an adequate degree of replication, and lack of bias. The size-frequency method involves data collection by a single investigator entirely *in-situ*, which no record of the data source. Once the investigator and the transect line/quadrat leave the bottom, there is no possible way to replicate the measurements or evaluate the data for bias or error. On the other hand, the photographic cover method produces a permanent record of the data source which can be analyzed repeatedly in an identical manner to arrive at reliable and repeatable estimates with elimination of bias.

An argument has also been made that size-frequency data is essential for determining compensatory mitigation. With respect to mitigation for dredging in Apra Harbor, particularly with respect to mitigation in the form of watershed improvement, size-frequency considerations are likely of limited value. Population structure in terms of sizes of corals between habitats influenced by substantially different physical conditions would be expected to be substantially different. With the case at hand, it is very likely that comparison of coral populations within the dredge footprint and buffer zone of well-protected Apra Harbor and open coastal areas downslope from watersheds along the southwestern shoreline of Guam will reveal considerably different coral communities. Such differences in structure are in response to a completely different set of physical environmental stressors. As a result, any notion of achieving one-to-one compensation in terms of size-frequency distribution is inappropriate and invalid. On the other hand, as percent coral cover is essentially independent of community structure, it can serve as a useful compensatory metric.

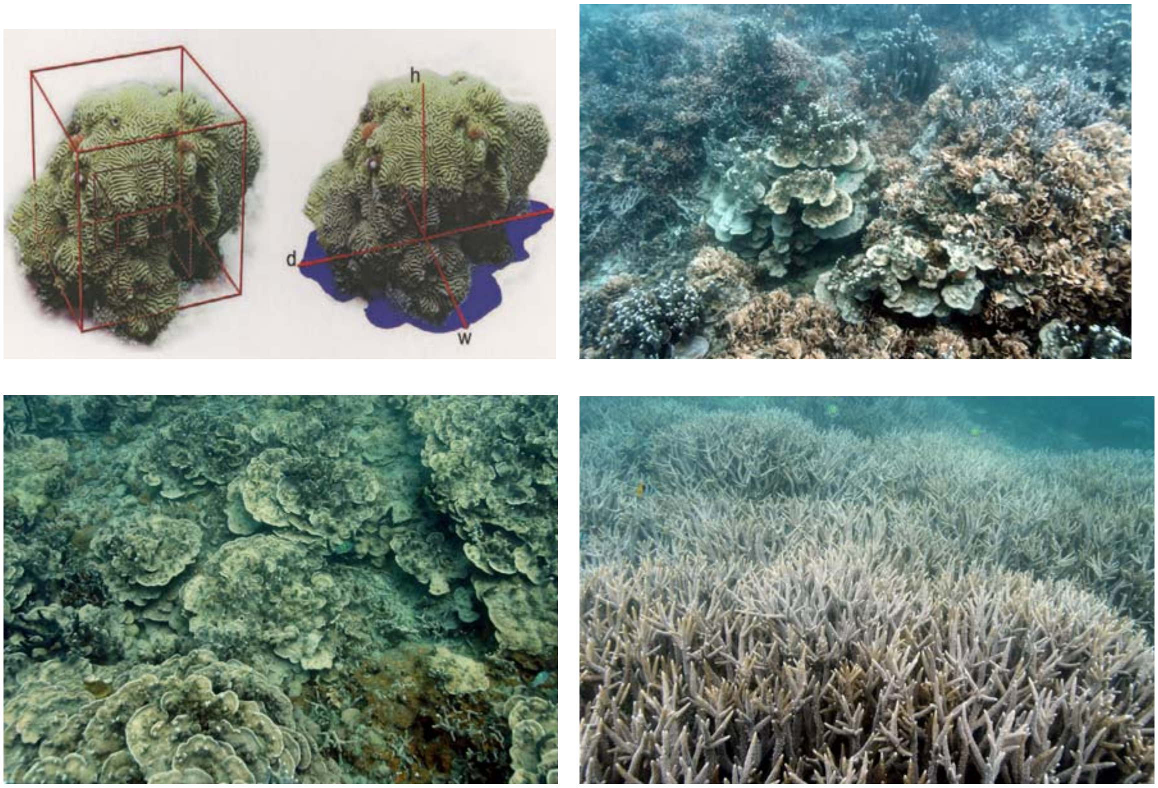

Figure 4. Conceptual method typically used to estimate sizes of discrete coral colonies using measurement in 3-dimensions to estimate colony volume (upper left) (from Fisher 2007). The proposed method for evaluating coral size in Apra Harbor would use only a single measurement of each colony. Photographs at upper right and bottom show three different reef communities within the study area of Apra Harbor. In these coral communities, corals occur as either amalgamated colonial assemblages, or fields of interconnected branches. The notion that these assemblages can be objectively and repeatedly be partitioned into discrete colonies does not represent a practicable scientific technique.

USEPA Stony Coral Rapid Bioassessment Protocol

The USEPA has developed a "Stony Coral Rapid Bioassessment Protocol," which utilizes three-dimensional measurements of coral colonies as a primary metric (Fisher 2007). While this protocol may have important value for some applications, it does not appear to provide a suitable model for assessment of the Apra Harbor scenario. To date, the EPA protocol has not been applied to habitats in the Pacific. For the reasons discussed above relating to lack of distinct colony growth forms, the metric of discrete colony volume would not be practicable in areas with branching or amalgamated growth forms (see Figure 4).

In addition, the purpose of the EPA protocol does not fit within the intent of the Navy work. Three passages from Fisher (2007) are quoted below.

1. “The Stony Coral Rapid Bioassessment Protocol addresses only the sampling methods applicable to development of a scientifically defensible, long-term monitoring program.” (page 6.)

2. “The protocol (SCRBP) is intended for use in a long-term biocriteria monitoring program, which requires exploratory biological surveys to inform and mold the monitoring design and strategy. Biological surveys provide the data to address reef classifications, metric variability, size and number of sampling units and reference conditions. Consequently, these preliminary surveys are indispensable to developing an efficient and defensible, long-term monitoring program.” (page 22)

3. “Moreover, the indicators provide an instantaneous reflection of grossly observable coral characteristics - they do not provide information on physiological function or identify causes of impairment” (pages 4-5).

From these quotes it is clear that the intent of EPA protocol was developed for use as a monitoring tool for making repeated samplings at the same location over time to evaluate changes to coral colonies and communities in response to a particular set of stressors. It is clearly not intended as the best method for a single initial assessment of a large area in a short time. In fact, the indispensable “exploratory biological surveys” in the quote above fit the bill exactly as a description of the assessment that has been performed by the Navy for the initial evaluation of the condition of the reef ecosystem in Apra Harbor. By the author’s statement, the EPA protocol is also not intended to provide a means of evaluating functional processes of coral populations.

In summary, the body of coral reef scientific literature contains hundreds, if not thousands, of peer-reviewed papers which utilize methods based on percentage cover of corals and other living and non-living bottom cover as the basis to describe coral reef ecosystem structure and function. Such methods have been employed since the initial studies of coral reefs decades ago, and have persisted through time (with substantial technological enhancement) because they provide the least equivocal, most practicable techniques to evaluate entire communities. On the other hand, the comparatively much smaller body of scientific literature utilizing size-frequency is generally aimed at evaluating effects to discrete populations of corals, rather than entire ecosystems which comprise both organisms and the physical and chemical components. While size-frequency can be an important parameter for addressing specific aspects of populations, particularly over time, it may not represent the best theoretical and most practicable scientific method for a baseline assessment of the various coral ecosystems in Guam, nor for providing input for compensatory mitigation. As with all field methods, there are certain limitations with benthic cover techniques, but for the reasons discussed, the approach used by the Navy for the assessment of Apra Harbor, as well as potential mitigation sites, is presently the best, most practicable science available.

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Appendix J
Supplemental Aircraft Carrier Marine Surveys

5. Final Comparison of a Photographic and an *In Situ* Method to Assess the Coral Reef Benthic Community in Apra Harbor, Guam. May 31,2010.

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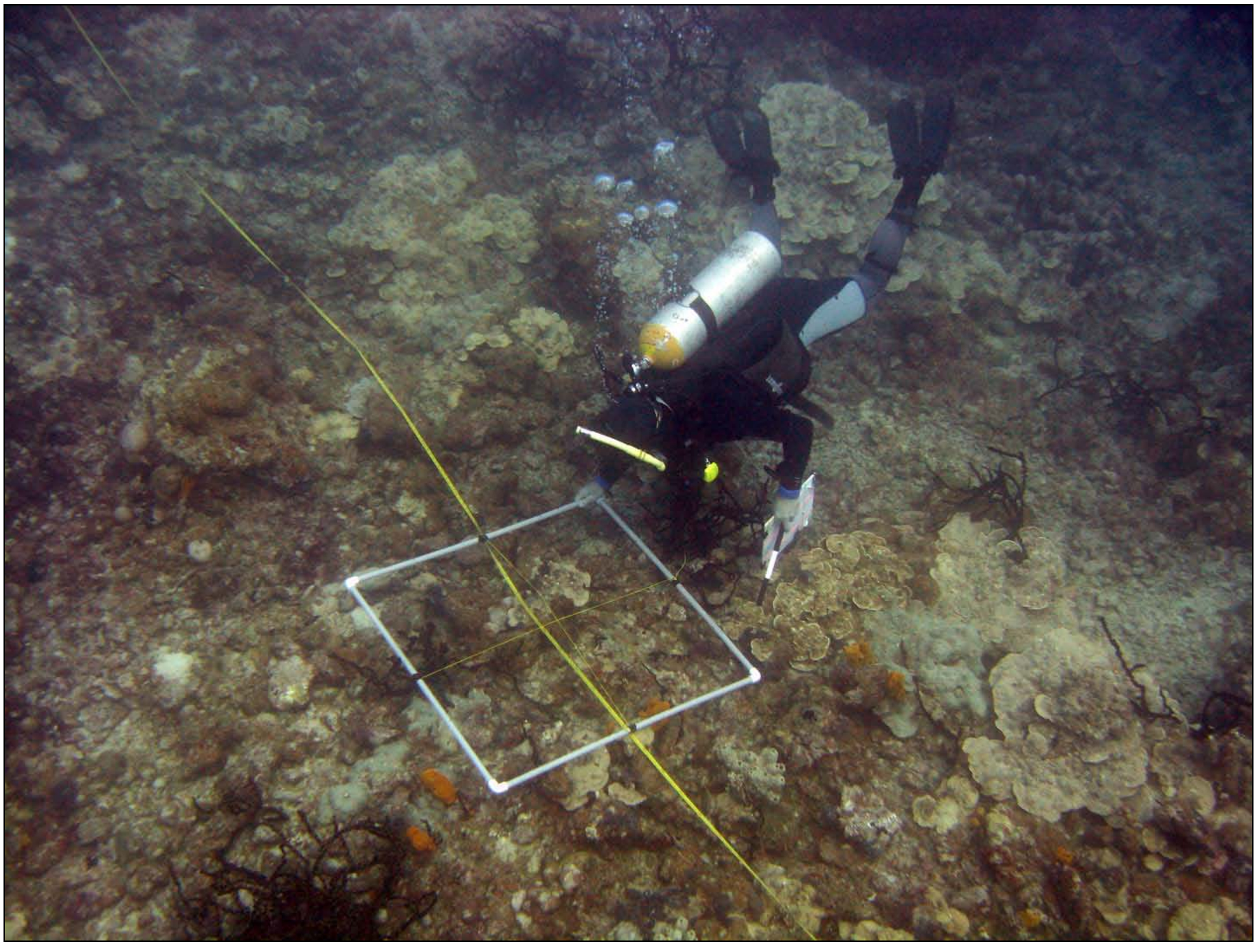

Photograph by Dave Burdick

PRELIMINARY
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May 31, 2010

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PRELIMINARY FINAL REPORT

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

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May 31, 2010

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

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Executive Summary

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

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

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

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

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

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

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

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

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

1.0 Introduction

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

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

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

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

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

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

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

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

2.0 Methods

2.1 Survey Sites

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

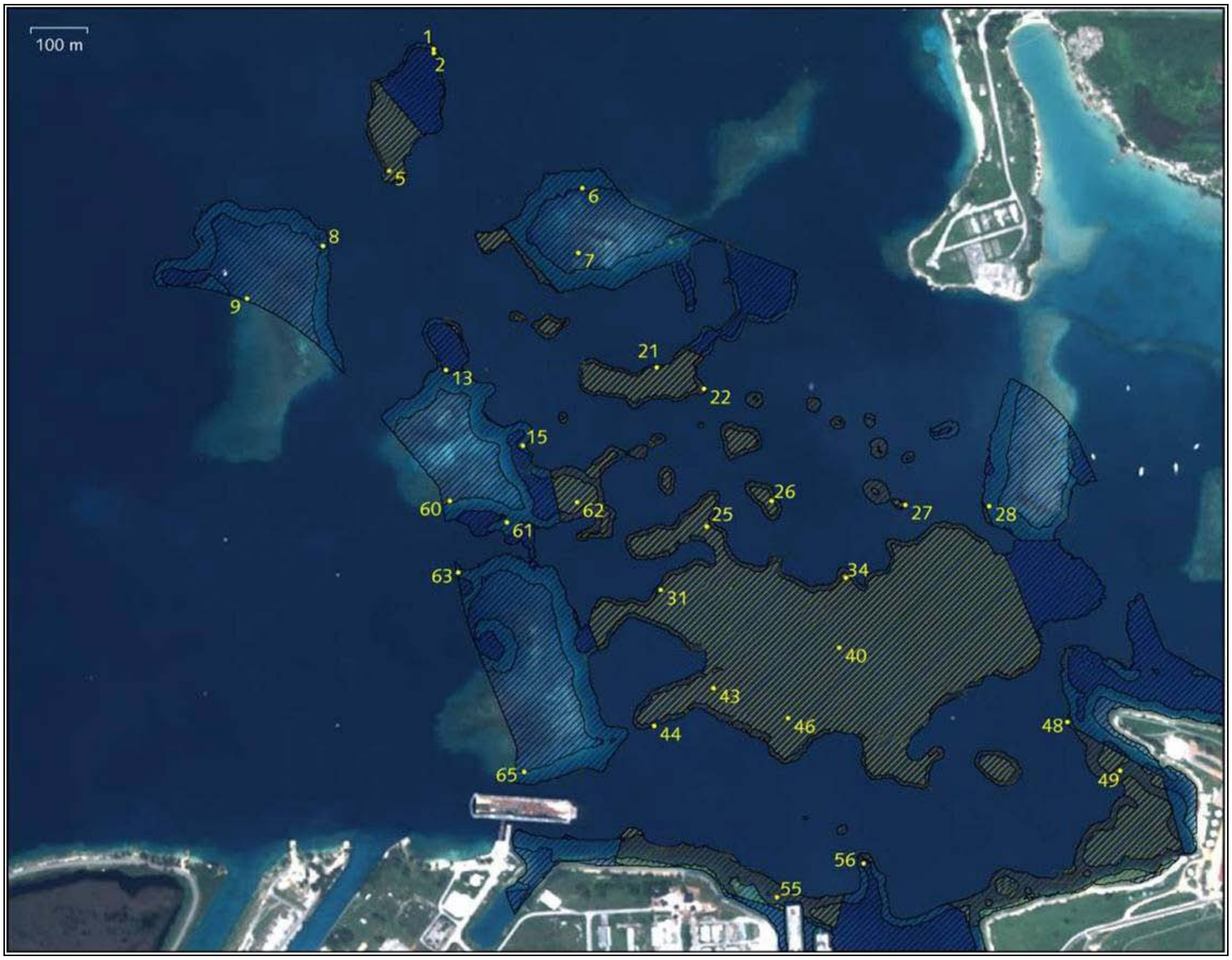


Figure 2.1. Map of the 30 survey sites analyzed in this study. Hatched areas are shallower than 18 m and comprised the survey area. Four strata were created: Indirect Impact-Slope, Indirect Impact-Flat, Direct Impact-Slope, and Direct Impact-Flat.

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

2.2 Variables Collected

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

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

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

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

2.3 Deployment of Transect Lines

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

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

2.4 Photographic Method

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

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

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

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

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

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

2.4.1 Methodological Errors

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

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

2.5 *In situ* Method

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

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

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

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

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

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

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

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

2.6 Statistical Analysis

2.6.1 Overview

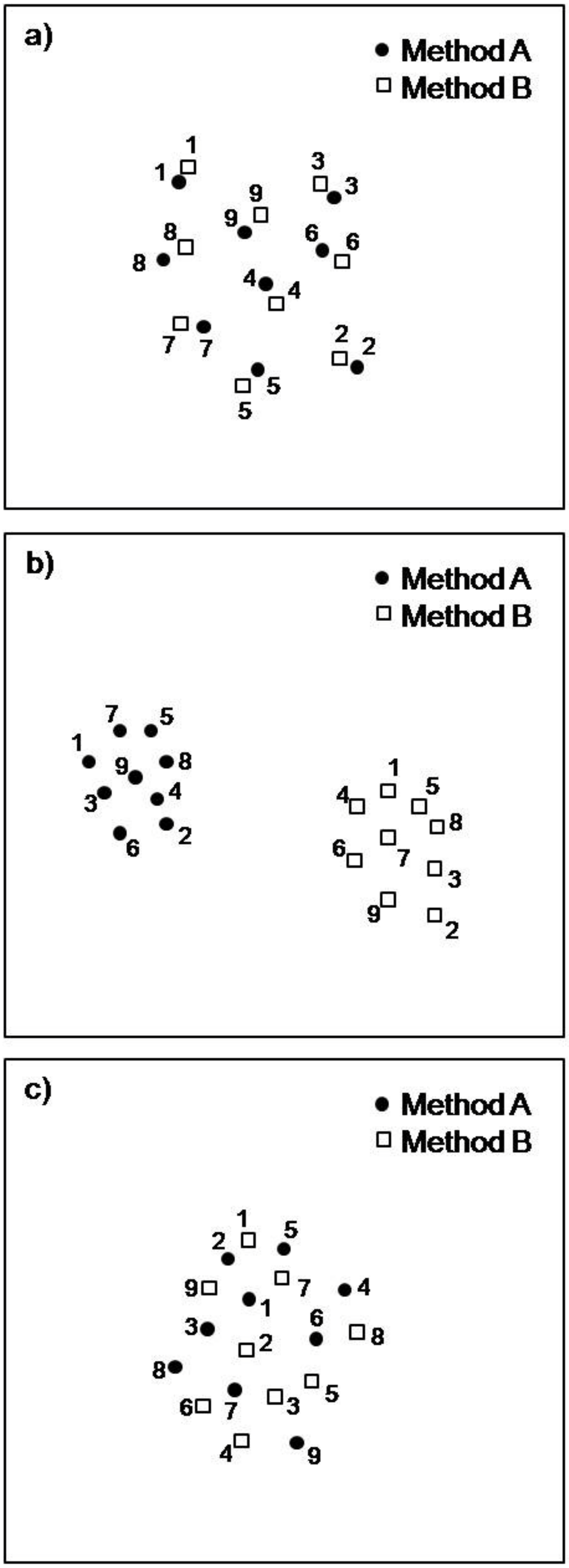
The statistical analysis was conducted to address two questions: (1) do the data obtained by the *in situ* method and the photographic methods directly compare to each other, and (2) are the benthic communities described by these two methods the same over a larger spatial area? Assuming each question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

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

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

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

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



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

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

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

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

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

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

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

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

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

2.6.2 Data Reconciliation

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

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

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

2.6.3 Comparison of Methods

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

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

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

2.6.4 Comparison of Communities

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

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

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

3.0 Results

3.1 Taxon Richness

3.1.1 Comparison of Methods

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

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

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

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

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

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

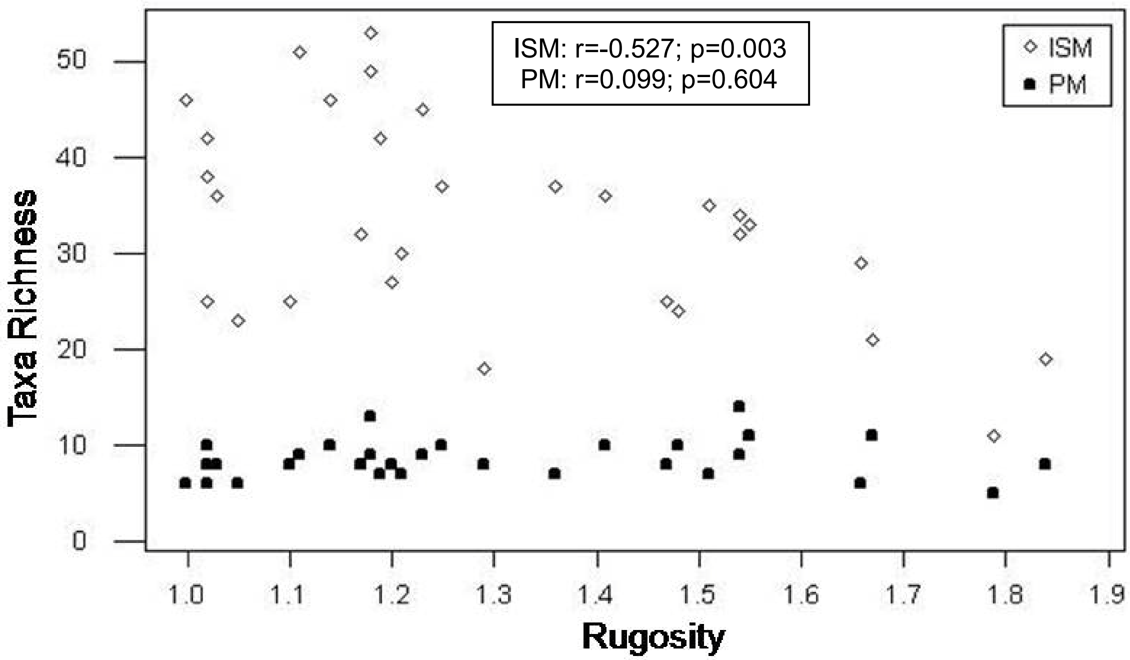


Figure 3.1. Taxon Richness found at a site using the ISM was negatively correlated with rugosity. No relationship was found between Taxon Richness and rugosity for the PM. This different relationship with rugosity resulted in greater comparability between the ISM and PM at higher rugosity, where Taxon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

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

The method-site pairs had an average similarity of only 15 percent and, with a median rank of 32, ranked significantly greater than one (Table 3.2). This means that the community described at a site using the PM was more similar to 31 other communities described at other sites by either method than it was to the community at the same site described using the ISM. Comparability between the two methods improved when only coral Taxon Richness was considered. The similarity increased to 49 percent, but the rank continued to be significantly greater than one.

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

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

3.1.2 Comparison of Communities

3.1.2.1 All Taxa

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

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

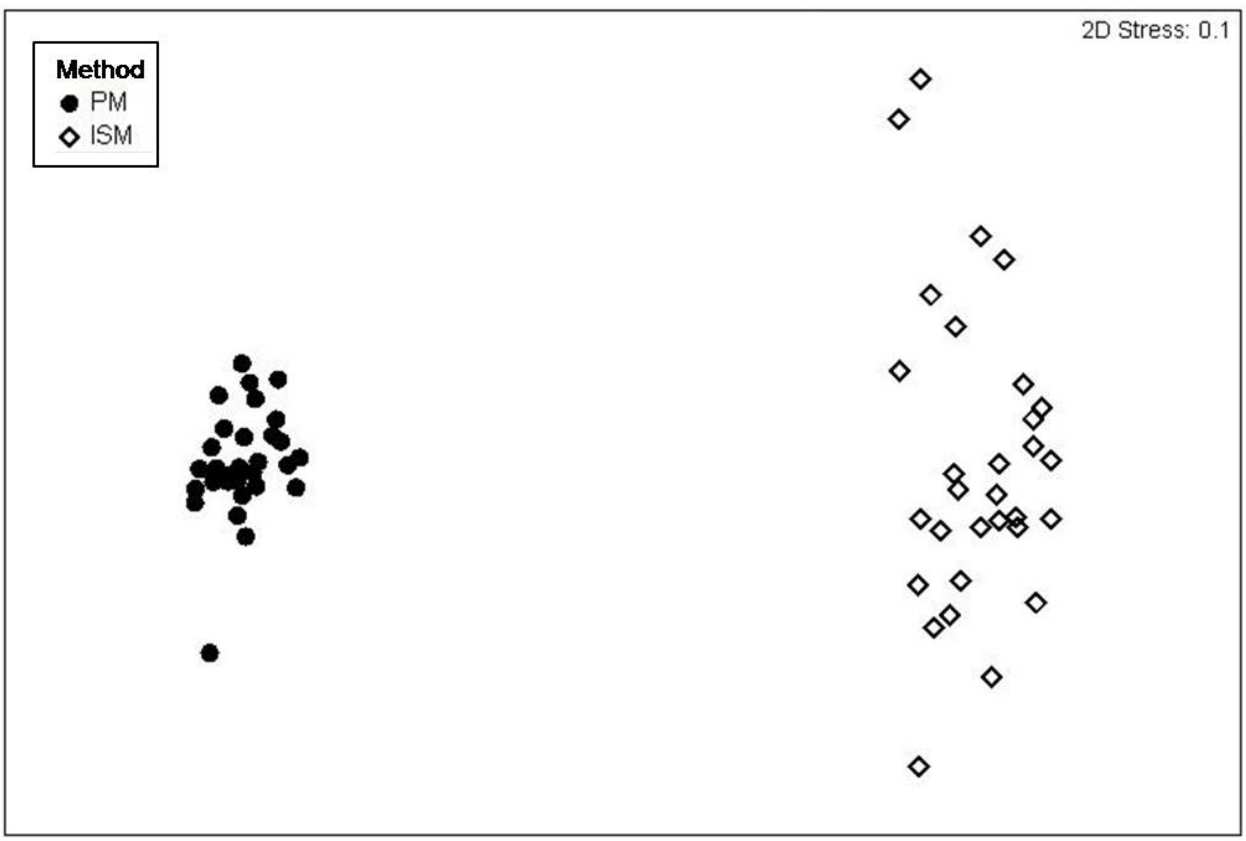


Figure 3.2. The nMDS plot for Taxon Richness. Symbols represent the benthic community described by either the ISM or PM at a survey site. The stress value is a measure of the distortion between the distance of the rankings in the nMDS configuration and the analogous rankings in the similarity matrix.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

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

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

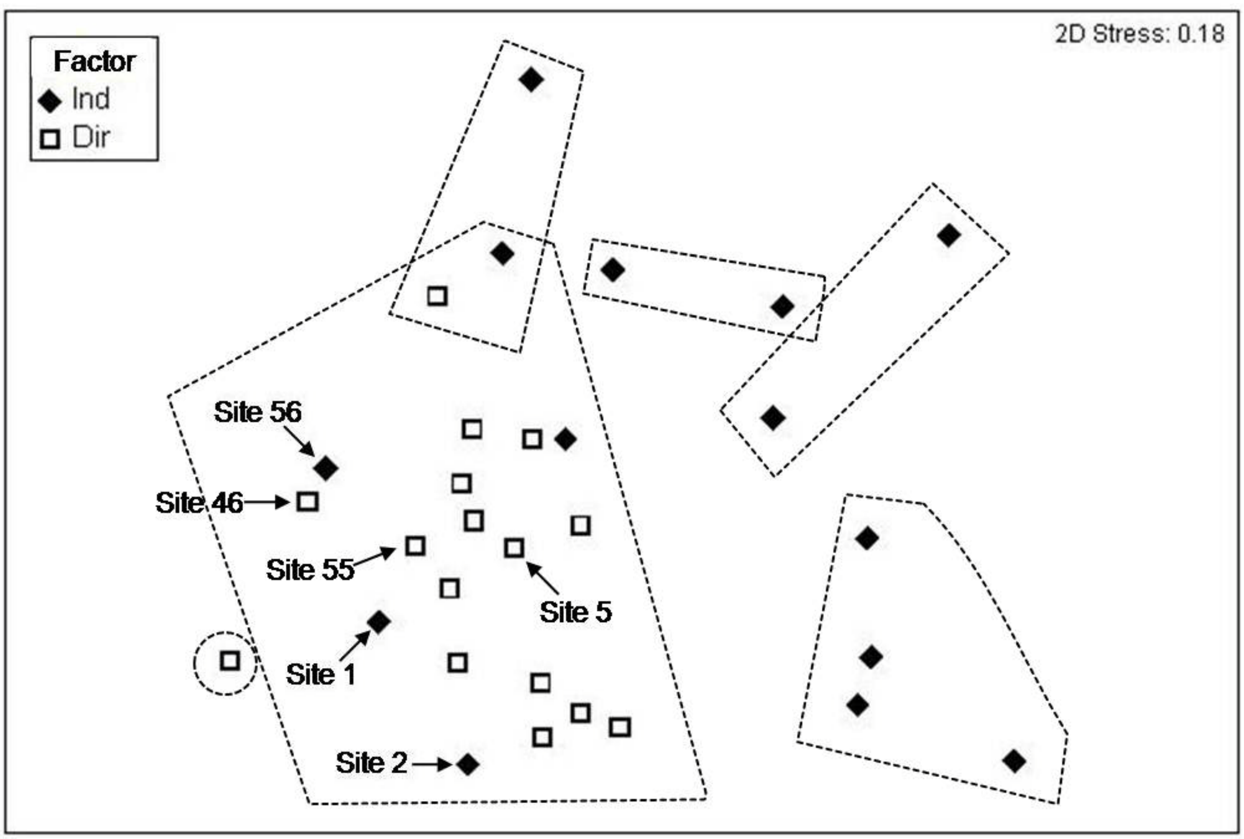


Figure 3.3. The nMDS plot for Taxon Richness by Indirect and Direct factors using the ISM data only. Each symbol represents the benthic community described by the ISM at a specific survey site. Dashed lines enclose clusters with at least 40% similarity, showing similarity among the Direct Impact sites,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

3.1.2.2 Coral

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

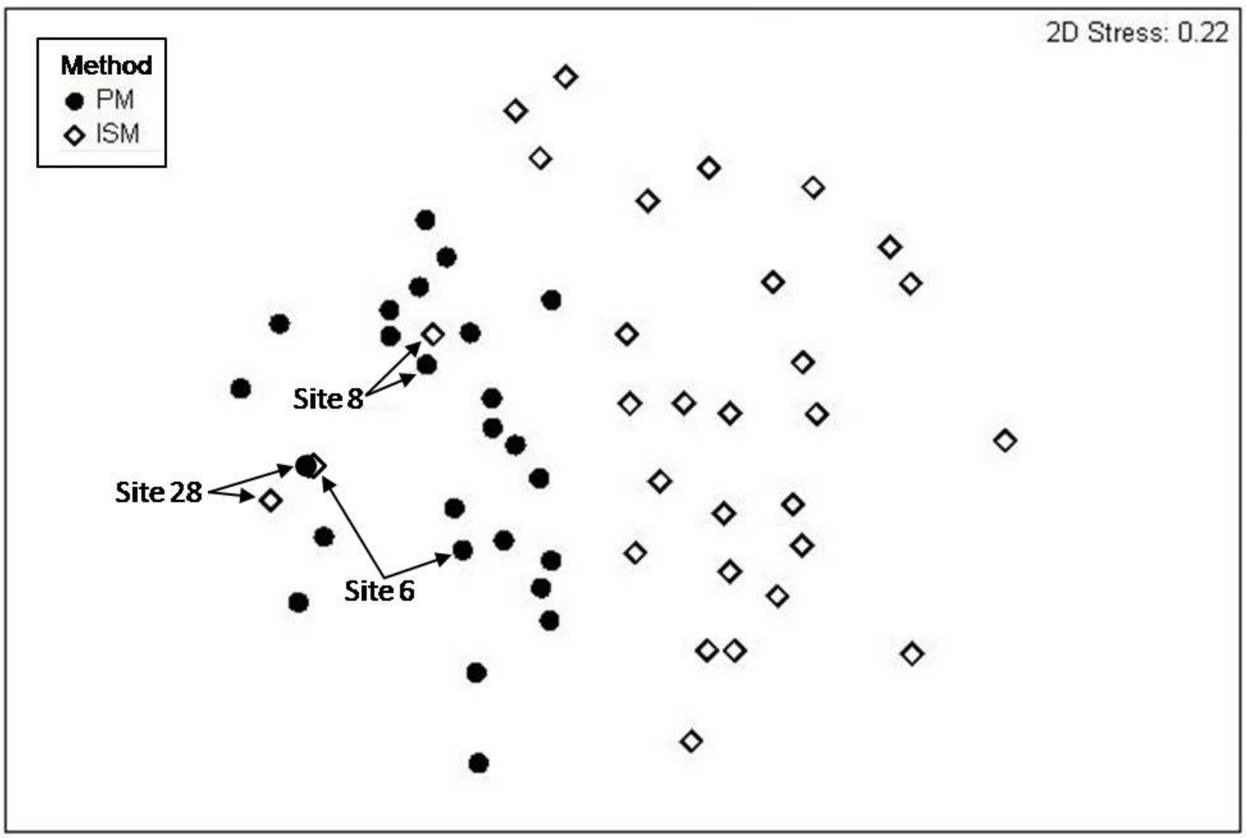


Figure 3.4. The nMDS plot for Coral Taxon Richness. Symbols represent the coral community described by either the ISM or PM at a survey site. See text for discussion of Sites 6, 8, and 28. Due to the high stress value, this figure should be viewed with caution.

3.2 Benthic Cover

3.2.1 Comparison of Methods

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

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

At each level of taxonomic resolution examined, the method-site pairs ranked significantly lower than one (Table 3.3). The similarity of the two methods increased from 36 to 89 percent as the taxonomic resolution became more coarse. However, even at the coarsest taxonomic grouping (*i.e.*, Grouped), the two methods did not achieve the top-ranked similarity.

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

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

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

3.2.2 Comparison of Communities

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

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

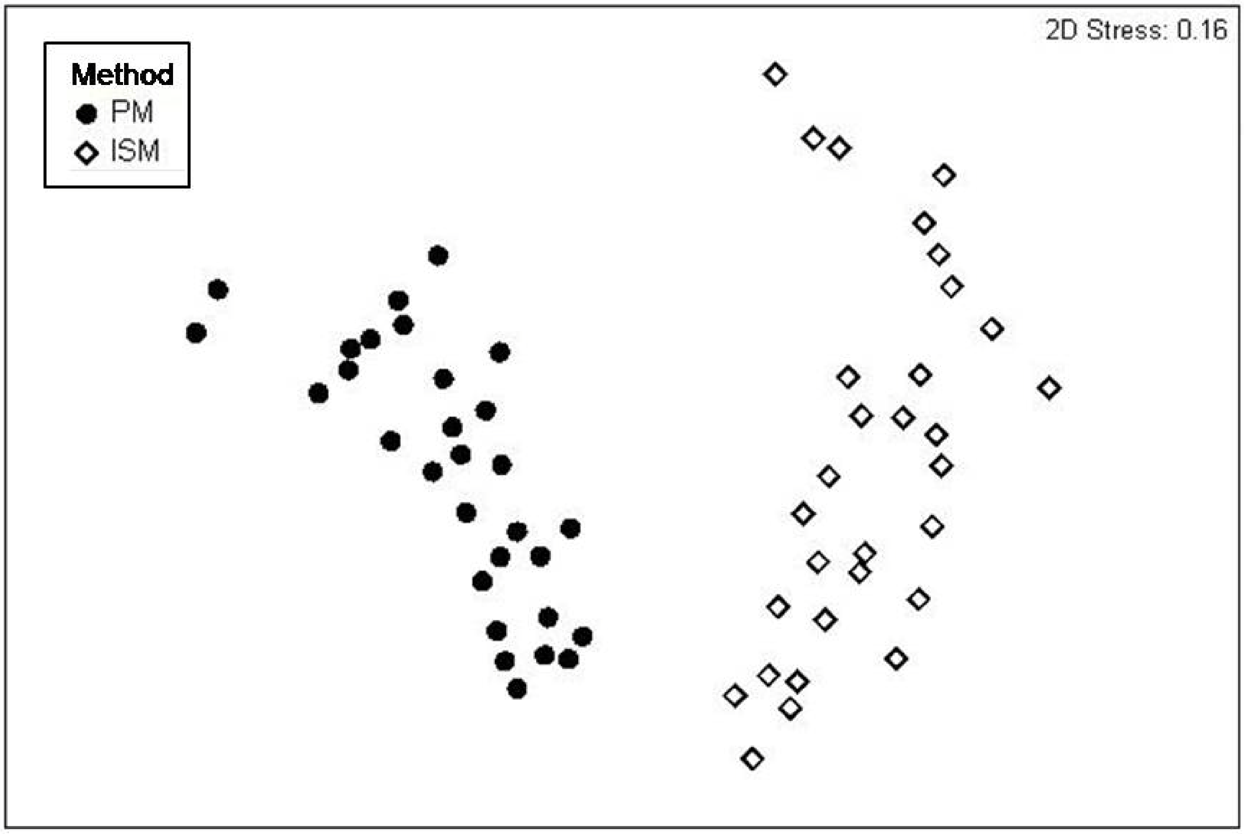


Figure 3.5. The nMDS plot for Benthic Cover of All Taxa. Symbols represent the benthic community described by either the ISM or PM at a survey site. A stress value of 0.16 falls within the range indicating that the plot represents a useful two-dimensional representation.

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

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

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

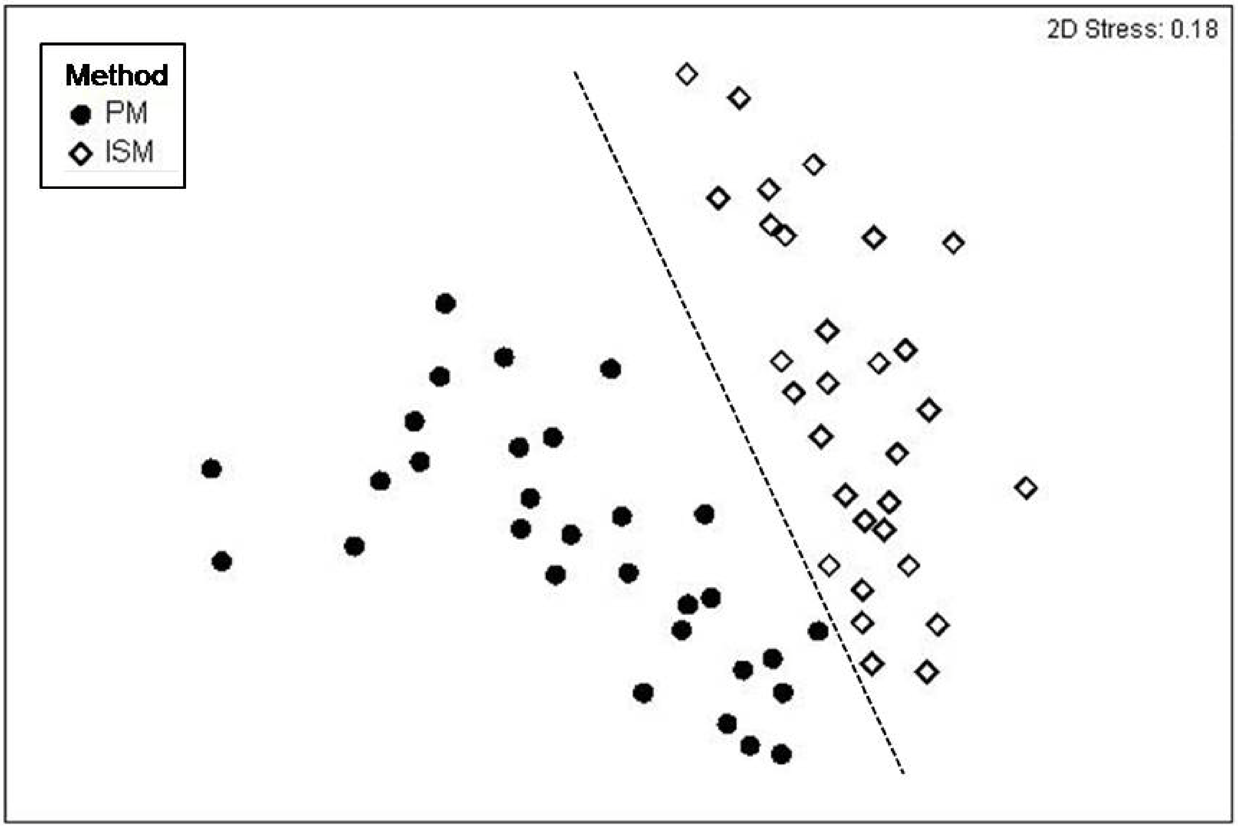


Figure 3.6. The nMDS plot for Benthic Cover of Reduced Taxa. Symbols represent the benthic community described by either the ISM (right of dotted line) or PM (left of dotted line) at a survey site. A stress value of 0.18 falls within the range indicating that the plot represents a useful two-dimensional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

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

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

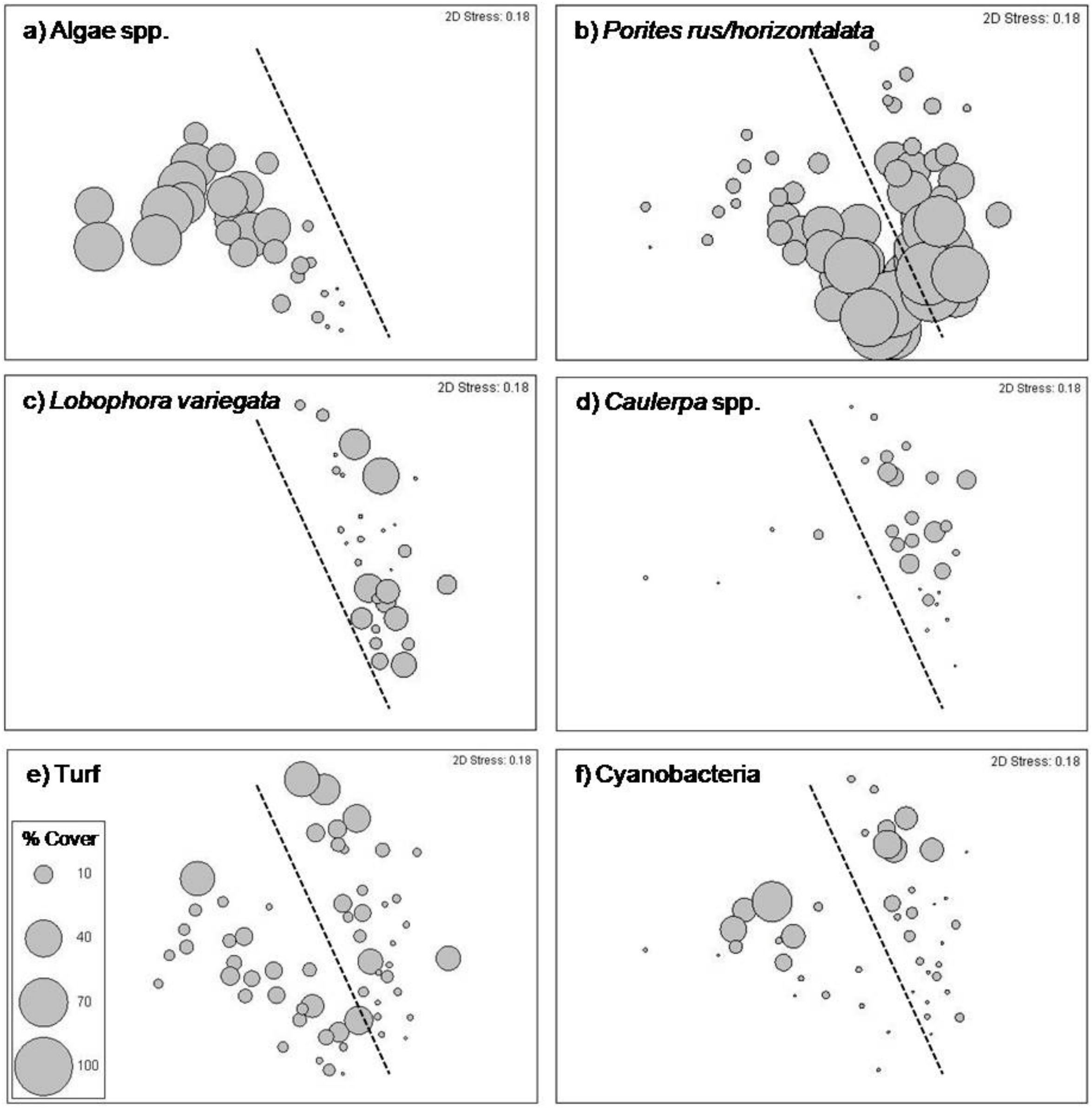


Figure 3.7. The percent cover of six taxa that explained >5% of the difference between the ISM (right of dotted line) and PM (left of dotted line) methods overlain on the nMDS plot from Figure 3.6. a) algae spp. (17.9% of the difference explained); b) *Porites rus/horizontalata* (10.4%); c) *Lobophora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

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

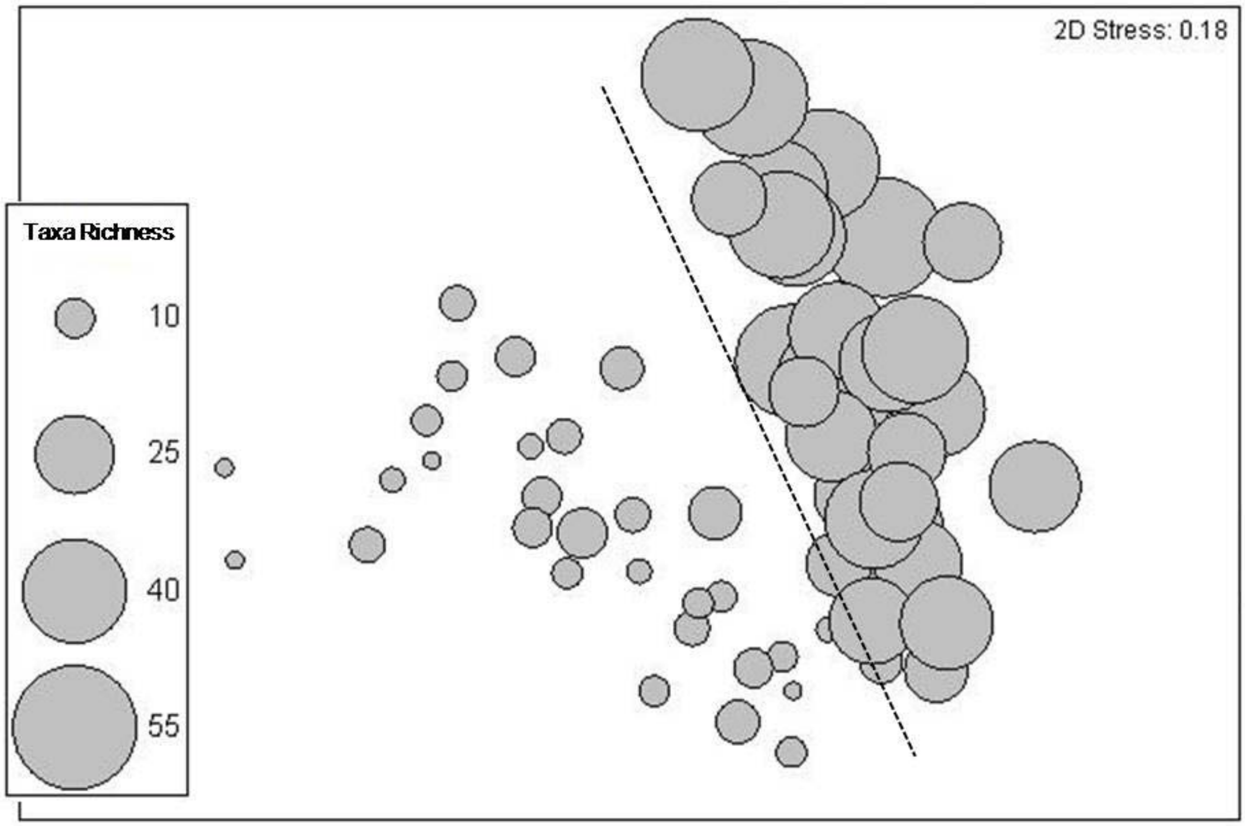


Figure 3.8. The difference between the ISM (right of dotted line) and PM (left of dotted line) is significantly correlated with Taxon Richness (ρ=0.402; p=0.01). The ISM identified more taxa than the PM.

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

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

3.2.2.4 Coral Taxa

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

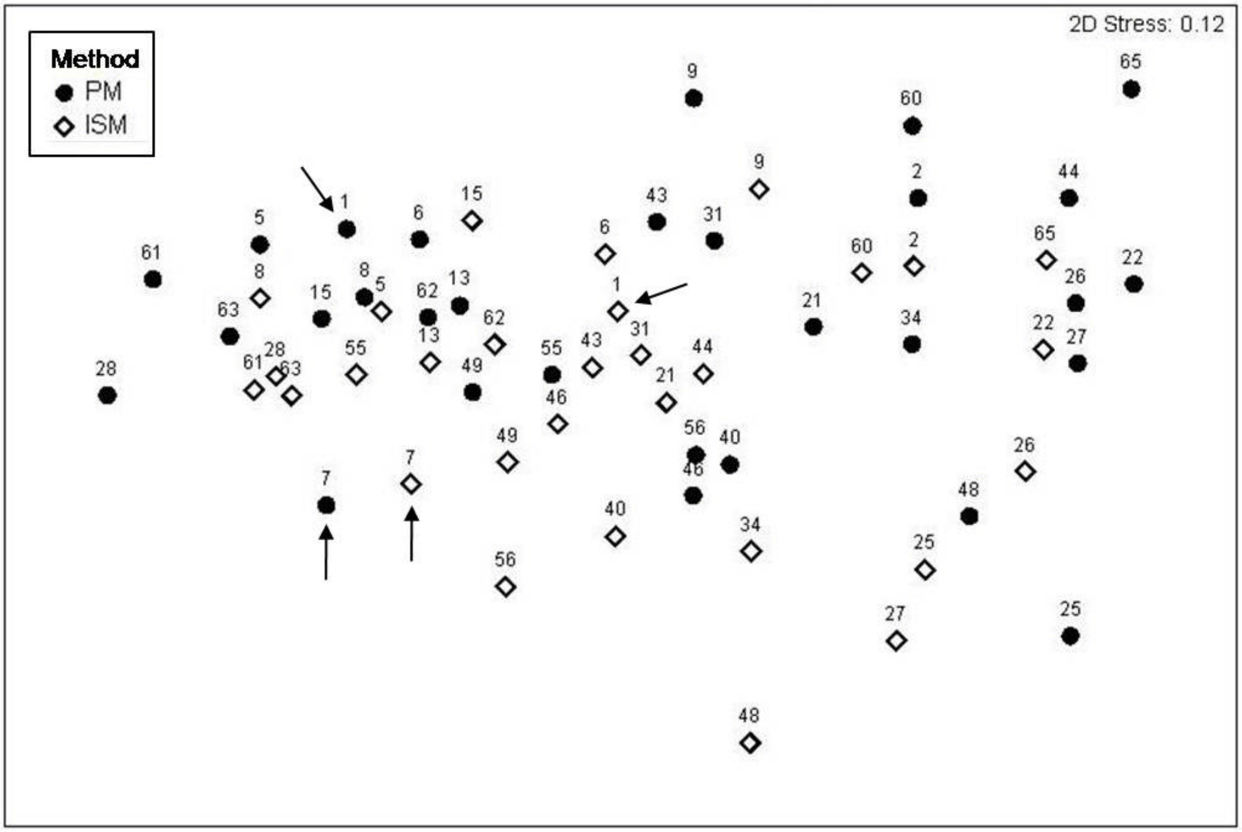


Figure 3.9. The nMDS plot for Benthic Cover of Grouped Taxa. Symbols represent the benthic community described by either the ISM or PM at a survey site. Numbers correspond to the survey site identification (see Figure 1.1). The communities described by the two methods did not differ. However, method-site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

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

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

3.2.2.5 Coral Morphological Groups

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

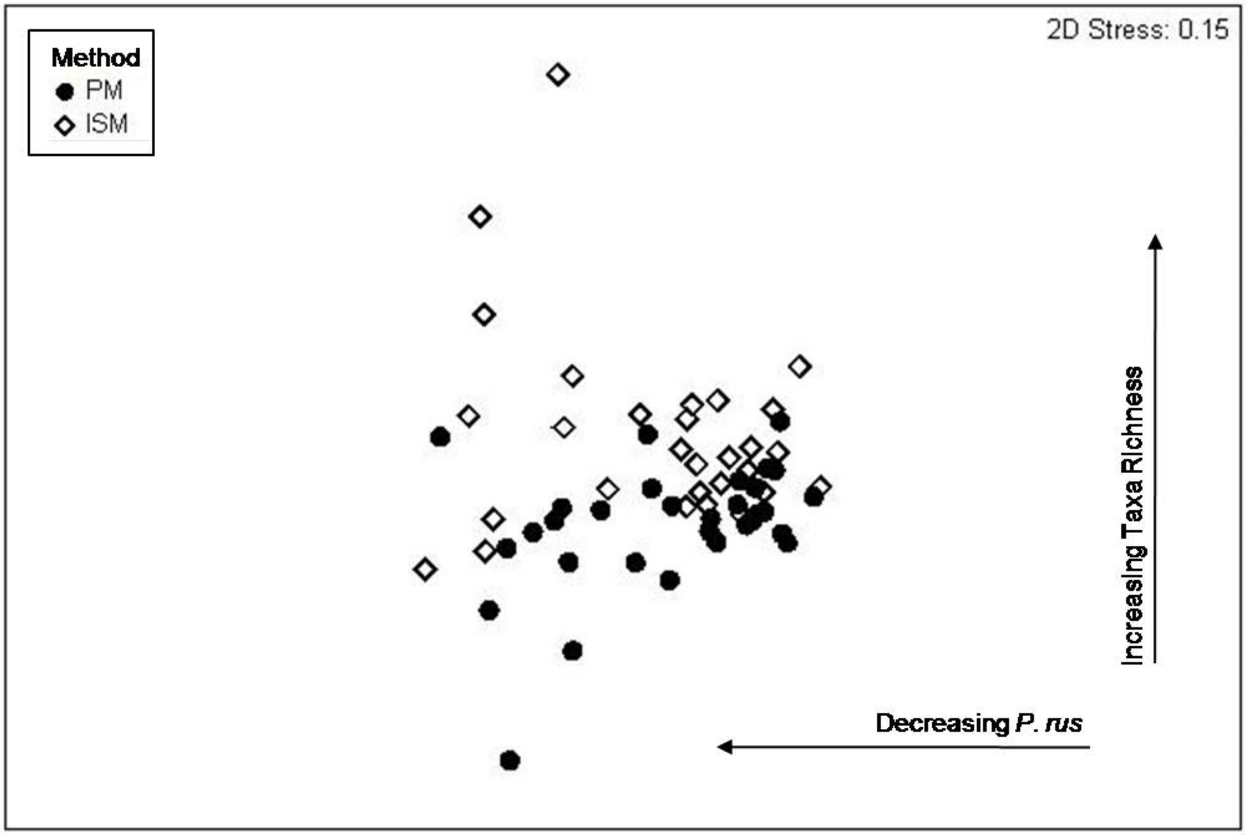


Figure 3.10. The nMDS plot for percent cover of Coral Taxa. Symbols represent the benthic community described by either the ISM or PM at a survey site. The communities described by the two methods did not differ. A stress value of 0.15 falls within the range indicating that the plot represents a useful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

3.3 Coral Colony Density

3.3.1 Comparison of Methods

On average, the Coral Colony Density found with the ISM was 207% higher than that found with the PM (Wilcoxon; W=30; p<0.001). The ISM found higher colony densities than the PM for nearly all taxa (Table 3.4). The difference in the colony density of *P. rus* accounted for most (81%) of the difference observed between the two methods.

Porites rus was a dominant coral in the study area, and discriminating colonies of this species can be challenging in some habitats, particular when the observer's viewing angle is restricted, as occurs with the PM. When *P. rus* was removed from the analysis, the ISM still found significantly greater Coral Colony Densities than the PM (Wilcoxon; W=85; p=0.007), suggesting that differences between the two methods are not entirely explained by P. *rus* alone.

Due to methodological errors, the PM systematically overestimated the "true" Coral Colony Density (see section 2.4.1). Therefore, the "true" density of coral colonies is lower than that estimated by the PM. When the overestimation is taken into consideration, the difference

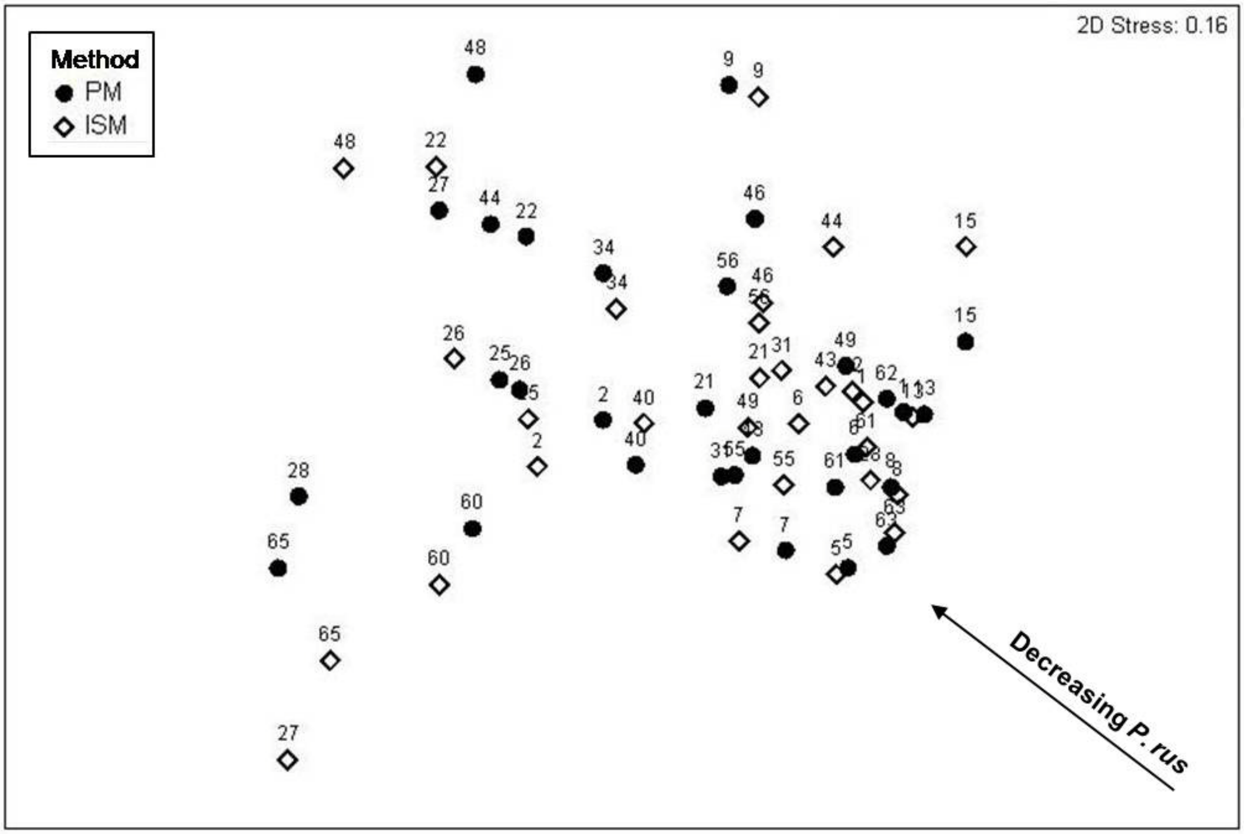


Figure 3.11. The nMDS plot for percent cover of coral taxa by general morphology. Symbols represent the benthic community described by either the ISM or PM at a survey site. Numbers correspond to the survey site identification (see Figure 1.1). The communities described by the two methods did not differ.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

between the two methods is magnified. Unfortunately, it is not possible to estimate the magnitude of the overestimation from the data available.

The ISM found significantly more coral colonies as rugosity increased (Pearson Product Moment; $r= 0.375$, $p=0.045$). In contrast, coral colony density and rugosity were uncorrelated for the PM (Pearson Product Moment; $r= 0.169$, $p=0.381$); the PM found the same density of coral colonies regardless of the of the bottom rugosity (Figure 3.12).

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

The method-site pairs had an average similarity of 63 percent and, with a median rank of 8, ranked significantly lower than one (Table 3.5). This means that the community described at a site using the PM was more similar to 7 other communities described at other sites by either method than it was to the community at the same site described using the ISM. Comparability

Table 3.4. The total number of coral colonies (n) and their percentage of the total (%) found using the PM and ISM for all coral taxa that accounted for >1% of the overall total.

	PM		ISM	
Taxa	n[1]	%	n	%
Porites rus/horizontalata	1654	57.5	4153	69.7
Pavona cactus	464	16.1	512	8.6
Porites cylindrical	345	12.0	539	9.1
Porites lutea	186	6.4	154	2.6
Pocillopora damicornis	52	1.8	68	1.1
Acropora spp. (corymbose)	49	1.7	69	1.1
Stylocoeniella armata	0	0	103	1.7
Pavona decussate	0	0	64	1.1
Other	127	4.5	294	5.0
TOTAL	2877		5956	

[1]Counts made by the PM are known to be overestimates (see section 2.4.1).

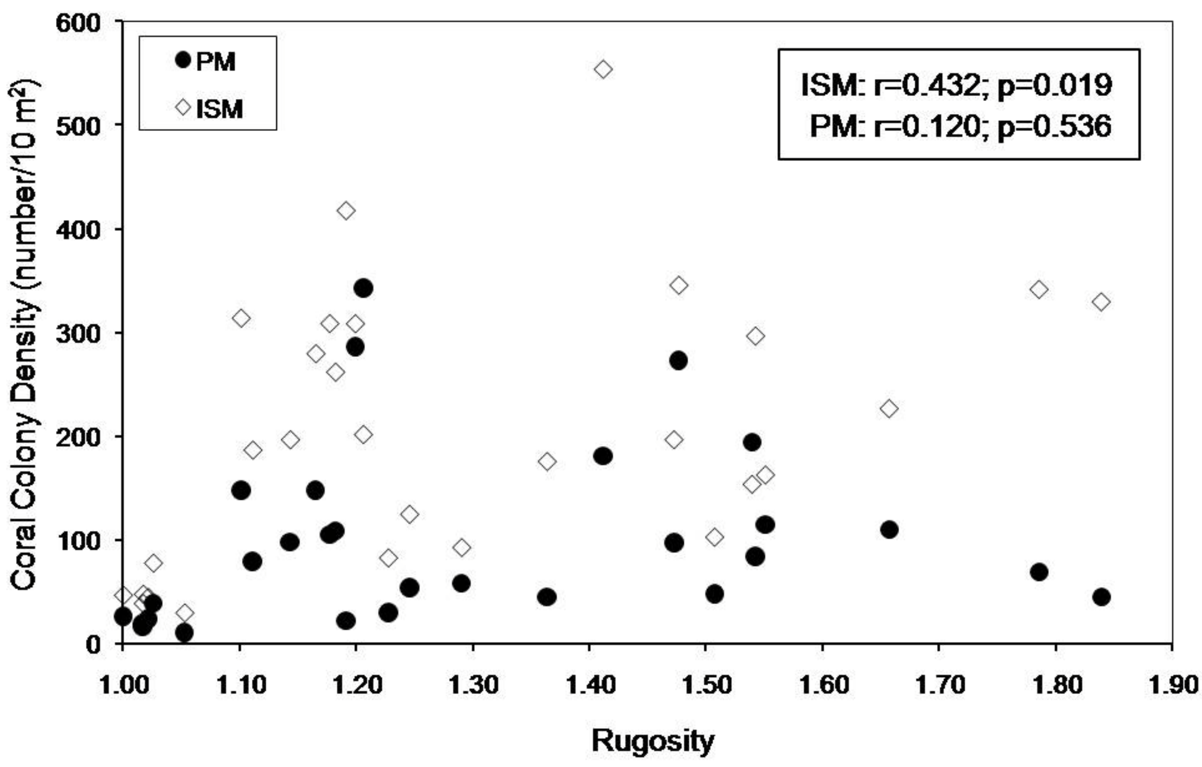


Figure 3.12. Coral Colony Density found at a site using the ISM was positively correlated with rugosity. No relationship was found between Coral Colony Density and rugosity for the PM.

Table 3.5. The mean (±SE) similarity between the method-site pairs and its median (with interquartile range) rank when compared to the 59 other similarity values for the method site. If the methods are directly comparable, the method-site pairs would have a similarity value of one hundred and a rank of one.

Taxa Resolution	Similarity	Rank	Wilcoxon Test
Coral Taxa	63.1 ± 1.9	8 (1-14)	W=946, p<0.001
Coral Taxa – No *P. rus*	46.9 ± 3.9	4 (1-10.5)	W=841, p<0.001
Coral Morph	68.4 ± 1.8	6 (1-14)	W=1081, p<0.001
Coral Morph – No *P. rus*	58.6 ± 3.5	4 (1-9)	W=780, p<0.001

between the two methods decreased when *P. rus* was removed from the analysis and the rank continued to be significantly greater than one. This pattern persisted when corals were combined into morphological categories.

3.3.2 Comparison of Communities

3.3.2.1 Coral Taxa

When Coral Colony Density was analyzed by taxa, a significant difference was found between the communities described by the ISM and the PM (ANOSIM; R=0.13; p=0.007). (A high stress value on the 2-dimensional MDS plot made it difficult to visually interpret, so it has not been presented.) A SIMPER analysis showed that no single taxa explained the majority of the difference between the communities described by the ISM and PM. Instead 11 coral taxa were necessary to explain 75 percent of the difference between the two methods.

When *P. rus* was removed from the analysis, the coral communities described by the two methods no longer significantly differed (ANOSIM; R=-0.34; p=0.186), suggesting that the two methods account for colonies of *P. rus* differently. No effect of strata was observed for either the ISM (ANOSIM; R=-0.03; p=0.775) or PM (ANOSIM; R=0.08; p=0.073).

3.3.2.2 Coral Morphological Groups

When the coral community was examined at the morphological level (see Appendix B for morphological categories), the communities described by the two methods continued to show significant differences (ANOSIM; R=0.12; p=0.018). (A high stress value on the 2-dimensional MDS plot made it difficult to visually interpret, so it has not been shown.) Once again, a SIMPER analysis showed that no single morphological category accounted for the majority of the observed difference. However, the "mixed" colony morphology, to which *P. rus* belongs, accounted for 30 percent of the observed difference, nearly twice that of the next morphological category. When the "mixed" category was removed from the analysis, the communities described by the two methods no longer differed (ANOSIM; R=0.03; p=0.242), further suggesting that the manner in which the two methods account for colonies of *P. rus* is of primary importance. No differences among strata were found for either method.

3.4 Coral Colony Size

Multiple methodological problems were identified with the Coral Colony Size data collected by the PM (see section 2.4.1). In addition to the overestimation error associated with the Coral Colony Densities, the size estimates as provided by the PM do not actually measure individual coral colony size. Size measurements were not made of the coral colony, only the longest visible dimension within the photo-quadrat. This artificially truncated any colony that extended beyond the border of the photo frame into a randomly-selected smaller size class with a maximum size limitation of 120 cm (the diagonal dimension of the photo-quadrat). As a result, the data collected has no easily interpretable biological or ecology meaning.

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

3.5 Coral fragments

A total of 1588 coral fragments from nine species were identified (Table 3.6) by the two methods, but the number of fragments found by the PM is known to be overestimated (see section 2.3.1). *Porites rus/horizontalata* accounted for over 54% of all observed fragments. Fragments were observed at every site but one (site 22), but the ISM found fragments at more sites (26 of 29) than the PM (22 of 29 sites).

Table 3.6. Total number of fragments (n) and their percent of the total (%) found using the PM and ISM.

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

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

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

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

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

Comparability between the methods decreased with increasing rugosity (ANCOVA; F=8.82, df= 1,24; p=0.007). At low rugosity, the two methods found similar numbers of fragments, but the difference between the methods increased as rugosity increased. When examined, the total number of coral fragments found using the PM was uncorrelated with rugosity (Pearson Product Moment; r= 0.250, p=0.190), whereas fragments found with the ISM increased with rugosity (Pearson Product Moment; r= 0.609, p<0.001).

Cover of *Porites rus* was significantly correlated with rugosity (Pearson Product Moment; r= 0.656, p<0.001) and was most likely the primary source of increasing topographic complexity within the survey area. For both methods, *P. rus* was a significant source of coral fragments (Table 3.6). The slope of the relationship between *P. rus* fragments and *P. rus* cover was steeper for the ISM than the PM (Figure 3.13). The correlation was also weaker for the ISM, as shown by the greater scatter of points. This different relationship between the two methods for the detection of *P. rus* fragments with changes in *P. rus* cover was responsible for lower comparability between the two methods at higher rugosity.

3.6 Percent Colonies with Complete Fission and Percent Colony Mortality

The ISM found a significantly higher proportion of the colonies at a site that had undergone complete fission than did the PM (Paired t-test; t=-8.22; df=28; p<0.001). The ISM identified 20 taxa having undergone complete fission, whereas the PM identified five taxa (Table 3.7). Of the colonies undergoing complete fission, the ISM estimated a significantly higher percent mortality that the PM (Paired t-test; t=-7.96; df=28; p<0.001).

Two taxa for which more than one colony was identified having undergone complete fission were identified by both methods. For *Pavona cactus*, the ISM found over five times more

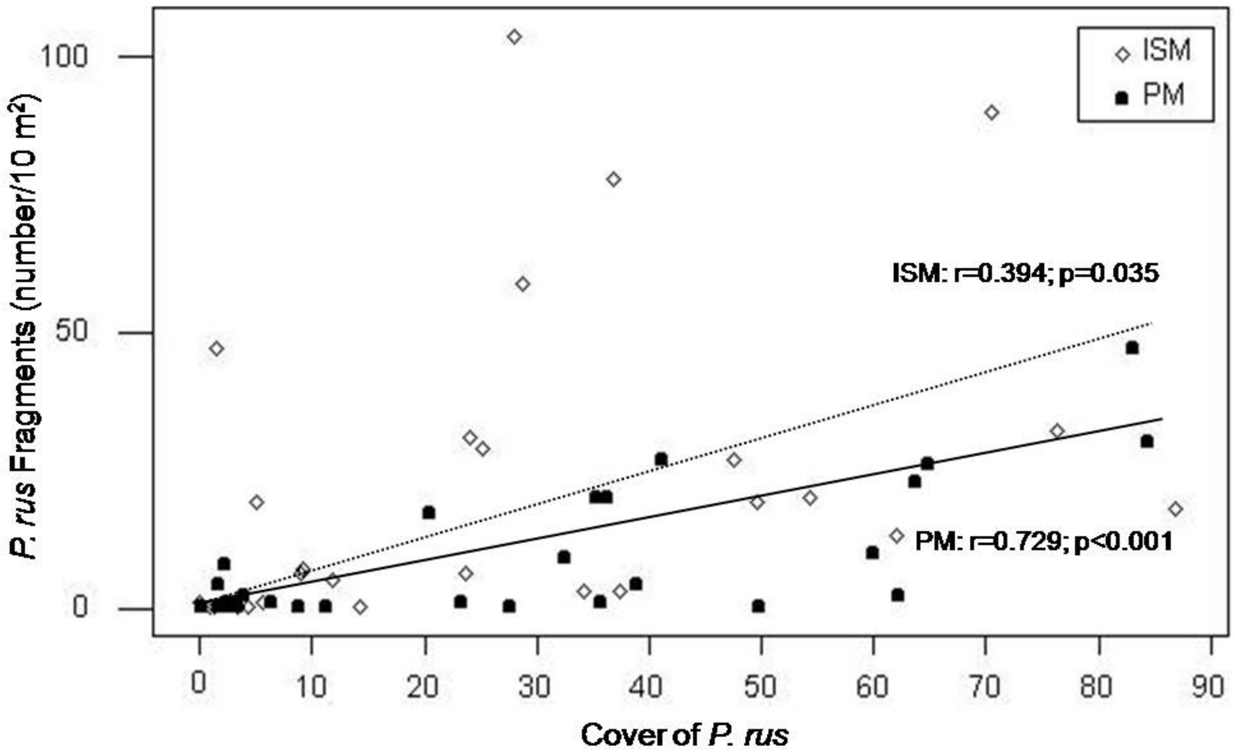


Figure 3.13. The slope of the relationship between *Porites rus* fragments and *P. rus* cover is steeper (yet more variable) for the ISM (dotted line) than for the PM (solid line). Both ISM and the PM correlations are significant.

colonies undergoing fission than did the PM. For *Porites rus*, this value was even greater; the ISM identified 34 times more colonies having undergone complete fission compared to the PM. For both taxa, the average percent mortality of those colonies that had undergone complete fission did not differ.

3.7 Coral Growth Anomalies

Neither method noted the presence of gross growth anomalies at any site. The PM noted the presence of several "unusual" conditions (Table 3.8). These "unusual" conditions were not collected as part of the data for the ISM. The PM observed these unusual conditions in photographs at 13 of the 30 survey sites.

4.0 Discussion

One of the most important decisions a field researcher must make is the selection of a survey method that will perform in the site-specific conditions of the study area to collect the target data with the resolution, precision, and accuracy necessary to achieve the research or survey objectives. This study compared the performance of a photo-quadrat method and an *in situ* quadrat method in the collection of a suite of coral reef benthic data within a heterogeneous coral reef ecosystem. While the primary goal of this study was to assess how well the two methods

Table 3.7. Mean (±SE) percent of colonies per site undergoing complete fission and mean (±SE) percent mortality of colonies that have undergone complete fission.

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

[1]No SE for n=1 colony

Table 3.8. "Unusual" coral conditions noted by the PM.

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

compared in a specific location (near Polaris Point, Apra Harbor, Guam), it was hoped that the study would also reveal some general insights into the wider applicability of each method. It is important to note that this report draws no conclusion about which method is "better." This conclusion involves a value judgment that can only be made after considering the project-specific objectives; the type, resolution, and precision of the data to be collected; and the site-specific conditions of the study area.

4.1 Method Comparison

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

The simplest explanation for the discrepancy in taxonomic resolution between the PM and ISM is that many taxa could not be identified from the photographs. This has been observed in other studies, where taxonomic richness from a PM approach was low relative to other *in situ* methods

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

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

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

(Foster et al. 1991, Miller et al. 2003). When making observations *in situ*, it is possible for observers to examine organisms from multiple angles, pick them up, and collect specimens, if necessary, for later laboratory identification by taxonomic specialists. This is not possible with the PM alone.

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

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

In this study, benthic rugosity had an important and somewhat unexpected influence on the results of the analysis. The coral *P. rus,* which has a variable and highly rugose growth form, was significantly correlated with rugosity. As *P. rus* increased in dominance, however, Taxon Richness at the site tended to decline for the ISM or remain constant in the case of the PM. As a result, the comparability of the methods was often uncorrelated with rugosity because the potential difficulties for the PM associated with higher rugosity were off-set by improved performance of the PM with the decrease in Taxon Richness. When rugosity effects were seen (*i.e.*, decrease in Taxon Richness, increase in number of coral fragments), they were consistent with what would be expected when a three-dimensional structure is reduced into a planar view: for the PM, data changed little or not at all with changes in rugosity while the ISM did change.

4.2 Community Comparisons

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

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

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

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

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

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

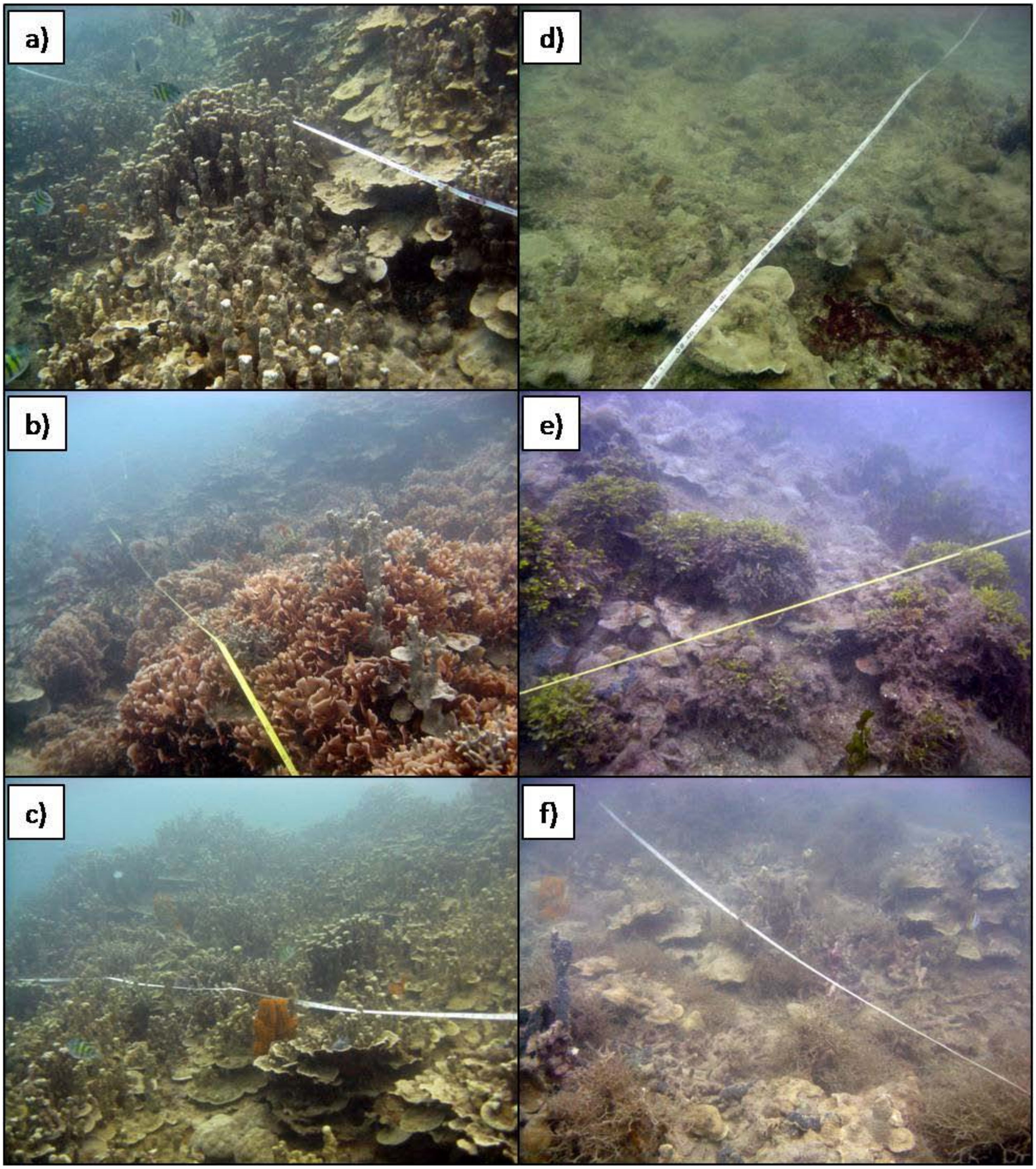


Figure 4.1. Habitat photos taken at three Indirect-Slope (a,b,c) and three Direct-Slope (d,e,f) sites. When only the benthic cover of coral taxa were used in the analysis, the PM was unable to distinguish between the coral communities within these two strata, whereas the ISM showed significant differences.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

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

4.3 Density-based and Coral Colony Size Data

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

Methodological issues (see section 2.4.1) and data inconsistencies either precluded analysis entirely (in the case of the Coral Colony Size data) or resulted in a "qualified" analysis in this report (in the case of Coral Colony Density data).

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

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

Because colonies along the edges of the photo-quadrats were not entirely visible, the PM as employed in this study, was unable to use the colony-center rule to determine if a colony should be included within a quadrat. However, counting colonies in which any part is within the quadrat leads to disproportionate sampling of larger colonies and overestimation of colony density, which Zvuloni et al. (2008) refer to as a Type II condition. The only way to correct the resulting error is to count corals that occur exclusively within the quadrat frame, leading to a

Type I condition (Zvuloni et al 2008). With a Type I condition, quadrat size become significant for the PM, because any coral that is larger than the quadrat frame will be excluded from any density and colony size estimate, making any correction to the Type I bias (underestimation of true density) problematic. Zvuloni et al. (2008) conclude that "…the method of photo-quadrats combined with the corrected type I approach is best for reefs with coral colonies that are small relative to the size of the sampling units" [page 151].

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

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

4.4. Selecting a Method

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

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

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

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

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

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

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

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

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

4.5 Adjustment Functions

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

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

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6.0 References

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Appendix A

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

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

Appendix B

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

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

Appendix J
Supplemental Aircraft Carrier Marine Surveys

6. Assessment of Benthic Community Structure in the Vicinity of the Proposed Turning Basin and Berthing Area for Carrier Vessel Nuclear (CVN), Apra Harbor Guam. July 12, 2009.

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ASSESSMENT OF BENTHIC COMMUNITY STRUCTURE IN THE VICINITY OF THE PROPOSED TURNING BASIN AND BERTHING AREA FOR CARRIER VESSELS NUCLEAR (CVN) APRA HARBOR, GUAM

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Submitted:

July 12, 2009

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1 EXECUTIVE SUMMARY

One component of the planned move of the Marine Expeditionary Force from Okinawa to Guam is the provision to provide safe access and new berthing facilities for nuclear aircraft carriers (CVN) in Apra Harbor, Territory of Guam. In order to accomplish this task, areas of the entrance channel and turning basin in the southeastern part of the Harbor, as well as areas selected for berthing, will require dredging to a depth of 51.5 ft. below MLLW. Although much of this area was previously dredged in 1946 during the creation of the present configuration of Apra Harbor, the proposed dredging to accommodate the CVN will result in removal of existing benthic marine communities within the dredge footprint. In addition, there is potential for indirect effects to benthic communities adjacent to the footprint from environmental changes associated with the dredging operation.

In April-May 2009, surveys were conducted to collect data to provide preliminary evaluation of the composition of benthic community structure within the area that will be affected by the proposed CVN operation. The purpose of the surveys was explicitly not to initiate a time-course monitoring protocol to evaluate changes from the activity, nor to conduct investigations of population dynamics or life histories of individual species. However, a stated objective of the surveys was to acquire data that could provide input metrics for development of Habitat Equivalency Analysis (HEA) models that will be used to evaluate compensation for lost services.

Owing to a limited timeframe, methods were selected to maximize data collection with the shortest duration of fieldwork possible. Benthic community composition was evaluated using a photo-quadrat belt transect method (each belt transect encompassed 10 m^2 of contiguous benthic surface) using a digital camera mounted on a frame that standardized distance from the camera to the substratum. Data analysis for 67 transects was performed "*ex situ*" using a visual basic program, Coral Point Count with excel extensions [CPCe], that has gained wide acceptance for coral reef monitoring studies. All benthic cover analyses were performed by three separate investigators and the final data set contained complete investigator agreement on all point counts. Other data collected in the field included calibration-validation information for developing a map of coral cover using spectral signatures of remote sensing imagery, spectral reflectances of representative corals to develop a "stress index," and analysis of sediment samples to determine composition of material that will affect communities during dredging operations.

Survey results indicated that the CVN survey area consists of a heterogeneous mix of a variety of biotopes ranging from mud flats to algal meadows to a wide structural array of reef coral communities (in terms of both species assemblages and physical forms). Bray-Curtis similarity indices revealed 7 distinct community groups with respect to the "general classes" of transect cover (e.g., algae, coral, sponges, sediment). When "detailed classes'" containing all identified species and substratum types were analyzed, 16 distinct community groups emerge.

When data from all transects were combined, algae accounted for about 40% of benthic cover, coral 22%, sponges 3% and sediment (sand, mud, and rubble) 35%. Algae occurred on all but one transect, and corals were present at 52 of the 67 survey sites. On transects with sediment cover greater than approximately 75%, corals were not present. All transects containing coral also contained algae. Coral cover was dominated by a single species, *Porites rus*, which accounted for about 74% of total coral cover. Along with *P. rus*, the next three most abundant species (*Porites lutea, Pavona cactus*, and *Porites cylindrica*) accounted for 95% of coral cover.

Transects were divided into four "strata" depending on two sets of conditions: location within (Direct) or adjacent to (Indirect) the dredge footprint, and angle of bottom topography (Flat ≤15 °; Slope >15°). Each strata contained transects with attributes that encompassed all of the major biotopes, although mean coral cover was higher in the two Indirect strata (25% Flat; 38% Slope) compared to the two Direct strata (14% both Flat and Slope). Multivariate analyses of transect data consistently revealed that transects within strata did not fall into distinct groupings within the entire data set.

Application of calibration-validation data collected in the field to spectral signatures of remote sensing imagery was used to create a map of coral cover over the entire survey area. For the SRF alternative, coral of all classes covered approximately 39% of the bottom within the dredge footprint compared to 35.4% in the Polaris Point alternative. For both alternatives, the highest areas of coverage occurred in the lowest abundance class (0%<coral≤10%). Coverage of the two highest level (>50%) was higher in the Indirect strata compared to the Direct strata for both alternatives. Overall accuracy of the map product was about 76%, although the accuracy to differentiate areas with any level of coral from areas with zero coral was 91%.

In situ spectral reflectances measured at the surfaces of the two most abundant species of coral (*Porites rus*, *P. lutea*) were used to compute the Normalized Difference Vegetation Index (NDVI) for 27 sites in CVN survey area. NDVI is a relative scale indicating amount of chlorophyll present; higher values indicate more chlorophyll, and therefore lower "stress." Although NDVI increased slightly with depth, there was no apparent trend in the horizontal spatial distribution of NDVI. The lack of a spatial pattern suggests no difference in chlorophyll between the Direct and Indirect strata, and hence no difference in relative stress.

Counts of mobile invertebrates at all transect sites revealed considerably higher mean density in the two Indirect strata (26 Flat; 24 Slope) compared to the Direct strata (12 Flat, 7 Slope). Mobile invertebrate species composition consisted primarily of molluscs, with smaller contributions from echinoderms and crustacea. Populations of sessile macroinvertebrates (other than stony corals) consisted predominantly of a wide variety of sponges (Porifera), with smaller contributions from the ascidians, molluscs and polycheates. Mean values of sessile invertebrates were higher on the Slope strata (92 Direct; 119 Indirect) than the Flat strata (71 Direct; 86 Indirect).

Analysis of composition of surface sediment collected within the proposed dredge area revealed carbonate composition (by weight) ranging from 78% to 96%. The remaining percentage is considered non-carbonate terrigenous material. There is a general gradient of increasing carbonate content with increasing distance from the entrance of Inner Apra Harbor.

The results of these surveys provide a baseline overview of the composition of the benthic marine habitats within the area of Apra Harbor that will be influenced by the CVN project. These findings can provide data to address reef classification, metric variability, and reference conditions. Consequently, these survey results will be valuable for input to modeling efforts to determine compensatory mitigation, as well as for developing efficient and defensible long-term monitoring programs that may be required.

2 PURPOSE

The United States (U.S.) Department of the Navy (Navy) proposes to construct a wharf and associated shoreside facilities at Apra Harbor, Territory of Guam, to continue to provide support for visiting nuclear aircraft carriers (Carrier Vessels Nuclear, or CVN). CVN are accompanied by aircraft and escort combatant ships, collectively referred to as a Carrier Strike Group (CSG). Apra Harbor currently supports an average of two 1-week CSG port calls of 7-day duration per year. Under the proposed action, there would be approximately three 21-day visits per year, or aggregate thereof, to support the increased CSG presence in the Western Pacific and Indian Oceans. The extended visits require 100 percent shoreside utility capability (i.e., power, wastewater management, potable water supply) to minimize or eliminate reliance on shipboard systems while in port.

To support the activity, the Navy proposes to construct a wharf and supporting infrastructure in Outer Apra Harbor capable of berthing visiting CVNs. Two proposed action alternatives are (1) a new wharf at Polaris Point, or (2) a new wharf (replacing existing finger piers) at the Former Ship Repair Facility (SRF) (Figure 1). The berthing areas for both alternatives border the entrance to the Inner Apra Harbor channel. The navigational approach through the Outer Apra Harbor Channel toward Inner Apra Harbor would generally follow the existing approach but will require widening to 600 ft. The navigational depth requirement for a CVN is -49.5 ft Mean Lower Low Water (MLLW). This depth requirement is met between the Outer Apra harbor Channel entrance and the sharp bend toward Inner Apra Harbor. Dredging of specific areas will be required between the bend and the alternative wharf sites to deepen the existing turning basin north of the wharf sites. The total dredge volume anticipated for Polaris Point and Former SRF alternatives is estimated at 608,000 cubic yards (CY) (464,849 cubic meters [m^3]) and 479,000 CY (366,222 m^3), respectively, including 2 ft (0.6 m) for overdredge (total dredge depth = 51.5 ft [15.7 m]).

The final design of the wharf is pending. A steel pile supported concrete platform was recommended in the CVN-Capable Berthing Study. There will be cut and fill at the shoreline. It is likely that the material removed could be reused at the site. The dredging methodology has not been determined and may include either or both hydraulic and mechanical dredge. The substrate may have to be pretreated using a mechanical chisel to facilitate the “grabbing” by the clamshell claw of a mechanical bucket. Dredge material disposal has not been determined and would include upland placement or ocean disposal at a designated site.

These activities will result in loss of habitat, either through direct removal of dredged material, or indirect effects of the dredging, particularly from effects of dredge-suspended sediment. A key critical component of evaluating the potential magnitude of environmental impacts, as well as developing effective and practical valuation of lost values and functions is gaining an insight into the overall habitat composition of the affected area. Because the area of interest consists in part of coral reefs and coral communities, consideration of impacts to these habitats will be one of the primary foci of the mitigation process. As a result, understanding the overall reef community composition of the affected area is a necessary component of the planning process.

The intent of this document is to present the methods and results of field studies conducted in April-May 2009 to assess and describe qualitatively and quantitatively the benthic habitat in the area that will be affected by the proposed actions to accommodate the proposed CVN project. At the direction of the Navy, the purpose of this assessment was to employ the most efficient techniques in the limited time available to gain a fundamental understanding of the broad-spectrum composition of entire affected community, with particular emphasis on providing input to Habitat Equivalency (HEA) Models. In this context, a community is the combined set of species living in a given physical setting at a given time. The intent of the study was explicitly not to investigate structure or life-history of particular populations, defined as all of the individuals of a single species living in a given place at a given time. The report is also not intended to provide exhaustive species lists. As the actual area of field surveys encompassed approximately only 0.1% of the entire affected area, any notion of "all-inclusiveness" by any survey method would not be accurate owing to the small area of study.

It is important to also note that the study was not intended to be the first stage in a monitoring program to specifically evaluate actual effects of the proposed action. Other methodological approaches would likely be far more effective for such monitoring. For example the U.S. Environmental Protection Agency has developed a "Stony Coral Rapid Bioassessment Protocol" (Fisher 2007). In the explanation of the intent of the protocol, the author states ..."The protocol is intended for use in a long-term biocriteria monitoring program, which requires exploratory biological surveys to inform and mold the monitoring design and strategy. Biological surveys provide date to address reef classification, metric variability, size and number of sampling units and reference conditions. Consequently, these preliminary surveys are indispensable to developing an efficient and defensible long-term monitoring program."

This description of the exploratory biological survey fits the purpose and objectives of the work carried out in Apra Harbor for evaluation of the habitats within the influence of the CVN project. Should future "monitoring" become a requirement, sampling protocols such as developed by the EPA should certainly be considered.

3 METHODS

3.1 TRANSECT SURVEY SITE SELECTION

With a relatively large and heterogeneous survey area (>150 acres), selection of representative, and statistically valid discrete survey sites is critical. It is not possible to perform a power analysis as reef community structure is inherently non-random; reefs generally exhibit strong geomorphic and ecological zonation (this was confirmed for the CVN survey). Sixty-seven survey sites were selected to provide an adequately robust and logistically feasible sample size. Because a large percentage of the CVN turning basin and entrance channel are composed of sand, selection of survey sites by a completely random selection process ran the risk of under-representing the hard-bottom communities. As a result, survey site selection was conducted using a stratified-random approach. The scenario at the CVN site is well suited for stratified random sampling as the overall communities are heterogeneous, and similar sub-communities (strata) can be isolated (Cochran 1978).

The selected strata were based on two physical components of the study area. One set of strata is defined within the outline of the combined area to be dredged under both the Polaris Point and SRF alternatives (termed "Direct Impact" stratum), and a 200-m-wide area bordering the dredge area (termed "Indirect Impact" stratum). The second set of strata is defined by the slope of the reef, divided into “Flat" stratum with bottom slope less that 15° and “Slope” stratum with bottom angle greater than 15°. All strata are bounded by the 60-ft depth contour.

Figures 2-6 show the progression of steps used to develop a set of 67 survey sites within the four strata. Figure 2 shows a Quickbird color satellite image of the study area in southeastern outer Apra Harbor, with the two dredge alternatives (SRF and Polaris Pt) outlined in red and blue lines, respectively. The 200-m-wide indirect stratum is also shown, as is the 60-ft depth contour. Figure 3 shows the same image that is optically “stretched” to highlight the deep reef areas (~>50 ft.) within the dredge area. This figure illustrates that these deep reef areas are clearly visible in the imagery and that areas of coral or algae are distinguishable from sand or rubble substratum.

Figure 4 shows color-coded bathymetry of the study area derived from LIDAR and acoustic data. In order to define strata based on topographic slope, LIDAR data was converted to reef slope angle as shown in Figure 5. Trial runs testing various slopes indicated that 15° produced a consistent visible outline throughout the study area. Hence, strata were defined as “flat” with topographical gradients less than or equal to 15˚, and “slope” with topographic gradients greater than 15°. Figure 6 shows a final stratification product, with each of the four stratified zones shown in a different color. Fifteen data points are randomly placed (using MATLAB) into each of the four zones (Direct Impact Flat, Direct Impact Slope, Indirect

Impact Flat, Indirect Impact Slope). In addition, data points were placed within each of the SRF and Polaris Pt wharf outlines, and within a patch reef at the northwestern end of the Fairway Channel within the Direct Impact area, resulting in a total of 67 survey sites.

3.2 TRANSECT SURVEY METHODS

All fieldwork was carried out from April 26-May 7, 2009. Field surveys were conducted using SCUBA with divers working from one 25' and one 18' boat. All diving operations were under the supervision of a safety officer and complied with all applicable Navy regulations.

Field surveys were conducted using a "Photo-Quadrat Belt Transect Method." Variations of this method have been a standard for evaluating and monitoring coral reef community structure for decades (see review by Nadon and Sterling 2006), and are widely used at present by numerous coral reef monitoring and assessment programs including the Global Coral Reef Monitoring Network, the Florida Keys National Marine Sanctuary Monitoring Program, and the Southeast Coral Reef Monitoring Network Program.

Single transects were evaluated at each of 67 sampling points (Figure 7). Each transect was 10-m long. This length was chosen to minimize the chance that transects would cross geomorphologic or ecological zone boundaries. Benthic cover on each transect was recorded within 15 photo-quadrats that were contiguously placed along the length of the transect. Each photo-quadrat had the dimensions of 1 m x 0.66 m, proportional to a photographic frame, resulting in total area covered by each transect of 10 m^2. The origins of transect locations were marked by the location of a weighted buoy dropped from the surface at the GPS coordinates of the transect station location (Appendix A shows coordinates of each sampling transect).

Field surveys were carried out by navigating to the pre-determined origin of each transect using differential GPS (typical horizontal error in Apra Harbor <3 m, personal experience). A buoy with an anchor-weight was dropped from the surface to mark the station location on the reef surface. At the location of the weight, a diver reeled out a marked fiberglas tape. If the location occurred on a distinguishable slope, the transect line was laid to follow the depth contour; if there was no distinguishable slope, transect orientation was in a random direction. Photo-quadrat data was collected by the second diver using a digital SLR camera (14 mm lens with 114° diagonal field of view) mounted on a 4-legged PVC quadrapod that positions the camera over the center of a 1 m x 0.67 m rectangular frame. The digital SLR contains a full-frame display that provides for *in situ* verification of each image. In addition to the transect photos, panoramic images of most transect sites were collected. At the conclusion of each field day, digital photos were copied onto separate media (e.g. hard drives).

An index of *in-situ* topographical relief (TR), or rugosity, was also measured on each transect as the ratio of a length of chain laid over the reef surface and the chord length of the transect line.

All photo-quadrats were analyzed in the lab by individuals who participated in the field work. Lab analysis employed the Coral Point Count with Excel Extensions (CPCe) software developed by the National Coral Reef Institute, which is a Visual Basic program for the determination of coral and substratum coverage using random point count methodology (see Kohler and Gill 2006 and www.nova.edu/ocean/cpce/ for complete descriptions of the software, and a list of 73 publications that have used the program for benthic community assessment). In brief, a matrix of 50 randomly distributed points was overlain on each photo-quadrat image, and the organism or substrate type lying beneath each point was identified to the lowest taxonomic classification possible. Customization options that were employed included determination of long diameters of coral colonies using the length calibration feature of the software. This feature allows for drawing measured lines across any objects on the image. Classification of growth forms into an index of morphology was also included in the data analysis.

In addition to coral and non-coral substratum, CPCe software-generated data products were used to assess benthic algae, motile macro-benthos and non-living categories of benthic cover (e.g., sand, mud, rubble). Zoom features of the software and the high resolution of the digital photographs (~10 megapixels) allowed delineation of corals to the level of distinguishing individual calices. Other "value-added" parameters, such as disease or bleaching, were evident on quadrat images. To evaluate consistency and estimate variability between investigators, a random sample of four transects was used for "training" and analysis was conducted jointly by all three observers. Subsequently, the remaining 63 transects were analyzed by all three investigators separately. At the conclusion of the analyses, results were compared, and any points that did not have complete agreement between investigators were jointly examined and defined by consensus to result in complete agreement of the data set.

3.3 REMOTE SENSING HABITAT MAPPING

All methods utilized in this report followed standard procedures for processing coral reef remote sensing imagery (e.g., Andréfouët et al. 2003, Green et al. 2000, Mumby et. al. 1998). The benthic habitat map was created based on commercially available satellite remote sensing imagery. A fully georeferenced Quickbird multispectral+panchromatic satellite image of Apra Harbor was purchased from the Image Library at DigitalGlobe.com (image data originally acquired February 18, 2007). The image had 7.9-ft (2.4-m) ground sample distance in the spectral (color) bands. The Quickbird image was processed to highlight submerged features, which revealed areas of different bottom composition (Figure 2).

Transect data represent a reef area of 670 m^2 (= 10 m x 1 m x 67 transects). The total reef area within the study region that is equal to or shallower than 60 ft. is approximately 728,000 m^2. Thus, the study area represented by the transects is about 0.1% of the entire area of interest. While the transect data are high in detail, they are of limited extent. Any inference about the totality of the study area would require significant extrapolation. Owing to the geomorphologic and ecological heterogeneity within Apra Harbor, such extrapolation would lead to an unknown degree of error. As the majority of Habitat Equivalency Assessment (HEA) models rely on metrics in terms of area-time (e.g. acre-years), minimizing the error of such metrics is paramount in maintaining optimal accuracy of model results (M. Donlan, personal communication).

To address the issue of developing area-wide marine community characterization, a remote sensing approach was used to characterize the marine environment. Remote sensing has two major advantages over discrete in-water survey methods. First, remote sensing provides a synoptic view that can provide a quantitative assessment of benthic cover for the entire 728,000 m^2 study area. The results provide important information about both the relative covers and the spatial distributions of the major reef bottom-types. Second, accuracy assessment is a routine part of remote sensing studies that enables identification and correction of errors in the analysis of the entire area of interest. Thus, accuracy assessment statistics provide a direct measure of the quality of the map product that is to be used for management decision-making.

We employed standard remote sensing practices for this study. The most recent, highest quality satellite imagery available from Quickbird (DigitalGlobe) and IKONOS (GeoEye) was obtained. Each of these sources provides very high-resolution (≤4 m ground sample distance) multispectral imagery.

Images were generated using a supervised classification approach: sea-truth calibration-validation (cal-val) data consisting of depth and benthic cover was determined at a set of georeferenced sites. It is important that cal-val data are at the same scale as the mapping unit, i.e. image pixels. For high-resolution imagery (small pixels), the preferred approach is to discretely sample small reef patches (roughly 2-3 times the area of a pixel) using photo-quadrats. We have found that a pooled composite of five photo-quadrats collected within an area of about 5 m^2 (analyzed in the lab as described above) provides a suitable overall value for each sea-truth site. Thus, cal-val data collection was conducted by acquiring five quadrat photos within an approximate area of 5 m^2 near the origin of each of the 67 transect locations. An additional 19 randomly selected sites were also evaluated for a total of 86 calibration-validation areas. The digital photographic images were analyzed for benthic cover as described above for the transect data using CPCe software.

These data were then used to train an image-object-based classifier. Image-objects are groups of connected pixels that share similar spectral signatures; that is, they are relatively homogenous patches of bottom-type at a constant depth on the reef. A classifier is simply a set of rules that a computer follows to assign appropriate labels to unknown observations, which in this case are image-objects. Once the classifier is trained with known image-objects, it is applied to the entire image, and the result is a thematic map showing the spatially-explicit, quantitative bottom cover at each pixel. An initial accuracy assessment was conducted to determine where errors occurred, followed by subsequent refinement of the classifiers to generate a new thematic map. We iterated this process until the map achieved an accuracy threshold of 75%.

Accuracy assessment is a critical component of the remote sensing and map-making process. Patterns in map accuracy guide the processing flow: if a particular map class exhibits low accuracy at one step in the processing, then the analysis is altered and the step is repeated. Accuracy is determined using the standard error matrix as described in Congalton and Green (1999). To populate the error matrix, we used the method of cross-validation. In cross-validation, all but one observation from the sea-truth data are used to build a classifier, and the classifier is tested on the withheld point. This process is repeated on every observation point in the data set. The result is the error matrix, with correct classifications on the diagonal and incorrect classification off-diagonal. Because each classifier is tested on a data point that was not used to build the classifier, the result is unbiased. Also, because the test classifiers use almost all the available data points, they more closely represent that classifier actually used to generate the image product (which used all data points). This is a more robust test of the classification than would be achieved by simply separating the sea-truth data into two halves (i.e., a "training" set and a "testing" set).

We also performed another analysis to determine overall reef rugosity, following the methods described in Brock et al. (2004) and Purkis et al. (2008). In this analysis, LIDAR data are processed to derive reef slope (vertical relief divided by horizontal distance) at each pixel in the scene. Since each pixel has the same horizontal distance, pixels with high slope indicate high vertical relief. Rugosity for a given pixel is calculated as the variance in the surrounding set of pixels; different rugosity scales simply incorporate different numbers of pixels. For example, for Quickbird with 2.4×2.4 m pixels, variance computed on a 3×3 window gives rugosity for a 51.84 m^2 area, while variance computed on a 5×5 window gives rugosity for a 144 m^2 area. Evaluating such different scales of rugosity has been shown to be an important tool for understanding functional aspects of reef communities, such as reef fish habitat utilization (Purkis et al. 2008).

In the lab, survey points were located on the geo-referenced satellite multispectral image which served as the basis for statistical image classification. “Training classes” (defined as the combination of geo-morphological zone and bottom cover) were created by assigning a class label to a survey point using the ground truth data for context. To spectrally define a “region of interest” for a training class, 20-30 adjoining pixels were isolated and included in the class. Because the same zone-cover combination could occur at different depths, the final classes could exhibit several different multispectral patterns. Thus, it was often necessary to merge several independent training classes to the same final class label. After the merging procedure, all training classes with the same spectral label were used to create the map showing the distribution of bottom cover over the reef. The resultant analysis produced maps showing six classifications of coral cover:

Class 1: coral = 0%
Class 2: 0% < coral ≤ 10%
Class 3: 10% < coral ≤ 30%
Class 4: 30% < coral ≤ 50%
Class 5: 50% < coral ≤ 70%
Class 6: 70% < coral ≤ 90%

3.4 NEAR-REAL-TIME ASSESSMENT OF CORAL STRESS

We measured and processed spectral reflectance *R* (implicitly a function of wavelength) for visible wavelengths (400–700 nm) following methods described in Hochberg and Atkinson (2006). The sampling unit consisted of a 2-m-long fiber optic cable (400 µm diameter) attached to an Ocean Optics USB2000 portable spectrometer (wavelength range 330–850 nm, with ~0.3-nm sample interval and ~1.3-nm optical resolution, wavelengths calibrated to Ocean Optics HG-1 Hg-Ar lamp), which in turn was operated by a palmtop computer. The spectrometer and computer were in a waterproof housing, which enabled the spectrometer to be fully diver-operated. The fiber optic cable connected to the spectrometer through the housing wall via a vacuum feedthrough (Ocean Optics). The fiber optic cable tip collected light over a solid angle of ~0.1 sr, which at a distance of 10 cm projected to a circular area of 10 cm^2 (diameter ~3.5 cm).

For each single measurement of *R*, a diver pointed the collecting tip of the fiber optic cable at the target on the coral and triggered acquisition (and storage on the palmtop) of the spectrum by pressing a button on the housing. Immediately thereafter, the diver pointed the collecting tip at a Spectralon (Labsphere) diffuse reflectance target (same depth as the target point on the coral) and triggered the storage of its spectrum. In this manner, both spectra could be acquired within 1–2

s. Because the spectrometer was a 12-bit system with limited dynamic response, we used a 10% reflectance Spectralon so that measured light intensity from the coral and the Spectralon were of the same order (coral *R* averages near 10%: Hochberg et al. 2004), thus maximizing the measurable coral signal. To ensure a constant ambient light field between the two measurements, the Spectralon was placed immediately adjacent to the target point on the coral, and the diver's position was held constant for the 1–2 s required for the measurements. If light flashes due to wave focusing were obvious at the time of sampling, we shaded both the coral and Spectralon from direct light so that they were illuminated only by the ambient diffuse light field. Spectra were acquired in units of digital counts.

We corrected all spectra for baseline electrical signal, then calculated *R* as the ratio of digital counts measured over the coral to the digital counts measured over the Spectralon, corrected to 100% reflectance, for each pair of measurements. We linearly interpolated *R* to 1-nm intervals over the wavelength range 400–700 nm, then filtered the result using the Savitsky–Golay method (Savitsky and Golay 1964; Steiner et al. 1972). For each coral, we measured 20-30 replicate *R*s across an area up to ~0.25 m^2 of coral surface (depending on colony size), and these were averaged for determination of NDVI. NDVI was calculated following Eq. 1, with NIR = 720 nm and RED = 673 nm.

3.5 INVERTEBRATE SURVEY METHODS

All visible unattached non-coral macro-invertebrates were identified and counted within one 25 x 4 m belt transect at each of 62 transect sites (Transects 15, 29, 52, 54 and 67 were not assessed for invertebrates). Surveys were conducted without manipulating the bottom (e.g., no rubble was turned) and only cursory checking of holes and crevices.

Taxa Richness data were collected by searching a 5 m belt centered on the transect and noting all visible unattached non-coral macro-invertebrates species. Search time varied, depending upon the amount of bottom time left after completing the quantitative data collection.

All individuals were identified to the lowest possible taxonomic level. Specimens not identified *in situ* were photographed and a portion taken as voucher for later identification in the lab or by an appropriate taxonomist as necessary. Abundance (density) of all sessile invertebrate taxa was assessed quantitatively using counts of all taxa within 0.5 m on either side of the 25m long transect line.

Surveys of transects 15, 49 and 61 were conducted during both day and night. Surveys of all other transects were conducted during the day only.

3.6 SEDIMENT COMPOSITION

As composition of sedimentary material (primarily calcium carbonate vs. terrigenous) has been shown to result in differential effects to corals, it was deemed important to determine composition of the sediments that will be dredged for the CVN project. Surface sediments were collected by divers at ten transect stations within the "Direct" impact strata. Collection sites were aligned roughly in a southeast-to-northwest orientation from stations near the mouth of Inner Apra Harbor and Sasa Bay, across the dredge area to the patch reef at the northwestern end of the Fairway.

Sediment samples were immediately sealed in vacuum bags and frozen until return to Honolulu. In the lab, sediment samples were dried and aliquots of approximately 20 g were weighed. Sediments were then subjected to repeated treatments of a 1N NaOAC buffered solution of HOAC until all carbonate material was dissolved. Dissolution was considered complete when additional treatments of HOAC produced no bubbling. Following completion of dissolution, samples were repeatedly rinsed with distilled DI water, dried, and weighed. Difference in weight of samples before and after acid treatment was used to determine carbonate and non-carbonate (i.e., terrigenous) fractions. Sediment composition analyses were conducted in the laboratory of Dr. Eric H. DeCarlo at the School of Ocean & Earth Science and Technology at UH Manoa. While time did not permit for inclusion in this document, residual sediment has been retained for analysis of organic fraction and mineralogical composition at a later date.

3.7 SURVEY PERSONNEL

The University of Hawaii (P. I.: S. Dollar) was responsible for overall coordination of all partners and facets of the project including field logistics, field sampling, data analysis, evaluation and compilation, interpretive results (including accuracy assessments) and report preparation. Dr. Dollar was also responsible for collection of all photo-transect data in the field and data transfer to Nova Southeastern University. Analysis of sediment composition was also conducted at the University of Hawaii.

Nova Southeastern University (P.I.: E. Hochberg) was responsible for providing personnel to assist in collection of field data, and data analysis of photo-transect data utilizing CPCe software, including multiple user accuracy assessments. Nova was also responsible for collecting all data, and developing remote sensing products, as well as collecting and processing all data for developing coral stress indices. Graduate students from NSU contribution to field work and data analysis were H. Hancock, C. LaPointe and M. Doctor. S. Dunne assisted with fieldwork, and A. Hudon assisted in the field and provided editorial support.

Invertebrate surveys were conducted by Dwayne Minton (U.S. Fish and Wildlife Service) and collaborative investigators from the University of Guam.

4 RESULTS

4.1 DESCRIPTIONS OF THE SURVEY AREA

The structure of the marine environment of the southeastern part of outer Apra Harbor containing the main channel and turning basin is composed primarily of three major regions. These three areas are 1) large flat-topped patch reefs; 2) dredged reefs in the turning basin and entrance channel; and 3) soft sediment areas in the turning basin and entrance channel.

The channel and turning basins are bordered by several large "patch reefs" that consist of shallow, flat-topped, steep-sided features. The largest three of these reefs are Jade and Western Shoals and Big Blue Reef (Figure 1). These reefs all consist of relatively flat, shallow upper surfaces that are covered primarily with sand, rubble and algae. The western facing slopes of Western Shoals and Big Blue Reef consist of near total cover of living corals to a depth of approximately 50 to 60 ft (15 to 18 m), where the slopes intersect the channel floor. Coral cover on the eastern slopes of these two reefs is more variable relative to the western slopes, possibly as a response to increased sediment loads in water flowing westward from Sasa Bay, or from resuspended sediment generated by ship movements within the approach channel to Inner Apra Harbor. Jade Shoals, located to the northeast of Western Shoals and Big Blue Reef, does not show the same degree of asymmetrical coral growth on the western edge, with most of the shoal ringed by slopes with high coral cover.

The area demarcated as the project area where dredging will take place for the CVN project presently does not contain any of the shallow shoal patch reefs (see Figure 4). This area was dredged in 1946 to allow safe access to the newly completed Inner Apra Harbor (R. Wescom, personal communication). As a result, the shallowest depth within the channel and turning basin is about 40 ft (12 m). It is likely that the large flat area in the southeastern end of the turning basin was another shoal area similar to the surrounding reefs prior to the 1946 dredging. Dredging likely removed the shallow area, resulting in the present configuration. While the top of the deep reef is essentially flat at a depth of approximately 40 ft (12 m), the remaining edges slope relatively steeply to the channel floor.

The dated dredging of the original channel suggests that much of the coral within the depth zone to be dredged for the CVN project (< 51.5 ft (15.7 m)) is regrowth following the 1946 dredging resulting in a community with a maximum age of 62 years.

4.2 DESCRIPTIONS OF BIOTOPES OF THE CVN SURVEY AREA

A biotope is defined as an area that is relatively uniform in environmental conditions and in its distribution of animal and plant life. Several distinct biotopes occur in the CVN area, distinguished by both physical structure and biotic composition. In addition, much of the CVN area consists of combinations or mixtures of the "pure" biotopes. Descriptions of all of these biotopes are presented below.

4.2.1 PORITES RUS "SUPRACOLONIES"

By far, the most common coral in Apra Harbor is *Porites Rus*. Colonies of *P. rus* can be massive, columnar, laminar, branching and encrusting, and single colonies can contain multiple growth forms. It is also common to see growth forms that fit under the definition coined by Pichon (1978) of "supracolonies." By this definition, one "colony" is a formation originating from one planula. As new colonies in close proximity grow in size, they fuse. Such a phenomenon, when constantly repeated, leads to a continuous living coral formation, composed of elements belonging to different generations. These conglomerate colonial structures, or supracolonies, may extend over tens or hundreds of square meters. In some instances supracolonies may be so large as to represent a whole ecological identity (i.e., sub-community) (Pichon 1978).

While *Porites rus* occurs throughout the survey area, it is particularly widespread on the outer (with respect to the CVN entry channel and tuning basin) sloping sides of the four large patch reefs (Jade, Western, Big Blue, and the unnamed reef). *Porites rus* occurs in a variety of contiguous supracolony structural forms that dominate the benthic surface. Most of these structures are composed of multitudes of overlapping thin semi-circular plates. Supracolonies have the form of vertical walls, massive dome-shaped structures, conical spires, masses of foliaceous cup-shaped and tabular plates (Figure 8). In addition, colonies and supracolonies of *P. rus* can assume a variety of branching forms that occur in contiguous thickets covering large sections of the benthic surface (Figure 9). It is also common to see multiple growth forms (branches growing out of laminar plates) (Figure 9).

4.2.2 MIXED CORAL COMMUNITIES

Coral community structure on some areas of the flatter sections of patch reef slopes as well as deep reef flats consisted of higher cover of a more diverse community than in the areas dominated solely by *Porites rus*. Along with *P. rus*, two branching species, *Porites cylindrica* and *Pavona cactus*, comprise substantial proportions of bottom cover (Figure 10). *Porites cylindrica* occurs as thin rounded upright branches, with individual branch separated each other by an encrusting matrix base. *Pavona cactus* occurs as thin, upright, contorted fronds, each attached to a solid base. Both of these corals grow in interconnected stands that can extend over large areas of the reef surface. In particular, on Transect 15, located on the eastern edge of the unnamed patch reef between Western Shoals and Big Blue Reef, *Pavona cactus, Porites cylindrica*, and *Porites rus* formed mixed complexes with substantial contributions from all three species (Figure 10). Thus, three of the four most abundant corals encountered in the CVN surveys (*P. rus, P. cylindrica* and *P. cactus*) often occur in what can described as indeterminate growth forms, in the form of supracolonies or spreading mats composed of multiple branches or fronds.

4.2.3 PATCH REEF MARGINS - PORITES LUTEA ZONE

Porites lutea generally occurs as hemispherical or helmet shaped colonies and are a major component of benthic cover on the margins of the tops of patch reefs in the CVN area. Water depth of these flats is the shallowest of all biotopes, and was generally in the range of 1-2 m. Within this zone, colonies of *P. lutea* are often densely packed together with adjacent colonies in contact with one another. Other dominant corals in this biotope included *Porites cylindrica* occurring in branched clusters, and *Porites rus*, which occurred primarily of flat-topped clusters of densely packed branches (Figure 11). Moving off the flat surfaces of the patch reefs, community structure rapidly changes to a more uniform cover of *P. rus* as described in the sections above.

4.2.4 PATCH REEF MARGINS - ACROPORA ASPERA MAT

Transect 9, located on the top of the northwestern edge of Western Shoals, consisted entirely of a contiguous mat of the branching coral *Acropora aspera* (Figure 12). The field of *A. aspera* was limited to the top of the patch reef, and did not extend beyond a depth of approximately 2-3 m, below which the benthic community was dominated by other species of *Porites* (Figure 12). This biotope was not observed anywhere else in the study area, at least in the vicinity of any of the other transects. The uniqueness of the biotope may be a result of orientation of the western edge of Western Shoals to the long axis of Outer Apra Harbor. During surveys, swells entering the Harbor mouth were breaking at the transect location. A distinctive characteristic of the *A. aspera* mat was the occurrence of large sections of dead branches that were encrusted with algae or cyanobacterial mats. As the dead portions of these *Acropora* stands were completely intact, the cause of mortality cannot be attributed to any type of physical forces applied to the fragile branching matrix.

In addition, there were distinct boundaries between areas of apparently healthy branches and patches of dead branches. Within the dead patches, there were also clumps of "new" live branches with no sign of any abnormalities. The likely cause of the patchy mortality of the *Acropora* field is infestation of a black sponge that occurred within the coral thicket, completely covering branches (Figure 12). While the smothering of live coral by the sponge may be the cause of mortality, the presence of the sponge appeared ephemeral, as it was not evident in much of the area of algal-encrusted coral skeletons. In addition, the presence of patches of apparently healthy coral resulting from either planular settlement or vegetative spreading within the thickets of dead branches suggests that there is an ongoing dynamic process of coral-sponge interactions of mortality and recovery within the biotope.

4.2.5 ALGAL BEDS

In addition to hermatypic corals, the other dominant benthos within the study area are macroalgae. While there are biotopes that consist of "coral-algal mixes" (see below), there are also areas of essentially pure stands of algae. Three genera of algae are most prevalent, and in some areas consist of nearly monospecific meadows that extend over hundreds of square meters. Probably the most common plant is the brown alga *Padina* spp, which was found throughout the survey area. This alga is characterized by large calcified, fan-shaped blades that grow in multiple clusters attached to rubble, sand or hard bottom (Figure 13). Also abundant is the calcareous green alga *Halimeda* spp., with fronds consisting of vertical series of connected flat segments. Much of the *Halimeda* observed in Apra Harbor was growing in dense beds over sandy bottoms. In these areas white calcified remains of plant segments form a component of the sandy substratum (Figure 13). The third dominant alga is *Dictyota* spp. which occurs as narrow, spirally twisting branches that are split on the ends. *Dictyota* was often seen in mats of mixed algae and mixed coral-algae, and was particularly abundant over sand-covered bottom (Figure 13).

4.2.6 RUBBLE, MUD AND SAND

Many regions of the CVN study area were not colonized by any epi-benthic biota. Benthic cover in these areas consisted of plains of fine grained sand-mud, primarily composed of calcium carbonate (Figure 14). Numerous burrows and mounds from infaunal organisms punctuated most of the sand-mud regions. In addition, the surface of the sediment was often covered with thin films of bacteria or micro-algae.

In addition to the sand-mud plains, some areas of the bottom were covered uniformly with a layer of mixed rubble and coarse sand. Most of the rubble is recognizable as dead coral fragments. The harbor floor fronting the shoreline off the SRF (Transects 52, 53,54, 67 and 67), and adjacent to the eastern tip of the Outer Apra Harbor entrance channel (Transects 57, 58) was composed almost entirely of rubble and sand (Figure 14).

4.2.7 MIXED CORAL-ALGAE

Several biotopes which comprise the majority of benthic cover consist of combinations of two or more of the "pure" communities described above. One of these combination biotopes can be termed "mixed coral-algae." One such combination consisted of hemispherical heads of *Porites lutea* amid stands of *Padina* spp. on the shallow tops and sides of patch reefs (Figure 15). In the deeper areas, particularly on the tops of the dredged platforms and pinnacles in the turning basin, combined algal-coral communities occurred in a variety of forms, including films of benthic bacteria on mud surfaces, short turfs on rubble fragments, and mats of *Halimeda* and *Dictyota* interspersed with colonies of *Porites* (Figure 15). A unique coral-algal assemblage occurred on Transect 9, where stands of living *Acropora aspera* were interspersed with sectors of dead branches encrusted with a layer of algal turf and cyanobacteria (Figure 12).

4.2.8 CORAL ON SEDIMENT

With the exception of stony coral skeletons, the substratum of the study area consists primarily of sediment of various grain sizes (mud, sand, rubble). As a result, an important aspect of coral community structure is the interaction between corals and soft sediment. Throughout the CVN study area, and particularly in the deeper survey sites, corals are growing on, or out of the sediment surface. *Porites rus*, in particular, occurs in a variety of growth forms that can be considered adapted to colonizing areas of soft sediment. Many of these colonies do not have solid attachment to the bottom, with upper living areas overlying a base of dead skeletal material that is partially buried in the mud (Figure 16). In addition, many colonies growing in areas of abundant sediment had portions of the colonies covered with fine-grained sand or mud. Supracolonies of *P. rus* in many of the deeper survey locations were made up of complexes of laminar plates comprised of sections of both dead and living tissue. Much of the dead plated surfaces on these structures contain an accumulation of fine grained sediment (Figure 17).

4.3 QUANTITATIVE EVALUATION OF BENTHIC COMMUNITY STRUCTURE

Photo-quadrats from 67 transects was analyzed using CPCe software to obtain a quantitative dataset that can be used to describe the community. Appendix B shows three representative quadrats from each transect to provide a view of the overall setting of each survey site. All photo-quadrats are available for post-processing at a future time if necessary.

Table 1 shows the mean percent cover of the "general classes" of benthic cover encountered in all transect photo-quadrats (Appendix C shows upper and lower 95% confidence limits for means of general classes of benthic cover on each transect). Percent cover is calculated as the proportion of total points that occur for each class. General classes consisted of Algae, Stony Coral, Sponges, Soft Coral, Ascidians, Echinoderms and Sediment. Sediment consisted of sand, mud and rubble. Algae and sediment each occurred on 66 transects, coral occurred on 52 transects, and sponges occurred on 55 transects. Ascidians occurred on 3 transects and echinoderms on 4 transects. In terms of ranges of cover of general classes, all classes had minimum cover of zero on at least one transect. Maximum transect cover of general classes ranged from 100% for algae and sediment, 88% for coral, 24% for sponges, 9% for soft coral, 1% for echinoderms, and about 0.3% for ascidians. Cumulative means of general classes for each transect reveal the overall pattern of decreasing algae and sediment with increasing coral cover (Figure 18).

Table 2 shows the percent cover of the "detailed classes" of benthic cover, which are defined as the 37 categories identified in transect photo-quadrats (Appendix D shows the upper and lower 95% confidence limits for the means of detailed classes). The most prevalent class of biota was mixed macroalgae, which occurred on 65 transects with a maximum transect cover of 74%. In terms of occurrence of single macroalgal species, the most common was *Halimeda*, which was present on 30 transects, with a maximum transect cover of 59%, followed by *Dictyota* (23 transects; max cover of 37%) and *Padina* (15 transects; max cover of 27%). With respect to distribution of corals, the most abundant was *Porites rus* which appeared on 47 transects with a maximum transect cover of 85%, followed by *Porites lutea* (26 transects; max of 37%), *Porites cylindrica* (18 transects; max of 12%) and *Pavona cactus* (13 transects; max transect cover of 43%).

Table 3 and Figures 19 and 20 show benthic cover of general classes separated into four strata (Direct-Flat, Direct Slope, Indirect Flat, Indirect Slope). Mean algal cover within strata varied from a low of 30.7% in the Indirect Slope stratum to a high of 47.9% on the Direct Slope transects. Mean coral cover had the mirror image with highest cover on the Indirect Slope (38.3%) and the lowest on the Direct Slope (14.4%). On the combined Direct strata transects, mean algal cover was 44.5%, while mean coral cover was 13.9%. On the combined Indirect transects, mean algal cover was 33.1% compared to mean coral cover of 31.9%. When all transects are combined, mean algal cover was 40.2% compared to mean coral cover of 21.9%.

When all species of coral are listed by order of abundance on transects, *Porites rus* was an order of magnitude higher than any other species, accounting for 74.4% of all coral (Table 4). Along with *Porites lutea*, *Pavona cactus*, and *Porites cylindrica*, the four most abundant species comprise about 95% of coral cover of the CVN survey area. When transects within a strata are ordered according to percent cover of *Porites rus*, the overall pattern of coral cover is similar in areas (Figure 21). In each zone, one-half of the transects had cover of *P. rus* less than 2% of bottom cover. Distribution of ranked order of *P. rus* throughout the other half of the transects within each strata occurred as a progressive increase with little overlap of mean cover up to the maximum value in each strata (Figure 21). As a result, the mean value of coral cover within any strata is influenced by both the relatively large number of transects with essentially no coral, as well as the steep gradient of increasing cover on transects that do contain coral.

Transect cover data were analyzed using the Bray-Curtis similarity index to construct cluster dendrograms (Figures 22 and 23). With a similarity threshold of 0.25, seven distinct clusters emerge from the general class data (Figure 22). Mean values of benthic cover of the general classes within each distinct cluster (Table 5) indicate that sediment cover dominates clusters 1 and 2, algae dominates clusters 3, 4, and 5, and coral dominates benthic cover in clusters 6 and 7 (Figure 22). These cluster groupings compare well with the general biotopes described in Section 4.2.

In order to select the most important community components in terms of percent of total variance explained, principal component analysis (PCA) was applied to the detailed class percent cover data. In PCA, the first principal component (PC) describes the highest proportion of variance in the data, the second PC describes the second highest proportion of variance, and so on. In the present data set, the first five PCs describe >90% of the variance (virtually all of the variability in the data is described by the first 14 PCs) (Figure 24). This result indicates that the data are essentially five-dimensional (as opposed to the 38 dimensions described by the individual detailed classes). By plotting the coefficient value for each PC against the individual detailed classes, it is possible to identify which detailed classes are responsible for each PC, and thus which detailed classes are responsible for the variance in the whole data set (Figure 24). For PC 1, the two detailed classes with the highest coefficient (absolute) values were mud and *Porites rus*. In PC 2, the two most important classes, other than the two from PC 1 (mud, *P. rus*), were mixed algae and *Halimeda* sp. In PC 3, the two most important additional classes were rubble and *P. lutea*. In PC 4, the two most important additional classes were *Padina* sp. and cyanobacteria. Finally, in PC 5, the two most important additional classes were turf algae and *Pavona cactus*. Together, these 10 classes are the most important to describe variability in benthic cover in the data set (Figure 24).

Bray-Curtis similarity cluster dendrograms for the ten detailed classes derived from the PCA provide a substantially more complex array than the general classes (Figure 23). At the 0.5 level, 14 detailed clusters emerge; 2 additional clusters consisting of single transects connect at higher levels. The two "unique" transects are 15, containing the unique attribute of 43% cover of *Pavona cactus*, and transect 9, which contained 34% turf algae (Table 5). When grouped by major habitat type, clusters 1-4 are sediment dominated, clusters 5-11 are macro-algal dominated, and clusters 12-15 are coral dominated.

Another method to demonstrate the relationship between the three major types of benthic cover (algae, sediment, coral) is with a ternary diagram (Figure 25). In this graphic, each vertex represents 100% cover for each bottom cover type, while edge of the triangle represents the "mixing line" between two cover types, with cover of the third type equal to zero. Points within the triangle represent mixing between all three classes.

Several interesting patterns emerge from the ternary plot. First, there are points that fall on the coral-algae and algae-sediment mixing lines, indicating that there are transects that include only there two cover types. However, there are no points on the coral-sediment mixing line, indicating that no coral occurs on transects without algae also occurring. Secondly, there is an empty area of the triangle defined in Figure 25 by a dashed line originating at the 100% coral vertex and extending to the mixing point of approximately 25% algae and 75% sediment. In the area above the line, coral cover is limited to no more than about 2% of bottom cover. Hence, when sediment cover exceeds approximately 75% of transect cover, there is essentially no coral cover. The relatively uniform distribution of points below the dashed line, where sediment cover is less than about 75% and coral cover above approximately 5%, indicates relatively even distribution between algae and coral throughout the survey area (Figure 25).

Transect points in Figure 25 are also color-coded by magnitude of rugosity index. With a single exception, all of the points lying on the sediment-algae mixing line are blue, indicating relatively low rugosity. There is a weak trend of increasing rugosity with increasing coral cover, as points with higher relative rugosity increase with proximity to the lower left corner of the plot.

Several statistical methods can be used to evaluate if transects within strata fall into distinct groupings. Classical multidimensional scaling (CMDS) can provide a qualitative sense of how similar the transect community structures are to each other. CMDS represents each transect by a single point, with transects having similar benthic community composition falling closer to each other than transects that are very different in terms of community structure. CMDS reduces the multi-dimensionality of the data so that they can be displayed two-dimensionally. When the first three dimensions of both the general (Figure 26) and ten detailed (Figure 27) classes are compared, clustering of points is not very evident, and the four strata appear evenly distributed across the data space. Such patterns indicate that there are no important differences between the four strata in terms of benthic community structure.

Principal component analysis (PCA) can also be used to reduce the dimensionality of the data space. Comparison of PCA of transects also give a qualitative representation of the similarities between transects. Again, there are no apparent trends or clusters in the general classes (Figure 28) or the detailed classes (Figure 29), indicating no differences between strata.

Finally, discriminant function analysis (DFA) can be performed using the general and detailed classes, respectively (Figures 30 and 31). DFA describes the separation of two or more predefined groups based on linear functions of multiple variables (Rencher 1995). As they are the linear combinations of the variables that best separate the groups, the discriminant functions describe the plane or planes on which the original multivariate data can be projected to optimally represent group configuration. DFA is equivalent to multivariate analysis of variance, which statistically describes group separation. In this case, again, the discriminant functions do not separate the strata, and thus the strata are not statistically different from each other in terms of benthic community structure. MANOVA tests confirm these results.

4.4 REMOTE SENSING ANALYSIS OF BENTHIC COMMUNITY STRUCTURE

A key component of the evaluation of environmental impacts and subsequent mitigation is gaining an insight into the overall habitat composition of the affected area. Because reef-building coral is a key component of the benthos, and a primary focus of regulatory considerations, understanding the overall coral community composition provides a good starting point for assessment of affected areas. One goal of the CVN survey is to create a benthic habitat map using state-of-the-art remote sensing technology that characterizes the overall composition of coral communities in the southeastern end of Outer Apra Harbor, Guam in the vicinity of the CVN channel and turning basin.

Analysis of remote sensing imagery acquired from airborne platforms has repeatedly demonstrated to be a useful tool for coral reef assessments. Appendix E lists approximately 40 peer-reviewed publications that demonstrate the use of remote sensing data for assessment or study of coral reef structure and function. These represent only a sample of the literature on the subject. Most of these papers focus on use of high-resolution multispectral imagery. Some of the papers discuss moderate-resolution multispectral imaging, and some discuss application of high-resolution LIDAR data to derivation of reef topography and rugosity. Papers discussing imaging spectrometry, sometimes referred to as hyperspectral imaging, are not included in the list because time constraints prohibit use of this technology for the current project (although future work could include hyperspectral analyses).

There are two main conclusions to draw from these (and other) papers. First, remote sensing is a well-established tool for observation of coral reefs. Second, given expert analysis and interpretation, under ideal conditions, remote sensing products typically achieve accuracies on the order of 80-90%. Thus, remote sensing products can be very accurate and provide critical information about the spatial distributions of important reef bottom-types (habitats). To acquire a commensurate data set entirely from in-water surveys is simply not logistically feasible. For the reader interested in becoming familiar with this field, we recommend the reviews by Kuchler et al. (1988), Green et al. (1996), Andréfouët et al. (2003) and Mumby et al. (2004), followed by the specific case studies listed in Appendix E.

Figure 32 shows the locations of 86 calibration-validation sites used to generate the classifiers for the benthic habitat maps. Figure 33 shows the final map produced by the supervised classification scheme described above for the Polaris Point and Former SRF alternatives, with the boundaries of the Direct and Indirect strata. Spectral resolution of the image allowed for distinction of six bottom classifications according to coral cover as described above.

A full cross-validation was used for error analysis. In cross-validation, all but one observation from the ground-truth data are used to build a classifier, which is tested on the withheld point. This process is repeated on every point in the data set. The result is a matrix of classification rates, with correct classifications on the diagonal and incorrect classification off-diagonal. Because each classifier is tested on a data point that was not used to build the classifier, the result is unbiased. Also, because the test classifiers use almost all the available data points, they more closely represent that classifier actually used to generate the image product (which used all data points). This is a more robust test of the classification than would be achieved by simply separating the sea-truth data into two halves (i.e., a "training" set and a "testing" set). It is important to note that this error matrix assesses the accuracy of the *classifier*, and it only represents the accuracy we would expect in the map product. The classifier is the set of decision rules that are used to assign class labels to unknown objects. For example, in cases of interactive photo-interpretation, the classifier is actually the thought and decision-making process inside the coral reef expert’s head. In the present case, the classifier is a computer-based, mathematical algorithm that has been “trained” with quantitative ground-truth data. Thus, the numbers in this table reflect the performance of that computer processing, given the available data. Because accuracy was assessed using full cross-validation, these values are unbiased estimates of the classification rates we would expect to find in the final map product.

Table 6 shows the confusion matrix (or error matrix) for the classification coral map created for the CVN area. The overall accuracy of the map is about 76%. Accuracy of differentiating between areas with zero coral and any of the other categories containing any amount of coral is about 91% (Table 6b). Hence, the map can provide a very accurate assessment of coral containing areas. Possible factors contributing to error were potential georeferencing offsets in the imagery and in the field, relative great depth of many of the survey stations, and high turbidity of the water column. Nevertheless, the level of accuracy of prediction of bottom cover is high compared to what would result from extrapolation from a relatively few survey points to the entire survey area.

Within Tables 6a, 6b, and 6c columns correspond with actual classes, while rows correspond with predicted classes. It is possible for an observation in any given actual class to be predicted as belonging either to that class (correct) or to any of the other classes (incorrect). In this case there are six classes; thus there are 36 possibilities. On the diagonal elements of the matrix, the predicted class is the same as the actual class. These elements represent correct classifications. For off-diagonal matrix elements, the predicted class is not the same as the actual class, and these elements represent confusions in the classification. The values in Table 6a are pixel counts: these are the observations for which we know both the actual and predicted classes. These counts can be interpreted in two useful ways.

The first interpretation is as the *producer* of the map (Table 6b). Matrix counts are converted to rates by dividing each element by its corresponding *column* total. These rates represent how often observations in a given class are assigned to each of the possible predicted classes. For example, 46.7% of the time, observations in the class "0% < coral ≤ 10%" are correctly classified (i.e., assigned to the correct predicted class). However, 12.3% of the time, observations in that class are incorrectly identified as belonging to the class "10% < coral ≤ 30%." These *producer* rates describe how well the classifier separates the observations into appropriate classes. (The classifier is the set of rules used to assign observations into classes, in this case multivariate quadratic classification functions.)

The second interpretation is as the *user* of the map (Table 6c). Matrix counts are converted to rates by dividing each element by its corresponding *row* total. These rates represent how often observations predicted to be in a given class are actually in that class, as opposed to actually belonging to another class. For example, 45.9% of the time, observations that are predicted to be "0% < coral ≤ 10%" do actually belong to that class. However, 16% of the time, those observations will actually belong to the class "10% < coral ≤ 30%." These *user* rates describe how well the map product (Figure 33) characterizes the survey area. In this example, 45.9% of the pixels in the map labeled as "0% < coral ≤ 10%" are correct, but 16% of those pixels are actually "10% < coral ≤ 30%."

The *user* rates allow for correction of area estimates. Using the same example as above, if the map predicts 100 m^2 to be "0% < coral ≤ 10%," then only 45.9 m^2 are actually that class, while 16 m^2 are "10% < coral ≤ 30%." This is the basis for the revised area estimates in Table 7.

Table 7 shows the area coverage of each corrected coral class in both square meters (m^2) and acres for each stratum for both the SRF and Polaris Point alternatives. Examination of the coral map and coverage table reveals several important points. The total area to be dredged is 71.18 ac (28 805 639 m^2) and 60.77 ac (245, 928 m^2) for Polaris Point and SRF, respectively. Based on pixel counts from the remote sensing map, total area with any level of coral coverage is 23.74 acres (96,083 m^2) for the SRF alternative and 25.20 acres (101,969 m^2) for the Polaris Point alternative. Hence, about 39% and 35.4% of the area to be dredged presently contains some level of coral coverage for the SRF and Polaris Point alternatives, respectively.

It is also evident that the area within the dredge boundaries contains relatively small areas of the densest classifications of very high cover (>50% coral). Areas that did contain the densest categories were generally along the sloping margins of the large patch reef outside of the dredge envelope. While the mapping results indicate that about 10-11% of bottom cover and 28-29% of coral cover for both alternatives is in the two highest cover classes (>50%), such areas are not concentrated in any particular biotope or region, but are spread across the dredge zones in relatively low densities (Figure 33).

Within the Direct strata for both the SRF and Polaris Point alternatives, the most-represented class is that of the lowest non-zero coral cover (Class 2 as described above). Of the area in both alternatives that contains any coral, the highest coverage is in the lowest cover level (0-10%). In both alternatives, about 60-62% of area with any coral cover is within Classes 2 and 3 (i.e., 0% < coral ≤ 30%).

It is also of interest to observe the pattern of coral coverage on the small oblong-shaped reef at the northernmost part of the sharp bend in the entrance channel. It is not apparent whether this area was previously dredged or has remained in a natural state. Results of mapping indicate that both the northern and southern "ends" of the reef contain coral predominantly in the higher cover classes (>50% cover). Similarly, the protruding finger at the western end of Jade Shoals that extends into the Direct Impact strata appears to contain relatively high coral cover (Figure 33).

The product of the mean coral abundance percentage and the area of the class can provide a weighted sum that can represent areas of "total coral" (Table 7). When cover is weighted in this manner, the 60% mean coral level contained the largest area for both alternatives. The 5% mean level contained the smallest weighted area for both alternatives. In terms of area of any level of coral cover, the Polaris Point alternative had slightly less cover than the SRF alternative (Table 7).

4.5 INDEX OF CORAL STRESS

We have developed a technique to quantify the stress status of individual *in situ* coral colonies using bio-optical measurements. These measurements provide an index to coral chlorophyll concentration, which is directly related to the integrated stress level of the coral. Corals contain within their tissues photosynthetic dinoflagellates called zooxanthellae. In this symbiosis, zooxanthellae receive protection, a stable light environment and nutrients from the coral (Muscatine 1967,1990). In turn, corals have the benefit of high productivity, and enhanced calcification (Gladfelter 1985).

Since corals and zooxanthellae participate in this mutualistic symbiosis, they are dependent upon each other to flourish. Stress to the coral invariably interrupts this balance, which in turn leads to declines in pigment concentrations through expulsion of zooxanthellae, loss of pigments directly, or both. When the stress is intense or prolonged, pigment loss can reveal the coral's underlying white carbonate skeleton, and the coral appears to have been "bleached." Though the magnitude of this stress response is variable, loss of pigments and/or zooxanthellae is ubiquitous and readily detectable through optical measurements (Hochberg et al. 2006).

Zooxanthellae pigments are the primary absorbing components of corals, and the optical signature (or, more simply, the color) of a coral is determined by its zooxanthellae density and pigment concentration (Hochberg et al. 2003). Inversely, the spectral reflectance of a coral can be used to quantitatively predict pigment concentrations (Hochberg et al. 2006). Spectral reflectance is the fraction of light that reflects from a material surface (i.e., not absorbed by the material) as a function of wavelength. Figure 34 (top) shows an example of coral spectral reflectances, highlighted with pertinent optical features. Based on the shape and magnitude of each spectrum, it is possible to derive corresponding pigment levels.

A common approach is to compute pigment levels on a relative scale, thus avoiding intercalibration issues. NDVI (Normalized Difference Vegetation Index) is one such index that is widely used as a measure of plant chlorophyll abundance and energy absorption (Myneni et al. 1995). NDVI is generally defined as

$$\text{NDVI} = (R_{\text{NIR}} - R_{\text{RED}}) \div (R_{\text{NIR}} + R_{\text{RED}}), \qquad \text{(Eq. 1)}$$

where R_{NIR} is reflectance at a waveband in the near-infrared (in the range 700-1000 nm), and R_{RED} is reflectance at a waveband in the red (600-700 nm) portion of the spectrum. Higher NDVI values correspond to higher chlorophyll concentrations; NDVI values between 0.5 and 1.0 are typically considered to be chlorophyll-rich.

In all, we measured NDVI for a total of 153 individual colonies of *Porites rus* and *P. lutea* at 27 CVN survey sites (Table 8). Figure 35 shows mean NDVI for each sampling site (4-13 corals per site), pooling the species. Figure 34 (bottom) also shows NDVI calculated for the same corals as in Figure 35, using 720 nm for the NIR waveband and 673 nm for the RED waveband.

There is no apparent trend in the horizontal spatial distribution of NDVI, though all values in this study would be generally considered to represent high chlorophyll content. NDVI does increase slightly with depth (not shown), which is a typical response to compensate for lower light (Falkowski et al. 1990).

Figure 36 shows the distribution of NDVI separated by species and by survey stratum. There is a good deal of overlap between species/strata, but a one-way ANOVA does find at least one significant difference in group means ($p << 0.05$). A post-hoc multiple comparison using Tukey-Kramer criteria finds that Direct-Flat *P. lutea* has mean NDVI significantly different (at level $\alpha = 0.05$) from Direct-Flat *P. rus*, Direct-Slope *P. rus*, Indirect-Flat *P. rus* and Indirect-Slope *P. lutea*.

Despite the statistical differences, it is difficult to discern a trend in NDVI with respect to location in the survey area. The exception is that NDVI seems to increase with depth, though this increase is otherwise independent of location. The overall interpretation is that chlorophyll was relatively abundant in all corals across the CVN survey area. This in turn indicates that the corals in the area were not generally stressed at the time of measurement.

4.6 SIZE-FREQUENCY ANALYSIS

Analysis of size-frequency of populations of corals can be an important tool to assess change across space and time (e.g., Bak and Meesters 1998, Meesters et al. 2001, Zvuloni et al. 2008, Viehman et al. 2009). However, while coral colony size frequency distributions can reveal important characteristics of populations on a reef, the metric, like all others, has certain limitations. As pointed out by Bak and Meesters (1998), size is generally dependent on species identity and on environmental setting, with variation between sites small in some species and large in others. Other confounding factors are that size is not always directly related to age, particularly in larger colonies that may not actually consist of true single colonies (Hughes and Jackson 1980). Hence, these authors indicate that the impact of the environment on variation in colony size can be great in some species and low in others. As a result, meaningful use of size-frequency is essentially species and site-specific, requiring the understanding of individual species' life histories under particular environmental regimes.

In addition, and perhaps most relevant for the CVN survey area, certain methodological criteria must be met before the metric of size-frequency can be assumed to provide valid measurements. These criteria include the ability to accurately and reproducibly differentiate colonies. Bak and Meesters (1998) point out the problem of defining individual colonies can usually be overcome, with the exception of branching colonies. Zvuloni et al. (2008) point out that the use of any correction factors to accurately estimate size-frequency of coral colonies is weakened when colonies are large relative to the frame of reference, and that colony size must be small in relation to the sampling unit (quadrat or transect). All of these factors, understanding size relationships for individual species in a particular setting, delineation of discrete colonies from non-discrete colonial growth forms (e.g., branching and conglomerate growth forms), and large colony size relative to sampling unit, come into play with respect to evaluation of coral populations in Apra Harbor.

Acknowledging these limitations, size-frequency of coral colonies was evaluated from transect photo-quadrats using a built-in function of CPCe software to determine greatest chord length. Colonies lying partially within the frame were measured as the section bounded by the quadrat. Correction factors developed by Zvuloni et al. (2008) were not applied as these empirical factors were developed using computer simulations with all colonies of a size that was small compared to the sampling unit. Such a condition clearly did not apply to the coral populations in Apra Harbor (see section 4.2). In addition, use of the "center rule" (Zvuloni et al. 2008) where colonies with centers within the sampling unit are included, but those with centers outside the sampling unit excluded, is not possible with photo-quadrats as centers of colonies outside the sample frame are not visible. As a result, there is an inherent bias in the size-frequency data toward smaller distributions as colonies on the boundaries of the sampling frame will appear smaller than actual size.

Size-frequency distribution of the longest chord length of the four most abundant corals in the CVN survey area are shown as histograms in Figure 37. Histograms are arranged left-to-right by coral species and top-to-bottom by survey stratum, and show mean values determined across all transects within a given stratum for seven size classes ($x < 2$, $2 \leq x < 5$, $5 \leq x < 10$, $10 \leq x < 20$, $20 \leq x < 40$, $40 \leq x < 80$, and $80 \leq x < 160$ cm). For all four corals in all four strata, the least abundant size classes are the smallest ($x<2$ cm) and largest ($80 \leq x < 160$ cm). Of the four species, the largest size occurs predominantly for *Porites rus*, and occasionally for the branching growth forms of *Porites cylindrica* and *Pavona cactus*. *Porites lutea*, which occurs as discrete hemispherical or lobate colonies was never encountered with a long dimension greater than 80 cm. While the mean number of colonies of *Porites rus* varied within each size class in each stratum, the pattern of size class abundance was similar in all stratum (Figure x). In all strata, the two size classes with a lower bound of 5 cm and an upper bound of 20 cm were the most abundant.

Size class distributions of the two branching species (*Porites cylindrica, Pavona cactus*) were similar in all strata, although the mean number of small (<10 cm) colonies of *P. cactus* was substantially higher in the Direct Slope stratum than elsewhere. *Porites lutea*, which occurred very rarely in the Direct Impact stratum, had identical patterns of size-frequency distribution in both the Indirect Flat and Indirect Slope strata (Figure x).

4.7 INVERTEBRATE COMMUNITY COMPOSITION

Summaries of invertebrate occurrence, in terms of mobile and sessile species are shown in Tables 9 and 10. Counts of mobile and sessile invertebrates at each transect within each strata are shown in Appendices F and G, respectively. Taxa richness for all invertebrate species is shown in Appendix H.

A total of 55 mobile species from 45 genera were encountered. The grand totals of the mean occurrence of mobile species (individuals per 100 m^2) were higher in both Indirect strata than Direct strata, and higher on the flats of each strata relative to the slopes (Table 9). With one exception, the most abundant phylum in each strata was the Mollusca, followed in order by the Echinodermata, Crustacea, Platyhelminthes, and Cnidaria (the exception being slightly higher crustaceans than echinoderms in the Indirect Slope stratum). Overall, abundance of each phylum was also greater in the indirect strata than direct strata.

A total of 62 sessile species from 34 genera were encountered during surveys (Table 10). Unlike mobile species, the grand totals of the means (individuals per 25 m^2) were higher in both Slope Strata compared to both Flat strata. Overall, there was no consistent pattern of greater abundance between the Direct and Indirect areas. The overwhelmingly dominant phylum of sessile invertebrates in all strata was the Porifera, followed by the Ascidia, and with minor contributions from the Molluscs and Polycheates (Table 10). Probably the most conspicuous member of the Porifera within the survey area was the "elephant-ear sponge" (*Ianthella* spp.), with individuals up to one meter in width commonly occurring in the deeper areas of the harbor floor (Figure 38).

Invertebrate surveys were replicated at three transects during the day and night. The grand total of counts on the three transects was higher at night than during day (Table 11). The greatest difference occurred on Transect 49, where a total of 144 individuals were counted at night compared to 10 during the day. The predominant difference was the occurrence of 117 crustacea at night compared to none during the day. Taxa richness at night was also greater on all transects compared to daytime (Table 12). The greatest difference again occurred on Transect 49 where 15 species of crustacea were encountered at night compared to none during the day.

4.8 SEDIMENT COMPOSITION

The interaction of suspended sediment with benthic communities, particularly corals, will be a topic of considerable importance in estimating the effects of the proposed dredging necessary for the CVN project. It has been documented that effects to corals from increased sedimentation rates can be a function of the composition of the sediment (in terms of carbonates and non-carbonates), as well as the duration and intensity of the sedimentation event (e.g., Weber et al. 2006, Te 2001).

In order to evaluate if such differential effects may be a consideration, composition of surface sediment throughout the Direct Impact area of the CVN survey site was evaluated (Figure 39). Percent calcium carbonate ranged from 79% to 96% (Figure 40), with the lowest value occurring at Transect 50, and the highest at Transects 55 and 35. With the exceptions of the peak values at Transects 55 and 35, there is a rough pattern of increasing percentage carbonate with distance toward the northwest (away from the sources of terrigenous input). Composition at all of the sampling sites seaward of the main dredge area (No's 25, 62, 14 and 4) ranged from 87% to 92% calcium carbonate.

While the landmass of Guam is composed of lithified calcium carbonate, terrigenous-derived sediment is likely to have a substantial carbonate fraction that will not be distinguishable from sediment of marine origin. However, any landmass supporting plant growth will also likely contain erodable soil fractions consisting of both organic material and other non-carbonate minerals. The observed rough gradient of increasing carbonates with distance from the sources of terrigenous material likely reflects such input from erosion and surface discharge. Relative to the total sediment mass, the non-carbonate fractions are relatively small, particularly in the outer regions of the dredge area that are closest to the large patch reefs that border the turning basin.

5 CONCLUSIONS AND DISCUSSION

The results of the surveys described in this report provide a baseline overview of the composition of the benthic marine habitats within the area of Apra Harbor that will be influenced by the CVN project. These findings provide data to address reef classification, metric variability, and reference conditions. Consequently, these surveys results will be valuable for input to modeling efforts to determine compensatory mitigation, as well as for developing future work, particularly with respect to developing efficient and defensible long-term monitoring programs that may be required.

Several major points emerge from the results of these surveys. First, when the entire "reef" community of the CVN area is considered, it is often viewed in a "coral-centric" context, as corals are both the most visually appealing and conspicuous assemblages. However, results of the present surveys indicate that the area is actually more of an algae reef, as overall algal cover (40%) is almost twice overall coral cover (22%). This is particularly true in the Direct Impact strata, where mean coral cover is about 14% of bottom cover for both the Slope and Flat zones. While it is clear that the regulatory process focuses on the coral component, it should be recognized that such an emphasis does not truly represent the whole integrated community.

It is also apparent that the marine habitats are extremely heterogeneous in terms of benthic composition. For instance, Transects 15 (Indirect Slope) and 16 (Indirect Flat) are located less than 50 m apart, and at similar depths (45, 51 ft. respectively). Both had about the same algal cover (~11-13%), but vastly different coral cover (69% T-15; 2% T-16) and sediment cover (14% T-15; 84% T-16). The vastly different composition within a small area indicates substantial variability, which was commonly observed throughout much of the region of study. In addition, multivariate analyses show that benthic communities within strata do not describe discrete groupings that separate the strata.

All of these results indicate that reasonable estimation of impacts is highly dependent on using appropriate survey methods. Because they are limited in area of coverage, and require substantial time in the field, traditional transect methods may not be the most appropriate tool for the question at hand. Based on remote sensing imagery, the area of the Direct Impact strata at depths equal to or shallower than 60 ft (merging the SRF and Polaris Pt. footprints) is about 330,220 m^2. It would take about 330 transects covering 10 m^2 to assess 1% of this region. Even with the relatively rapid *ex situ* field method used in the present study, it would take approximately 55 field days to produce such results, with an even longer amount of time necessary to evaluate the Indirect Strata, as it is larger in size (398,137 m^2). Using estimates of field time per transect for *in situ* methods utilized by Resource Agencies (~3 per day), would require on the order of at least 200 days of field time to survey 1% of the Direct and Indirect areas of concern. Even with such enormous investments of time, there is no certainty that extrapolating data from 1% of the area to the entire region of interest, without utilizing other methods, will provide a valid interpretation on the larger scale.

Similar concerns have obviously occurred in many other studies, and have led to such techniques as Manta tows (e.g., Hill and Wilkinson 2004, Kenyon et al. 2006). Several studies comparing field methods for evaluating reef community structure suggest that many smaller sampling units provide a better estimate than fewer, larger units. For example, Kinzie and Snider (1978) found that the best procedure for evaluating reef composition was to make as many "quick and dirty" short transects as possible, rather than few very detailed surveys. The application of remote sensing to coral reef science, discussed throughout this report, is specifically aimed at providing methods to accurately assess large-scale composition and function of reef communities. Hence, it is of utmost importance that the appropriate methods are utilized to support collecting the best and most appropriate data to answer the question at hand.

Another important issue that emerges from the CVN surveys is that the study area within Apra Harbor represents what may be considered a somewhat unique coral reef setting. Particularly within the dredging envelop, virtually the entire non-living benthic surface consists of calcareous sediment, ranging in grain size from fine silty muds to coral rubble. In addition, in areas where the predominant grain size is in the mud-silt range, sediment is easily re-suspended with subsequent re-deposition. As a result, all of the biotic components of the community must have the physiological adaptations to deal with a physical environment characterized by soft bottoms.

Roy and Smith (1971) were perhaps the first to point out that…"*Lack of light and excessive sediment deposition rates are factors limiting coral reef development. The presence of very turbid water and muddy bottom does not mean, however, that coral growth is prohibited."* These authors go on to describe two distinctly different coral reef communities that both grow on muddy bottoms in Fanning Lagoon. They note that reefs in turbid water (31% coral cover) were ecologically different in terms of such factors as predominant growth forms than communities in clear water (62% cover), but both have the ability to clean themselves of sediment with no lasting impacts, and both are considered equally viable "coral reefs."

A very similar pattern of community composition appears to occur in the CVN survey area. Corals that inhabit the area, and predominantly *Porites rus*, must have the physiological ability to withstand the existing sediment regime. The relatively small number of coral species that make up the preponderance of the coral community may be limited to those with the physiological capability to deal with consistent sediment resuspension and settlement, as well as limited unsedimented surfaces for settlement. As the majority of the Direct impact strata were previously dredged approximately 65 years ago, it can be assumed that the existing communities, particularly on the flat areas, consist primarily of regrowth. As corals occur throughout the area, although with patchy distribution, it is evident that recolonization occurred under high sediment regimes. Observations of corals growing out of the mud, and with areas of muddy deposition on otherwise healthy colonies, indicate that these species have the physiological capabilities to deal well with the existing conditions. In addition, the overwhelming preponderance of *Porites rus* in terms of both area cover and structural magnitude on the patch reef slopes facing away from the turning basin indicate that this species is particularly well adapted to the entire range of physical oceanographic conditions in Apra Harbor.

6 REFERENCES CITED

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TABLE 1. Summary table of general classes of benthic cover on 67 transects in CVN study area of southwestern outer Apra Harbor determined from point counts of photo-quadrats using CPCe software.

TRANSECT NUMBER	ALGAE	CORAL	SOFT CORAL	SPONGE	ASCIDIAN	ECHINO-DERM	SEDIMENT	TOTAL
1	12.00	52.55	0	20.36	0	0	15.09	100
2	73.33	10.80	0	8.13	0	1.07	6.67	100
3	32.00	1.45	0	3.09	0	0	63.45	100
4	36.93	51.33	0	5.87	0	0	5.87	100
5	8.80	70.93	0	17.73	0	0	2.53	100
6	24.13	62.53	0	13.20	0.13	0	0	100
7	18.13	68.80	1.73	0.40	0	0.13	10.80	100
8	16.13	66.00	0	10.13	0	0	7.73	100
9	53.47	21.73	0	23.60	0	0	1.20	100
10	82.46	0.92	0	1.23	0	0.31	15.08	100
11	92.80	0	0	3.07	0	0	4.13	100
12	99.87	0	0	0.00	0	0	0.13	100
13	26.93	61.60	0	3.60	0	0	7.87	100
14	33.87	48.13	0	3.20	0.27	0	14.53	100
15	11.07	68.53	0	6.53	0	0	13.87	100
16	12.93	1.87	0	1.33	0	0	83.87	100
17	36.67	14.40	0	5.87	0	0	43.07	100
18	52.93	27.07	0	1.47	0	0	18.53	100
19	34.27	51.60	0	2.13	0	0	12.00	100
20	90.27	3.33	0	1.07	0	0	5.33	100
21	50.27	20.80	0	0.93	0	0	28.00	100
22	89.20	3.33	0	0.53	0	0	6.93	100
23	63.33	15.33	0	5.73	0	0	15.33	100
24	32.80	4.00	0	0.00	0	0.13	63.07	100
25	61.87	4.00	0	0.80	0	0	33.33	100
26	82.27	4.80	0	1.20	0	0	11.73	100
27	53.73	1.73	0	1.07	0	0	43.47	100
28	5.07	84.53	0	0.00	0	0	10.40	100
29	32.13	40.53	0	0.00	0	0	27.33	100
30	13.60	52.67	8.67	0.13	0	0	24.93	100
31	61.20	30.67	0	2.13	0.13	0	5.87	100
32	4.13	0.80	0	0.00	0	0	95.07	100
33	38.13	1.60	0	0.53	0	0	59.73	100
34	54.80	6.40	0	2.27	0	0	36.53	100
35	23.71	0	0	0.00	0	0	76.29	100
36	3.20	0	0	0.67	0	0	96.13	100
37	20.80	0	0	0.40	0	0	78.80	100
38	0.31	0	0.62	0.00	0	0	99.08	100
39	73.87	5.47	0	0.13	0	0	20.53	100
40	28.13	16.13	0	0.93	0	0	54.80	100
41	65.00	0.86	0	5.86	0	0	28.29	100
42	1.08	0	0	0.00	0	0	98.92	100
43	49.33	34.67	0	1.73	0	0	14.27	100
44	72.13	2.53	0	0.80	0	0	24.53	100
45	66.53	21.07	0	1.73	0	0	10.67	100
46	26.13	19.87	0	0.40	0	0	53.60	100
47	62.80	0.67	0	0.00	0	0	36.53	100
48	37.07	6.00	0	0.00	0	0	56.93	100
49	18.80	48.13	0	3.47	0	0	29.60	100
50	82.67	0	0	0.53	0	0	16.80	100
51	86.15	0.46	0	0.62	0	0	12.77	100
52	8.53	0	0	2.53	0	0	88.93	100
53	0.00	0	0	0.00	0	0	100.00	100
54	21.47	0	0	2.40	0	0	76.13	100
55	23.47	36.93	0	4.80	0	0	34.80	100
56	26.00	12.53	0	6.67	0	0	54.80	100
57	50.67	0	0	0.40	0	0	48.93	100
58	26.40	0	0	2.27	0	0	71.33	100
59	19.33	24.53	0	1.47	0	0	54.67	100
60	85.47	10.00	0	1.60	0	0	2.93	100
61	2.40	86.80	0	6.67	0	0	4.13	100
62	21.87	65.20	0	1.60	0	0	11.33	100
63	7.73	87.87	0	4.00	0	0	0.40	100
64	7.14	0	0	0.14	0	0	92.71	100
65	87.87	0.80	0	1.07	0	0	10.27	100
66	8.14	0.00	0	0.00	0	0	91.86	100
67	56.80	0.27	0	1.33	0	0	41.60	100

TABLE 2. Summary table of percent benthic cover of detailed classes on 67 transects in CVN study area of southwestern Apra Harbor, Guam.

	ALGAE									CORAL																					ECHINODERMS			SEDIMENT				
TRANSECT NUMBER	*Caulerpa* sp.	Coralline algae	Cyanobacteria	*Dictyota* sp.	*Halimeda* sp.	*Hydrolithon gardineri*	Mixed/Unidentified	*Padina* sp.	Turf Algae	*Acropora aspera*	*Acropora nasuta*	*Astreopora myriophthalma*	*Astreopora randalli*	*Fungia echinata*	*Galaxea horrescens*	*Herpolitha limax*	*Lobophyllia (cf.) hataii*	*Lobophyllia corymbosa*	*Lobophyllia hemprichii*	*Montipora verrucosa*	*Pachyseris speciosa*	*Pavona cactus*	*Pavona varians*	*Pocillopora damicornis*	*Porites cylindrica*	*Porites lutea*	*Porites rus*	Soft Coral	Sponge	Ascidian	*Acanthaster planci*	*Bohadshi* sp.	*Holothuria* sp.	Dead Coral	Mud	Rubble	Sand	TOTAL
1	0	0	0.18	0	0	0	0.18	0	11.6	0	0	0	0	0	0	0	0	0	0	0	0	15	0	0	1.5	0.2	36	0	20	0	0	0	0	0	1.45	13.6	0	100
2	0	6.1	12.5	0	0	0	45.5	0	9.2	0	0	0.8	0	0	0	0	0	0	0	0.3	0	0	0	0	0	0.9	8.8	0	8.1	0	1.1	0	0	0.1	3.2	3.33	0	100
3	0	0	24.6	0.73	0.91	0	3.64	0	2.18	0	0	0.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0.2	0.4	0	3.1	0	0	0	0	0	34.0	29.5	0	100
4	0	0	0	0	0	0	18.4	0	18.5	0	0	0	0	0	0	0	0	0	0	0	0.1	11	0	0	0	0	40	0	5.9	0	0	0	0	0	0.93	4.93	0	100
5	0	0	0	0	0	0.8	1.2	0	6.8	0	0	0	0	0	0	0	0	0	0.7	0	0.1	28	0	0	0	1.2	41	0	18	0	0	0	0	0	1.6	0.93	0	100
6	0	0	0	0.13	0.27	0	0.4	23.1	0.27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0	62	0	13	0.1	0	0	0	0	0	0	0	100
7	0.1	3.6	0.8	0.13	3.6	0.1	2.93	1.47	5.33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	8.3	25	36	1.7	0.4	0	0	0.13	0	0.1	0.93	1.6	8.1	100
8	0	0.1	0	0	1.33	0	4.67	4.67	5.33	0	0	0	0	0	0	0	0	0	0	0	0	0.7	0	0	0	0.4	65	0	10	0	0	0	0	0	7.07	0.67	0	100
9	0	0.1	0	0	4.0	0	14.3	0.8	34.3	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0.3	0	0	2.3	0	24	0	0	0	0	0.8	0.13	0.27	0	100
10	0	1.2	9.54	7.08	12.6	0	48.6	0	3.38	0	0	0	0	0	0.2	0	0	0	0.2	0	0	0	0	0	0	0.3	0.3	0	1.2	0	0	0.31	0	0	14.5	0.62	0	100
11	0	0	0	0	34.3	0	58.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.1	0	0	0	0	0	3.07	1.07	0	100
12	0	0	0	0	59.1	0	40.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.13	0	0	100
13	0	2.1	0	0	0	0	0.67	0	24.1	0	0	0	0	0	0	0	0	0	0	0	0	11	0.1	0	1.1	0	50	0	3.6	0	0	0	0	0	3.6	4.13	0.1	100
14	0	0.1	0	0	0	0	24.0	0	9.73	0	0	0	0	0	0.1	0.1	0	0.7	0	0	0	3.3	0	0	0	0	44	0	3.2	0.3	0	0	0	0	4.4	10.1	0	100
15	0	0	0	0	0	0	7.87	0	3.2	0	0	0	0	0	0	0.1	0	0	0	0	0	43	0	0.3	2	0	23	0	6.5	0	0	0	0	0.4	12.4	1.07	0	100
16	0	0	0	0	0	0	5.73	6	1.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.9	0	0	1.3	0	0	0	0	0	83.3	0.53	0	100
17	0	0.1	0	0.4	8.93	0	19.7	1.33	6.13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	2.1	10	1.7	0	5.9	0	0	0	0	0	25.6	17.5	0	100
18	0	0	0.27	5.73	0	0	43.5	0	3.47	0	0	0	0	0	0	0	0.3	0	0	0.3	0	0	0	0	0	0	27	0	1.5	0	0	0	0	0	10.7	7.87	0	100
19	0	0	0	0	0	0	19.2	0	15.1	0	0	0	0	0	0	0.8	0	0	0	0	0	0	0	0	0	0	51	0	2.1	0	0	0	0	0	7.2	4.8	0	100
20	0	0	0	11.5	37.2	0	41.6	0	0	0	0	0	0	0.3	0	2.5	0	0	0	0	0	0.5	0	0	0	0	0	0	1.1	0	0	0	0	0	5.33	0	0	100
21	0	0	6.4	0.13	2.27	0	32.3	2.67	6.53	0	0	0	0.1	0	0	0	0	0	0.1	0	0	0	0	0	0	0	21	0	0.9	0	0	0	0	0	24.8	3.2	0	100
22	0	0.3	12.7	1.2	17.6	0	53.1	0	4.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.3	0	0.5	0	0	0	0	0	6.0	0.93	0	100
23	0	0	0.67	0	0.8	0	60.7	0	1.2	0	0	0	0	0	0	0.4	0	0	0	0	0	0	0.3	0	0	1.6	13	0	5.7	0	0	0	0	0	15.3	0	0	100
24	0	0	0	0	9.73	0	23.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0.13	0	63.1	0	0	100
25	0.4	0.3	36.1	1.73	0.4	0	19.7	0	3.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.7	3.3	0	0.8	0	0	0	0	0	32.4	0.93	0	100
26	0	0	15.5	0	2.93	0	59.3	0.8	3.73	0	0	0	0	0	0	0	0	0	0.8	0	0	0	0	0	0	0	4	0	1.2	0	0	0	0	0	10.8	0.93	0	100
27	0	0.3	4	0	0	0	43.9	0	5.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.7	0	1.1	0	0	0	0	0	42.4	1.07	0	100
28	0	0.4	0.27	0	0	0	0.4	0	4.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	85	0	0	0	0	0	0	0.4	2.53	7.47	0	100
29	0	0.3	0.53	0	0.67	0	16.9	0	13.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.3	37	2	0	0	0	0	0	0	0	26.5	0.8	0	100
30	0	0	0.27	0	0	0	2.93	0	10.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.1	31	21	8.7	0.1	0	0	0	0	0	20.8	4.13	0	100
31	0	0.3	0.67	1.6	0	0.4	50.9	0	7.33	0	0	0	0.5	0	0	0.3	0	1.6	0.4	0	0.1	0	0	0	0	0	28	0	2.1	0.1	0	0	0	0	4.67	1.2	0	100
32	0	0	0.4	0	0	0	3.73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.8	0	0	0	0	0	0	0	95.1	0	0	100
33	0	0	0.53	7.07	8.27	0	21.1	0	1.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	1.1	0	0.5	0	0	0	0	0	55.6	4.0	0.1	100
34	0	0.1	0.93	7.07	0	0	41.6	0	5.07	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6.4	0	2.3	0	0	0	0	0	30.3	6.27	0	100
35	0	0	16.4	0	0	0	7.29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	76.3	0	0	100
36	0	0	2.4	0	0	0	0.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.7	0	0	0	0	0	96.1	0	0	100
37	0	0	0.8	0	0	0	20.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.4	0	0	0	0	0	78.8	0	0	100
38	0	0	0.31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.6	0	0	0	0	0	0	99.1	0	0	100
39	0	0.3	1.07	11.1	28.4	0	32.4	0	0.67	0	0	0	0	0	0	0	0	0	0	0	0	3.1	0	0	0	0	2.4	0	0.1	0	0	0	0	0	18.7	1.87	0	100
40	0	0	0	3.07	0	0	15.2	0	9.87	0	0	1.1	0	0	0.8	0	0	0	0	0	0	0	0	0	0.1	2.5	12	0	0.9	0	0	0	0	0	54.5	0.27	0	100
41	0	0	0	13.4	0	0	47.3	0	4.29	0	0	0	0	0	0.3	0	0	0	0	0	0	0	0	0	0	0	0.6	0	5.9	0	0	0	0	0	28.3	0	0	100
42	0	0	0	0	0	0	0.31	0	0.77	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	98.9	0	0	100
43	0	2	0	4.27	0	0	34.4	0	8.67	0	0	0	0	0	0	0.7	0	0	0	0	0	0	0	0	0.1	1.3	33	0	1.7	0	0	0	0	0	7.87	6.4	0	100
44	0.1	0	0.13	0	1.07	0	67.6	0	3.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.5	0	0.8	0	0	0	0	0	23.3	1.2	0	100
45	0	0	0	36.7	0	0	27.1	0	2.8	0	0	0	0	0.4	0	3.3	0	0	0	0	0	2.5	0	0	3.3	0	11	0	1.7	0	0	0	0	0	6.8	3.87	0	100
46	2.5	0.7	1.73	5.87	2.27	0	12.0	0	1.07	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.3	12	0	7.9	0	0.4	0	0	0	0	0	51.3	2.27	0	100
47	0	0	1.87	7.87	1.87	0	50.7	0	0.53	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0.5	0	0	0	0	0	0	0	36.0	0.53	0	100
48	0.4	0	0.4	0	0	0	36.3	0	0	0	0	0	0	0	0	0	0	0	0	0	4.1	0	0	0	0	0	1.9	0	0	0	0	0	0	0	56.9	0	0	100
49	0	0	0.53	0	0	0	2.93	0	15.3	0	0	0	0	0	0	0.3	0	0	0	0	0	0	0	0	8.7	0.1	39	0	3.5	0	0	0	0	0	19.9	9.73	0	100
50	0	0	0.13	0	21.7	0	60.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0	0	0	0	16.8	0	0	100
51	0	0	0	9.69	2.77	0	73.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0	0.6	0	0	0	0	0	12.8	0	0	100
52	0	0	0.13	0	6.0	0	1.47	0	0.93	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.5	0	0	0	0	0	35.9	53.1	0	100
53	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	100
54	0	0	0	0.53	0	0	11.6	9.33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.4	0	0	0	0	0	75.6	0.53	0	100
55	0	0	1.2	0	0	0	14.0	0	8.27	0	0	0.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0.7	35	0	4.8	0	0	0	0	0	32.9	1.87	0	100
56	0	0	0.13	0	0	0	20.4	0	5.47	0	0	0	0	0	0	0.7	0	0	0	0	0.1	0	0	0	0.4	0	11	0	6.7	0	0	0	0	0	54.7	0.13	0	100
57	0	0	0	0	0.13	0	50.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.4	0	0	0	0	0	21.1	27.9	0	100
58	0	0	0.93	0	2.4	0	16.0	7.07	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.3	0	0	0	0	0	29.7	41.6	0	100
59	0	0	3.87	0	0	0	12.9	0	2.53	0.4	0	0	0	0	0	0	0	0	0.1	0	0	0	0	0	0.8	0.1	23	0	1.5	0	0	0	0	0	50	4.67	0	100
60	0	0	0	0	0	0	62.9	20.1	2.4	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0.1	1.6	0	5.9	2.3	0	1.6	0	0	0	0	0	1.47	1.33	0.1	100
61	0	0	0	0	0	0	0.53	0	1.87	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.5	1.1	83	0	6.7	0	0	0	0	0	1.07	3.07	0	100
62	0	0.1	0	10.5	0	0	7.33	0	3.87	0	0	0	0	0	0	0	0	0	0	0	0	0.3	0	0	4.8	0	60	0	1.6	0	0	0	0	0	7.07	4.27	0	100
63	0	1.2	0	0	0	0	3.33	1.73	1.47	0	17	0	0	0	0.3	0	0	1.1	0	0	0	0	0	0.4	4.9	0	64	0	4	0	0	0	0	0	0.27	0.13	0	100
64	0	0	1	0	0.29	0	5.86	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0	0	0	92.7	0	0	100
65	0	0	0	0	0	0	60.5	27.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0.5	0.1	0	1.1	0	0	0	0	0	9.47	0.8	0	100
66	0	0	0	0	0.14	0	7.86	0.14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	91.7	0.14	0	100
67	0	0	0.0	0	2.0	0	53.5	1.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0.3	0	0	0	0.3	0	0	1.3	0	0	0.0	0.0	0	17.9	23.7	0	100

TABLE 3. Point count and percent cover of general classes of benthic cover on 67 transects within four strata in the CVN study area of Apra Harbor.

DIRECT FLAT

POINT COUNTS								PERCENT COVER						
Transect	Algae	Coral	Echino.	SoftCor	Sponge	Sediment	Total	Algae	Coral	Echino.	SoftCor	Sponge	Sediment	Total
5	66	532	0	0	133	19	750	8.8	70.9	0	0	17.7	2.5	100
11	696	0	0	0	23	31	750	92.8	0	0	0	3.1	4.1	100
23	475	115	0	0	43	115	748	63.5	15.4	0	0	5.7	15.4	100
25	464	30	0	0	6	250	750	61.9	4.0	0	0	0.8	33.3	100
26	617	36	0	0	9	88	750	82.3	4.8	0	0	1.2	11.7	100
31	459	230	0	0	16	44	749	61.3	30.7	0	0	2.1	5.9	100
32	31	6	0	0	0	713	750	4.1	0.8	0	0	0	95.1	100
34	411	48	0	0	17	274	750	54.8	6.4	0	0	2.3	36.5	100
35	166	0	0	0	0	534	700	23.7	0	0	0	0	76.3	100
38	2	0	0	4	0	644	650	0.3	0	0	0.6	0	99.1	100
39	554	41	0	0	1	154	750	73.9	5.5	0	0	0.1	20.5	100
40	211	121	0	0	7	411	750	28.1	16.1	0	0	0.9	54.8	100
42	7	0	0	0	0	643	650	1.1	0	0	0	0	98.9	100
43	370	260	0	0	13	107	750	49.3	34.7	0	0	1.7	14.3	100
46	196	149	0	0	3	402	750	26.1	19.9	0	0	0.4	53.6	100
47	471	5	0	0	0	274	750	62.8	0.7	0	0	0	36.5	100
50	620	0	0	0	4	126	750	82.7	0	0	0	0.5	16.8	100
54	161	0	0	0	18	571	750	21.5	0	0	0	2.4	76.1	100
57	380	0	0	0	3	367	750	50.7	0	0	0	0.4	48.9	100
59	145	184	0	0	11	410	750	19.3	24.5	0	0	1.5	54.7	100
62	164	489	0	0	12	85	750	21.9	65.2	0	0	1.6	11.3	100
Subtotal	6666	2246	0	4	319	6262	15497	43.0	14.5	0	0	2.1	40.4	100

DIRECT SLOPE

POINT COUNTS								PERCENT COVER						
Transect	Algae	Coral	Echino.	SoftCor	Sponge	Sediment	Total	Algae	Coral	Echino.	SoftCor	Sponge	Sediment	Total
4	277	385	0	0	44	44	750	36.9	51.3	0	0	5.9	5.9	100
10	536	6	2	0	8	98	650	82.5	0.9	0.3	0	1.2	15.1	100
12	749	0	0	0	0	1	750	99.9	0	0	0	0	0.1	100
14	254	361	0	0	24	109	748	34.0	48.3	0	0	3.2	14.6	100
21	377	156	0	0	7	210	750	50.3	20.8	0	0	0.9	28.0	100
22	669	25	0	0	4	52	750	89.2	3.3	0	0	0.5	6.9	100
27	403	13	0	0	8	326	750	53.7	1.7	0	0	1.1	43.5	100
33	286	12	0	0	4	448	750	38.1	1.6	0	0	0.5	59.7	100
37	52	0	0	0	1	197	250	20.8	0	0	0	0.4	78.8	100
44	541	19	0	0	6	184	750	72.1	2.5	0	0	0.8	24.5	100
45	499	158	0	0	13	80	750	66.5	21.1	0	0	1.7	10.7	100
48	278	45	0	0	0	427	750	37.1	6	0	0	0	56.9	100
49	141	361	0	0	26	222	750	18.8	48.1	0	0	3.5	29.6	100
51	560	3	0	0	4	83	650	86.2	0.5	0	0	0.6	12.8	100
52	64	0	0	0	19	667	750	8.5	0	0	0	2.5	88.9	100
53	0	0	0	0	0	600	600	0	0	0	0	0	100	100
55	176	277	0	0	36	261	750	23.5	36.9	0	0	4.8	34.8	100
58	198	0	0	0	17	535	750	26.4	0	0	0	2.3	71.3	100
Subtotal	6060	1821	2	0	221	4544	12648	47.9	14.4	0	0	1.7	35.9	100

INDIRECT FLAT

POINT COUNTS								PERCENT COVER						
Transect	Algae	Coral	Echino.	SoftCor	Sponge	Sediment	Total	Algae	Coral	Echino.	SoftCor	Sponge	Sediment	Total
2	550	81	8	0	61	50	750	73.3	10.8	1.1	0	8.1	6.7	100
3	176	8	0	0	17	349	550	32.0	1.5	0	0	3.1	63.5	100
6	181	469	0	0	99	0	749	24.2	62.6	0	0	13.2	0	100
7	136	516	1	13	3	81	750	18.1	68.8	0.1	1.7	0.4	10.8	100
9	401	163	0	0	177	9	750	53.5	21.7	0	0	23.6	1.2	100
13	202	462	0	0	27	59	750	26.9	61.6	0	0	3.6	7.9	100
16	97	14	0	0	10	629	750	12.9	1.9	0	0	1.3	83.9	100
18	397	203	0	0	11	139	750	52.9	27.1	0	0	1.5	18.5	100
24	246	30	1	0	0	473	750	32.8	4	0.1	0	0	63.1	100
29	241	304	0	0	0	205	750	32.1	40.5	0	0	0	27.3	100
36	24	0	0	0	5	721	750	3.2	0	0	0	0.7	96.1	100
56	195	94	0	0	50	411	750	26.0	12.5	0	0	6.7	54.8	100
60	641	75	0	0	12	22	750	85.5	10	0	0	1.6	2.9	100
Subtotal	3487	2419	10	13	472	3148	9549	36.5	25.3	0.1	0.1	4.9	33	100

INDIRECT SLOPE

POINT COUNTS								PERCENT COVER						
Transect	Algae	Coral	Echino.	SoftCor	Sponge	Sediment	Total	Algae	Coral	Echino.	SoftCor	Sponge	Sediment	Total
1	66	289	0	0	112	83	550	12.0	52.5	0	0	20.4	15.1	100
8	121	495	0	0	76	58	750	16.1	66.0	0	0	10.1	7.7	100
15	83	514	0	0	49	104	750	11.1	68.5	0	0	6.5	13.9	100
17	275	108	0	0	44	323	750	36.7	14.4	0	0	5.9	43.1	100
19	257	387	0	0	16	90	750	34.3	51.6	0	0	2.1	12	100
20	677	25	0	0	8	40	750	90.3	3.3	0	0	1.1	5.3	100
28	38	634	0	0	0	78	750	5.1	84.5	0	0	0	10.4	100
30	102	395	0	65	1	187	750	13.6	52.7	0	8.7	0.1	24.9	100
41	455	6	0	0	41	198	700	65.0	0.9	0	0	5.9	28.3	100
61	18	651	0	0	50	31	750	2.4	86.8	0	0	6.7	4.1	100
63	58	659	0	0	30	3	750	7.7	87.9	0	0	4.0	0.4	100
64	50	0	0	0	1	649	700	7.1	0	0	0	0.1	92.7	100
65	659	6	0	0	8	77	750	87.9	0.8	0	0	1.1	10.3	100
66	57	0	0	0	0	643	700	8.1	0	0	0	0	91.9	100
67	426	2	0	0	10	312	750	56.8	0.3	0	0	1.3	41.6	100
Subtotal	3342	4171	0	65	446	2876	10900	30.7	38.3	0	0.6	4.1	26.4	100

ALL STRATA

POINT COUNTS								PERCENT COVER						
Transect	Algae	Coral	Echino.	SoftCor	Sponge	Sediment	Total	Algae	Coral	Echino.	SoftCor	Sponge	Sediment	Total
1-67	19555	10657	12	82	1458	16830	48594	40.2	21.9	0	0.2	3.0	34.6	100

TABLE 4. Prevalence of all coral species identified in photo-quadrats ranked in decreasing order from in point counts from photo-quadrat transect data collected in the CVN survey area.

Coral Species	Count	Fraction	Percentage	Cumulative Pecentage
Porites rus	7935	0.745	74.458	74.458
Porites lutea	959	0.090	8.999	83.457
Pavona cactus	849	0.080	7.967	91.423
Porites cylindrica	409	0.038	3.838	95.261
Acropora aspera	147	0.014	1.379	96.641
Acropora nasuta	130	0.012	1.220	97.861
Herpolitha limax	69	0.006	0.647	98.508
Pachyseris speciosa	35	0.003	0.328	98.836
Astreopora myriophthalma	26	0.002	0.244	99.080
Lobophyllia corymbosa	25	0.002	0.235	99.315
Pocillopora damicornis	24	0.002	0.225	99.540
Lobophyllia hemprichii	17	0.002	0.160	99.700
Acrhelia horrescens	12	0.001	0.113	99.812
Astreopora randalli	5	0.000	0.047	99.859
Fungia echinata	5	0.000	0.047	99.906
Montipora verrucosa	4	0.000	0.038	99.944
Pavona varians	4	0.000	0.038	99.981
Lobophyllia (cf.) hataii	2	0.000	0.019	100.000
TOTAL CORAL POINTS	10657			

TABLE 5. Mean percent benthic cover of clusters derived from Bray-Curtis similarity indices. Top table shows means for six general classes shown in Figure 22. Bottom table shows means for ten detailed classes shown in Figure 23. Note that the values for the detailed clusters do not add to 100% owing to cover of the various uncommon classes that were not included in the 10 detailed groups. For example, in cluster 16, the 10 classes only sum to ~56%. This cluster contains a single transect (#9) that had a very high cover of *A. aspera* , which is not in the subset of 10 detailed classes because it only occurs on this single transect. However, the relatively high cover of turf algae on this transect resulted in separation to a unique cluster.

GENERAL

Cluster	Algae	Coral	Echinoderm	Soft Coral	Sponge	Sediment	TOTAL
1	10.6	0.2	0	0	0.7	88.4	100
2	30.7	11.2	0	0	2.1	56.0	100
3	58.8	22.8	0.1	0	5.7	12.6	100
4	87.9	2.4	0	0	1.1	8.6	100
5	61.3	2.4	0	0	1.4	34.9	100
6	14.0	70.5	0	0.2	7.7	7.7	100
7	27.6	47.1	0	1.2	2.8	21.3	100

DETAILED

Cluster	Mud/Sand	*Porites rus*	Mixed Algae	*Halimeda sp.*	Rubble	*Porites lutea*	*Padina sp.*	Cyanobacteria	Turf Algae	*Pavona cactus*	TOTAL
1	97.0	0.1	1.8	0	0	0	0	0.7	0.1	0	100
2	78.5	0	11.2	0	0.3	0.5	3.8	4.3	0.3	0	99
3	55.2	8.1	20.1	2.9	1.6	1.0	0	1.0	2.9	0	93
4	31.5	1.1	12.1	3.7	28.5	2.2	1.7	12.3	2.5	0	96
5	8.6	4.1	51.6	8.3	1.5	0.3	0.2	12.6	5.2	0	92
6	17.1	3.9	65.7	6.6	0.3	0.5	0	0.2	1.1	0	95
7	5.5	1.2	61.7	0	1.1	3.2	23.7	0	1.2	0.1	98
8	34.2	2.3	45.9	0.5	2.0	0	0	1.7	3.9	0	91
9	19.5	0	52	1.1	25.8	0.1	0.7	0	0	0	99
10	11.0	23.8	37.6	0.5	4.5	0.3	0.5	1.5	5.8	0.5	86
11	9.0	0.8	44.2	33.3	1	0	0	0.4	0.2	1.2	90
12	8.0	37.4	13.5	6.6	5.6	0.2	0	0.2	12.2	7.5	91
13	3.0	69.8	2.8	0.3	2.6	0.2	4.9	0	2.8	0.2	87
14	12.4	23.3	7.9	0	1.1	0	0	0	3.2	42.8	91
15	16.1	19.5	7.6	1.4	2.2	30.9	0.5	0.5	9.8	0	89
16	0.1	2.3	14.3	4.0	0.3	0	0.8	0	34.3	0	56

Table 6a. Confusion matrix for satellite-derived habitat map of CVN survey area. Values are counts of pixels. Diagonal values represent correct classifications; off-diagonal values are misclassifications. To read the table, find the column of the ACTUAL CLASS of interest, then find the row of the PREDICTED CLASS to see how often the former is predicted to be the latter.

		ACTUAL CLASSES					
		coral = 0%	0% < coral ≤ 10%	10% < coral ≤ 30%	30% < coral ≤ 50%	50% < coral ≤ 70%	70% < coral ≤ 90%
PREDICTED CLASSES	coral = 0%	**1508**	85	51	11	15	25
	0% < coral ≤ 10%	80	**129**	45	9	12	6
	10% < coral ≤ 30%	39	34	**59**	15	15	19
	30% < coral ≤ 50%	8	1	5	**42**	16	0
	50% < coral ≤ 70%	10	26	12	25	**127**	10
	70% < coral ≤ 90%	15	1	1	1	5	**33**

Table 6b. Confusion matrix for satellite-derived habitat map of CVN survey area. Values are classification rates (units %). Diagonal values represent correct classifications; off-diagonal values are misclassifications. To read the table, find the column of the ACTUAL CLASS of interest, then find the row of the PREDICTED CLASS to see the rate at which the former is predicted to be the latter. This table evaluates the ability of the classification algorithm to assign observations into appropriate classes (the so-called "producer's accuracy"). For example, 46.7% of the time, the class "0% < coral ≤ 10%" is accurately predicted to be "0% < coral ≤ 10%." Conversely, 12.3% of the time, the same class is incorrectlypredicted to be "10% < coral ≤ 30%."

		ACTUAL CLASSES					
		coral = 0%	0% < coral ≤ 10%	10% < coral ≤ 30%	30% < coral ≤ 50%	50% < coral ≤ 70%	70% < coral ≤ 90%
PREDICTED CLASSES	coral = 0%	**90.8**	30.8	29.5	10.7	7.9	26.9
	0% < coral ≤ 10%	4.8	**46.7**	26	8.7	6.3	6.5
	10% < coral ≤ 30%	2.3	12.3	**34.1**	14.6	7.9	20.4
	30% < coral ≤ 50%	0.5	0.4	2.9	**40.8**	8.4	0
	50% < coral ≤ 70%	0.6	9.4	6.9	24.3	**66.8**	10.8
	70% < coral ≤ 90%	0.9	0.4	0.6	1	2.6	**35.5**

Table 6c. Confusion matrix for satellite-derived habitat map of CVN survey area. Values are observation rates (units %). Diagonal values represent correct classifications; off-diagonal values are misclassifications. To read the table, find the row of the PREDICTED CLASS of interest, then find the column of the ACTUAL CLASS to see the rate at which the former represents the latter. This table evaluates how well the classification product - i.e., the map - represents reality on the ground (the so-called "user's accuracy"). For example, 45.9% of the time, observations predicted as "0% < coral ≤ 10%" are actually that class. Conversely, 16% of the time, observations predicted to be that class are actually "10% < coral ≤ 30%." The rates in this table allow for adjustment of class area estimates.

		ACTUAL CLASSES					
		coral = 0%	0% < coral ≤ 10%	10% < coral ≤ 30%	30% < coral ≤ 50%	50% < coral ≤ 70%	70% < coral ≤ 90%
PREDICTED CLASSES	coral = 0%	**89**	5	3	0.6	0.9	1.5
	0% < coral ≤ 10%	28.5	**45.9**	16	3.2	4.3	2.1
	10% < coral ≤ 30%	21.5	18.8	**32.6**	8.3	8.3	10.5
	30% < coral ≤ 50%	11.1	1.4	6.9	**58.3**	22.2	0
	50% < coral ≤ 70%	4.8	12.4	5.7	11.9	**60.5**	4.8
	70% < coral ≤ 90%	26.8	1.8	1.8	1.8	8.9	**58.9**

TABLE 7. Coral cover for Direct and Indirect strata of SRF and Polaris Pt. alternatives of CVN project, Apra Harbor Guam derived from corrected classified habitat map using Quickbird satellite image. Coral cover is shown as area of 6 classes in top tables, and as weighted sums in bottom tables.

AREA (i.e., number of pixels multiplied by 5.76 m²/pixel)

Coral Level	SRF					
	DIRECT		INDIRECT		TOTAL	
	m^2	acres	m^2	acres	m^2	acres
coral = 0%	149,841	37.03	189,026	46.71	338,867	83.74
0% < coral ≤ 10%	34,445	8.51	53,436	13.20	87,880	21.72
10% < coral ≤ 30%	24,123	5.96	37,204	9.19	61,327	15.15
30% < coral ≤ 50%	9,274	2.29	34,502	8.53	43,776	10.82
50% < coral ≤ 70%	18,190	4.49	44,628	11.03	62,819	15.52
70% < coral ≤ 90%	10,051	2.48	21,266	5.25	31,317	7.74
TOTAL W/CORAL	**96,083**	**23.74**	**191,036**	**47.21**	**287,119**	**70.95**

Coral Level	POLARIS PT.					
	DIRECT		INDIRECT		TOTAL	
	m^2	acres	m^2	acres	m^2	acres
coral = 0%	186,065	45.98	219,997	54.36	406,063	100.34
0% < coral ≤ 10%	37,411	9.24	54,541	13.48	91,953	22.72
10% < coral ≤ 30%	26,058	6.44	38,523	9.52	64,581	15.96
30% < coral ≤ 50%	9,590	2.37	32,527	8.04	42,117	10.41
50% < coral ≤ 70%	17,960	4.44	41,898	10.35	59,858	14.79
70% < coral ≤ 90%	10,950	2.71	19,642	4.85	30,591	7.56
TOTAL W/CORAL	**101,969**	**25.20**	**187,131**	**46.24**	**289,100**	**71.44**

WEIGHTED SUMS

Coral Level	SRF					
	DIRECT		INDIRECT		TOTAL	
	m^2	acres	m^2	acres	m^2	acres
5%	1,722	0.43	2,672	0.66	4,394	1.09
20%	4,825	1.19	7,441	1.84	12,265	3.03
40%	3,709	0.92	13,801	3.41	17,510	4.33
60%	10,914	2.70	26,777	6.62	37,691	9.31
80%	8,041	1.99	17,013	4.20	25,054	6.19
TOTAL	**29,211**	**7.22**	**67,703**	**16.73**	**96,915**	**23.95**

Coral Level	POLARIS PT.					
	DIRECT		INDIRECT		TOTAL	
	m^2	acres	m^2	acres	m^2	acres
5%	1,871	0.46	2,727	0.67	4,598	1.14
20%	5,212	1.29	7,705	1.90	12,916	3.19
40%	3,836	0.95	13,011	3.21	16,847	4.16
60%	10,776	2.66	25,139	6.21	35,915	8.87
80%	8,760	2.16	15,713	3.88	24,473	6.05
TOTAL	**30,454**	**7.53**	**64,295**	**15.89**	**94,749**	**23.41**

Table 8. Normalized Difference Vegetation Index (NDVI) for *Porites rus* and *P. lutea* in CVN survey area of Apra Harbor. Each row in the table represents an individual coral colony. Mean spectral reflectance R(λ) for each colony was calculated from 15-20 measurements.NDVI was calculated as [R(720) - R(673)] / [R(720) + R(673)]. NDVI is a relative index that increases with increasing chlorophyll content to a maximum value of one.

DIRECT - FLAT

TRANSECT	SPECIES	DEPTH (m)	NDVI
5	*Porites rus*	18.0	0.603
5	*Porites rus*	18.0	0.727
5	*Porites rus*	18.0	0.641
5	*Porites lutea*	18.0	0.692
5	*Porites rus*	18.0	0.674
5	*Porites rus*	18.0	0.737
25	*Porites lutea*	15.2	0.657
25	*Porites lutea*	15.2	0.677
25	*Porites lutea*	15.2	0.622
25	*Porites rus*	15.2	0.665
25	*Porites rus*	15.2	0.523
25	*Porites lutea*	15.2	0.652
26	*Porites rus*	14.9	0.679
26	*Porites rus*	14.9	0.616
26	*Porites rus*	14.9	0.549
26	*Porites rus*	14.9	0.646
26	*Porites rus*	14.9	0.615
31	*Porites rus*	16.8	0.717
31	*Porites lutea*	16.8	0.818
31	*Porites rus*	16.8	0.729
31	*Porites rus*	16.8	0.633
31	*Porites rus*	16.8	0.696
32	*Porites lutea*	14.6	0.708
32	*Porites lutea*	14.6	0.807
32	*Porites lutea*	14.6	0.802
32	*Porites lutea*	14.6	0.762
32	*Porites lutea*	14.6	0.832
32	*Porites lutea*	14.6	0.647
40	*Porites lutea*	14.6	0.829
40	*Porites lutea*	14.6	0.702
40	*Porites lutea*	14.6	0.580
40	*Porites lutea*	14.6	0.766
43	*Porites rus*	14.0	0.528
43	*Porites rus*	14.0	0.741
43	*Porites lutea*	14.0	0.742
43	*Porites rus*	14.0	0.551
43	*Porites rus*	14.0	0.683
46	*Porites rus*	15.2	0.578
46	*Porites rus*	15.2	0.631
46	*Porites lutea*	15.2	0.678
46	*Porites lutea*	15.2	0.756

DIRECT - SLOPE

TRANSECT	SPECIES	DEPTH (m)	NDVI
14	*Porites rus*	16.2	0.586
14	*Porites lutea*	16.2	0.716
14	*Porites rus*	16.2	0.673
14	*Porites lutea*	16.2	0.575
14	*Porites rus*	16.2	0.660
21	*Porites lutea*	16.5	0.768
21	*Porites rus*	16.5	0.596
21	*Porites rus*	16.5	0.648
21	*Porites lutea*	16.5	0.799
21	*Porites lutea*	16.5	0.676
22	*Porites rus*	15.2	0.681
22	*Porites rus*	15.2	0.688
22	*Porites rus*	15.2	0.669
22	*Porites rus*	15.2	0.586
22	*Porites rus*	15.2	0.619
44	*Porites rus*	14.9	0.622
44	*Porites lutea*	14.9	0.658
44	*Porites lutea*	14.9	0.516
44	*Porites rus*	14.9	0.649
44	*Porites rus*	14.9	0.613
44	*Porites lutea*	14.9	0.768
45	*Porites lutea*	14.9	0.719
45	*Porites rus*	14.9	0.612
45	*Porites rus*	14.9	0.628
45	*Porites rus*	14.9	0.536
45	*Porites lutea*	14.9	0.492
51	*Porites lutea*	3.7	0.632
51	*Porites lutea*	3.0	0.518
51	*Porites lutea*	2.7	0.599
51	*Porites lutea*	4.0	0.521
51	*Porites rus*	3.4	0.585
51	*Porites lutea*	4.6	0.661
53	*Porites lutea*	18.3	0.717
53	*Porites lutea*	18.3	0.633
53	*Porites lutea*	18.3	0.728
53	*Porites lutea*	18.3	0.705
53	*Porites lutea*	18.3	0.732

INDIRECT - FLAT

TRANSECT	SPECIES	DEPTH (m)	NDVI
2	*Porites rus*	16.2	0.608
2	*Porites rus*	16.2	0.692
2	*Porites rus*	16.2	0.687
2	*Porites rus*	16.2	0.575
2	*Porites lutea*	16.2	0.777
18	*Porites rus*	16.5	0.737
18	*Porites rus*	16.5	0.562
18	*Porites rus*	16.5	0.547
18	*Porites lutea*	16.5	0.682
18	*Porites lutea*	16.5	0.726
18	*Porites rus*	16.5	0.686
24	*Porites lutea*	0.9	0.653
24	*Porites lutea*	0.9	0.647
24	*Porites lutea*	0.9	0.625
24	*Porites lutea*	0.9	0.649
24	*Porites lutea*	0.9	0.618
29	*Porites lutea*	0.9	0.575
29	*Porites lutea*	0.9	0.667
29	*Porites lutea*	0.9	0.702
29	*Porites lutea*	0.9	0.608
29	*Porites lutea*	0.9	0.727
29	*Porites rus*	0.9	0.425
56	*Porites rus*	16.8	0.720
56	*Porites rus*	16.8	0.663
56	*Porites rus*	16.8	0.634
56	*Porites lutea*	16.8	0.757
56	*Porites rus*	16.8	0.542
60	*Porites lutea*	0.9	0.776
60	*Porites lutea*	0.9	0.558
60	*Porites lutea*	0.9	0.727
60	*Porites rus*	0.9	0.610
60	*Porites lutea*	0.9	0.729
60	*Porites rus*	0.9	0.663

INDIRECT - SLOPE

TRANSECT	SPECIES	DEPTH (m)	NDVI
15	*Porites lutea*	13.7	0.437
15	*Porites lutea*	13.7	0.612
15	*Porites rus*	13.7	0.577
15	*Porites rus*	13.7	0.647
15	*Porites lutea*	12.2	0.527
15	*Porites rus*	12.8	0.732
15	*Porites lutea*	12.2	0.760
15	*Porites lutea*	12.8	0.689
15	*Porites rus*	12.8	0.637
15	*Porites rus*	13.1	0.670
15	*Porites lutea*	12.2	0.722
15	*Porites rus*	12.2	0.687
15	*Porites rus*	11.6	0.608
17	*Porites lutea*	2.4	0.525
17	*Porites lutea*	2.4	0.556
17	*Porites rus*	2.4	0.635
17	*Porites rus*	2.4	0.588
17	*Porites lutea*	2.4	0.522
17	*Porites rus*	2.4	0.588
17	*Porites lutea*	2.4	0.608
19	*Porites rus*	15.2	0.658
19	*Porites rus*	15.2	0.796
19	*Porites rus*	15.2	0.842
19	*Porites rus*	15.2	0.719
19	*Porites rus*	15.2	0.680
19	*Porites rus*	15.2	0.673
30	*Porites lutea*	3.7	0.602
30	*Porites rus*	3.7	0.649
30	*Porites lutea*	3.7	0.630
30	*Porites rus*	3.7	0.621
30	*Porites lutea*	3.7	0.606
30	*Porites rus*	3.7	0.555
30	*Porites rus*	3.7	0.586
41	*Porites rus*	12.8	0.685
41	*Porites lutea*	12.8	0.660
41	*Porites rus*	12.8	0.716
41	*Porites rus*	12.8	0.673
41	*Porites lutea*	12.8	0.697
65	*Porites lutea*	2.1	0.533
65	*Porites lutea*	2.1	0.715
65	*Porites lutea*	2.1	0.638
65	*Porites lutea*	2.1	0.609

TABLE 9. Mean (SE) density of mobile invertebrates (individuals per100 m^2) by strata.

			STRATA			
Phylum	**Genus**	**Species**	**Direct-Flat**	**Direct-Slope**	**Indirect-Flat**	**Indirect-Slope**
Cnidaria	Boloceroides	mcmurrichi	0.05 (0.01)	0 (0)	0 (0)	0 (0)
Cnidaria Total			0.05 (0.01)	0 (0)	0 (0)	0 (0)
Crustacea	Alpheus	sp.	0 (0)	0 (0)	0 (0)	0.07 (0.02)
	Calcinus	minutus	0.15 (0.03)	0.31 (0.08)	0.75 (0.22)	0.21 (0.06)
		pulcher	0.05 (0.01)	0.38 (0.1)	0.33 (0.1)	1 (0.27)
		spp.	0.1 (0.02)	0.13 (0.03)	0.75 (0.22)	0.93 (0.25)
	crab	sp.	0 (0)	0 (0)	0 (0)	0.07 (0.02)
		sp. (blue)	0.05 (0.01)	0 (0)	0 (0)	0 (0)
	Dardanus	guttatus	0 (0)	0 (0)	0.17 (0.05)	0 (0)
	Palaemonid	sp.	0 (0)	0 (0)	0 (0)	0.07 (0.02)
	Periclimenes	soror	0.05 (0.01)	0 (0)	0.08 (0.02)	0 (0)
	Saron	marmoratus	0 (0)	0.06 (0.02)	0 (0)	0 (0)
	seethrough shrimp	(blank)	0.2 (0.04)	0.13 (0.03)	0 (0)	0.14 (0.04)
	shrimp	sp. (clear)	0 (0)	0.06 (0.02)	0 (0)	0 (0)
		sp. (goby)	0.05 (0.01)	0 (0)	0.58 (0.17)	0 (0)
Crustacea Total			0.65 (0.15)	1.06 (0.27)	2.67 (0.77)	2.5 (0.67)
Echinodermata	Actinpyga	mauritiana	0 (0)	0 (0)	0.08 (0.02)	0 (0)
	Bohadschia	argus	0.05 (0.01)	0 (0)	0.33 (0.1)	0.14 (0.04)
	Culcita	novaeguineae	0.35 (0.08)	0.19 (0.05)	0.17 (0.05)	0.07 (0.02)
	Echinaster	luzonicus	0 (0)	0.06 (0.02)	0 (0)	0 (0)
	Echinometra	mathei	0.05 (0.01)	0.06 (0.02)	0.42 (0.12)	0.29 (0.08)
	Echinostrephus	aciculatus	0 (0)	0 (0)	0.92 (0.27)	0.14 (0.04)
	Echinothrix	sp.	0 (0)	0 (0)	0.08 (0.02)	0 (0)
	Euapta	godeffroyi	0 (0)	0.06 (0.02)	0 (0)	0 (0)
	Holothuria	atra	0 (0)	0 (0)	1.75 (0.51)	0.79 (0.21)
	Linkia	laevigata	0 (0)	0 (0)	0 (0)	0.14 (0.04)
		multifera	0 (0)	0 (0)	0.17 (0.05)	0.07 (0.02)
	Ophiocoma	sp.	0 (0)	0 (0)	0 (0)	0.07 (0.02)
	Ophiomastix	caryophyllata	0 (0)	0.25 (0.06)	0 (0)	0.07 (0.02)
	Ophiurid	sp.1	2.15 (0.48)	0.06 (0.02)	0 (0)	0.14 (0.04)
		sp.2 (small)	0.05 (0.01)	0 (0)	0 (0)	0 (0)
	Pearsonothuria	graeffei	0 (0)	0.19 (0.05)	0 (0)	0.07 (0.02)
Echinodermata Total			2.65 (0.59)	0.88 (0.22)	3.92 (1.13)	2 (0.53)
Mollusca	Cerithium	columna	1.4 (0.31)	2.44 (0.61)	2.67 (0.77)	1.43 (0.38)
	Chromodoris	fidelis	0.05 (0.01)	0 (0)	0 (0)	0 (0)
	Clypeomorus	nympha	0.4 (0.09)	0 (0)	0.42 (0.12)	2.36 (0.63)
	Coralliophila	violacea	1.5 (0.34)	1.69 (0.42)	5.83 (1.68)	14 (3.74)
	Cymatium	nicobaricum	0 (0)	0 (0)	0 (0)	0.07 (0.02)
		sp.	0 (0)	0 (0)	0.08 (0.02)	0 (0)
	Cypraea	contaminata	0 (0)	0 (0)	0 (0)	0.07 (0.02)
		erosa	0 (0)	0 (0)	0 (0)	0.07 (0.02)
		mappa	0 (0)	0.06 (0.02)	0 (0)	0 (0)
	Euplica	deshayesii	0.35 (0.08)	0.19 (0.05)	9 (2.6)	0.36 (0.1)
	Glossodoris	atromarginata	0.05 (0.01)	0 (0)	0 (0)	0.14 (0.04)
	Habromorula	spinosa	0 (0)	0.75 (0.19)	0.17 (0.05)	0.64 (0.17)
	Hypselodoris	whitei	0 (0)	0 (0)	0 (0)	0.07 (0.02)
	Lambis	lambis	0.1 (0.02)	0.13 (0.03)	0.08 (0.02)	0.07 (0.02)
	Mitra	sp.	0 (0)	0.06 (0.02)	0 (0)	0 (0)
	Nerita	sp.	0 (0)	0 (0)	0.08 (0.02)	0 (0)
	Noumea	angustolutea	0 (0)	0.06 (0.02)	0 (0)	0 (0)
	Pteraeolidia	ianthina	0 (0)	0 (0)	0 (0)	0.07 (0.02)
	snail	spp.	0.05 (0.01)	0 (0)	0 (0)	0 (0)
	Strombus	gibberulus	0 (0)	0.06 (0.02)	0.17 (0.05)	0 (0)
		luhuanus	4.9 (1.1)	0 (0)	0.25 (0.07)	0.14 (0.04)
	Thais	sp.	0 (0)	0 (0)	0.08 (0.02)	0 (0)
	Trochus	niloticus	0 (0)	0 (0)	0.42 (0.12)	0 (0)
	Vasum	turbinellus	0 (0)	0 (0)	0 (0)	0.07 (0.02)
Mollusca Total			8.8 (1.97)	5.44 (1.36)	19.25 (5.56)	19.57 (5.23)
Platyhelminthes	flatworm	sp.	0 (0)	0.06 (0.02)	0 (0)	0 (0)
Platyhelminthes Total			0 (0)	0.06 (0.02)	0 (0)	0 (0)
Grand Total			12.15 (2.72)	7.44 (1.86)	25.83 (7.46)	24.07 (6.43)

TABLE 10. Mean (SE) density of sessile invertebrates (individuals per 25 m^2) by strata.

			STRATA			
Phylum	Genus	Species	Direct-Flat	Direct-Slope	Indirect-Flat	Indirect-Slope
ASCIDIA	Ascidia	sp.	0.1 (0.02)	0.06 (0.02)	0.08 (0.02)	0.14 (0.04)
	Clavelina	moluccensis	1.35 (0.3)	0.69 (0.17)	0.08 (0.02)	0 (0)
	Lissoclinum	calycis	0.05 (0.01)	0 (0)	0.08 (0.02)	0.21 (0.06)
	Phallusia	julinea	2.95 (0.66)	3.94 (0.99)	3.5 (1.01)	10.43 (2.79)
	Polycarpa	sp.	0.7 (0.16)	0.75 (0.19)	0.83 (0.24)	1.71 (0.46)
	Rhopalaea	crassa	0.65 (0.15)	0.88 (0.22)	0.92 (0.27)	2 (0.53)
		sp.	3.8 (0.85)	5.56 (1.39)	3.75 (1.08)	6.29 (1.68)
ASCIDIA Total			9.6 (2.15)	11.88 (2.97)	9.25 (2.67)	20.79 (5.56)
MOLLUSCA	Pinctada	sp.	0.4 (0.09)	0.56 (0.14)	0.83 (0.24)	0.86 (0.23)
MOLLUSCA Total			0.4 (0.09)	0.56 (0.14)	0.83 (0.24)	0.86 (0.23)
POLYCHEATA	Sabellastarte	indica	0 (0)	0 (0)	0 (0)	0.43 (0.11)
POLYCHEATA Total			0 (0)	0 (0)	0 (0)	0.43 (0.11)
PORIFERA	Aplysinella	rhax	7.95 (1.78)	14.38 (3.6)	10.5 (3.03)	7.57 (2.02)
	Axinella	sp.	0 (0)	0 (0)	0.67 (0.19)	0.07 (0.02)
	Axynissa	sp.	2.75 (0.61)	4.81 (1.2)	3.92 (1.13)	3.57 (0.95)
	Callyspongia	diffusa	3.6 (0.8)	6.38 (1.6)	0.33 (0.1)	1.64 (0.44)
		sp.	0.45 (0.1)	0.06 (0.02)	0.58 (0.17)	0.71 (0.19)
	Ceratopsion	sp.	4.1 (0.92)	2.56 (0.64)	3.17 (0.92)	1.93 (0.52)
	Chelonaplysilla	sp.	0.05 (0.01)	0.19 (0.05)	0 (0)	0.14 (0.04)
	Cinachyra	sp.	0.05 (0.01)	0.13 (0.03)	0.08 (0.02)	0.29 (0.08)
	Clathria	basilana	0.85 (0.19)	0.13 (0.03)	0.08 (0.02)	1.64 (0.44)
		eurypa	4.25 (0.95)	5.69 (1.42)	6.08 (1.76)	3 (0.8)
		hirsuta	0.05 (0.01)	0.94 (0.24)	0.42 (0.12)	0.71 (0.19)
		mima	0.3 (0.07)	0.81 (0.2)	0.58 (0.17)	0.64 (0.17)
		sp.	0.1 (0.02)	0.19 (0.05)	0.17 (0.05)	0.36 (0.1)
	Corticum	sp.	0.05 (0.01)	0.5 (0.13)	0.08 (0.02)	0.57 (0.15)
	Craniella	abracadabra	0 (0)	0.06 (0.02)	0 (0)	0 (0)
	Dragmacidon	sp.	2.05 (0.46)	2 (0.5)	0.25 (0.07)	4.5 (1.2)
		(blank)	0.25 (0.06)	0 (0)	0 (0)	0 (0)
	Dysidea	sp.	0.2 (0.04)	0.38 (0.1)	0.33 (0.1)	0.93 (0.25)
	Haliclona	(Reniera)	3.4 (0.76)	6.19 (1.55)	2.08 (0.6)	4.71 (1.26)
		sp. (blue)	3.65 (0.82)	2.5 (0.63)	3.25 (0.94)	7.43 (1.99)
	Hyrtios	altum	0.05 (0.01)	0.06 (0.02)	1.17 (0.34)	1.79 (0.48)
		erecta	0 (0)	0.06 (0.02)	0.42 (0.12)	0 (0)
	Ianthella	basta	0.35 (0.08)	1.75 (0.44)	0.67 (0.19)	0.36 (0.1)
		ditrochota	0 (0)	0 (0)	0 (0)	0.14 (0.04)
	Iotrochota	baculifera	0.2 (0.04)	0.31 (0.08)	0 (0)	0.21 (0.06)
		ditrochota	2 (0.45)	4.06 (1.02)	5.42 (1.56)	1.71 (0.46)
		protea	8.9 (1.99)	6.5 (1.63)	4.83 (1.39)	7.43 (1.99)
	Liosina	cf. granulosa	1.8 (0.4)	3.88 (0.97)	4.25 (1.23)	5.93 (1.58)
	Melophlus	sarasinorum	0.75 (0.17)	1.5 (0.38)	3 (0.87)	1.93 (0.52)
	Monanchora	clathrata	0.05 (0.01)	0.25 (0.06)	0 (0)	0 (0)
	Paratetilla	bacca	0.05 (0.01)	0 (0)	0 (0)	0.07 (0.02)
	Plakina	sp.	0.3 (0.07)	1.13 (0.28)	0.58 (0.17)	0.29 (0.08)
	Porifera	sp.1 (Sponge tough)	0.1 (0.02)	0.13 (0.03)	0 (0)	0.07 (0.02)
		sp.10 (Fake myrmekioderma)	0 (0)	0.06 (0.02)	0 (0)	0 (0)
		sp.11 (Haliclona osiris)	0 (0)	0 (0)	0 (0)	0.07 (0.02)
		sp.12 (white Dysidea 166)	0 (0)	0.06 (0.02)	0 (0)	0 (0)
		sp.13 (Dysidea/Clathria like 179-180)	0.05 (0.01)	0 (0)	0 (0)	0 (0)
		sp.14 (brown Xestospongia-like 183)	0 (0)	0 (0)	0.08 (0.02)	0 (0)
		sp.2 (Sponge green)	0 (0)	0 (0)	0 (0)	0.07 (0.02)
		sp.3 (orange/red Haliclona like)	0.65 (0.15)	0.38 (0.1)	1.42 (0.41)	0.79 (0.21)
		sp.4 (Dysidea like 0021)	0 (0)	0 (0)	0 (0)	0.07 (0.02)
		sp.5 (white Callyspongia)	0 (0)	0 (0)	0 (0)	0.14 (0.04)
		sp.6 (green Clathria)	0 (0)	0.19 (0.05)	0.17 (0.05)	0 (0)
		sp.7 (green/purple Tedania 141)	0 (0)	0.19 (0.05)	0 (0)	0 (0)
		sp.8 (Haliclona gracilis)	0 (0)	0 (0)	0.08 (0.02)	0 (0)
		sp.9 (black net cover 101)	0 (0)	0 (0)	0.08 (0.02)	0 (0)
	Pseudoceratina	sp.	0.65 (0.15)	0.38 (0.1)	0.42 (0.12)	0.21 (0.06)
	Sylissa	massa	1.5 (0.34)	3.06 (0.77)	4.92 (1.42)	7.71 (2.06)
	Tedania	meandrica	2.55 (0.57)	2.13 (0.53)	2.33 (0.67)	4.21 (1.13)
		sp.	0.05 (0.01)	0 (0)	0.08 (0.02)	0 (0)
	Ulosa	spongia	3.55 (0.79)	4.19 (1.05)	2.08 (0.6)	7.5 (2)
	Xestospongia	carbonaria	2 (0.45)	0.88 (0.22)	11 (3.18)	15.29 (4.09)
		exigua	1.3 (0.29)	0.63 (0.16)	0.42 (0.12)	0.36 (0.1)
PORIFERA Total			60.95 (13.63)	79.63 (19.91)	76 (21.94)	96.79 (25.87)
Grand Total			70.95 (15.86)	92.06 (23.02)	86.08 (24.85)	118.86 (31.77)

TABLE 11. Macro Invertebrate counts on three tramsects (15, 49, 61) during the day and at night. Surveys were conducted on the same belt transect.

			15		49		61	
Phylum	**Genus**	**Species**	**Day**	**Night**	**Day**	**Night**	**Day**	**Night**
Cnidaria	Ceriantharia	sp.				1		
Cnidaria Total						1		
Crustacea	Alpheus	sp.				1		
	Calcinus	pulcher					4	
		spp.						4
	Carupa	ohashi						1
	Cinetorhynchus	concolor		1		18		
		hawaiiensis		9		72		7
		hendersoni				1		
		reticulatus				3		
	Dardanus	guttatus						1
	Galtheid	sp.		1				
		sp.1				1		
		sp.2				2		
	Palaemonid	sp.		1		1		
	Periclimenes	sp.				1		1
	Portunid	sp.2						1
		sp.3				4		
		sp.4		1				
		sp.5		1				
		sp.6		5				
		sp.7		1				
	Saron	marmoratus		2				
		sp.				2		
	Shrimp	sp.				4		
	Thalamita	cerasma		1		4		1
		sp.				3		
	Xanthid	sp.		1				
Crustacea Total				24		117	4	16
Echinodermata	Echinometra	mathei		4	1	3		3
	Euapta	godeffroyi				1		1
	Linkia	guildingi						2
		multifera						4
	Ophiurid	sp.1					2	3
	Phyllacanthus	imperialis						5
	Tripneustes	gratilla				1		
Echinodermata Total				4	1	5	2	18
Mollusca	Cerithium	columna	3	6		1	2	21
		echinatum		2				
		sp.						1
	Clypeomorus	nympha	1				2	16
	Coralliophila	violacea	15	8	5		19	9
	Costellarid	sp.				1		
	Cypraea	carneola						1
		mappa			1			
		tigris						1
		vitellus		1				
	Drupella	rugosa		1				
		sp.		1				
	Euplica	deshayesii		4	3	1		
	Habromorula	spinosa				1	2	1
	Jorunna	funebris				1		
	Vexillum	sp.				16		
Mollusca Total			19	23	9	21	25	50
Grand Total			19	51	10	144	31	84

TABLE 12. Macro Inverebrate Taxa Richness at three sites during the day and at night. Surveys were conducted on the same belt transects.

TRANSECT			15		49		61	
Phylum	**Genus**	**Species**	**Day**	**Night**	**Day**	**Night**	**Day**	**Night**
Cnidaria	Aptasia	sp.						1
	Ceriantharia	sp.				1		
Cnidaria Total						1		1
Crustacea	Alpheus	sp.				1	1	
	Atergatis	latissimus				1		
	Calcinus	pulcher					1	
		spp.						1
	Carupa	ohashi						1
	Cinetorhynchus	concolor		1		1		
		hawaiiensis		1		1		1
		hendersoni				1		
		reticulatus				1		
	Dardanus	guttatus						1
	Galtheid	sp.		1				
		sp.2				1		
	Glatheid	sp.1				1		
	Palaemonid	sp.		1		1		
	Periclimenes	sp.				1		1
	Portunid	sp.2						1
		sp.3				1		
		sp.4		1				
		sp.5		1				
		sp.6	1	1				
		sp.7		1				
		sp.8		1				
	Saron	marmoratus		1				
		sp.				1		
	Shrimp	sp.				1		
	Stenopus	hispidus						1
	Thalamita	cerasma		1		1		1
		sp.				1		
	Xanthid	sp.		1				
Crustacea Total			1	12		15	2	8
Echinodermata	Echinometra	mathei		1	1	1		1
	Euapta	godeffroyi				1		1
	Leiaster	lechii						1
	Linkia	guildingi						1
		multifera						1
	Ophiactis	savignyi						1
	Ophiurid	sp.1					1	1
	Phyllacanthus	imperialis						1
	Tripneustes	gratilla				1		
Echinodermata Total				1	1	3	1	8
Mollusca	Arca	avellana		1				
		ventricosa	1	1		1	1	1
	Cerithium	columna	1	1		1	1	1
		echinatum		1				
		sp.						1
	Chama	iostoma			1	1		
	Clypeomorus	nympha	1				1	1
	Conus	geographicus						1
	Coralliophila	violacea	1	1	1		1	1
	Costellarid	sp.				1		
	Cypraea	carneola						1
		mappa			1			
		tigris						1
		vitellus		1				
	Dendropoma	maxima	1	1			1	1
	Drupella	rugosa		1				
		sp.		1				
	Euplica	deshayesii		1	1	1		
	Habromorula	spinosa				1	1	1
	Isognomon	sp.			1	1	1	1
	Jorunna	funebris				1		1
	Lithophagia	sp.	1	1	1	1	1	1
	Malleus	decurtatus	1					
	Spondylous	violacenscens					1	
	Vexillum	sp.				2		
Mollusca Total			7	11	6	11	9	13
Polychaeta	Sabellastarte	spectabilis		1	1	1	1	
Polychaeta Total				1	1	1	1	
Grand Total			8	25	8	31	13	30

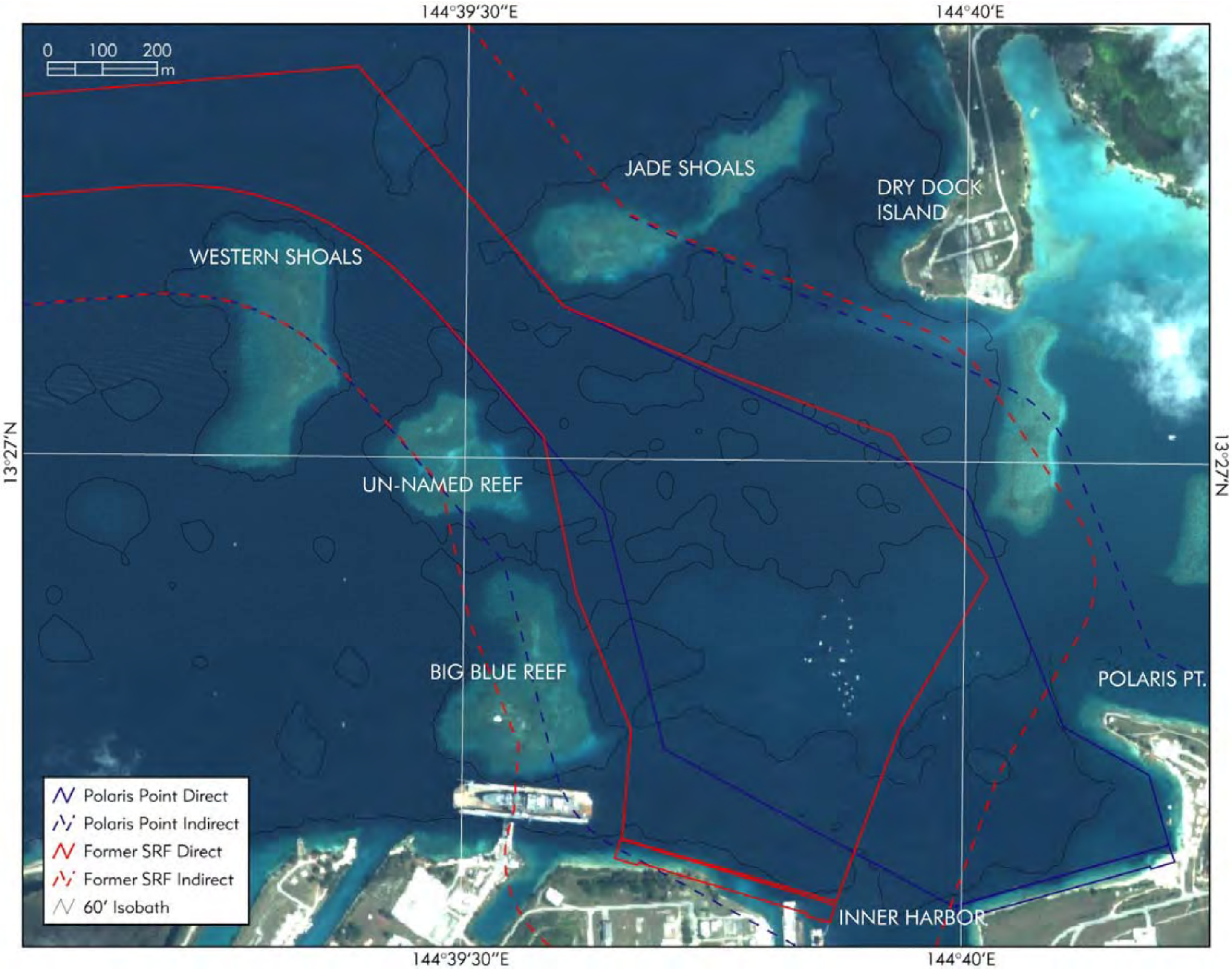


FIGURE 1. Quickbird satellite image of southeastern Apra Harbor, Guam showing outlines of proposed alternatives for the CVN (Carrier Vessel Nuclear) transit, turning basin and berthing facilities. "SRF" option is shown in red; Polaris Point alternative is shown in blue. "Direct" areas (solid lines) indicate footprint within which dredging will take place; "Indirect" areas (dashed lines) delineate an envelope 200 m wide around each Direct alternative boundary. Also shown in black is the 60-foot depth contour, which marks the deepest survey depth within the project boundaries.

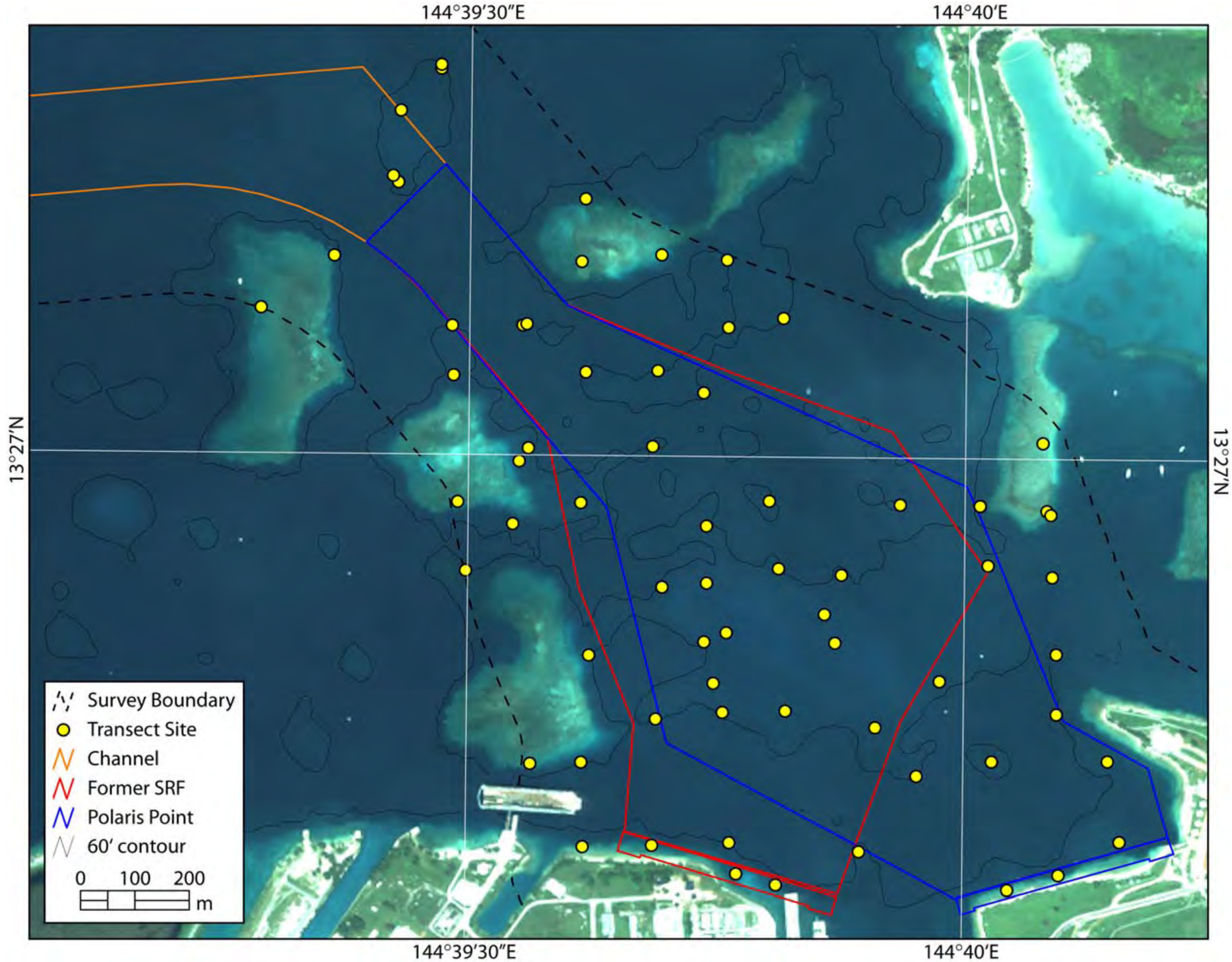


FIGURE 2. RGB (red-green-blue) image of study area. Image source is Quickbird satellite, acquired in 2003. Also shown are boundaries of SRF and Polaris Pt. CVN alternatives (red and blue lines, respectively), a 200-m (656 ft.) indirect impact buffer zone (dashed black line), and 60 ft. depth contour. Yellow circles are stratified random sampling points selected in four strata: 1) Dredge area "flat"; 2) Dredge area "slope"; 3) Indirect "flat", and 4) Indirect "slope". Fifteen (15) points are within each strata, with additional points added in the SRF and Polaris Wharf locations for a total of 67 sampling sites.

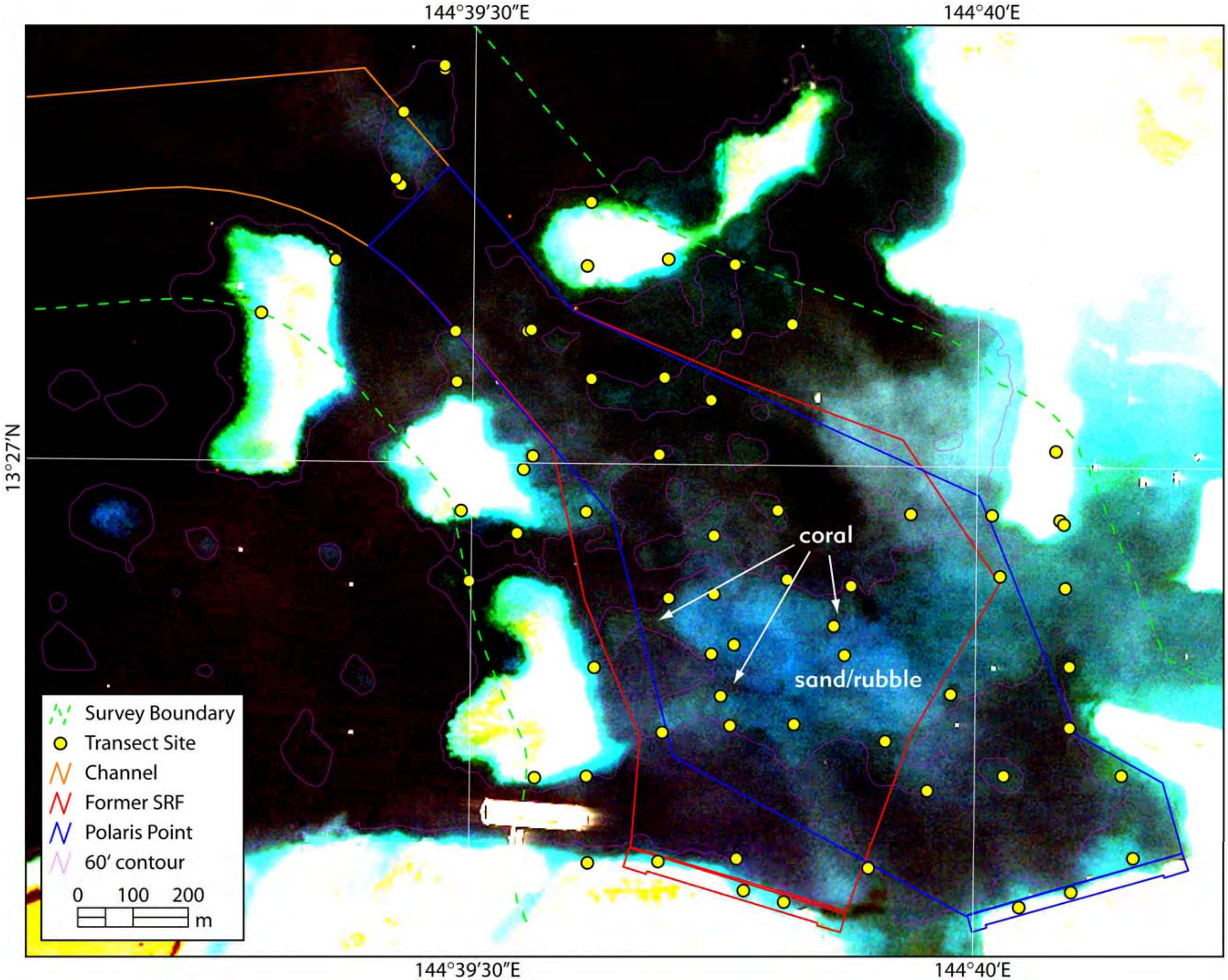


FIGURE 3. RGB (red-green-blue) image of study area (same as Figure 1) optically color-stretched to highlight deep reef areas within the CVN dredge area. Bright areas on the deep reef are likely sand/rubble, while darker areas, particularly on the reef edge are likely coral/algal rich.

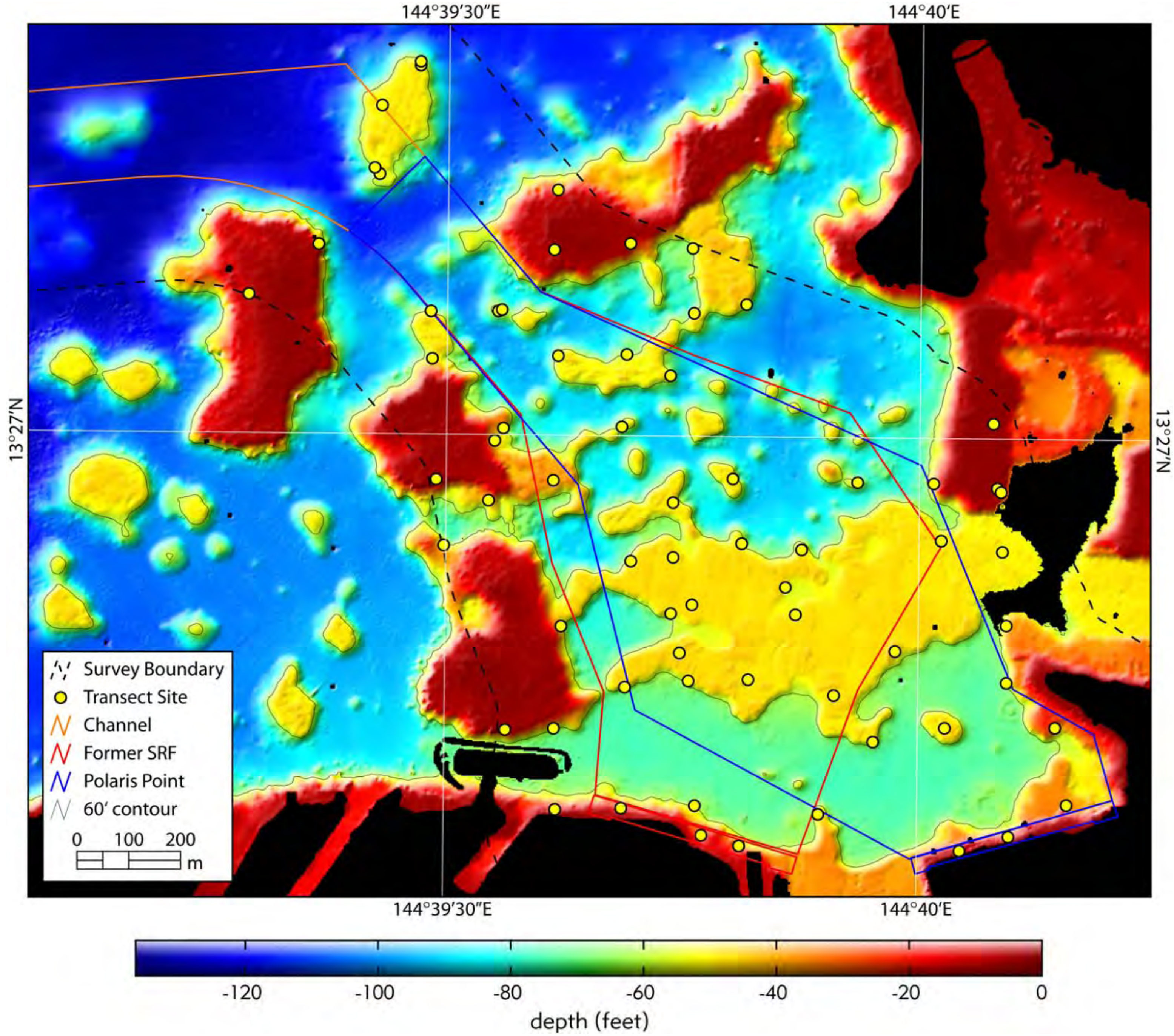


FIGURE 4. Color-coded bathymetry of CVN survey area generated from LIDAR (light detection and ranging) and acoustic surveys (data provided by TEC.

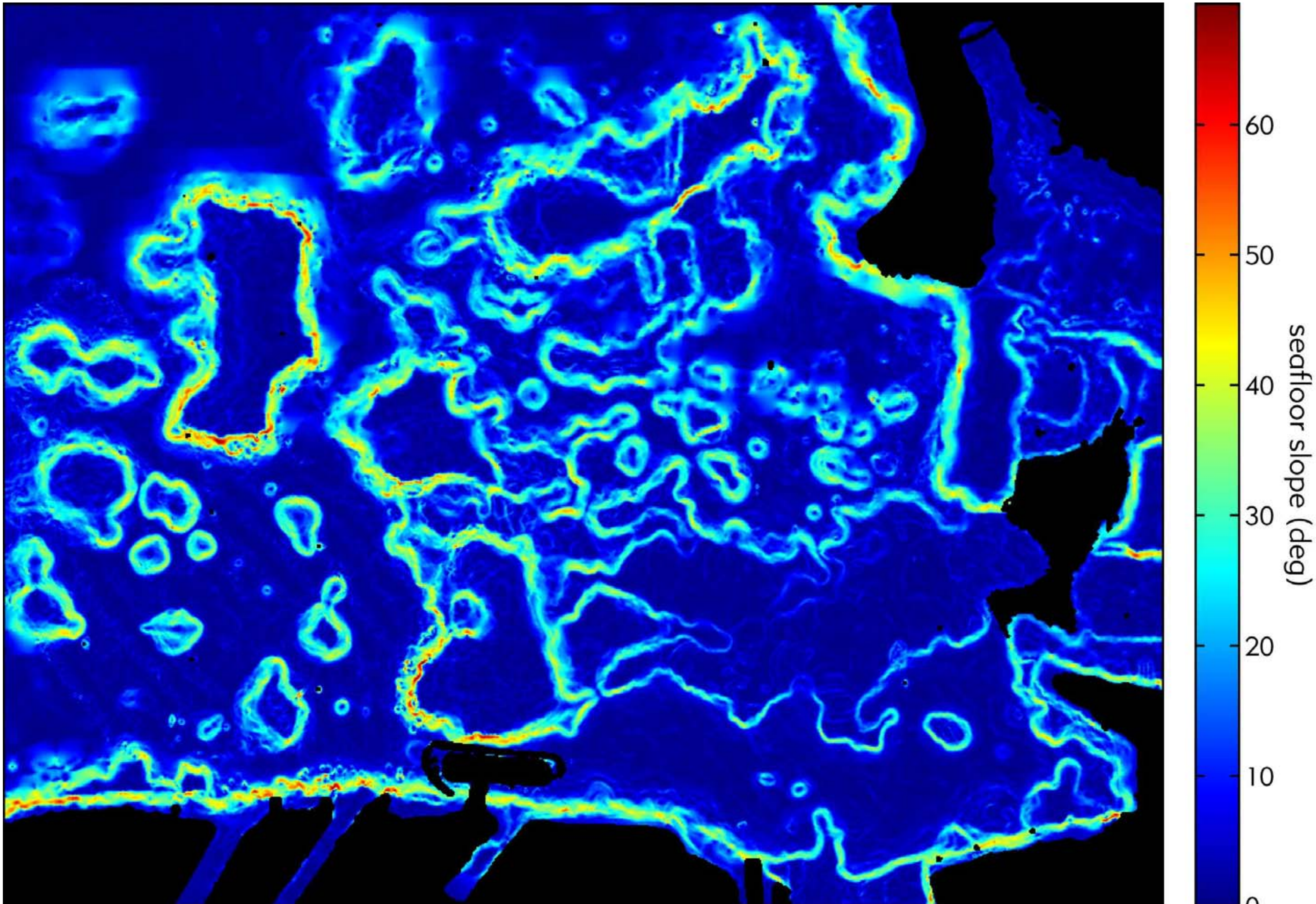


FIGURE 5. Color-coded slope (degrees) of bathymetry of CVN survey area generated from LIDAR (light detection and ranging) and acoustic surveys (data provided by TEC).

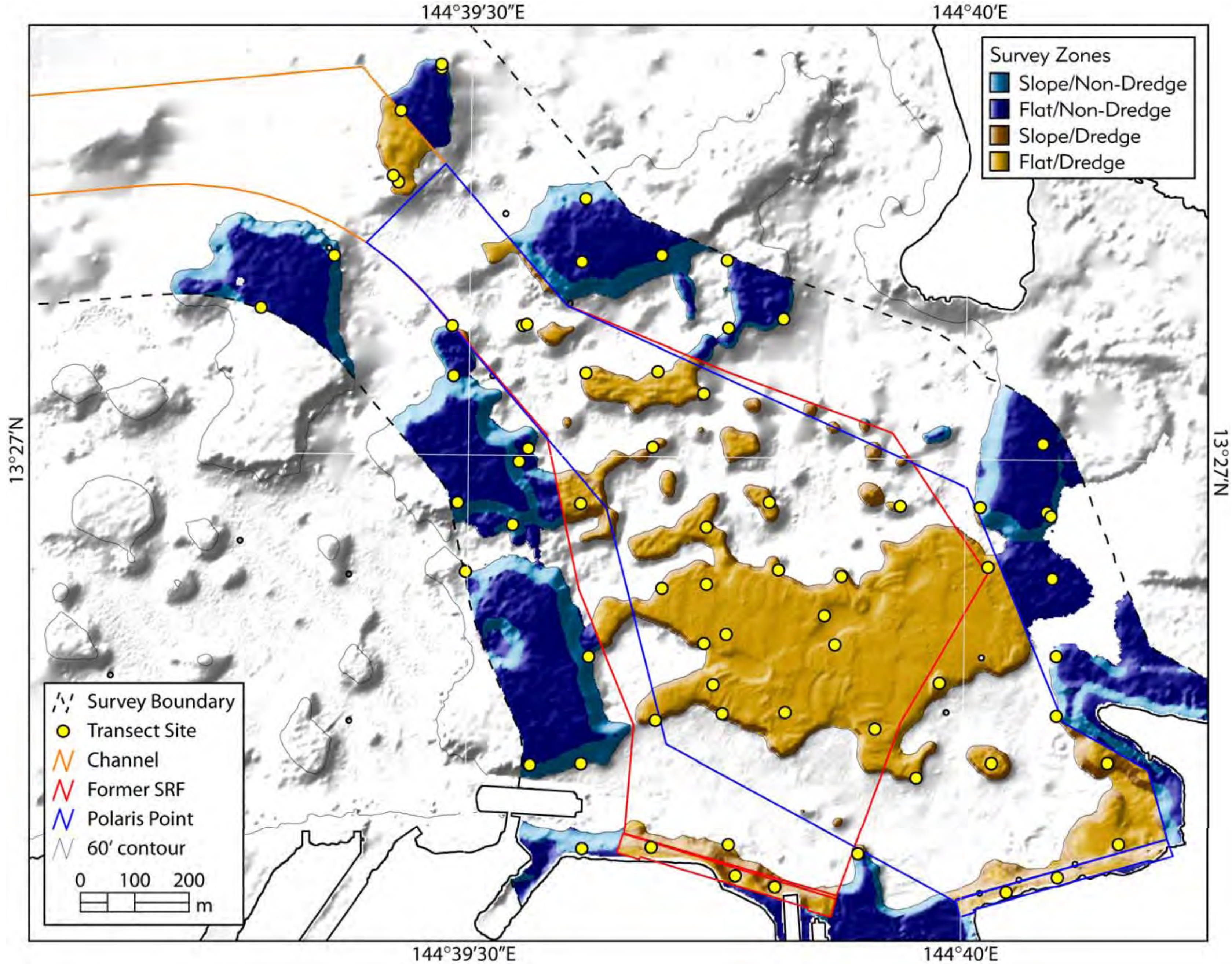


FIGURE 6. Final stratification product showing four zones used for random stratified sampling replicating GIS product Figure 1 provided by USFWS. Zones are bounded by 60-foot depth contour and 200-m wide indirect impact zone. Dredge "flat" (light brown) and Indirect Impact "flat" (dark blue) areas have <15° seafloor gradient; Dredge slope (dark brown) and Indirect Impact slope (light blue) have ≥15° seafloor gradient. Fifteen data points are randomly selected in each strata using MATLAB. Extra points are added to each berthing area for a total of 67 sampling stations.

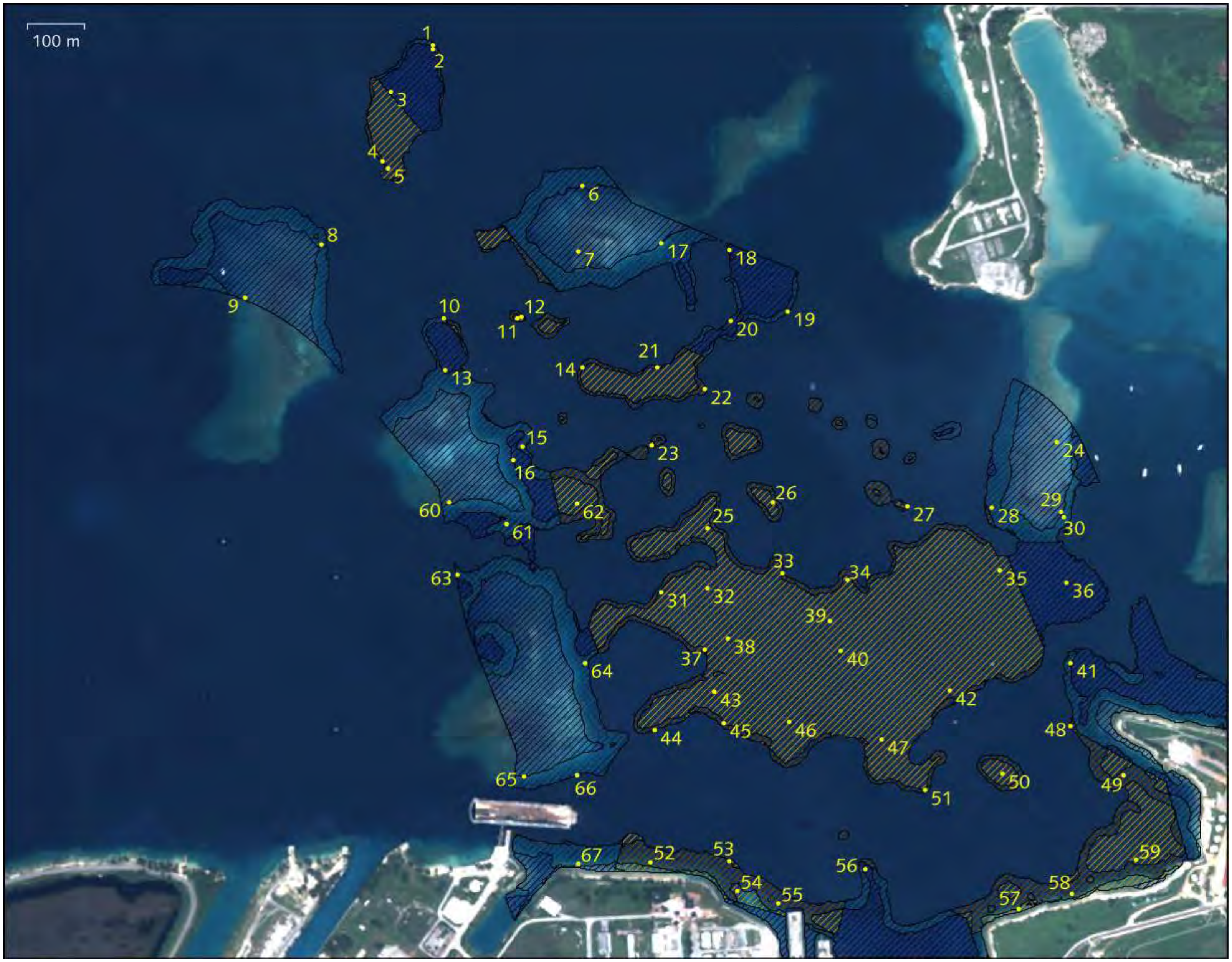


FIGURE 7. Satellite image of southwestern Apra Harbor showing locations of 67 transect stations that were surveyed for benthic community composition. Black hatched areas delineate the "Direct" Impact area where dredging will take place, including the areas for both the SRF and Polaris Point alternatives, and the blue hatched area delineates the "Indirect" Impact area which has been deemed to have the potential to be affected by sediment created by the dredging. The lines within the perimeters of each area differentiate "slope" areas with bottom topography greater than 15°, and "flat" areas with slope angle less than 15°.

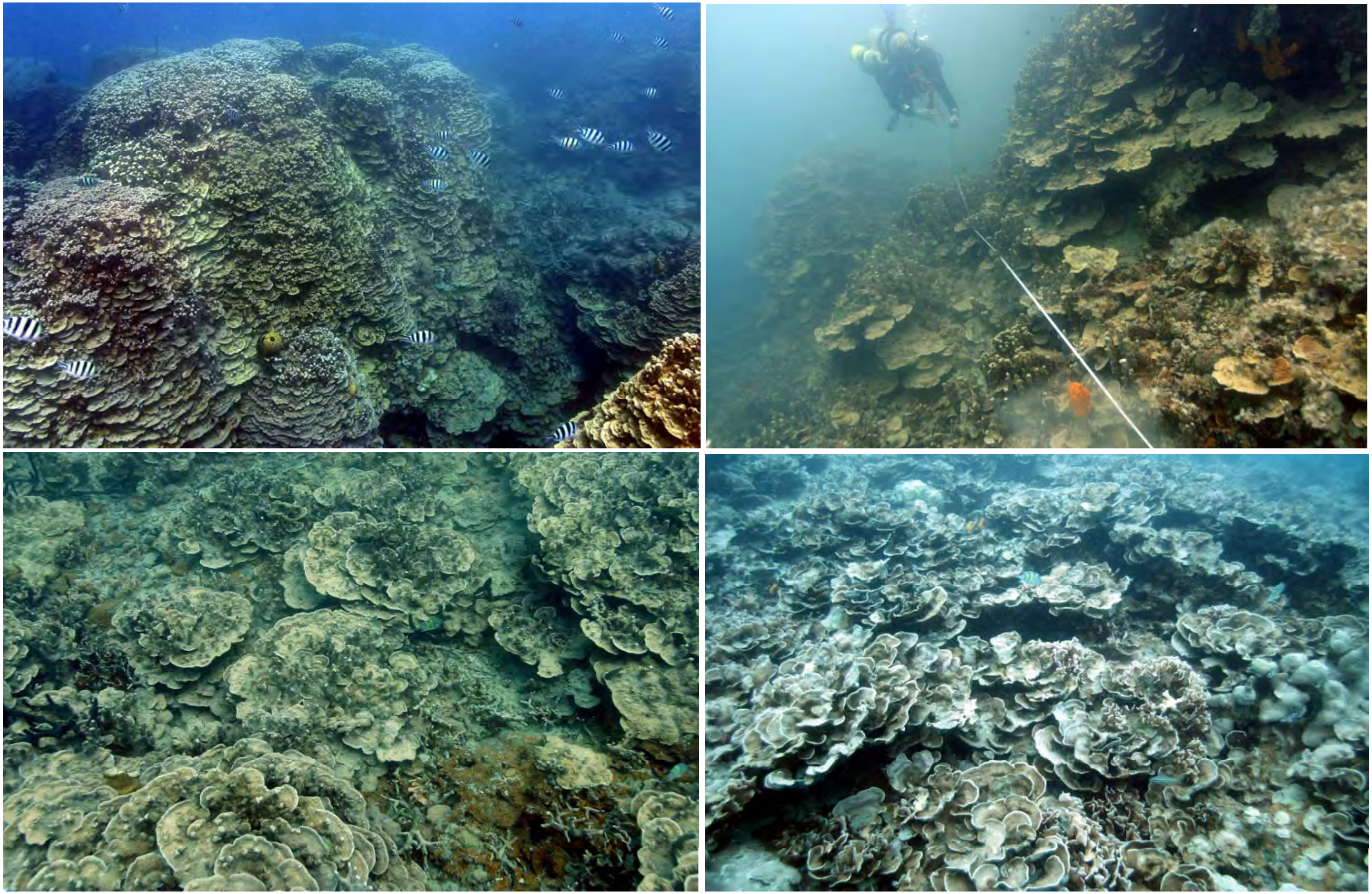


FIGURE 8. Various plating and laminar growth forms of *Porites rus* that occur throughout the CVN survey area. Photo at upper left shows a "supracolony" of *P. rus* comprised of the amalgamation of numerous smaller colonies that measures approximately 12 m in length. Photo at upper right shows overlapping laminar plates growing on the near-vertical face of the lower part of a patch reef slope. Bottom photos show two views of deep reef flats covered with overlapping amalgamated plates of semi-circular plates that fuse to form nearly mono-specific complexes.

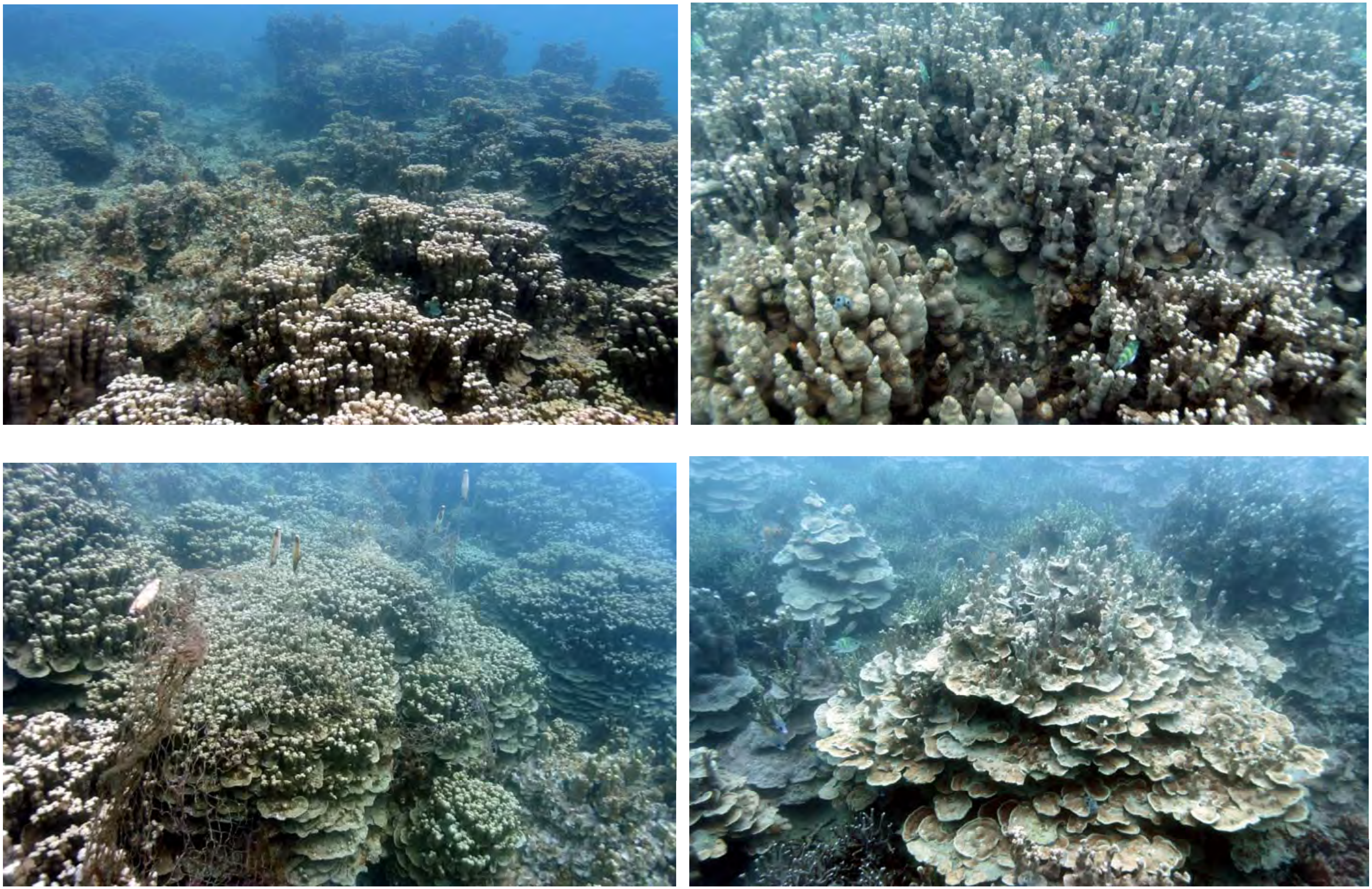


FIGURE 9. Various branching growth forms of *Porites rus* that occur throughout the CVN survey area. Photo at lower left shows monofilament fence net tangled on coral colonies in the vicinity of Transect 6. Photo at lower right shows colony of *P. rus* near Transect 15 with upper portion consisting of upright branches growing out of laminar plates.

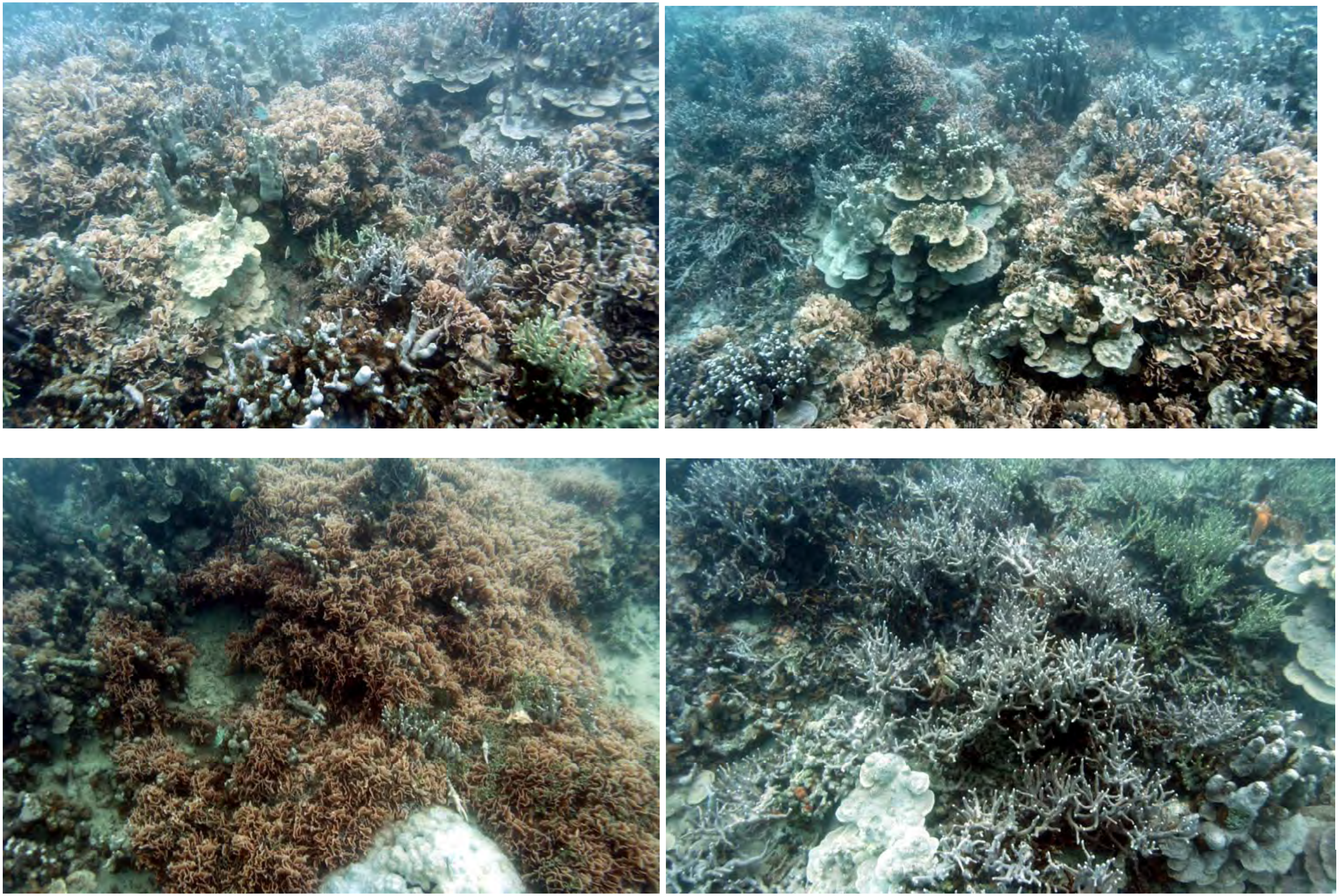


FIGURE 10. High coral cover communities in the vicinity of Transect 15 comprised of mixed assemblages of species including *Porites rus*, *P. cylindrica*, and *Pavona cactus*.

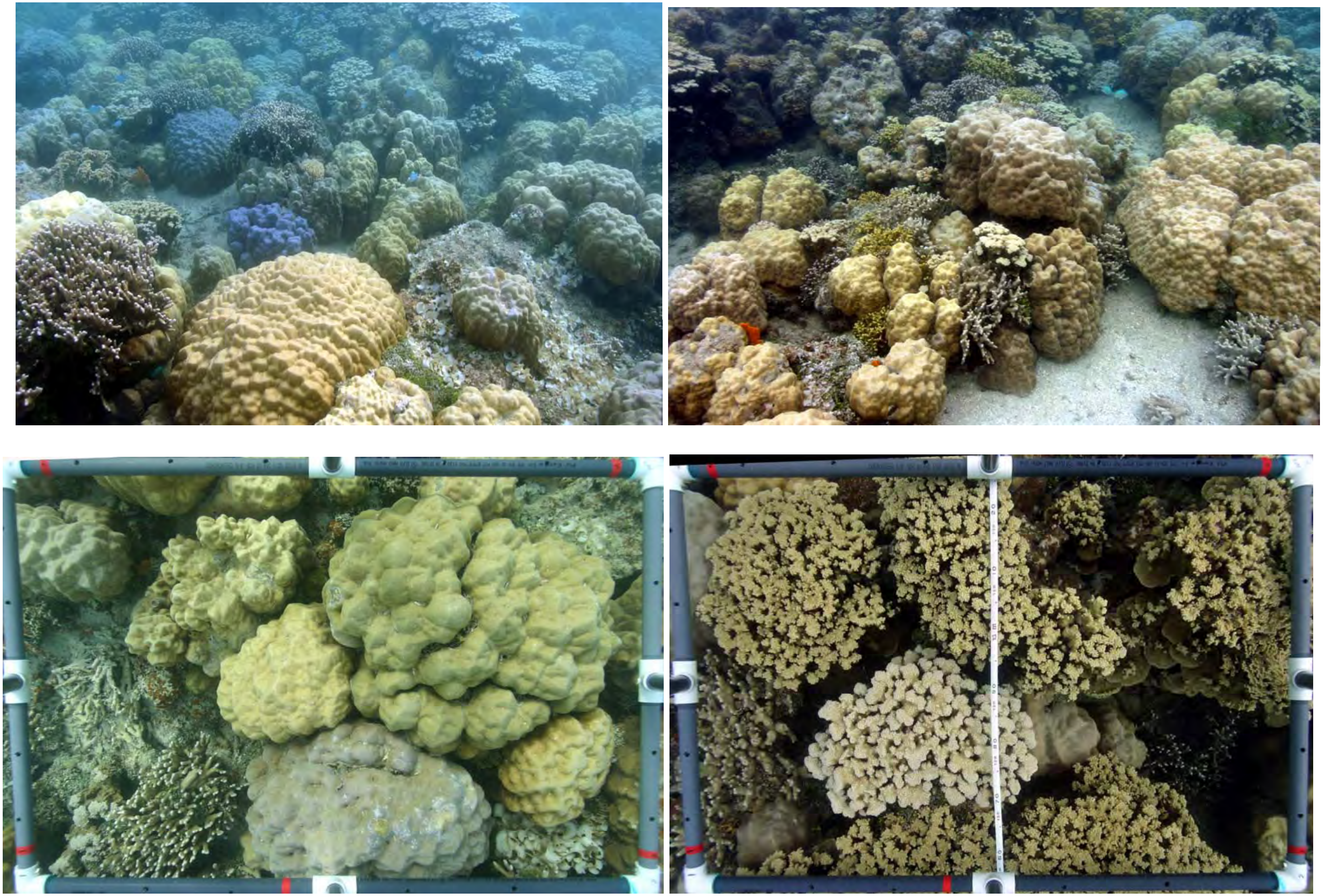


FIGURE 11. Benthic cover of upper edges of patch reefs in the CVN study area can be dominated by hemispherical colonies of *Porites lutea* (Transect 21, upper left; Transect 7 upper right). Photo-quadrats from Transect 7 show areas of tightly packed colonies of *P. lutea* (bottom left) and a knobby, short-branched growth form of *Porites rus* (bottom right).

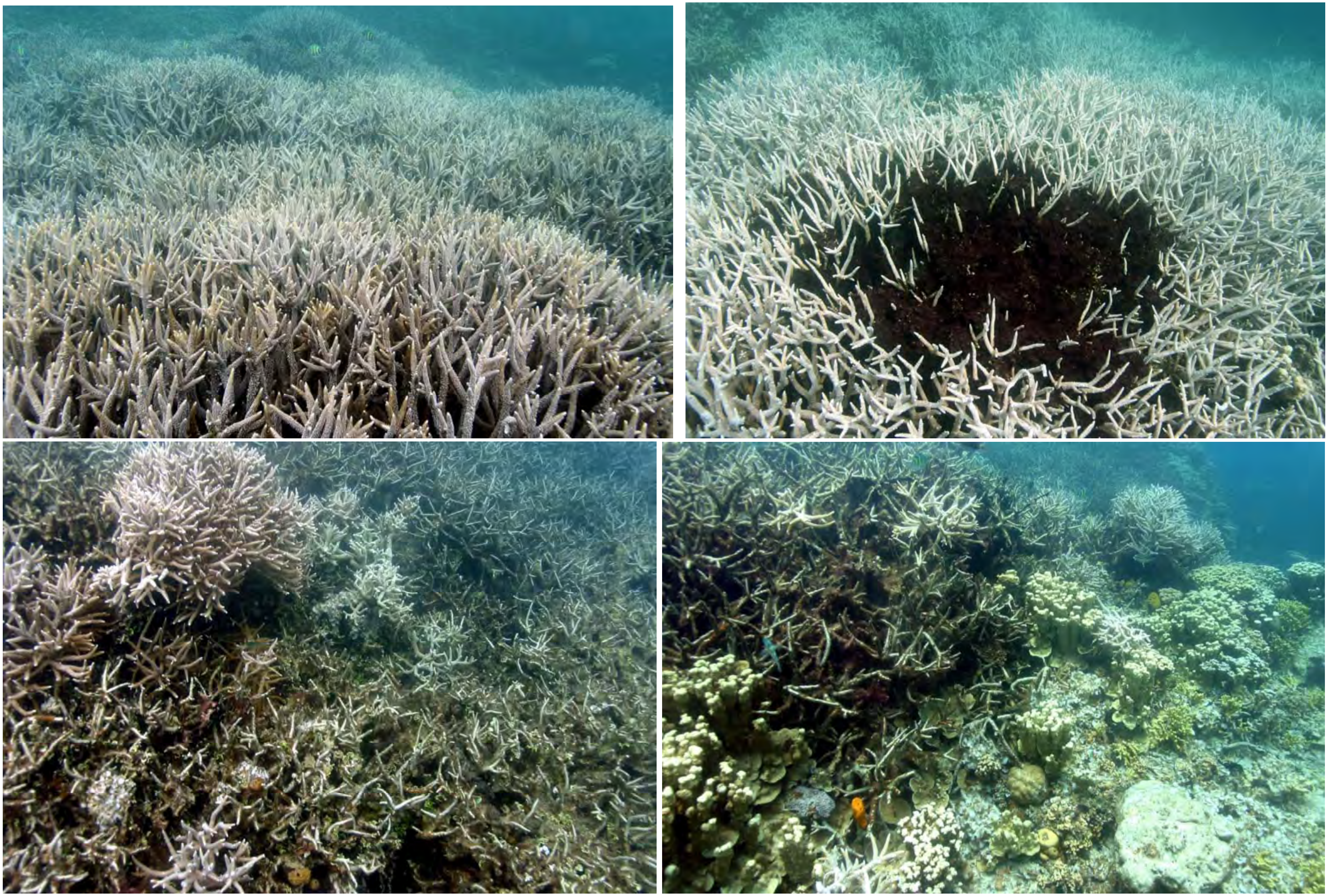


FIGURE 12. Monospecific field of *Acropora aspera* located on the top of the western side of Western Shoals (Transect 9) (top left). Areas of the stand were overgrown by dense patches of the black sponge, resulting in mortality to sections of the field of *Acropora* (top right). Area of dead algal encrusted branches of *A. aspera* interspersed with clusters of either newly recruited, or unaffected branching coral (bottom left). Boundary of the *A. aspera* field is clearly delineated at a depth contour just off the top of the patch reef on the western side of Western Shoals (bottom right).

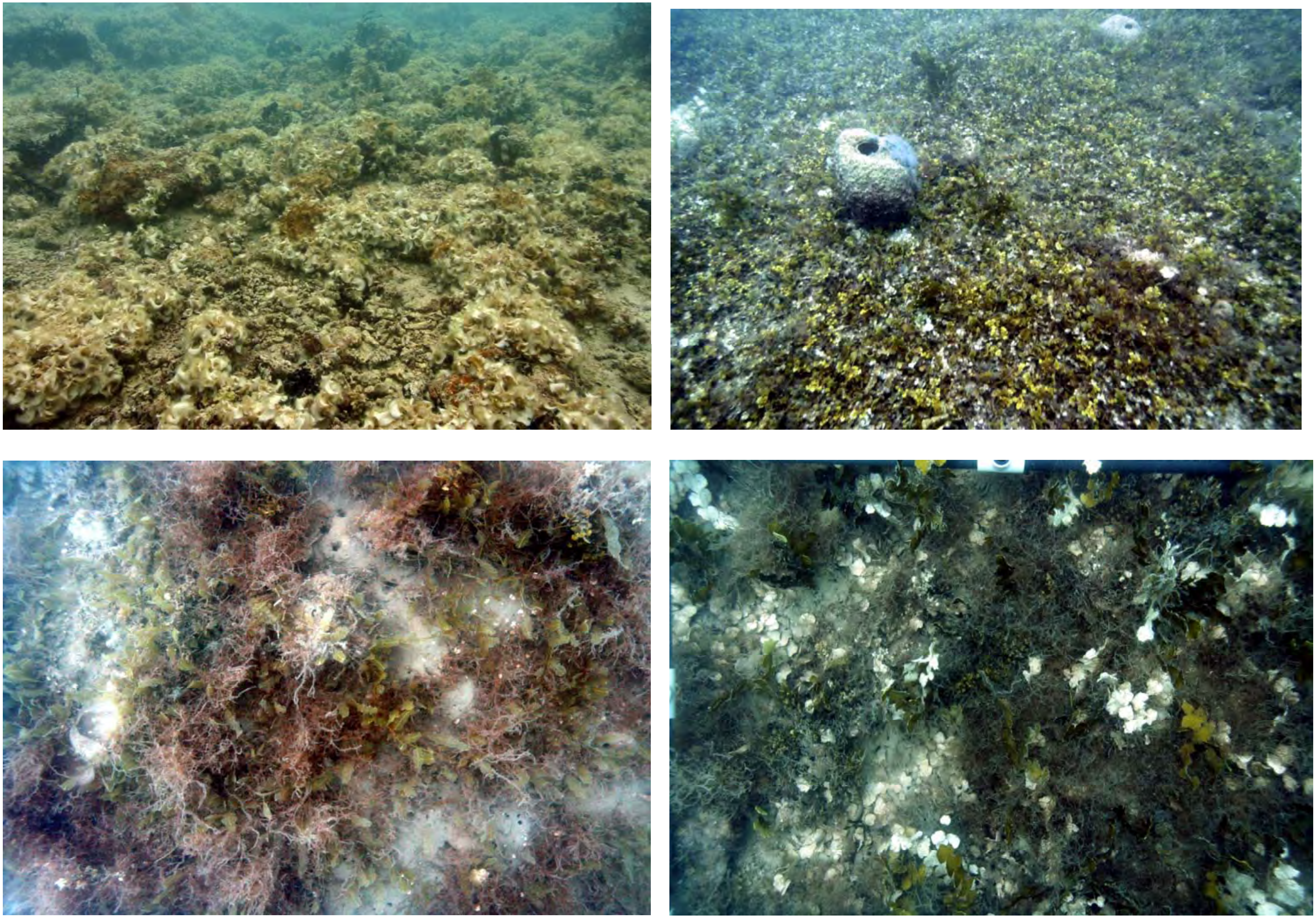


FIGURE 13. Algae dominated areas of the CVN study area include mats of *Padina* spp (top left) and *Halimeda* spp. (top right). Common mixed algal assemblages included *Dictyota* sp. and *Caulerpa* spp. (bottom left), and *Dictyota* and *Halimeda* (bottom right).

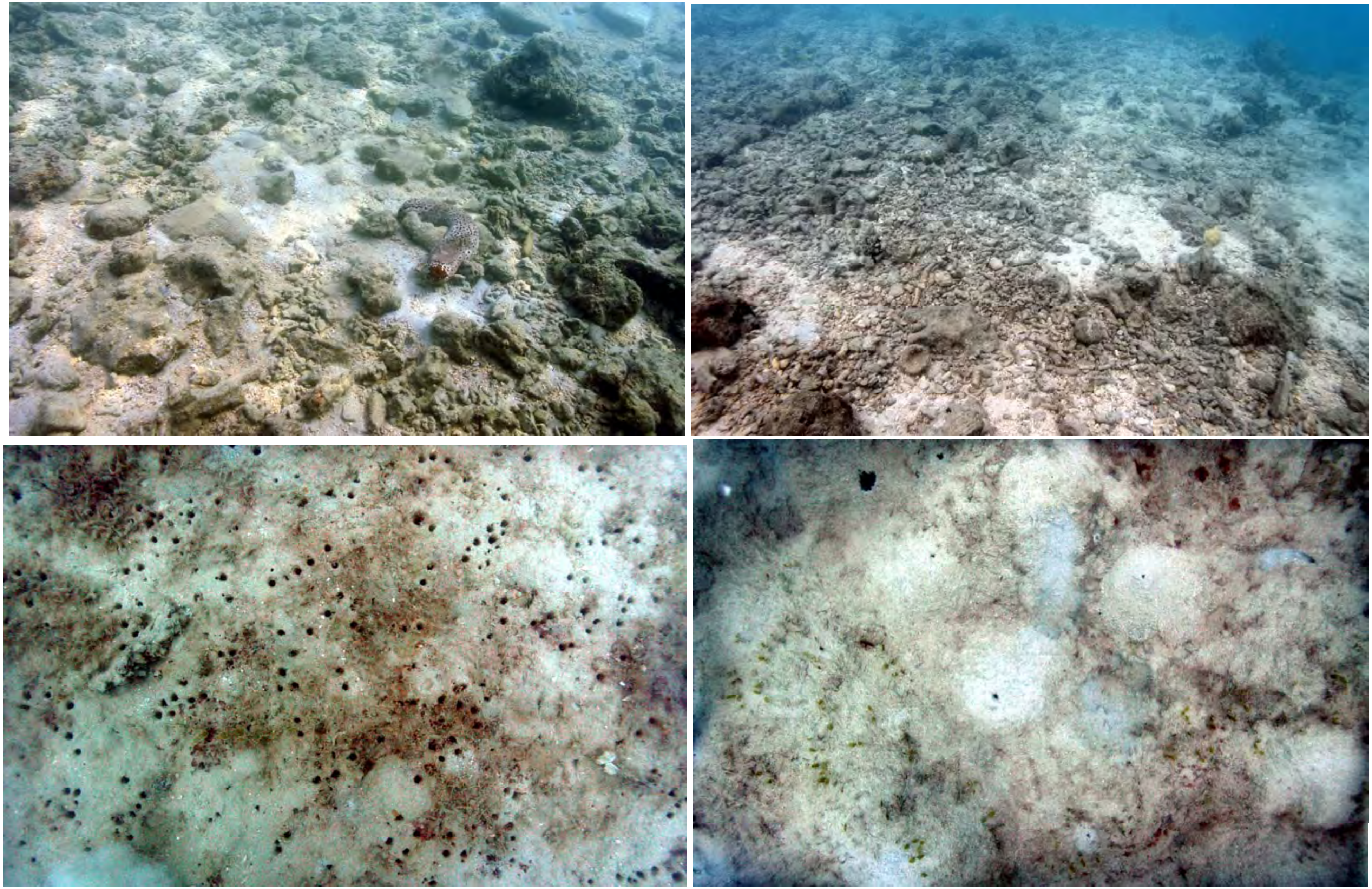


FIGURE 14. Bottom cover consisting of sand-rubble at Transects 67 (upper left) and 58 (upper right). Fine-grained calcareous mud comprising the benthic surface typically contains numerous burrow holes, and is covered with brown or black bacterial films (Transect 35 at lower left; Transect 32 lower right).

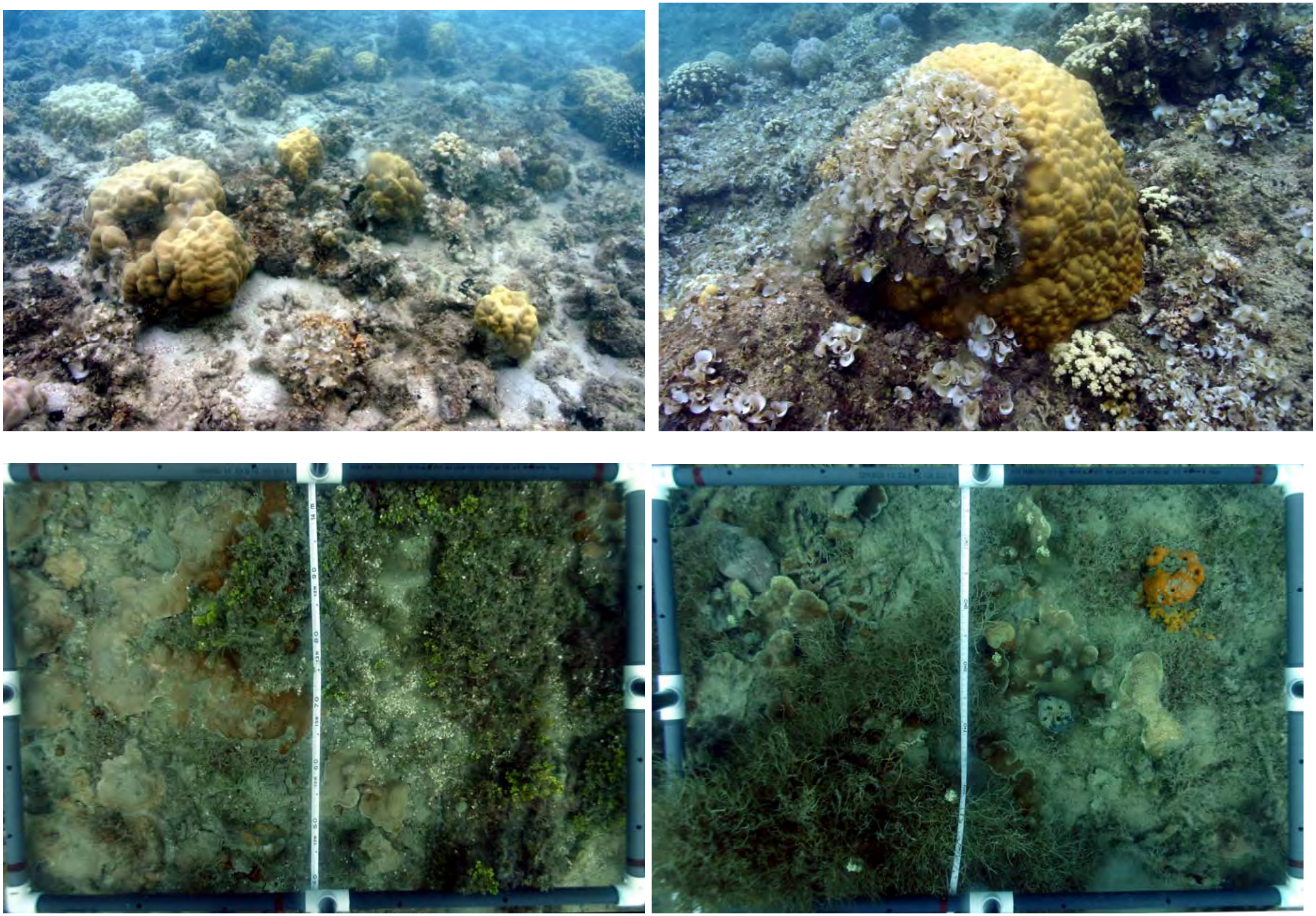


FIGURE 15. Representative areas of mixed algae and coral. Tops of large patch reefs were typically populated with hemispherical heads of *Porites lutea* amid clumps of *Padina* (Transect 17, top left; Transect 60 top right). Bottom row shows photo-quadrates occupied by corals and *Halimeda* (Transect 21, bottom left), and *Dictyota* (Transect 43, bottom right).

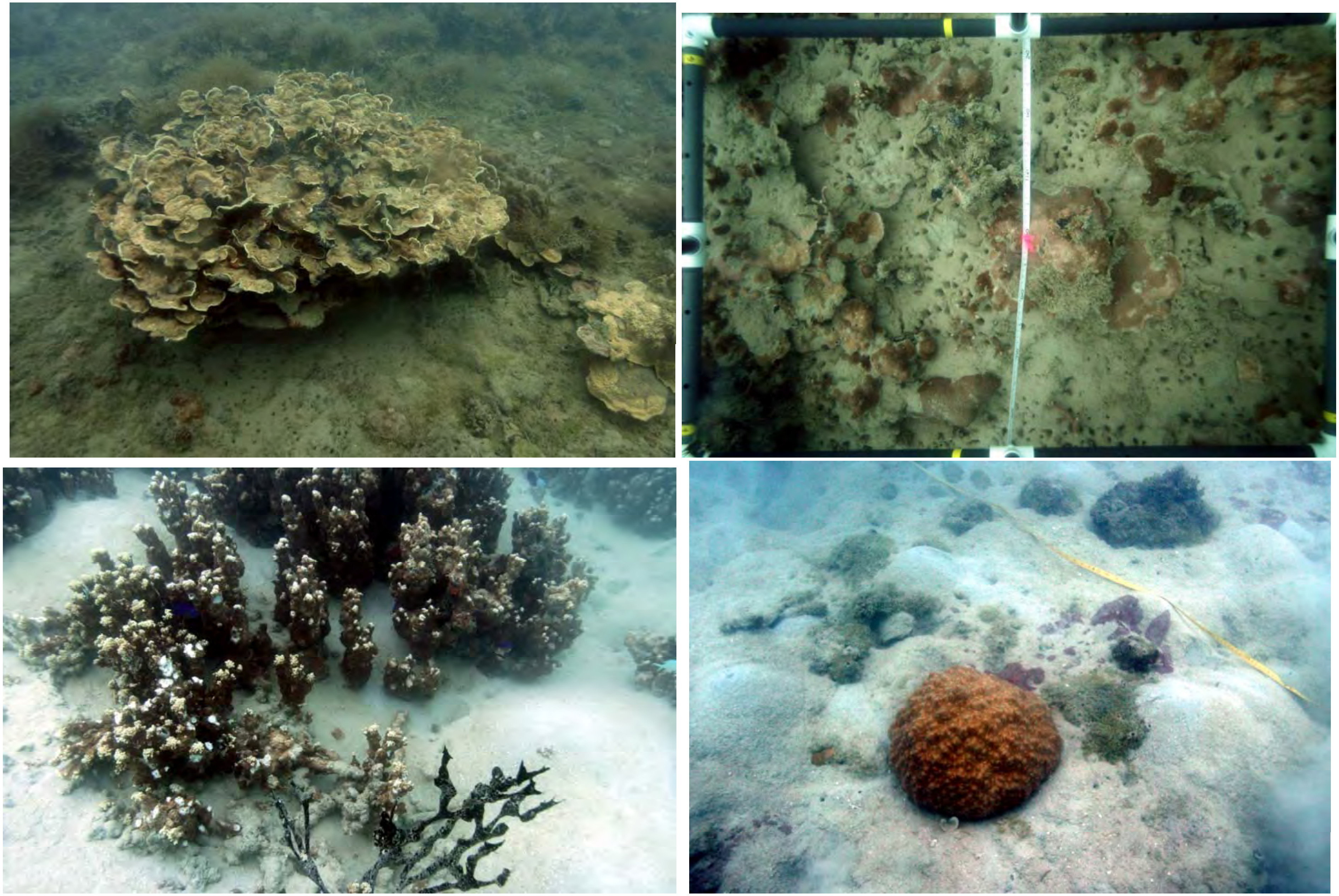


FIGURE 16. Examples of corals in the CVN study area growing on sandy substratum.. Various growth forms of *Porites rus* include large undercut structures with the growing surfaces raised above the sediment surface near Transect 45 (top left), smaller encrusting plates or lobes on the sediment surface on Transect 56 (upper right) and columnar branches growing out of the sediment near Transect 16 (lower left). A hemispherical colony of *Astreapora myriophthalma* growing on the sand at Transect 32 is shown at bottom right.

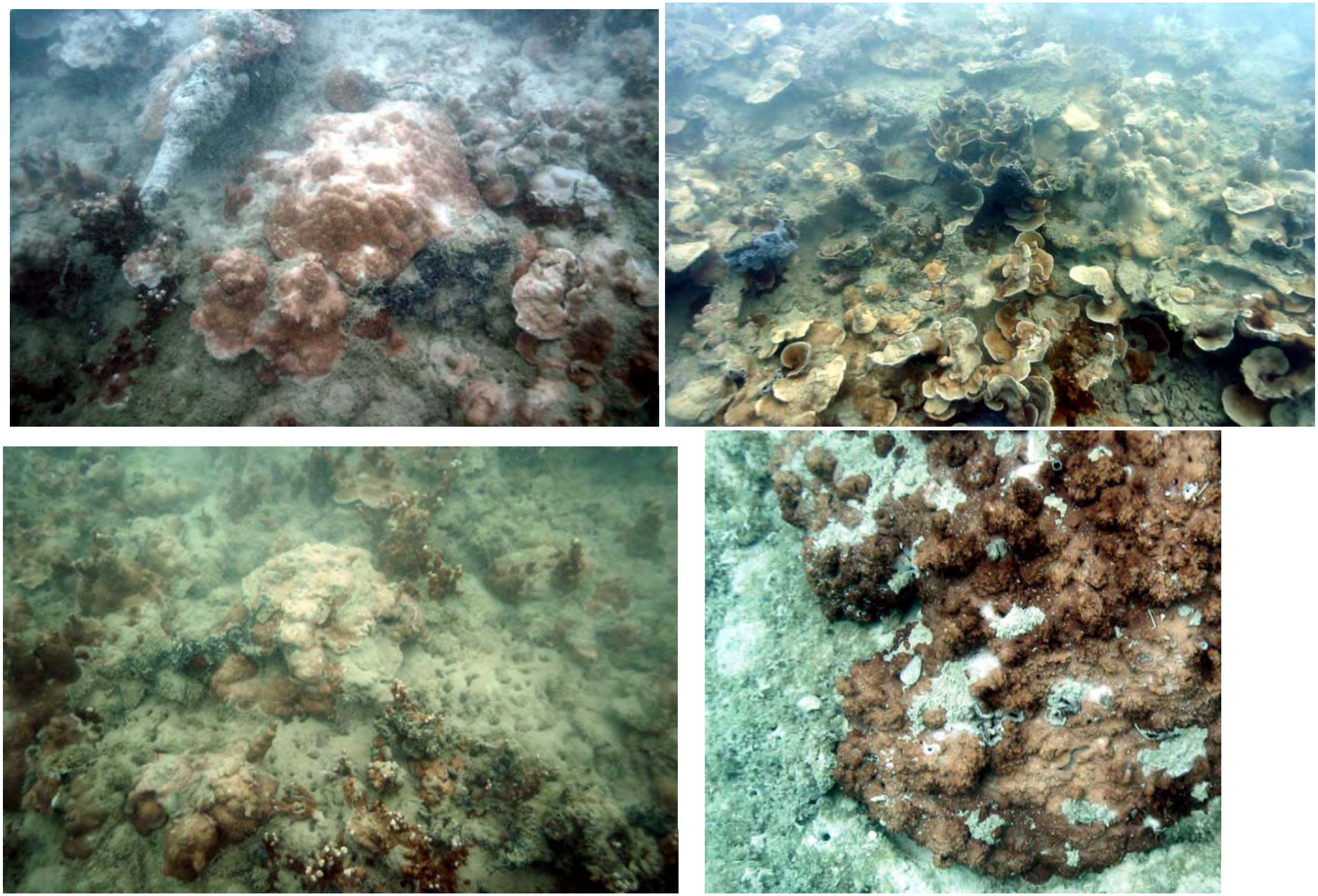


FIGURE 17. Colonies of *Porites rus* growing with upper living surfaces partially covered with sediment. Photos on upper and lower left in the vicinity of Transect 56, while upper and lower right are from the vicinity of Transect 21.

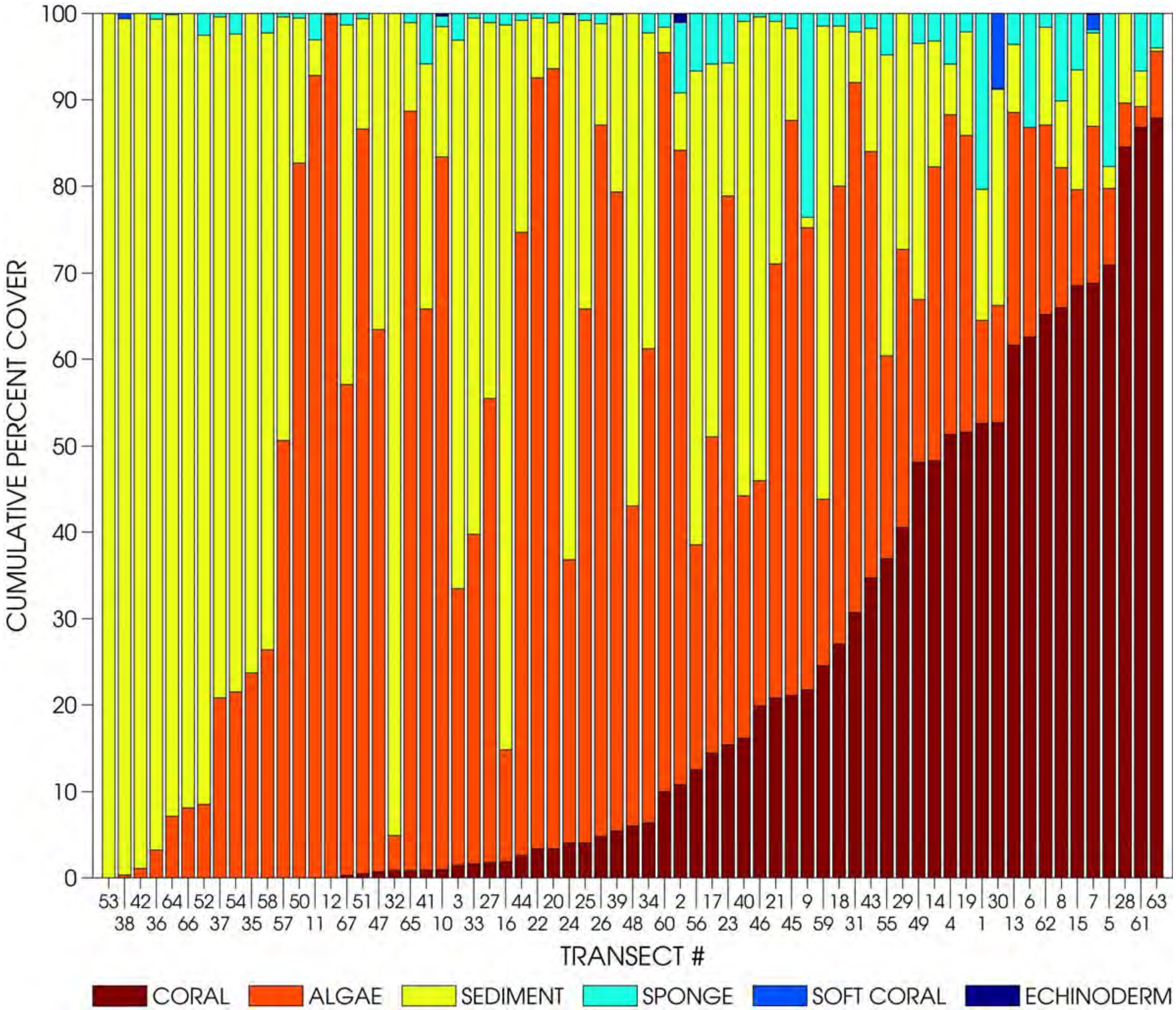


FIGURE 18. Stacked bar graph showing cumulative percent covers for each general class in each transect. Transects are arranged in order of lowest to highest coral cover.

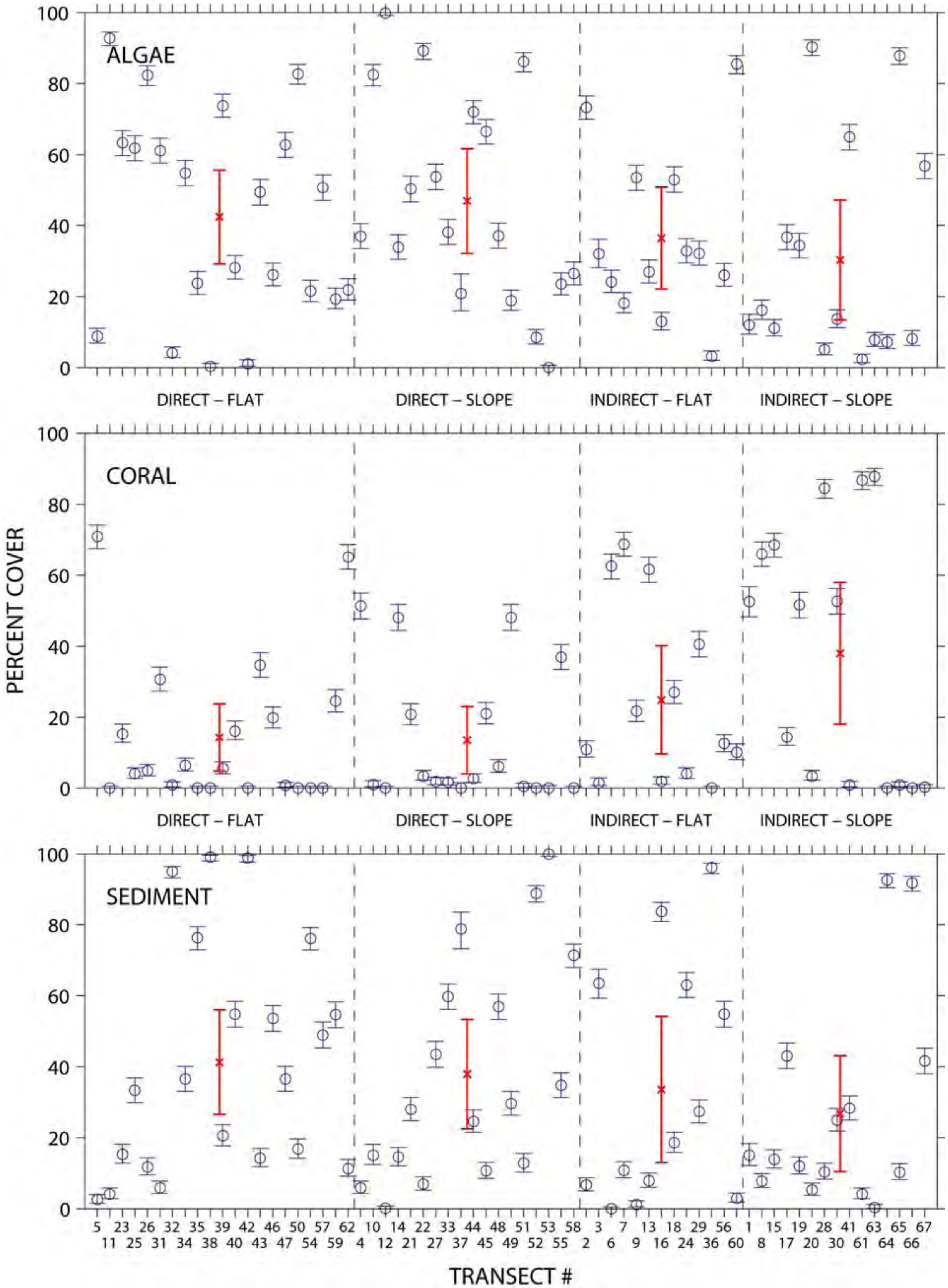


FIGURE 19. Percent covers of algae (top), coral (middle) and sediment (bottom) on each transect in each strata. Blue circles show percent cover in each transect calculated as the number of points identified as a given class divided by the total number of points in the transect, then multiplied by 100. Error bars on blue circles are computed by fitting a binomial distribution to each proportional cover, and show lower and upper 95% confidence intervals based on binomial distribution. Red crosses show mean percent covers for each class in each survey stratum; error bars are ±95% confidence intervals on the mean.

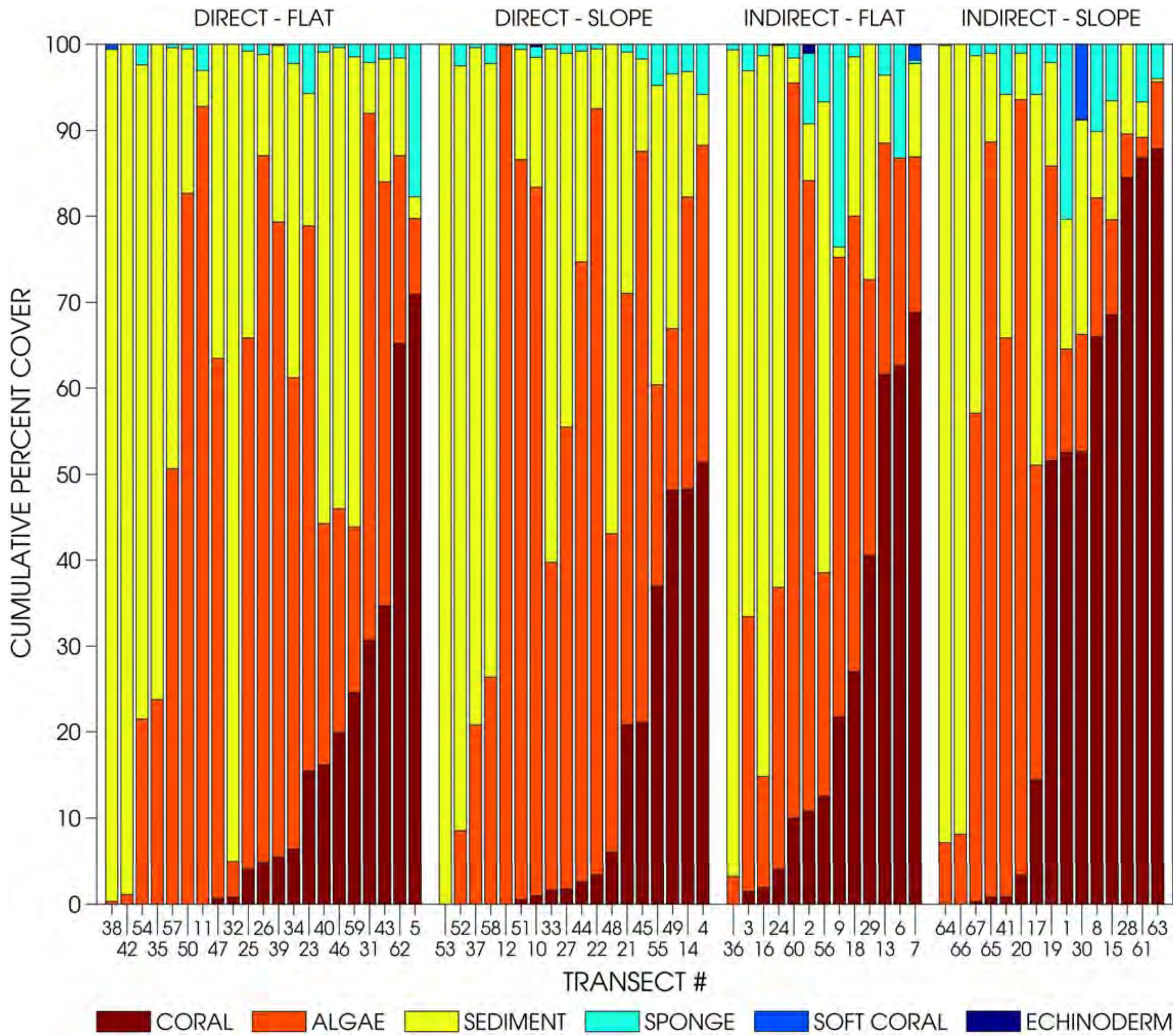


FIGURE 20. Stacked bar graph showing cumulative percent covers for each general class in each transect, arranged by survey stratum. Within each stratum, transects are arranged in order of lowest to highest coral cover. Coral, algae and sediment cover vary widely within each stratum; overall, the Indirect–Slope stratum has slightly higher coral cover than the other three strata.

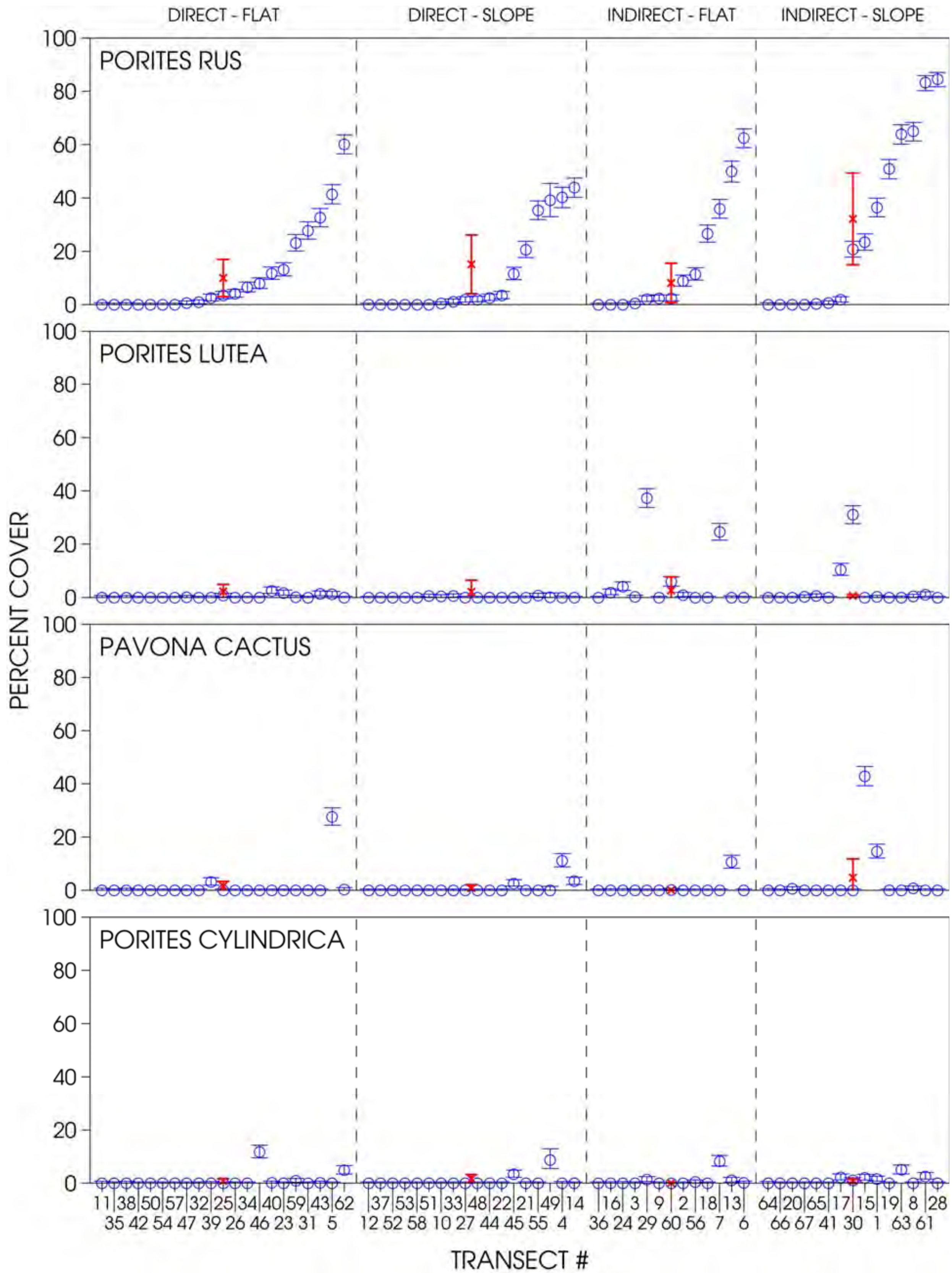


FIGURE 21. Percent covers on each transect in each zone of *Porites rus* (top), *Porites lutea* (upper-middle), *Pavona cactus* (lower-middle) and *Porites cylindrica* (bottom). Blue circles show percent cover in each transect calculated as the number of points identified as a given class divided by the total number of points in the transect, then multiplied by 100. Error bars on blue circles are computed by fitting a binomial distribution to each proportional cover; error bars show lower and upper 95% confidence intervals based on binomial distribution. Red crosses show mean percent covers for each class in each survey stratum; error bars are ±95% confidence intervals on the mean. Transects within each stratum are arranged in increasing cover of *P. rus*.

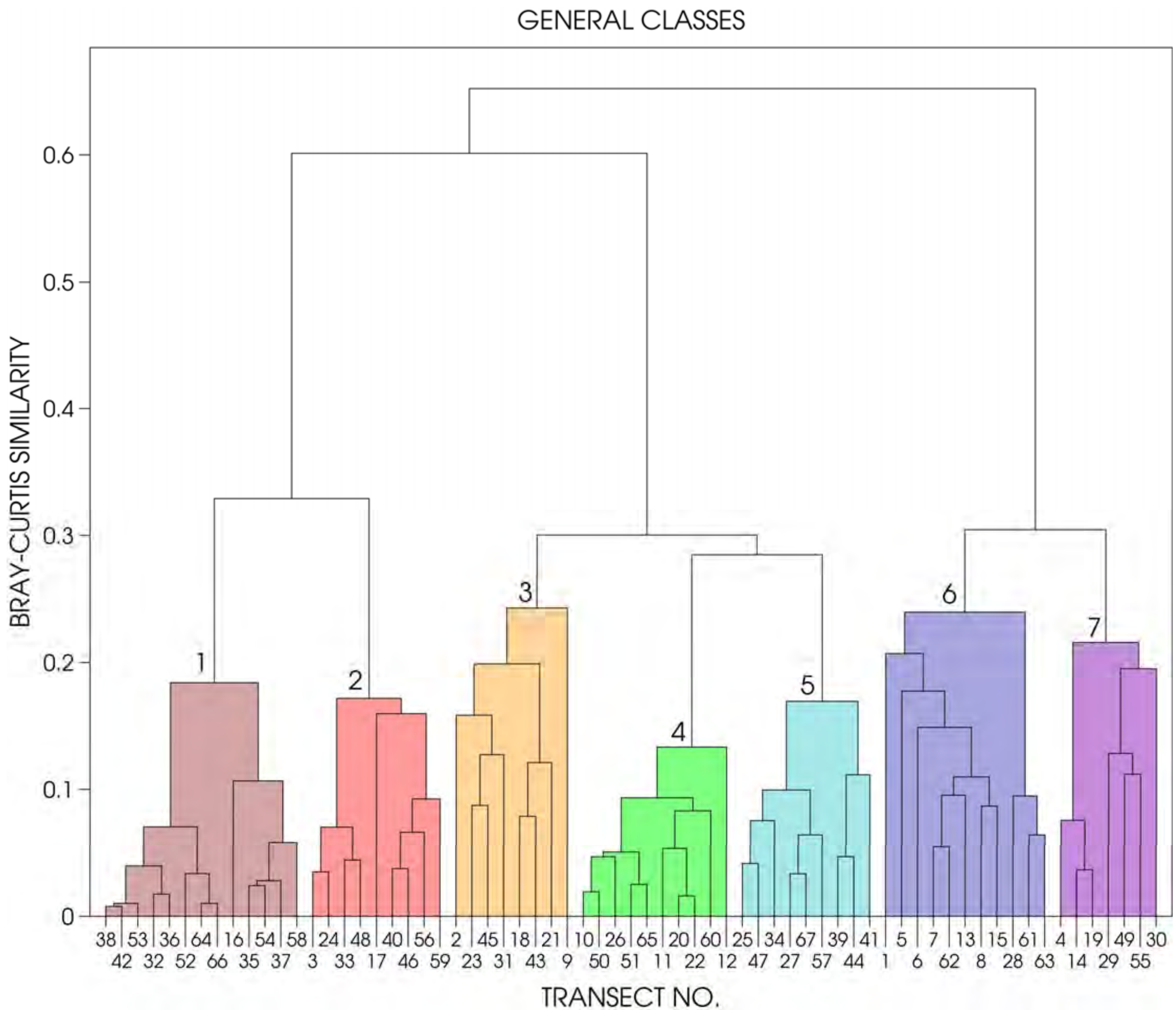


FIGURE 22. Cluster analysis dendrogram using percent covers of general classes. Vertical distances are calculated a pairwise Bray-Curtis similarity between 67 transects. Clusters are determined using average linkage and a threshold of 0.25. In general, sediment dominates clusters 1 and 2; algae dominates clusters 3, 4 and 5; and coral dominates clusters 6 and 7. See Table 5 for mean percent covers in each cluster.

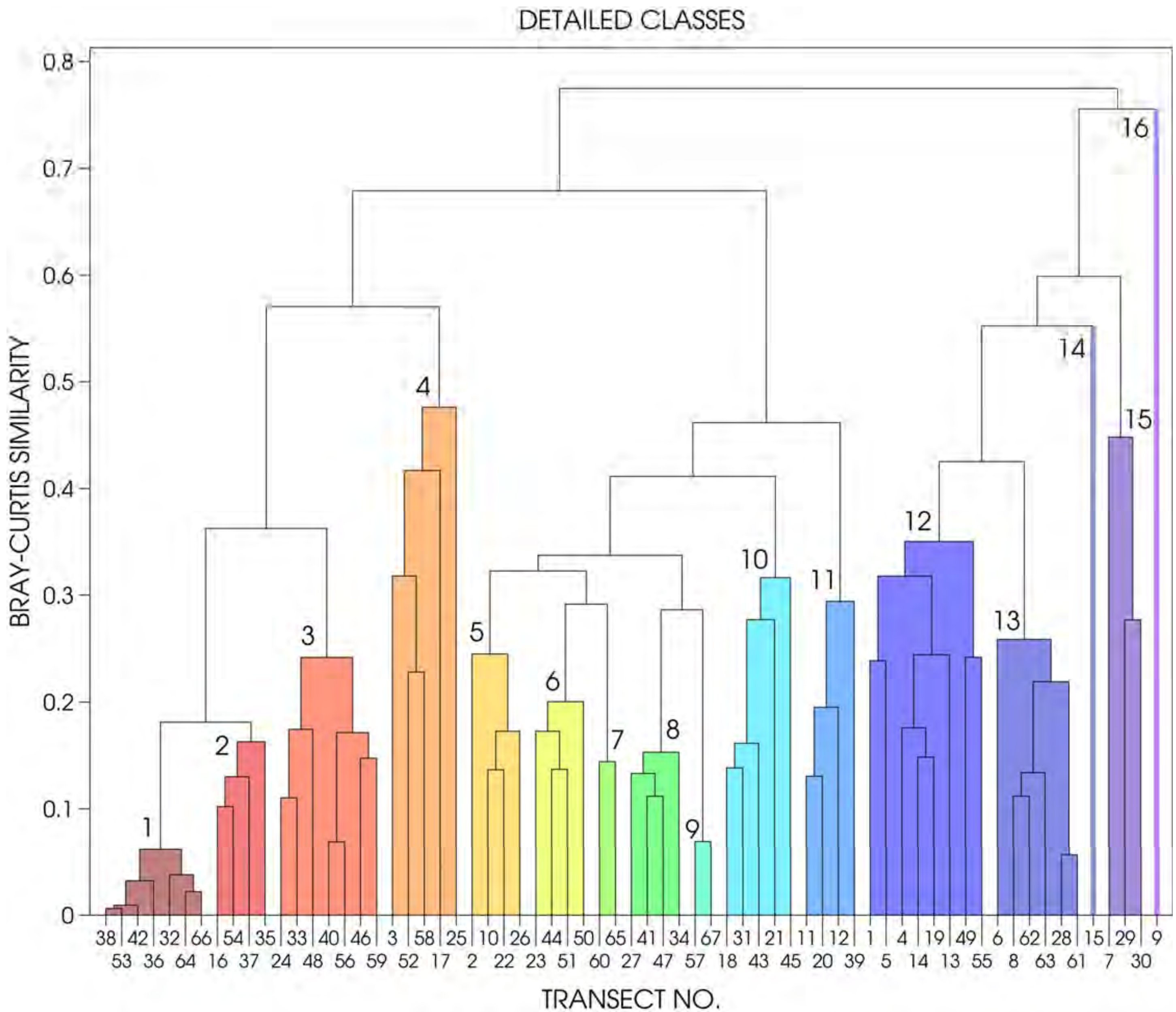


FIGURE 23. Cluster analysis dendrogram using percent covers of the subset of 10 detailed classes. Distances are calculated a pairwise Bray-Curtis similarity between transects. Clusters are determined using average linkage and visual inspection of dendrogram. See Table 5 for mean percent covers in each cluster.

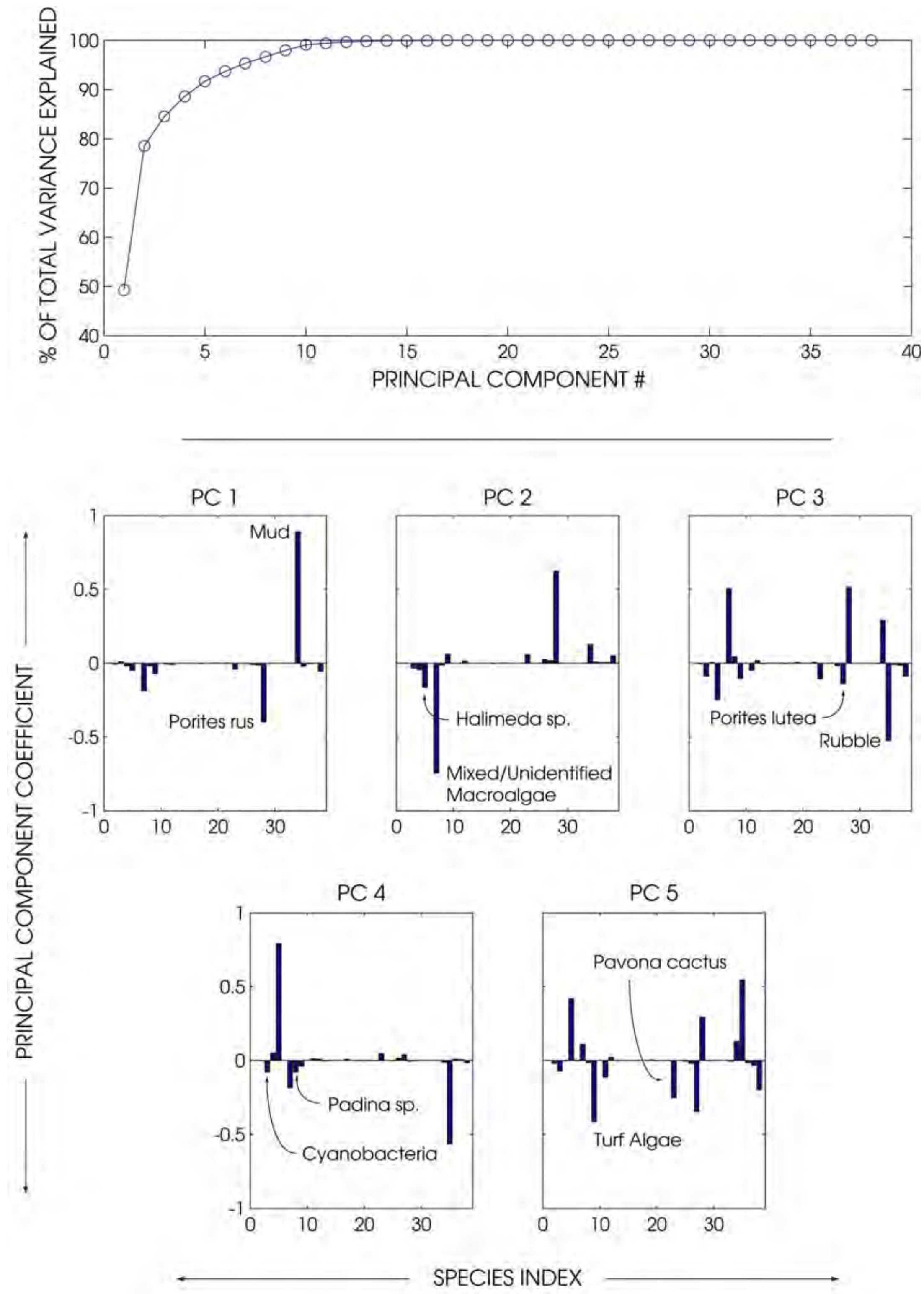


FIGURE 24. Selection of 10 detailed classes that contribute most to variance in the data set. Principal component analysis (PCA) was used to explain total variance in the detailed class percent cover data. The first five PCs describe >90% of the variance (virtually all of the variability in the data is described by the first 14 PCs) (Top). Plotting the coefficient value for each PC against the individual detailed classes, it is possible to identify which detailed classes are responsible for each PC, and thus which detailed classes are responsible for the variance in the whole data set (Bottom). In PC 1, the two detailed classes with the highest coefficient (absolute) values were mud and *Porites rus*. In PC 2, the two most important classes, other than the two from PC 1 (mud, *P. rus*), were mixed algae and *Halimeda* sp. In PC 3, the two most important additional classes were rubble and *P. lutea*. In PC 4, the two most important additional classes were *Padina* sp. and cyanobacteria. Finally, in PC 5, the two most important additional classes were turf algae and *Pavona cactus*.

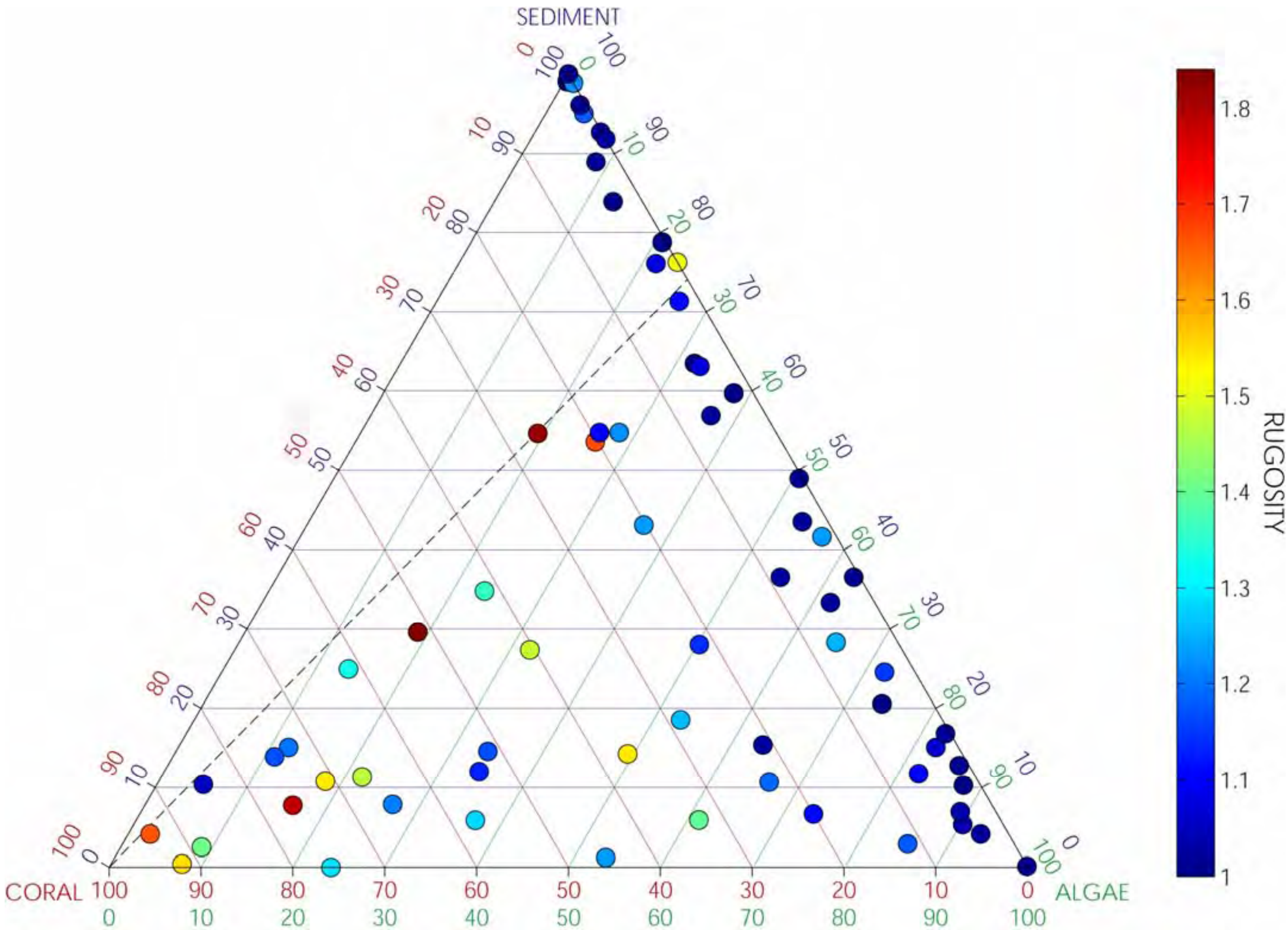


FIGURE 25. Ternary diagram showing relationship coral, algae and sediment percent cover at each transect. Vertices represent 100% cover of the respective classes. Edges of the triangle represent mixing lines between two classes, with the other class at 0% cover (e.g., the bottom of the triangle is mixing between coral and algae, with no sediment). Points within the triangle represent mixing between all three classes. The dashed line shows an apparent threshold in community structure: above the line, essentially no coral occurs. In addition, no coral occurs without the presence of algae. Color of points represents chain rugosity index. There is a weak trend of increasing rugosity with increasing coral cover.

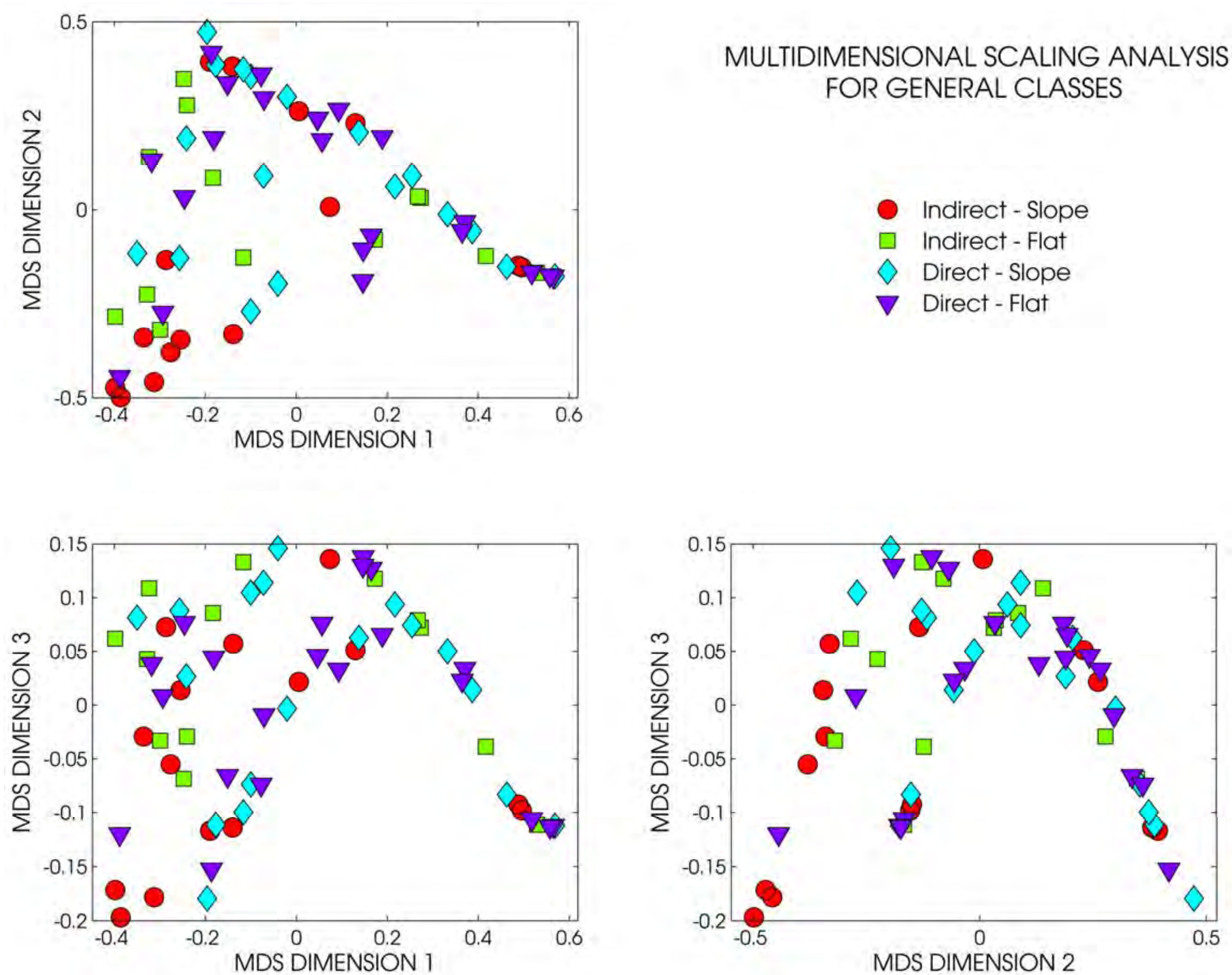


FIGURE 26. Plots of classical multidimensional scaling (CMDS), which give a qualitative sense of how near or far points are from each other, or in this case how similar the transect community structures are to each other. CMDS reduces the dimensionality of the data so that they can be displayed two-dimensionally. Each transect is represented by a single point representing six general classes, and transects that have similar benthic communities appear closer to each other than transects that are very different in terms of community structure. Comparisons of the first three dimensions indicate that clustering of points is not very evident, and the four strata appear evenly distributed across the data space. This indicates that there is no important difference between the different strata in terms of benthic community structure.

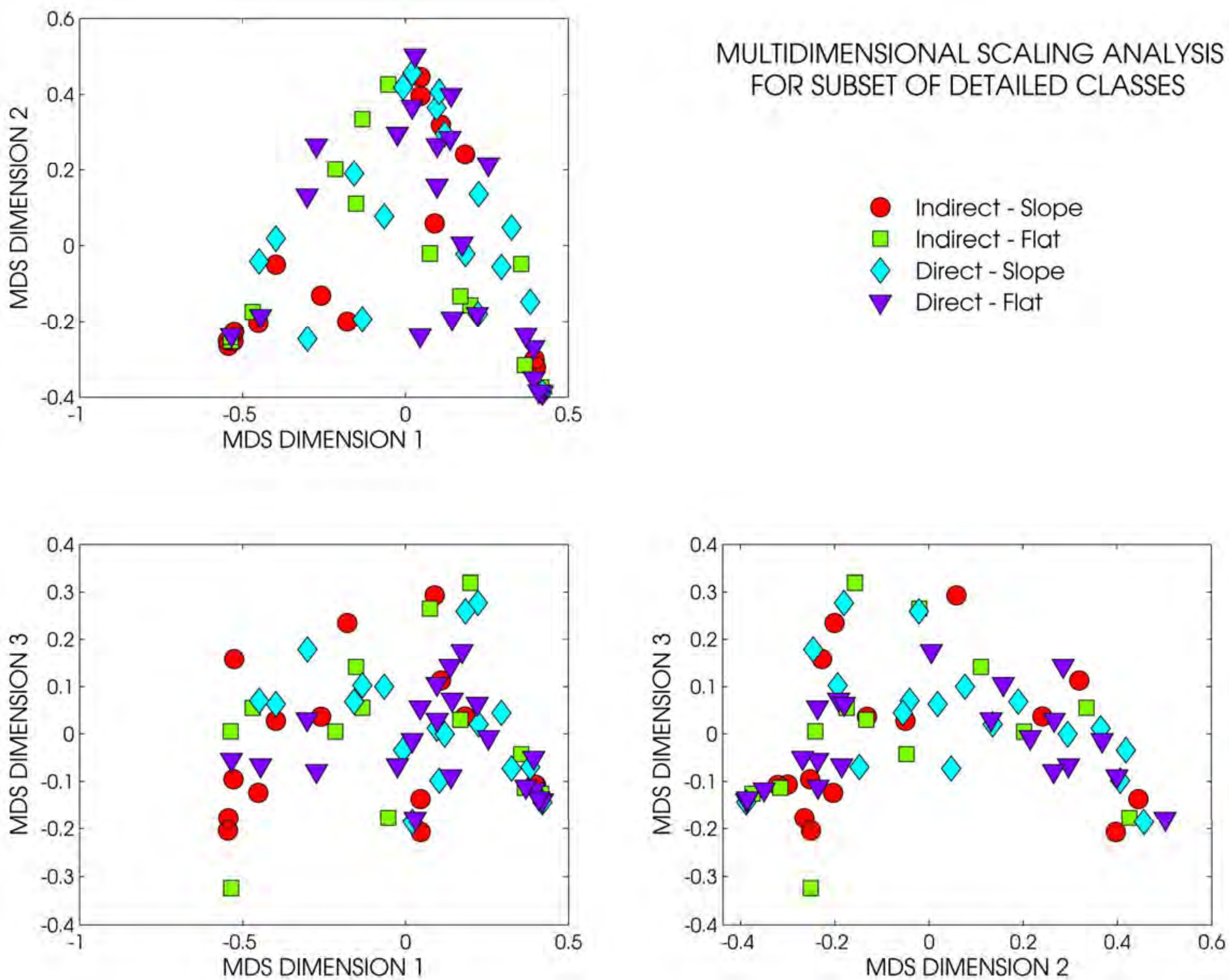


FIGURE 27. Plots of classical multidimensional scaling (CMDS), which give a qualitative sense of how near or far points are from each other, or in this case how similar the transect community structures are to each other. CMDS reduces the dimensionality of the data so that they can be displayed two-dimensionally. Each transect is represented by a single point representing ten detailed classes, and transects that have similar benthic communities appear closer to each other than transects that are very different in terms of community structure. Comparisons of the first three dimensions indicate that clustering of points is not very evident, and the four strata appear evenly distributed across the data space. This indicates that there is no important difference between the different strata in terms of benthic community structure.

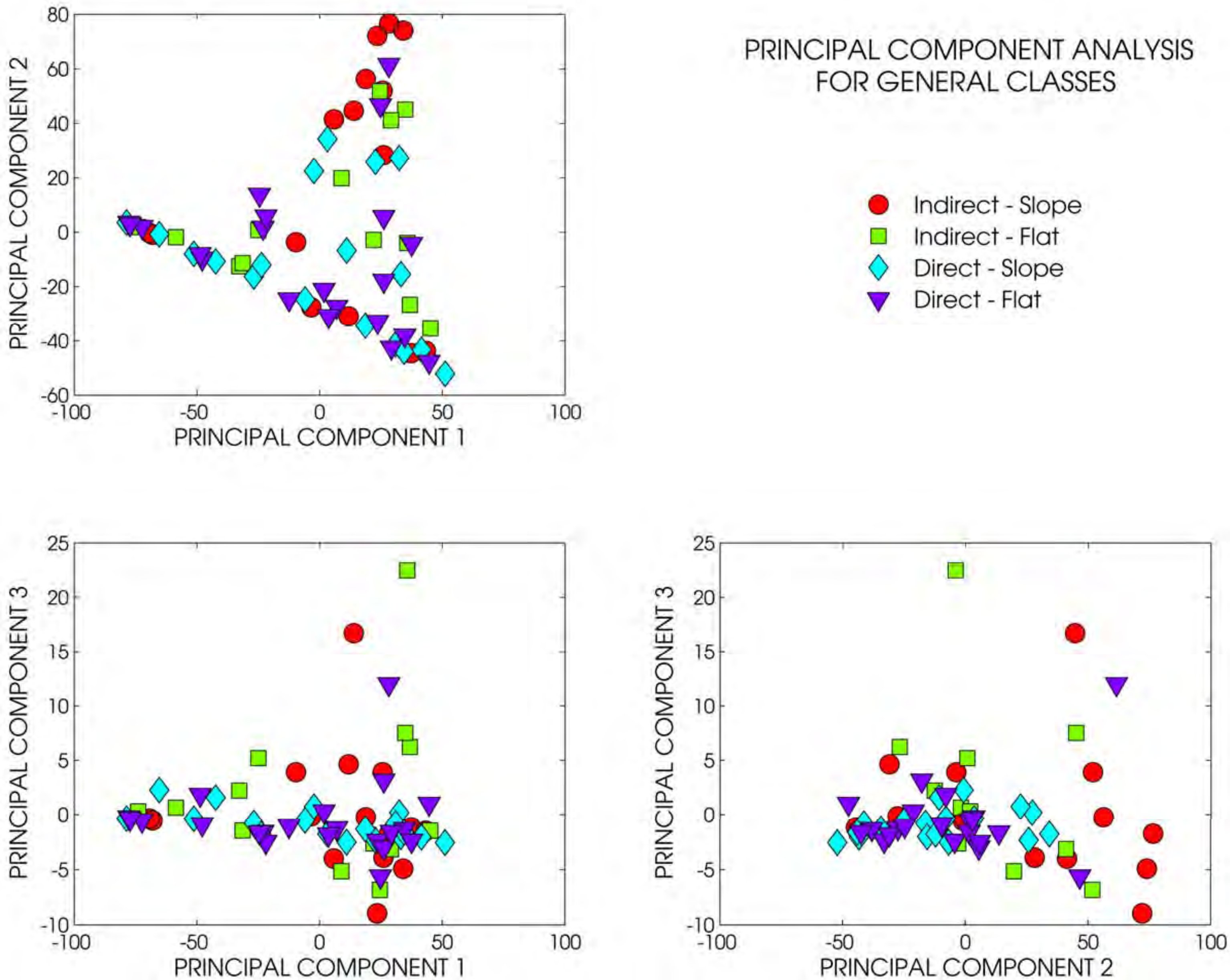


FIGURE 28. Plots of component analysis (PCA) that reduce the dimensionality of the data space for six general classes. As with multidimensional scaling, these plots also give a qualitative representation of the similarities between transects. Again, there are no apparent trends or clusters, indicating no overall differences between strata.

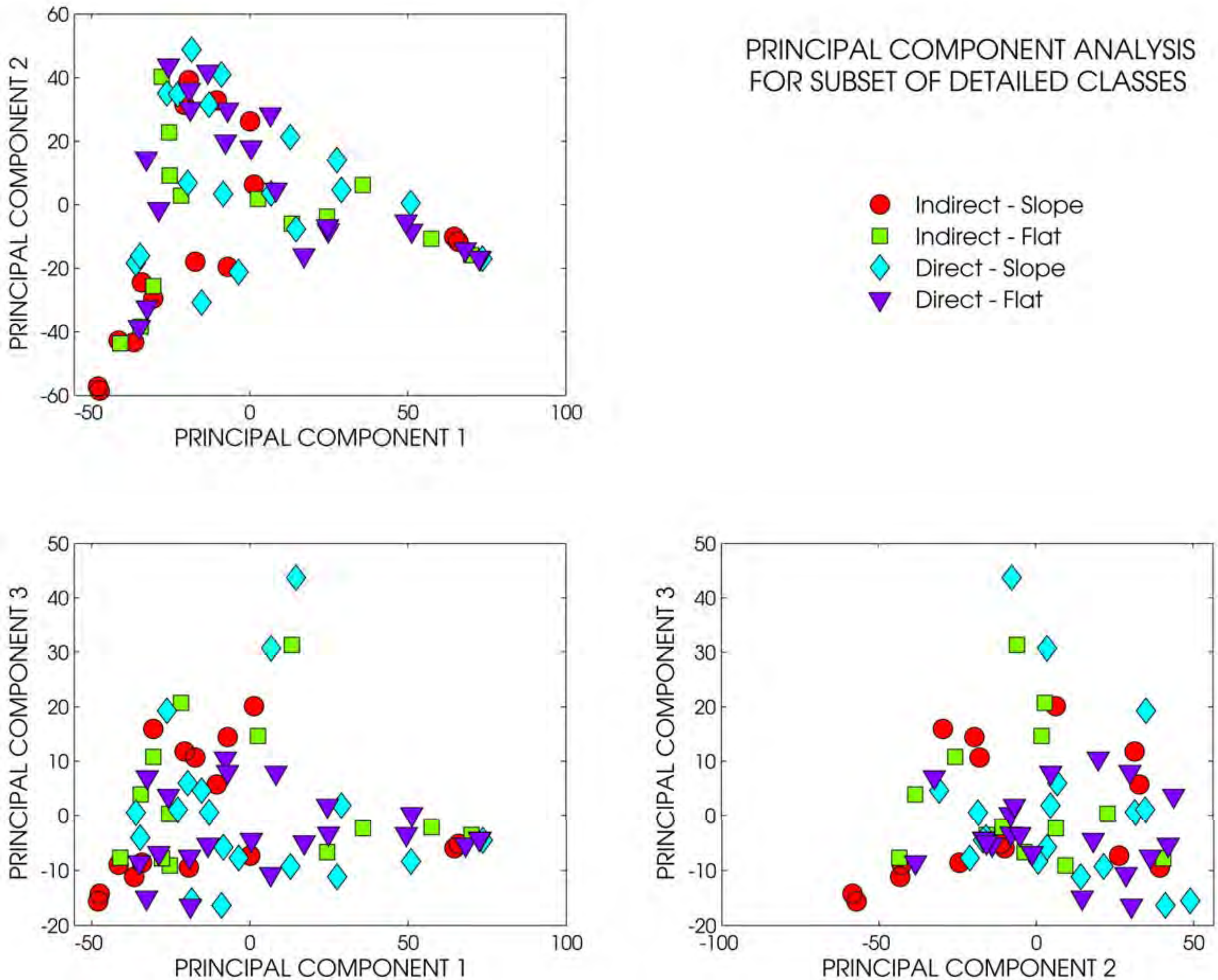


FIGURE 29. Plots of component analysis (PCA) that reduce the dimensionality of the data space for ten detailed classes. As with multidimensional scaling, these plots also give a qualitative representation of the similarities between transects. Again, there are no apparent trends or clusters, indicating no overall differences between strata.

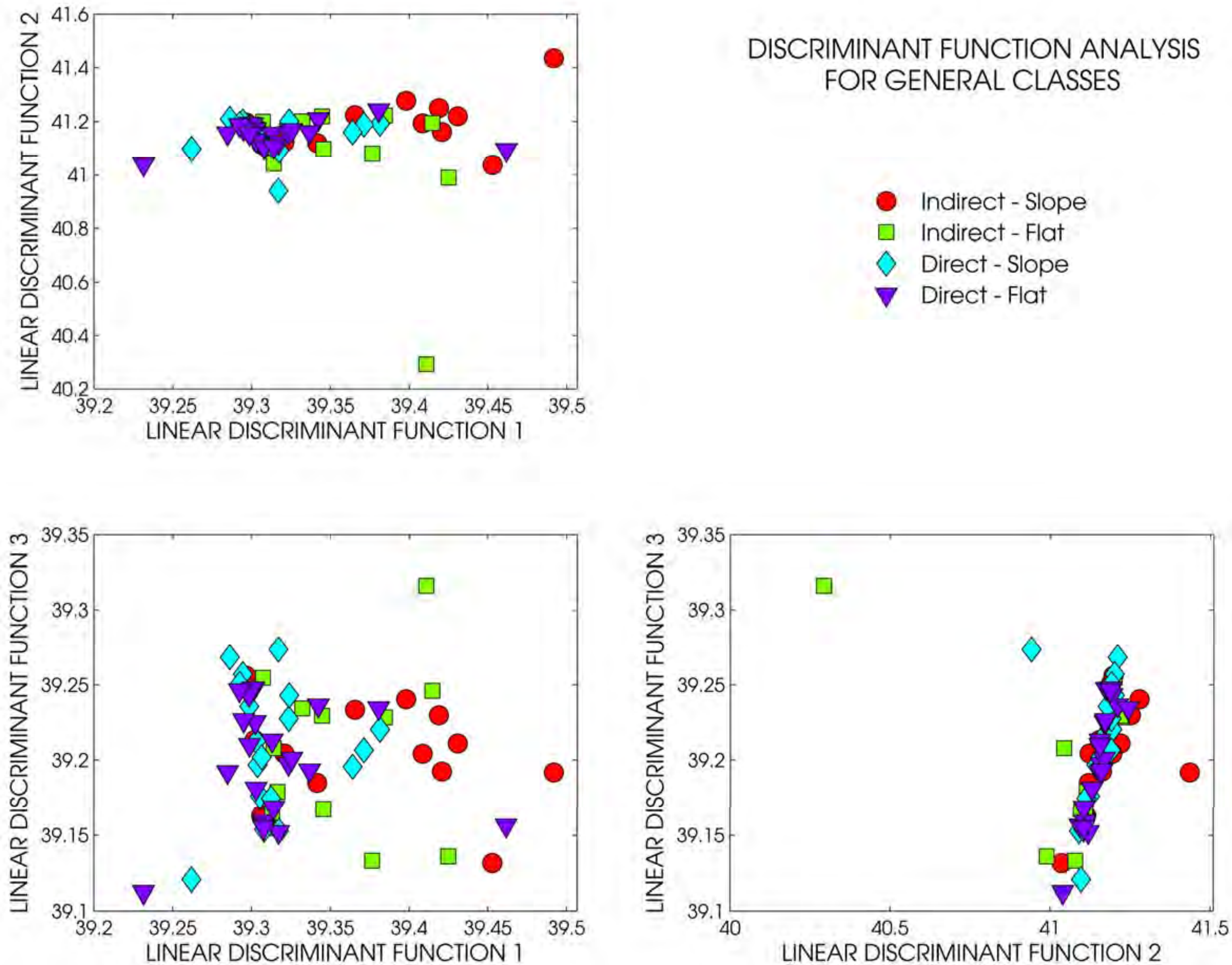


FIGURE 30. Plots showing results of discriminant function analysis (DFA) performed using six general classes. DFA describes the separation of two or more predefined groups based on linear functions of multiple variables. In this case, the discriminant functions do not separate the strata, and thus the strata are not statistically different from each other in terms of benthic community structure

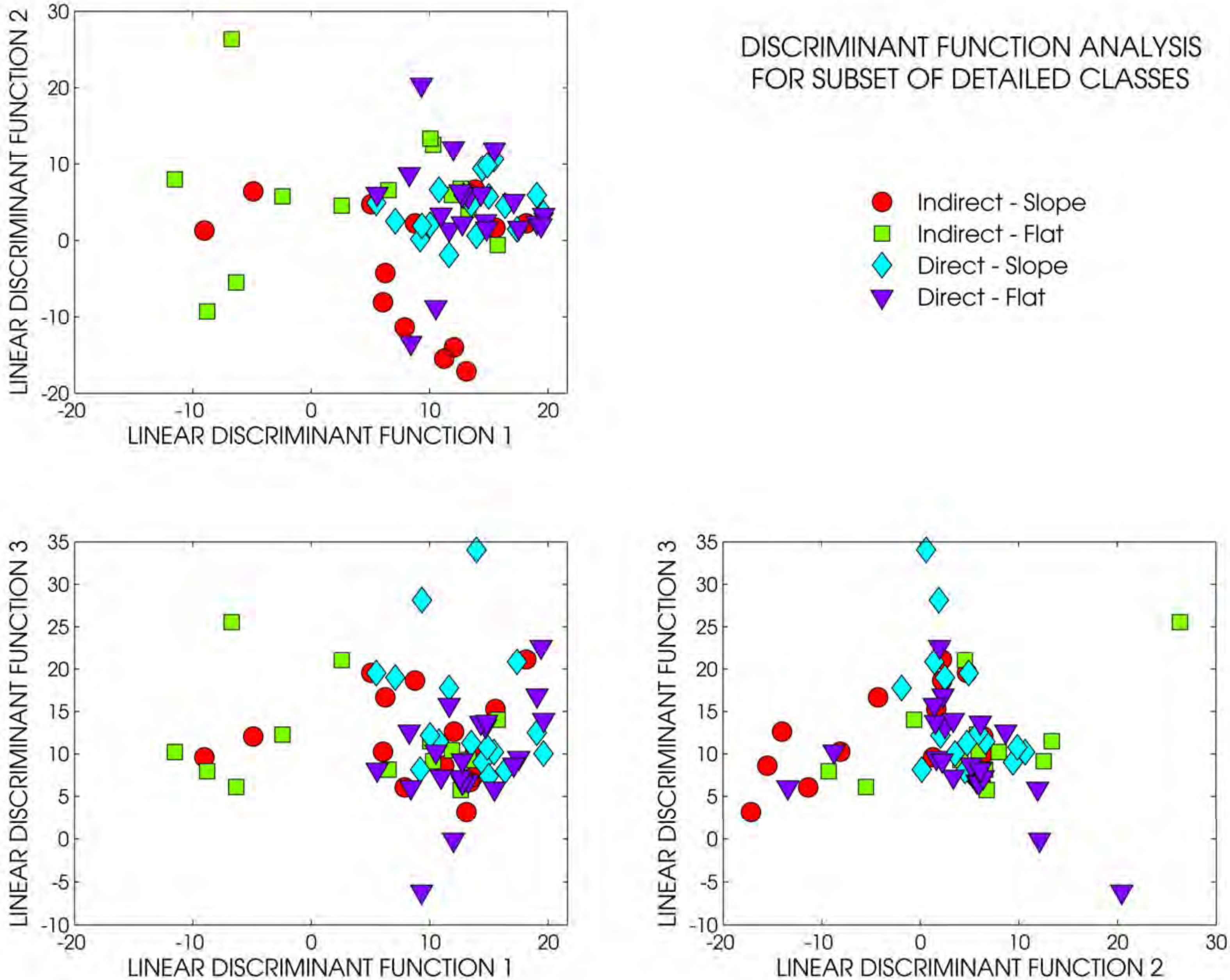


FIGURE 31. Plots showing results of discriminant function analysis (DFA) performed using ten detailed classes. DFA describes the separation of two or more predefined groups based on linear functions of multiple variables. In this case, the discriminant functions do not separate the strata, and thus the strata are not statistically different from each other in terms of benthic community structure

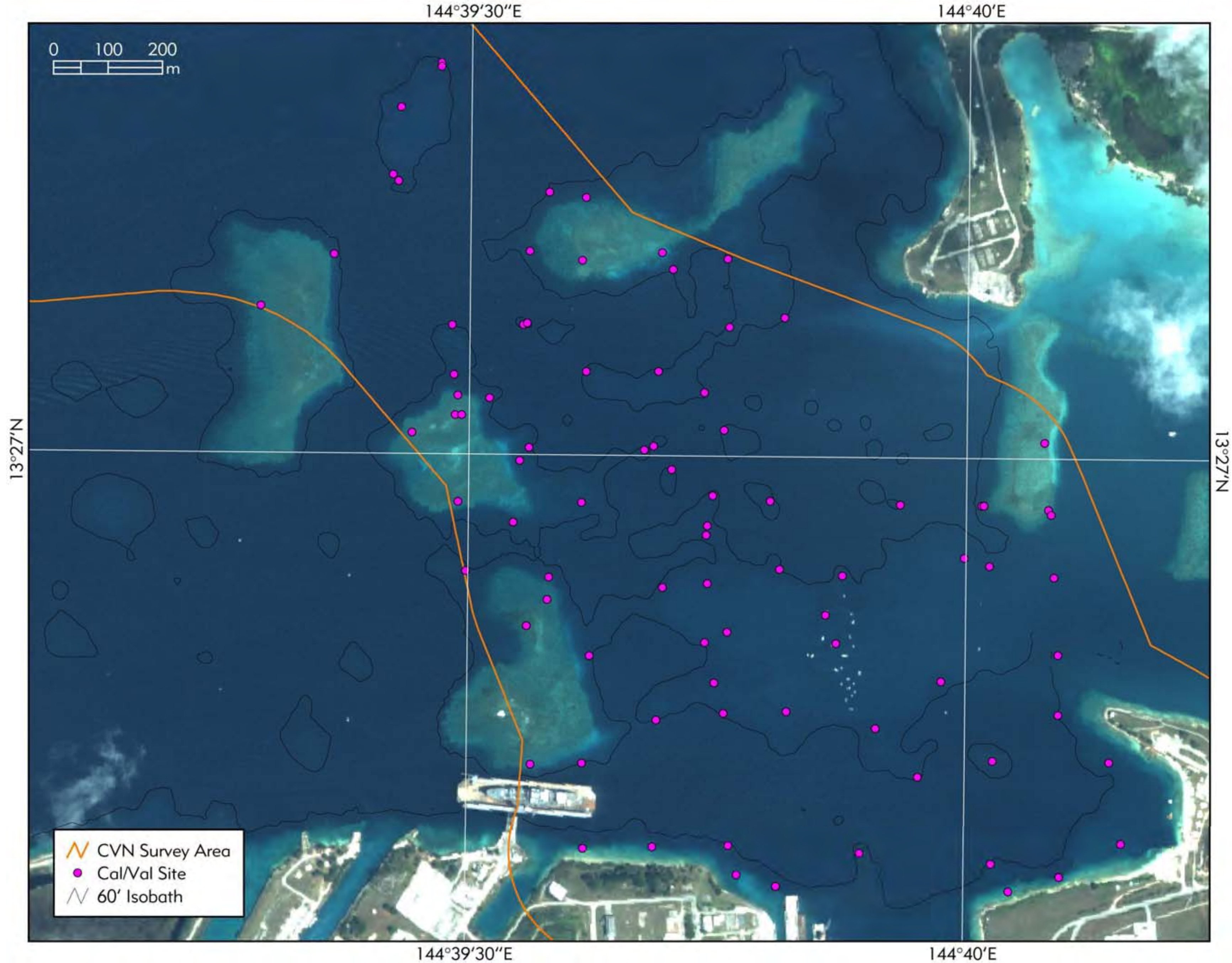


FIGURE 32. Satellite image of CVN region of Apra Harbor showing locations of calibration-validation sites used for generating classifiers for benthic habitat maps.

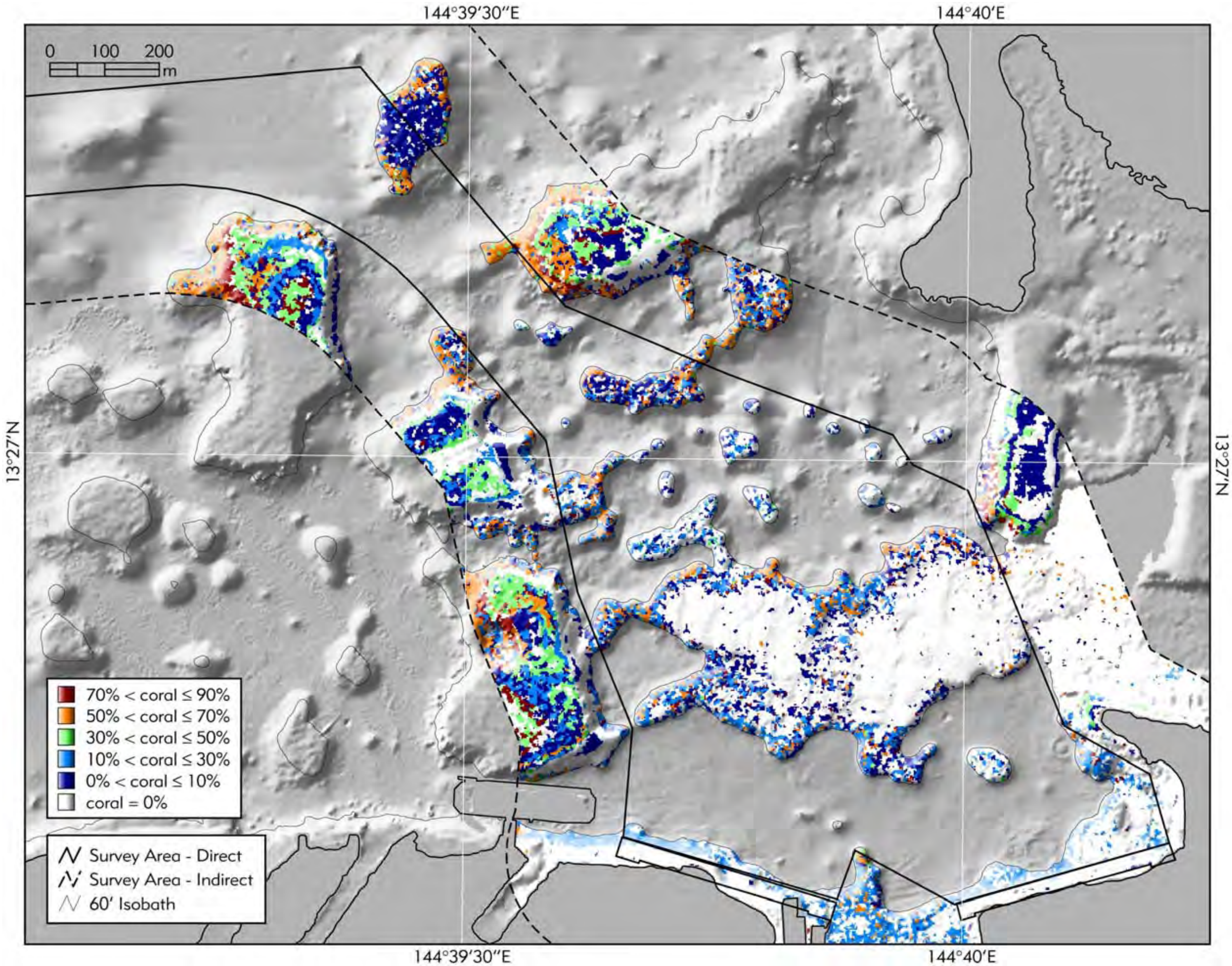


FIGURE 33. Classification map showing percent cover of coral in CVN survey area. Cal/val data were co-located with pixels in the Quickbird image, which were used to build a set of classification rules (quadratic classifier using Mahalanobis distance). The classification rules were applied to the entire Quickbird image. The resulting map was masked to show only the reef surface within the study area to a depth of 60 feet.

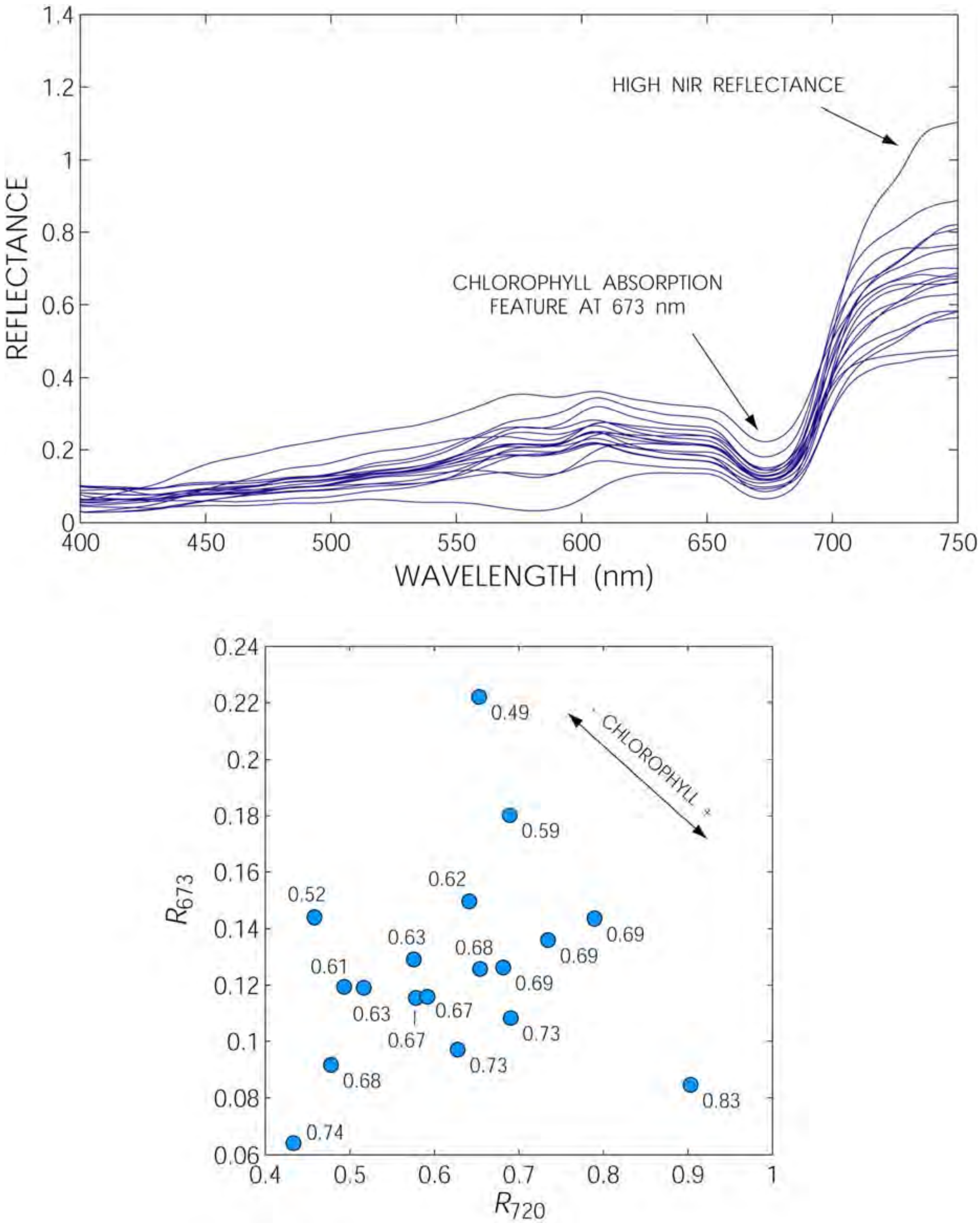


FIGURE 34. Example of NDVI (Normalized Difference Vegetation Index) for selected corals in CVN survey. Top panel shows spectral reflectance of 18 different corals. Higher reflectance indicates brighter/paler color. Even though some corals are brighter than others, all corals have a strong chlorophyll signature, evidenced by an absorption feature at 673 nm and high NIR reflectance. Bottom panel shows R_673 plotted against R_720 for each of the corals in the top panel. Each dot is labeled with its corresponding NDVI value. Chlorophyll concentration increases toward the bottom right and decreases toward the top left of the plot.

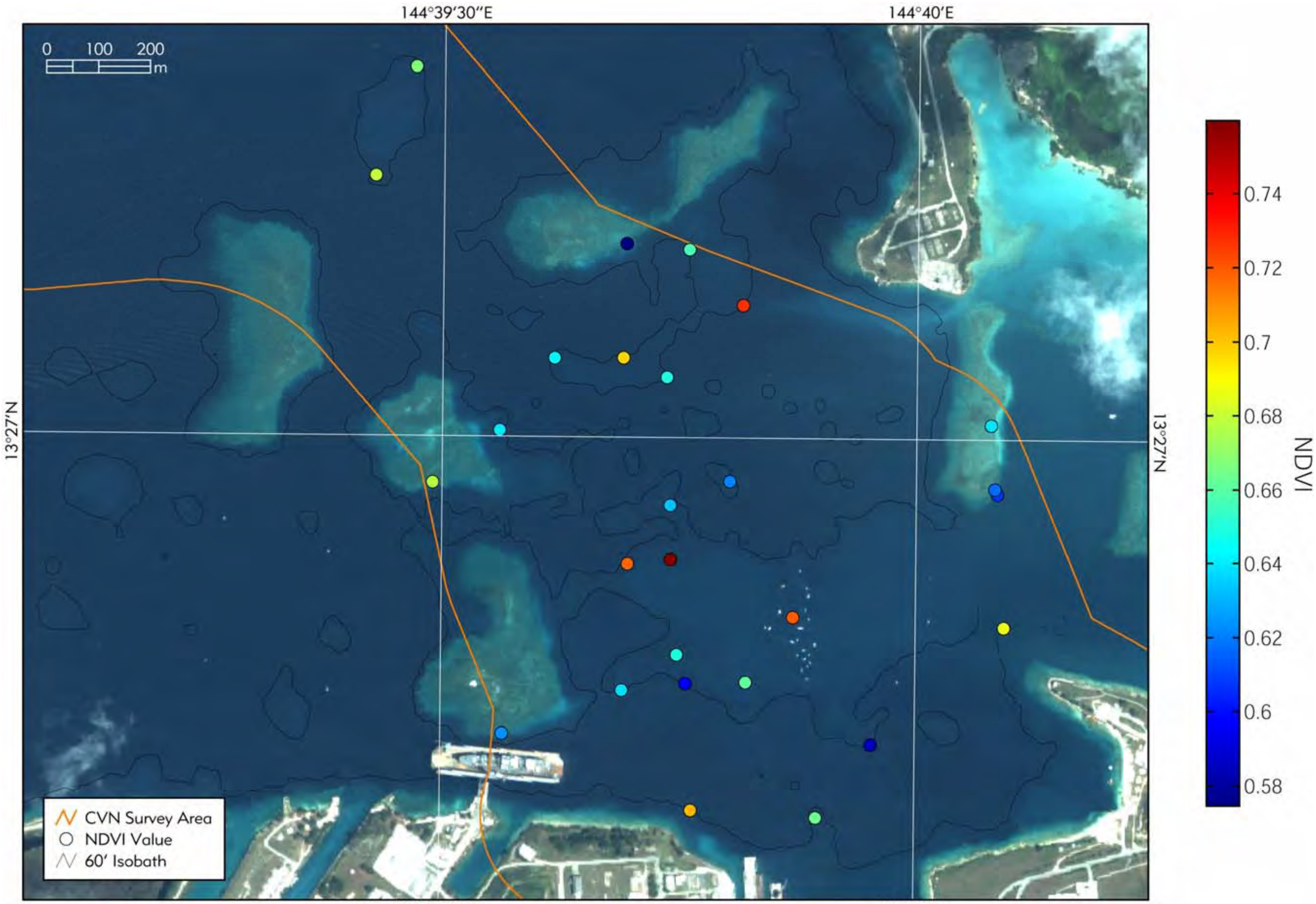


FIGURE 35. Normalized Difference Vegetation Index (NDVI) for 27 sites in CVN survey area. NDVI is computed from spectral reflectances of corals measured in situ. It is a relative scale indicating amount of chlorophyll present; higher values indicate more chlorophyll. Values are averages of 4-6 corals at each site.There is no apparent trend in the horizontal spatial distribution of NDVI, though all values in this study would be generally considered to represent high chlorophyll content. NDVI does increase slightly with depth (not shown).

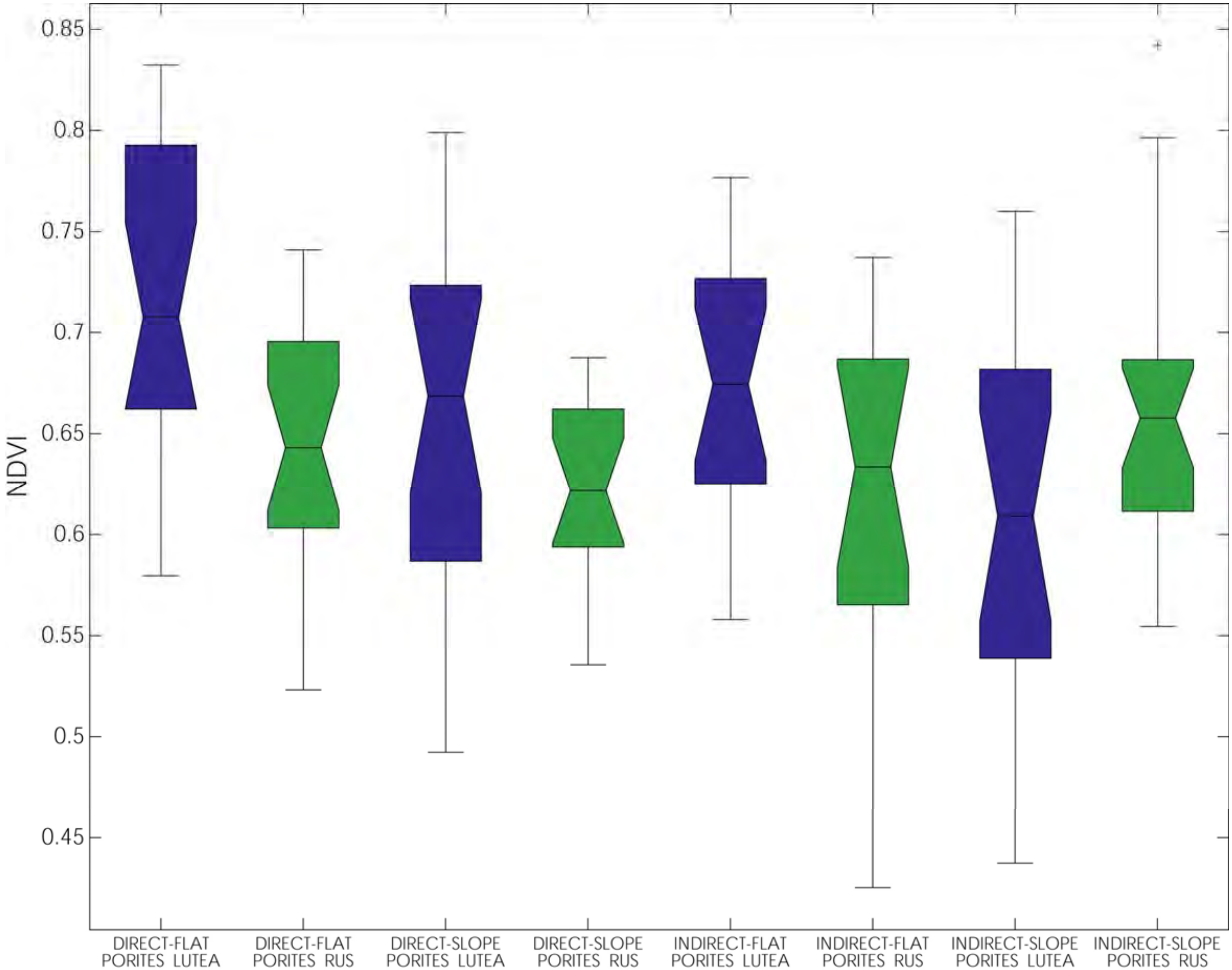


FIGURE 36. Distribution of Normalized Difference Vegetation Index (NDVI) by survey strata for the two most abundant corals (*Porites rus* [green*]*, *P. lutea* [blue]) in the CVN survey area. On each box, the central mark is the median, the upper and lower edges of the box are the first and third quartiles, respectively, the whiskers extend to the most extreme data points not considered outliers, and outliers are plotted individually. Following the 1.5*IQR rule, there is only a single outlier, occurring in Indirect-Slope/*Porites rus*. All of the corals in all of the strata generally share the same range of NDVI, though within strata *P. lutea* tends to have a slightly wider distribution and slightly higher values.

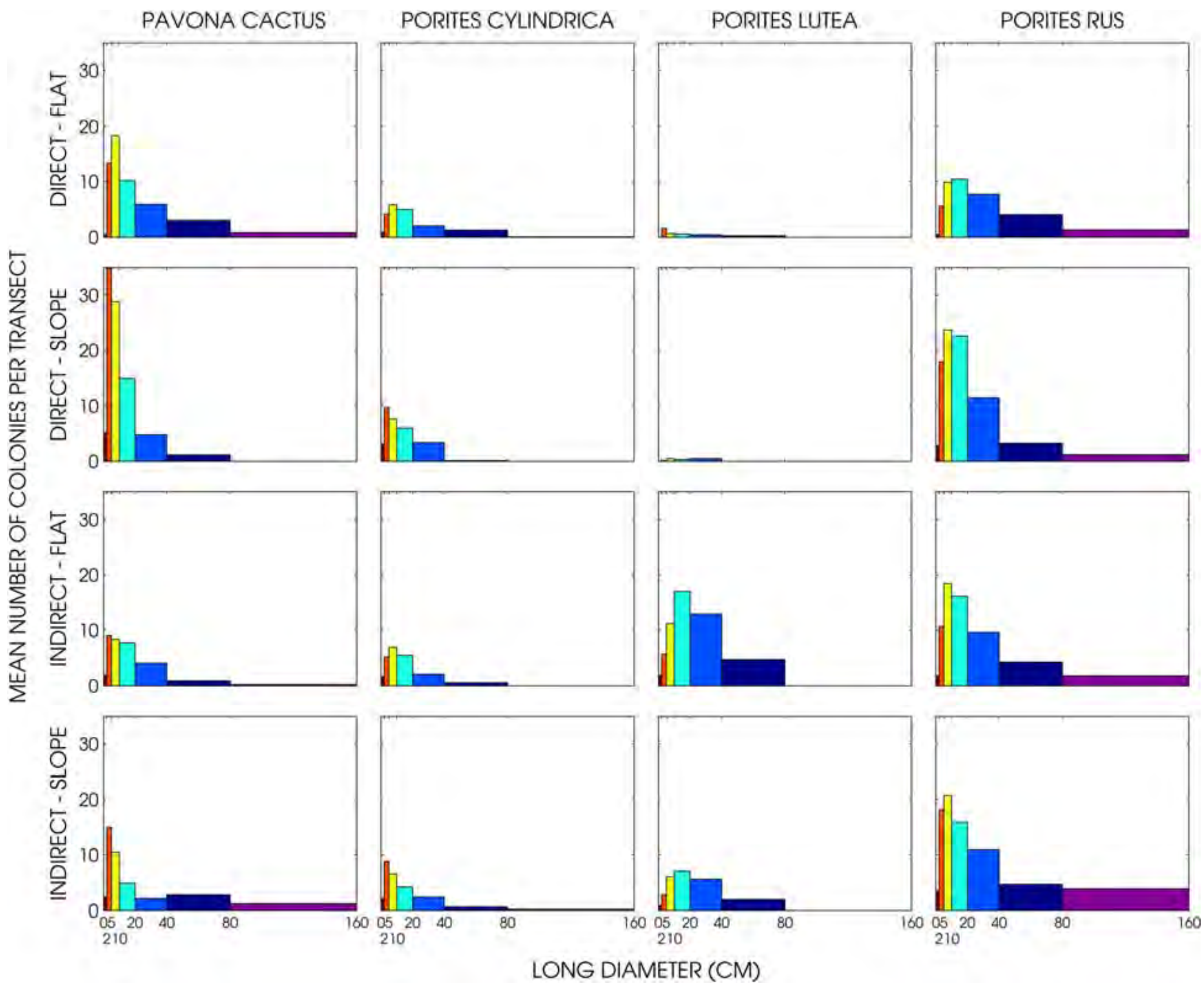


FIGURE 37. Size-frequency distribution of the four most abundant corals in Apra survey area. Histograms are arranged left-to-right by coral species and top-to-bottom by survey stratum. Histograms show mean values determined across all transects within a given stratum. Size classes are x < 2, 2 ≤ x < 5, 5 ≤ x < 10, 10 ≤ x < 20, 20 ≤ x < 40, 40 ≤ x < 80, and 80 ≤ x < 160.

FIGURE 38. Four photographs of large sponges common in Apra Harbor. Blue "elephant ear" sponges (*Ianthella* sp.) commonly occur in the deeper regions of the Apra Harbor turning basin. The upper photos are from Transect 31, photo at lower left from Transect 56, and photo at lower right from Transect 1.

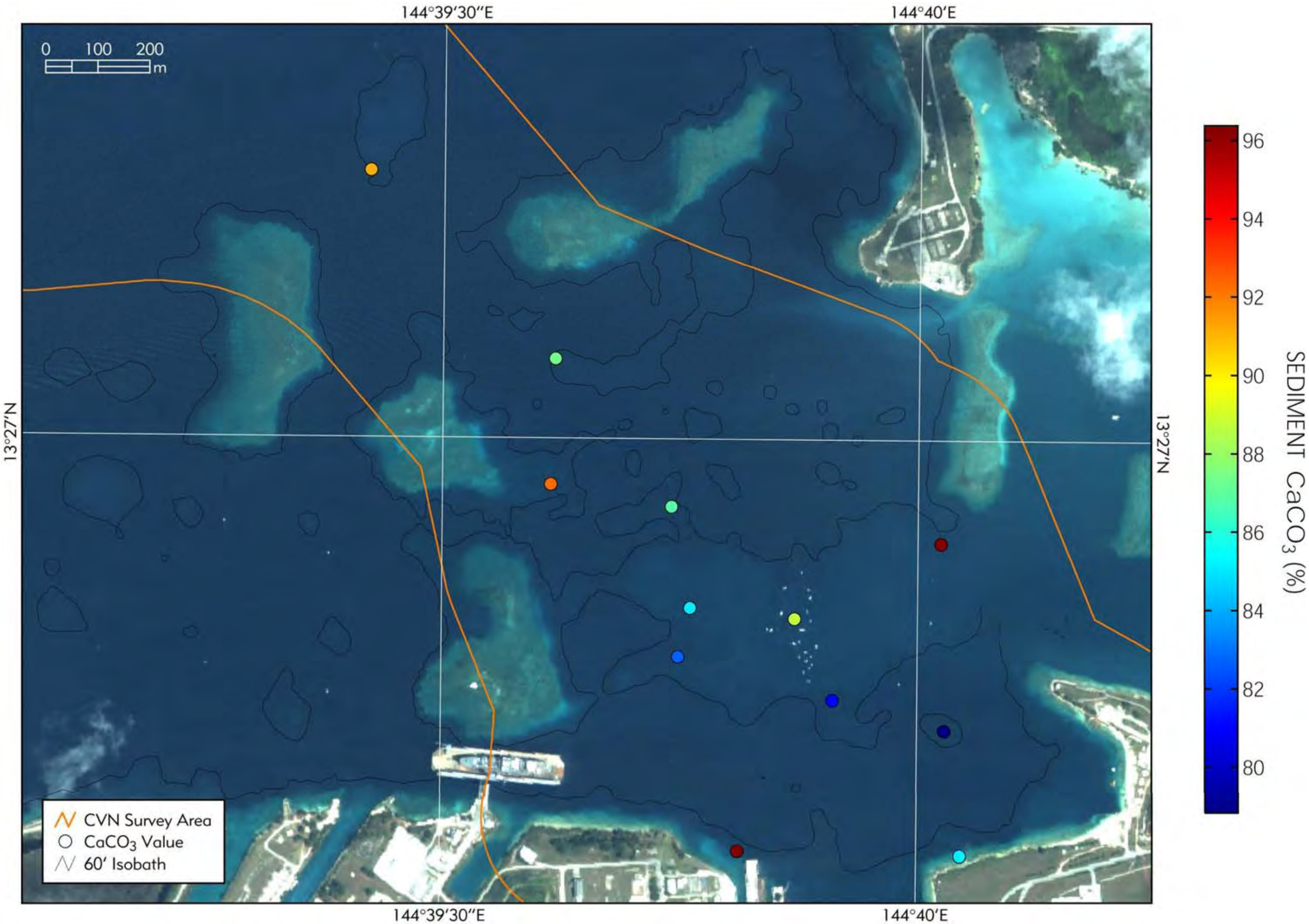


FIGURE 39. CVN survey area showing percent of $CaCO_3$ in surface sediment samples collected at twelve transect sites.

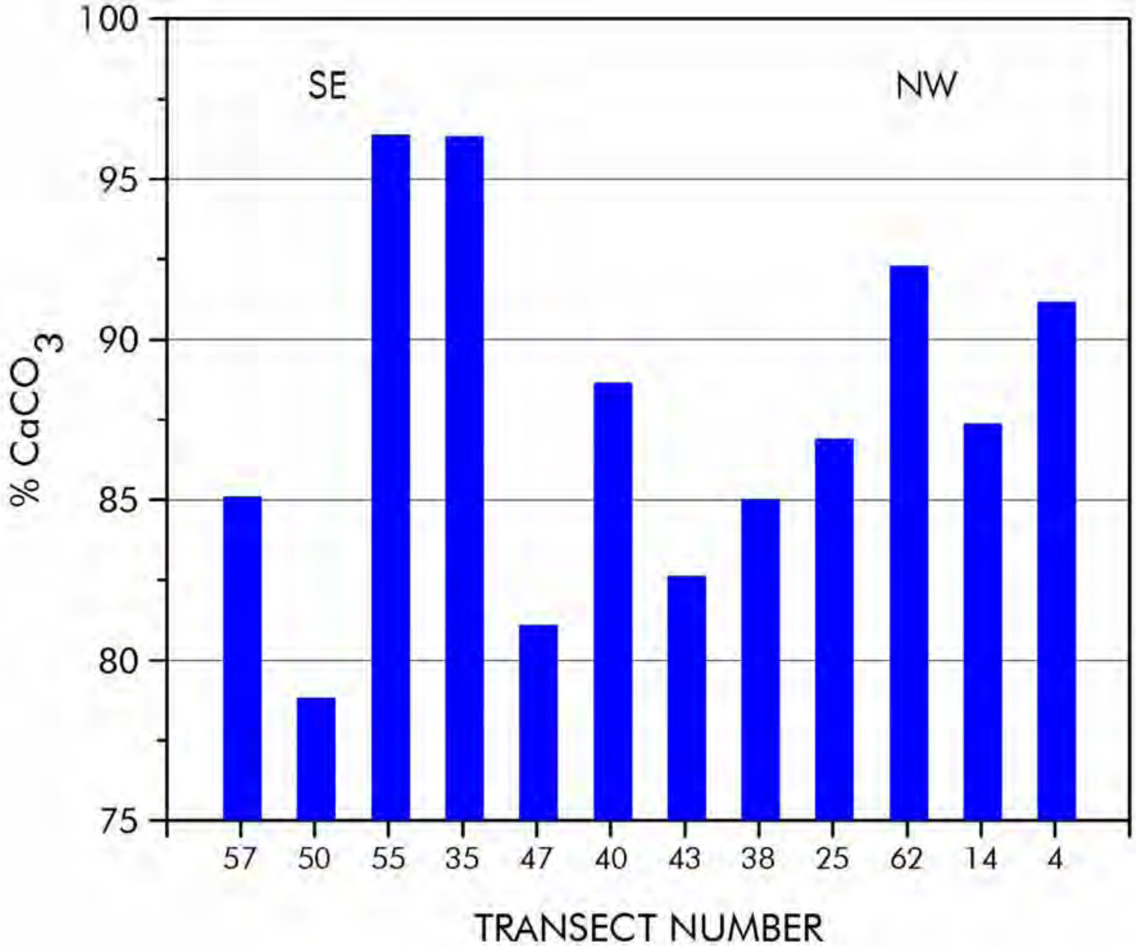


FIGURE 40. Percent calcium carbonate composition of sediment samples collected at 12 transect locations with the Direct Impact strata of the CVN study area in southeastern Apra Harbor, Guam. Sampling locations extended from the southeast (SE) to northwest (NW) from near the mouth of Inner Apra Harbor to the submerged patch reef at the northern end of the Fairway. For location of sampled transects, see Figure 39.

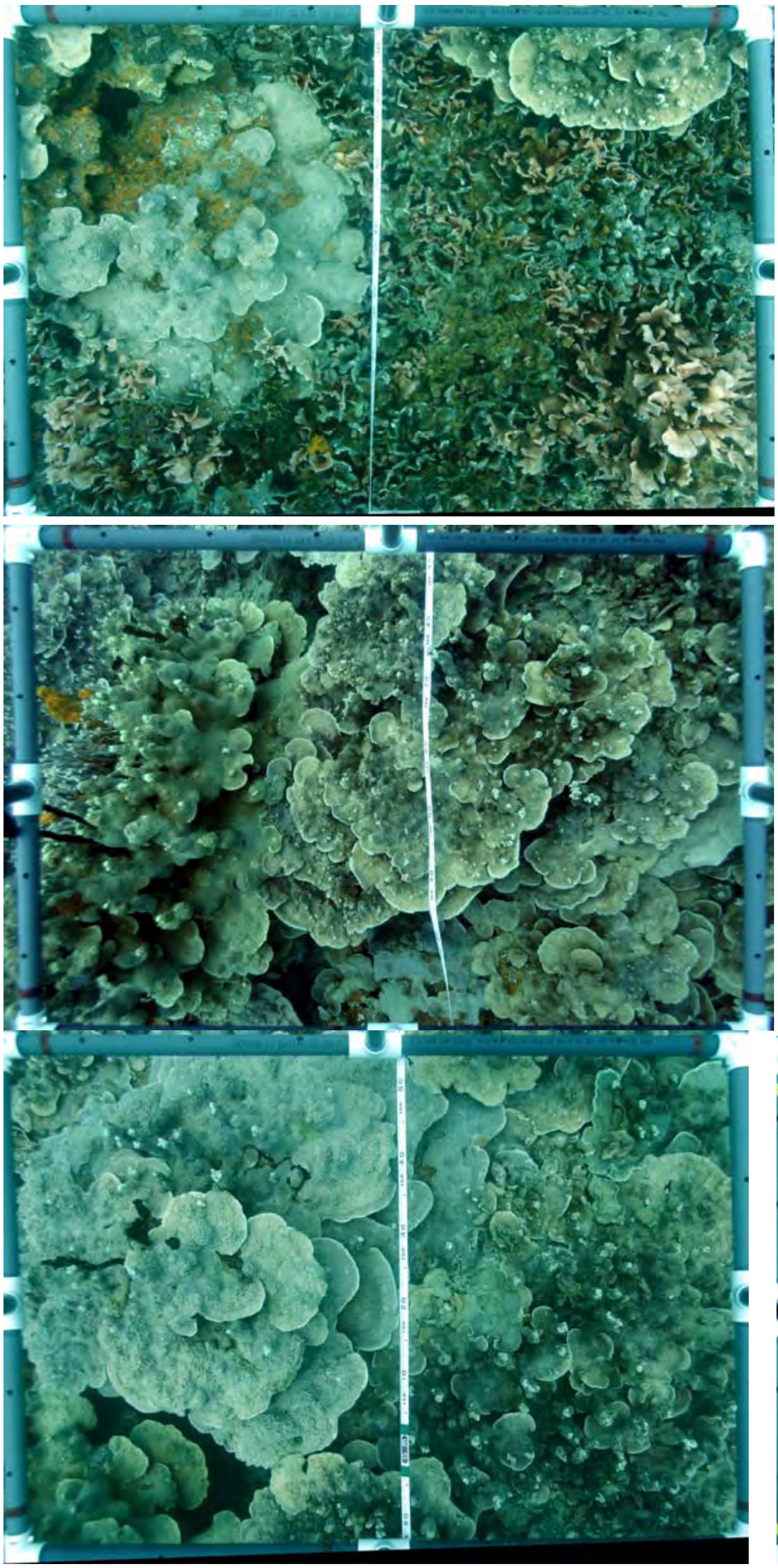
APPENDICES

BENTHIC SURVEYS OF SOUTHEASTERN APRA HARBOR IN THE VICINITY OF THE CVN PROJECT

Jyly 2009

APPENDIX A. Coordinates and strata designations for 67 transect sites in southeastern outer Apra Harbor surveyed for CVN benthic assessment.

TRANSECT NUMBER	LABEL	LATITUDE	LONGITUDE	STRATA		DEPTH
				Direct/Indirect	Flat/Slope	(ft)
1	CVN-I-S1	13.4565	144.6578	Indirect	Slope	55
2	CVN-I-F1	13.4564	144.6578	Indirect	Flat	52
3	CVN-I-F2	13.4557	144.6571	Indirect	Flat	47
4	CVN-D-S1	13.4546	144.6570	Direct	Slope	58
5	CVN-D-F1	13.4545	144.6571	Direct	Flat	57
6	CVN-I-F3	13.4543	144.6602	Indirect	Flat	11
7	CVN-I-F4	13.4532	144.6602	Indirect	Flat	3
8	CVN-I-S2	13.4533	144.6560	Indirect	Slope	22
9	CVN-I-F5	13.4524	144.6548	Indirect	Flat	8
10	CVN-D-S2	13.4521	144.6580	Direct	Slope	60
11	CVN-D-F2	13.4522	144.6592	Direct	Flat	55
12	CVN-D-S3	13.4522	144.6593	Direct	Slope	57
13	CVN-I-F6	13.4513	144.6580	Indirect	Flat	46
14	CVN-D-S4	13.4514	144.6603	Direct	Slope	54
15	CVN-I-S3	13.4501	144.6593	Indirect	Slope	51
16	CVN-I-F7	13.4499	144.6592	Indirect	Flat	45
17	CVN-I-S4	13.4534	144.6615	Indirect	Slope	11
18	CVN-I-F8	13.4533	144.6626	Indirect	Flat	57
19	CVN-I-S5	13.4523	144.6636	Indirect	Slope	56
20	CVN-I-S6	13.4521	144.6627	Indirect	Slope	55
21	CVN-D-S5	13.4514	144.6615	Direct	Slope	56
22	CVN-D-S6	13.4511	144.6623	Direct	Slope	57
23	CVN-D-F3	13.4502	144.6614	Direct	Flat	60
24	CVN-I-F9	13.4503	144.6680	Indirect	Flat	2
25	CVN-D-F4	13.4488	144.6623	Direct	Flat	48
26	CVN-D-F5	13.4493	144.6634	Direct	Flat	48
27	CVN-D-S7	13.4492	144.6656	Direct	Slope	58
28	CVN-I-S7	13.4492	144.6670	Indirect	Slope	37
29	CVN-I-F10	13.4492	144.6681	Indirect	Flat	5
30	CVN-I-S8	13.4491	144.6681	Indirect	Slope	12
31	CVN-D-F6	13.4478	144.6616	Direct	Flat	49
32	CVN-D-F7	13.4479	144.6623	Direct	Flat	47
33	CVN-D-S8	13.4481	144.6636	Direct	Slope	58
34	CVN-D-F8	13.4480	144.6646	Direct	Flat	48
35	CVN-D-F9	13.4482	144.6671	Direct	Flat	49
36	CVN-I-F11	13.4480	144.6682	Indirect	Flat	51
37	CVN-D-S9	13.4469	144.6623	Direct	Slope	53
38	CVN-D-F10	13.4471	144.6627	Direct	Flat	46
39	CVN-D-F11	13.4474	144.6643	Direct	Flat	50
40	CVN-D-F12	13.4469	144.6645	Direct	Flat	48
41	CVN-I-S9	13.4467	144.6683	Indirect	Slope	42
42	CVN-D-F13	13.4463	144.6663	Direct	Flat	44
43	CVN-D-F14	13.4462	144.6625	Direct	Flat	44
44	CVN-D-S10	13.4456	144.6615	Direct	Slope	59
45	CVN-D-S11	13.4457	144.6626	Direct	Slope	48
46	CVN-D-F15	13.4458	144.6637	Direct	Flat	48
47	CVN-D-F16	13.4455	144.6652	Direct	Flat	47
48	CVN-D-S12	13.4458	144.6683	Direct	Slope	58
49	CVN-D-S13	13.4450	144.6691	Direct	Slope	35
50	CVN-D-F17	13.4450	144.6672	Direct	Flat	48
51	CVN-D-S14	13.4447	144.6659	Direct	Slope	51
52	CVN-D-S15	13.4435	144.6615	Direct	Slope	14
53	CVN-D-S16	13.4436	144.6627	Direct	Slope	56
54	CVN-D-F18	13.4431	144.6629	Direct	Flat	24
55	CVN-D-S17	13.4429	144.6635	Direct	Slope	30
56	CVN-I-F12	13.4434	144.6650	Indirect	Flat	48
57	CVN-D-F19	13.4428	144.6675	Direct	Flat	3
58	CVN-D-S18	13.4431	144.6683	Direct	Slope	14
59	CVN-D-F20	13.4436	144.6694	Direct	Flat	34
60	CVN-I-F13	13.4492	144.6581	Indirect	Flat	3
61	CVN-I-S10	13.4489	144.6590	Indirect	Slope	37
62	CVN-D-F21	13.4492	144.6602	Direct	Flat	37
63	CVN-I-S11	13.4481	144.6583	Indirect	Slope	49
64	CVN-I-S12	13.4467	144.6604	Indirect	Slope	49
65	CVN-I-S13	13.4449	144.6594	Indirect	Slope	5
66	CVN-I-S14	13.4449	144.6602	Indirect	Slope	60
67	CVN-I-S15	13.4435	144.6603	Indirect	Slope	9



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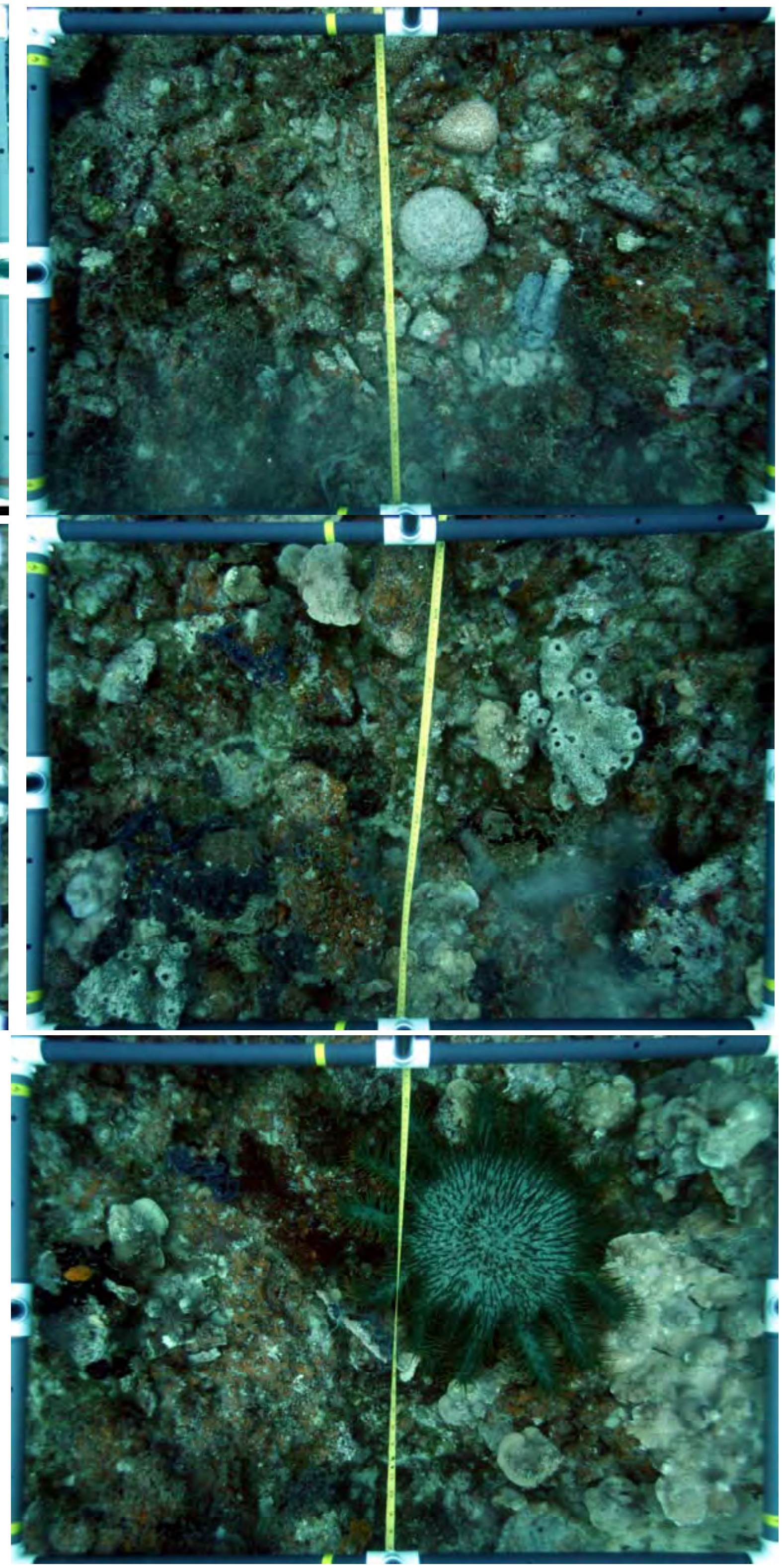

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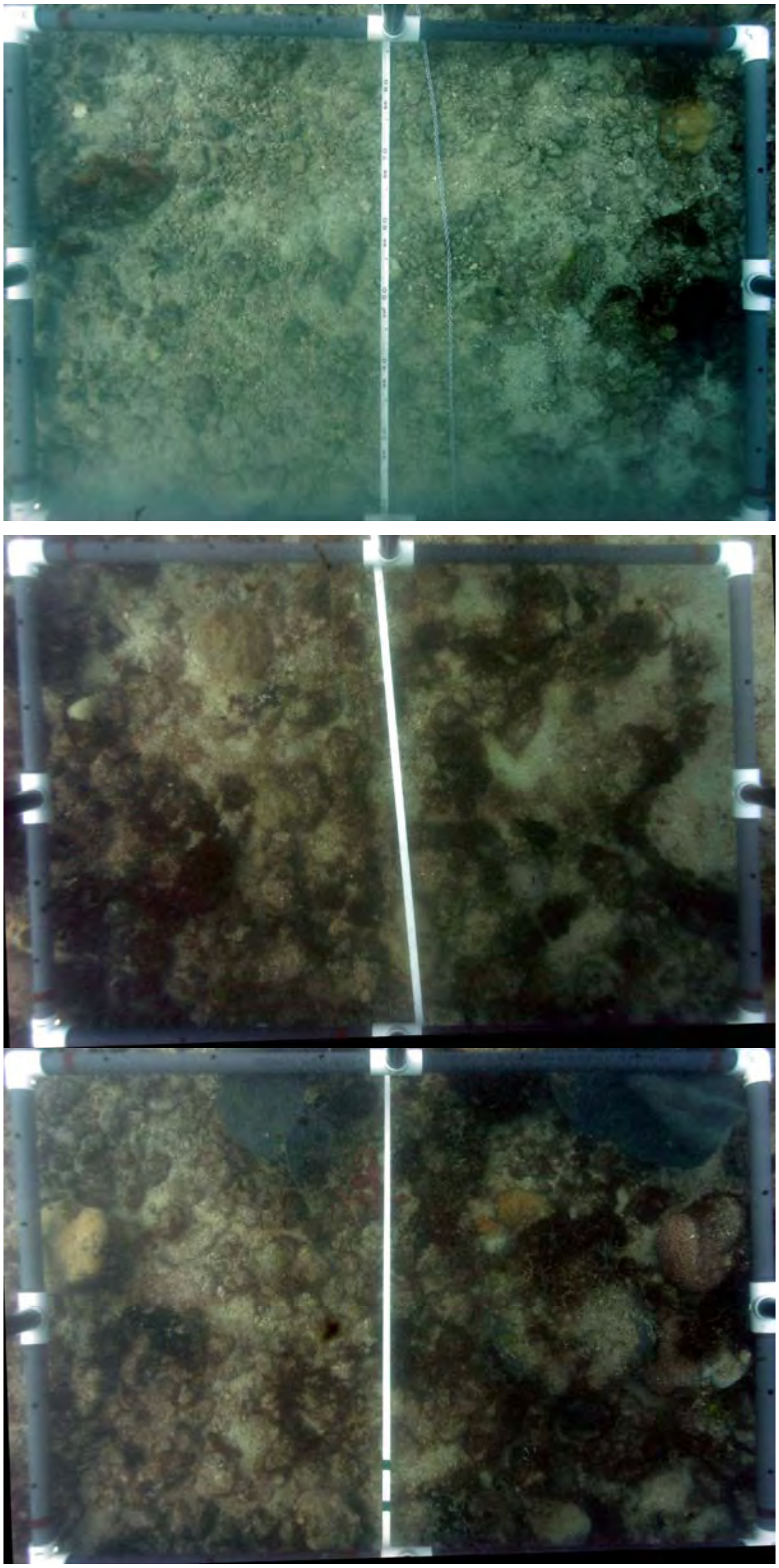

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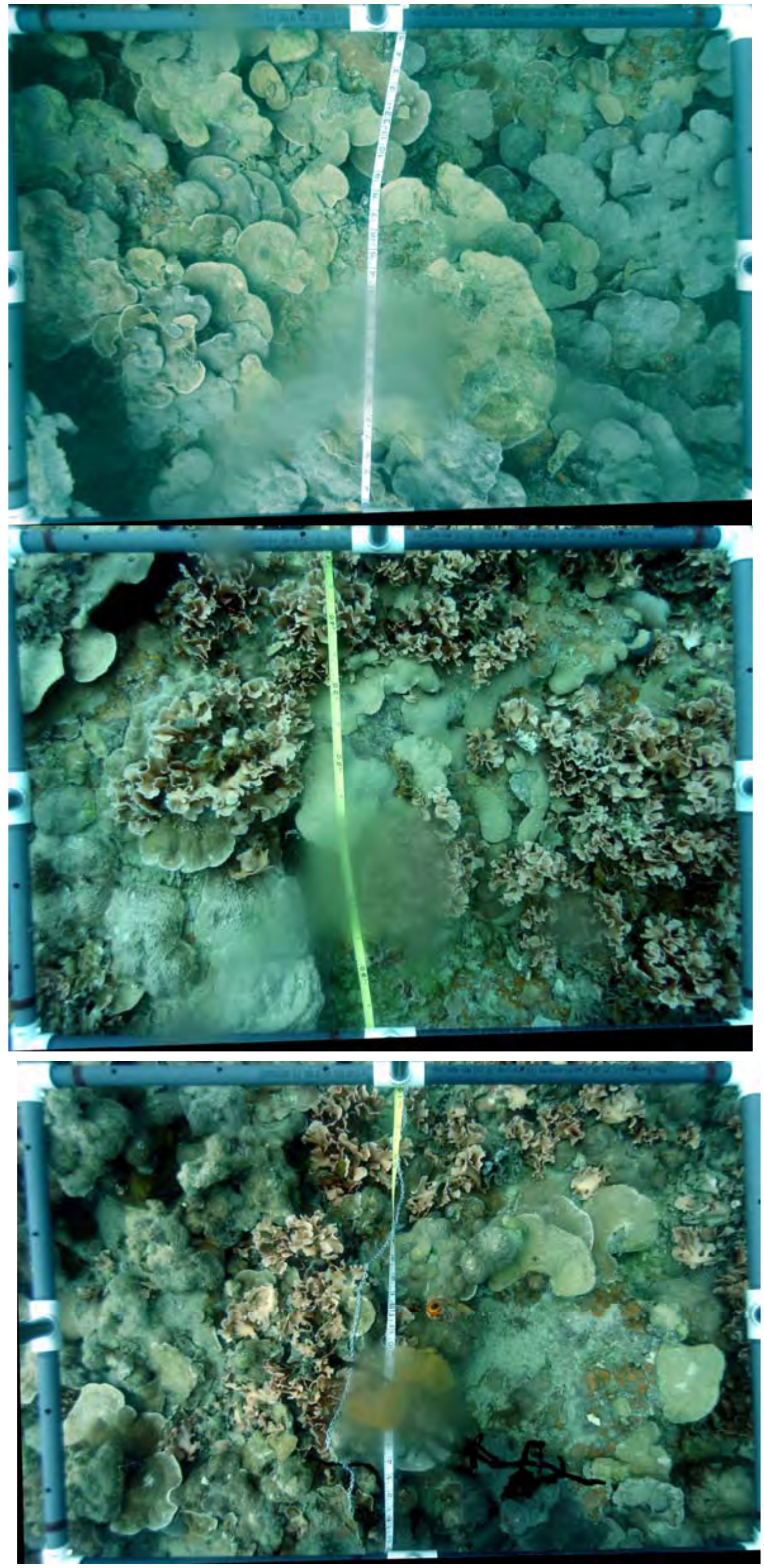

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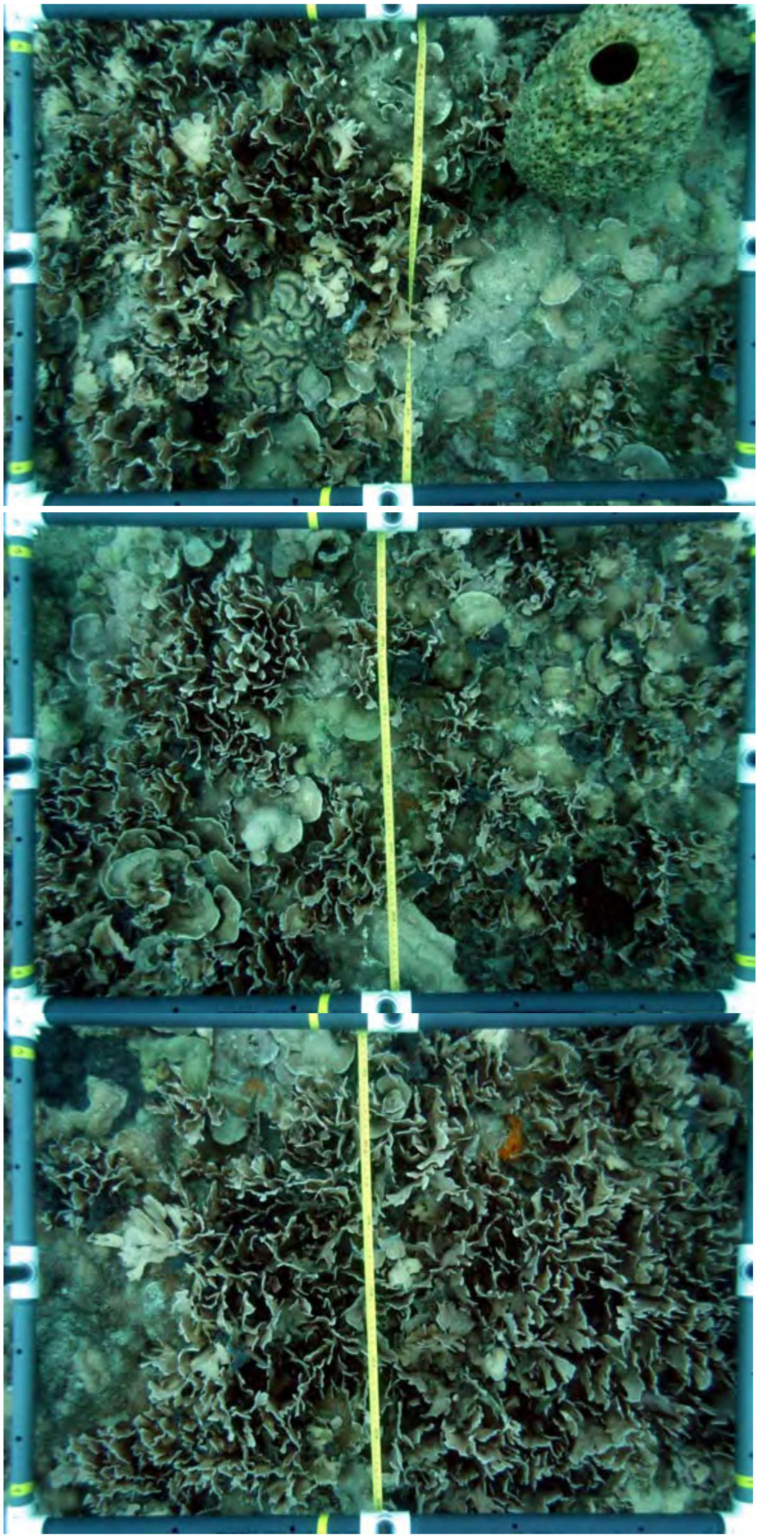

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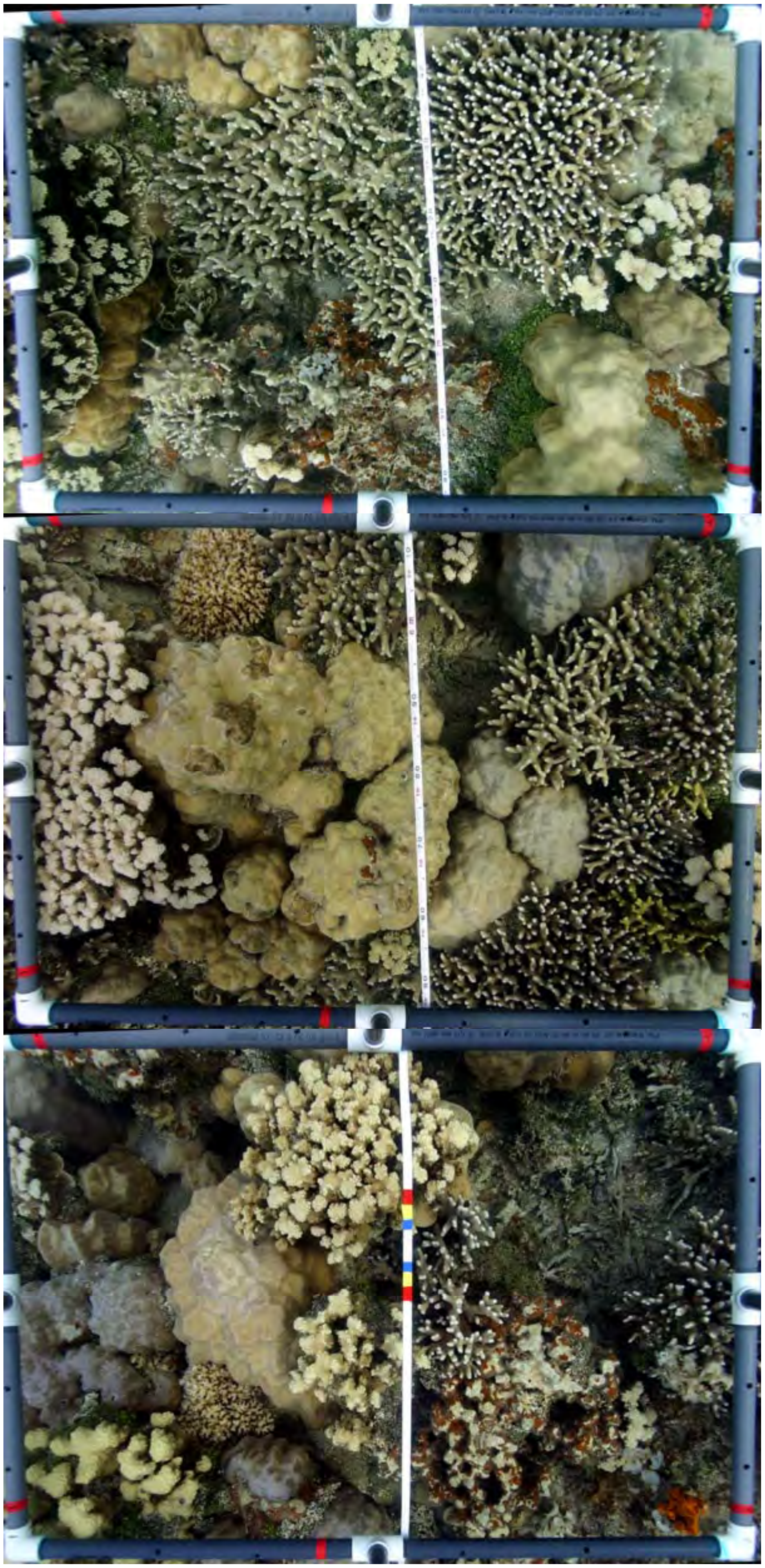

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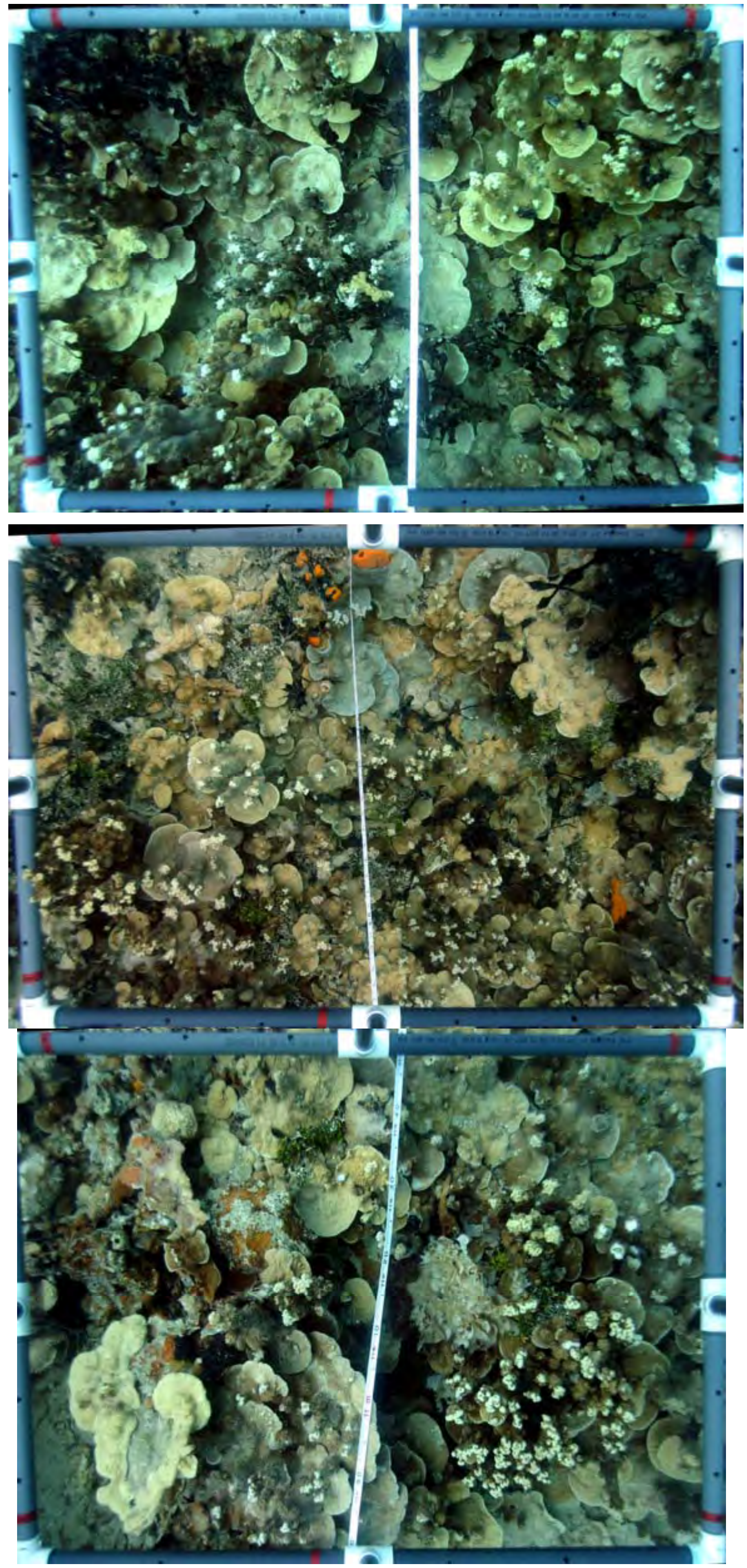

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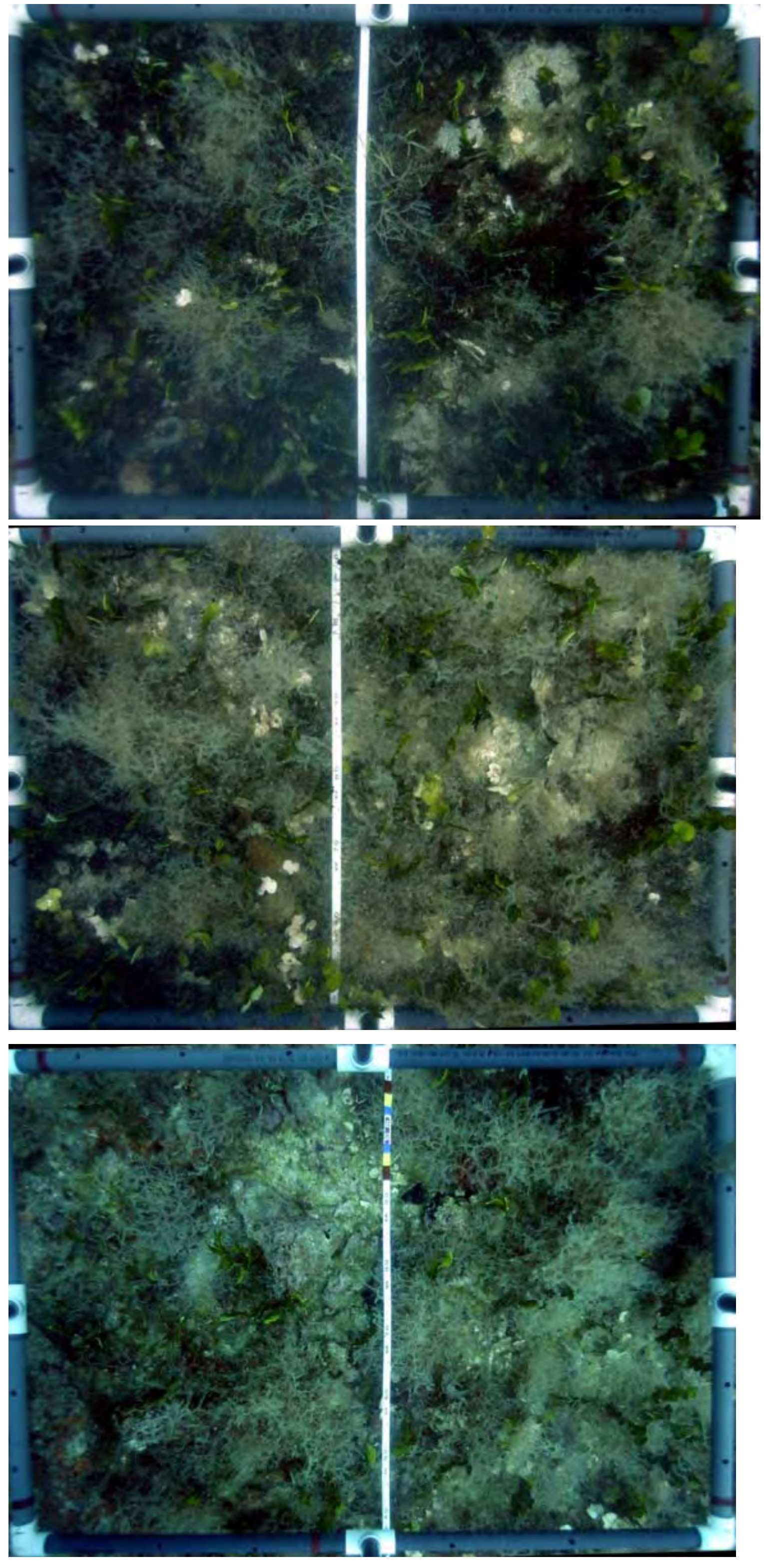

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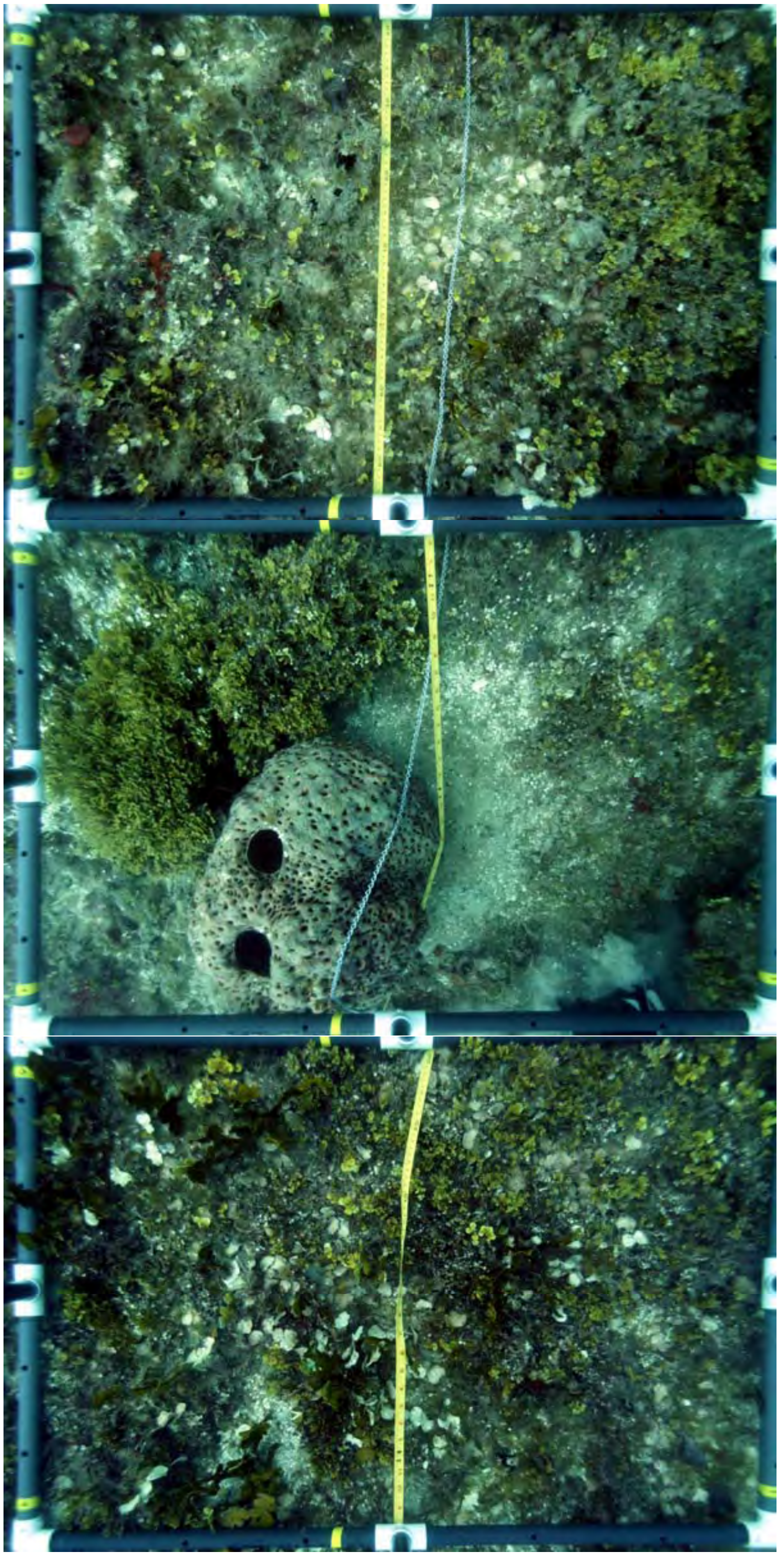

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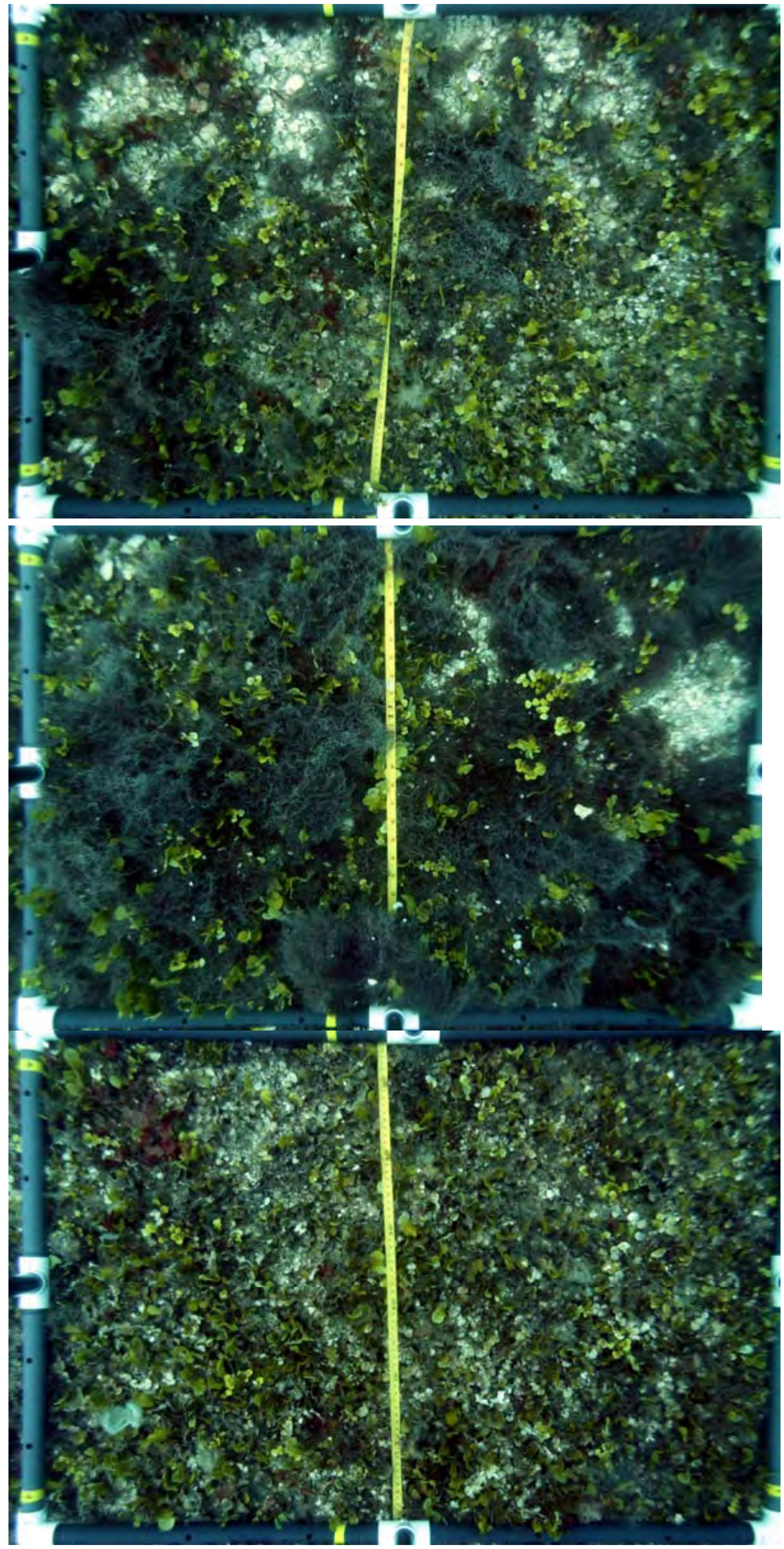

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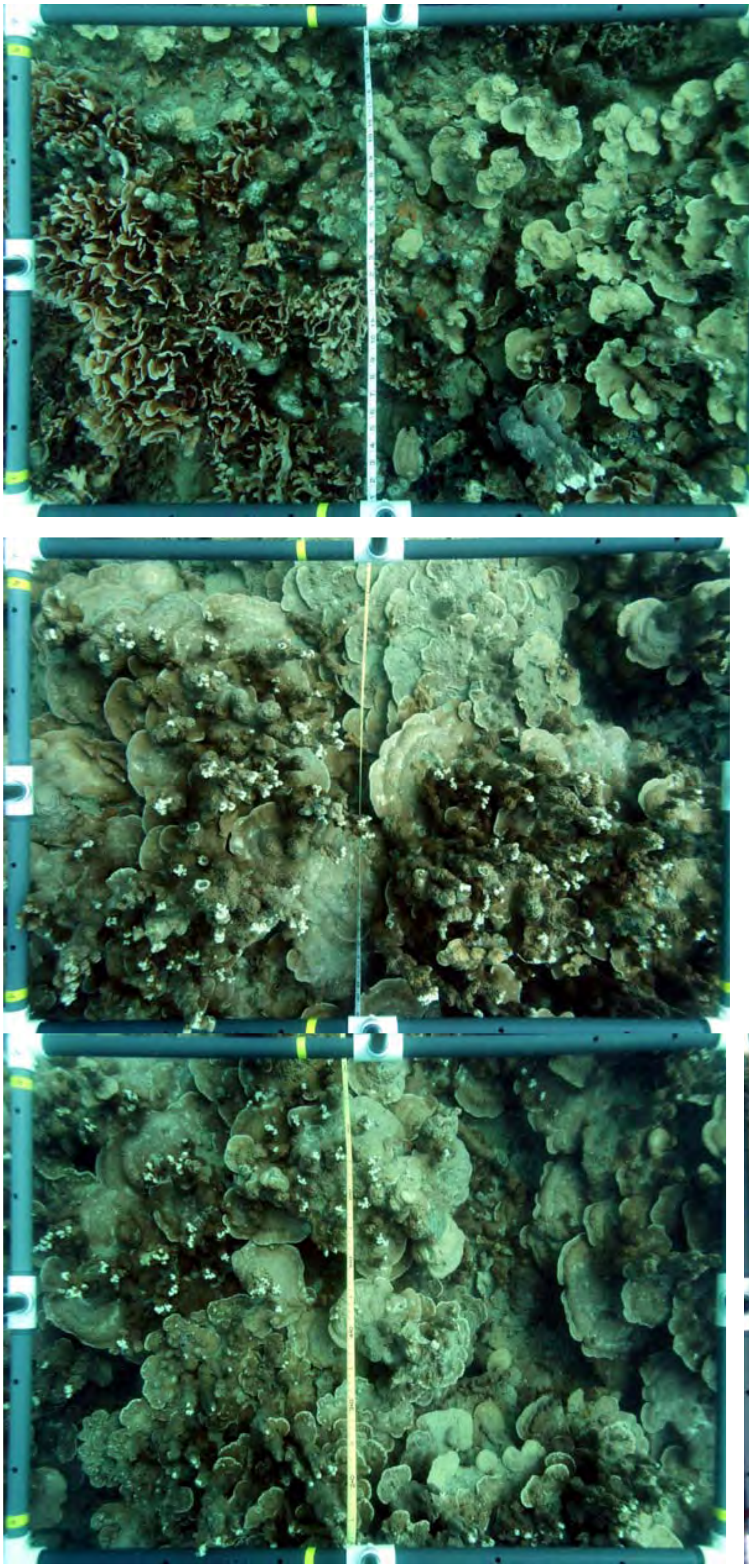

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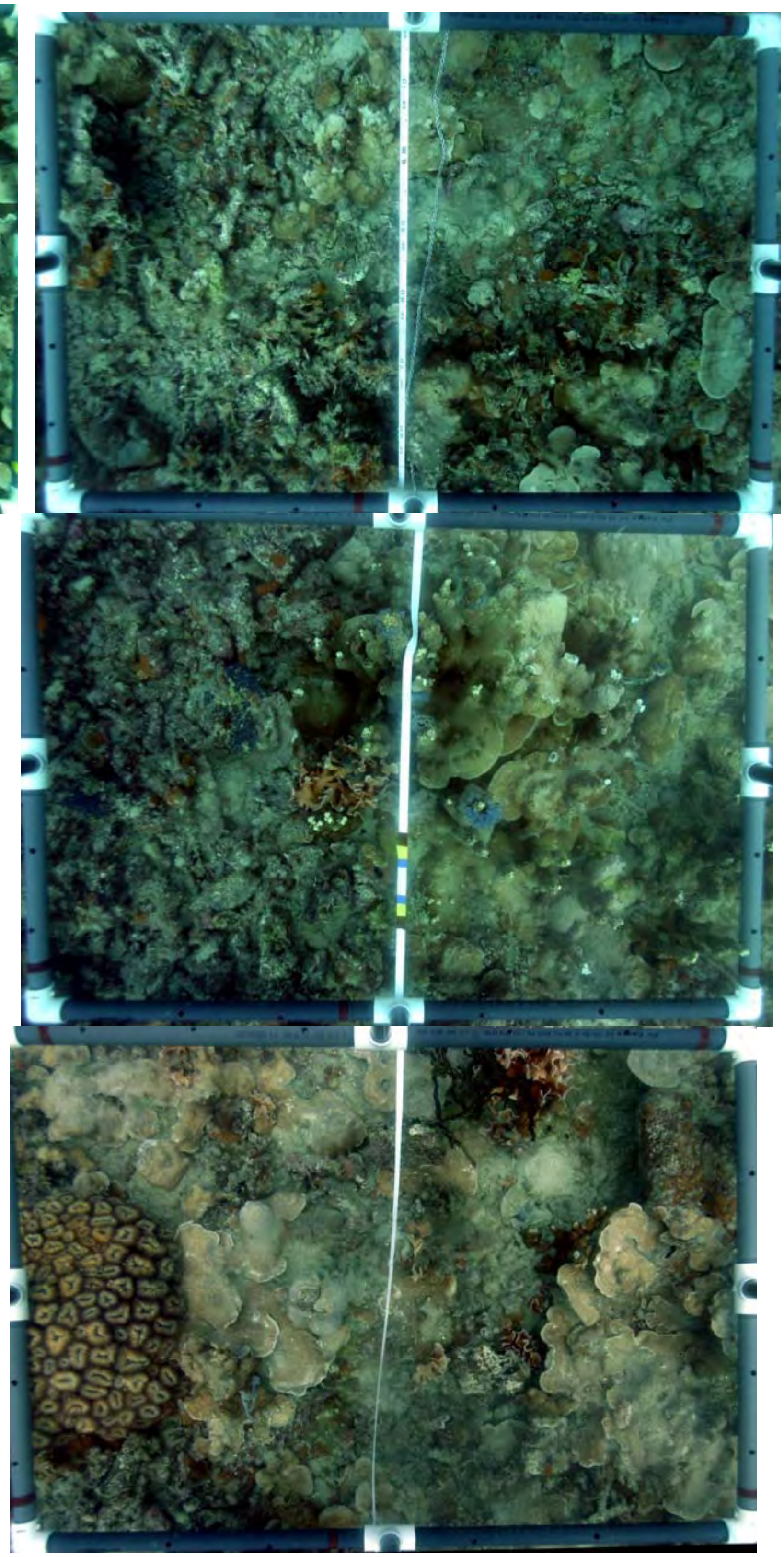

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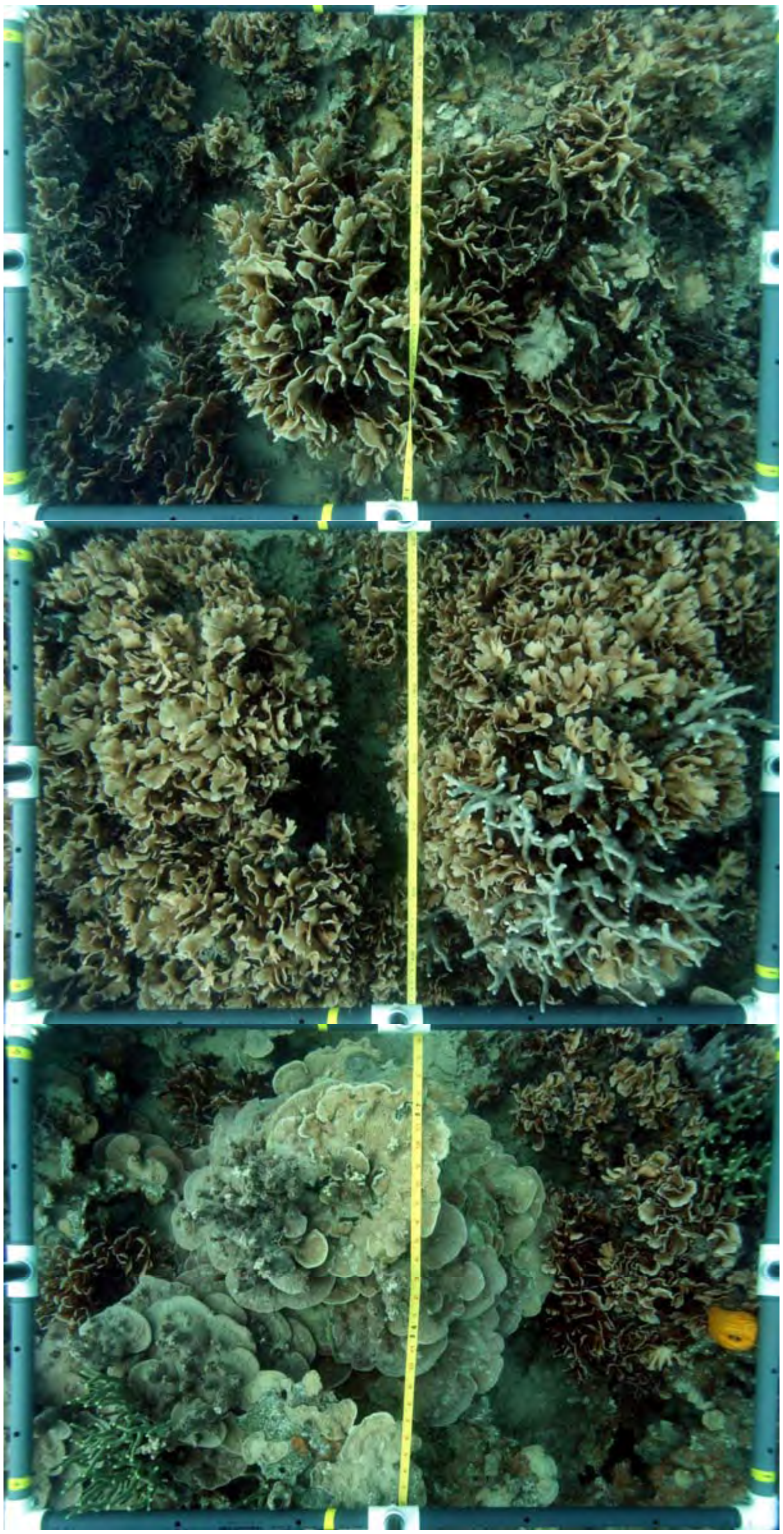

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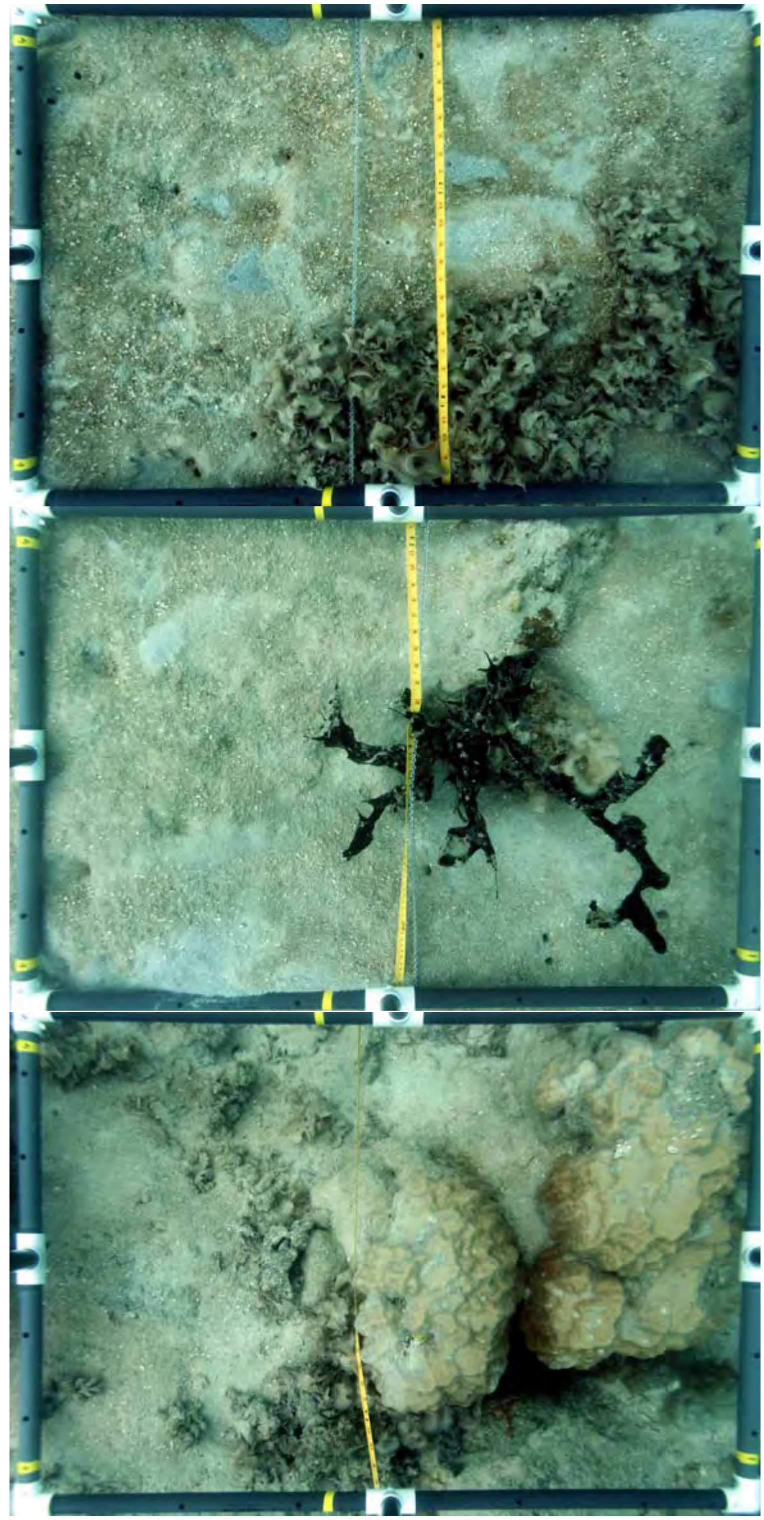

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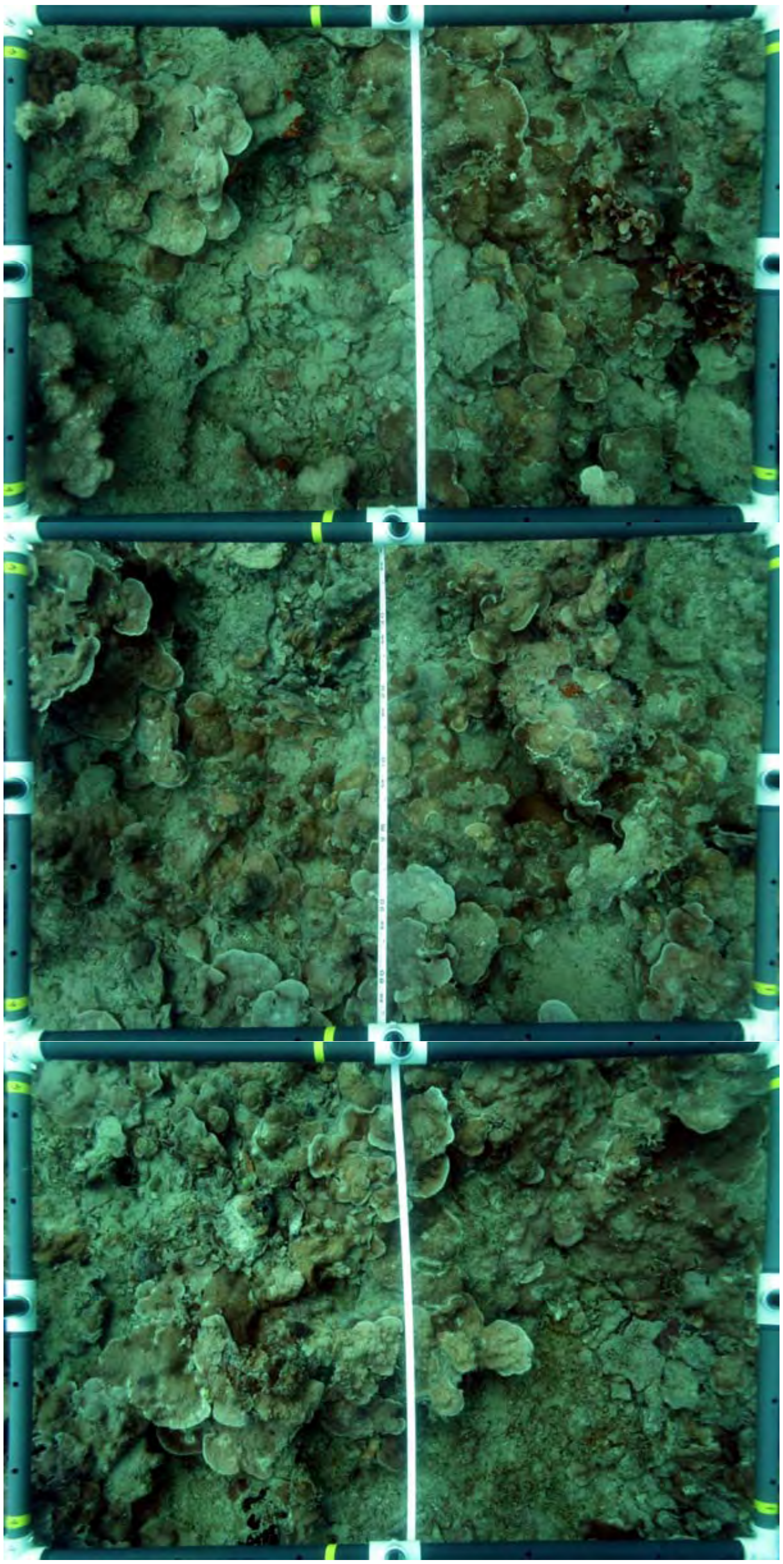

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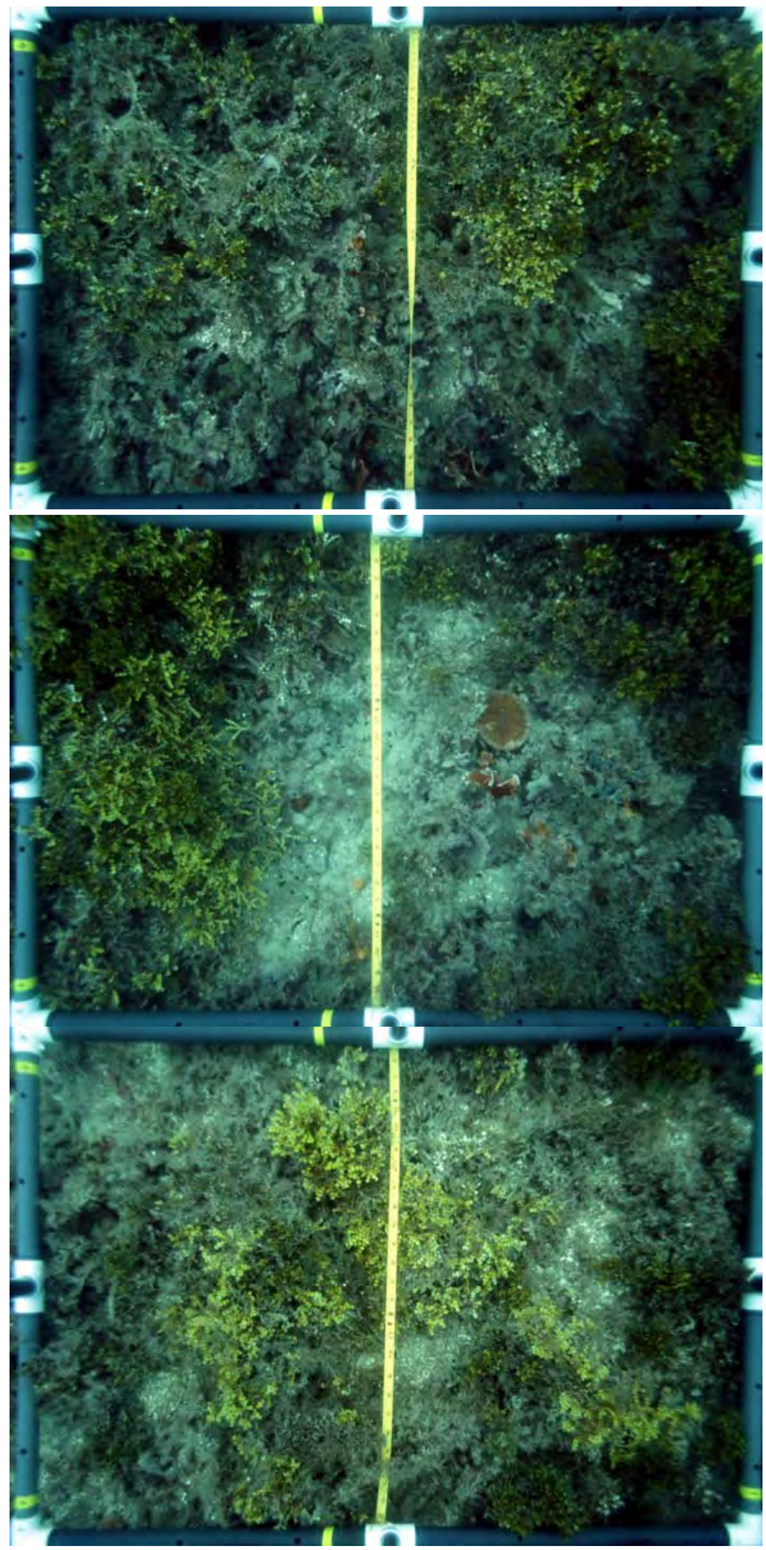

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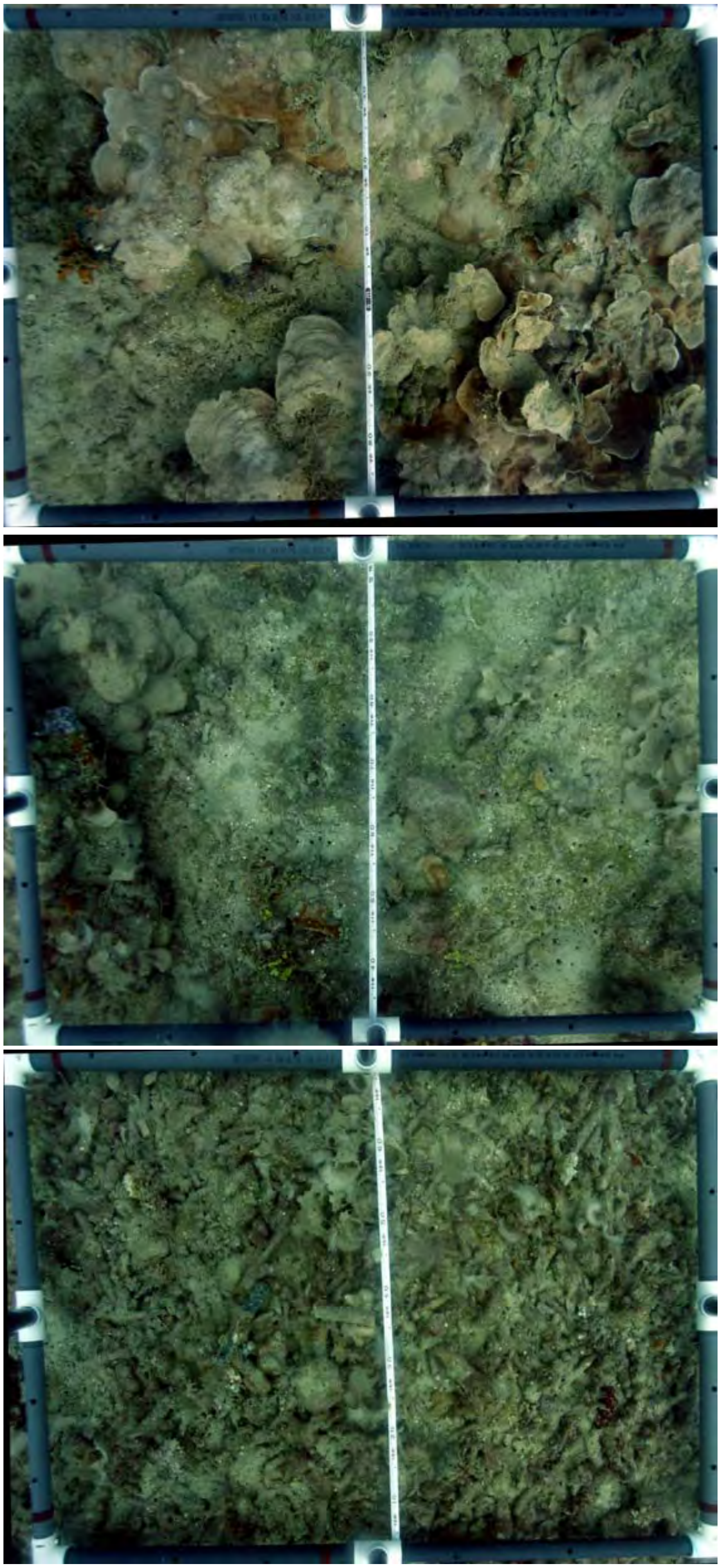

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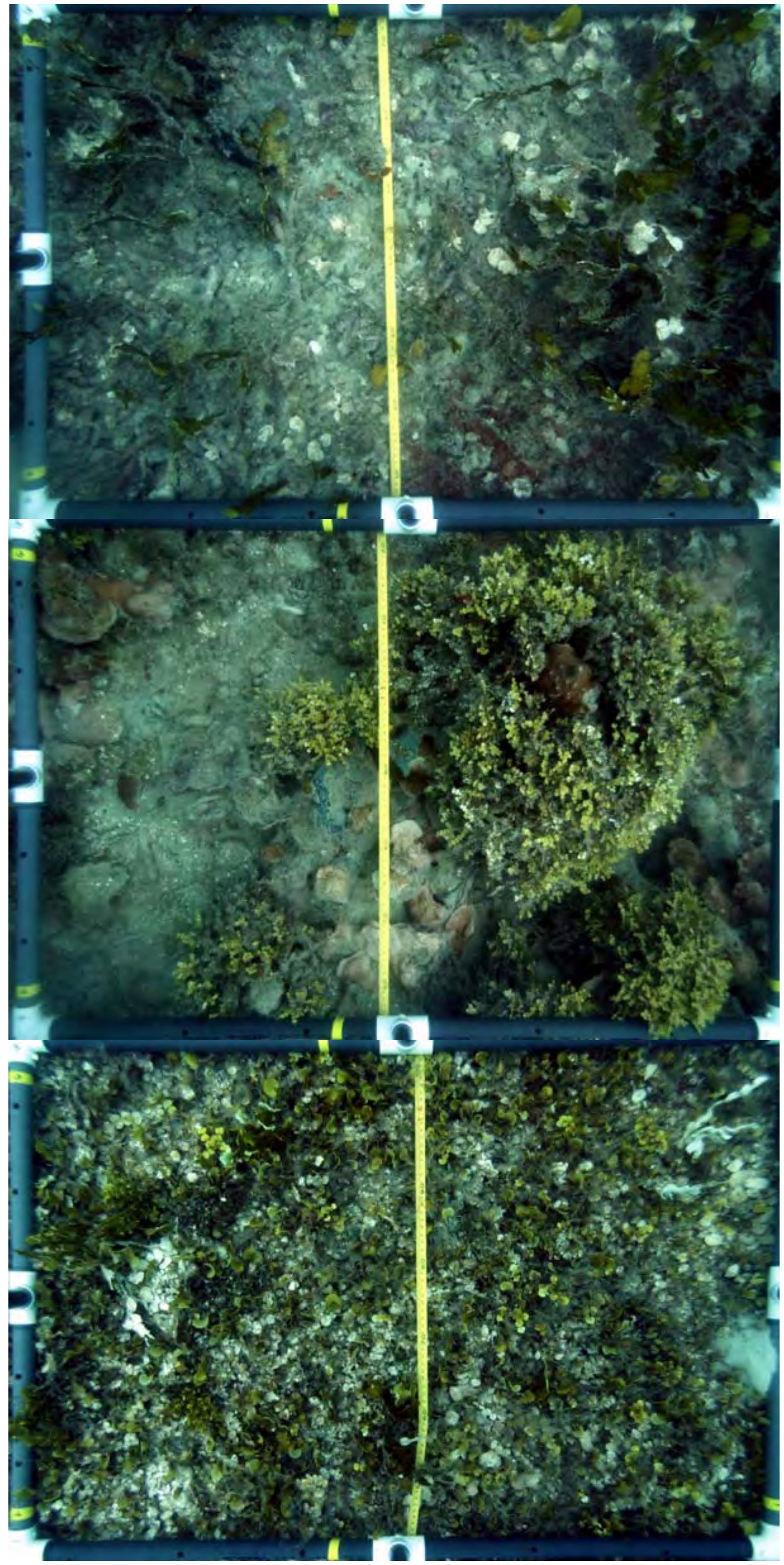

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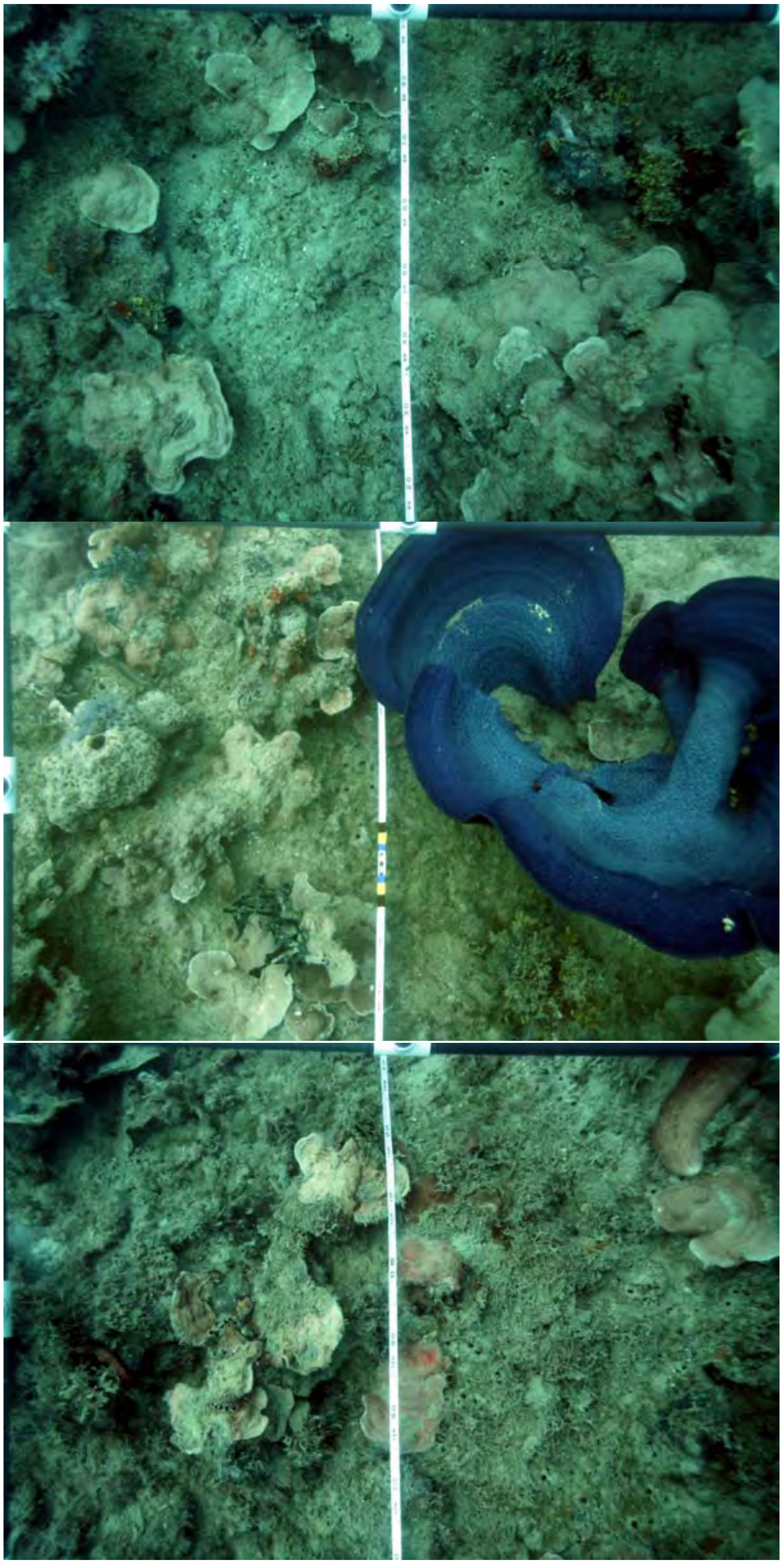

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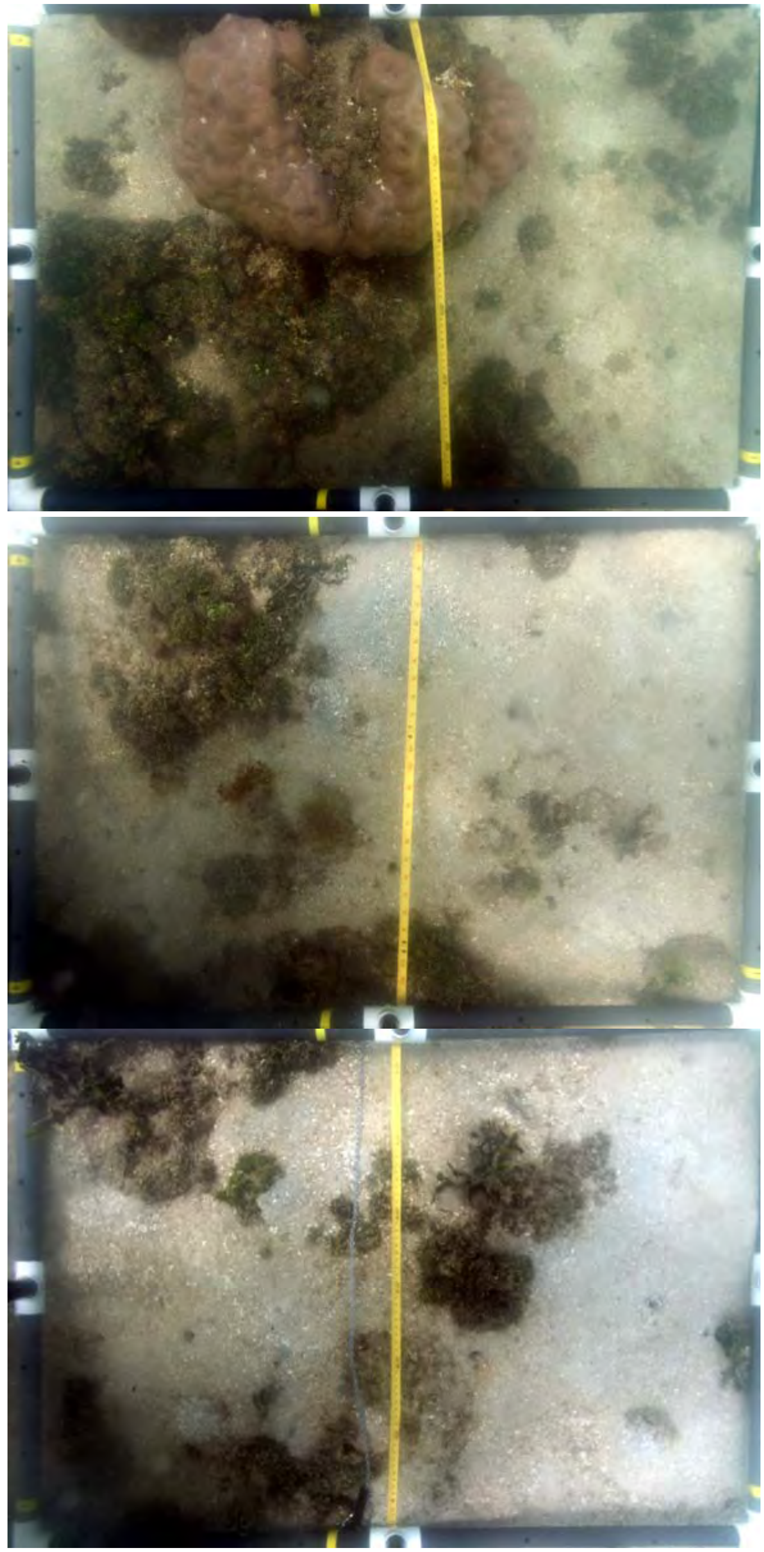

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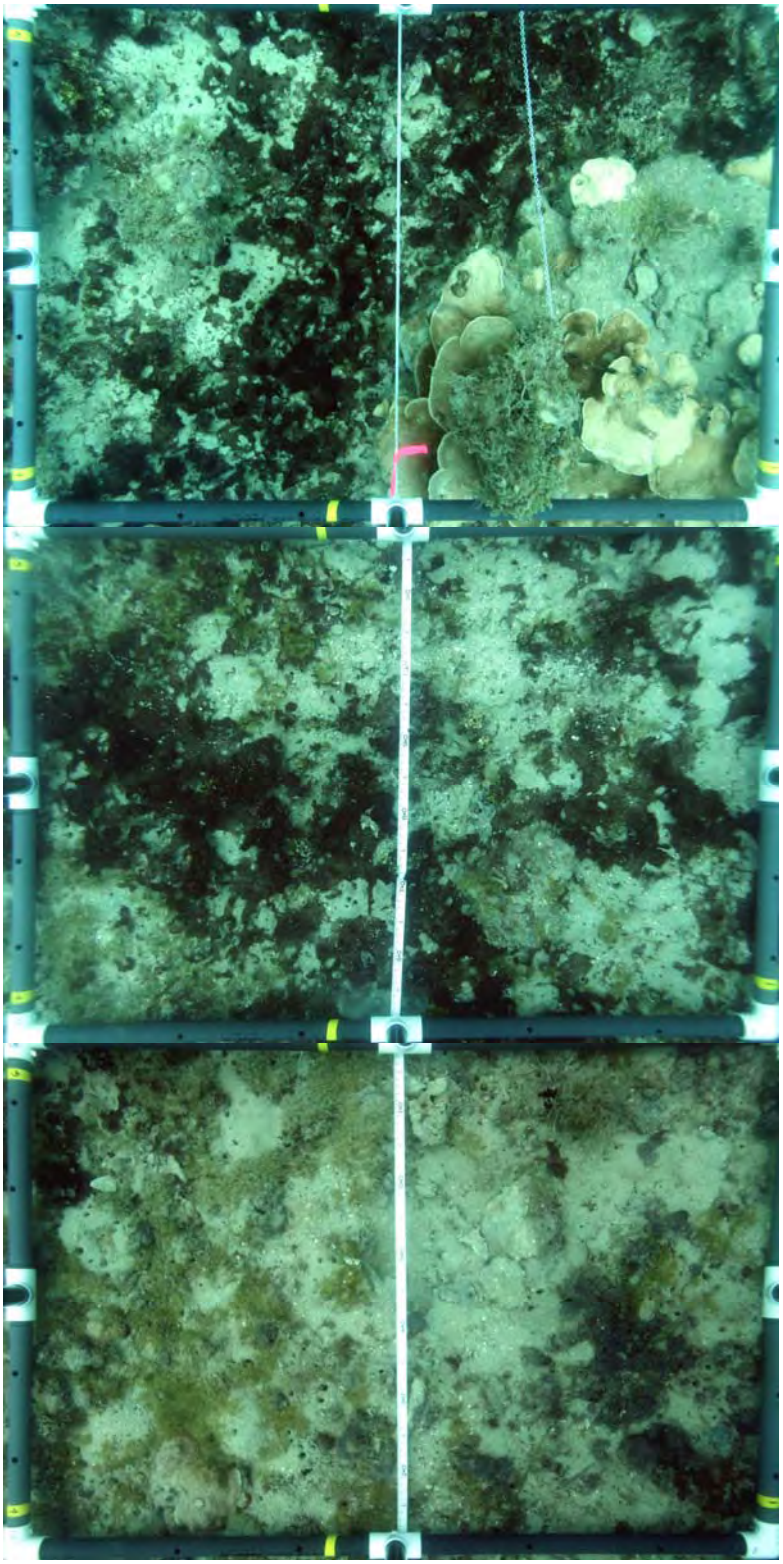

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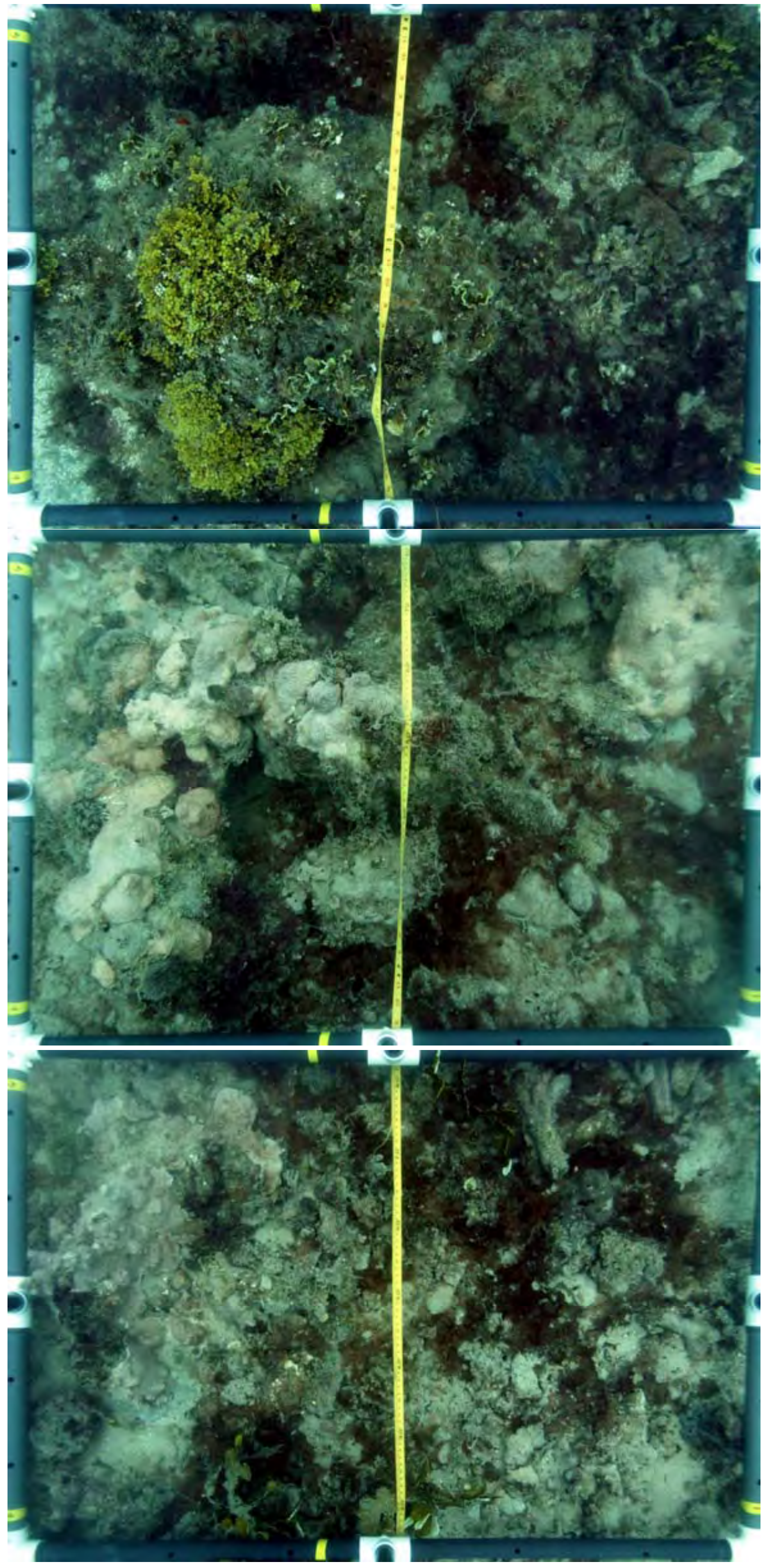

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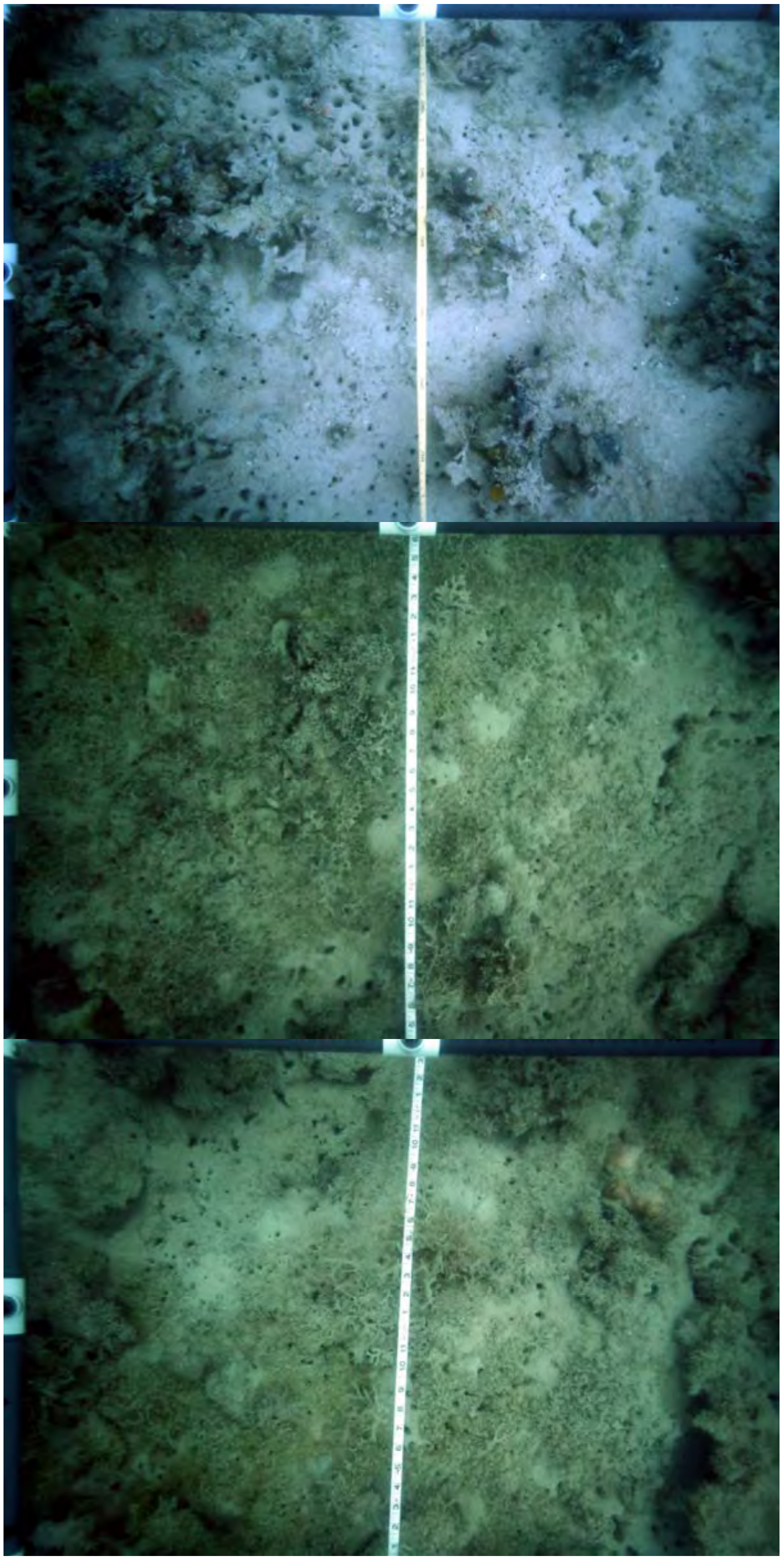

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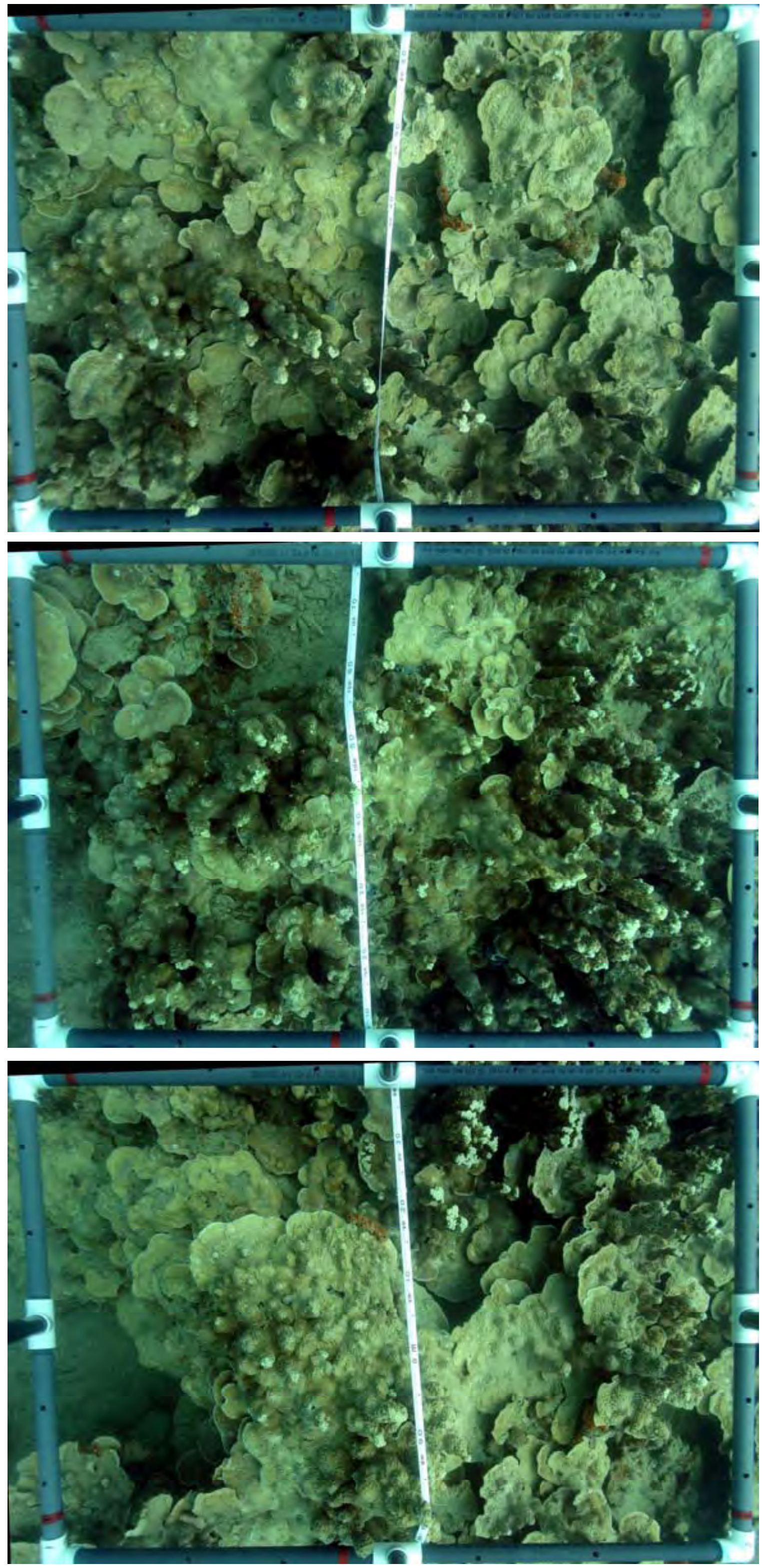

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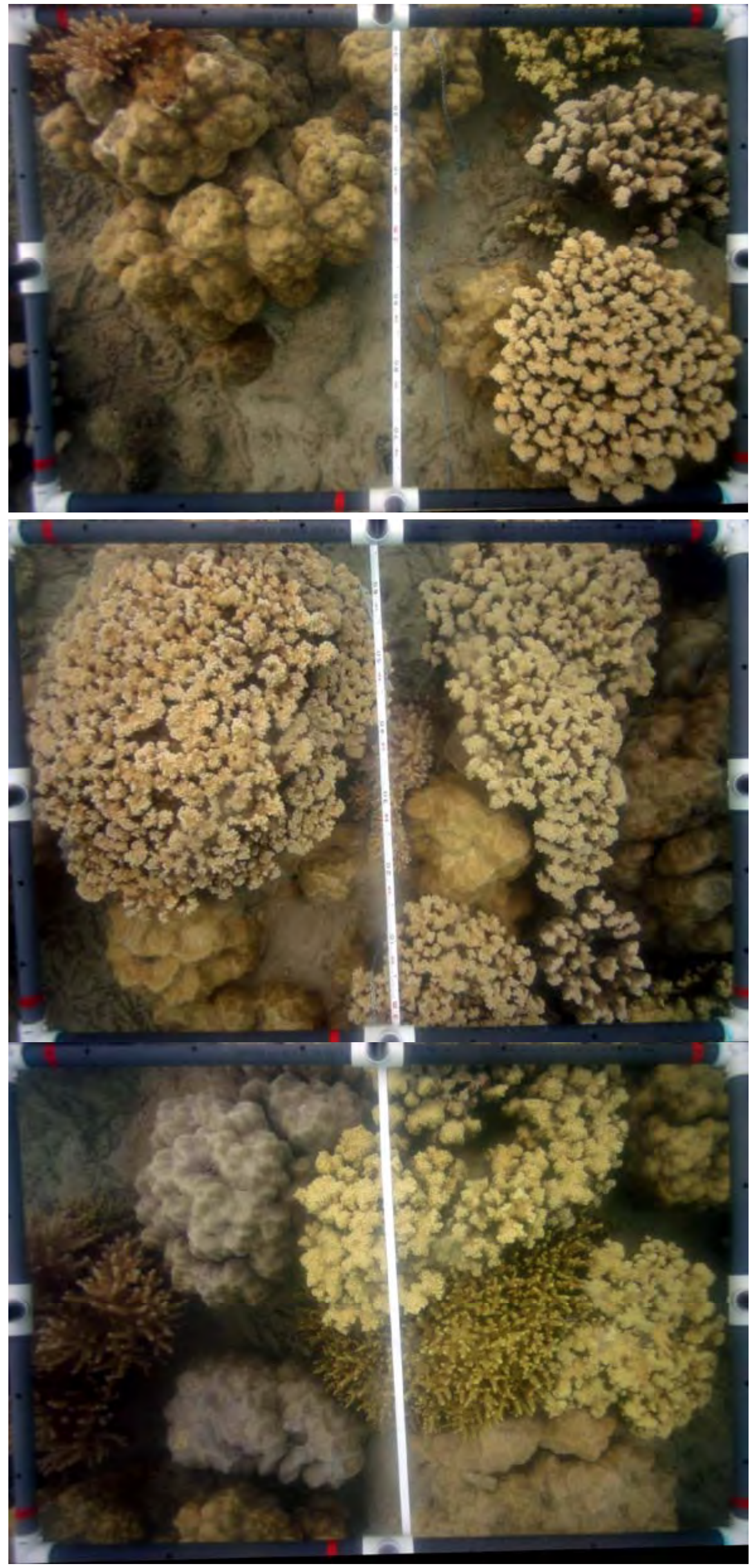

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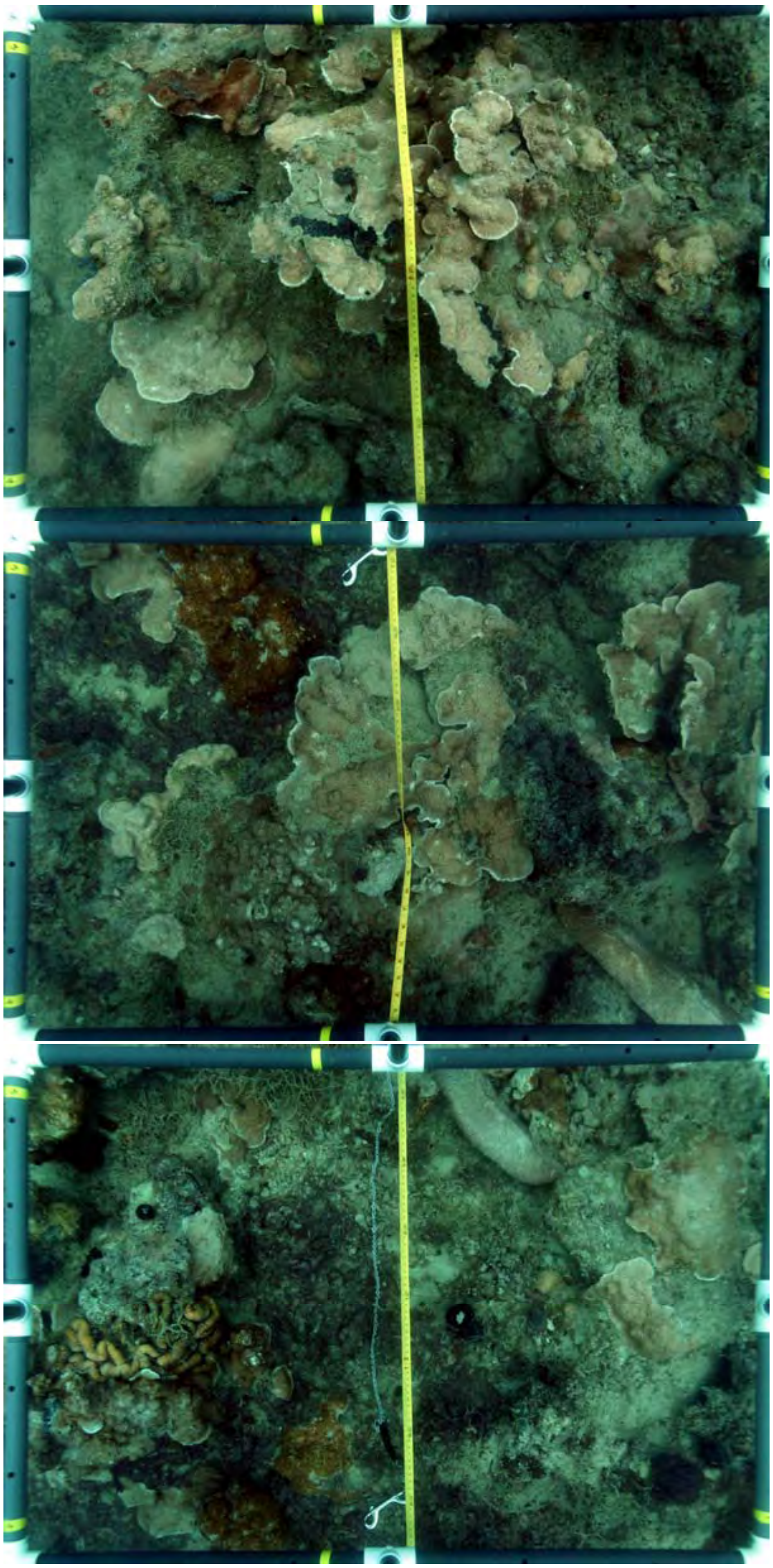

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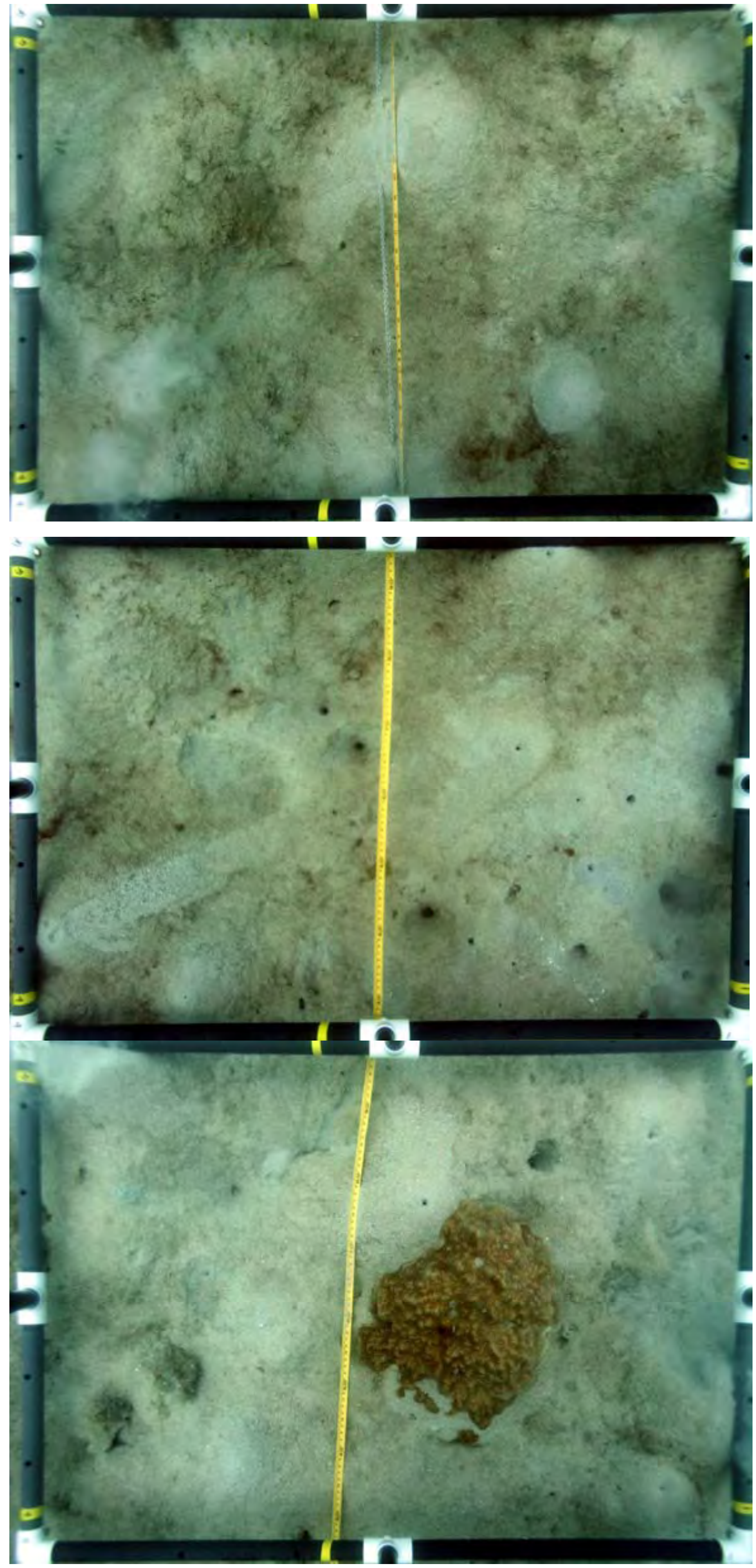

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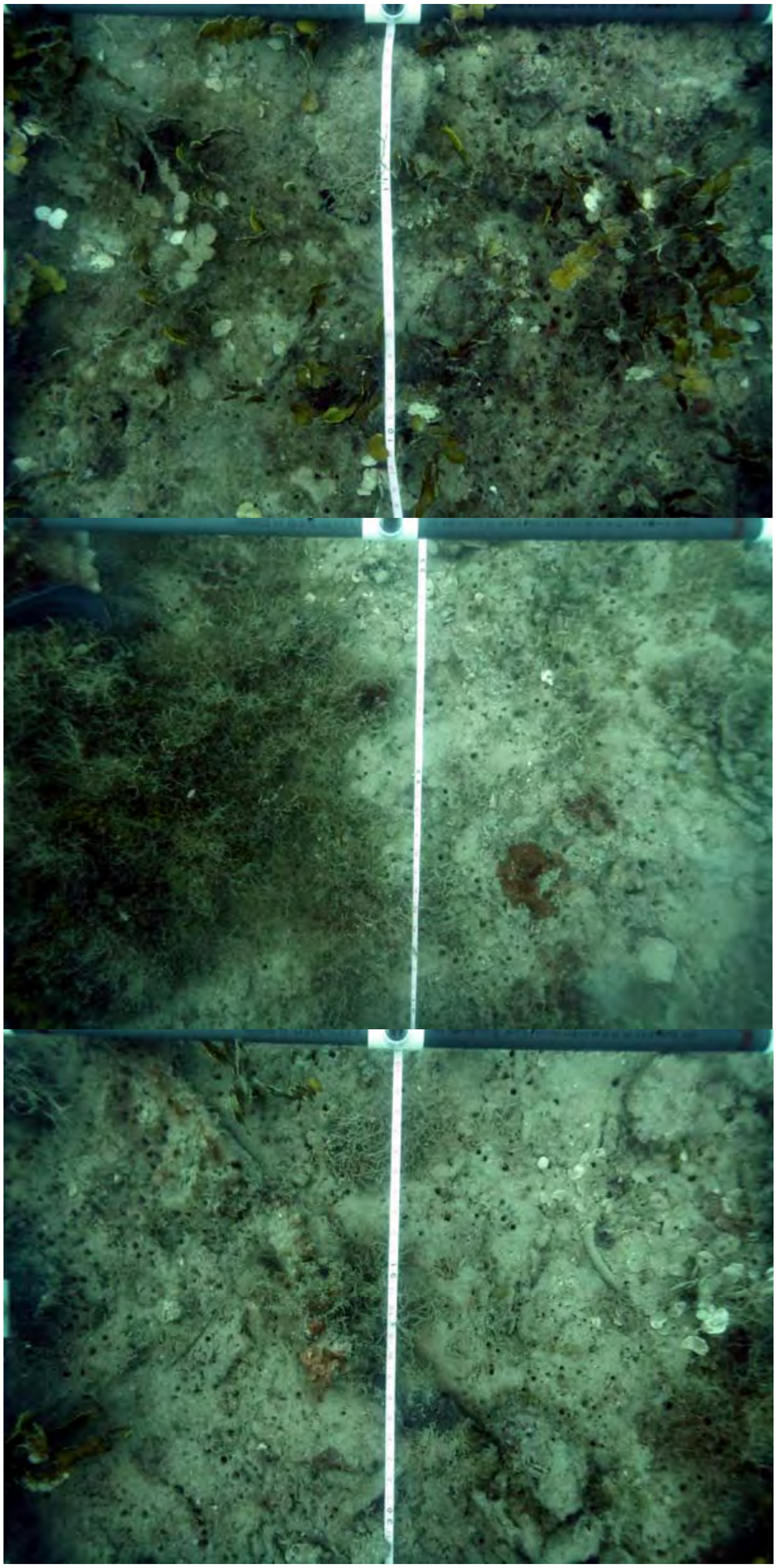

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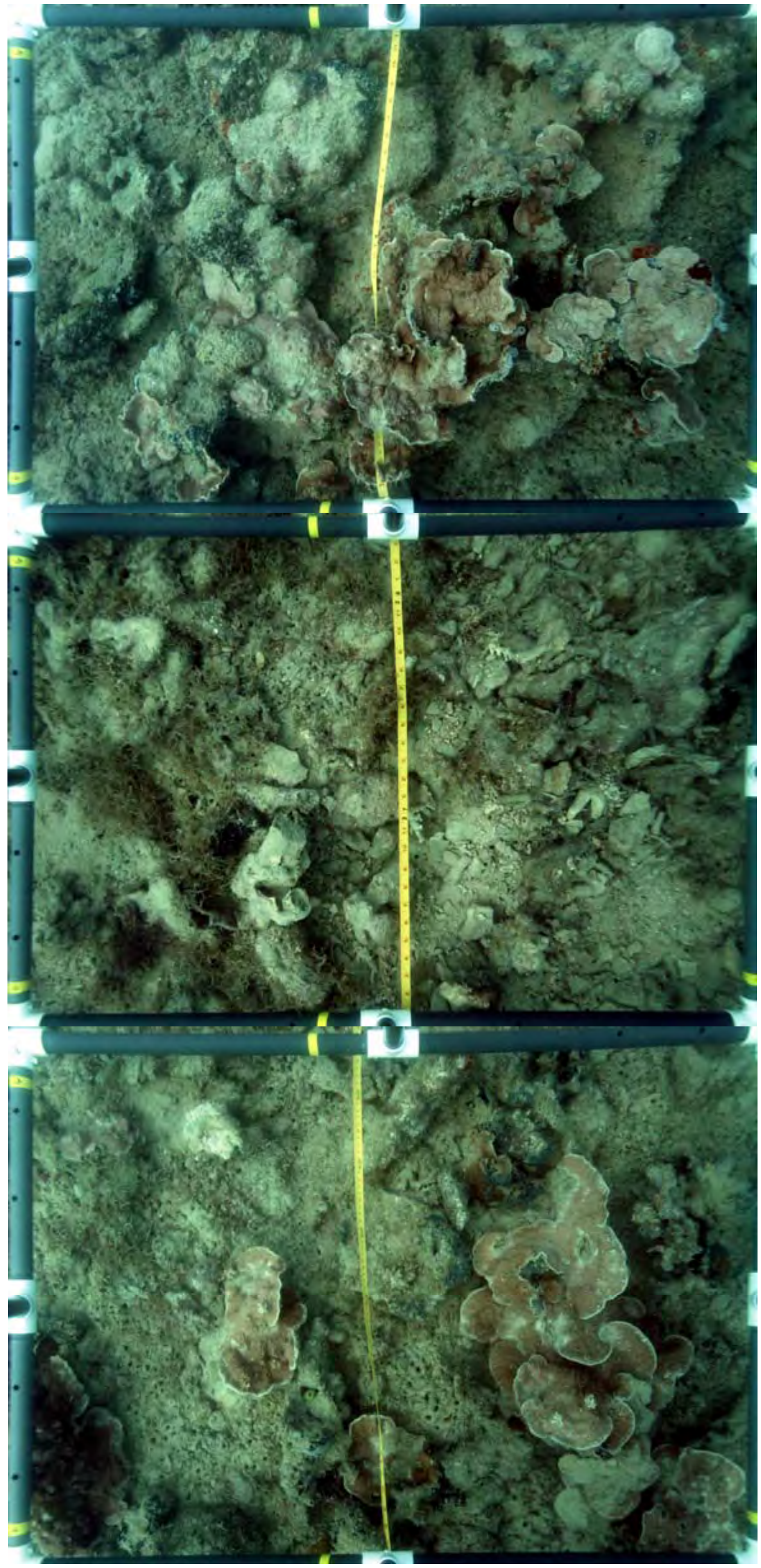

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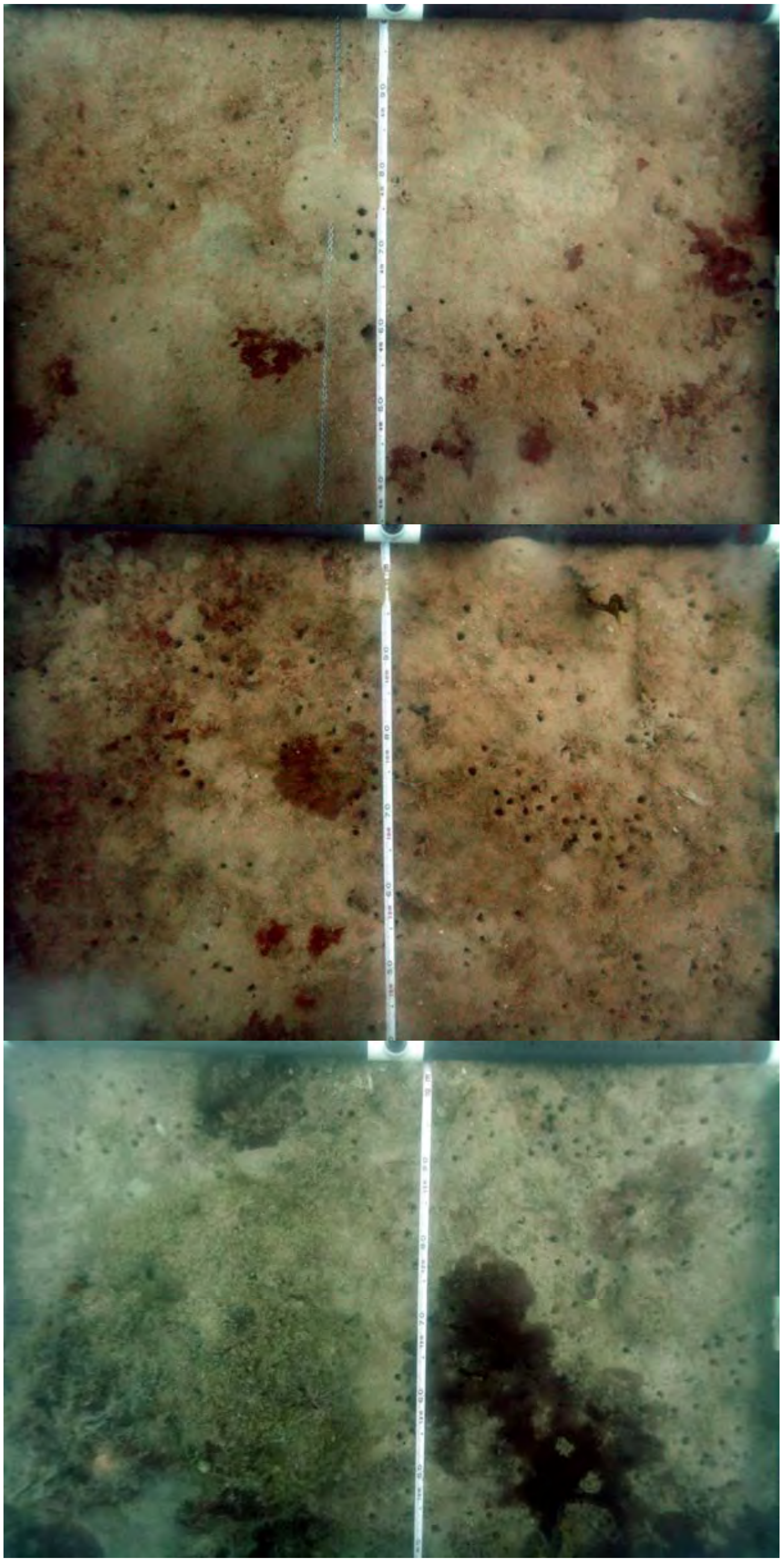

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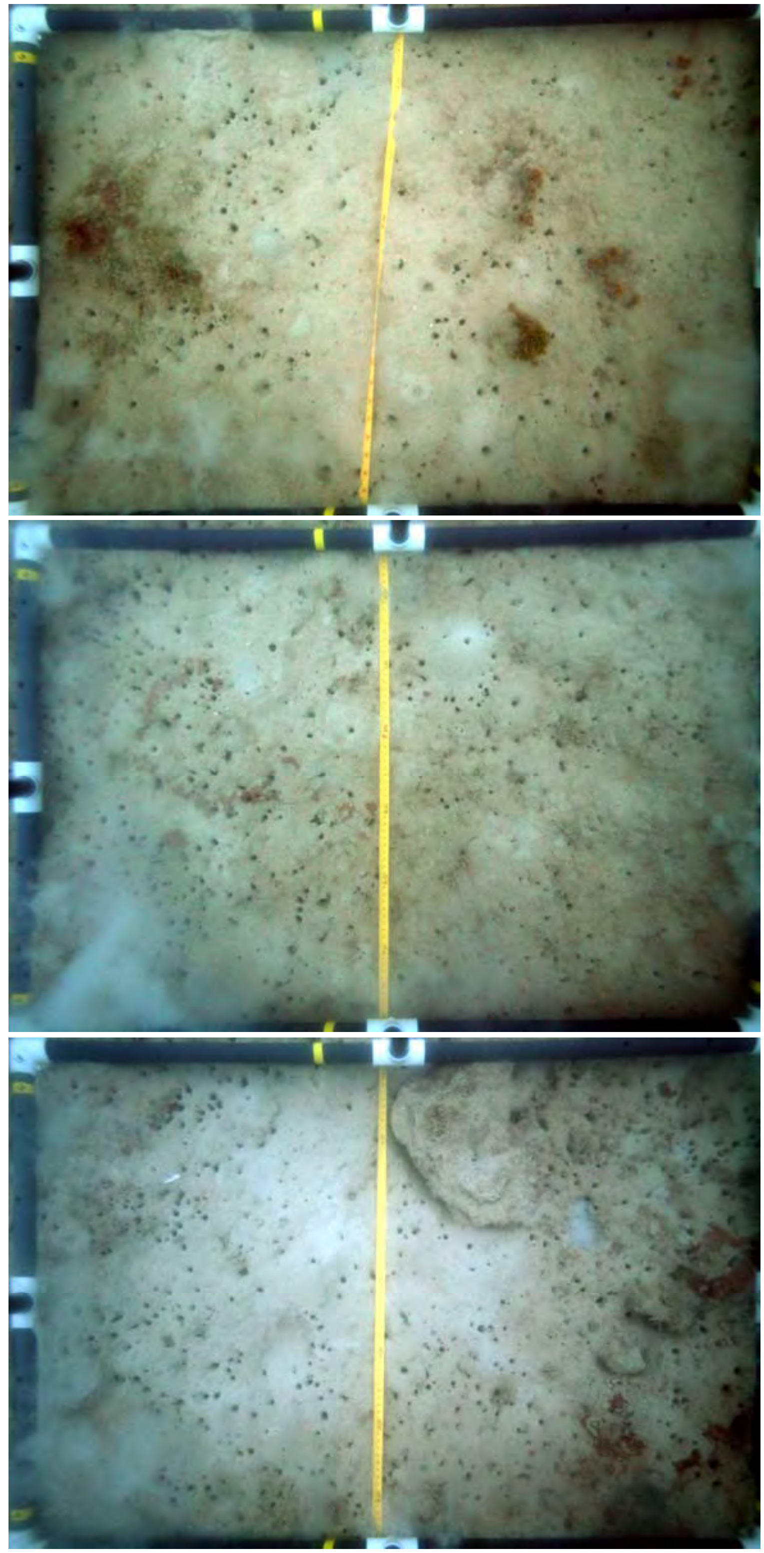

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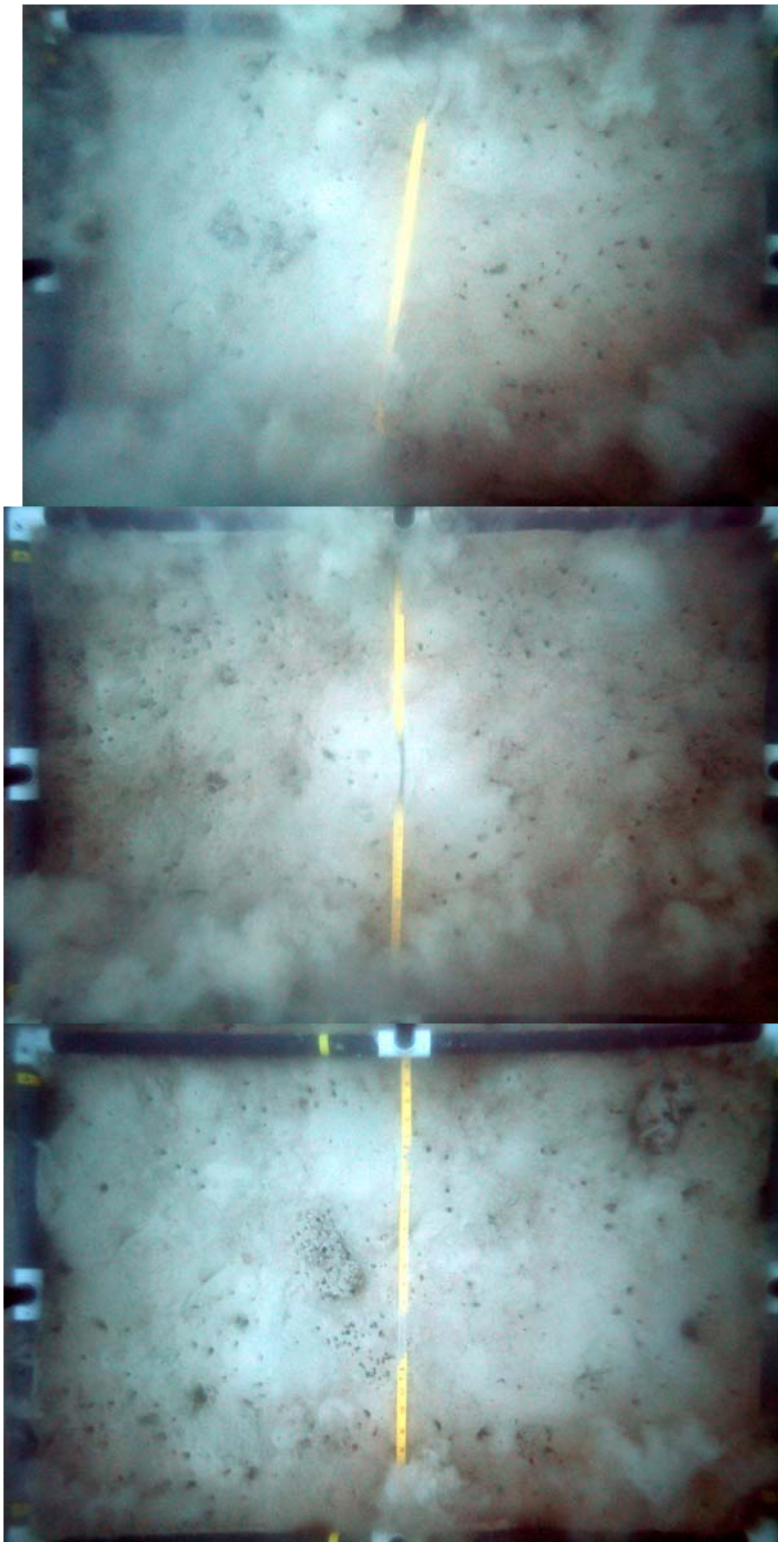

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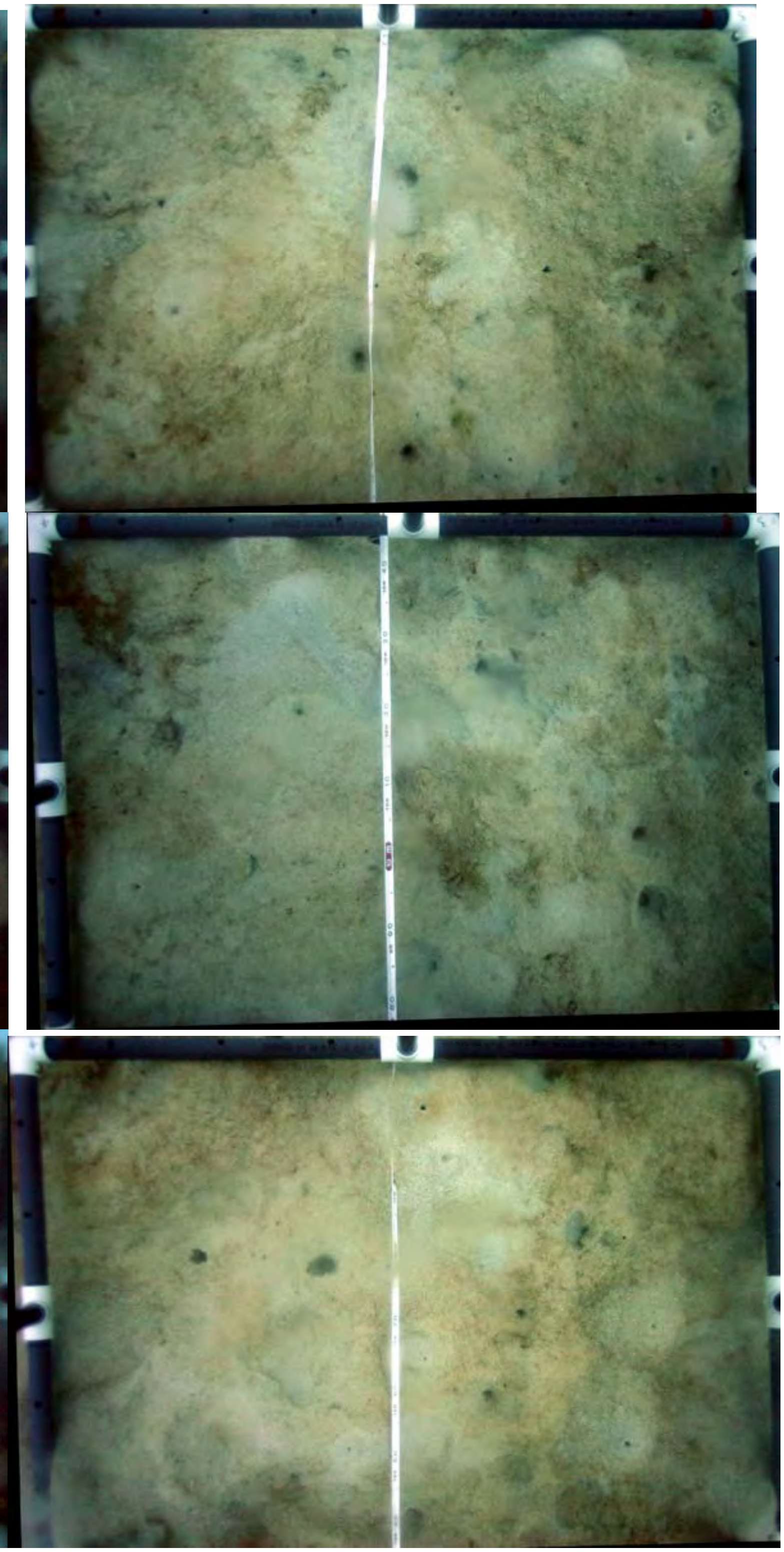

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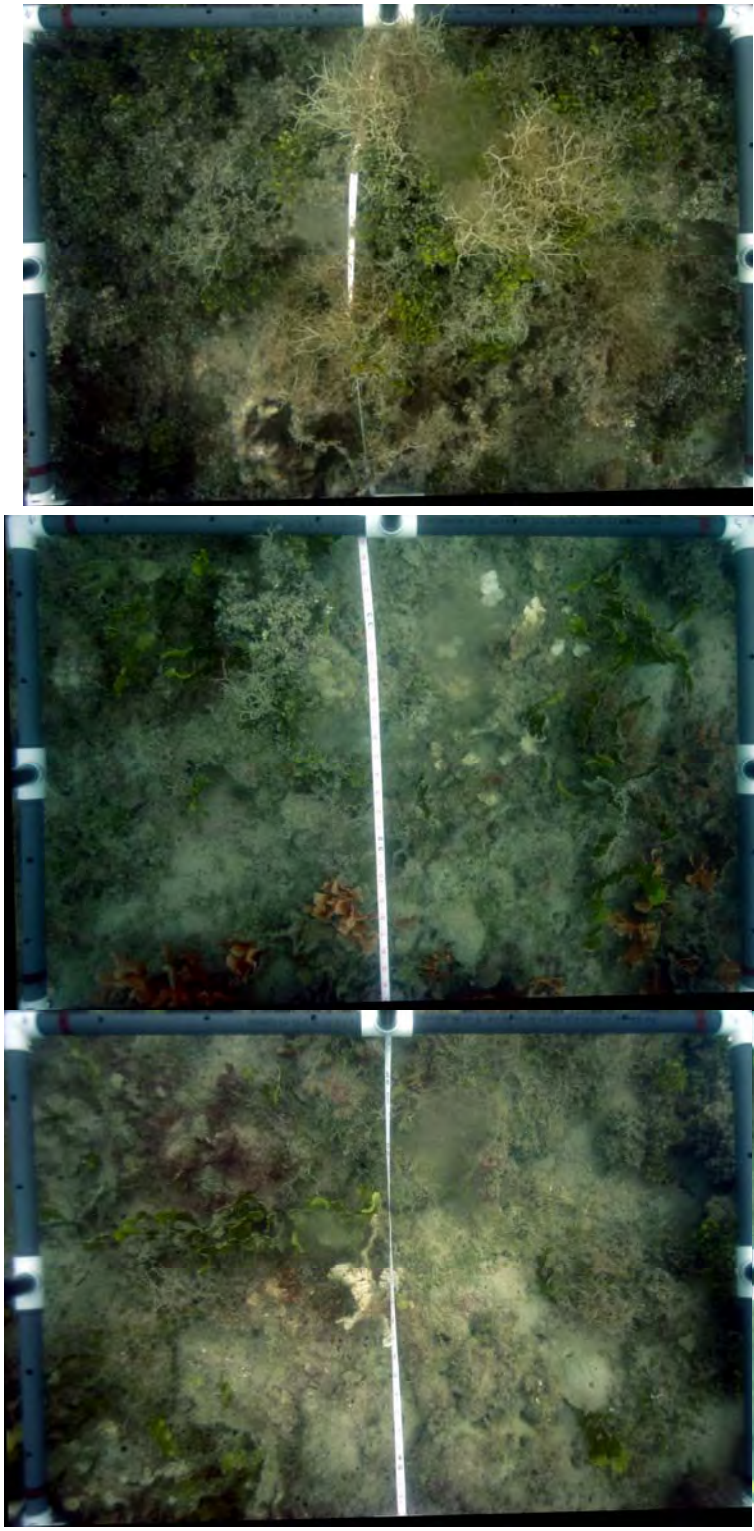

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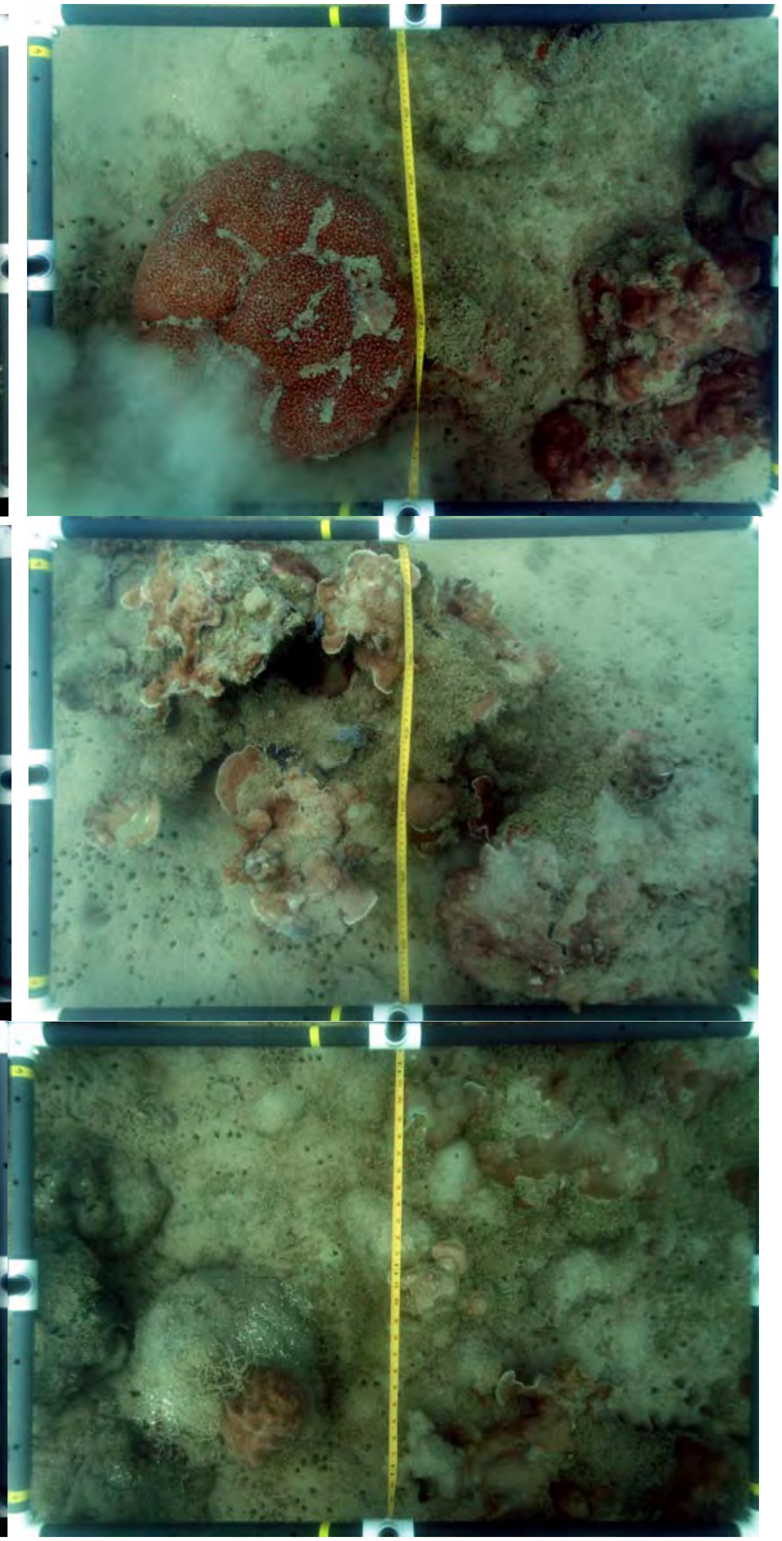

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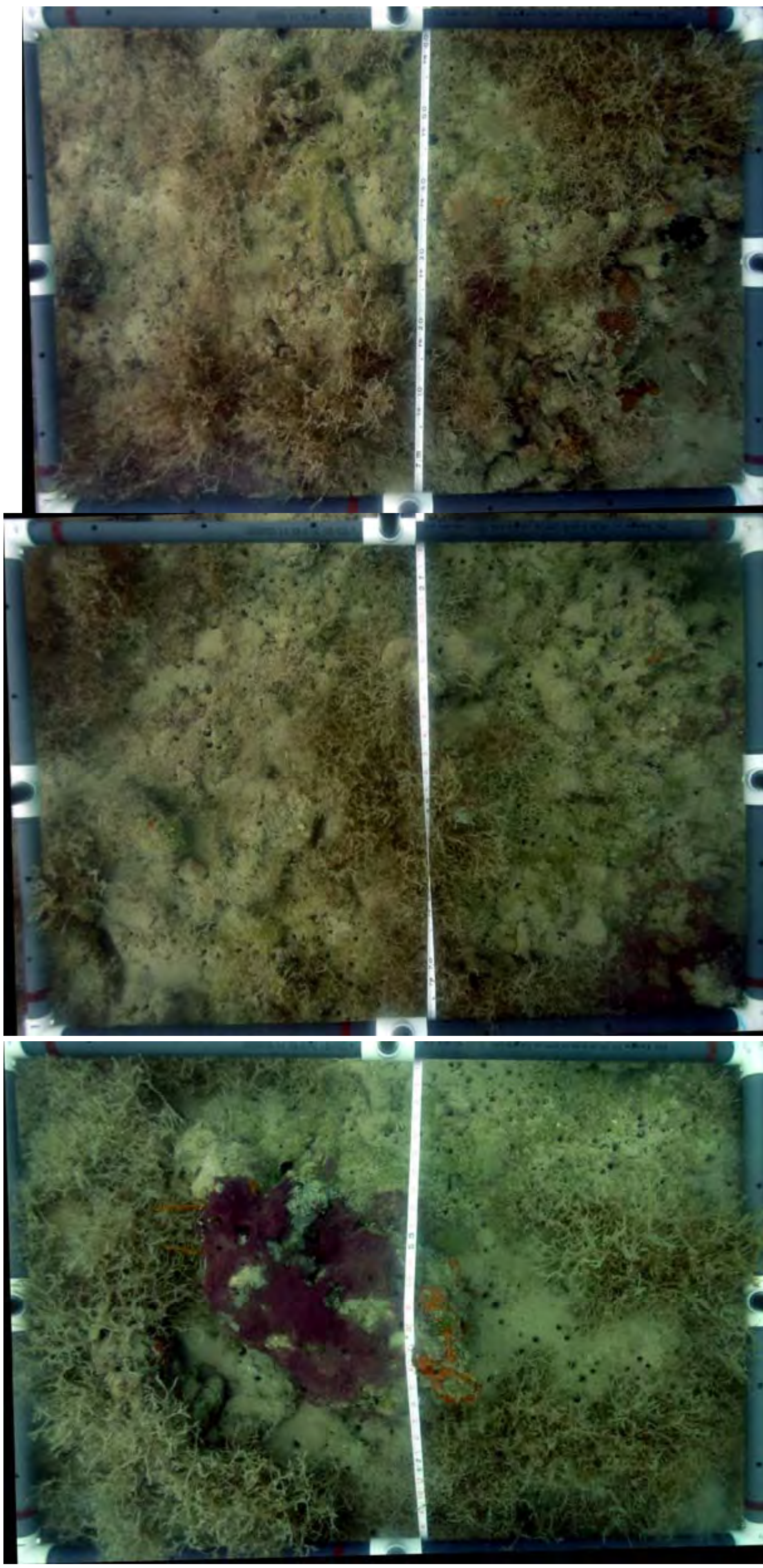

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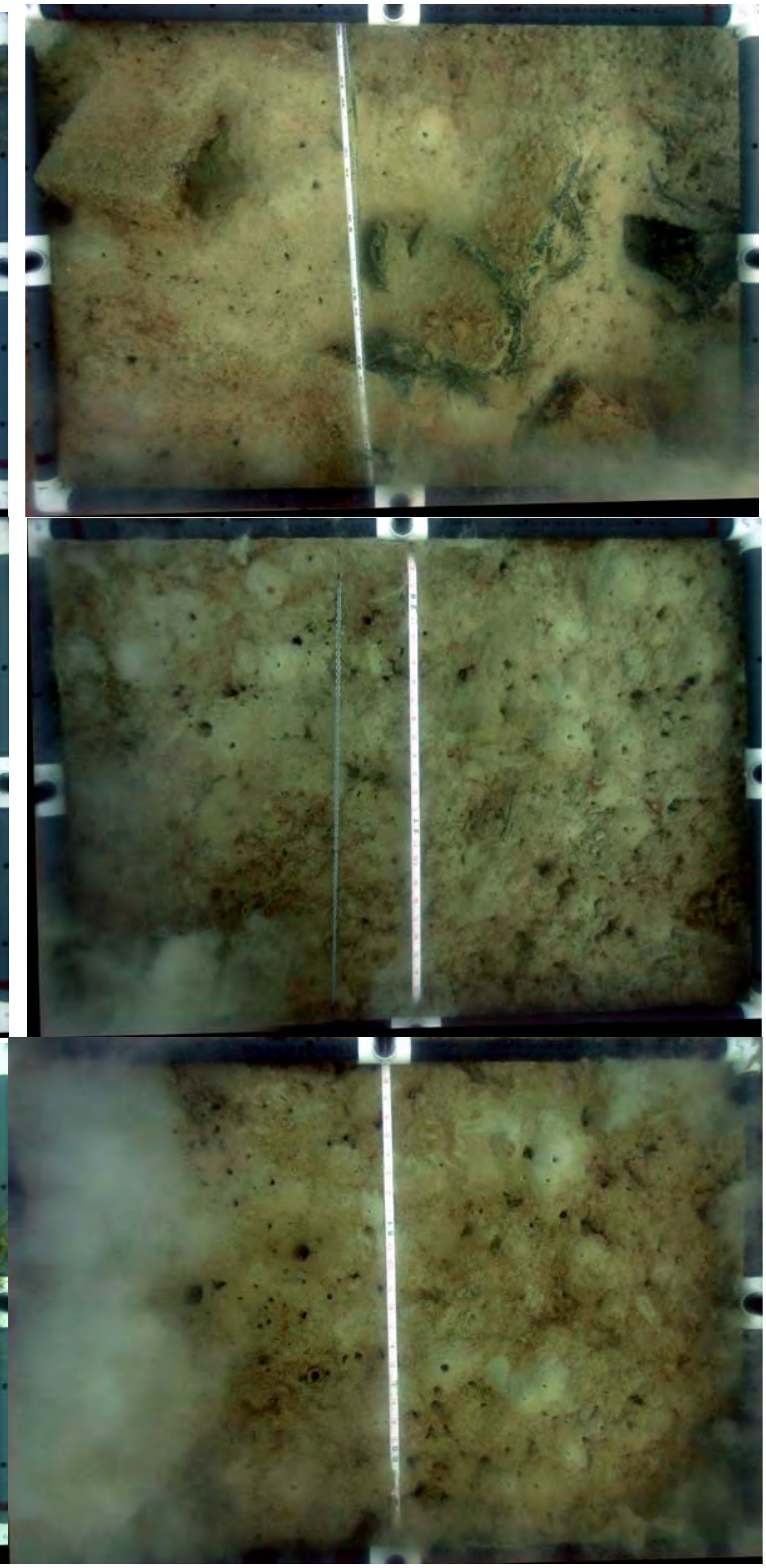

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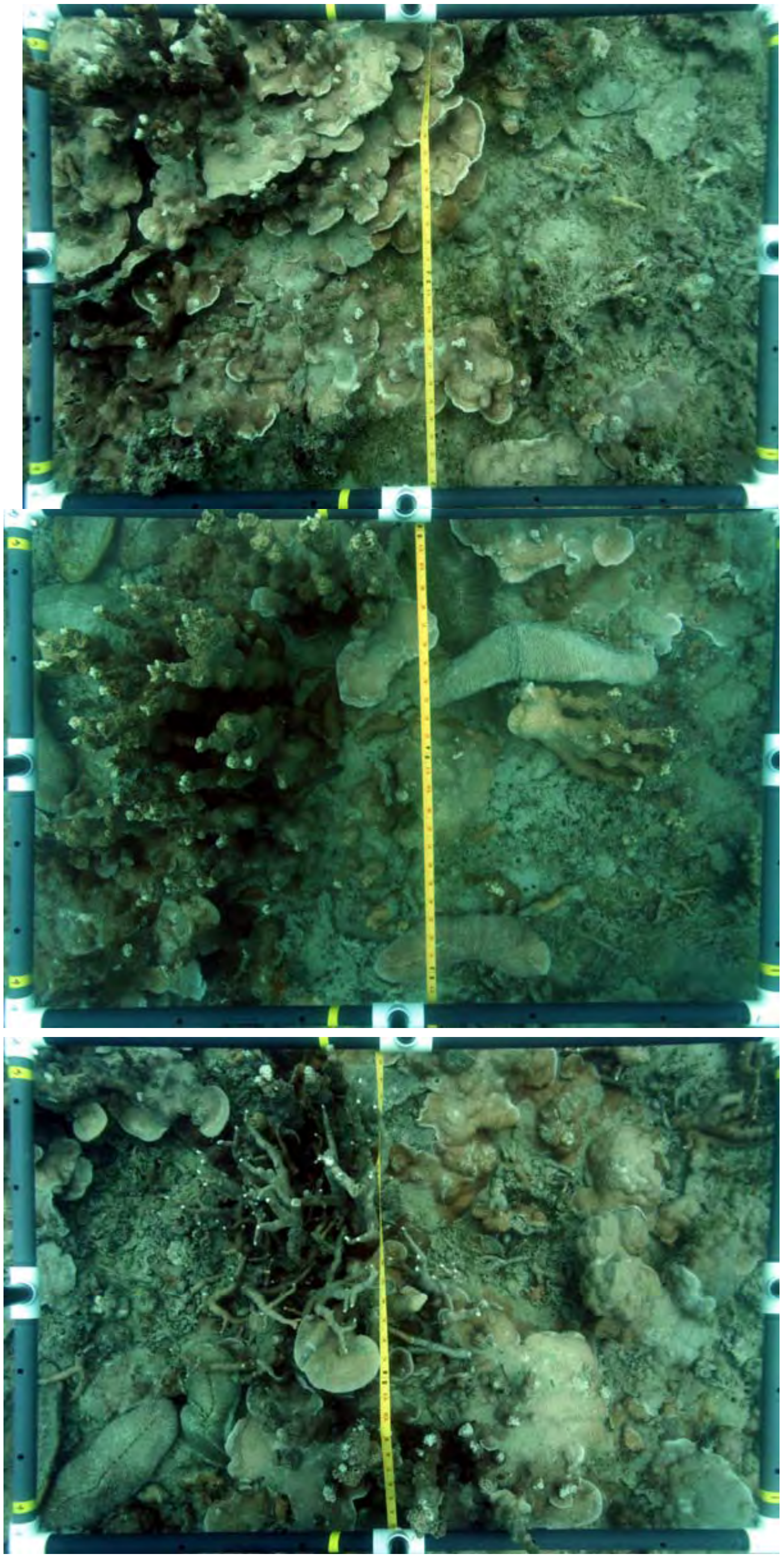

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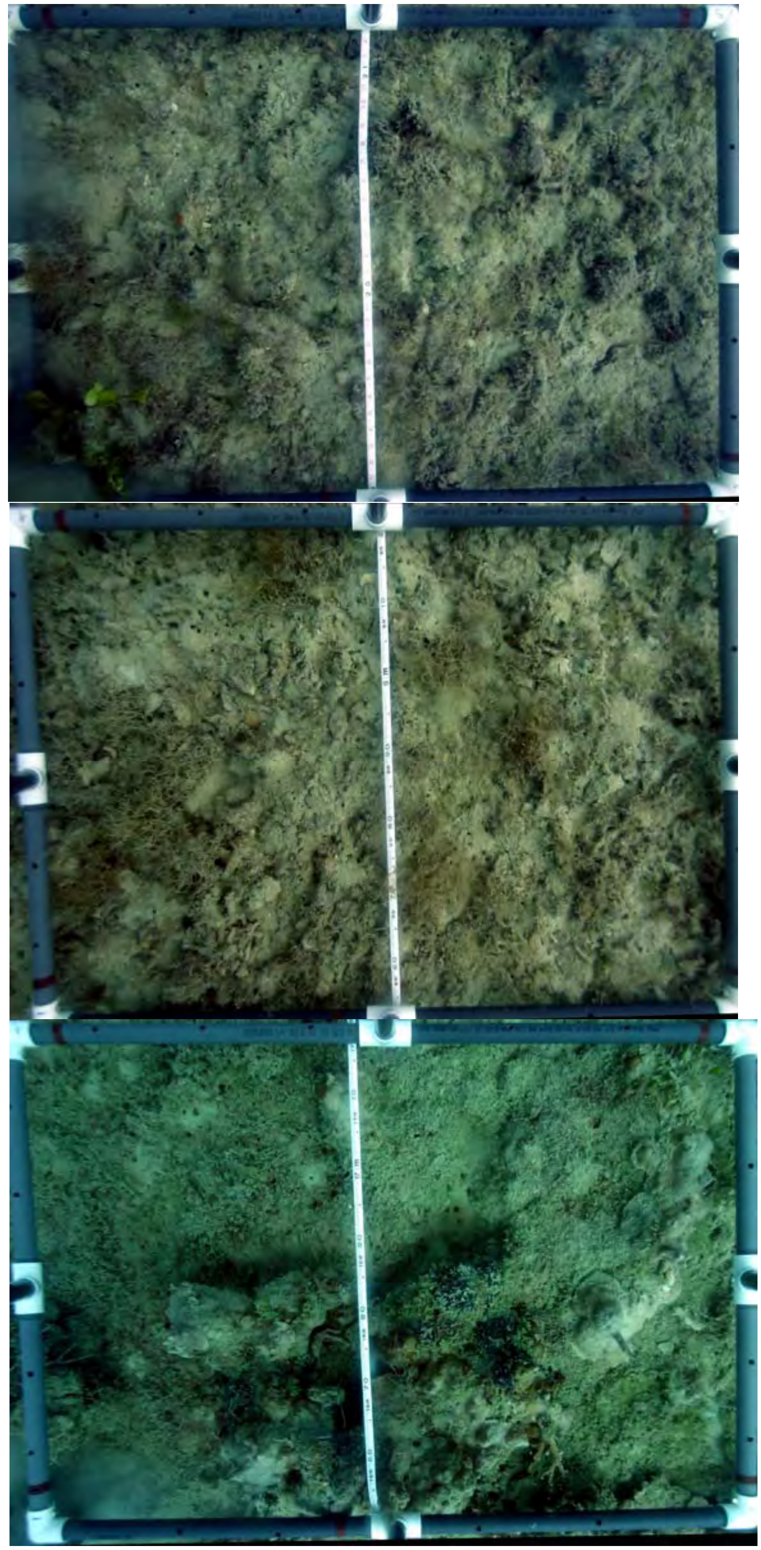

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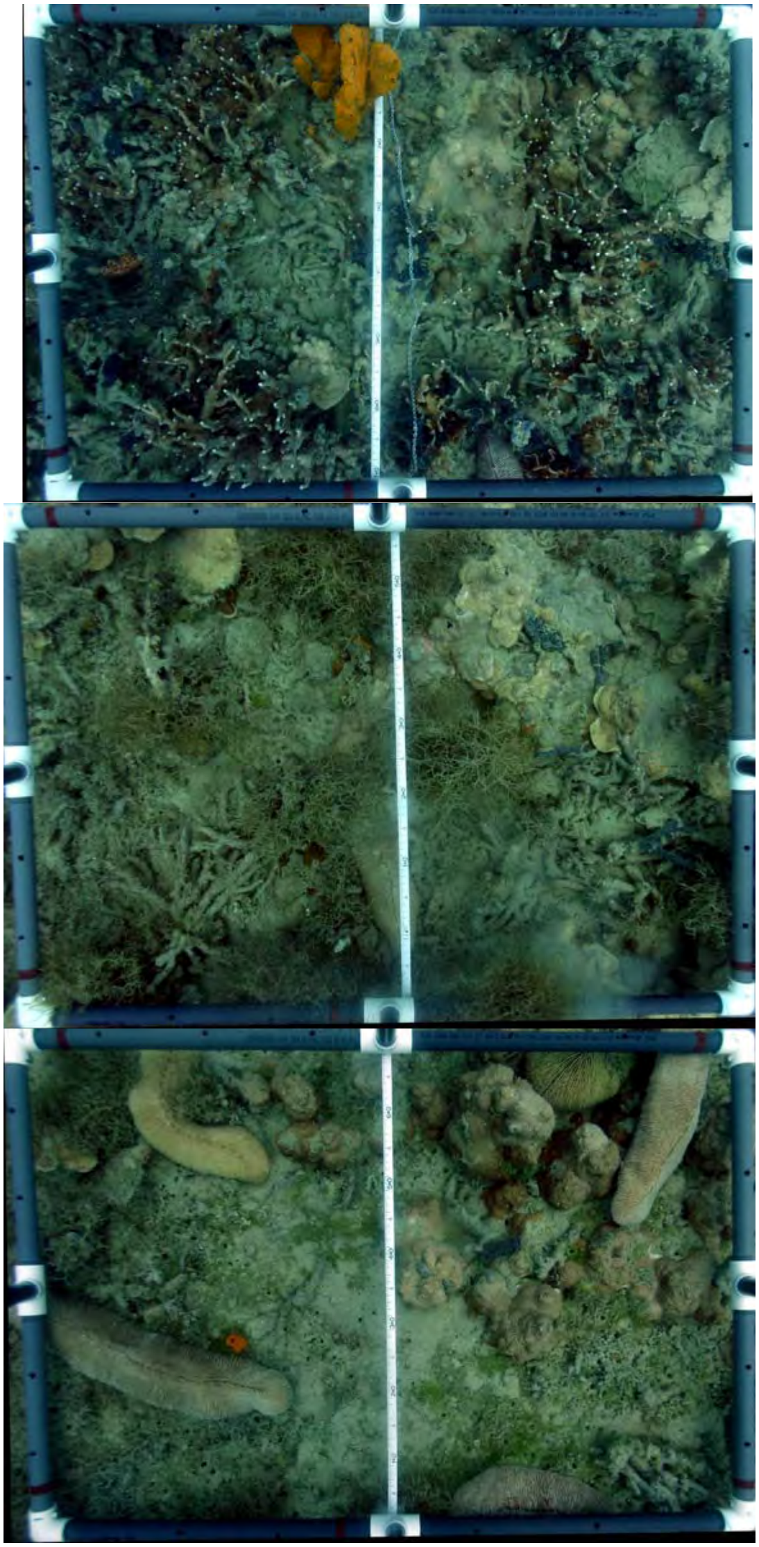

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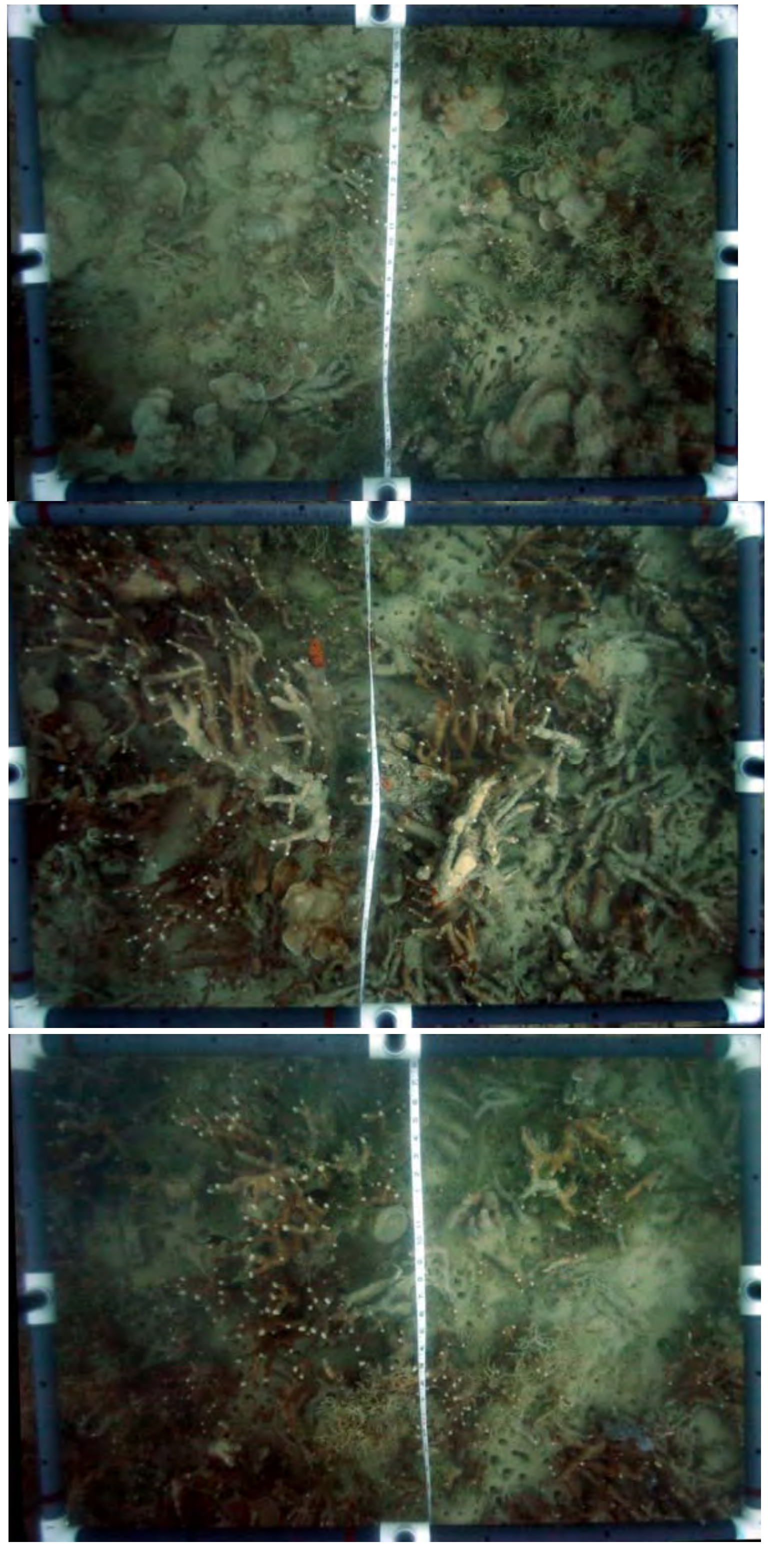

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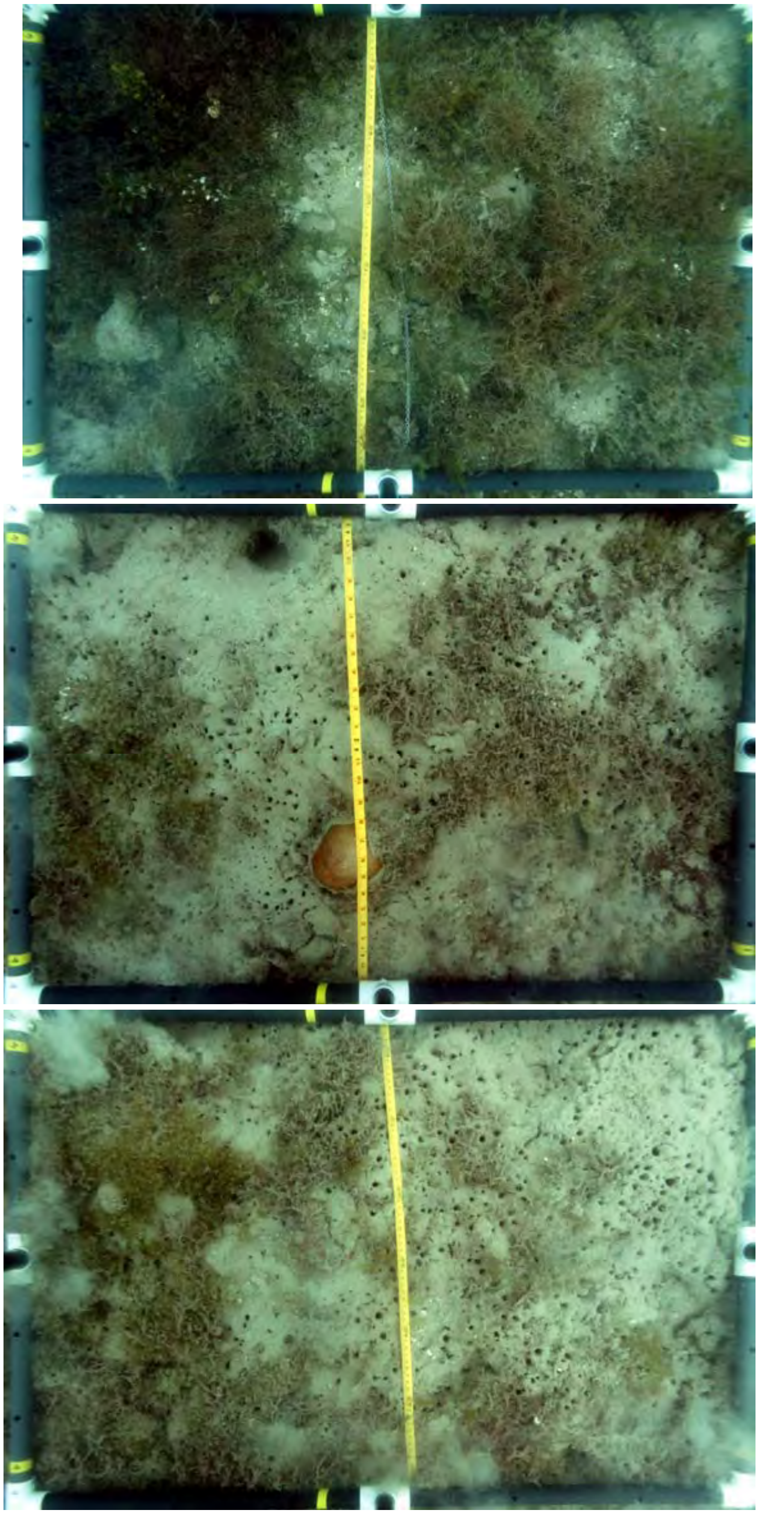

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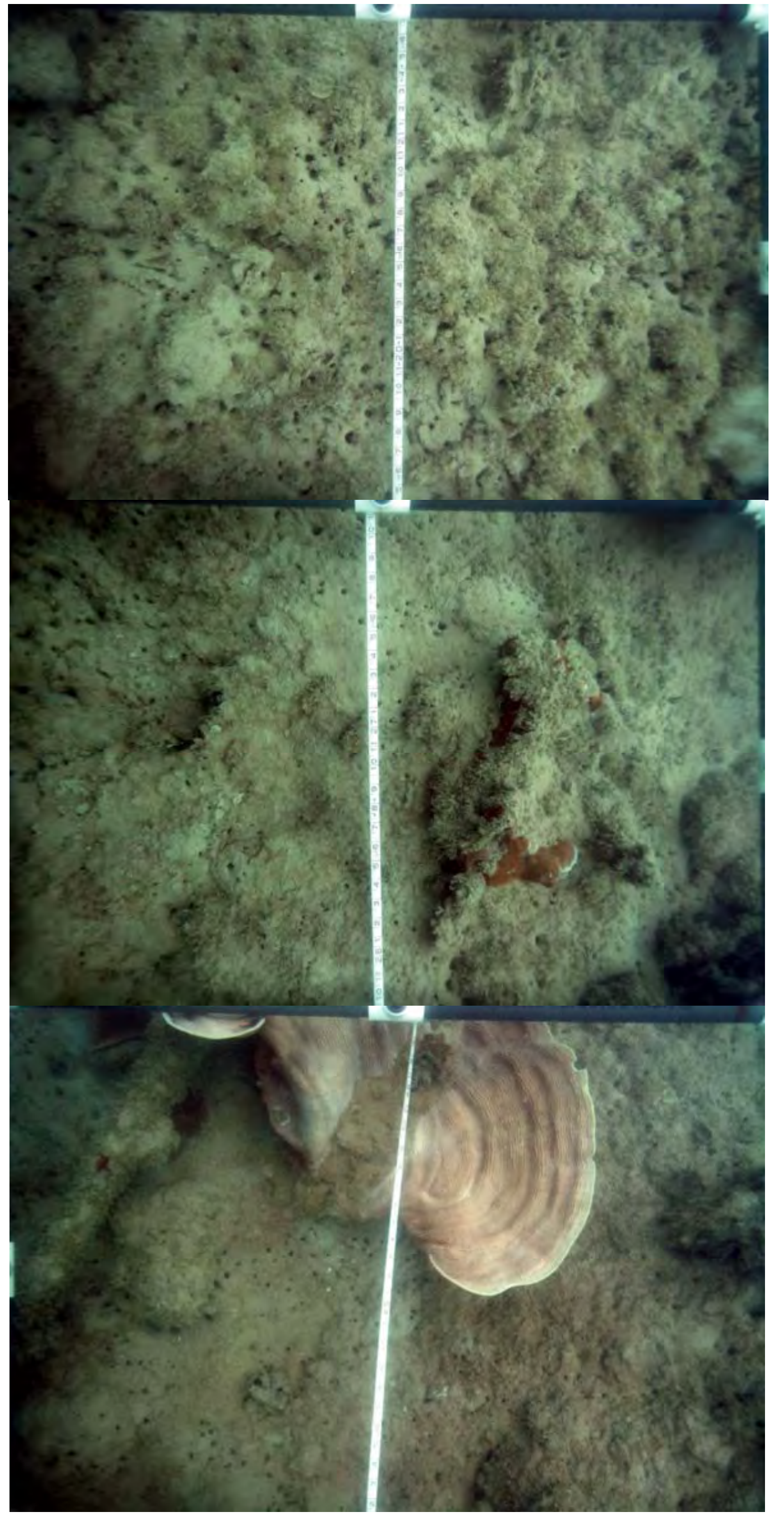

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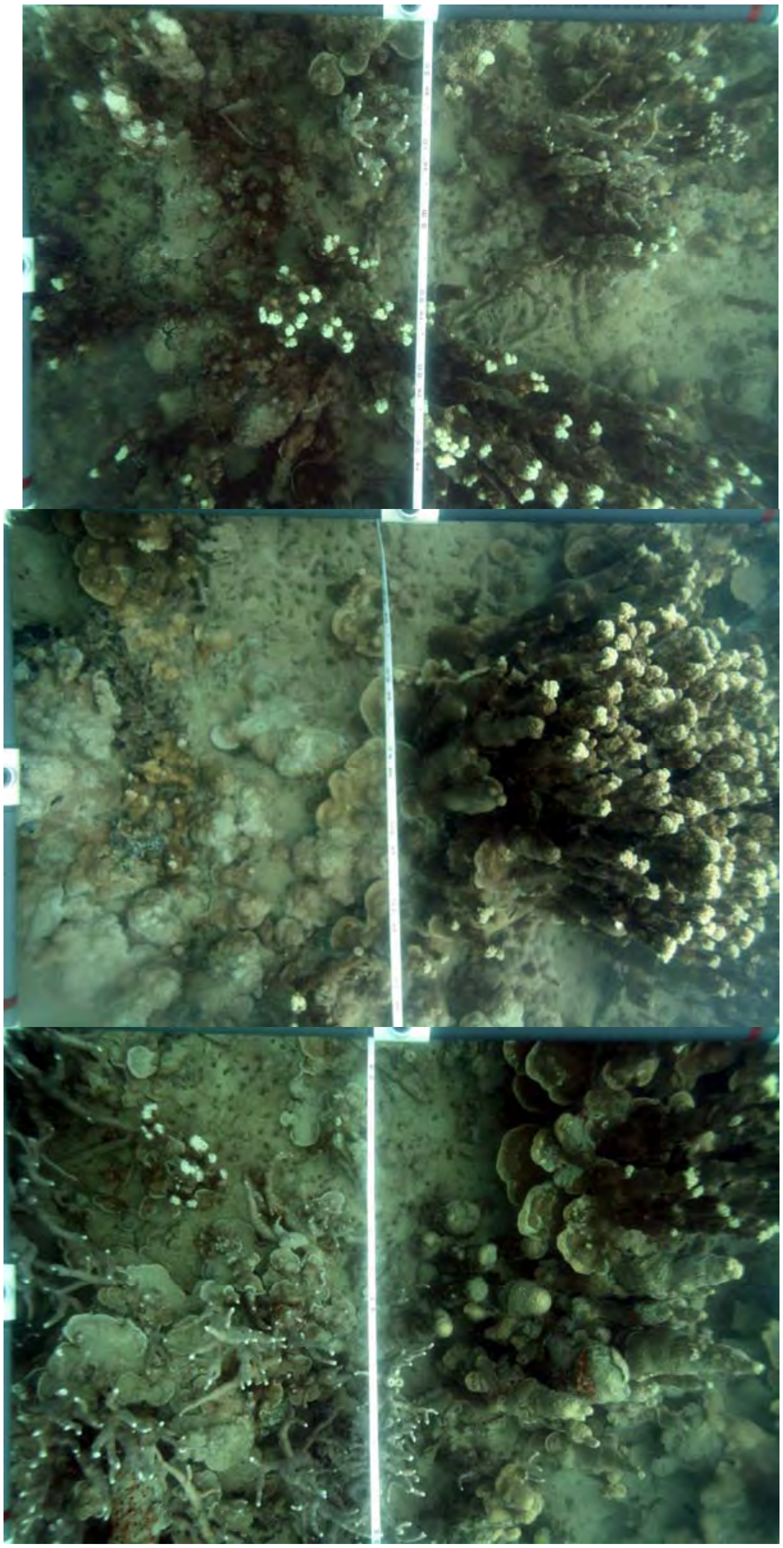

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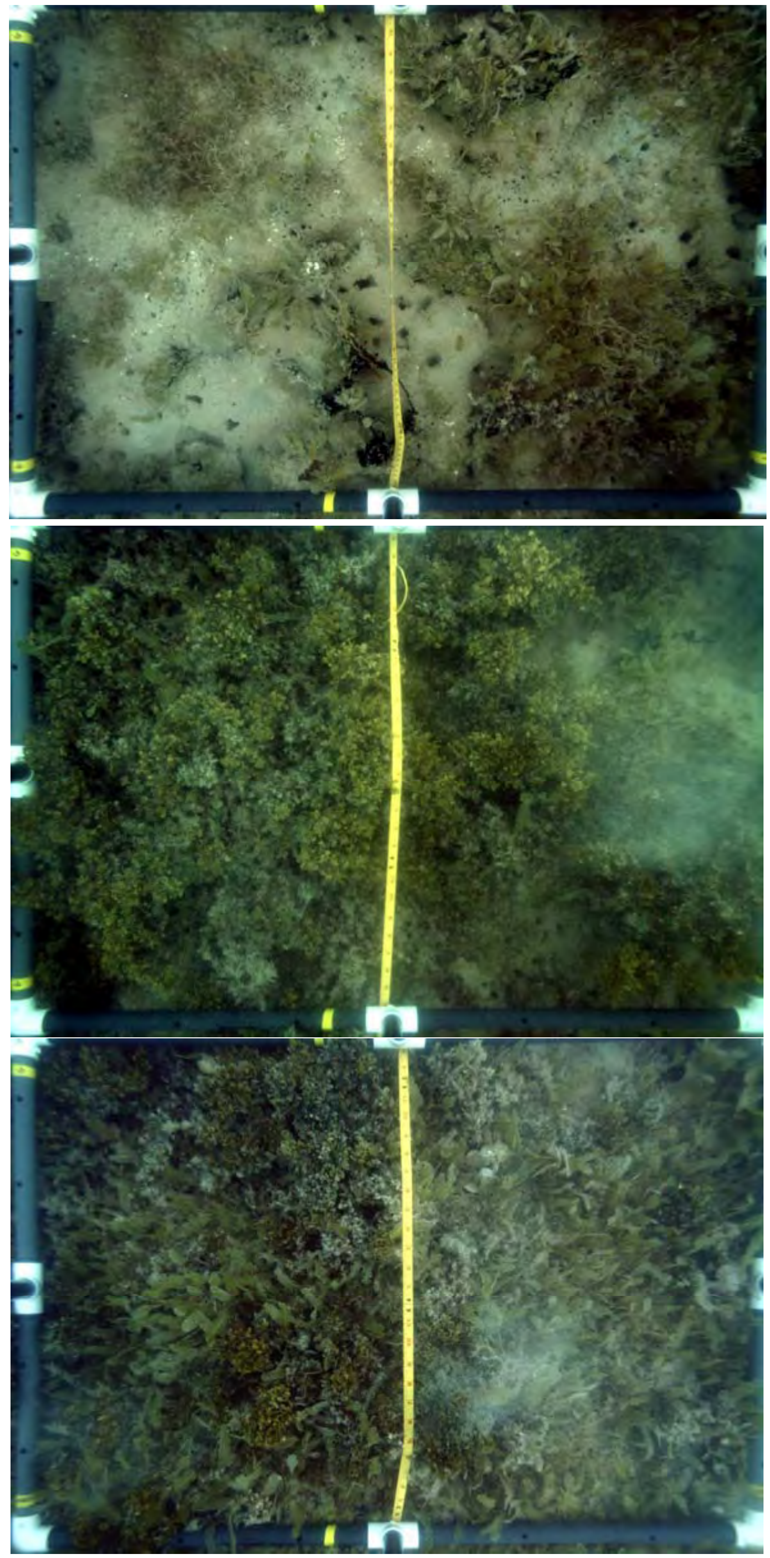
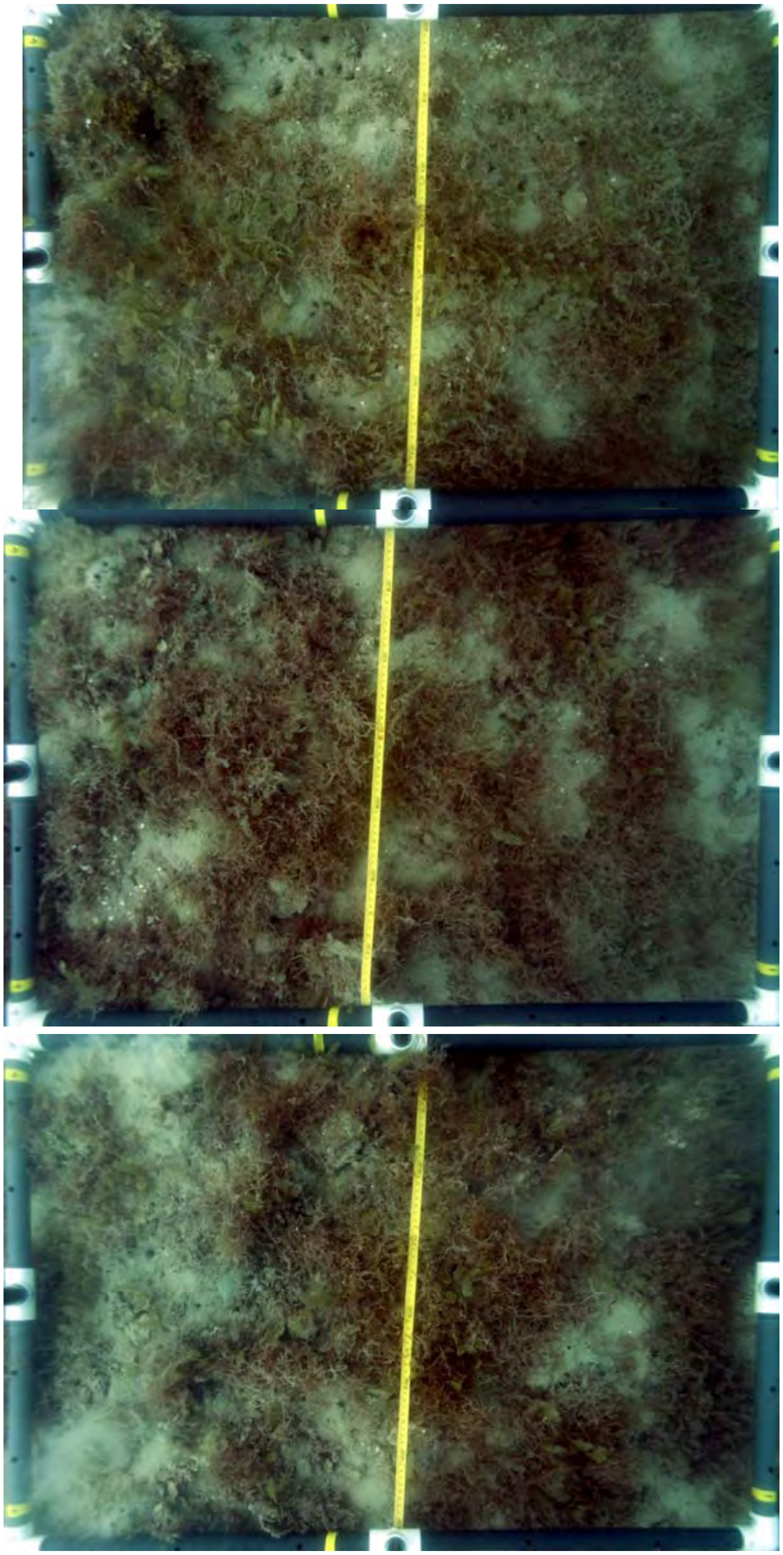


TRANSECT 50



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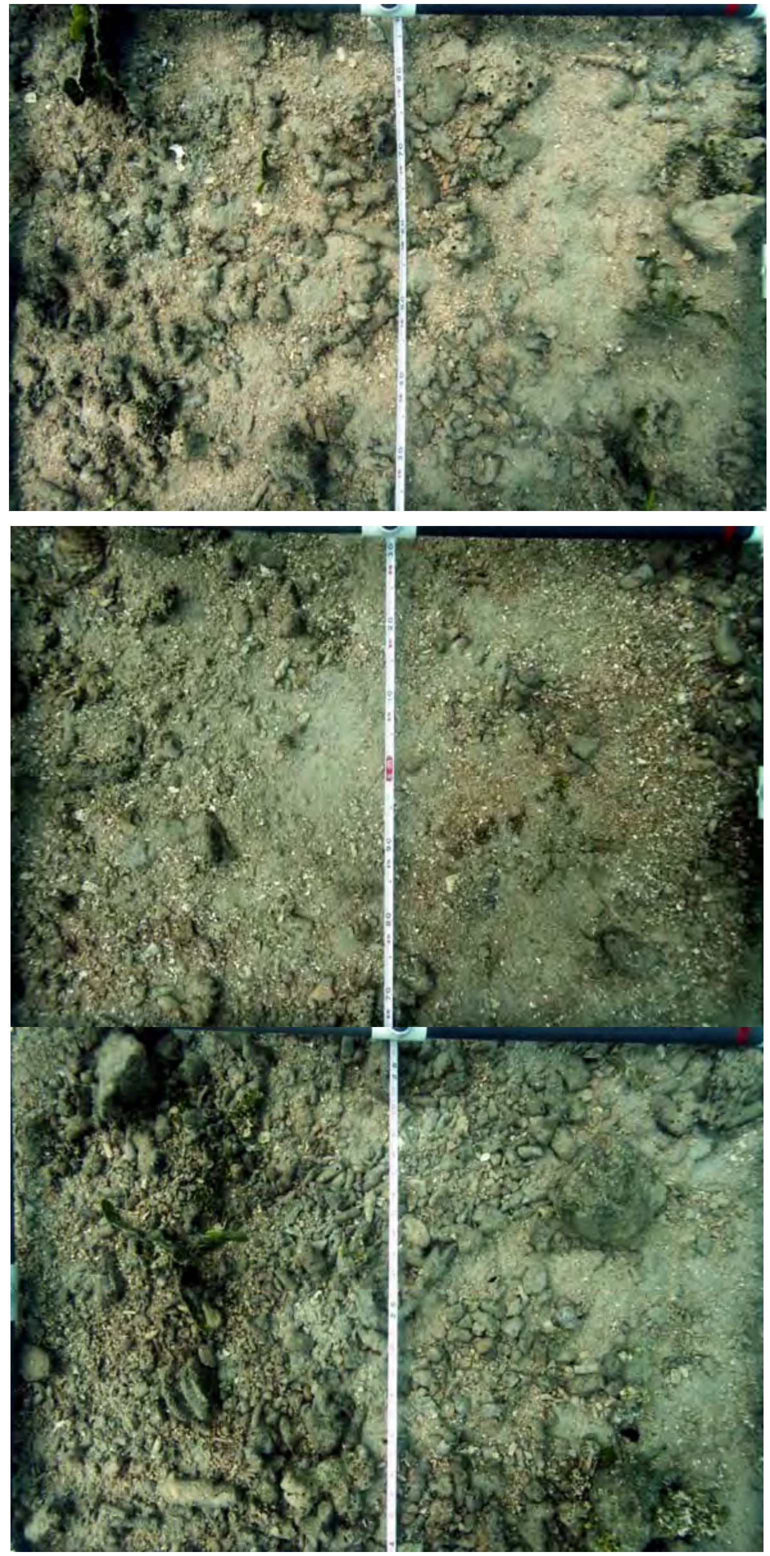
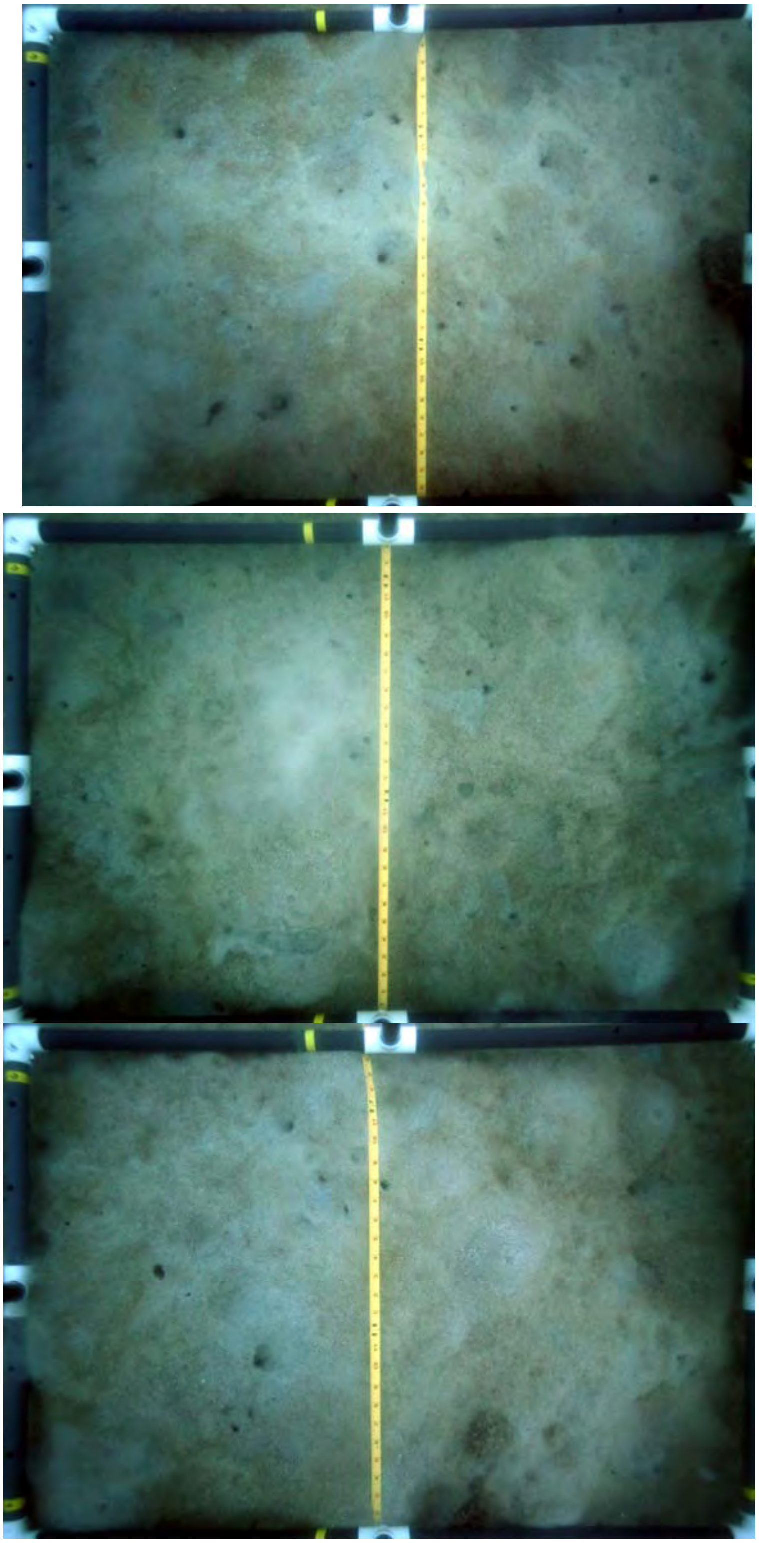


TRANSECT 52



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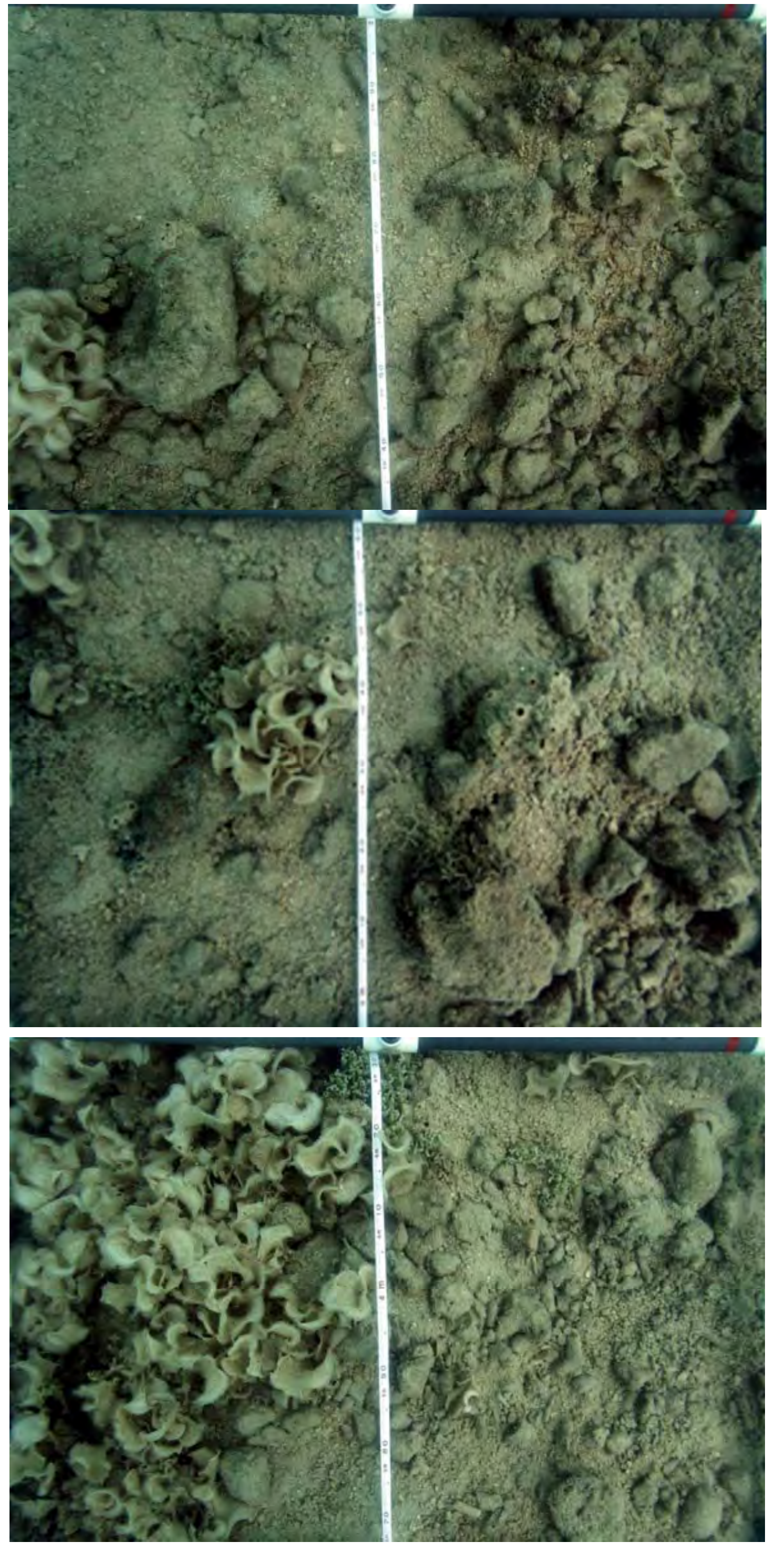

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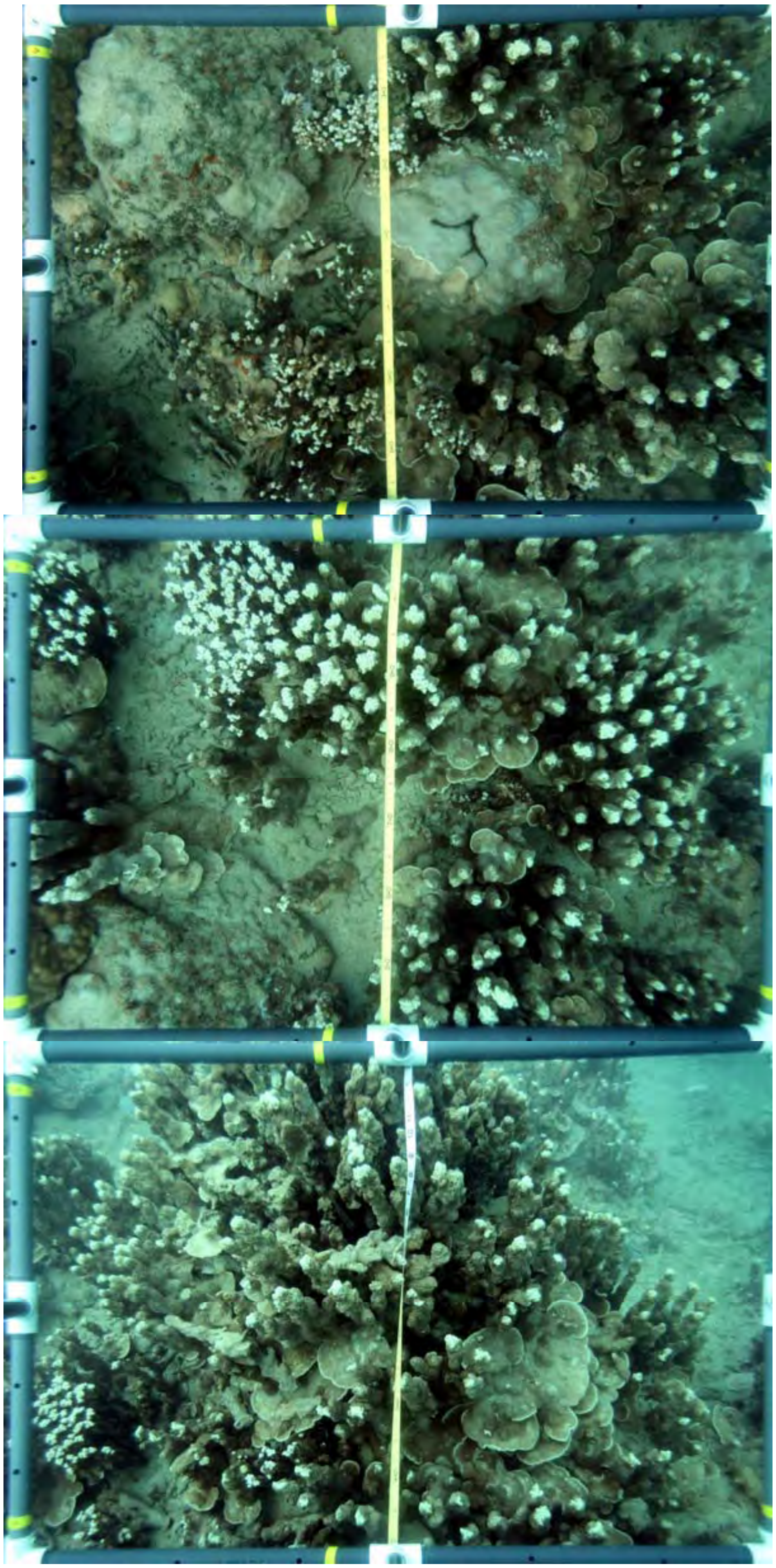
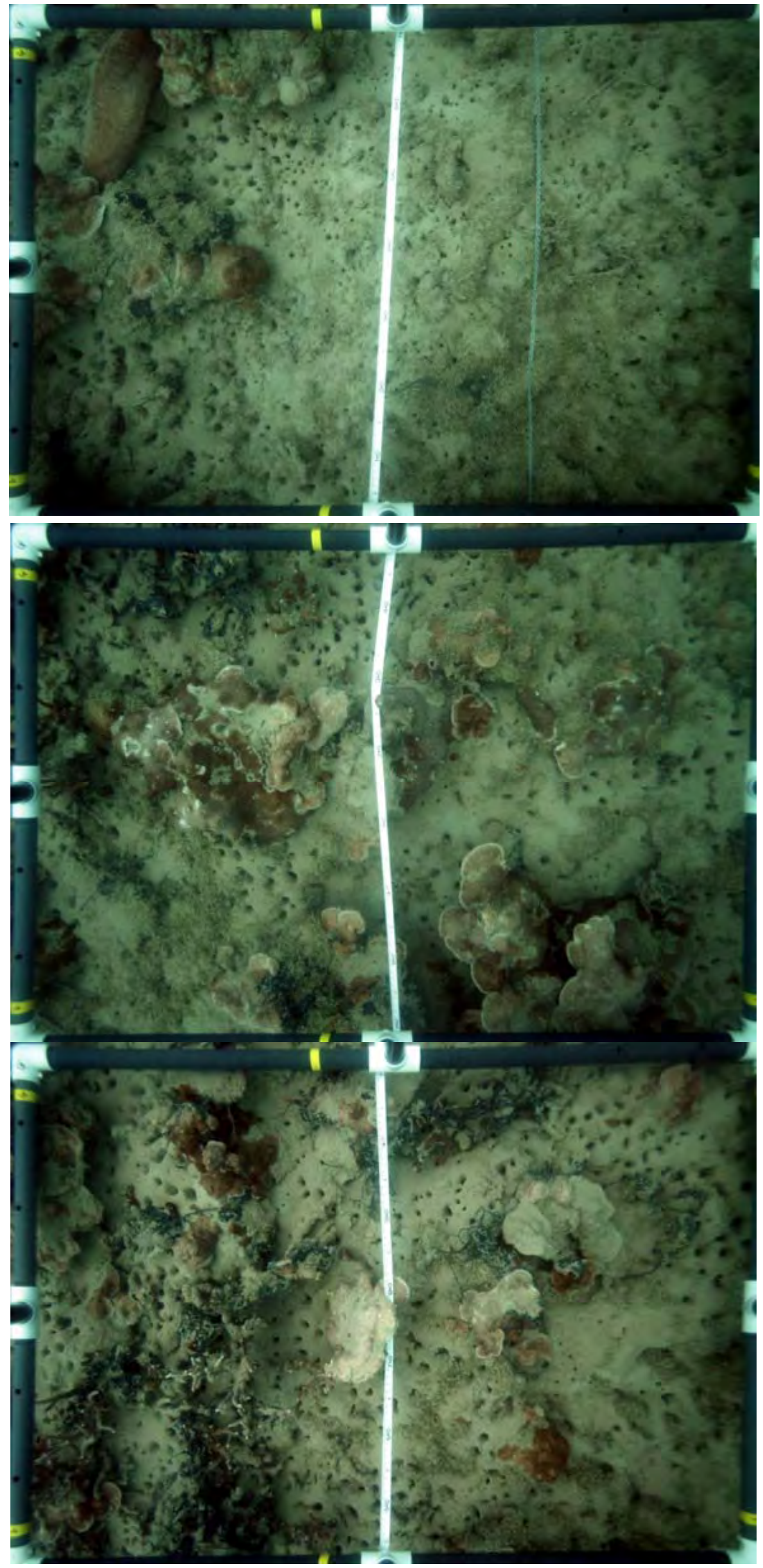
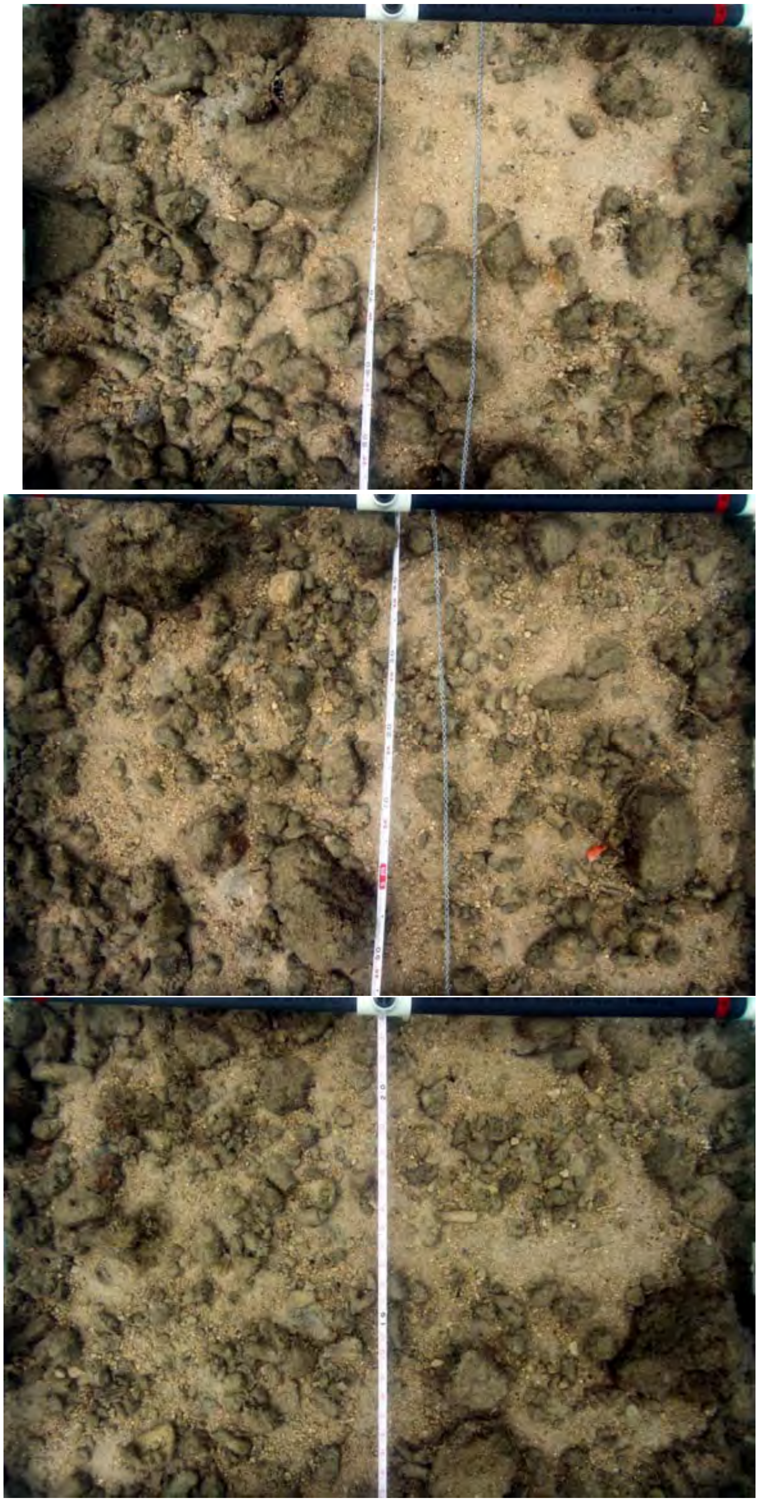
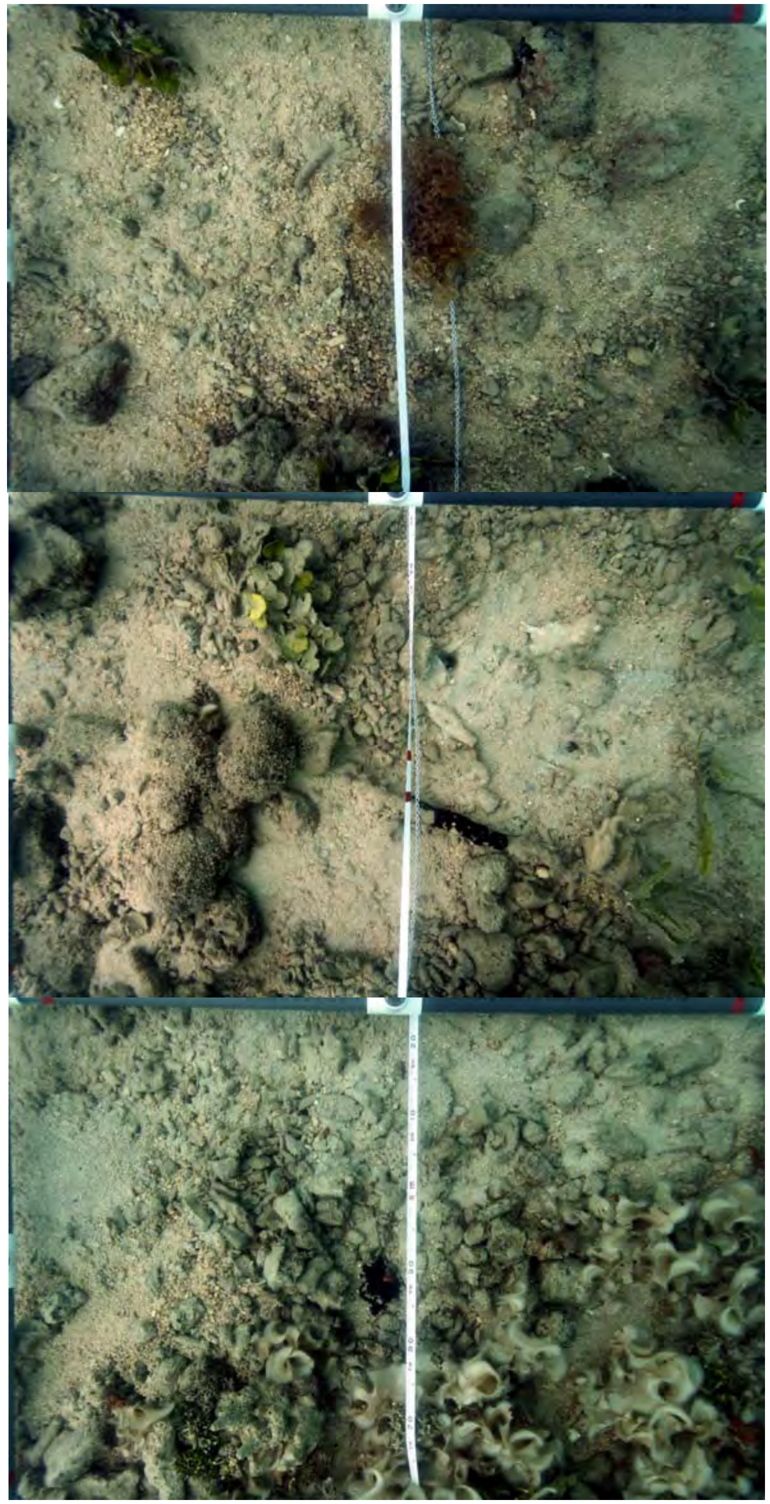




TRANSECT 55

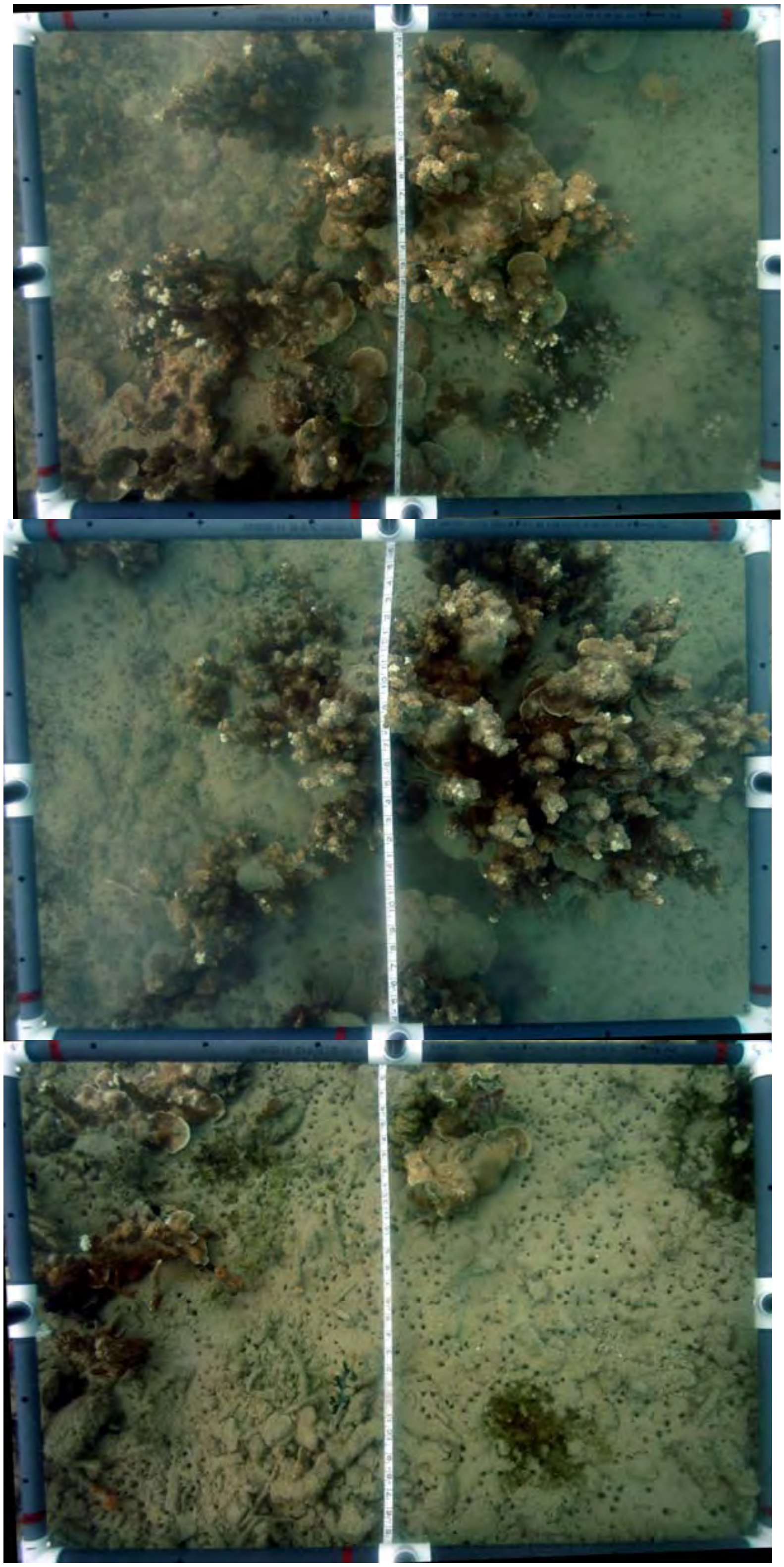
TRANSECT 56





TRANSECT 57

TRANSECT 58



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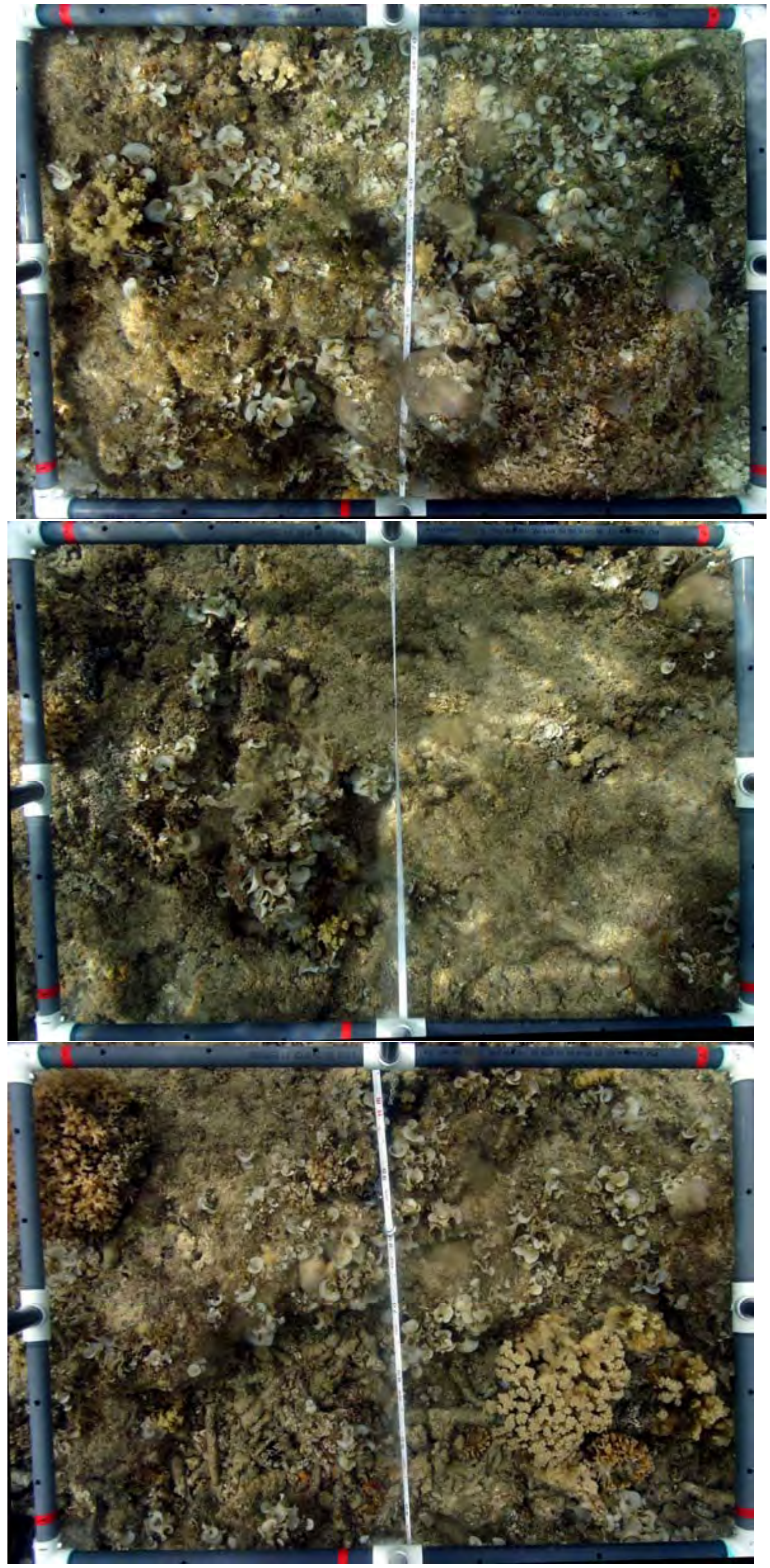
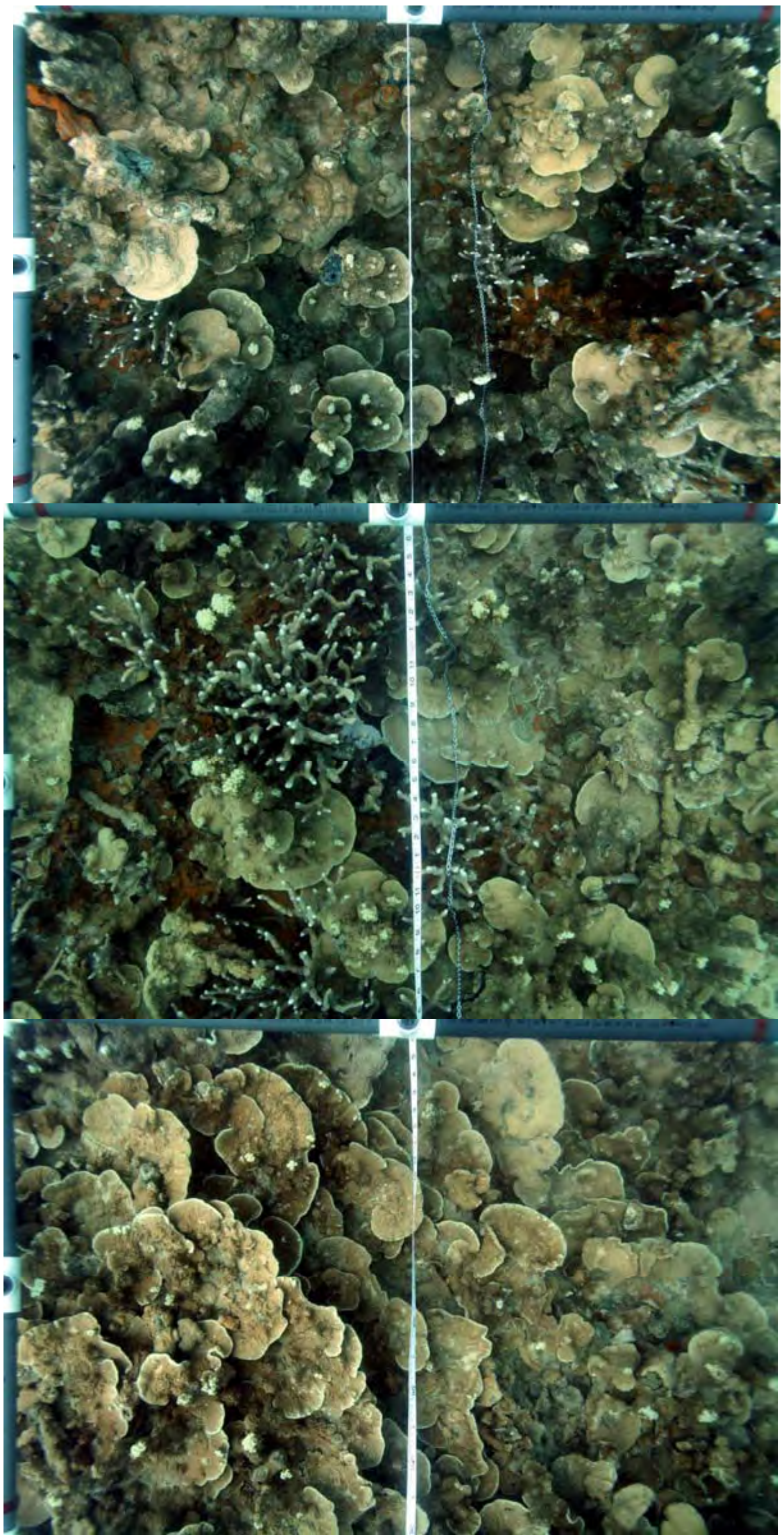
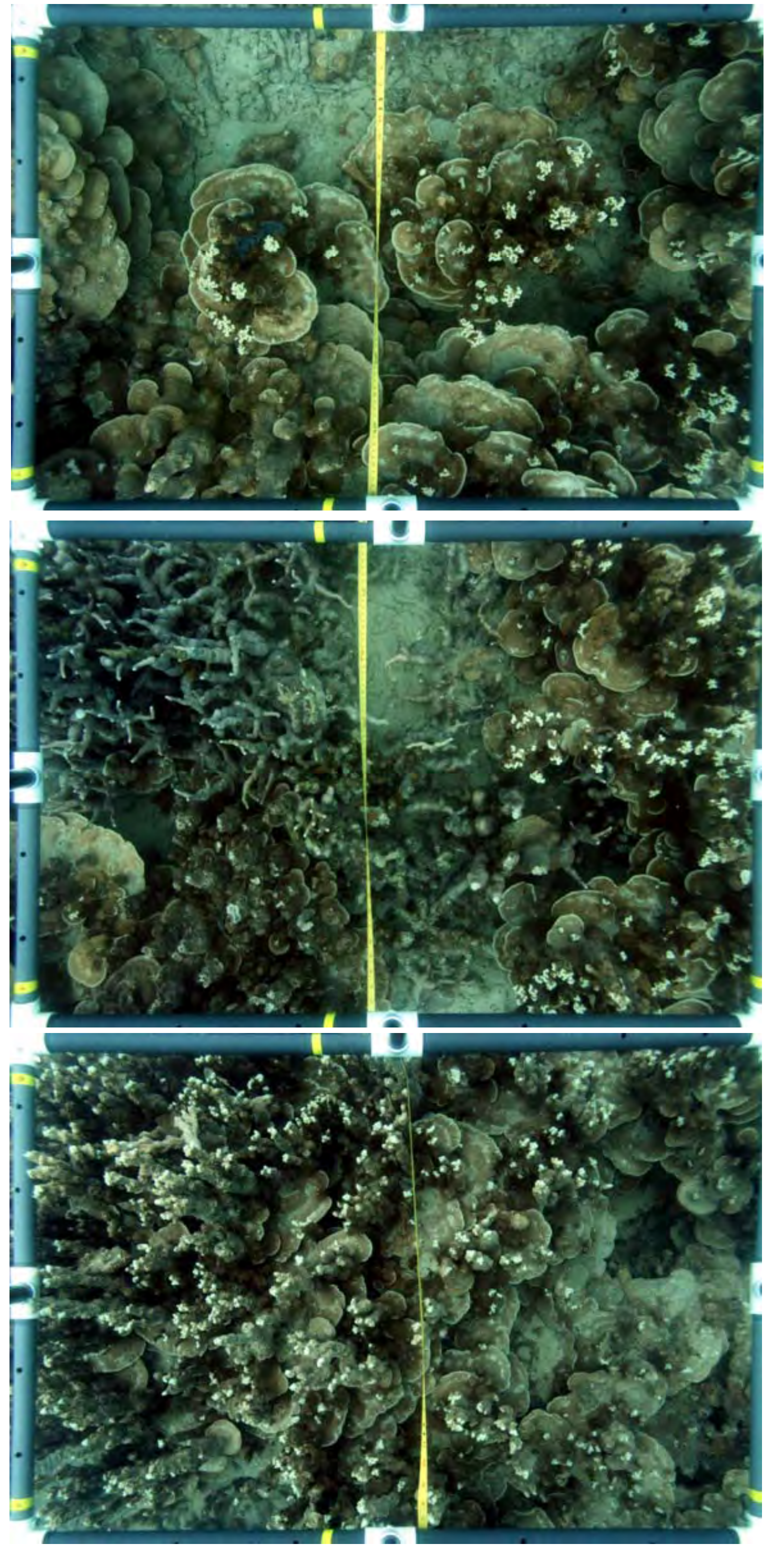


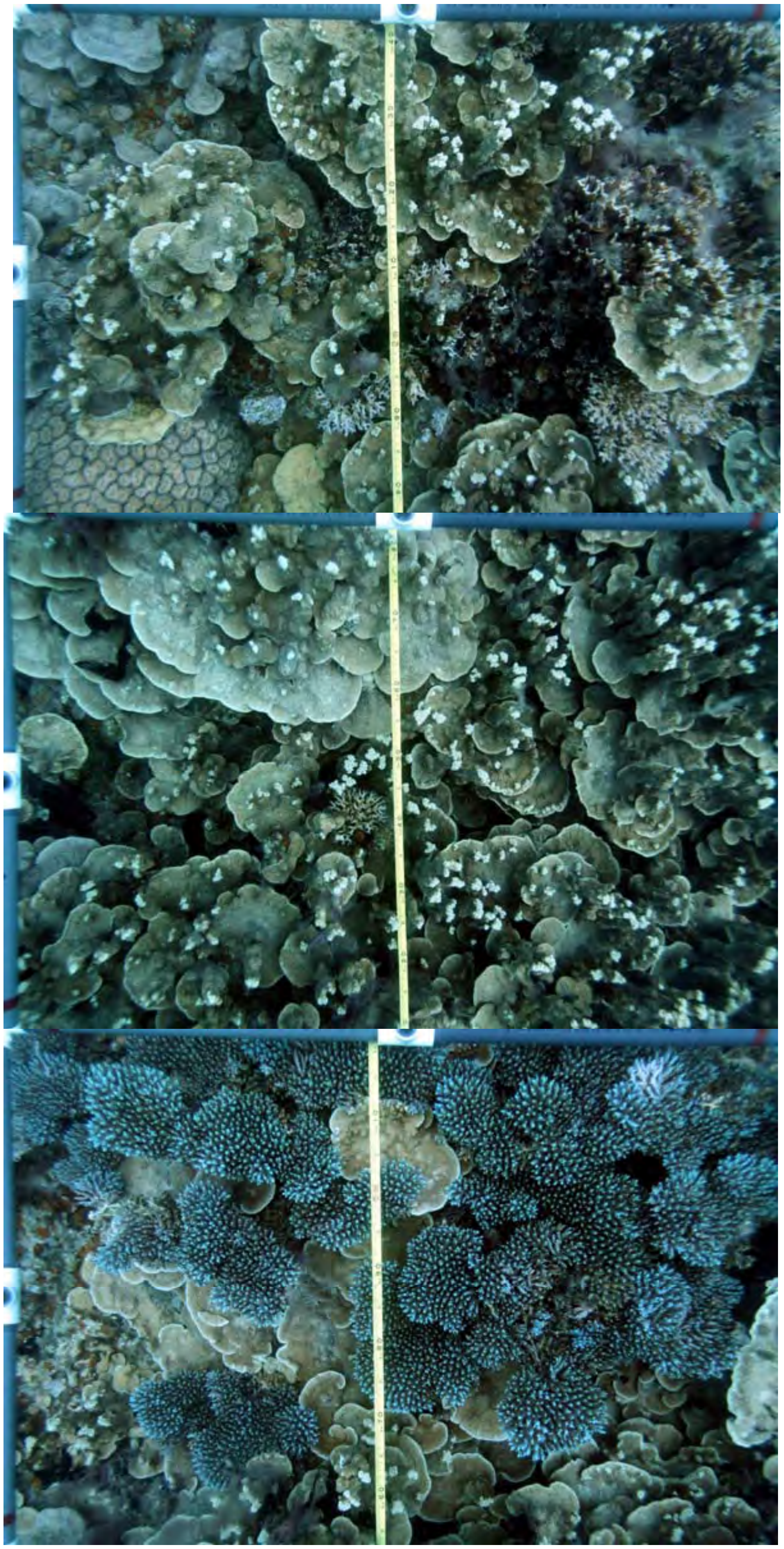
TRANSECT 60



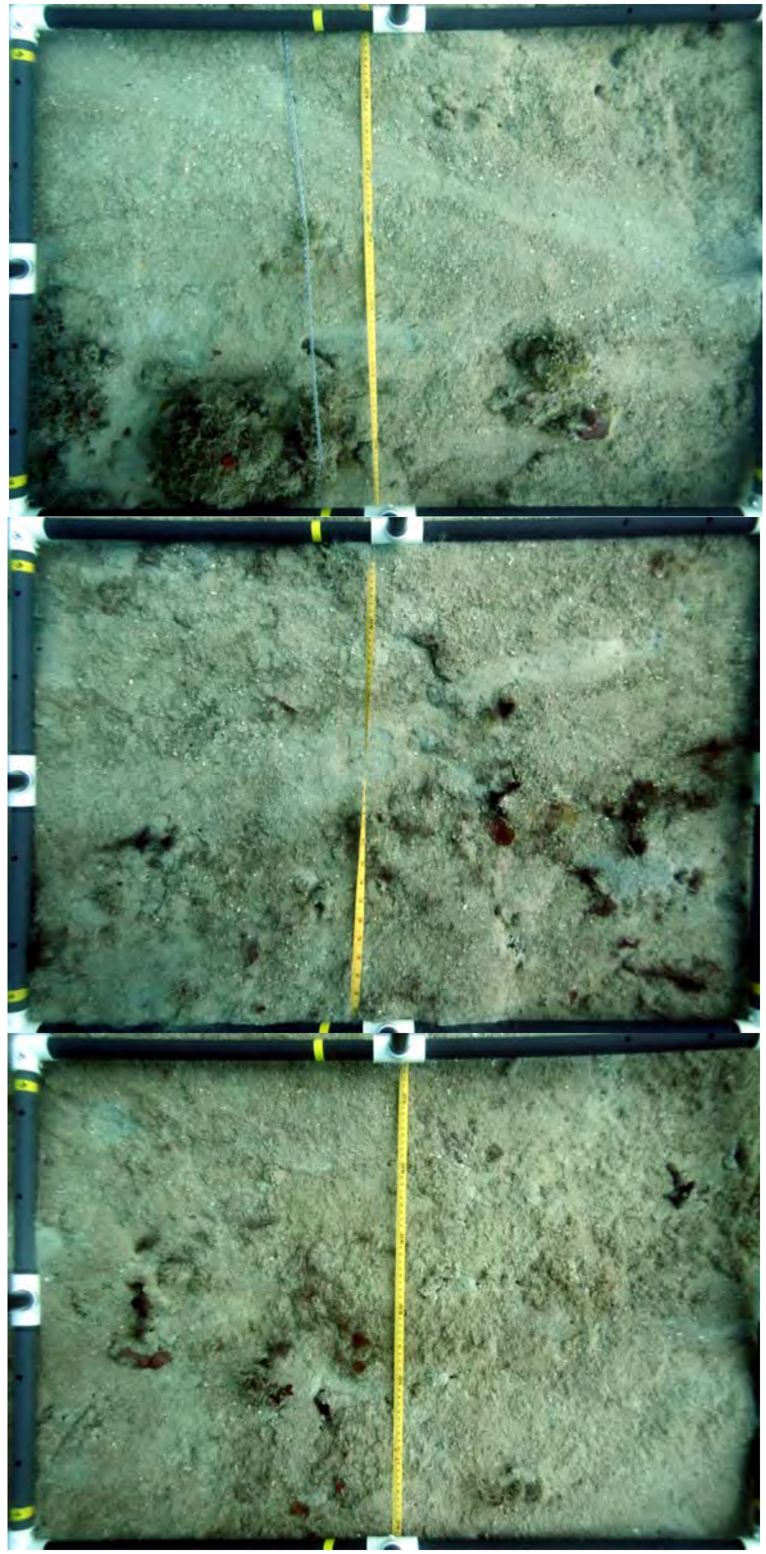
TRANSECT 61



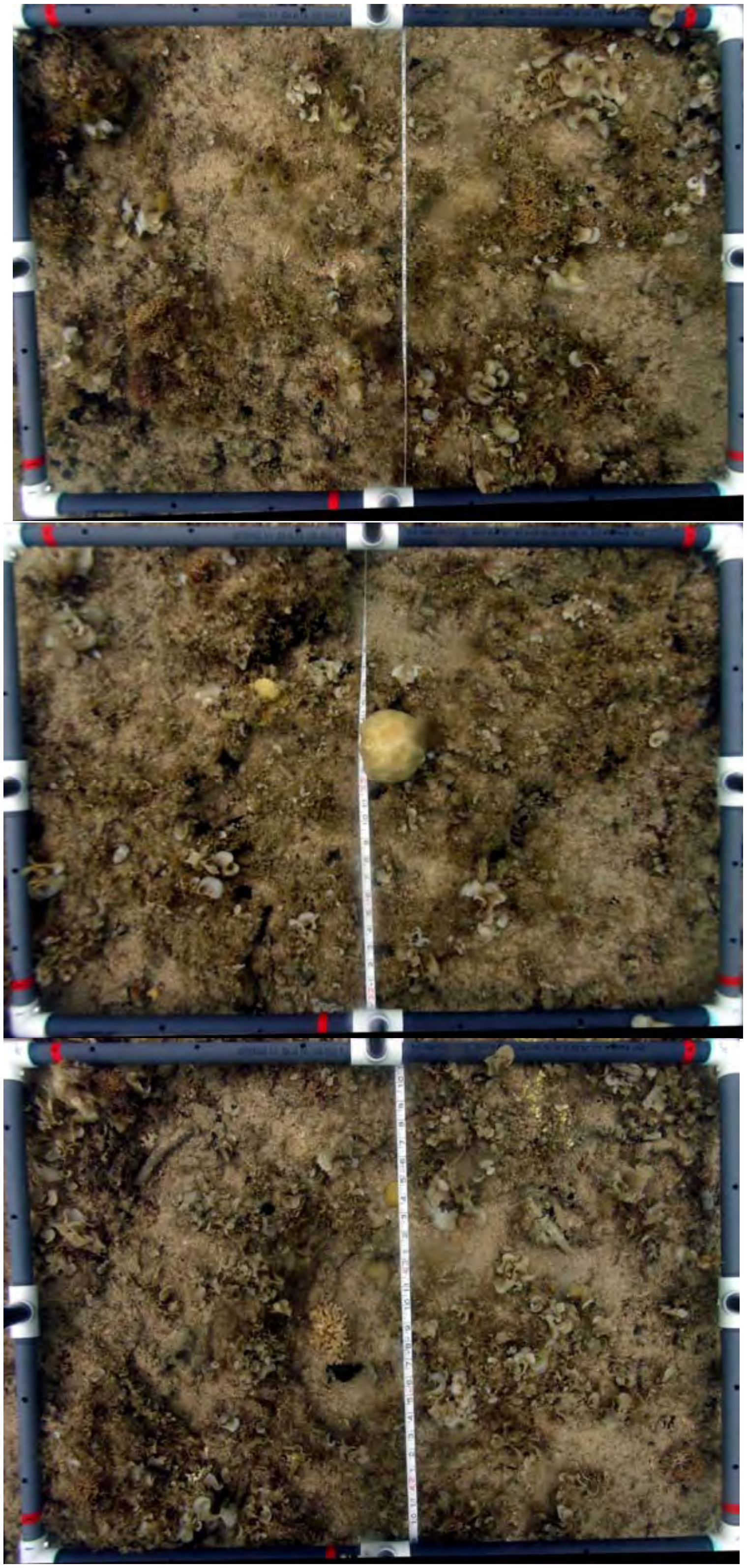
TRANSECT 62



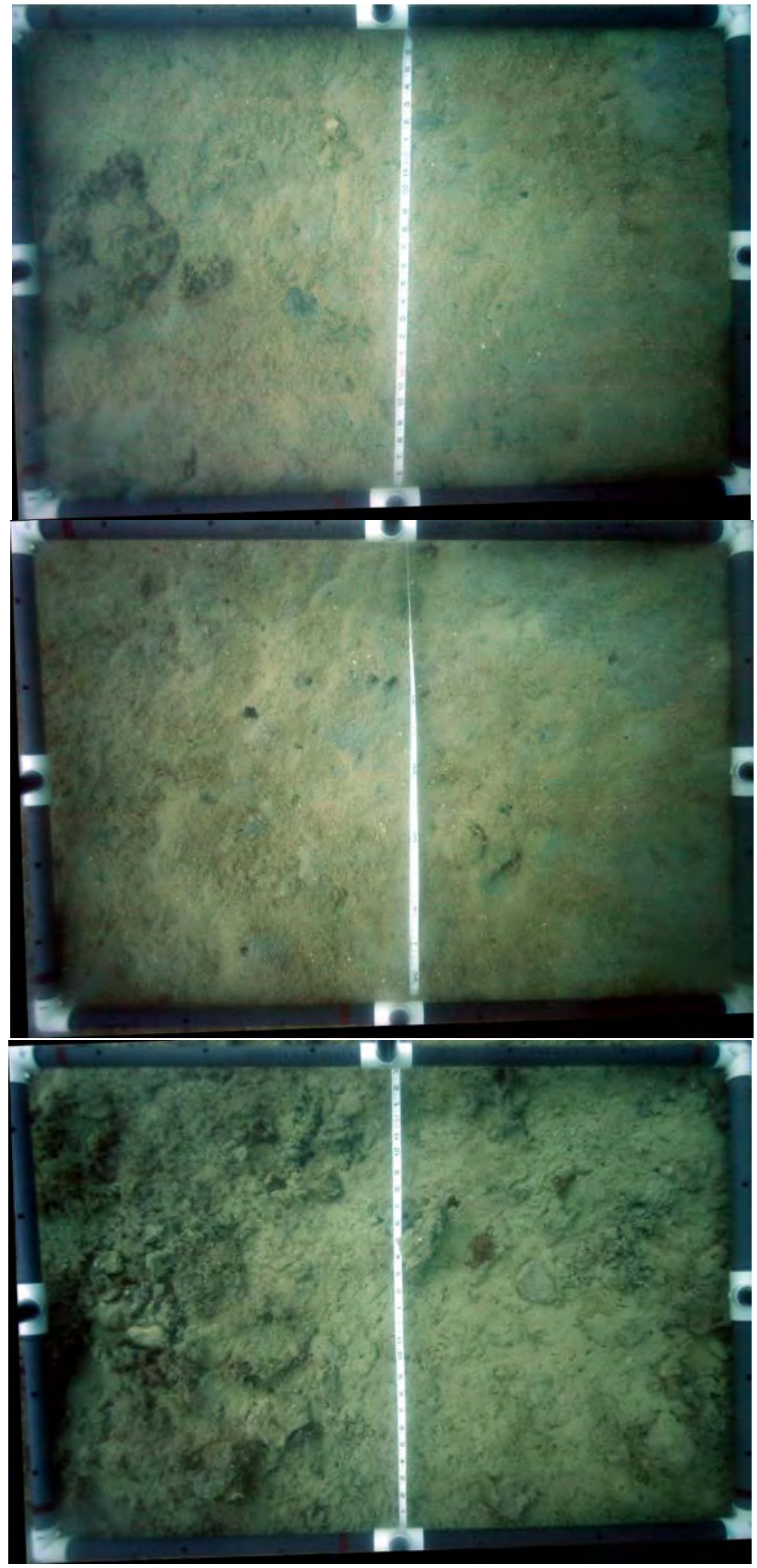
TRANSECT 63



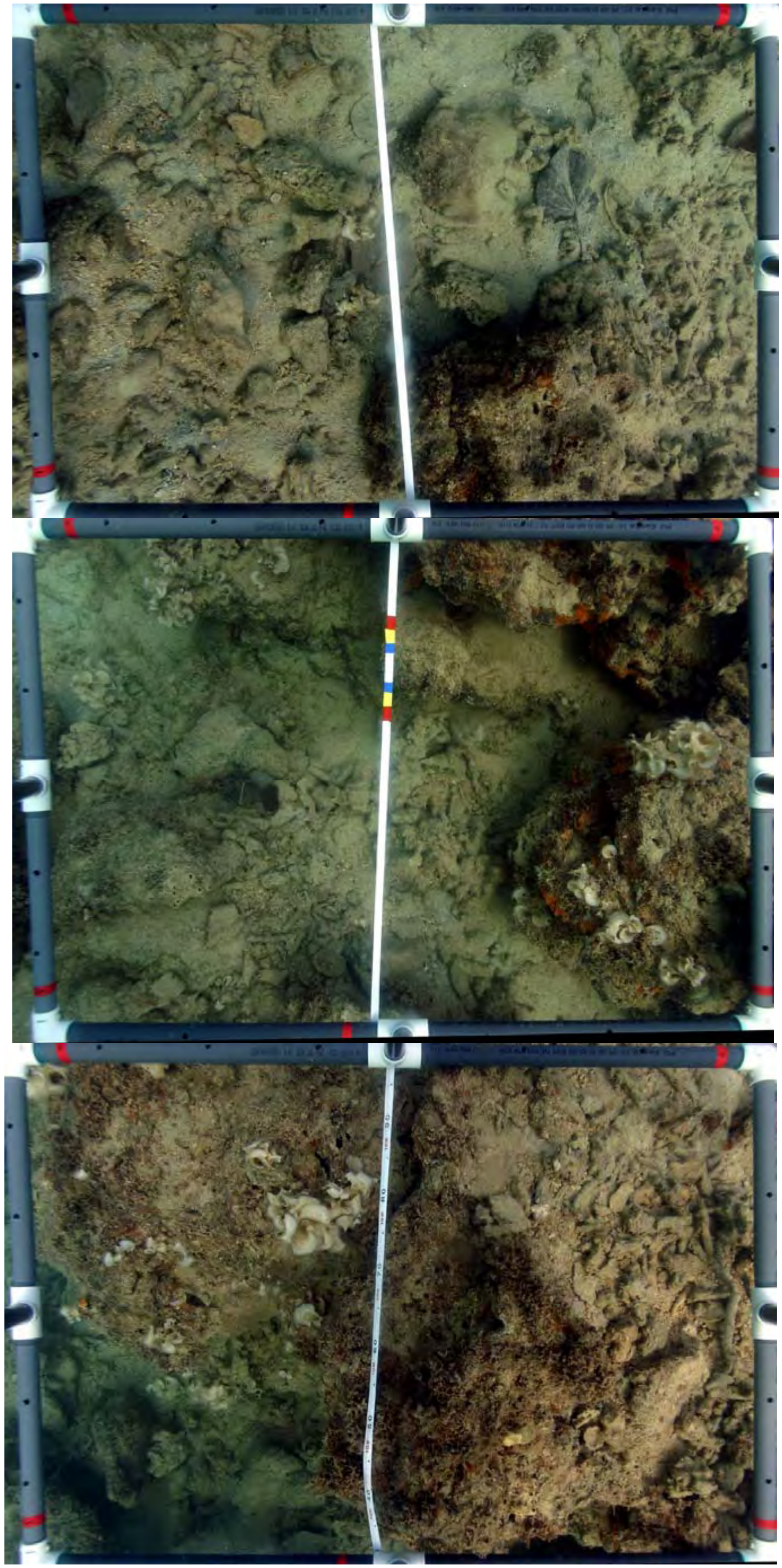
TRANSECT 64



TRANSECT 65



TRANSECT 66



TRANSECT 67

APPENDIX C. Means and 95% upper and lower 95% confidence limits (CI) of percent benthic cover of general classes from photo-quadrat transects in the CVN survey area of Apra Harbor, Guam.

TRANSECT	ALGAE		CORAL		SOFT CORAL		SPONGE		ECHINODERMS		ASCIDIAN		FISH		SEDIMENT	
	MEAN	CI	MEAN	CI	MEAN	CI	MEAN	CI	MEAN	CI	MEAN	CI	MEAN	CI	MEAN	CI
1	12	9.4 15	52.5	48.3 56.8	0	0 0.7	20.4	17.1 24	0	0 0.7	0	0 0.7	0	0 0.7	15.1	12.2 18.4
2	73.3	70 76.5	10.8	8.7 13.2	0	0 0.5	8.1	6.3 10.3	1.1	0.5 2.1	0	0 0.5	0	0 0.5	6.7	5 8.7
3	32	28.1 36.1	1.5	0.6 2.8	0	0 0.7	3.1	1.8 4.9	0	0 0.7	0	0 0.7	0	0 0.7	63.5	59.3 67.5
4	36.9	33.5 40.5	51.3	47.7 55	0	0 0.5	5.9	4.3 7.8	0	0 0.5	0	0 0.5	0	0 0.5	5.9	4.3 7.8
5	8.8	6.9 11.1	70.9	67.5 74.2	0	0 0.5	17.7	15.1 20.7	0	0 0.5	0	0 0.5	0	0 0.5	2.5	1.5 3.9
6	24.1	21.1 27.4	62.5	59 66	0	0 0.5	13.2	10.9 15.8	0	0 0.5	0.1	0 0.7	0	0 0.5	0	0 0.5
7	18.1	15.4 21.1	68.8	65.3 72.1	1.7	0.9 2.9	0.4	0.1 1.2	0.1	0 0.7	0	0 0.5	0	0 0.5	10.8	8.7 13.2
8	16.1	13.6 19	66	62.5 69.4	0	0 0.5	10.1	8.1 12.5	0	0 0.5	0	0 0.5	0	0 0.5	7.7	5.9 9.9
9	53.5	49.8 57.1	21.7	18.8 24.9	0	0 0.5	23.6	20.6 26.8	0	0 0.5	0	0 0.5	0	0 0.5	1.2	0.6 2.3
10	82.5	79.3 85.3	0.9	0.3 2	0	0 0.6	1.2	0.5 2.4	0.3	0 1.1	0	0 0.6	0	0 0.6	15.1	12.4 18.1
11	92.8	90.7 94.5	0	0 0.5	0	0 0.5	3.1	2 4.6	0	0 0.5	0	0 0.5	0	0 0.5	4.1	2.8 5.8
12	99.9	99.3 100	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0.1	0 0.7
13	26.9	23.8 30.3	61.6	58 65.1	0	0 0.5	3.6	2.4 5.2	0	0 0.5	0	0 0.5	0	0 0.5	7.9	6 10
14	33.9	30.5 37.4	48.1	44.5 51.8	0	0 0.5	3.2	2.1 4.7	0	0 0.5	0.3	0 1	0	0 0.5	14.5	12.1 17.3
15	11.1	8.9 13.5	68.5	65.1 71.8	0	0 0.5	6.5	4.9 8.5	0	0 0.5	0	0 0.5	0	0 0.5	13.9	11.5 16.5
16	12.9	10.6 15.5	1.9	1 3.1	0	0 0.5	1.3	0.6 2.4	0	0 0.5	0	0 0.5	0	0 0.5	83.9	81 86.4
17	36.7	33.2 40.2	14.4	12 17.1	0	0 0.5	5.9	4.3 7.8	0	0 0.5	0	0 0.5	0	0 0.5	43.1	39.5 46.7
18	52.9	49.3 56.6	27.1	23.9 30.4	0	0 0.5	1.5	0.7 2.6	0	0 0.5	0	0 0.5	0	0 0.5	18.5	15.8 21.5
19	34.3	30.9 37.8	51.6	48 55.2	0	0 0.5	2.1	1.2 3.4	0	0 0.5	0	0 0.5	0	0 0.5	12	9.8 14.5
20	90.3	87.9 92.3	3.3	2.2 4.9	0	0 0.5	1.1	0.5 2.1	0	0 0.5	0	0 0.5	0	0 0.5	5.3	3.8 7.2
21	50.3	46.6 53.9	20.8	17.9 23.9	0	0 0.5	0.9	0.4 1.9	0	0 0.5	0	0 0.5	0	0 0.5	28	24.8 31.4
22	89.2	86.8 91.3	3.3	2.2 4.9	0	0 0.5	0.5	0.1 1.4	0	0 0.5	0	0 0.5	0	0 0.5	6.9	5.2 9
23	63.3	59.8 66.8	15.3	12.8 18.1	0	0 0.5	5.7	4.2 7.6	0	0 0.5	0	0 0.5	0.3	0 1	15.3	12.8 18.1
24	32.8	29.4 36.3	4	2.7 5.7	0	0 0.5	0	0 0.5	0.1	0 0.7	0	0 0.5	0	0 0.5	63.1	59.5 66.5
25	61.9	58.3 65.4	4	2.7 5.7	0	0 0.5	0.8	0.3 1.7	0	0 0.5	0	0 0.5	0	0 0.5	33.3	30 36.8
26	82.3	79.3 84.9	4.8	3.4 6.6	0	0 0.5	1.2	0.6 2.3	0	0 0.5	0	0 0.5	0	0 0.5	11.7	9.5 14.3
27	53.7	50.1 57.3	1.7	0.9 2.9	0	0 0.5	1.1	0.5 2.1	0	0 0.5	0	0 0.5	0	0 0.5	43.5	39.9 47.1
28	5.1	3.6 6.9	84.5	81.7 87	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	10.4	8.3 12.8
29	32.1	28.8 35.6	40.5	37 44.1	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	27.3	24.2 30.7
30	13.6	11.2 16.3	52.7	49 56.3	8.7	6.8 10.9	0.1	0 0.7	0	0 0.5	0	0 0.5	0	0 0.5	24.9	21.9 28.2
31	61.2	57.6 64.7	30.7	27.4 34.1	0	0 0.5	2.1	1.2 3.4	0	0 0.5	0.1	0 0.7	0	0 0.5	5.9	4.3 7.8
32	4.1	2.8 5.8	0.8	0.3 1.7	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	95.1	93.3 96.5
33	38.1	34.6 41.7	1.6	0.8 2.8	0	0 0.5	0.5	0.1 1.4	0	0 0.5	0	0 0.5	0	0 0.5	59.7	56.1 63.3

APPENDIX C (cont.).

TRANSECT	ALGAE		CORAL		SOFT CORAL		SPONGE		ECHINODERMS		ASCIDIAN		FISH		SEDIMENT	
	MEAN	CI	MEAN	CI	MEAN	CI	MEAN	CI	MEAN	CI	MEAN	CI	MEAN	CI	MEAN	CI
34	54.8	51.2	6.4	4.8	0	0	2.3	1.3	0	0	0	0	0	0	36.5	33.1
		58.4		8.4		0.5		3.6		0.5		0.5		0.5		40.1
35	23.7	20.6	0	0	0	0	0	0	0	0	0	0	0	0	76.3	73
		27		0.5		0.5		0.5		0.5		0.5		0.5		79.4
36	3.2	2.1	0	0	0	0	0.7	0.2	0	0	0	0	0	0	96.1	94.5
		4.7		0.5		0.5		1.5		0.5		0.5		0.5		97.4
37	20.8	15.9	0	0	0	0	0.4	0	0	0	0	0	0	0	78.8	73.2
		26.4		1.5		1.5		2.2		1.5		1.5		1.5		83.7
38	0.3	0	0	0	0.6	0.2	0	0	0	0	0	0	0	0	99.1	98
		1.1		0.6		1.6		0.6		0.6		0.6		0.6		99.7
39	73.9	70.6	5.5	4	0	0	0.1	0	0	0	0	0	0	0	20.5	17.7
		77		7.3		0.5		0.7		0.5		0.5		0.5		23.6
40	28.1	24.9	16.1	13.6	0	0	0.9	0.4	0	0	0	0	0	0	54.8	51.2
		31.5		19		0.5		1.9		0.5		0.5		0.5		58.4
41	65	61.3	0.9	0.3	0	0	5.9	4.2	0	0	0	0	0	0	28.3	25
		68.5		1.9		0.5		7.9		0.5		0.5		0.5		31.8
42	1.1	0.4	0	0	0	0	0	0	0	0	0	0	0	0	98.9	97.8
		2.2		0.6		0.6		0.6		0.6		0.6		0.6		99.6
43	49.3	45.7	34.7	31.3	0	0	1.7	0.9	0	0	0	0	0	0	14.3	11.8
		53		38.2		0.5		2.9		0.5		0.5		0.5		17
44	72.1	68.8	2.5	1.5	0	0	0.8	0.3	0	0	0	0	0	0	24.5	21.5
		75.3		3.9		0.5		1.7		0.5		0.5		0.5		27.8
45	66.5	63	21.1	18.2	0	0	1.7	0.9	0	0	0	0	0	0	10.7	8.5
		69.9		24.2		0.5		2.9		0.5		0.5		0.5		13.1
46	26.1	23	19.9	17.1	0	0	0.4	0.1	0	0	0	0	0	0	53.6	50
		29.4		22.9		0.5		1.2		0.5		0.5		0.5		57.2
47	62.8	59.2	0.7	0.2	0	0	0	0	0	0	0	0	0	0	36.5	33.1
		66.3		1.5		0.5		0.5		0.5		0.5		0.5		40.1
48	37.1	33.6	6	4.4	0	0	0	0	0	0	0	0	0	0	56.9	53.3
		40.6		7.9		0.5		0.5		0.5		0.5		0.5		60.5
49	18.8	16.1	48.1	44.5	0	0	3.5	2.3	0	0	0	0	0	0	29.6	26.4
		21.8		51.8		0.5		5		0.5		0.5		0.5		33
50	82.7	79.8	0	0	0	0	0.5	0.1	0	0	0	0	0	0	16.8	14.2
		85.3		0.5		0.5		1.4		0.5		0.5		0.5		19.7
51	86.2	83.3	0.5	0.1	0	0	0.6	0.2	0	0	0	0	0	0	12.8	10.3
		88.7		1.3		0.6		1.6		0.6		0.6		0.6		15.6
52	8.5	6.6	0	0	0	0	2.5	1.5	0	0	0	0	0	0	88.9	86.5
		10.8		0.5		0.5		3.9		0.5		0.5		0.5		91.1
53	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	99.4
		0.6		0.6		0.6		0.6		0.6		0.6		0.6		100
54	21.5	18.6	0	0	0	0	2.4	1.4	0	0	0	0	0	0	76.1	72.9
		24.6		0.5		0.5		3.8		0.5		0.5		0.5		79.1
55	23.5	20.5	36.9	33.5	0	0	4.8	3.4	0	0	0	0	0	0	34.8	31.4
		26.7		40.5		0.5		6.6		0.5		0.5		0.5		38.3
56	26	22.9	12.5	10.2	0	0	6.7	5	0	0	0	0	0	0	54.8	51.2
		29.3		15.1		0.5		8.7		0.5		0.5		0.5		58.4
57	50.7	47	0	0	0	0	0.4	0.1	0	0	0	0	0	0	48.9	45.3
		54.3		0.5		0.5		1.2		0.5		0.5		0.5		52.6
58	26.4	23.3	0	0	0	0	2.3	1.3	0	0	0	0	0	0	71.3	68
		29.7		0.5		0.5		3.6		0.5		0.5		0.5		74.5
59	19.3	16.6	24.5	21.5	0	0	1.5	0.7	0	0	0	0	0	0	54.7	51
		22.3		27.8		0.5		2.6		0.5		0.5		0.5		58.3
60	85.5	82.7	10	7.9	0	0	1.6	0.8	0	0	0	0	0	0	2.9	1.8
		87.9		12.4		0.5		2.8		0.5		0.5		0.5		4.4
61	2.4	1.4	86.8	84.2	0	0	6.7	5	0	0	0	0	0	0	4.1	2.8
		3.8		89.1		0.5		8.7		0.5		0.5		0.5		5.8
62	21.9	19	65.2	61.7	0	0	1.6	0.8	0	0	0	0	0	0	11.3	9.2
		25		68.6		0.5		2.8		0.5		0.5		0.5		13.8
63	7.7	5.9	87.9	85.3	0	0	4	2.7	0	0	0	0	0	0	0.4	0.1
		9.9		90.1		0.5		5.7		0.5		0.5		0.5		1.2
64	7.1	5.3	0	0	0	0	0.1	0	0	0	0	0	0	0	92.7	90.5
		9.3		0.5		0.5		0.8		0.5		0.5		0.5		94.5
65	87.9	85.3	0.8	0.3	0	0	1.1	0.5	0	0	0	0	0	0	10.3	8.2
		90.1		1.7		0.5		2.1		0.5		0.5		0.5		12.7
66	8.1	6.2	0	0	0	0	0	0	0	0	0	0	0	0	91.9	89.6
		10.4		0.5		0.5		0.5		0.5		0.5		0.5		93.8
67	56.8	53.2	0.3	0	0	0	1.3	0.6	0	0	0	0	0	0	41.6	38
		60.4		1		0.5		2.4		0.5		0.5		0.5		45.2

APPENDIX D. Means and upper and lower bounds of 95% confidence limits (CL) of detailed percent benthic cover from photo-quadrat transects in the CVN survey area of Apra Harbor, Guam.

TRANSECT	*Caulerpa* sp.		Coralline algae		Cyanobacteria		*Dictyota* sp.		*Halimeda* sp.		*Hydrolithon gardineri*		Mixed Macroalgae		*Padina* sp.		Turf Algae	
	MEAN	CL	MEAN	CL	MEAN	CL	MEAN	CL	MEAN	CL	MEAN	CL	MEAN	CL	MEAN	CL	MEAN	CL
1	0	 0.7	0	0 0.7	0.2	0 1	0	0 0.7	0	0 0.7	0	0 0.7	0.2	0 1	0	0 0.7	11.6	9.1 14.6
2	0	0 0.5	6.1	4.5 8.1	12.5	10.2 15.1	0	0 0.5	0	0 0.5	0	0 0.5	45.5	41.9 49.1	0	0 0.5	9.2	7.2 11.5
3	0	0 0.7	0	0 0.7	24.5	21 28.4	0.7	0.2 1.9	0.9	0.3 2.1	0	0 0.7	3.6	2.2 5.6	0	0 0.7	2.2	1.1 3.8
4	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	18.4	15.7 21.4	0	0 0.5	18.5	15.8 21.5
5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0.8	0.3 1.7	1.2	0.6 2.3	0	0 0.5	6.8	5.1 8.8
6	0	0 0.5	0	0 0.5	0	0 0.5	0.1	0 0.7	0.3	0 1	0	0 0.5	0.4	0.1 1.2	23.1	20.1 26.3	0.3	0 1
7	0.1	0 0.7	3.6	2.4 5.2	0.8	0.3 1.7	0.1	0 0.7	3.6	2.4 5.2	0.1	0 0.7	2.9	1.8 4.4	1.5	0.7 2.6	5.3	3.8 7.2
8	0	0 0.5	0.1	0 0.7	0	0 0.5	0	0 0.5	1.3	0.6 2.4	0	0 0.5	4.7	3.3 6.4	4.7	3.3 6.4	5.3	3.8 7.2
9	0	0 0.5	0.1	0 0.7	0	0 0.5	0	0 0.5	4	2.7 5.7	0	0 0.5	14.3	11.8 17	0.8	0.3 1.7	34.3	30.9 37.8
10	0	0 0.6	1.2	0.5 2.4	9.5	7.4 12.1	7.1	5.2 9.3	12.6	10.2 15.4	0	0 0.6	48.6	44.7 52.5	0	0 0.6	3.4	2.1 5.1
11	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	34.3	30.9 37.8	0	0 0.5	58.5	54.9 62.1	0	0 0.5	0	0 0.5
12	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	59.1	55.5 62.6	0	0 0.5	40.8	37.3 44.4	0	0 0.5	0	0 0.5
13	0	0 0.5	2.1	1.2 3.4	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0.7	0.2 1.5	0	0 0.5	24.1	21.1 27.4
14	0	0 0.5	0.1	0 0.7	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	24	21 27.2	0	0 0.5	9.7	7.7 12.1
15	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	7.9	6 10	0	0 0.5	3.2	2.1 4.7
16	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	5.7	4.2 7.6	6	4.4 7.9	1.2	0.6 2.3
17	0	0 0.5	0.1	0 0.7	0	0 0.5	0.4	0.1 1.2	8.9	7 11.2	0	0 0.5	19.7	16.9 22.8	1.3	0.6 2.4	6.1	4.5 8.1
18	0	0 0.5	0	0 0.5	0.3	0 1	5.7	4.2 7.6	0	0 0.5	0	0 0.5	43.5	39.9 47.1	0	0 0.5	3.5	2.3 5
19	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	19.2	16.4 22.2	0	0 0.5	15.1	12.6 17.8
20	0	0 0.5	0	0 0.5	0	0 0.5	11.5	9.3 14	37.2	33.7 40.8	0	0 0.5	41.6	38 45.2	0	0 0.5	0	0 0.5
21	0	0 0.5	0	0 0.5	6.4	4.8 8.4	0.1	0 0.7	2.3	1.3 3.6	0	0 0.5	32.3	28.9 35.7	2.7	1.6 4.1	6.5	4.9 8.5
22	0	0 0.5	0.3	0 1	12.7	10.4 15.3	1.2	0.6 2.3	17.6	14.9 20.5	0	0 0.5	53.1	49.4 56.7	0	0 0.5	4.4	3 6.1
23	0	0 0.5	0	0 0.5	0.7	0.2 1.5	0	0 0.5	0.8	0.3 1.7	0	0 0.5	60.7	57.1 64.2	0	0 0.5	1.2	0.6 2.3
24	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	9.7	7.7 12.1	0	0 0.5	23.1	20.1 26.3	0	0 0.5	0	0 0.5
25	0.4	0.1 1.2	0.3	0 1	36.1	32.7 39.7	1.7	0.9 2.9	0.4	0.1 1.2	0	0 0.5	19.7	16.9 22.8	0	0 0.5	3.2	2.1 4.7
26	0	0 0.5	0	0 0.5	15.5	13 18.3	0	0 0.5	2.9	1.8 4.4	0	0 0.5	59.3	55.7 62.9	0.8	0.3 1.7	3.7	2.5 5.4
27	0	0 0.5	0.3	0 1	4	2.7 5.7	0	0 0.5	0	0 0.5	0	0 0.5	43.9	40.3 47.5	0	0 0.5	5.6	4.1 7.5
28	0	0 0.5	0.4	0.1 1.2	0.3	0 1	0	0 0.5	0	0 0.5	0	0 0.5	0.4	0.1 1.2	0	0 0.5	4	2.7 5.7
29	0	0 0.5	0.3	0 1	0.5	0.1 1.4	0	0 0.5	0.7	0.2 1.5	0	0 0.5	16.9	14.3 19.8	0	0 0.5	13.7	11.3 16.4
30	0	0 0.5	0	0 0.5	0.3	0 1	0	0 0.5	0	0 0.5	0	0 0.5	2.9	1.8 4.4	0	0 0.5	10.4	8.3 12.8
31	0	0 0.5	0.3	0 1	0.7	0.2 1.5	1.6	0.8 2.8	0	0 0.5	0.4	0.1 1.2	50.9	47.3 54.6	0	0 0.5	7.3	5.6 9.4
32	0	0 0.5	0	0 0.5	0.4	0.1 1.2	0	0 0.5	0	0 0.5	0	0 0.5	3.7	2.5 5.4	0	0 0.5	0	0 0.5
33	0	0 0.5	0	0 0.5	0.5	0.1 1.4	7.1	5.3 9.1	8.3	6.4 10.5	0	0 0.5	21.1	18.2 24.2	0	0 0.5	1.2	0.6 2.3

TRANSECT	*Acropora aspera*		*Acropora nasuta*		*Astreopora myriophthalma*		*Astreopora randalli*		*Fungia echinata*		*Galaxea horrescens*		*Herpolitha limax*		*Lobophyllia (cf.) hataii*		*Lobophyllia corymbosa*		*Lobophyllia hemprichii*	
	MEAN	CL	MEAN	CL	MEAN	CL	MEAN	CL	MEAN	CL	MEAN	CL	MEAN	CL	MEAN	CL	MEAN	CL	MEAN	CL
1	0	0 0.7	0	0 0.7	0	0 0.7	0	0 0.7	0	0 0.7	0	0 0.7	0	0 0.7	0	0 0.7	0	0 0.7	0	0 0.7
2	0	0 0.5	0	0 0.5	0.8	0.3 1.7	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
3	0	0 0.7	0	0 0.7	0.9	0.3 2.1	0	0 0.7	0	0 0.7	0	0 0.7	0	0 0.7	0	0 0.7	0	0 0.7	0	0 0.7
4	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0.7	0.2 1.5
6	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
7	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
8	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
9	19.2	16.4 22.2	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
10	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6	0.2	0 0.9	0	0 0.6	0	0 0.6	0	0 0.6	0.2	0 0.9
11	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
12	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
13	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
14	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0.1	0 0.7	0.1	0 0.7	0	0 0.5	0.7	0.2 1.5	0	0 0.5
15	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0.1	0 0.7	0	0 0.5	0	0 0.5	0	0 0.5
16	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
17	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
18	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0.3	0 1	0	0 0.5	0	0 0.5
19	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0.8	0.3 1.7	0	0 0.5	0	0 0.5	0	0 0.5
20	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0.3	0 1	0	0 0.5	2.5	1.5 3.9	0	0 0.5	0	0 0.5	0	0 0.5
21	0	0 0.5	0	0 0.5	0	0 0.5	0.1	0 0.7	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0.1	0 0.7
22	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
23	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0.4	0.1 1.2	0	0 0.5	0	0 0.5	0	0 0.5
24	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
25	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
26	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0.8	0.3 1.7
27	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
28	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
29	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
30	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
31	0	0 0.5	0	0 0.5	0	0 0.5	0.5	0.1 1.4	0	0 0.5	0	0 0.5	0.3	0 1	0	0 0.5	1.6	0.8 2.8	0.4	0.1 1.2
32	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
33	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5

APPENDIX D. (cont.)

TRANSECT	*Caulerpa* sp. MEAN	*Caulerpa* sp. CL	Coralline algae MEAN	Coralline algae CL	Cyanobacteria MEAN	Cyanobacteria CL	*Dictyota* sp. MEAN	*Dictyota* sp. CL	*Halimeda* sp. MEAN	*Halimeda* sp. CL
34	0	0 0.5	0.1	0 0.7	0.9	0.4 1.9	7.1	5.3 9.1	0	0 0.5
35	0	0 0.5	0	0 0.5	16.4	13.8 19.4	0	0 0.5	0	0 0.5
36	0	0 0.5	0	0 0.5	2.4	1.4 3.8	0	0 0.5	0	0 0.5
37	0	0 1.5	0	0 1.5	0.8	0.1 2.9	0	0 1.5	0	0 1.5
38	0	0 0.6	0	0 0.6	0.3	0 1.1	0	0 0.6	0	0 0.6
39	0	0 0.5	0.3	0 1	1.1	0.5 2.1	11.1	8.9 13.5	28.4	25.2 31.8
40	0	0 0.5	0	0 0.5	0	0 0.5	3.1	2 4.6	0	0 0.5
41	0	0 0.5	0	0 0.5	0	0 0.5	13.4	11 16.2	0	0 0.5
42	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6
43	0	0 0.5	2	1.1 3.3	0	0 0.5	4.3	2.9 6	0	0 0.5
44	0.1	0 0.7	0	0 0.5	0.1	0 0.7	0	0 0.5	1.1	0.5 2.1
45	0	0 0.5	0	0 0.5	0	0 0.5	36.7	33.2 40.2	0	0 0.5
46	2.5	1.5 3.9	0.7	0.2 1.5	1.7	0.9 2.9	5.9	4.3 7.8	2.3	1.3 3.6
47	0	0 0.5	0	0 0.5	1.9	1 3.1	7.9	6 10	1.9	1 3.1
48	0.4	0.1 1.2	0	0 0.5	0.4	0.1 1.2	0	0 0.5	0	0 0.5
49	0	0 0.5	0	0 0.5	0.5	0.1 1.4	0	0 0.5	0	0 0.5
50	0	0 0.5	0	0 0.5	0.1	0 0.7	0	0 0.5	21.7	18.8 24.9
51	0	0 0.6	0	0 0.6	0	0 0.6	9.7	7.5 12.2	2.8	1.6 4.3
52	0	0 0.5	0	0 0.5	0.1	0 0.7	0	0 0.5	6	4.4 7.9
53	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6
54	0	0 0.5	0	0 0.5	0	0 0.5	0.5	0.1 1.4	0	0 0.5
55	0	0 0.5	0	0 0.5	1.2	0.6 2.3	0	0 0.5	0	0 0.5
56	0	0 0.5	0	0 0.5	0.1	0 0.7	0	0 0.5	0	0 0.5
57	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0.1	0 0.7
58	0	0 0.5	0	0 0.5	0.9	0.4 1.9	0	0 0.5	2.4	1.4 3.8
59	0	0 0.5	0	0 0.5	3.9	2.6 5.5	0	0 0.5	0	0 0.5
60	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
61	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
62	0	0 0.5	0.1	0 0.7	0	0 0.5	10.5	8.4 13	0	0 0.5
63	0	0 0.5	1.2	0.6 2.3	0	0 0.5	0	0 0.5	0	0 0.5
64	0	0 0.5	0	0 0.5	1	0.4 2	0	0 0.5	0.3	0 1
65	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
66	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0.1	0 0.8
67	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	2	1.1 3.3

TRANSECT	*Hydrolithon gardineri* MEAN	*Hydrolithon gardineri* CL	Mixed Macroalgae MEAN	Mixed Macroalgae CL	*Padina* sp. MEAN	*Padina* sp. CL	Turf Algae MEAN	Turf Algae CL	*Acropora aspera* MEAN	*Acropora aspera* CL
34	0	0 0.5	41.6	38 45.2	0	0 0.5	5.1	3.6 6.9	0	0 0.5
35	0	0 0.5	7.3	5.5 9.5	0	0 0.5	0	0 0.5	0	0 0.5
36	0	0 0.5	0.8	0.3 1.7	0	0 0.5	0	0 0.5	0	0 0.5
37	0	0 1.5	20	15.2 25.5	0	0 1.5	0	0 1.5	0	0 1.5
38	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6
39	0	0 0.5	32.4	29.1 35.9	0	0 0.5	0.7	0.2 1.5	0	0 0.5
40	0	0 0.5	15.2	12.7 18	0	0 0.5	9.9	7.8 12.2	0	0 0.5
41	0	0 0.5	47.3	43.5 51.1	0	0 0.5	4.3	2.9 6.1	0	0 0.5
42	0	0 0.6	0.3	0 1.1	0	0 0.6	0.8	0.3 1.8	0	0 0.6
43	0	0 0.5	34.4	31 37.9	0	0 0.5	8.7	6.8 10.9	0	0 0.5
44	0	0 0.5	67.6	64.1 70.9	0	0 0.5	3.2	2.1 4.7	0	0 0.5
45	0	0 0.5	27.1	23.9 30.4	0	0 0.5	2.8	1.7 4.2	0	0 0.5
46	0	0 0.5	12	9.8 14.5	0	0 0.5	1.1	0.5 2.1	0	0 0.5
47	0	0 0.5	50.7	47 54.3	0	0 0.5	0.5	0.1 1.4	0	0 0.5
48	0	0 0.5	36.3	32.8 39.8	0	0 0.5	0	0 0.5	0	0 0.5
49	0	0 0.5	2.9	1.8 4.4	0	0 0.5	15.3	12.8 18.1	0	0 0.5
50	0	0 0.5	60.8	57.2 64.3	0	0 0.5	0	0 0.5	0	0 0.5
51	0	0 0.6	73.7	70.1 77	0	0 0.6	0	0 0.6	0	0 0.6
52	0	0 0.5	1.5	0.7 2.6	0	0 0.5	0.9	0.4 1.9	0	0 0.5
53	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6
54	0	0 0.5	11.6	9.4 14.1	9.3	7.3 11.6	0	0 0.5	0	0 0.5
55	0	0 0.5	14	11.6 16.7	0	0 0.5	8.3	6.4 10.5	0	0 0.5
56	0	0 0.5	20.4	17.6 23.5	0	0 0.5	5.5	4 7.3	0	0 0.5
57	0	0 0.5	50.5	46.9 54.2	0	0 0.5	0	0 0.5	0	0 0.5
58	0	0 0.5	16	13.4 18.8	7.1	5.3 9.1	0	0 0.5	0	0 0.5
59	0	0 0.5	12.9	10.6 15.5	0	0 0.5	2.5	1.5 3.9	0.4	0.1 1.2
60	0	0 0.5	62.9	59.4 66.4	20.1	17.3 23.2	2.4	1.4 3.8	0	0 0.5
61	0	0 0.5	0.5	0.1 1.4	0	0 0.5	1.9	1 3.1	0	0 0.5
62	0	0 0.5	7.3	5.6 9.4	0	0 0.5	3.9	2.6 5.5	0	0 0.5
63	0	0 0.5	3.3	2.2 4.9	1.7	0.9 2.9	1.5	0.7 2.6	0	0 0.5
64	0	0 0.5	5.9	4.2 7.9	0	0 0.5	0	0 0.5	0	0 0.5
65	0	0 0.5	60.5	56.9 64.1	27.3	24.2 30.7	0	0 0.5	0	0 0.5
66	0	0 0.5	7.9	6 10.1	0.1	0 0.8	0	0 0.5	0	0 0.5
67	0	0 0.5	53.5	49.8 57.1	1.3	0.6 2.4	0	0 0.5	0	0 0.5

TRANSECT	*Acropora nasuta* MEAN	*Acropora nasuta* CL	*Astreopora myriophthalma* MEAN	*Astreopora myriophthalma* CL	*Astreopora randalli* MEAN	*Astreopora randalli* CL	*Fungia echinata* MEAN	*Fungia echinata* CL	*Galaxea horrescens* MEAN	*Galaxea horrescens* CL
34	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
35	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
36	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
37	0	0 1.5	0	0 1.5	0	0 1.5	0	0 1.5	0	0 1.5
38	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6
39	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
40	0	0 0.5	1.1	0.5 2.1	0	0 0.5	0	0 0.5	0.8	0.3 1.7
41	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0.3	0 1
42	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6
43	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
44	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
45	0	0 0.5	0	0 0.5	0	0 0.5	0.4	0.1 1.2	0	0 0.5
46	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
47	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
48	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
49	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
50	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
51	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6
52	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
53	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6
54	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
55	0	0 0.5	0.9	0.4 1.9	0	0 0.5	0	0 0.5	0	0 0.5
56	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
57	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
58	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
59	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
60	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
61	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
62	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
63	17.3	14.7 20.2	0	0 0.5	0	0 0.5	0	0 0.5	0.3	0 1
64	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
65	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
66	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
67	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5

TRANSECT	*Herpolitha limax* MEAN	*Herpolitha limax* CL	*Lobophyllia* (cf.) *hataii* MEAN	*Lobophyllia* (cf.) *hataii* CL	*Lobophyllia corymbosa* MEAN	*Lobophyllia corymbosa* CL	*Lobophyllia hemprichii* MEAN	*Lobophyllia hemprichii* CL
34	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
35	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
36	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
37	0	0 1.5	0	0 1.5	0	0 1.5	0	0 1.5
38	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6
39	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
40	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
41	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
42	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6
43	0.7	0.2 1.5	0	0 0.5	0	0 0.5	0	0 0.5
44	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
45	3.3	2.2 4.9	0	0 0.5	0	0 0.5	0	0 0.5
46	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
47	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
48	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
49	0.3	0 1	0	0 0.5	0	0 0.5	0	0 0.5
50	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
51	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6
52	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
53	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6
54	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
55	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
56	0.7	0.2 1.5	0	0 0.5	0	0 0.5	0	0 0.5
57	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
58	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
59	0	0 0.5	0	0 0.5	0	0 0.5	0.1	0 0.7
60	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
61	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
62	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
63	0	0 0.5	0	0 0.5	1.1	0.5 2.1	0	0 0.5
64	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
65	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
66	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
67	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5

APPENDIX A. (cont.)

TRANSECT	Montipora verrucosa MEAN	CL	Pachyseris speciosa MEAN	CL	Pavona cactus MEAN	CL	Pavona varians MEAN	CL	Pocillopora damicornis MEAN	CL	Porites cylindrica MEAN	CL	Porites lutea MEAN	CL	Porites rus MEAN	CL	Soft Coral MEAN	CL	Sponge MEAN	CL
1	0	0 0.7	0	0 0.7	14.5	11.7 17.8	0	0 0.7	0	0 0.7	1.5	0.6 2.8	0.2	0 1	36.4	32.3 40.5	0	0 0.7	20.4	17.1 24
2	0.3	0 1	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0.9	0.4 1.9	8.8	6.9 11.1	0	0 0.5	8.1	6.3 10.3
3	0	0 0.7	0	0 0.7	0	0 0.7	0	0 0.7	0	0 0.7	0	0 0.7	0.2	0 1	0.4	0 1.3	0	0 0.7	3.1	1.8 4.9
4	0	0 0.5	0.1	0 0.7	11.1	8.9 13.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	40.1	36.6 43.7	0	0 0.5	5.9	4.3 7.8
5	0	0 0.5	0.1	0 0.7	27.6	24.4 30.9	0	0 0.5	0	0 0.5	0	0 0.5	1.2	0.6 2.3	41.3	37.8 45	0	0 0.5	17.7	15.1 20.7
6	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0.1	0 0.7	0	0 0.5	62.4	58.8 65.9	0	0 0.5	13.2	10.9 15.8
7	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0.1	0 0.7	8.3	6.4 10.5	24.5	21.5 27.8	35.9	32.4 39.4	1.7	0.9 2.9	0.4	0.1 1.2
8	0	0 0.5	0	0 0.5	0.7	0.2 1.5	0	0 0.5	0	0 0.5	0	0 0.5	0.4	0.1 1.2	64.9	61.4 68.4	0	0 0.5	10.1	8.1 12.5
9	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0.3	0 1	0	0 0.5	0	0 0.5	2.3	1.3 3.6	0	0 0.5	23.6	20.6 26.8
10	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6	0.3	0 1.1	0.3	0 1.1	0	0 0.6	1.2	0.5 2.4
11	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	3.1	2 4.6
12	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
13	0	0 0.5	0	0 0.5	10.5	8.4 13	0.1	0 0.7	0	0 0.5	1.1	0.5 2.1	0	0 0.5	49.9	46.2 53.5	0	0 0.5	3.6	2.4 5.2
14	0	0 0.5	0	0 0.5	3.3	2.2 4.9	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	43.9	40.3 47.5	0	0 0.5	3.2	2.1 4.7
15	0	0 0.5	0	0 0.5	42.8	39.2 46.4	0	0 0.5	0.3	0 1	2	1.1 3.3	0	0 0.5	23.3	20.3 26.5	0	0 0.5	6.5	4.9 8.5
16	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	1.9	1 3.1	0	0 0.5	0	0 0.5	1.3	0.6 2.4
17	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0.1	0 0.7	2.1	1.2 3.4	10.4	8.3 12.8	1.7	0.9 2.9	0	0 0.5	5.9	4.3 7.8
18	0.3	0 1	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	26.5	23.4 29.8	0	0 0.5	1.5	0.7 2.6
19	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	50.8	47.2 54.4	0	0 0.5	2.1	1.2 3.4
20	0	0 0.5	0	0 0.5	0.5	0.1 1.4	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	1.1	0.5 2.1
21	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	20.5	17.7 23.6	0	0 0.5	0.9	0.4 1.9
22	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	3.3	2.2 4.9	0	0 0.5	0.5	0.1 1.4
23	0	0 0.5	0	0 0.5	0	0 0.5	0.3	0 1	0	0 0.5	0	0 0.5	1.6	0.8 2.8	13.1	10.7 15.7	0	0 0.5	5.7	4.2 7.6
24	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	4	2.7 5.7	0	0 0.5	0	0 0.5	0	0 0.5
25	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0.7	0.2 1.5	3.3	2.2 4.9	0	0 0.5	0.8	0.3 1.7
26	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	4	2.7 5.7	0	0 0.5	1.2	0.6 2.3
27	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	1.7	0.9 2.9	0	0 0.5	1.1	0.5 2.1
28	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	84.5	81.7 87	0	0 0.5	0	0 0.5
29	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	1.3	0.6 2.4	37.2	33.7 40.8	2	1.1 3.3	0	0 0.5	0	0 0.5
30	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	1.1	0.5 2.1	30.9	27.6 34.4	20.7	17.8 23.7	8.7	6.8 10.9	0.1	0 0.7
31	0	0 0.5	0.1	0 0.7	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	27.7	24.6 31.1	0	0 0.5	2.1	1.2 3.4
32	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0.8	0.3 1.7	0	0 0.5	0	0 0.5
33	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0.5	0.1 1.4	1.1	0.5 2.1	0	0 0.5	0.5	0.1 1.4

TRANSECT	Acanthaster planci MEAN	CL	Bohadshi sp. MEAN	CL	Holothuria sp. MEAN	CL	Unidentified Ascidian MEAN	CL	Unidentified Fish MEAN	CL	Dead Coral MEAN	CL	Mud MEAN	CL	Rubble MEAN	CL	Sand MEAN	CL
1	0	0 0.7	0	0 0.7	0	0 0.7	0	0 0.7	0	0 0.7	0	0 0.7	1.5	0.6 2.8	13.6	10.9 16.8	0	0 0.7
2	1.1	0.5 2.1	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0.1	0 0.7	3.2	2.1 4.7	3.3	2.2 4.9	0	0 0.5
3	0	0 0.7	0	0 0.7	0	0 0.7	0	0 0.7	0	0 0.7	0	0 0.7	34	30 38.1	29.5	25.7 33.5	0	0 0.7
4	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0.9	0.4 1.9	4.9	3.5 6.7	0	0 0.5
5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	1.6	0.8 2.8	0.9	0.4 1.9	0	0 0.5
6	0	0 0.5	0	0 0.5	0	0 0.5	0.1	0 0.7	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5
7	0	0 0.5	0.1	0 0.7	0	0 0.5	0	0 0.5	0	0 0.5	0.1	0 0.7	0.9	0.4 1.9	1.6	0.8 2.8	8.1	6.3 10.3
8	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	7.1	5.3 9.1	0.7	0.2 1.5	0	0 0.5
9	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0.8	0.3 1.7	0.1	0 0.7	0.3	0 1	0	0 0.5
10	0	0 0.6	0.3	0 1.1	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6	14.5	11.8 17.4	0.6	0.2 1.6	0	0 0.6
11	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	3.1	2 4.6	1.1	0.5 2.1	0	0 0.5
12	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0.1	0 0.7	0	0 0.5	0	0 0.5
13	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	3.6	2.4 5.2	4.1	2.8 5.8	0.1	0 0.7
14	0	0 0.5	0	0 0.5	0	0 0.5	0.3	0 1	0	0 0.5	0	0 0.5	4.4	3 6.1	10.1	8.1 12.5	0	0 0.5
15	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0.4	0.1 1.2	12.4	10.1 15	1.1	0.5 2.1	0	0 0.5
16	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	83.3	80.5 85.9	0.5	0.1 1.4	0	0 0.5
17	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	25.6	22.5 28.9	17.5	14.8 20.4	0	0 0.5
18	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	10.7	8.5 13.1	7.9	6 10	0	0 0.5
19	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	7.2	5.5 9.3	4.8	3.4 6.6	0	0 0.5
20	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	5.3	3.8 7.2	0	0 0.5	0	0 0.5
21	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	24.8	21.7 28.1	3.2	2.1 4.7	0	0 0.5
22	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	6	4.4 7.9	0.9	0.4 1.9	0	0 0.5
23	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0.3	0 1	0	0 0.5	15.3	12.8 18.1	0	0 0.5	0	0 0.5
24	0	0 0.5	0	0 0.5	0.1	0 0.7	0	0 0.5	0	0 0.5	0	0 0.5	63.1	59.5 66.5	0	0 0.5	0	0 0.5
25	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	32.4	29.1 35.9	0.9	0.4 1.9	0	0 0.5
26	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	10.8	8.7 13.2	0.9	0.4 1.9	0	0 0.5
27	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	42.4	38.8 46	1.1	0.5 2.1	0	0 0.5
28	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0.4	0.1 1.2	2.5	1.5 3.9	7.5	5.7 9.6	0	0 0.5
29	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	26.5	23.4 29.8	0.8	0.3 1.7	0	0 0.5
30	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	20.8	17.9 23.9	4.1	2.8 5.8	0	0 0.5
31	0	0 0.5	0	0 0.5	0	0 0.5	0.1	0 0.7	0	0 0.5	0	0 0.5	4.7	3.3 6.4	1.2	0.6 2.3	0	0 0.5
32	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	95.1	93.3 96.5	0	0 0.5	0	0 0.5
33	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	55.6	52 59.2	4	2.7 5.7	0.1	0 0.7

APPENDIX A. (cont.)

TRANSECT	*Montipora verrucosa*		*Pachyseris speciosa*		*Pavona cactus*		*Pavona varians*		*Pocillopora damicornis*		*Porites cylindrica*		*Porites lutea*		*Porites rus*		Soft Coral		Sponge		*Acanthaster planci*		*Bohadshi* sp.		*Holothuria* sp.		Unidentified Ascidian		Unidentified Fish		Dead Coral		Mud		Rubble		Sand	
	MEAN	CL	MEAN	CL	MEAN	CL	MEAN	CL	MEAN	CL	MEAN	CL	MEAN	CL	MEAN	CL	MEAN	CL	MEAN	CL	MEAN	CL	MEAN	CL	MEAN	CL	MEAN	CL	MEAN	CL	MEAN	CL	MEAN	CL	MEAN	CL	MEAN	CL
34	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	6.4	4.8 8.4	0	0 0.5	2.3	1.3 3.6	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	30.3	27 33.7	6.3	4.6 8.2	0	0 0.5
35	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	76.3	73 79.4	0	0 0.5	0	0 0.5
36	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0.7	0.2 1.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	96.1	94.5 97.4	0	0 0.5	0	0 0.5
37	0	0 1.5	0	0 1.5	0	0 1.5	0	0 1.5	0	0 1.5	0	0 1.5	0	0 1.5	0	0 1.5	0	0 1.5	0.4	0 2.2	0	0 1.5	0	0 1.5	0	0 1.5	0	0 1.5	0	0 1.5	0	0 1.5	78.8	73.2 83.7	0	0 1.5	0	0 1.5
38	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6	0.6	0.2 1.6	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6	99.1	98 99.7	0	0 0.6	0	0 0.6
39	0	0 0.5	0	0 0.5	3.1	2 4.6	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	2.4	1.4 3.8	0	0 0.5	0.1	0 0.7	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	18.7	15.9 21.6	1.9	1 3.1	0	0 0.5
40	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0.1	0 0.7	2.5	1.5 3.9	11.6	9.4 14.1	0	0 0.5	0.9	0.4 1.9	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	54.5	50.9 58.1	0.3	0 1	0	0 0.5
41	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0.6	0.2 1.5	0	0 0.5	5.9	4.2 7.9	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	28.3	25 31.8	0	0 0.5	0	0 0.5
42	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6	98.9	97.8 99.6	0	0 0.6	0	0 0.6
43	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0.1	0 0.7	1.3	0.6 2.4	32.5	29.2 36	0	0 0.5	1.7	0.9 2.9	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	7.9	6 10	6.4	4.8 8.4	0	0 0.5
44	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	2.5	1.5 3.9	0	0 0.5	0.8	0.3 1.7	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	23.3	20.3 26.5	1.2	0.6 2.3	0	0 0.5
45	0	0 0.5	0	0 0.5	2.5	1.5 3.9	0	0 0.5	0	0 0.5	3.3	2.2 4.9	0	0 0.5	11.5	9.3 14	0	0 0.5	1.7	0.9 2.9	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	6.8	5.1 8.8	3.9	2.6 5.5	0	0 0.5
46	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0.3	0 1	11.7	9.5 14.3	0	0 0.5	7.9	6 10	0	0 0.5	0.4	0.1 1.2	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	51.3	47.7 55	2.3	1.3 3.6	0	0 0.5
47	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0.1	0 0.7	0.5	0.1 1.4	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	36	32.6 39.6	0.5	0.1 1.4	0	0 0.5
48	0	0 0.5	4.1	2.8 5.8	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	1.9	1 3.1	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	56.9	53.3 60.5	0	0 0.5	0	0 0.5
49	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	8.7	6.8 10.9	0.1	0 0.7	39.1	35.6 42.7	0	0 0.5	3.5	2.3 5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	19.9	17.1 22.9	9.7	7.7 12.1	0	0 0.5
50	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0.5	0.1 1.4	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	16.8	14.2 19.7	0	0 0.5	0	0 0.5
51	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6	0.5	0.1 1.3	0	0 0.6	0	0 0.6	0.6	0.2 1.6	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6	12.8	10.3 15.6	0	0 0.6	0	0 0.6
52	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	2.5	1.5 3.9	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	35.9	32.4 39.4	53.1	49.4 56.7	0	0 0.5
53	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6	0	0 0.6	100	99.4 100	0	0 0.6	0	0 0.6
54	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	2.4	1.4 3.8	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	75.6	72.4 78.6	0.5	0.1 1.4	0	0 0.5
55	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0.7	0.2 1.5	35.3	31.9 38.9	0	0 0.5	4.8	3.4 6.6	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	32.9	29.6 36.4	1.9	1 3.1	0	0 0.5
56	0	0 0.5	0.1	0 0.7	0	0 0.5	0	0 0.5	0	0 0.5	0.4	0.1 1.2	0	0 0.5	11.3	9.2 13.8	0	0 0.5	6.7	5 8.7	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	54.7	51 58.3	0.1	0 0.7	0	0 0.5
57	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0.4	0.1 1.2	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	21.1	18.2 24.2	27.9	24.7 31.2	0	0 0.5
58	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	2.3	1.3 3.6	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	29.7	26.5 33.1	41.6	38 45.2	0	0 0.5
59	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0.8	0.3 1.7	0.1	0 0.7	23.1	20.1 26.3	0	0 0.5	1.5	0.7 2.6	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	50	46.4 53.6	4.7	3.3 6.4	0	0 0.5
60	0	0 0.5	0	0 0.5	0.1	0 0.7	0.1	0 0.7	1.6	0.8 2.8	0	0 0.5	5.9	4.3 7.8	2.3	1.3 3.6	0	0 0.5	1.6	0.8 2.8	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	1.5	0.7 2.6	1.3	0.6 2.4	0.1	0 0.7
61	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	2.5	1.5 3.9	1.1	0.5 2.1	83.2	80.3 85.8	0	0 0.5	6.7	5 8.7	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	1.1	0.5 2.1	3.1	2 4.6	0	0 0.5
62	0	0 0.5	0	0 0.5	0.3	0 1	0	0 0.5	0	0 0.5	4.8	3.4 6.6	0	0 0.5	60.1	56.5 63.7	0	0 0.5	1.6	0.8 2.8	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	7.1	5.3 9.1	4.3	2.9 6	0	0 0.5
63	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0.4	0.1 1.2	4.9	3.5 6.7	0	0 0.5	63.9	60.3 67.3	0	0 0.5	4	2.7 5.7	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0.3	0 1	0.1	0 0.7	0	0 0.5
64	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0.1	0 0.8	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	92.7	90.5 94.5	0	0 0.5	0	0 0.5
65	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0.1	0 0.7	0	0 0.5	0.5	0.1 1.4	0.1	0 0.7	0	0 0.5	1.1	0.5 2.1	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	9.5	7.5 11.8	0.8	0.3 1.7	0	0 0.5
66	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	91.7	89.4 93.6	0.1	0 0.8	0	0 0.5
67	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0.3	0 1	0	0 0.5	0	0 0.5	1.3	0.6 2.4	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	0	0 0.5	17.9	15.2 20.8	23.7	20.7 26.9	0	0 0.5

APPENDIX E. Selected Multispectral Remote Sensing Reference

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APPENDIX F. Counts of mobile invertebrates along 25 x 4 m belt transects.

Count of Taxa			Strata	Site Number																																		
			Direct-Flat																				Direct-Flat	Direct-Slope																Direct-Slope
Phylum	Genus	Species	5	11	23	25	26	31	32	34	35	38	39	40	42	43	46	47	50	57	59	62	Total	4	10	14	21	22	27	33	37	44	45	48	49	51	53	55	58	Total
Cnidaria	*Boloceroides*	*mcmurrichi*				1																	1																	
Cnidaria Total						1																	1																	
Crustacea	*Alpheus*	sp.																																						
	Calcinus	*minutus*											1							2			3										1				1		3	5
		pulcher																				1	1					3											3	6
		spp.	1													1							2				2													2
	crab	sp.																																						
		sp. (blue)									1												1																	
	Dardanus	*guttatus*																																						
	Palaemonid	sp.																																						
	Periclimenes	*soror*												1									1																	
	Saron	*marmoratus*																																				1		1
	seethrough shrimp	(blank)							1				1							2			4							1									1	2
	shrimp	sp. (clear)																																				1		1
		sp. (goby)										1											1																	
Crustacea Total			1						1		1	1	2	1		1				4		1	13				2	3		1			1				1	2	7	17
Echinodermata	*Actinpyga*	*mauritiana*																																						
	Bohadschia	*argus*														1							1																	
	Culcita	*novaeguineae*			3		1							1		1	1						7					1				1	1							3
	Echinaster	*luzonicus*																						1																1
	Echinometra	*mathei*					1																1												1					1
	Echinostrephus	*aciculatus*																																						
	Echinothrix	sp.																																						
	Euapta	*godeffroyi*																														1								1
	Holothuria	*atra*																																						
	Linkia	*laevigata*																																						
		multifera																																						
	Ophiocoma	sp.																																						
	Ophiomastix	*caryophyllata*																						2	1	1														4
	Ophiurid	sp.1	38				2	1														2	43					1												1
		sp.2 (small)										1											1																	
	Pearsonothuria	*graeffei*																						3																3
Echinodermata Total			38		3		4	1				1		1		2	1					2	53	6	1	1		2				2	1		1					14
Mollusca	*Cerithium*	*columna*	21					1	1										1	2	1	1	28	30	5								1			1			2	39
	Chromodoris	*fidelis*															1						1																	
	Clypeomorus	*nympha*	7																			1	8																	
	Coralliophila	*violacea*	8			1				1						1						19	30									12			7			8		27
	Cymatium	*nicobaricum*																																						
		sp.																																						
	Cypraea	*contaminata*																																						
		erosa																																						
		mappa																																	1					1
	Euplica	*deshayesii*	6						1														7												3					3
	Glossodoris	*atromarginata*						1															1																	
	Habromorula	*spinosa*																																				12		12
	Hypselodoris	*whitei*																																						
	Lambis	*lambis*																		2			2					2												2
	Mitra	sp.																									1													1
	Nerita	sp.																																						
	Noumea	*angustolutea*																									1													1
	Pteraeolidia	*ianthina*																																						
	snail	spp.			1																		1																	
	Strombus	*gibberulus*																																					1	1
		luhuanus																		98			98																	
	Thais	sp.																																						
	Trochus	*niloticus*																																						
	Vasum	*turbinellus*																																						
Mollusca Total			42		1	1		2	2	1						1	1		1	102	1	21	176	30	5		2	2				12	1		11	1		20	3	87
Platyhelminthes	flatworm	sp.																												1										1
Platyhelminthes Total																														1										1
Grand Total			81		4	2	4	3	3	1	1	2	2	2		4	2		1	106	1	24	243	36	6	1	4	7		2		14	3		12	1	1	22	10	119

APPENDIX F. (cont.)

Count of Taxa			Indirect-Flat												Indirect-Flat	Indirect-Slope														Indirect-Slope	GRAND
Phylum	Genus	Species	2	3	6	7	9	13	16	18	24	36	56	60	Total	1	8	15	17	19	20	28	30	41	61	63	64	65	66	Total	TOTAL
Cnidaria	*Boloceroides*	*mcmurrichi*																													1
Cnidaria Total																															1
Crustacea	*Alpheus*	sp.																				1								1	1
	Calcinus	*minutus*			2	5	1				1				9				1							2				3	20
		pulcher			2		1	1							4	2		1							7	4				14	25
		spp.			9										9		11					1						1		13	26
	crab	sp.																									1			1	1
		sp. (blue)																													1
	Dardanus	*guttatus*					2								2																2
	Palaemonid	sp.														1														1	1
	Periclimenes	*soror*	1												1																2
	Saron	*marmoratus*																													1
	seethrough shrimp	(blank)																						1			1			2	8
	shrimp	sp. (clear)																													1
		sp. (goby)									7				7																8
Crustacea Total			1		13	5	4	1			8				32	3	11	1	1			2		1	7	6	2	1		35	97
Echinodermata	*Actinpyga*	*mauritiana*												1	1																1
	Bohadschia	*argus*				1					1			2	4				2											2	7
	Culcita	*novaeguineae*	1										1		2									1						1	13
	Echinaster	*luzonicus*																													1
	Echinometra	*mathei*			3	1								1	5											1		3		4	11
	Echinostrephus	*aciculatus*												11	11													2		2	13
	Echinothrix	sp.			1										1																1
	Euapta	*godeffroyi*																													1
	Holothuria	*atra*									13			8	21													11		11	32
	Linkia	*laevigata*																										2		2	2
		multifera			1		1								2		1													1	3
	Ophiocoma	sp.																				1								1	1
	Ophiomastix	*caryophyllata*																		1										1	5
	Ophiurid	sp.1																							2					2	46
		sp.2 (small)																													1
	Pearsonothuria	*graeffei*														1														1	4
Echinodermata Total			1		5	2	1				14		1	23	47	1	1		2	1		1		1	2	1		18		28	142
Mollusca	*Cerithium*	*columna*	12	9	1		5	3			1	1			32	5	2	3			1			1	3	4	1			20	119
	Chromodoris	*fidelis*																													1
	Clypeomorus	*nympha*			3		1	1							5	15		1							1	16				33	46
	Coralliophila	*violacea*	10		11		10	38						1	70	48	21	29				19			27	52				196	323
	Cymatium	*nicobaricum*															1													1	1
		sp.												1	1																1
	Cypraea	*contaminata*																										1		1	1
		erosa																										1		1	1
		mappa																													1
	Euplica	*deshayesii*	28	1	8	1	66				1			3	108		1	1						1				2		5	123
	Glossodoris	*atromarginata*																									2			2	3
	Habromorula	*spinosa*			1			1							2							3			2	4				9	23
	Hypselodoris	*whitei*																										1		1	1
	Lambis	*lambis*							1						1													1		1	6
	Mitra	sp.																													1
	Nerita	sp.					1								1																1
	Noumea	*angustolutea*																													1
	Pteraeolidia	*ianthina*																										1		1	1
	snail	spp.																													1
	Strombus	*gibberulus*									2				2																3
		luhuanus									3				3				1									1		2	103
	Thais	sp.											1		1																1
	Trochus	*niloticus*					1							4	5																5
	Vasum	*turbinellus*																										1		1	1
Mollusca Total			50	10	24	1	84	43	1		7	1	1	9	231	68	25	34	1		1	22		2	33	76	3	9		274	768
Platyhelminthes	flatworm	sp.																													1
Platyhelminthes Total																															1
Grand Total			52	10	42	8	89	44	1		29	1	2	32	310	72	37	35	4	1	1	25		4	42	83	5	28		337	1009

APPENDIX G. Counts of sessile invertebrates within 25 x 1 m belt transects.

Count of Taxa			Strata Site Number																																					
			Direct-Flat																				Total	Direct-Slope																Total
Phylum	Genus	Species	5	11	23	25	26	31	32	34	35	38	39	40	42	43	46	47	50	57	59	62		4	10	14	21	22	27	33	37	44	45	48	49	51	53	55	58	
ASCIDIA	*Ascidia*	sp.			1														1				2																1	1
	Clavelina	*moluccensis*		9	15				3														27		8	2					1									11
	Lissoclinum	*calycis*				1																	1																	
	Phallusia	*julinea*	10		5	2	1	7	2	5				2		7					3	15	59	7	7	2	3		2	3	3	4			7			17	8	63
	Polycarpa	sp.	3				1	1		1				1					1		5	1	14	1								4			5				2	12
	Rhopalaea	*crassa*	1	1	3		1			2			1						1			3	13	1	2			1	1	2	2	1	1		1		1	1		14
		sp.	4		9	10	9	10	5	6	1	1	4	2	1	3		2	5		1	3	76	4	11	6	11	4	12	9	3	6	2	5		1	3	5	7	89
ASCIDIA Total			18	10	33	13	12	18	10	14	1	1	5	5	1	10		2	8		9	22	192	13	28	10	14	5	15	14	9	15	3	5	13	1	4	23	18	190
MOLLUSCA	*Pinctada*	sp.																			3	5	8												9					9
MOLLUSCA Total																					3	5	8												9					9
POLYCHEATA	*Sabellastarte*	indica																																						
POLYCHEATA Total																																								
PORIFERA	*Aplysinella*	*rhax*	16	2	15	3	10	21	1	36	6		9	20		3	8	1	8				159	23	36	27	27	23		14	9	15	5	4		9	20	7	11	230
	Axinella	sp.																																						
	Axynissa	sp.	2			1	3	13		8	4		1	1	6	8	3	1				4	55	1	7	3	6	7	7	7	1	12	1		18			7		77
	Callyspongia	*diffusa*	15		5	1	2	11	1	4	5		2	14		12							72	23	20	25	6			7	3	7	2			1		8		102
		sp.														1			1			7	9												1					1
	Ceratopsion	sp.	3			3	11	8		23				10		11						13	82	6		2	8	2		1		10						12		41
	Chelonaplysilla	sp.								1													1					3												3
	Cinachyra	sp.																			1		1	1		1														2
	Clathria	*basilana*						1									16						17	1											1					2
		eurypa	4		11	16	16	15		12	1			1	1	6	1		1				85	9	17	16	8	12	6	11	5	1				1	4		1	91
		hirsuta			1																		1	1	1	13														15
		mima				1			1									2			2		6	2		2			2			1				3			3	13
		sp.															2						2								1			1			1			3
	Corticum	sp.			1																		1	1	2	3				1									1	8
	Craniella	*abracadabra*																								1														1
	Dragmacidon	sp.							7		4	1			13			2	6		8		41	1	6	5					6		1			3	2		8	32
		(blank)								4				1									5																	
	Dysidea	sp.																1	2		1		4				3						1	1					1	6
	Haliclona	(Reniera)	2		3	7	14	7		7	3		10			9		4	2				68		21	11		11	1	8	6	17	6	3			14		1	99
		sp. (blue)	8			1		6	1	1	2					10	18		4	1	4	17	73	14	3		1		1						19			2		40
	Hyrtios	*altum*			1																		1			1														1
		erecta																													1									1
	Ianthella	*basta*			4	1		1										1					7		7	2		3			1		1				1		13	28
		ditrochota																																						
	Iotrochota	*baculifera*											2								2		4			3				1						1				5
		ditrochota	16		14					1	3		1	3		2							40	22	16	10				6	4						7			65
		protea	4		8	15	7	8	11	12	7	3	7	23	1	12	6		8	34	11	1	178	1	10	4	16	9		3	3	6	7	8	3	2		5	27	104
	Liosina	*cf. granulosa*	3		8	1	5	2	3					2	1		1			4	6		36	1	4	12					1		1		9		3	1	30	62
	Melophlus	*sarasinorum*	10		4										1								15	15	5	4														24
	Monanchora	*clathrata*																			1		1													3			1	4
	Paratetilla	*bacca*																				1	1																	
	Plakina	sp.					1	3		2													6		1	11	1			2	1	1						1		18
	Porifera	sp.1 (Sponge tough)				1	1																2			1			1											2
		sp.10 (Fake myrmekioderma)																							1															1
		sp.11 (Haliclona osiris)																																						
		sp.12 (white Dysidea 166)																													1									1
		sp.13 (Dysidea/Clathria like 179-180)											1										1																	
		sp.14 (brown Xestospongia-like 183)																																						
		sp.2 (Sponge green)																																						
		sp.3 (orange/red Haliclona like)									1	1	2					2	5	1	1		13							1	4					1				6
		sp.4 (Dysidea like 0021)																																						
		sp.5 (white Callyspongia)																																						
		sp.6 (green Clathria)																						1	1	1														3
		sp.7 (green/purple Tedania 141)																						2		1														3
		sp.8 (Haliclona gracilis)																																						
		sp.9 (black net cover 101)																																						
	Pseudoceratina	sp.	2			1		1		3							4		2				13	1					1			3	1							6
	Sylissa	*massa*	2		1	2	8	7	1					1		5	2					1	30	5	11	3			4		5	4	2		9			6		49
	Tedania	*meandrica*	9			1		3		4			2	1		4	6		1		7	13	51	3	2	7	2			2	1	4			2			8	3	34
		sp.			1																		1																	
	Ulosa	*spongia*			1	7	3	6		3	6		3	10		5	1	2	12		12		71		12	9	2	1	2	4		8	2		24				3	67
	Xestospongia	*carbonaria*				2				5	2						12		11			8	40		1			2			1	2			5	1			2	14
		exigua		19			3	2											1		1		26		2	1	2	2			1	2								10
PORIFERA Total			96	21	78	64	84	115	26	126	44	5	40	87	23	88	80	16	64	40	57	65	1219	134	186	179	82	75	25	68	55	93	30	17	91	25	52	57	105	1274
Grand Total			114	31	111	77	96	133	36	140	45	6	45	92	24	98	80	18	72	40	69	92	1419	147	214	189	96	80	40	82	64	108	33	22	113	26	56	80	123	1473

APPENDIX G. (cont.)

Strata Site Number																															
Indirect Flat															Total	Indirect-Slope														Total	GRAND
Phylum	Genus	Species	2	3	6	7	9	13	16	18	24	36	56	60		1	8	15	17	19	20	28	30	41	61	63	64	65	66		TOTAL
ASCIDIA	*Ascidia*	sp.		1											1					1	1									2	6
	Clavelina	*moluccensis*							1						1																39
	Lissoclinum	*calycis*	1												1			3												3	5
	Phallusia	*julinea*	11	4	5		3	14		1		1		3	42	12	15	11	1	16	1	15	17	10	24	16	3	5		146	310
	Polycarpa	sp.	1					3				1		5	10	2		8		2			7	2	2			1		24	60
	Rhopalaea	*crassa*	3	3		3		1					1		11	4	11				2	1		2	3	2			3	28	66
		sp.	15	5	7			6	1	3		4	4		45	13	1	4		12	4			9	15	23	7			88	298
ASCIDIA Total			31	13	12	3	3	24	2	4		6	5	8	111	31	27	26	1	31	8	16	24	23	44	41	10	6	3	291	784
MOLLUSCA	*Pinctada*	sp.										1		9	10					1			5				1	5		12	39
MOLLUSCA Total												1		9	10					1			5				1	5		12	39
POLYCHEATA	*Sabellastarte*	indica																				2	4							6	6
POLYCHEATA Total																						2	4							6	6
PORIFERA	*Aplysinella*	*rhax*	41	37						4		3	41		126	26	11	3		12	21			19			2		12	106	621
	Axinella	sp.											8		8			1												1	9
	Axynissa	sp.	4	36		1				2			3	1	47	9		4	1	8	9	9	2	2			5	1		50	229
	Callyspongia	*diffusa*	2									2			4					6	11						6			23	201
		sp.						7							7	2		5							1	2				10	27
	Ceratopsion	sp.	5				6	14	1				5	7	38	3		15			1	2		6						27	188
	Chelonaplysilla	sp.																1						1						2	6
	Cinachyra	sp.									1				1			2					1		1					4	8
	Clathria	*basilana*											1		1	6									15	2				23	43
		eurypa	19	45			6							3	73	6	2		7	11	5	1		3	4	1	2			42	291
		hirsuta				1						4			5										6	1	3			10	31
		mima										7			7	2	4										3			9	35
		sp.							1			1			2				2	2	1									5	12
	Corticum	sp.										1			1					5	3									8	18
	Craniella	*abracadabra*																													1
	Dragmacidon	sp.							1	2					3					13			26	24						63	139
		(blank)																													5
	Dysidea	sp.						2		2					4		3	1				1		6	1		1			13	27
	Haliclona	(Reniera)	5	2						1			17		25	6		3		3	10			29			15			66	258
		sp. (blue)	6	1	9			21			1		1		39	15	5	18		16		22	3		18	5	2			104	256
	Hyrtios	*altum*											14		14	21	4													25	41
		erecta		1						3		1			5																6
	Ianthella	*basta*	2										6		8						2			2			1			5	48
		ditrochota																									2			2	2
	Iotrochota	*baculifera*																		1							2			3	12
		ditrochota	32	31				2							65	14				9	1									24	194
		protea	18	14		2		1	1		1	11	6	4	58	13	2	1	21	18	1	2	18	21			4		3	104	444
	Liosina	*cf. granulosa*	23	7			5		3	2	4		2	5	51	9	9		29	10		4	6	6	5	3	2			83	232
	Melophlus	*sarasinorum*	1	4			25	6							36	3	2				3				1	17	1			27	102
	Monanchora	*clathrata*																													5
	Paratetilla	*bacca*																1												1	2
	Plakina	sp.	4		3										7		1				1						1		1	4	35
	Porifera	sp.1 (Sponge tough)																									1			1	5
		sp.10 (Fake myrmekioderma)																													1
		sp.11 (Haliclona osiris)																					1							1	1
		sp.12 (white Dysidea 166)																													1
		sp.13 (Dysidea/Clathria like 179-180)																													1
		sp.14 (brown Xestospongia-like 183)									1				1																1
		sp.2 (Sponge green)														1														1	1
		sp.3 (orange/red Haliclona like)								10		7			17				2	1	8									11	47
		sp.4 (Dysidea like 0021)																						1						1	1
		sp.5 (white Callyspongia)																						2						2	2
		sp.6 (green Clathria)		2											2																5
		sp.7 (green/purple Tedania 141)																													3
		sp.8 (Haliclona gracilis)		1											1																1
		sp.9 (black net cover 1		1											1																1
	Pseudoceratina	sp.	4									1			5			1						2						3	27
	Sylissa	*massa*	19	6	24			5						5	59	7	22	12		9	9	18	6	2	9	6	4	4		108	246
	Tedania	*meandrica*			5	7		16							28	2		23		13	1		13	1	2	1	2	1		59	172
		sp.			1										1																2
	Ulosa	*spongia*	11				3			4		6	1		25		23			10	2	21	14	16	3	1	8	4	3	105	268
	Xestospongia	*carbonaria*			36		42	9	4	6			16	19	132		23	37	22		2	2			14	40	12	61	1	214	400
		exigua					2			2				1	5				1					1				3		5	46
PORIFERA Total			196	188	78	11	89	83	11	38	8	44	121	45	912	145	111	128	85	147	91	82	90	144	80	79	79	74	20	1355	4760
Grand Total			227	201	90	14	92	107	13	42	8	51	126	62	1033	176	138	154	86	179	99	100	123	167	124	120	90	85	23	1664	5589

APPENDIX H. Taxa Richness of all invertbrate species for each survey site

			Direct-Flat																			
Phylum	**Genus**	**Species**	**5**	**11**	**23**	**25**	**26**	**31**	**32**	**34**	**35**	**38**	**39**	**40**	**42**	**43**	**46**	**47**	**50**	**57**	**59**	**62**
Ascidia	Ascidia	sp.			1					1									1			1
	Clavelina	moluccensis	1	1	1	1	1	1	1	1												1
	Phallusia	julinea	1		1	1	1	1	1	1	1	1	1	1	1	1		1	1		1	1
	Polycarpa	sp.	1				1	1		1				1					1		1	1
	Rhopalaea	crassa	1	1	1	1	1	1	1	1	1	1	1	1		1			1			1
		sp.	1		1	1	1	1	1	1		1	1	1	1	1	1	1	1		1	1
Ascidia Total			5	2	5	4	5	5	4	6	2	3	3	4	2	3	1	2	5		3	6
Cnidaria	Anthozoa	sp.																				
	Boloceroides	mcmurrichi				1																
	Entacmaea	quadricolor																				
	Pennaria	disticha																				
Cnidaria Total						1																
Crustacea	Alpheus	sp.						1		1						1						1
	Aniculus	sp.																				
	Calcinus	minutus		1	1				1		1	1	1		1			1	1	1	1	
		pulcher		1	1				1		1	1	1		1			1	1	1	1	1
		spp.	1													1						
	Carupa	ohashii																				
	crab	sp.		1	1				1		1	1	1		1			1	1	1	1	
		sp. (blue)		1	1				1		1	1	1		1			1	1	1	1	
		sp. (gall)														1						
	Dardanus	guttatus																				
	Echinometra	mathei																				
	Hapalocarcinus	marsupialis																				
	Hermit	spp.																				
	Palaemonid	sp.																				
	Periclimenes	soror												1								
	Portunid	sp.6																				
		sp.7																				
		sp.9																				1
	Saron	marmoratus																				
	Shrimp	sp.	1																			
		sp. (clear)		1	1				1		1	1	1		1			1	1	1	1	
		sp. (Fungia)				1				1												
		sp. (goby)		1	1		1		1	1	1	1	1	1	1			1	1	1	1	
	Thalamita	sp.1																				
	Xanthid	sp.																				
Crustacea Total			2	6	6	1	1	1	6	3	6	6	6	2	6	3		6	6	6	6	3
Echinodermata	Acanthaster	planci																				
	Actinopyga	mauritiana																				
	Bohadschia	argus		1	1				1		1	1	1		1	1		1	1	1	1	
	Ceriantharia	sp.																				1
	Cerithium	columna					1															
	Culcita	novaeguineae		1	1		1		1		1	1	1	1	1	1	1	1	1	1	1	
	Echinaster	luzonicus		1	1				1		1	1	1		1			1	1	1	1	
	Echinometra	mathei					1															
	Echinostrephus	aciculatus																				
	Echinothrix	calamaris																				
	Entacmaea	quadricolor																				
	Euapta	godeffroyi																				
	Holothuria	atra		1	1				1		1	1	1		1			1	1	1	1	
	Linkia	laevigata																				
		multifera																				
	Ophiocoma	sp.																				
	Ophiomastix	caryophyllata		1	1				1		1	1	1		1			1	1	1	1	
	Ophiurid	sp.1	1				1	1														1
		sp.2 (small)		1	1				1		1	1	1		1			1	1	1	1	
	Pearsonothuria	graeffei		1	1				1		1	1	1		1			1	1	1	1	
Echinodermata Total			1	7	7		4	1	7		7	7	7	1	7	2	1	7	7	7	7	2
Mollusca	Arca	sp.	1																			
		ventricosa					1			1												1
	Barbatia	sp.																				
	Cerithium	columna	1	1	1			2	1	1	1	1	1	1	1			1	1	1	1	2
		echinatum														1						
		sinensis																				
	Chama	iostoma																				
		lazarus														1						1
	Chromodoris	fidelis															1					
	Clypeomorus	nympha	1																			1
	Conus	sp.																				
	Coralliophila	violacea	1			1				1						1						
	Cymatium	nicobaricum																				
		sp.																				
	Cypraea	annularis																				
		carneola																				
		contaminata																				
		erosa																				
		isabella																				
		mappa				1										1						
	Dendropoma	maxima																				1
	Diodora	sp.																				
	Drupella	elata																				1
		sp.																				
	Euplica	deshayesii	1	1	1				1		1	1	1	1	1			1	1	1	1	1
	Gastrochaena	sp.						1														
	Gastrochaenea	sp.																				
	Glossodoris	atromarginata		1	1			1	1		1	1	1		1			1	1	1	1	
	Habromorula	spinosa	1																			
	Hypselodoris	whitei																				
	Isognomon	perna														1						
		sp.						1														
	Lambis	lambis		1	1				1		1	1	1		1			1	1	1	1	
	Lithophagia	sp.	1			1	1	1		1				1		1						1
	Malleus	decurtatus					1							1		1						1
	Mitra	sp.																				
	Modulus	sp.	1																			
	Morula	uva																				
	Nassarius	castus				1																
	Noumea	angustolutea																				
	Octopus	sp.																				
	Pectinidae	sp.1																				
		sp.2																				
	Pedum	spondyloideum																				
	Pinctada	sp.																			1	1
	Pteraeolidia	ianthina																				
	snail	spp.		1	1				1		1	1	1		1			1	1	1	1	
	Spondylous	violacenscens																				
	Streptopinna	saccata					1															
	Strombus	gibberulus		1	1				1		1	1	1		1			1	1	1	1	
		luhuanus		1	1				1		1	1	1		1			1	1	1	1	
	Thais	sp.																				
	Trochus	niloticus																				
	Vasum	turbinellus																				
	Vexillum	sp.																				
Mollusca Total			8	7	7	4	4	6	7	4	7	7	7	4	7	7	1	7	7	7	8	11

APPENDIX H. (cont.)

Platyhelminthe	Flatworm	sp.		1	1				1		1	1	1		1			1	1	1	1	
Platyhelminthes Total				1	1				1		1	1	1		1			1	1	1	1	
Polychaeta	Sabellastarte	indica																				
		spectabilis																				1
Polychaeta Total																						1
Porifera	Aka	sp.																				
	Aplysinella	rhax	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1			
	Axinella	sp.																				
	Axynissa	sp.	1			1	1	1	1	1	1		1	1	1	1	1	1				1
	Callyspongia	diffusa	1		1	1	1	1	1	1	1		1	1		1			1			
		sp.														1			1			1
	Ceratopsion	sp.	1			1	1	1		1				1		1	1					1
	Chelonaplysilla	sp.								1												
	Cinachyra	sp.	1																		1	
	Clathria	basilana						1									1					
		eurypa	1		1	1	1	1		1	1		1	1	1	1	1		1			1
		hirsuta			1																	
		mima				1		1	1			1						1			1	
		sp.													1		1					
	Corticum	sp.			1																	
	Craniella	abracadabra																				
	Dragmacidon	sp.							1	1	1	1		1	1			1	1		1	
	Dysidea	sp.								1	1			1				1	1		1	
	Haliclona	(Reniera)	1	1	1	1	1	1	1	1	1		1			1		1	1			1
		sp. (blue)	1			1		1	1	1	1		1	1		1	1		1	1	1	1
	Hyrtios	altum			1																	
		erecta																				
	Ianthella	basta		1	1	1	1	1		1		1	1			1		1			1	
	Iotrochota	baculifera											1								1	
		ditrochota	1	1	1					1	1		1	1		1						
		protea	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Leucetta	cf. chagosensis																				
	Liosina	cf. granulosa	1		1	1	1	1	1	1				1	1		1			1	1	1
	Lissoclinum	calycis				1																
	Melophlus	sarasinorum	1	1	1			1							1							
	Monanchora	clathrata													1						1	
	Paratetilla	bacca																				1
	Plakina	sp.				1	1	1		1							1					1
	Porifera	sp.1 (Sponge tough)				1	1			1												
		sp.10 (Fake myrmekioderma)																				
		sp.11 (Haliclona osiris)																				
		sp.12 (white Dysidea 166)																	1			
		sp.13 (Dysidea/Clathria like 179-180)											1									
		sp.14 (brown Xestospongia-like 183)																				
		sp.2 (Sponge green)																				
		sp.3 (orange/red Haliclona like)									1	1	1					1	1	1	1	
		sp.4 (Dysidea like 0021)																				
		sp.5 (white Callyspongia)																				
		sp.6 (green Clathria)																				
		sp.7 (green/purple Tedania 141)																				
		sp.8 (Haliclona gracilis)																				
		sp.9 (black net cover 101)																				
	Pseudoceratina	sp.	1			1		1		1			1			1	1		1			
	Rhabdastrella	sp.																				
	Sylissa	massa	1		1	1	1	1	1	1			1	1		1	1		1			1
	Tedania	meandrica	1			1		1		1	1		1	1		1	1		1		1	1
		sp.			1																	
	Ulosa	spongia			1	1	1	1	1	1	1		1	1		1	1	1	1		1	
	Xestospongia	carbonaria				1				1	1						1		1			1
		exigua		1		1	1	1											1		1	
Porifera Total			15	6	15	20	14	19	11	21	14	6	16	14	8	15	15	10	17	4	14	13
Grand Total			31	29	41	30	28	32	36	34	37	30	40	25	31	30	18	33	43	25	39	36

			Direct-Slope															
Phylum	**Genus**	**Species**	**4**	**10**	**14**	**21**	**22**	**27**	**33**	**37**	**44**	**45**	**48**	**49**	**51**	**53**	**55**	**58**
Ascidia	Ascidia	sp.												1				1
	Clavelina	moluccensis		1	1	1				1	1		1				1	
	Phallusia	julinea	1	1	1	1	1	1	1	1	1	1		1		1	1	1
	Polycarpa	sp.	1								1			1			1	1
	Rhopalaea	crassa	1	1			1	1	1	1	1	1	1	1		1	1	1
		sp.	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1
Ascidia Total			4	4	3	3	3	3	3	4	5	3	3	4	1	3	5	5
Cnidaria	Anthozoa	sp.																
	Boloceroides	mcmurrichi																
	Entacmaea	quadricolor																
	Pennaria	disticha																
Cnidaria Total																		
Crustacea	Alpheus	sp.															1	
	Aniculus	sp.																
	Calcinus	minutus	1	1	1				1	1		1			1	1		1
		pulcher	1	1	1		1		1	1		1			1	1		1
		spp.				1												
	Carupa	ohashii																
	crab	sp.	1	1	1				1	1		1			1	1		1
		sp. (blue)	1	1	1				1	1		1			1	1		1
		sp. (gall)																
	Dardanus	guttatus																
	Echinometra	mathei																
	Hapalocarcinus	marsupialis																
	Hermit	spp.																
	Palaemonid	sp.																
	Periclimenes	soror																
	Portunid	sp.6																
		sp.7																
		sp.9																
	Saron	marmoratus															1	
	Shrimp	sp.																
		sp. (clear)	1	1	1				1	1		1			1	1	1	1
		sp. (Fungia)									1							
		sp. (goby)	1	1	1		1		1	1		1			1	1	1	1
	Thalamita	sp.1																
	Xanthid	sp.																
Crustacea Total			6	6	6	1	2		6	6	1	6			6	6	4	6
Echinodermata	Acanthaster	planci																
	Actinopyga	mauritiana																
	Bohadschia	argus	1	1	1				1	1		1			1	1		1
	Ceriantharia	sp.																
	Cerithium	columna																
	Culcita	novaeguineae	1	1	1		1		1	1	1	1	1		1	1		1
	Echinaster	luzonicus	1	1	1				1	1		1			1	1		1
	Echinometra	mathei												1				
	Echinostrephus	aciculatus																
	Echinothrix	calamaris																
	Entacmaea	quadricolor																
	Euapta	godeffroyi									1							
	Holothuria	atra	1	1	1				1	1		1			1	1		1
	Linkia	laevigata																
		multifera																
	Ophiocoma	sp.																
	Ophiomastix	caryophyllata	1	1	1				1	1		1			1	1		1
	Ophiurid	sp.1					1											
		sp.2 (small)	1	1	1				1	1		1			1	1		1
	Pearsonothuria	graeffei	1	1	1				1	1		1			1	1		1
Echinodermata Total			7	7	7		2		7	7	2	7	1	1	7	7		7
Mollusca	Arca	sp.																
		ventricosa											1					
	Barbatia	sp.																
	Cerithium	columna	1	1	1		1		1	1		1			1	1	1	1
		echinatum				1												
		sinensis																
	Chama	iostoma												1				
		lazarus															1	
	Chromodoris	fidelis																
	Clypeomorus	nympha																
	Conus	sp.																
	Coralliophila	violacea									1			1			1	
	Cymatium	nicobaricum																
		sp.																
	Cypraea	annularis																
		carneola																
		contaminata																
		erosa																
		isabella																
		mappa												1				
	Dendropoma	maxima																
	Diodora	sp.															1	
	Drupella	elata																
		sp.																
	Euplica	deshayesii	1	1	1	1			1	1		1		1	1	1		1
	Gastrochaena	sp.																
	Gastrochaenea	sp.																
	Glossodoris	atromarginata	1	1	1				1	1		1			1	1		1
	Habromorula	spinosa															1	
	Hypselodoris	whitei																
	Isognomon	perna																
		sp.												1				
	Lambis	lambis	1	1	1		1		1	1		1			1	1		1
	Lithophagia	sp.					1				1			1			1	
	Malleus	decurtatus															1	
	Mitra	sp.				1												
	Modulus	sp.																
	Morula	uva																
	Nassarius	castus																
	Noumea	angustolutea				1												
	Octopus	sp.									1							
	Pectinidae	sp.1																
		sp.2																
	Pedum	spondyloideum																
	Pinctada	sp.												1				
	Pteraeolidia	ianthina																
	snail	spp.	1	1	1				1	1		1			1	1		1
	Spondylous	violacenscens																
	Streptopinna	saccata																
	Strombus	gibberulus	1	1	1		1		1	1		1			1	1		1
		luhuanus	1	1	1				1	1		1			1	1		1
	Thais	sp.																
	Trochus	niloticus																
	Vasum	turbinellus																
	Vexillum	sp.																
Mollusca Total			7	7	7	4	4		7	7	3	7	1	7	7	7	7	7

Platyhelminthe	Flatworm	sp.	1	1	1				1	1		1			1	1		1
Platyhelminthes Total			1	1	1				1	1		1			1	1		1
Polychaeta	Sabellastarte	indica																
		spectabilis									1			1			1	
Polychaeta Total											1			1			1	
Porifera	Aka	sp.																1
	Aplysinella	rhax	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1
	Axinella	sp.																
	Axynissa	sp.	1	1	1	1	1	1	1	1	1	1		1			1	1
	Callyspongia	diffusa	1	1	1	1	1		1	1	1	1			1	1	1	
		sp.												1				
	Ceratopsion	sp.	1		1	1	1		1		1						1	
	Chelonaplysilla	sp.					1											
	Cinachyra	sp.	1		1													
	Clathria	basilana	1											1				
		eurypa	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1
		hirsuta	1	1	1													
		mima	1		1			1			1				1	1		1
		sp.						1		1			1			1		1
	Corticum	sp.	1	1	1				1			1						1
	Craniella	abracadabra			1													
	Dragmacidon	sp.	1	1	1		1			1		1			1	1		1
	Dysidea	sp.				1						1	1					1
	Haliclona	(Reniera)		1	1		1	1	1	1	1	1	1			1		1
		sp. (blue)	1	1		1		1						1			1	1
	Hyrtios	altum			1													
		erecta								1								
	Ianthella	basta	1	1	1	1	1		1	1	1	1			1	1		1
	Iotrochota	baculifera			1				1						1			
		ditrochota	1	1	1				1	1	1					1		
		protea	1	1	1	1	1		1	1	1	1	1	1	1		1	1
	Leucetta	cf. chagosensis																
	Liosina	cf. granulosa	1	1	1	1	1			1	1	1		1		1	1	1
	Lissoclinum	calycis																
	Melophlus	sarasinorum	1	1	1		1											
	Monanchora	clathrata													1			1
	Paratetilla	bacca																
	Plakina	sp.		1	1	1	1		1	1	1						1	
	Porifera	sp.1 (Sponge tough)			1			1								1		
		sp.10 (Fake myrmekioderm		1														
		sp.11 (Haliclona osiris)																
		sp.12 (white Dysidea 166)								1								
		sp.13 (Dysidea/Clathria like 179-180)																
		sp.14 (brown Xestospongia-like 183)																
		sp.2 (Sponge green)																
		sp.3 (orange/red Haliclona like)							1	1		1			1			
		sp.4 (Dysidea like 0021)																
		sp.5 (white Callyspongia)																
		sp.6 (green Clathria	1	1	1													
		sp.7 (green/purple	1		1													
		sp.8 (Haliclona gracilis)																
		sp.9 (black net cover 101)																
	Pseudoceratina	sp.	1					1			1	1						
	Rhabdastrella	sp.														1		
	Sylissa	massa	1	1	1		1	1	1	1	1	1		1		1	1	
	Tedania	meandrica	1	1	1	1			1	1	1	1		1			1	1
		sp.																
	Ulosa	spongia		1	1	1	1	1	1		1	1		1		1		1
	Xestospongia	carbonaria		1			1			1	1			1	1			1
		exigua		1	1	1	1			1	1							
Porifera Total			22	22	27	14	17	11	16	19	18	16	5	11	11	14	11	20
Grand Total			47	47	51	22	28	14	40	44	30	40	10	24	33	38	28	45

APPENDIX H. (cont.)

			Indirect-Flat												Indirect-Slope													
Phylum	**Genus**	**Species**	**2**	**3**	**6**	**7**	**9**	**13**	**16**	**18**	**24**	**36**	**56**	**60**	**1**	**8**	**15**	**17**	**19**	**20**	**28**	**30**	**41**	**61**	**63**	**64**	**65**	**66**
Ascidia	Ascidia	sp.		1	1												1		1	1					1		1	
	Clavelina	moluccensis	1	1		1		1	1						1	1								1	1			
	Phallusia	julinea	1	1	1		1	1	1	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Polycarpa	sp.	1				1	1	1			1	1	1	1		1		1			1	1	1			1	
	Rhopalaea	crassa	1	1		1		1	1				1		1	1	1		1	1	1		1	1	1	1		1
		sp.	1	1	1			1	1	1		1	1		1	1	1		1	1			1	1	1	1		
Ascidia Total			5	5	3	2	2	5	5	2		3	4	2	5	4	5	1	5	4	2	2	4	5	5	3	3	2
Cnidaria	Anthozoa	sp.	1																									
	Boloceroide	mcmurrichi													1													
	Entacmaea	quadricolor			1		1																					
	Pennaria	disticha												1														
Cnidaria Total			1		1		1							1	1													
Crustacea	Alpheus	sp.	1		1			1						1	1		1				1				1			
	Aniculus	sp.													1													
	Calcinus	minutus		1	1	1	1		1	1	1	1						1	1	1		1	1		1	1		1
		pulcher		1	1		1	1	1	1	1	1			1		1	1	1	1		1	1	1	1	1		1
		spp.														1					1						1	
	Carupa	ohashii			1																							
	crab	sp.		1					1	1	1	1						1	1	1		1	1			1		1
		sp. (blue)		1					1	1	1	1						1	1	1		1	1			1		1
		sp. (gall)																										
	Dardanus	guttatus					1																					
	Echinometr	mathei													1													
	Hapalocarc	marsupialis												1														
	Hermit	spp.			1																							
	Palaemonid	sp.													1													
	Periclimene	soror	1												1													
	Portunid	sp.6															1											
		sp.7					1																					
		sp.9																										
	Saron	marmoratus																										
	Shrimp	sp.																										
		sp. (clear)		1					1	1	1	1						1	1	1		1	1			1		1
		sp. (Fungia)											1															
		sp. (goby)		1					1	1	1	1						1	1	1		1	1			1		1
	Thalamita	sp.1																			1							
	Xanthid	sp.																									1	
Crustacea Total			2	6	5	1	4	2	6	6	6	6	1	2	6	1	3	6	6	6	3	6	6	1	3	6	2	6
Echinoderm	Acanthaste	planci	1																									
	Actinopyga	mauritiana												1														
	Bohadschia	argus		1		1			1	1	1	1		1				1	1	1		1	1			1	1	1
	Cerianthari	sp.																										
	Cerithium	columna																										
	Culcita	novaeguineae	1	1					1	1	1	1	1		1			1	1	1		1	1			1		1
	Echinaster	luzonicus		1					1	1	1	1						1	1	1		1	1			1		1
	Echinometr	mathei			1	1								1											1		1	
	Echinostrep	aciculatus												1													1	
	Echinothrix	calamaris			1																						1	
	Entacmaea	quadricolor				1																						
	Euapta	godeffroyi																										
	Holothuria	atra		1					1	1	1	1		1				1	1	1		1	1			1	1	1
	Linkia	laevigata																									1	
		multifera			1		1	1								1												
	Ophiocoma	sp.																			1							
	Ophiomasti	caryophyllata		1					1	1	1	1						1	1	1		1	1			1		1
	Ophiurid	sp.1																						1				
		sp.2 (small)		1					1	1	1	1						1	1	1		1	1			1		1
	Pearsonoth	graeffei		1					1	1	1	1			1			1	1	1		1	1			1		1
Echinodermata Total			2	7	3	3	1	1	7	7	7	7	1	5	2	1		7	7	7	1	7	7	1	1	7	6	7
Mollusca	Arca	sp.																										
		ventricosa			1	1		1					1		1	1	1				1			1	1			
	Barbatia	sp.																			1							
	Cerithium	columna	1	1			1	1	1	1	1	1					1	1	1	1		1	1			1		1
		echinatum				1									1	1								1	1			
		sinensis			1																							
	Chama	iostoma														1					1							
		lazarus	1					1								1					1						1	
	Chromodor	fidelis																										
	Clypeomoru	nympha			1		1	1							1		1							1	1			
	Conus	sp.														1												
	Coralliophil	violacea	1		1		1	1						1	1	1	1				1			1	1			
	Cymatium	nicobaricum																									1	
		sp.												1														
	Cypraea	annularis																									1	
		carneola													1	1											1	
		contaminata																									1	
		erosa																									1	
		isabella			1											1												
		mappa																										
	Dendropom	maxima				1	1	1						1		1	1				1			1	1		1	
	Diodora	sp.																										
	Drupella	elata																										
		sp.	1																		1							
	Euplica	deshayesii	1	1	1	1	1		1	1	1	1		1		1	1	1	1	1		1	1			1	1	1
	Gastrochae	sp.															1											
	Gastrochae	sp.																							1			
	Glossodoris	atromarginata		1					1	1	1	1						1	1	1		1	1			1		1
	Habromoru	spinosa			1		1	1									1				1			1	1			
	Hypselodor	whitei																									1	
	Isognomon	perna																										
		sp.			1									1	1	1					1			1			1	
	Lambis	lambis		1					1	1	1	1						1	1	1		1	1			1	1	1
	Lithophagia	sp.	1		1	1	1	1						1	1		1				1			1	1		1	
	Malleus	decurtatus	1					1								1	1								1			
	Mitra	sp.																										
	Modulus	sp.					1																					
	Morula	uva																			1							
	Nassarius	castus																										
	Noumea	angustolutea																										
	Octopus	sp.																										
	Pectinidae	sp.1																							1			
		sp.2																									1	
	Pedum	spondyloideum																							1			
	Pinctada	sp.	1			1						1		1					1			1	1		1	1	1	
	Pteraeolidia	ianthina																									1	
	snail	spp.		1					1	1	1	1						1	1	1		1	1			1		1
	Spondylous	violacenscens													1									1				
	Streptopinn	saccata			1																							
	Strombus	gibberulus		1					1	1	1	1						1	1	1		1	1			1		1
		luhuanus		1					1	1	1	1				1		1	1	1		1	1			1	1	1
	Thais	sp.											1															
	Trochus	niloticus					1							1														
	Vasum	turbinellus																									1	
	Vexillum	sp.														1												
Mollusca Total			8	7	10	6	9	9	7	7	7	8	2	8	8	14	10	7	8	7	11	8	8	9	12	8	17	7

APPENDIX H. (cont.)

Platyhelmin	Flatworm	sp.		1					1	1	1	1						1	1	1		1	1			1		1
Platyhelminthes Total				1					1	1	1	1						1	1	1		1	1			1		1
Polychaeta	Sabellastart	indica																			1	1						
		spectabilis	1		1		1									1	1				1			1	1		1	
Polychaeta Total			1		1		1									1	1				2	1		1	1		1	
Porifera	Aka	sp.																										
	Aplysinella	rhax	1	1				1		1		1	1		1	1	1		1	1			1			1		1
	Axinella	sp.											1				1											
	Axynissa	sp.	1	1		1			1	1			1	1	1		1	1	1	1	1	1	1			1	1	
	Callyspongi	diffusa	1							1		1	1						1	1						1		1
		sp.				1		1							1		1				1			1	1			
	Ceratopsion	sp.	1				1	1	1				1	1	1		1			1	1		1					
	Chelonaplys	sp.															1						1					
	Cinachyra	sp.							1		1			1			1				1	1		1			1	
	Clathria	basilana		1							1		1		1									1	1			
		eurypa	1	1			1	1	1				1	1	1	1	1	1	1	1	1		1	1	1	1	1	
		hirsuta				1						1												1	1	1		
		mima										1			1	1										1		
		sp.							1			1						1	1	1								
	Corticum	sp.										1							1	1								
	Craniella	abracadabra																										
	Dragmacido	sp.							1	1									1			1	1					
	Dysidea	sp.	1			1		1		1						1	1				1		1	1		1	1	
	Haliclona	(Reniera)	1	1						1			1		1		1		1	1			1			1		
		sp. (blue)	1	1	1			1	1	1	1		1	1	1	1	1		1		1	1		1	1	1		
	Hyrtios	altum		1				1	1				1		1	1												
		erecta		1						1		1																
	Ianthella	basta	1	1									1							1			1			1		
	Iotrochota	baculifera																	1							1		
		ditrochota	1	1				1							1	1			1	1	1					1		
		protea	1	1		1		1	1		1	1	1	1	1	1	1	1	1	1	1	1	1			1		1
	Leucetta	cf. chagosensis														1					1							
	Liosina	cf. granulosa	1	1			1		1	1	1		1	1	1	1	1	1	1		1	1	1	1	1	1	1	
	Lissoclinum	calycis	1														1											
	Melophlus	sarasinorum	1	1		1	1	1							1	1	1		1	1				1	1	1		
	Monanchor	clathrata																										
	Paratetilla	bacca															1											
	Plakina	sp.	1		1											1				1						1		1
	Porifera	sp.1 (Sponge tough)																								1		
		sp.10 (Fake myrmekioderma)																										
		sp.11 (Haliclona osiris)																				1						
		sp.12 (white Dysidea 166)																										
		sp.13 (Dysidea/Clathria like 179-180)																										
		sp.14 (brown Xestospongia-like 183)									1																	
		sp.2 (Sponge green)													1													
		sp.3 (orange/red Haliclona like)								1		1						1	1	1								
		sp.4 (Dysidea like 0021)																					1					
		sp.5 (white Callyspongia)																					1					
		sp.6 (green Clathria)		1																								
		sp.7 (green/purple Tedania 141)																										
		sp.8 (Haliclona gracilis)		1																								
		sp.9 (black net cover 101)		1																								
	Pseudocera	sp.	1					1				1					1				1		1					
	Rhabdastre	sp.																										
	Sylissa	massa	1	1	1			1	1	1	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
	Tedania	meandrica			1	1	1	1					1		1		1		1	1		1	1	1	1	1	1	
		sp.			1																							
	Ulosa	spongia	1	1			1		1	1		1	1			1		1	1	1	1	1	1	1	1	1	1	1
	Xestospong	carbonaria			1		1	1	1	1			1	1		1	1	1		1	1			1	1	1	1	1
		exigua					1			1				1				1					1				1	
Porifera Total			18	18	6	7	8	14	13	14	7	11	17	10	17	15	20	10	18	18	15	10	18	13	11	21	10	6
Grand Total			37	44	29	19	26	31	39	37	28	36	25	28	39	36	39	32	45	43	34	35	44	30	33	46	39	29

Appendix J
Supplemental Aircraft Carrier Marine Surveys

7. Peer Review of Assessment of Benthic Community Structure in the Vicinity of the Proposed Turning Basin and Berthing Area for Carrier Vessel Nuclear (CVN), Apra Harbor Guam. August 2009.

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EMAIL LETTER FROM JT

-----Original Message-----
From: Hesse, JT T CIV NAVFAC PAC, EV2 [mailto:jeffrey.hesse@navy.mil]
Sent: Wednesday, September 16, 2009 9:30 AM
To: Molzan, Darrell J CIV OASN (I&E), Joint Guam Program Office; Egeland, Tom A CIV ASSTSECNAV IE WASHINGTON DC, OASN(I&E); Hautzenroder, Joseph E CIV (NAVFACHQ); Hassell, Mary CIV NAVFAC HQ, ENV
Cc: Pepi, Vanessa E CIV NAVFAC PAC ; Cecchini, Joseph D CIV NAVFAC PAC, EV; Suwa, Alan M CIV NAVFAC Pacific, EV; Sumida, Karen C CIV NAVFAC PAC ; Loo, Debra F CIV NAVFAC PAC ; Smith, Stephen H CIV NFESC; Jameson, Stephen C CIV NAVFAC Pacific, EV2; Caplan, Faith R.
Subject: Independent Peer Review of Navy CVN survey methods

All,

Per your request here are the eight peer reviews of the coral survey methods used by the Navy contractors (University of Hawaii and National Coral Reef Institute). The reviewers are some of the coral reef elite from around the world and their opinions carry significant weight within the community. All in all a very positive response to the methods used. Please note that not a single expert suggested that coral colony size frequency or coral colony density (the resource agency argument) would be a better means of capturing "coral reef ecological function" or provide a more meaningful input into a HEA.

When the request to review was initially made, a list of questions were provided to encourage thought on specific points. You will note that all answered the questions as well as provided additional information that should be considered for future method refinement. Provided below is the list of questions asked.

Questions

1. Do the methods used in this study provide data to make reasonable conclusions about the status of the coral reef habitat under study?

2. Does the accuracy rate for the remote sensing map created from sea-truth data meet scientific rigor for acceptance as a viable means for extrapolation to the greater area?

3. Do the methods used have the capability to provide replicate data that is testable for ensuring valid and unbiased results?

4. Do the results of this report represent a reasonable and cost effective characterization of the affected coral reef habitat?

5. How would you define and measure coral reef ecosystem function?

6. Would application of the data derived from this study provide the necessary input to a habitat equivalency analysis (HEA) model to meet accepted scientific standards for assessing direct physical impacts (dredging) to coral reefs?

It is our intention to share this information with the resource agencies and the USACE in the upcoming meeting on September 25th. The reviews will also be included as an appendix to the EIS to substantiate the methods used.

Bottom line, if there was any question whether the Navy was using an appropriate method this should provide significant reassurance. For your reference I am also including a word document that provides a description of each reviewers affiliation and credentials. If anyone has any questions, please feel free to give me a yell.

I just wanted give credit where it is due Dr. Stephen Jameson (NAVFAC PAC) was instrumental in identifying these experts and helped to facilitate their involvement.

JT

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-----Original Message-----
From: McClanahan, Tim [mailto:tmcclanahan@wcs.org]
Sent: Sunday, August 23, 2009 3:58
To: Jameson, Stephen C CIV NAVFAC Pacific, EV2
Cc: Hesse, JT T CIV NAVFAC PAC, EV2
Subject:

Stephen and Jeffrey,

Apologies for being a bit late, I got caught up in a airline strike in Nairobi last week that caused me to go round in circles, checking in three times to leave the country and then when I arrived in Reunion there was a workload and email problems that slowed the submission. Regardless, I have read and evaluated the report and find my comments below.

Best if you can wire the payment to this bank.

Tim R McClanahan
Wells Fargo
Bank Routing No. - 121042882
Acc #7216963608
. BROADWAY-GRANT AVENUE
1160 GRANT AVE,
SAN FRANCISCO, CA 94133
Tel: 4153962744

Tim McClanahan

Sending both a Word and PDF format of the review

CVN Survey review

Questions

1. Do the methods used in this study provide data to make reasonable conclusions about the status of the coral reef habitat under study?

Yes, the sample sizes and coverage are large particularly for the coral reef environments. The data are well documented in raw form that will allow for a repetition of the surveys. The analysis of the strata is weak in terms of tests of significance but stronger in terms of the multivariate analyses that allow for distinguishing community types. Multivariate findings are that the strata are not strongly different but that the local factors of community succession or other patterns associated with water flow, temperature or other disturbance regimes may be more important. I think, however, that this can be established more rigorously by including a few more tests of significance. Given that the strata effect is not a strong factor suggesta that the researchers have not identified the factors that cause the observed patterns. Perhaps other strata such as distance from shore or water flow are more important and should be considered in determining strata that will ultimately be useful in the determination of the natural factors that influence the community. The study is weak on the physico-chemical factors that might have influenced patterns, such as water flow, sediment rates, light, depth, water quality, temperature variation, etc. This makes is hard to determine the patterns of coral community, but also what might be influencing the large amount of algae in the many study sites. The chosen strata are not what coral reef ecologists would chose as things that influence coral communities but maybe chosen for the dredging purposes. Additionally, better quantification of those areas represented by regrowth after the 1946 dredging would help to understand this possible strong effect, and to include this previously dredged region as one of the strata in the design may be more useful then the current design. Can this be done or would this be too speculative? The authors speculate on this but it is not well-quantified or tested for significance.

I believe the epibenthic cover on soft bottoms was not well sampled and it is hard to determine if it was done well or not, as there is no data on this particular habitat, which often has large numbers of echinoderms, for example. This is the largest weakness of the study and needs to be described in more detail why little in terms of field surveys or no echinoderms, etc are reported.

2. Does the accuracy rate for the remote sensing map created from sea-truth data meet scientific rigor for acceptance as a viable means for extrapolation to the greater area?

This seems to be the state of the art and should be sufficient to do gross scale mapping. Given the low number of communities and high dominance within communities observed the current accuracy should be sufficient for a good mapping program.

3. Do the methods used have the capability to provide replicate data that is testable for ensuring valid and unbiased results?

Yes, in terms of the coral communities it is fine. It is weak and unrepeatable in the soft bottom communities.

4. Do the results of this report represent a reasonable and cost effective characterization of the affected coral reef habitat?

The results are reasonable but the cost was probably considerable, which will limit the amount of times this sort of work will be repeated. The costs of photo quadrats are high and this method creates a good historical record but costs are likely to limit the replication of this study after the impact.

5. How would you define and measure coral reef ecosystem function?

Factors that influence calcification are critical and there are various ways to estimate this from the data that they have. The ratio of corals to turf and fleshy algae is one good way and the authors have the opportunity to do this in that report with their data. They also have data on coralline algal cover, which is also very important, so a ratio of calcifying to non-calcifying organisms is possible with the data that they have and I would suggest they analyze their data in this regard. They may consider using these metrics to plot out its distribution in the study sites.

They also have a measure of chlorophyll and this should be useful, although the current data are not showing strong patterns. The question will be if the impact will produce repeatable results with this method. Is the measure sensitive enough to pick up moderate stress? The method is somewhat new and without a strong history so there is some possibility that the method is not sufficiently well established to pick up impacts after disturbances and the range of sensitivity is not well known. I would suggest that support this method more with information they may have on sensitivity or to actually do some experiments on sediments and stress at various levels and see if their methods are sensitive to these experimental manipulations. This methods needs to be developed further in the scientific and environmental impact literature.

6. Would application of the data derived from this study provide the necessary input to a habitat equivalency analysis (HEA) model to meet accepted scientific standards for assessing direct physical impacts (dredging) to coral reefs?

I found this part of the study to be weak at the HEA was not well explained in the introduction and may have assumed too much prior knowledge that I do not have. I would suggest that this part of the report be presented in more detail in the introduction and that the conclusion section of the paper readdress this part of the work. I assume that they have good data and can do this but it is not described and concluded on well in the report and leaves this aspect of the study poorly covered.

Conclusions

The study is thorough in the field sampling and collecting the information on coral reef habitats that are required for impacts but the design is weakly presented and the lack of significance suggests that the design elements are not the factors influencing the coral communities. The HEA is also not well described or concluded on, the soft bottom study is weak, and the stress measurements of chlorophyll estimates are not developed rigorously at this point and may prove to be problematic unless sensitivity is evaluated in more detail. The mapping program is the best currently available and this simple system may be fairly easy to map.

More effort at developing synthetic indices of calcification proxies may be more important than the community structure work that is presented. More evaluation of the biodiversity in terms of the numbers of taxa seen for given similar levels of sampling would provide a basis for evaluating future effects on biodiversity. The focus is more on community structure, which is useful in this high dominance systems but, given the inability of their design and strata to distinguish these communities, these measures may have limited usefulness in distinguishing impacts and augmenting with proxies of calcification and biodiversity would be useful to cover for a more thorough analysis. More effort to understand the natural factors that influence coral communities and developing a design that includes these would give the study a stronger basis for determining impacts. This would probably require more oceanographic measurements but also could be as simple as evaluated previously dredge and undredged areas. The paper would benefit from stronger organization or sections, paragraphs, and sentences as well as more description of key aspects of the study design and method, and less speculation in the results section but more tests of significance. Below are some comments that were generated while reading the report.

Editorial comments while reading.

Abstract
The acronym SRF is used in the abstract but not defined. This paragraph is hard to follow and needs editing and more clarity about what is being compared. Accuracy is not defined and clear about how this would be calculated.

A sentence or two more about the habitat equivalency model would help as the authors are focused on what this survey is not more than what it is in this section. Given that we are asked to evaluate the report in this respect it is hard to do this with the very short description given here and the lack of discussion on the results at the end.

The authors are being ambivalent about whether this could or could not be a monitoring program. It is implied that it could be in the abstract but stated that it is not in the introduction. I think this text is more for the discussion. The intro has caveats before the proposed purpose is even described in any detail. The authors have done thorough work so this could certainly be used for monitoring but the costs may be prohibitive. The costs are not clearly laid out and so this is difficult to evaluate. Can a table of effort be given in terms of person-days spent on the various activities so we can see what is expected for the replication?

Methods

I would think a study sites section would appropriate in the methods, perhaps 4.1 should be move here after removing some of the sections that should be in the Results section?

The report is taking an apologetic tone before we see any results in terms of justification and methods. Power analyses can be done within strata, so the apology here is not really justified. A better justification is the large sample size for an area with low diversity or high dominance and the limits set by the costs of doing the work.

Sentences and paragraphs starting with "Fig x shows…" is a poor compositional style as it is unclear what the purpose of the sentence and paragraph are other than to show an element of the report. What are the purposes of these paragraphs other than to show a photo, there must be a good reason for showing the photo, so focus on this in the opening. I think most of this is results and not methods.

There is really no study design section and why the particular system of sampling was used, so the reader is given weak context followed by lots of information that is not as important. There are four strata sampled. This can be said simply and followed by what was sampled in each strata. The report is too long on unimportant information and details and too short on key aspects of design, key findings, achieving the expected results, etc. Needs some revision in this respect.

Here "Figures 2-6 show the progression of steps used to develop a set of 67 survey sites within the four strata." We should be given some rationale for the photo method, but the report just starts out with a description of what was done without context. Would these not be results rather than methods? Try "In order to determine the location of the four strata…"

P8 – not sure I believe there is high ecological diversity here. There are a few community types and high dominance, so it seems appropriate for mapping. Again, apologetic and presumption before the data are evaluated. Why not come up with some standardized measure of biodiversity here, numbers of taxa per site for the same sampling effort, for example? This overfocus on community structure without a biodiversity measure is a big weakness.

A paragraph on statistical methods used would be useful. Some are mentioned in the results but should be given their own section. One on ANOVA type tests that were done and another paragraph on multivariate methods.

Results

Seems that it is speculation about what has regrown in the original dredge area. Can this be quantified? Much of the results is speculation and should be in the discussion section. Some of the results are methods in terms of definitions and citing papers and should be moved there.

4.2.6. There are usually starfish and other echinoderms in these areas but not data are presented on this and the authors state there were no epi-benthic biota here, but that is very unusual and not clear how much effort was made to determine this "result". This is a major weakness of the report.

Caps are often used inappropriately, i.e Rus, Algae..

The large amount of description without tests of significance for differences between the four strata is disappointing.

Discussion

It seems to me that the high erect algal cover is unusual and this probably results from corals death in recent times and the colonization of their skeletons by algae. This could be due to recent coral bleaching but can also result from coral sedimentation or eutrophication. The sedimentation effect is not given serious consideration here for the possible impact of recently dead coral.

Table 1 – How is algae defined here, is this including small turf algae?

Tables – A MANOVA test is needed along with the data in many of the tables. The results briefly mention non-significance but not details are given of the F, p, etc values.

-----Original Message-----
From: Terry Hughes [mailto:terry.hughes@jcu.edu.au]
Sent: Sunday, August 23, 2009 3:49
To: Jameson, Stephen C CIV NAVFAC Pacific, EV2; Hesse, JT T CIV NAVFAC PAC, EV2
Subject: Re: US Navy - Guam CVN - Paid Peer Review Request

Dear Stephen and Jeffrey,

Attached is my review of the Apra Harbor report by Steven Dollar and colleagues.

My mailing address, where payment and further enquiries can be sent, appears below.

Best wishes,

Terry

Prof. Terry Hughes FAA
Federation Fellow and Director, ARC Centre of Excellence for Coral Reef Studies
Fellow of the Beijer Institute of Ecological Economics

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Visit the ARC CENTRE OF EXCELLENCE FOR CORAL REEF STUDIES at http://www.coralcoe.org.au/ <http://www.coralcoe.org.au/> Linked to >500 pdfs of our latest publications from 2005-2009

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<http://www.coralcoe.org.au/annualreport08.pdf> Visit the Beijer Institute of Ecological Economics at http://w <http://www.beijer.kva.se> ww.beijer.kva.se <http://www.beijer.kva.se>

Report Review

Assessment of Benthic Community Structure in the Vacinity of the Proposed Turning Basin and Berthing Area for Carrier Vessels Nuclear (CVN), Apra Harbor, Guam

Submitted: August 21st, 2009

GENERAL COMMENTS

The report is generally well-written and clear. It could be improved by moving existing text around and avoiding some duplication of text and especially of figures. The Results section has a significant amount of background material that could be combined into an an Introduction.

The bulk of the information comes from analysis of photo-transects. The transect methods and analyses of the photographs are both appropriate and are well executed. The presentation of results is exhaustive, and many of the graphs (see below) could be eliminated without a significant loss of information. We don't need so many maps. The contours on some of them (see below) are hard to distinguish from the background. The remote sensing data adds little more than another map of coral habitat, which is readily visible from the sea surface. Additional information on sediments, macro-invertebrates, spectral reflectance and size-frequencies of corals are preliminary and limited in scope, and could be presented more succinctly.

I recommend that metric units are used throughout rather than feet, yards and acres. Detailed comments below are arranged page by page, with reference to figures and tables corresponding to their first mention in the text.

In answer to the questions posed about the report:

1. Do the methods used in this study provide data to make reasonable conclusions about the status of the coral reef habitat under study? Yes, they do (see full review below).

2. Does the accuracy rate for the remote sensing map created from sea-truth data meet scientific rigor for acceptance as a viable means for extrapolation to the greater area? Probably not, but I don't believe this is a problem. The in situ photo-transect data is much more informative (see report below).

3. Do the methods used have the capability to provide replicate data that is testable for ensuring valid and unbiased results? Yes, the data on status of the coral reef habitat are rigorous and can be validated and re-measured.

4. Do the results of this report represent a reasonable and cost effective characterization of the affected coral reef habitat? The report characterizes the affected coral reef habitat very well. I can't comment on cost-effectiveness.

5. How would you define and measure coral reef ecosystem function? I'm not sure what this question means in the context of the report, which makes no attempt to measure ecosystem function. The term describes the biophysical processes that take place within an ecosystem. These are usually characterized separately from any human role in ecosystem dynamics (e.g., herbivory, fish recruitment). Ecosystem services refers to the beneficial outcomes for human societies that result from ecosystem functions (e.g. fishing, reef tourism, cultural values of reefs). This report does not measure ecosystem

function or ecosystem services.

6. Would application of the data derived from this study provide the necessary input to a habitat equivalency analysis (HEA) model to meet accepted scientific standards for assessing direct physical impacts (dredging) to coral reefs? The data provided would certainly contribute some information relevant for a HEA service-to-service approach or resource equivalency analysis (REA). However, a critical issue is the calculation of an appropriate discount factor, which the report does not address. The loss of services from Apra Bay will be semi-permanent, and the technology of coral rehabilitation is still poorly developed. Most restoration attempts on coral reefs are very small in scale (a few 10s of metres), and most fail within a few years. Consequently, the area required for compensation of the lost services from Apra Bay may be very large.

EXECUTIVE SUMMARY

P.1, 1st para. The dredging depth of 51ft (16m or so) begs the question what proportion of the area is shallower than that, and what volume of material will be removed. This information and the size (area) of the dredging operation should be included in the summary.

P1, 3rd para. Briefly state how the 67 transects were deployed.

P1, final para. I'm not sure that "community group" is an appropriate term for these 16 clusters. It appears that the 10m^2 transects tended to be dominated by sediment, algae, or by one or two species of corals. The 16 clusters seem to be alternative patches within the pooled area of 670m^2, rather than distinct communities. See comments below for p18.

P2, 2nd para. The terms "strata" and reef "flat" are confusing (see comments for p6, below).

P2, 3rd para. The "SRF alternative" is unclear until the reader gets to the Purpose section. We don't yet know what SRF stands for, or that it is an alternative site for the dredging. The term "corals of all classes" is unclear. Presumably, it means abundance classes, as explained later, but it could equally be species, growth forms, etc. The accuracy percentages for the remote sensing were much poorer for individual abundance classes than the summary here suggests.

P2, final para. Insert units for the macro-invertebrates. It isn't clear if they refer to abundances or species richness, or what the area of measurement is.

PURPOSE

Normally the purpose or objectives of a report would be included as part of an Introduction. This structure of the report seems to have displaced introductory text into the Methods and Results sections, which is reduced the clarity of the report.

P4. The final paragraph mentions "indirect" impacts of dredging, meaning the effects of sediment re-suspension on immediately adjoining areas. This impact is likely to be very considerable, so "indirect" is probably not a good descriptor. What is the rationale for a 200m buffer zone?

P5. Here, and throughout the report, the point is made that the area surveyed by transects is a very small fraction of the overall study area. Of course it is. This is true of all sampling regimes.

Figure 1. The blue lines are hard to see, and the black contours are virtually invisible. Ditto for Figure 2.

METHODS

P6. A stratified sampling design is entirely appropriate. However, the term "strata" is confusing given its common usage in geology and related fields. "Flat" is also problematic because reef flat refers to a specific very shallow habit. Its use here for much deeper previously-dredged horizontal areas is potentially very confusing.

Figure 2. It would be clearer to color code the yellow dots to illustrate the four substrate types ("strata").

Figure 3. The purple depth contours are invisible against the black background. What are the coral arrows for?

Figure 4 is much clearer. It could easily replace Figures 1-3, with no loss of information.

Figure 5. Doesn't add much.

Figure 6. Almost the same as Figure 4. I suggest retaining 4 or 6, and removing the other five versions.

P7, 4^{th} paragraph. This is only one sentence. Why is rugosity being measured?

P7, final para. The first sentence should explain what is being characterized in the photographs and why. The current overly long sentence seems to be about promoting a piece of software.

Figure 7. The site numbers could be added to figure 4 or 6 instead of adding an additional map. In the caption "deemed" is an odd choice of words to describe the width of the 200m buffer zone. Deemed by whom and on what basis?

P8. 2nd para. "areas of different bottom composition" is vague. I think it means with or without some amount of corals. It doesn't seem to mean species composition.

P8. 3rd para, line 1. Why "reef" area of transects, given that some transects were on soft sediments? What does "total reef area" of 728,000m^2 mean? Is it the area of hard substrate? Why is it more than the 600,000m^2 mentioned in the last paragraph for the whole study area? Is "study region" the same as "study area"?

P9. 3rd para. Provide a justification for 75% as the accuracy threshold. It seems low.

P10. 1st para. What is the reason for measuring overall reef rugosity?

P10. The heading should be "Assessment of spectral reflectance". Assessment of coral stress could be many things. In this case, stress is inferred rather than measured directly.

P11. Line 1. "collecting tip" should probably be "measuring" or "recording tip". The heading would be clearer if "macro-invertebrates" was used.

P12. The analysis of sediments is very superficial, limited to ascertaining the carbonate composition. The rationale for this part of the study is that suspended terrigenous and carbonate-rich sediments each affect corals in different ways. However, the difference is largely due to particle size and organic composition rather than the carbonate fraction per se. Sediment grain size and organic content were not examined. We're told later on p13 that parts of the turning basin are only 40ft (13m) deep, so the analysis of surface sediments collected by divers is of limited use. Much of the sediment generated by the dredging will be meters below the current surface.

P13. Line 1. "Macro"-invertebrates.

RESULTS

P13. 2nd para, line 1. It's not clear what "structure of the marine environment means". Does it mean geomorphology, bathymetry?

P13. 3rd para. Don't the eastern rather than western slopes of Western Shoals and Big Blue Reef intersect the channel floor?

P14. 2nd para. The supracolony paragraph highlights the limitation of measuring colony size-frequencies, presented later. What exactly does "a whole ecological identity" mean?

Figure 8. The caption should provide the depth. Clearly, reef "flat" is not appropriate – these are deeper-water assemblages. Reef flats by definition occur in shallow water behind the reef crest.

P15. 2nd para, line 4. Delete "other" before "species of *Porites*".

P15. 3rd last line. "essentially pure stands" sounds odd. I think you should replace "algae" with "macro-algae" almost everywhere in the report.

P16. Line 1. *Padina* is only very, very lightly calcified. It is usually though of as "fleshy".

P17, 3rd and 4th para. It should be noted here that coral species richness is low (only 18 spp.), and cover of algae is high. The dominance of *Porites rus* makes most of the later analysis (Figures 22-31) of species composition unnecessary, or at least predictable.

Table 1. The two decimal places for abundances on each transect are not justified.

Table 2 uses one or no decimal places. I suggest using one for both tables.

Table 3 has two redundant halves. Use the percent cover.

P18, 1st para. I realize that 30.7% was the lowest cover of algae, but it is not "low". If the Direct Slope has the lowest coral cover of 14.4%, how can it in combination with the Direct Flats be lower still at 13.9%?

P18, 2nd para. Point out that the remaining 14 coral species only account for 5% cover.

Figure 21 doesn't add much. The dominance of *Porites rus* is very clear from the text and tables.

Figure 22 doesn't support 7 clusters very well – it looks more like three (corals, macroalgae and mud). Later the PCA finds no support for clear assemblages.

Figure 23. There is no text for this. It appears to include "clusters" based on one (7, 9) or two (15) transects. There's no explanation of the composition of each cluster. These are distinctive transects rather than discrete assemblages of species. Delete.

P18, last para. I don't think Figure 24 adds anything beyond the information provided in the text. The first two PC account for about 90% of the variation, and the rest count for little. Not surprisingly, mud and the overwhelmingly dominant coral, *Porites rus*, are important, and nothing else is.

P19, 2nd para. I don't think it's necessary to show four alternative analyses of benthic composition (Bray-Curtis, the ternary plot, PCA and DFA), often with multiple graphs for each one. I don't see any "habitat type" in Table 5. Later, on p20, the PCA shows no difference in species composition among the four "strata". Figures 26-31 should be deleted or at most replaced with one, showing no clear assemblages.

P19, 4th para, line 3. A typo – "include only there two cover types".

P19, para 5 and Figure 25. It seems rather obvious that mud would have low rugosity compared to coral-dominated areas.

P20. The background text on remote sensing at bottom half of the page and the first paragraph of the next is not results, and is of limited value. If it is included in the report it could go in the introduction or methods, but not here.

P21. I don't agree with the final sentence. The remote sensing could distinguish corals from sediment, but could not discern the amount of coral very well. It provides no information on species composition, The transects provided far more information, with much greater precision.

P22, last para. It would be useful to standardize units of area and tabulate the figures that are scattered around the report. The numbers provided here don't match those on p8. Presumably this is because here we're looking at the area to be dredged, not the "study area". What is the total area of live coral that will be dredged?

P23. See comment about "coral stress" on p10. The material after the heading is not results, and neither is Figure 34. It would be better place in an Introduction.

P24. The results start in the 3rd last paragraph. Why was a 2-way ANOVA not done to separate out the differences (shown in Figure 35) between species and habitat separately? It don't find it surprising that two species and shallow versus deeper reefs would show a difference in spectral reflectances. I'm not sure what the purpose of these measurements was – to test for differences in reflectance among species and depths? Why?

Figure 34 is more or less redundant with Table 8.

P25. This is introduction and methods, not results. Given the small size of the photo-transect relative to the larger corals, and the extent of asexual fragmentation in all of the common corals examined, this section is rather weak. Again, the objective of measuring colony sizes is unclear.

P26. Figure x should be 37. The sample sizes in each size class are quite small, which is presumably the reason why there are no statistical analyses.

P27. As noted above for p12, the information on sediment composition is minimal. Without data on grain size, organic content, bathymetry of sediment, and hydrodynamic information (currents, wave height), the limited information provided here can shed very little light on predicting the extent of transport and damage from sediment re-suspended by the dredging. The 200m buffer zone appears to be a guess, and may be too small. The inference seems to be that a high carbonate fraction will limit the impact of re-suspension, which is not supported by the information in the report.

Figure 39 should be in the Methods.

Figure 40. The Y-axis originates at 75%, making the differences between samples appear larger than they really are.

CONCLUSIONS

The conclusions are very brief (2 pp). Some discussion material scattered through the results section could be moved here to improve the structure of the report.

P28, line 4. "metric" is vague.

P28, 2nd paara. Describing the area as "an algal reef" is not particularly accurate or useful. Much of the area is soft sediment, not reef. The hard substrate was created by corals, not macro-algae, so in that sense they are coral reefs. *Halimeda* mounds on soft sediments are sometimes referred to as algal reefs in the literature. Certainly, macroalgal cover on the reef "flat" and slopes is high, but so too is coral cover in numerous locations. The reefs can justifiably be regarded as human-impacted. Coral species richness is low, and the high cover of macro-algae points to high nutrient levels and overfishing of herbivores. Nonetheless, Figure 18 shows that about one-third of transects have more than 30% coral cover. That's more than many reefs around the world.

P28, final para. This text on remote sensing repeats the material on p20.

P29, 2nd para. I don't find the argument here very convincing. Remote sensing added very little information to the current study since it cannot distinguish levels of coral cover or say anything about coral or macroalgal composition.

From: Tim Cooper [mailto:t.cooper@aims.gov.au]
Sent: Friday, August 21, 2009 6:39 PM
To: Jameson, Stephen C CIV NAVFAC Pacific, EV2
Cc: Hesse, JT T CIV NAVFAC PAC, EV2
Subject: RE: US Navy - Guam CVN - Paid Peer Review Request

Dear Stephen,
Please find attached the amended review incorporating a discussion on ecosystem function - my apologies for the blurb on ecosystem health... Although I have adjusted the commentary, it doesn't really change my thoughts on how disturbances to an ecosystem should be measured; as I think the IBI approach forces people to take a wider view of the processes operating within an ecosystem rather than approaching an environmental assessment whilst wearing 'blinkers'.

I hope you find these thoughts useful.

Kind regards,
Tim

-----Original Message-----
From: Jameson, Stephen C CIV NAVFAC Pacific, EV2
[mailto:stephen.jameson@navy.mil]
Sent: Tuesday, 18 August 2009 06:36 AM
To: Tim Cooper
Cc: Hesse, JT T CIV NAVFAC PAC, EV2
Subject: RE: US Navy - Guam CVN - Paid Peer Review Request

Aloha Tim,

As a follow-up to your comments.

Could you please address question #5 on the definition of "function", without interpreting function to mean "health"?

Please incorporate your new answer into the revised PDF and return the entire set of comments to me.

Thanks!

Best regards,

Dr. Stephen C. Jameson
Naval Facilities Engineering Command Pacific (EV21)
258 Makalapa Dr. Suite 100
Pearl Harbor, HI 96860-3134
Office: 808-472-1602, Fax: 808-474-5419
Email: stephen.jameson@navy.mil
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-----Original Message-----
From: Tim Cooper [mailto:t.cooper@aims.gov.au]
Sent: Sunday, August 16, 2009 18:06
To: Jameson, Stephen C CIV NAVFAC Pacific, EV2
Cc: Hesse, JT T CIV NAVFAC PAC, EV2
Subject: RE: US Navy - Guam CVN - Paid Peer Review Request

Dear Stephen,
Please find attached my review of the report on benthic habitats in Apra Harbour. I found it to be comprehensive and well designed, and it should provide a sound basis for the development of future monitoring programs in Apra Harbour. I think the authors have done a good job within the guidelines that were provided to them. I hope you find this review useful?

As an aside, I would be grateful if you kept me in mind for any Porites lutea colonies that might be in the direct footprint of either option, and hence removed from the reef during any dredging operations. Even dead, these corals contain a wealth of historical environmental information in their skeletons and an analyses of their growth records could make for a nice collaborative study between AIMS and the US Navy?

Kind regards,
Tim

~~~~~~
Dr Tim Cooper
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-----Original Message-----
From: Jameson, Stephen C CIV NAVFAC Pacific, EV2
[mailto:stephen.jameson@navy.mil]
Sent: Saturday, 8 August 2009 02:20 AM
To: Tim Cooper
Cc: Hesse, JT T CIV NAVFAC PAC, EV2; Pepi, Vanessa E CIV NAVFAC PAC ;
Rosen, Liane K CIV NAVFAC PAC
Subject: US Navy - Guam CVN - Paid Peer Review Request

Aloha Tim,

I am trying to gather some independent peer reviews of:

"Assessment of benthic community structure in the vicinity of the proposed turning basin and berthing area for carrier vessels nuclear (CVN) Apra Harbor, Guam".

The US Navy is willing to pay $500 for your review. The paper, which is an interesting and easy read, can be downloaded at:

ftp://ftp.soest.hawaii.edu/hochberg/
~~~~~~

Below is a list of questions we would need answered as part of the review (by 21 August, 2009).

Any other appropriate comments on the marine assessment would also be welcome.

After receiving your review (via email to me, with a copy to JT Hesse), the US Navy will send you payment. Please provide the mailing address where you would like the payment sent, in your review email, and JT Hesse (jeffrey.hesse@navy.mil) will arrange payment.

* Please drop me an email (with a copy to jeffrey.hesse@navy.mil) to confirm you can accomplish this review by the 21 August deadline.

Thank you very much for your assistance in this peer review process.

Questions

1. Do the methods used in this study provide data to make reasonable conclusions about the status of the coral reef habitat under study?

2. Does the accuracy rate for the remote sensing map created from sea-truth data meet scientific rigor for acceptance as a viable means for extrapolation to the greater area?

3. Do the methods used have the capability to provide replicate data that is testable for ensuring valid and unbiased results?

4. Do the results of this report represent a reasonable and cost effective characterization of the affected coral reef habitat?

5. How would you define and measure coral reef ecosystem function?

6. Would application of the data derived from this study provide the necessary input to a habitat equivalency analysis (HEA) model to meet accepted scientific standards for assessing direct physical impacts (dredging) to coral reefs?

Best regards,

Dr. Stephen C. Jameson
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Review of *Assessment of benthic community structure in the vicinity of the proposed turning basin and berthing area for carrier vessels nuclear (CVN) Apra Harbor, Guam*

General comments

This report provides a qualitative and quantitative preliminary assessment of the benthic habitats that would be affected by proposed dredging operations to facilitate a turning basin for US Navy vessels in Apra Harbour, Guam. The study represents a significant amount of work that achieves the stated criteria of "using the most efficient techniques in the limited time available" to gain a preliminary insight to the benthic communities that would be affected by the proposed development. Moreover, the authors state on several occasions that this study is not intended to provide the basis of any long-term monitoring program, rather the objective is to provide data that will guide the process of developing a scientifically robust long-term monitoring program. The report is well written, uses appropriate statistical analyses and incorporates remote sensing data to assist with the experimental designs and the development of a habitat map for Apra Harbour. In this regard, the authors should be complimented for the use of data available at remote sensing scales to drive the design of the fine-scale field surveys of benthic habitat classification and validate inputs of the spatial habitat map.

Specific comments

As stated above, this is a comprehensive first assessment of benthic habitats in Apra Harbour. I have only minor quibbles relating to the use of (i) unconventional bioindicators and (ii) sampling design.

(i) Monitoring programs frequently use responses of biotic parameters to examine effects of disturbances on organisms and/or assemblages. As described, the main disturbances to benthic communities in Apra Harbour will be as a result of direct physical disturbance due to dredging operations; and indirect effects of changes in water quality due to resuspended sediments, e.g. increased sedimentation, turbidity and light attenuation and the potential for remobilization of any contaminants contained within the sediments. Issues associated with the consequences of sediment quality, e.g. exposure to heavy metals and/or other pollutants associated with the terrigenous sediments, were not provided in the report nor are they considered further in this review. A wide range of bioindicators are available for the use in the assessments of disturbances on coral reefs. A total of five bioindicators were used here: community structure (based on field surveys and remote sensing data), coral pigments measured by spectral reflectance to calculate a Normalised Difference Vegetation Index (NDVI), coral demography, abundance and composition of other invertebrates, and sediment analyses. Most of these measures have been used widely in the scientific literature to measure stress responses of corals to various disturbances including changes in water quality. Whilst it is acknowledged that the authors have considerable expertise using spectral reflectance measurements on zooxanthellate corals, a search of the scientific literature did not yield any information on the validity or applicability of the NDVI to zooxanthellate corals. There are more conventional sublethal measures such as chlorophyll fluorescence that can be used to provide a rapid assessment of coral physiological performance and these should be considered in any future environmental assessments at Apra Harbour. Related to this, I disagree with the statement at the end of the first paragraph on Page 25. There are many studies to show that increases in pigment concentrations and zooxanthellae density are in fact a negative response to exposure to nutrients (nitrogen and phosphorus; e.g. see studies by Hoegh-Guldberg and Smith 1989; Stambler et al 1991, 1994) in addition to the well known physiological responses to changes in irradiance. Clearly, the NDVI needs to be interpreted cautiously until further studies are completed and presented in the literature.

(ii) Validation of the responses of potential coral bioindicators with logically constructed experiments, and field sampling programs, is required to ensure that they are actually demonstrating a response to the disturbance in question. Measuring and validating such responses is, however, a complex process given the natural spatial and temporal variability inherent in biological systems. Notwithstanding this, it is now clear that sampling at a range of spatial and temporal scales is an appropriate way to measure environmental responses (e.g. Green 1979; Stewart-Oaten et al. 1986). In addition to the guidelines for long term monitoring provided by the US EPA, the use of Before/After/Control/Impact (BACI) sampling designs described by Underwood (1991) should also be considered in any attempts to measure the ecological effects of the proposed development in Apra Harbour. This approach allows comparisons of estimates of the response variability at disturbed areas with natural variability at reference areas, which have not been affected by the disturbance. If, following a disturbance, the response measure at the disturbed area differs in some way from the variability measured at reference areas, then it can be assumed that the response was due to the disturbance.

Specific questions

1. Do the methods used in this study provide data to make reasonable conclusions about the status of the coral reef habitat under study?

This study uses an innovative approach by combining conventional field surveys with information available from remote sensing techniques. The use of photo quadrats/transects within a random stratified design are widely accepted in the literature, scientifically robust and appropriate for making an assessment of the coral reef in Apra Harbour.

2. Does the accuracy rate for the remote sensing map created from sea-truth data meet scientific rigor for acceptance as a viable means for extrapolation to the greater area?

In absence of any regional context, it is uncertain whether the accuracy rate from the remote sensing community structure analyses is sufficient to provide a valid extrapolation for the greater area. My feeling is that it most likely would be acceptable for extrapolation but this could be tested simply by initiating field surveys at appropriate reference locations and then running blind comparisons of the human classification versus the model generated using remote sensing data.

3. Do the methods used have the capability to provide replicate data that is testable for ensuring valid and unbiased results?

The methods used will provide replicated data that can be analysed with uni- and multi-variate statistical techniques, such as those used the current study. The main criticism of the study, which must be addressed during any monitoring studies (see above comments on 'Beyond BACI' sampling designs) is that the results are not placed into any spatial or temporal context. For example, are these patterns consistent throughout the year; is the abundance of macroalgae seasonal being greater in warmer months and lower at other times of the year; how representative are these habitats of other coral reefs around Guam? It seems that there are other marinas with fringing coral reefs to the north of the study area. These could have been sampled to determine how representative the communities inside Apra Harbour are compared with benthic communities adjacent to other boating/shipping facilities at Guam?

4. Do the results of this report represent a reasonable and cost effective characterization of the affected coral reef habitat?

The study has used an entirely appropriate sampling design to characterise the benthic habitats that would be potentially impacted by the proposed development. The use of remote sensing imagery to fine-tune the stratified sampling design is innovative and it is considered that the study represents a reasonable and cost effective preliminary assessment of benthic habitats in Apra Harbour.

5. How would you define and measure coral reef ecosystem function?

Ecosystem function can be defined as the interactions between biota and processes that operate within an ecosystem such as disturbance and nutrient cycling. Controls on ecosystem function include bottom-up factors whereby changes to the nutrient supply of primary producers have important influences on how an ecosystem functions. For example, increases in primary production due to elevated nutrient supply will result in changes at higher trophic levels due to increased availability of food. On the other hand, top-down controls on ecosystem function is a contrasting theory. Here, predation by higher trophic levels on lower trophic levels is considered to have important controls on ecosystem function. For example, an increase in herbivores will lead to a decrease in primary producers. Since bottom-up and top-down factors are thought to operate simultaneously within biological systems (perhaps interactive or synergistic), measuring ecosystem function is likely to be a complex process. Bioindicator responses to bottom-up controls will be strongest at the primary-producer level whereas the opposite is most likely true for top-down responses, which should show the strongest responses at higher trophic levels.

Information on the condition and performance of ecosystems is essential for the management of any natural resource. It will be necessary to understand the relative contribution of bottom-up and top-down controls to predict any ecological responses under changing environmental conditions such as those that might occur in Apra Harbour during the proposed dredging operations. Examples of exactly how this might be done are sparse in the literature. I would recommend the approach suggested by Jameson et al. (2001) who described the value of using a multimetric index; known as the Index of Biotic Integrity (IBI), through the combination of information from different components of the coral reef ecosystem (e.g. sessile epibenthos, benthic macroinvertebrates, fish, marine vegetation, phytoplankton and zooplankton), to produce an environmental score that can be used to communicate information about the condition of coral reefs to resource managers. It is becoming increasingly clear that a composite of bioindicators applied in an integrated framework of assessment resulting in a numerical index (such as the IBI) for a coral reef will provide resource managers with an understanding of the effectiveness of mitigative strategies to improve water quality. The data resulting from any long-term monitoring at Apra Harbour may be amenable to the development of such an IBI provided that the final choice of bioindicators actually respond specifically to changes in water quality and not some other disturbance.

6. Would application of the data derived from this study provide the necessary input to a habitat equivalency analysis (HEA) model to meet accepted scientific standards for assessing direct physical impacts (dredging) to coral reefs?

It is considered that the remote sensing techniques and associated analysis of benthic habitats potentially affected by either development option, i.e. Polaris Point or SRF, would provide sufficient data to undertake a meaningful HEA on the coral reefs of Guam.

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-----Original Message-----
From: Gregor Hodgson [mailto:gregorh@reefcheck.org]
Sent: Thursday, September 03, 2009 21:25
To: Jameson, Stephen C CIV NAVFAC Pacific, EV2
Cc: Hesse, JT T CIV NAVFAC PAC, EV2
Subject: RE: [Spam-Filter] RE: US Navy - Guam CVN - Paid Peer Review Request

Stephen,

There is obviously some latitude in the interpretation of this method that was designed for terrestrial habitats and feel free to interpret this how you like. However the bottom line is that damage compensation is designed to cover both loss of actual habitat AND the services provided including ALL those provided by the animals living there. Just to take one example the fact that a single parrot fish can produce one ton of sand per year is a rather important service. HEA is simply a tool and the tool needs to include a mechanism to restore/pay for ALL loses including in the case of the Guam situation fish. There are a variety of examples of how not including e.g.
fish will result in problems.

If we don't know how many fish are living there to begin with then how can you calculate how much habitat of a given type that you need to restore/pay for? Different types of reef will support different populations of fish and on the other hand the client could end up paying for more than they should if certain assumptions are made. This is not a straight line relationship.
Many of the fish will be found off the reefs but are associated with the reefs, so the calculation will be skewed to underestimate the damage if we only count e.g. the fish living on the reef. Because of the length of time it takes for fish to reproduce, recruit and grow and mature, simply creating an equivalent habitat (reef) of a certain type does not guarantee that the new habitat will include the fish populations that were originally found at the damaged site. To recreate equivalent fish populations you may require ecosystem features found offsite. You cant assume a certain habitat will produce a certain biota.

I offer a NOAA document that may put this into perspective. Perhaps HEA is not the best way to try to capture all this type of info?

Best,
Greg

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Habitat Equivalency Analysis: An Overview

Damage Assessment and Restoration Program
National Oceanic and Atmospheric Administration
Department of Commerce

March 21, 1995
(Revised October 4, 2000 and May 23, 2006)

1. Introduction

1.1 Goals of the paper

Natural resource trustees are authorized to act on behalf of the public to protect the resources of the nation's environment. Serving as a trustee for coastal and marine resources, NOAA determines the damage claims to be filed against parties responsible for injuries to natural resources resulting from discharges of oil, releases of hazardous substances, or physical injury such as vessel groundings.[1] Habitat equivalency analysis (HEA) is a methodology used to determine compensation for such resource injuries. The principal concept underlying the method is that the public can be compensated for past losses of habitat resources through habitat replacement projects providing additional resources of the same type. Natural resource trustees have employed HEA for groundings, spills and hazardous waste sites. Habitats involved in these analyses include seagrasses, coral reefs, tidal wetlands, salmon streams, and estuarine soft-bottom sediments.

The goals of this paper are to present an overview of HEA and illustrate the method with a simple, hypothetical example. In section 1.2 below, we outline briefly the natural resource damage context for HEA applications and the conditions for use of HEA. An example of how HEA is used to estimate the appropriate level of compensation for injuries to natural resources is presented in section 2. Appendices A through C present an algebraic representation of the HEA calculations and provide detailed tables from the example.

[1] The Under Secretary for Oceans and Atmosphere (NOAA Administrator) acts on behalf of the Secretary of Commerce as a Federal trustee for natural resources under the Comprehensive Environmental Response, Compensation, and Liability Act ("CERCLA"; 42 U.S.C. § 9601 *et seq.*), the Clean Water Act (33 U.S.C. § 1251 *et seq.*) , the National Marine Sanctuaries Act (16 U.S.C. § 1431 *et seq.*), and the 1990 Oil Pollution Act ("OPA"; 33 U.S.C. § 2701 *et seq.*).

1.2 Use of HEA in natural resource damage assessments

Natural resource damage claims have three basic components: (1) the cost of restoring [2] the injured resources to baseline, or "primary restoration," (2) compensation for the interim loss of resources from the time of injury until the resources recover to baseline *plus* (3) the reasonable costs of performing the damage assessment.[3] Following statutory requirements, all recovered damages are used to restore, replace, rehabilitate or acquire the equivalent of the injured resources (or to cover the costs of assessments). Consequently, recoveries for interim losses are spent on "compensatory restoration" actions providing resources and services equivalent to those lost. To ensure full compensation for interim losses, the trustees determine the scale of the proposed compensatory restoration actions for which the gains provided by the actions equal the losses due to the injury. The damage claim then is the cost of implementing the selected primary and compensatory restoration actions (plus the costs of the assessment) or alternatively, the responsible parties may be allowed to implement the projects themselves, subject to performance criteria established by the trustees. To develop the restoration plan, trustees must determine and quantify injury, develop restoration alternatives that consist of primary and compensatory actions, scale restoration alternatives, and select a preferred restoration alternative. This paper examines a method for scaling restoration alternatives, HEA.[4]

For compensatory restoration actions, the scaling question is: what scale of compensatory restoration action will compensate for the interim loss of natural resources and services from the time of the incident until full recovery of the resources? The scale of compensatory restoration actions is conditional upon the choice of primary restoration actions. Consequently, for each

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[2] Restoration refers to human actions taken after the removal of the cause of injury (e.g., after remediation of a hazardous waste site, removal of the vessel in the event of a grounding), to return an injured resource to its pre-injury conditions. We use the term in its broad sense, to encompass the statutory concepts of "restoration, rehabilitation, replacement, and/or acquisition of the equivalent" of the injured resources.

[3] At any point in time, baseline refers to the condition of the natural resources and services that would have existed had the incident not occurred. If the resources are not expected to recover fully, interim losses will be calculated in perpetuity.

[4] This description characterizes the process outlined in the natural resource damage assessment (NRDA) regulations implementing OPA (15 CFR Part 990) and in the proposed statutory changes to the CERCLA NRDA provisions (43 CFR Part 11).

restoration alternative under consideration, the type and scale of the primary restoration actions are to be identified first.[5] Then the compensatory components of restoration alternatives can be scaled.

The process of scaling a project involves adjusting the size of a restoration action to ensure that the present discounted value of project gains equals the present discounted value of interim losses. There are two major scaling approaches: the valuation approach and the simplified service-to-service approach, which applies under certain conditions.

HEA is an example of the service-to-service approach to scaling. The implicit assumption of HEA is that the public is willing to accept a one-to-one trade-off between a unit of lost habitat services and a unit of restoration project services (i.e. the public equally values a unit of services at the injury site and the restoration site).[6] HEA does not necessarily assume a one-to-one trade-off in resources, but instead in the services they provide. Consider a marsh as the resource and primary productivity a resource service. Suppose the replacement project provides only 50 percent of the productivity per acre of marsh as the injured site would have provided, but-for the injury. In order to restore the equivalent of lost productivity per year, then, the replacement project requires twice as many acres of marsh. Habitat equivalency analysis is applicable so long as the services provided are comparable.

The assumption of comparable services between the lost and restored habitats may be met when, in the judgment of the trustees, the proposed restoration action provides services of the same type and quality, and of comparable value as those lost due to injury. In this context, there is a one-to-one tradeoff between the resource services at the compensatory restoration site and the injury site. Therefore, the scaling analysis simplifies to determining the scale of a restoration action that provides a quantity of discounted replacement services equal to the quantity of discounted services lost due to the injury.

In cases where services at the compensatory restoration site are not of the same type and quality or of comparable value to those injured, then the assumption of a one-to-one trade-off between the resources at the injury site and the compensatory restoration site may be

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[5] This includes identifying the recovery trajectory from primary restoration.

[6] The concept of services refers to functions a resource serves for other resources and for humans. For example, a wetland habitat may provide on-site ecological services such as faunal food and shelter, sediment stabilization, nutrient cycling, and primary production. Off-site services may include commercial and/or recreational fishing, bird watching along the flyway, water quality improvements due to on-site water filtration, and storm protection for on-

inappropriate. In these cases, NOAA recommends that trustees evaluate whether the conditions for HEA are met and consider using the valuation approach as an alternative to determining the trade-off between injuries and compensatory restoration actions.

Necessary conditions for the applicability of HEA include that (1) a common metric (or indicator) can be defined for natural resource services that captures the level of services provided by the habitats and captures any significant differences in the quantities and qualities of services provided by injury and replacement habitats, and (2) the changes in resources and services (due to the injury and the replacement project) are sufficiently small that the value per unit of service is independent of the changes in service levels. [7] When choosing a metric to evaluate the quantity and quality of services provided per unit of habitat, the trustees should examine the *capacity*, *opportunity* and the *payoff* (*i.e.* benefits) of the services being provided as well as *equity* issues involved with the potential compensation projects (*i.e.* who loses and who gains as a result of the injury and the potential compensation projects). *On-site biophysical* characteristics (e.g., soil, vegetative cover, and hydrology) affect the *capacity* of an ecosystem to provide ecological and human services. *Landscape context* affects whether the ecosystem will have the *opportunity* to supply many of the ecological and human services and strongly influences whether humans will value the opportunities for services.[8]

Consider, for example, the wetland function of sediment trapping. A wetland's capacity to provide this function depends on such factors as slope and vegetative cover. The opportunity for the wetland to trap sediments depends on the expected flow of sediments from adjacent land, which will depend upon types of upland land uses (i.e., landscape context). The total value generated from water quality improvements due to sediment trapping will depend upon the uses

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shore properties due to the creation of wave breaks. Human services include both use and non-use services, so the HEA approach measures and accounts for non-use services in the damage claim.

[7] A counterexample shows when this condition is not satisfied. Consider the value of harvesting another salmon when salmon are in abundant supply versus the value of another salmon when the harvest has failed in Alaska. The value of providing another pound of salmon may be substantially greater when the salmon are in scarce supply, all else equal.

[8] For a further discussion of these issues, see, *Scaling Compensatory Restoration Actions, Guidance Document for Natural Resource Damage Assessment Under the Oil Pollution Act of 1990,* National Oceanic and Atmospheric Administration, Damage Assessment and Restoration Program, 1997 and King, Dennis M., *Comparing Ecosystem Services and Values*, Report prepared for the National Oceanic and Atmospheric Administration, Damage Assessment and Restoration Program, January 1997.

of the affected downstream water bodies: the value will be greater if there are nearby shellfish beds and finfish spawning areas than if the water flows into a fast-moving river.

The choice of a metric to characterize services is essential to determining whether HEA is applicable in a given context. On-site ecological attributes, such as stem density, canopy structure (density multiplied by height), or fish density, are sometimes used as a proxy for services; however, they are primarily indicators of *capacity*. It is critical to evaluate the role of landscape context to evaluate the *opportunity* to provide off-site, as well as on-site, ecological and human services.

2. Habitat Equivalency Analysis: An Example

In this section we provide a simplified example to illustrate the method. To complement the example, we provide the algebraic formula for solving an HEA in Appendix A.

We construct the following hypothetical scenario.[9] A heavy fuel oil released from a grounded tanker covered 20 acres of marsh composed primarily of smooth cordgrass (*Spartina alterniflora*) in 2000. The oil smothered significant portions of the marsh, penetrating the sediments in many areas and killing much of the biota. This injury impairs the function of the marsh habitat; the marsh provides food and shelter for animals, water quality improvements for downstream resources, shoreline stabilization and other natural resource services. In addition, the loss of marsh affects human services. For example, marsh habitat supports off-site human services through the production of fish that provide recreational and commercial services and through nutrient filtration that provides water quality enhancement.

Trustees identified a feasible restoration action for compensation: transplanting *Spartina alterniflora* at the injury site for primary restoration and transplanting *Spartina alterniflora* along with some minor regrading at a nearby site. The projects are expected to restore the same type and quality of resources and services. Further, given the similar landscape context of the injury and restoration sites, the trustees judged the projects would restore resources and services of comparable value as those lost.

[9] The size and the description of the hypothetical injury are not based on actual events and have been chosen simply to demonstrate the HEA calculation.

Under these conditions, HEA applies as a framework for scaling compensatory restoration. The basic steps for implementation include:

1. Document and estimate the duration and extent of injury, from the time of injury until the resource recovers to baseline, or possibly to a maximum level below baseline;
2. Document and estimate the services provided by the compensatory project, over the full life of the habitat;
3. Calculate the size of the replacement project for which the total increase in services provided by the replacement project equals the total interim loss of services due to the injury; and
4. Calculate the costs of the replacement project, or specify the performance standards in cases where the responsible party will be implementing the compensatory habitat project.

In the first two steps, trustees must specify numerical values for ecological parameters for both the injured site and the compensatory project site. For each point in time at both sites, the level of services must be characterized as a percent of the baseline level of services at the injured site. As previously noted, the baseline of services is the level of services that would have been provided at the injured site *but for* the injury. In our example, we assume that local experts consider grass shrimp (*Palaemonetes pugio*) to be a very important (or key) species in this habitat and they believe that the presence of grass shrimp is highly correlated with many services provided by the marsh. The presence and density of grass shrimp may indicate the general health of the marsh vegetation and the availability of food for higher trophic levels. Therefore, we assume that service levels for the injured site and for the compensatory project site are a function of the baseline mean density of grass shrimp in the marsh. Studies indicate that the spill reduced the mean density of grass shrimp by approximately 50%. Using the mean density of grass shrimp as a metric for marsh services, we assume that the service level of the injured marsh prior to any restoration actions is 50% of its baseline service level. [10]

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[10] Depending on the exact nature and extent of an injury, the mean density of grass shrimp relative to the baseline density may or may not serve as a good metric for the services provided by the marsh. Additional potential indicators of marsh services might include macrofaunal abundance, fish utilization, vegetative density and percent vegetative cover.

In step three, we calculate the size of the compensatory project for which the total increase in services provided by the replacement project just equals the total interim loss of services due to the injury. Because losses and gains are occurring in different years, we discount the losses and gains so that units reflect what they are worth in the present year, 2000. This makes units from different time periods comparable. The discount rate incorporates the standard economic assumptions that people place a greater value on having resources available in the present than on having their availability delayed until the future. This process is analogous to financial calculations where, if a dollar is put into the bank today at 3% interest, there will be $1.03 in one year. A person is willing to deposit money in such an interest bearing account only if having $1.03 is (at least) as good as having $1 today. There are a variety of discounting approaches, but mean accounting was applied in the example in this document. Mean accounting involves taking the arithmetic mean of service levels at the beginning and end of each period and crediting that resulting service level as accruing at the midpoint of the period.

The annual discount rate used in a HEA calculation represents the public's preference towards having a restoration project in the present year, rather than waiting until next year. The economics literature supports a discount rate of approximately 3%. [11]

We list below the parameters necessary to complete a simple HEA.

Injured Area Parameters:

- Baseline level of services at the injury site;
- Extent and nature of the injury: the spatial extent of injury (in acres for example) and the initial reduction in service level from baseline at the injured site (characterized as a percent of the baseline level of services). These parameters may be combined to measure the "service-acres" of an injury; [12]

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[11] For a further discussion of discounting see: National Oceanic and Atmospheric Administration (1999) *Discounting and the Treatment of Uncertainty in Natural Resource Damage Assessment*. Damage Assessment and Restoration Program, Damage Assessment Center, Resource Valuation Branch. Technical Paper 99-1. Silver Spring, MD, February.

[12] Service-acres may be illustrated with an example. If 30% services remain on an injured 100 acre site, the injury totals 70 service-acres (100 * (1-0.3) = 70). Note that the percent is represented by its decimal equivalent.

- Injury recovery function (with primary restoration or natural recovery): the rate of (incremental) service recovery and the maximum level of services to be achieved (characterized as a percent of the baseline level of services);
- Recovery period for injured resources: the dates when recovery starts and when maximum level of services will be achieved.

Replacement Area Parameters:

- Initial level of services at the replacement project site, measured as a percent of baseline services at injury site;
- Replacement project maturity function: the rate of (incremental) service growth and the maximum level of services at the replacement project site (as a percent of the baseline level of services at injury site);
- Maturity period for replacement resources: the dates when services begin to increase and when the maximum level of services will be achieved;
- Replacement/creation project duration: lifetime of increased services.

Discount Rate

- Annual real discount rate

In the following section, we walk through the each of the steps and show how ecological parameters are developed from the injury and how the HEA equation is solved.

Step 1: Quantifying the losses from the injury. For our example, parameter values characterizing the injury are listed in the table below. As shown, we denote the injury to 20 acres of marsh function by specifying that, after injury, 20 acres provide 50% of the services relative to baseline at the time of the injury (2000). The site is projected to maintain a 50% service level until the primary restoration project (transplanting *Spartina alterniflora* at the injury site) is completed in 2001. The injured area is then projected to recover in eight years following a linear growth path to baseline.[13]

Table 1: Injury Parameter Values

Baseline Information of the Injured Resource:	
Habitat type injured:	Marsh
Year of injury	2000
# of injured acres:	20
Level of services in injury year (relative to baseline services):	50%
Recovery of Injured Habitat following Primary Restoration:	
Year restoration project ends and recovery starts:	2002
Years until full recovery:	8
Services at maximum recovery (relative to baseline):	100%
Shape of recovery function:	Linear
Discount Rate:	
Real annual discount rate	3.0%

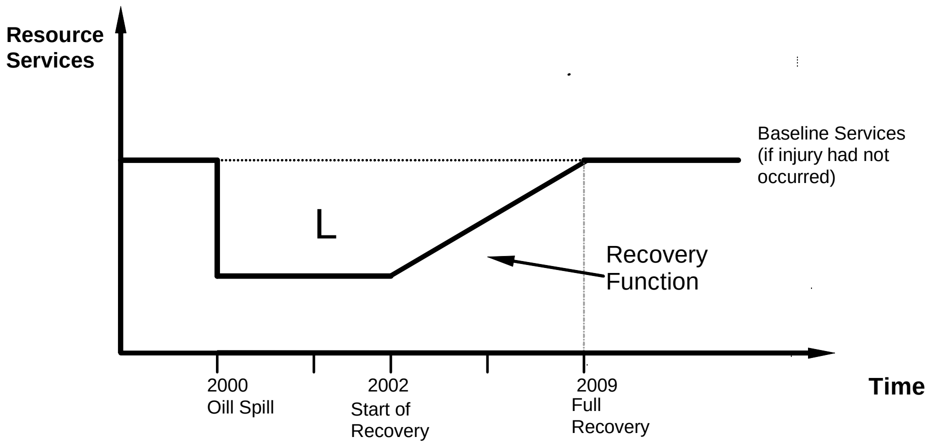
The recovery of services provided by the injured habitat is illustrated in Figure 1. On the vertical axis is the level of services provided by the injured resource, measured in "service-acres". The service-acres for a given year are calculated as the product of the percent of baseline marsh services provided by an acre of the injured site multiplied by the number of acres injured.[14] When the injury occurs, in year 2000, the number of service-acres drops from 20 to 10, because 50% services remain at the site. Services increase along a linear path beginning in 2002, until full recovery to the baseline at the end of 2009. Interim losses are represented in the diagram by the area labeled "L".

[13] The length and shape of the recovery function are chosen in order to simplify the presentation. An alternative recovery function, such as a constant growth rate or other non-linear growth path, and an alternative length of recovery, could be chosen if applicable to the injured resource.

[14] In the multiplication, the percent is represented by the decimal equivalent, so the baseline level of acres is (1.00*20)=20. In 2005, the site is projected to operate at 75% of baseline, so the effective service level is

Figure 1:

Resource Service Levels at the Injury Site



To calculate the measure of interim loss in present value terms, we must apply the yearly discount factor to the losses in each year. We calculate an interim loss of 55.106 discounted service-acre-years by summing over all years of the injury. Appendix B presents the specific steps for calculating the discounted interim loss in services.

Step 2: Quantifying the gains from the habitat replacement project. The parameters characterizing the habitat creation project are listed in the table below. Prior to the compensation project, the nearby site offers 25% marsh services relative to the pre-injured marsh site. Service flows from compensation project commence when the project is completed in 2002. We project that marsh services increase during a 10-year growth period along a linear path and reach a maximum service level equal to 100% of the baseline service level of the injured site. We further project that the site will continue to function at the maximum service level in perpetuity.

((1-.75) * 20) = 5.

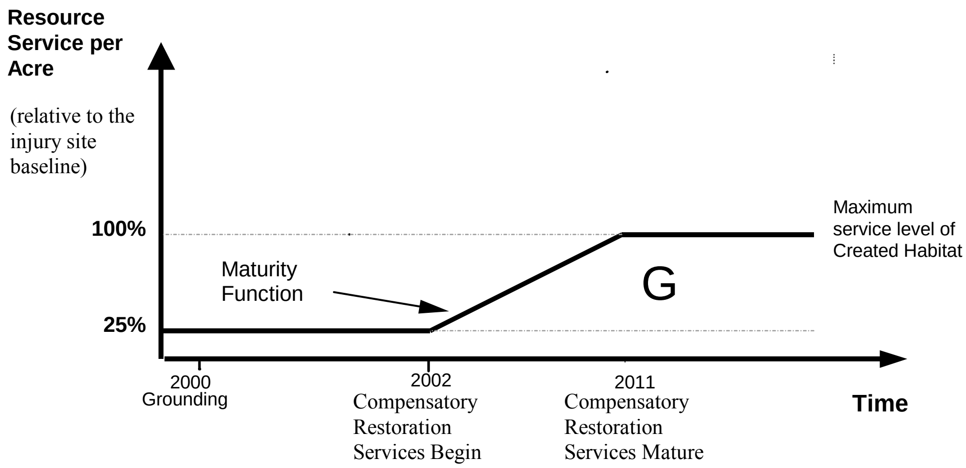
Table 2. Replacement Project Parameters

Replacement Project Characteristics:	
Replacement habitat type:	Marsh
Initial level of services	25%
Year creation/replacement project starts	2001
Year services start increasing	2002
Year in which maximum service level is reached (end of period)	2011
Maximum service level	100%
Shape of recovery function	Linear
Expected length of service increase	Infinity
Replacement Project Comparison Parameter:	
Ratio of maximum services per acre at the compensatory site and the baseline services per acre at injured habitat.	1:1

The increase of services at the habitat creation site is illustrated in Figure 2. The vertical axis measures the services per acre of a replacement project as a percent of the baseline services per acre at the *injured site*. As shown, services begin at 25% and start increasing in 2002, following a linear path until the services reach full maturity in 2011. The services continue to function at the maximum level in perpetuity. The total increase or gain in services per acre, is shown as area "G", which is the area between the maturity function and the 25% service level.

Figure 2:

Resource Service Levels at Replacement Project Site



To calculate service gains in the present value terms, we must apply the yearly discount factor to the gains in each year and sum over the lifetime of the replacement project. This calculation, presented in more detail in Appendix C, indicates that each acre of replacement project provides 21.015 discounted service-acre-years.

Step 3: Determining the Size of the Replacement Project. To determine the size of the compensatory project needed to compensate for the losses, we divide the total loss in discounted service-acre-years by the gain per acre of replacement and get 2.62 acres, as outlined in Table 3.

***Table 3.* Determining the Size of a Project to Compensate for Interim Losses**

- Injured Area = **20** acres

Present discounted interim losses = **55.106** service-acre-years (See Appendix B)

- Present discounted lifetime gains per acre of replacement project = **21.015** service-acre-years per acre (See Appendix C)
- Let **R** = # replacement habitat acres required for compensation.
- Equating lost services and replacement project gains:

  55.106 lost service-acre-years = **21.015** service-acre-years/ acre * **R** acres
- *Solving for the size R of the replacement project yields:*

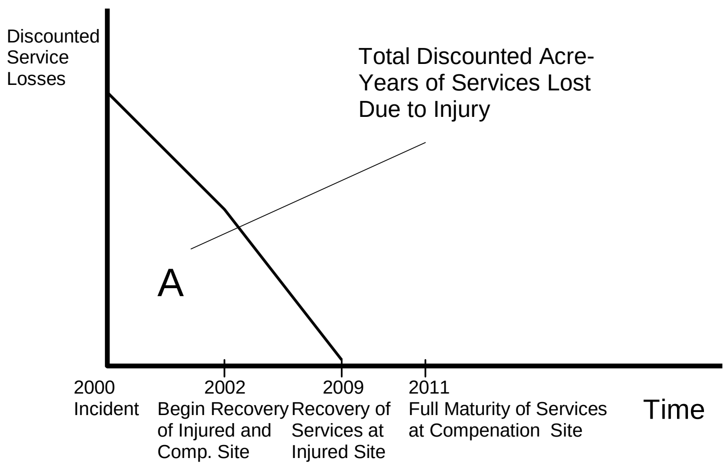
  R = 55.106/21.015

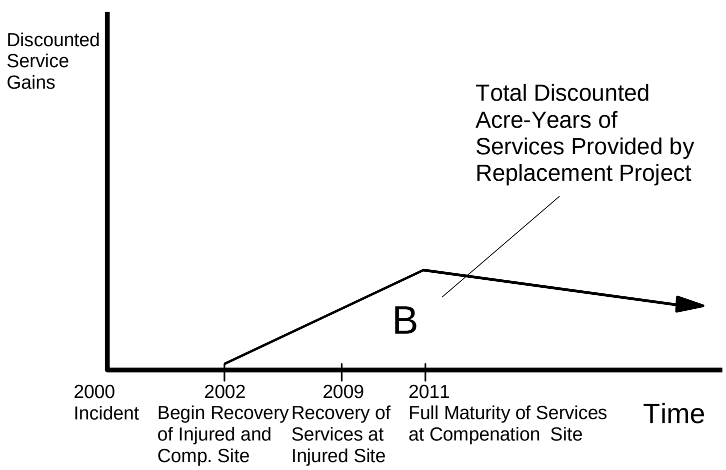
  = **2.62** acres of replacement habitat

The top graph in Figure 3 illustrates the discounted service losses resulting from the injury and the bottom graph illustrates the discounted service gains resulting from the replacement project. At the time of the incident, 2000, service losses occur and, although recovery doesn't start until the year restoration is completed in 2002, the value of future losses decreases in the year 2001 because the losses are discounted. The discounted losses reach zero in the year 2009, when the recovery of services at the injured site is complete. The total discounted service losses are equal to area "A" in the top graph.

The replacement project begins providing service gains in the year 2002, the year the compensation project is completed. In 2011, the compensation project reaches maturity and continues providing services at the same level in perpetuity. However, the value of these services declines over time, eventually approaching a value very close to zero (the value of the service gains approaches zero asymptotically) because the value of service gains is discounted. The total discounted service gains are equal to area "B" in the bottom graph. A replacement project of 2.62 acres will provide just enough service gains to equal the service losses resulting from the injury. That is, area "B" in the bottom graph of Figure 3 is made equivalent to area "A" in the top graph.

Figure 3:





Step 4: Calculating the Cost of the Replacement Project. Step four of HEA, which would be required for any damage assessment and restoration plan regardless of the methodology used in the assessment, occurs after the trustees have calculated the scale of the project. The damages claim is based on the costs of the replacement project.[15] Categories of project costs include the following:

[15] Again, it should be noted that the responsible parties may perform the replacement project, subject to performance criteria established by the trustees.

- planning and design
- environmental impact assessment
- permitting
- construction
- monitoring
- mid-course corrections

Some of the categories of cost can be characterized on a per-acre basis; others impose fixed costs (permitting). We do not calculate project costs in this example.

Appendix A: Algebra of HEA

Below, we outline the generic formula employed to calculate the appropriate scale of the compensation project. We first provide the notation for the HEA calculations.

Let *t* refer to time (in years), where the following events occur in the identified years:

$t=0$, the injury occurs

$t=C$, the base for discounting (when discount factor = 1.0)

$t=B$, the injured habitat recovers to baseline

$t=N$, the injured resource reaches maximum service provision

$t=I$, compensatory project begins to provide services

$t=M$, compensatory project reaches full maturity

$t=L$, compensatory project stops yielding services

Other variables in the analysis include:

V_j , the value per acre-year of the services provided by the injured habitat (without injury)

V_p , the value per acre-year of the services provided by the replacement habitat

x_t^j, the level of services per acre provided by the injured habitat at the end of year t

b^j , the baseline (without injury) level of services per acre of the injured habitat[16]

x_t^p, the level of services per acre provided by the compensatory project at the end of year t

b^p , the initial level of services per acre of the compensatory projects

r, is the discount rate for the time period

J, the number of injured acres

P, the size of the replacement project

We select a metric, x, for capturing overall level of habitat services, or habitat function, which could represent a single service flow from the resource or an index that represents a

[16] We simplify the representation of the baseline to be constant through time. Seasonal or inter-annual (or other) forms of variation could be incorporated, by adding time subscripts to the baseline variable *b*.

weighted average of multiple service flows. In the chosen metric, we define: x_t^j as the level of services per acre provided by the injured habitat at the end of year *t,* and b^j as the baseline level of services of the injured habitat; consequently, (b^j - x_t^j) is the extent of injury in year *t.*[17] Analogously, we define x_t^p, as the level of services provided by the replacement habitat at the end of year *t,* and b^p as the initial level of services of the replacement habitat, prior to any enhancement activities; consequently, (x_t^p - b^p) represents the *increment* in resource services provided by the replacement project - which is the relevant measure for our analysis. In our discussion in the text in the body of this paper, however, we referred to habitat services as a percent of the baseline level of services of the injured habitat, b^j; in this format, (b^j - x_t^j)/ b^j represents the percent reduction in services per acre at the injured site from the injured site baseline, and (x_t^p- b^p)/b^j represents the percent increase in services per acre, relative to the injured site baseline, for the replacement site.

To translate the quantity in year *t* into its appropriate value in the year of the claim, *C*, we apply the discount factor based upon the annual discount rate, *r*. Finally, the number of injured acres is *J*. The goal of the habitat equivalency analysis is to solve for the size of the replacement project, *P*.

The equation equating the sum of the present discounted value of the services lost at the injured site with the sum of the present discounted value of the services provided at the replacement site is:

$$J * V_j * \sum_{t=0}^{N+1}\left[(1+r)^{C-t} * \frac{b^j - 0.5\left(x_{t-1}^j + x_t^j\right)}{b^j}\right] + \left[\left(\frac{b^j - x_{t=N+1}^j}{b^j}\right) * \frac{1}{r} * (1+r)^{C-(N+1)}\right] =$$

$$P * V_p * \sum_{t=I}^{M+1}\left[(1+r)^{C-t} * \frac{0.5\left(x_{t-1}^p + x_t^p\right) - b^p}{b^j}\right] + \left[\left(\frac{x_{t=M+1}^p - b^p}{b^j}\right) * \frac{1}{r} * (1+r)^{C-(M+1)}\right]$$

Under the assumption that the per unit value of replacement habitat services, V_p , is equal to the per unit value of injury habitat services, V_j , the calculation to solve for the size of the

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[17] More precise estimates of the level of discounted service flows could be obtained by using smaller time periods (e.g. semi-annual or monthly). If smaller time periods are used the discount rate should be adjusted to keep the annual discount rate unchanged.

replacement project is simplified because the term $\frac{V_j}{V_p} = 1$. The equation to solve for the amount of compensatory restoration required is:

$$P = J * \frac{V_j}{V_p} * \frac{\sum_{t=0}^{N+1}\left[(1+r)^{C-t} * \frac{b^j - 0.5\left(x_{t-1}^j + x_t^j\right)}{b^j}\right] + \left[\left(\frac{b^j - x_{t=N+1}^j}{b^j}\right) * \frac{1}{r} * (1+r)^{C-(N+1)}\right]}{\sum_{t=I}^{M+1}\left[(1+r)^{C-t} * \frac{0.5\left(x_{t-1}^p + x_t^p\right) - b^p}{b^j}\right] + \left[\left(\frac{x_{t=M+1}^p - b^p}{b^j}\right) * \frac{1}{r} * (1+r)^{C-(M+1)}\right]}$$

The ratio of $\frac{V_j}{V_p}$ is greater than one if the per unit value of the injured services is greater than the per unit value of the replacement services. Subsequently, more of the replacement project habitat would be needed than if the per unit values were equal. Less of the replacement project habitat would be needed if the per unit value of the injury habitat is less than the per unit value of the replacement habitat.

Appendix B: Interim Losses from a Marsh Oiling

Table B1 documents the injury and recovery of services on an annual basis and presents the sum of total discounted service-acre-years lost. There is a unique row for each year between the time of injury and the time when the resource returns to baseline conditions, and these rows are designated in Column 1 by year. Column 2 provides some descriptive information on the status of the resource. Columns 3 and 4 provide information about the percent service loss at the beginning and end of each period, respectively. Note habitat services grow for eight years following a linear recovery path, starting in 2002. The beginning of period service loss in each period is equal to the end of period service loss in the previous period, except for the year of initial injury. The beginning percent service loss in the first period is equal to the service loss experienced by the resource immediately following the injury. The end of period service loss, Column 4, declines as the resource recovers toward baseline conditions. See the algebraic notations that follow Table 1 for the precise calculation used in Column 4. Column 5 is the arithmetic mean percent service loss experienced over the period, and is accurate if the overall recovery function is linear or can be reasonably approximated as linear within each period. Column 6 is the number of service-acre-years lost in each period, and is the product of the mean percent service loss and the area of injury. Column 7 is the discount factor, which is multiplied by the number of service-acre-years lost to yield the discounted service-acre-years lost in Column 8.

Table B1. Interim marsh service loss calculations.

1	2	3	4	5	6	7	8
Period	**Project Status**	**% Service Loss**			**Service-Acre-Years Lost**	**Discount Factor**	**Discounted Service-Acre-Years Lost**
		Beginning of Period	**End of Period**	**Mean**			
2000		50.00%	50.00%	50.00%	10.000	1.000	10.000
2001	Primary Restoration	50.00%	50.00%	50.00%	10.000	0.971	9.709
2002	Recovery Begins	50.00%	43.75%	46.875%	9.375	0.943	8.837
2003		43.75%	37.50%	40.625%	8.125	0.915	7.436
2004		37.50%	31.25%	34.375%	6.875	0.888	6.108
2005		31.25%	25.00%	28.125%	5.625	0.863	4.852
2006		25.00%	18.75%	21.875%	4.375	0.837	3.664
2007		18.75%	12.50%	15.625%	3.125	0.813	2.541
2008		12.50%	6.25%	9.375%	1.875	0.789	1.480
2009	Recovery Complete	6.25%	0.00%	3.125%	0.625	0.766	0.479
2010		0.00%	0.00%	0.000%	0.000	0.744	0.000
2011		0.00%	0.00%	0.000%	0.000	0.722	0.000
				Total Discounted Service-Acre-Years Lost =			**55.106**

Algebraic notation for Table B1 calculations:

Column 3: $= \frac{b^j - x_{t-1}^j}{b^j}$, except for *t=0* which = initial loss after injury

Column 4: = $\frac{b^j - x_t^j}{b^j}$

Column 5: = $\frac{b^j - 0.5\left(x_{t-1}^j + x_t^j\right)}{b^j}$ OR 0.5 * (*Column 3* + *Column 4)*

Column 6: = $J * \frac{b^j - 0.5\left(x_{t-1}^j + x_t^j\right)}{b^j}$ OR *J * Column 5*

Column 7: = $\frac{1}{(1+r)^{t-C}}$

Column 8: = $J * \frac{b^j - 0.5\left(x_{t-1}^j + x_t^j\right)}{b^j} * \frac{1}{(1+r)^{t-C}}$ OR *Column 6 * Column 7*

Appendix C: Service Gains from Compensatory Restoration Project

In Table C1, the increase in services of the compensatory habitat is calculated per acre of replacement project. The first five columns in Table C1 contain information analogous to that in Columns 1 through 5 of Table B1. As the benefits of compensatory restoration are always quantified per unit area (acres in this example), Table C1 does not contain a column similar to the service-acre-years lost. Instead, the annual discounted service-acre-years of gains per acre of compensatory restoration (Column G) are derived by multiplying the mean percent service level (Column E) by the discount factor (Column F). At the bottom of the table, the total discounted service-acre-years per acre are summed.

Table C1. Calculation of marsh service provision gains from compensatory restoration.

A	B	C	D	E	F	G
Period	Project Status	% Service Gain			Discount Factor	Discounted Service-Acre-Years Gained per Acre of Restoration
		Beginning of Period	End of Period	Mean		
2000		0.0%	0.0%	0.00%	1.000	0.000
2001	Replacement Project Begins	0.0%	0.0%	0.00%	0.971	0.000
2002	Service Increase Begins	0.0%	7.5%	3.75%	0.943	0.035
2003		7.5%	15.0%	11.25%	0.915	0.103
2004		15.0%	22.5%	18.75%	0.888	0.167
2005		22.5%	30.0%	26.25%	0.863	0.226
2006		30.0%	37.5%	33.75%	0.837	0.283
2007		37.5%	45.0%	41.25%	0.813	0.335
2008		45.0%	52.5%	48.75%	0.789	0.385
2009		52.5%	60.0%	56.25%	0.766	0.431
2010		60.0%	67.5%	63.75%	0.744	0.474
2011	Services Reach Maximum	67.5%	75.0%	71.25%	0.722	0.515
Beyond 2011		75.0%	75.0%	75.00%	--	18.061
Total Discounted Service-Acre-Years Gained per Acre of Restoration =						**21.015**

Algebraic notation for Table C1 calculations:

Column C: $= \dfrac{x_{t-1}^{p} - b^{p}}{b^{j}}$

Column D: = $\dfrac{x_{t}^{p} - b^{p}}{b^{j}}$

Column E: $= \dfrac{0.5\left(x_{t-1}^{p} + x_{t}^{p}\right) - b^{p}}{b^{j}}$ OR 0.5 * (*Column 3 + Column 4)*

Column F: = $\dfrac{1}{(1+r)^{t-C}}$

Column G: = $\dfrac{0.5\left(x_{t-1}^{p} + x_{t}^{p}\right) - b^{p}}{b^{j}} * \dfrac{1}{(1+r)^{t-C}}$ OR *Column 5 * Column 6*

-----Original Message-----
From: Katharina Fabricius [mailto:k.fabricius@aims.gov.au]
Sent: Wednesday, August 19, 2009 0:26
To: Jameson, Stephen C CIV NAVFAC Pacific, EV2
Cc: Hesse, JT T CIV NAVFAC PAC, EV2
Subject: RE: US Navy - Guam CVN - Paid Peer Review Request

Dear Stephen,

please find attached a first draft of my comments to the study. I am sorry to say that my overall assessment of this study is not overly positive. Please let me know if there are aspects in my assessment you find less than helpful for your task at hand, or aspects that are missing. I am happy to change things around if needed.

I don't have a pdf maker on this computer (mine is in repair), so please convert to pdf or strip off document properties id before sending this off to the authors.

Best wishes

Dr. Katharina Fabricius
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TO Dr. Stephen C. Jameson
Cc JT Hesse

stephen.jameson@navy.mil , jeffrey.hesse@navy.mil

This report provides a baseline study of the benthic marine habitats near Apra Harbor, Guam. The study provides a range of diverse data sets on habitat structure and variability, including benthic over assessed by transects and remote sensing analysis, data on rugosity, coral size frequencies, coral pigmentation, macro-invertebrates and sediment composition. The study is well written, and the wide range of data collected are useful.

Specific comments to the questions posed:

1. Do the methods used in this study provide data to make reasonable conclusions about the status of the coral reef habitat under study?

The chosen ecological parameters, namely benthic cover (high-level categories and more detailed groupings) based on transects, high-level cover groups based on remote sensing analysis, rugosity, size frequency, coral pigmentation, macro-invertebrates and sediment composition, are widely accepted to be suitable metrics to quantify reef status. I have do however have some concerns about the methods and the integration of the results across the data sets:

- The benthic survey protocol is somewhat unusual. Photo transect length of only 10 m is shorter than most protocols recommend (usually 25 or 50 m, which is more adequate to represent rare taxa and habitat heterogeneity). In contrast, sampling 50 points per image (i.e., on average on point every 4 x 4 cm in a 0.6 m2 image) is higher than usually recommended (5 to 20 pts are more usual), and may result in high autocorrelation problems.
- The data on ‘size frequency’ should probably be re-named to ‘density of small colonies’. The photo method used does not allow to assess neither frequency nor size of large colonies (they don’t fit into the photo frames).
- Rugosity is an important and useful measure, and it is good to see that this measure has been analysed using two different methods. Given the importance of rugosity for fish communities, these data appear somewhat under-represented in the Results section.
- The results on pigmentation are overall valid, and probably similar to what would have been obtained from the more traditional PAM fluorometry to determine the photophysiological health of corals. (However as a side comment: I believe the connotation of dark = healthy is considered somehow simplistic, given the increase in pigmentation in corals exposed to high levels of nutrients. Also, a question out of curiosity: do the *Acropora* stands depicted in Fig. 12 appear bleached?).

- It is not quite clear why the macroinvertebrate surveys were not statistically analyzed in combination with the other benthic data. It is difficult to see patterns based on the Table of counts. Surely these communities bear as much information about habitat status as the ones in the photo transects?
- In the longer term, it will also be useful to collect sediment grain size distribution data, which determine many properties of soft bottom communities as well as stress effects on corals.

One less then ideal aspect of this study is the choice of 4 pre-defined strata:

- Although slope angle may be a useful predictor to categorize benthic habitats, if used in isolation from depth (as done in this study), the <=15 degrees category will combine seafloor sites with reef top sites (as shown in Fig 5), which is obviously ecologically meaningless. Traditionally, a second stratification of shallow-water benthic habitats would have been based on depth, and/or windward/leeward onshore-offshore orientation, rather than on slope angle. Depth is a fundamental factor that determines most ecosystem processes in coral reefs, and assessments of benthic communities are likely to miss the main explanatory factor and source of variation if depth is not included. Habitat data from Fig 4 (depth) and 5 (slope) and/or orientation could be combined to provide for a stronger and potentially ecologically sounder stratification.
- The separation by their future fate ('directly' and 'indirectly' exposed) appears practical and useful. Equally important may have been a comparison of the previously dredged area with the non-dredged area (see below).

Since the choice of strata determined the location of transects, the choice of slope to define the strata could have easily led to some under-representation of certain benthic categories. However, fortunately, Figures 4 and 5 suggest that both shallow and deeper habitats were covered by the sampling sites, and that many aspects of orientation have also been covered.

In the present uni- and multivariate analyses, little structure has been revealed despite the (somehow unselective and redundant) consecutive use of cluster, PCA, MDA, ternery plots *and* DFA analyses. It is generally not more informative to add more than 1 or 2 types of multivariate analyses, if no structure is discovered by those. It appears that sufficient data are available to include some of the environmental data into the analyses, such as depth, east-west or onshore-offshore orientation, currents, sedimentation rates or water transparency, potentially revealing some important structure in the data.

2. Does the accuracy rate for the remote sensing map created from sea-truth data meet scientific rigor for acceptance as a viable means for extrapolation to the greater area?

Remote sensing data can be useful for large-scale studies to describe patchy benthic habitats with sufficient accuracy and low bias. The remote sensing accuracy achieved in this study was 76%, i.e., slightly lower than some other reef studies who have achieved 80 – 90%; apparently due to the high turbidity and great depth of some sites. Indeed, the correct classification in some of the cells of Table 6 is below 50%. Nevertheless, assuming the post-hoc corrections for the misclassifications are valid, Fig 33 and Table 7, which are derived from the remote sensing analyses, are very useful.
The additional advantages of photo transects over remote sensing such as data on species composition, partial mortality from sedimentation, and coral health measurements have to be carefully weighed up against each other. The need to use remote sensing data seems slightly overstated, since the area under investigation here is small (0.73 km2) and well structured, with some patch reefs in known locations and extended areas of sand that are quick to survey. The area is therefore perfectly amenable to surveys using alternative methods such as photo transects, manta tows and towed video for the deeper sections (which were not covered here). The argument that only 0.1% of the area has been covered by the photo transects is inconsequential, given that all estimates are based on subsampling – not the percentage area covered is relevant, but whether the surveys have been based on a representative sampling regime (hence the importance of a sound choice of strata).

3. Do the methods used have the capability to provide replicate data that is testable for ensuring valid and unbiased results?

Yes, only techniques are used that combine low bias with adequate precision. The methods used are described in detail, enabling replication of the study with minimum sampling bias. The methods used for data analysis are also explained clearly and transparently.

4. Do the results of this report represent a reasonable and cost effective characterization of the affected coral reef habitat?

Overall, yes. It is however not clear why the photo data were not taken in a way that allowed to meet both purposes, the characterization of benthos and the ground-truthing of the remote sensing images simultaneously? If both sets of data had been combined, more sites or more images per sites might have been available. Also, sediment samples could have been collected at the beginning of each transect; sediment properties vary at small spatial scales and a few more replicates may have started showing some patterns (processing sediment samples is inexpensive). These sediment data could then also be used as predictor variable for the benthic data.

Also, previous studies on the effects of dredging on coral communities have shown that dredge effects may be as serious in deep as in shallow communities, and measured much further than 200 m away from the channel, depending on the hydrodynamics of a site. The chosen total area that excluded >60 ft sites, and the area investigated as 'indirect' may therefore not have represented the full coral reef area that will potentially be affected.

5. How would you define and measure coral reef ecosystem function?

Any attempt to defining coral reef ecosystem functions in a few general terms must remain simplistic, since reefs are the most complex of all marine ecosystems and come in a great variety of forms. However, from an ecological perspective, the most important functions of coral reefs include (1) the maintenance of biodiversity and trophic complexity, (2) the maintenance of resilience (defined as the time it takes a reef system to recover from a disturbance), and (3) the maintenance of habitat.

- Maintenance of biodiversity and trophic complexity may be measured using photo transects, invertebrate and fish counts, and measures of coral health (photophysiology, rate of calcification, recent mortality; or proxies for the health of their zooxanthellae, including measurements of light levels, water temperature, salinity, nutrients and sedimentation). The biotic data are to be analyzed for abundances/taxonomic richness, grouping by trophic guilds, and the abundance of keystone species such as herbivorous fishes.
- Maintenance of resilience may be measured by assessing the coral recruitment capacity of reefs (density of young corals in relation to available space), the balance between corals and macroalgal cover, and again the abundance of keystone species such as herbivorous fishes and coral health.
- Maintenance of habitat may be measured as 3-dimensional structural rugosity, and diversity and cover of corals, which form the habitat, feeding, breeding and nursery grounds for a multitude of reef-associated bacteria, fungi, plants, invertebrates and fishes. The ratio of calcification to bioerosion/storm erosion is also a relevant measure to assess habitat maintenance. The maintenance of habitat has to be viewed in the context of interactions with its surrounding ecosystems (algal meadows, seagrass beds, estuaries, mangroves and freshwater systems).

From an economic perspective, major measures of ecosystem functions and services are linked to (1) tourism, (2) fishery yields and (3) shoreline protection. Tourism may be measured as the number of visitation days in a community attributable to reef experience, and the average spending per visitor day. Fishery yields are assessed using standard methods (catch per unit effort, fish densities etc). Assessing the ability of a reef to provide shoreline protection requires a hydrodynamics and wave model to assess altered shoreline erosion patterns from new exposure to regular wave erosion or extreme high-tide and storm events.

6. Would application of the data derived from this study provide the necessary input to a habitat equivalency analysis (HEA) model to meet accepted scientific standards for assessing direct physical impacts (dredging) to coral reefs?

Yes for shallow water, no for the >60 ft areas which may also contain important habitat. For the shallow water, the study provides several data (esp coral cover, rugosity, coral and invertebrate biodiversity) that may serve as a single or composite metric to quantify the ecosystem functions of the lost area. It appears that a composite of multiple metrics may be the most appropriate approach for estimating the losses Individual metrics may be z-transformed and then averaged, potentially using some weighting factor to give greatest emphasis to coral cover and rugosity. Data on recovery times should be available from other studies of coastal reefs of Pacific Islands, and from comparing the previously dredged area and surroundings with adjacent areas not influenced by that dredging event (ie., was there complete recovery even in deeper areas in the 46 years since dredging). One problem to consider here is the issue of 'shifting baseline', i.e., the reefs under consideration may not presently express all of their potential ecosystem functions (e.g., reef flats and other patches may have reduced coral cover and diversity) due to the present-day coastal activity, shipping and terrestrial runoff, and/or from the past dredging.

-----Original Message-----
From: John McManus [mailto:jmcmanus@rsmas.miami.edu]
Sent: Saturday, August 22, 2009 17:22
To: Jameson, Stephen C CIV NAVFAC Pacific, EV2
Cc: Hesse, JT T CIV NAVFAC PAC, EV2
Subject: RE: US Navy - Guam CVN - Paid Peer Review Request

Dear Stephen,

Enclosed please find my review of the study report:
"Assessment of benthic community structure in the vicinity of the proposed turning basin and berthing area for carrier vessels nuclear (CVN) Apra Harbor, Guam".

Please let me know if I can provide any further information.

My preferred mailing address is:

John McManus
1432 NW 132nd Ave.
Pembroke Pines, Fl. 33028
954-438-0808 (H)

Sincerely,

John

John W. McManus, PhD
Director, National Center for Coral Reef Research (NCORE) Professor, Marine Biology and Fisheries Coral Reef Ecology and Management Lab (CREM Lab) Rosenstiel School of Marine and Atmospheric Science (RSMAS) University of Miami, 4700 Rickenbacker Causeway, Miami, 33149 jmcmanus@rsmas.miami.edu
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"If I cannot build it, I do not understand it."
--Richard Feynman, Nobel Laureate

Peer Review of:

Assessment of benthic community structure in the vicinity of the proposed turning basin and berthing area for carrier vessels nuclear (CVN) Apra Harbor, Guam

John W. McManus, PhD
Director, National Center for Coral Reef Research (NCORE)
Professor, Marine Biology and Fisheries, RSMAS, University of Miami

Overview

This study of benthic communities at the proposed dredging site and a 200 meter zone of potential indirect effects is a cutting-edge analysis by world-class scientists. Unfortunately, perhaps because of the terms of reference and time constraints, there was no effort to more properly determine the area in which the indirect impacts of the dredging will take place. Our observations of dredging impacts in the Dominican Republic (DR) indicate that sediments from the dredging of calcareous sediments can be carried for kilometers from the dredging site. These sediments can have severely deleterious effects on coral communities throughout this range, reducing live coral cover substantially and impacting associated benthos. I am not aware of any dredging curtaining system which is fully effective amid the complex topography of a coral reef.

Although the corals in the Guam study tend to be reasonably sediment tolerant, this does not mean that they will be tolerant to the changes in sediment type and loading that will be generated by the dredging. Coral communities tend to develop to the limits of environmental perturbation and stress characteristics of a particular site. Additional loading of sediments can easily overwhelm the sediment removal mechanisms of the existing corals, especially in places which are somewhat shielded from strong current flow. Hus, in our study of sediment impacts associated with mining in the central Philippines, the massive *Porites* colonies and other corals were forced to release large amounts of mucous to remove the unusually high loads of sediment. The currents were not strong enough to remove this heavy mass of sediment-laden mucous, and nearly all corals in the impacted area basically ‘smothered’ to death. That area had been similarly inhabited by moderately sediment-tolerant corals. Some corals, such as species of *Goniopora,* have polyps long enough to dig out from under considerable sediment loads. However, these highly sediment-tolerant corals were not characteristic of the Guam site.

Some of the currents that dispersed the sediments in the DR study were not known in advance, and consisted of reversing flows which were sometimes depth specific in layers as thin as a meter. Thus, the proper delimitation of the area of potential impacts must involved measurements of vertical current profiles at many points, during a variety of weather and tide conditions. Accounting for seasonal differences due to changing dominant wind patterns would be important in the Guam situation. Once the currents are known, they can be used with information on the sediment characteristics to develop a sediment transport model, using an approach appropriate to highly complex underwater terrain such as a Lattice-Boltzmann hydrodynamic model with sediment transport.

Thus, an otherwise excellent study which could easily have served as a model for such studies is rendered ineffective due to the unrealistically restricted area in which it was focused.

Responses to Posed Review Questions

1. Do the methods used in this study provide data to make reasonable conclusions about the status of the coral reef habitat under study?

The methods are highly appropriate to the analysis of the delimited study area. The researchers involved have applied state-of-the-art methodologies and analytical approaches. However, the delimited area by no means represents the area potentially to be impacted by dredging. There is presently no effective way to control sediment dispersion during dredging in a highly topographically complex coral reef environment. The abrasive calcareous sediments from the dredging are likely to be widely dispersed for many hundreds of meters to more than a kilometer in the direction of currents which may shift substantially over time. Prior studies have indicated that these sediments can severely damage corals. Because corals often proliferate to the maximal extent permitted by local environmental conditions, a substantial change in a factor such as sediment load can damage even corals in communities believed to be relatively sediment tolerant. There seems to have been no effort to determine the directions, speeds, or sediment transport characteristics of the currents of the area adjacent to the proposed dredging. Properly doing this would require determining vertical current velocity profiles and wave characteristics in the area at many points over changes in tides, weather, and preferably season. Sediment transportation potentials would likely require sediment modeling. The present study may have been contracted in such a way that this sediment transport analysis was not feasible. However, without these efforts to more effectively delimit the potential impact area, this analysis has limited value.

2. Does the accuracy rate for the remote sensing map created from sea-truth data meet scientific rigor for acceptance as a viable means for extrapolation to the greater area?

The use of remote sensing to extrapolate analyses across the study area was highly appropriate. The point made about the difficulties in obtaining reasonable areal coverage via diving surveys is entirely valid. Studies of the accuracy of diver sampling-based extrapolations often indicate that much poorer estimates of benthic cover have been obtained than that indicated in this study.

3. Do the methods used have the capability to provide replicate data that is testable for ensuring valid and unbiased results?

From the context of the study area as presently delimited, the replicates are entirely appropriate for the tests employed, and every effort was employed to minimize bias.

4. Do the results of this report represent a reasonable and cost effective characterization of the affected coral reef habitat?

As stated above, the potential area of impact was not actually delimited in any appropriate way, other than for the area to actually be dredged.

5. How would you define and measure coral reef ecosystem function?

Ecosystem function must be defined with regard to particular evaluation purposes. In the present case, the function would most appropriately evaluated in terms of the provision of ecosystem services in socioeconomic and cultural terms. Thus, one would determine the primary socioeconomic values of the reef in local terms, with some additions in terms of global value. Then, one would determine what impacts one would expect to occur should various aspects of ecosystem function be altered. For example, the loss of overhangs can impact grouper populations, which can impact fisheries around all of Guam. The loss of branching coral might reduce survivability of juvenile herbivorous parrotfish and wrasses, reducing overall herbivory in the local and adjacent reef areas, leaving the reef with increased sensitivity to nutrient overload (resulting in algal displacement or overgrowth), and reducing reef resilience to storm damage – all reducing ecosystem service value such as value for fisheries and tourism.

6. Would application of the data derived from this study provide the necessary input to a habitat equivalency analysis (HEA) model to meet accepted scientific standards for assessing direct physical impacts (dredging) to coral reefs?

As indicated, within the actual dredging area, this is certainly the case. This study uses truly cutting-edge and highly reliable approaches. However, the study is not at all effective with respect to broader dredging impacts beyond to rather limited 200 m adjacency area.

Other Specific Comments

pg 4 Briefly explain "SRF" here.

pg 4 'strata' is used in an odd way here. Usually a stratum is a layer in a sedimentary formation. Although the living community might someday influence a stratum, it isn't there yet. I would have used 'primary area' and 'adjacent area'.

pg 5 Suggest change "noncarbonate terrigenous material" to "non-carbonate reefal material and material from terrigenous sources".

pg 7 "provide date" -> "provide data"

pg 7 Suggest "be considered" -> "be considered. However, as the nature of the disturbance in this case is known, a more locally specific, statistically valid protocol may be more appropriate -- a site-specific sampling strategy based on preliminary field sampling and estimates of the spatial variance of potential change over time."

All Field Photos:

Very few fish are seen in the photos. This could not be the case in a reef with a healthy herbivorous fish assemblage, even with the noisiest of divers. Guam is heavily fished, and this is probably the cause. These reefs thus will have a low resilience to nutrient-induced macroalgal growth, as witnessed in the high algal estimates.

Fig 4. Add final parenthesis.

Fig 16. Astreapora -> Astreopora.

pg 20 Principal Components Analysis of community structure data has a widely known problem in which the nonlinearities artificially produce an ‘arch-effect’ where a straighter line pattern would be expected. This can lead to improper interpretations and sometimes misleading axis values. The problem comes from the common property of species of having overlapping roughly bell-shaped optima as one proceeds across any given environmental gradient important to the species. The results in this particular study have been investigated using multiple approaches, and thus they are robust to these potential mathematical problems. However, for future reference, one should consult any of several references on the problem, such as Pielou’s 1984 book on ‘The Interpretation of Ecological Data’.

Pg 21. For the classical multidimensional scaling analysis, the dissimilarity value calculations were not described. It is a little known fact that the Bray-Curtis Measure should not be used in any ordination analysis of this type (despite the fact that it was first introduced for use in an ordination approach). This measure violates the triangle inequality rule, which states that for any three points A, B and C, the sum of distances AB and BC should be greater than or equal to distance AC. Thus, it makes no sense to plot this data in a Cartesian plot, no matter how much one processes the distances via ordination calculations such as MDS. Even ‘non-metric’ multidimensional scaling does not overcome this deficiency with this measure, because the non-metric in this case refers to the analytical process (which strives to preserve an appropriate sense of spatial relationships), not the input matrix. However, the problem is not likely to have altered the results, and is widely (improperly) ignored. More appropriate measures are reviewed in Pielou’s 1984 book.

pg 31 Sediment effects on corals depend greatly on species and position with respect to cleansing currents and waves. Corals tend to grow to close to their tolerance levels. Thus, although these corals are growing in sediment laden waters, this does not mean that adding substantially to the sediment load will have no detrimental effect. The authors do not necessarily imply this, but this is something of which anyone reading the report should be aware.

-----Original Message-----
From: Sheppard, Charles [mailto:Charles.Sheppard@warwick.ac.uk]
Sent: Thursday, August 13, 2009 3:54
To: Jameson, Stephen C CIV NAVFAC Pacific, EV2
Cc: Hesse, JT T CIV NAVFAC PAC, EV2; Pepi, Vanessa E CIV NAVFAC PAC ; Rosen, Liane K CIV NAVFAC PAC
Subject: RE: US Navy - Guam CVN - Paid Peer Review Request

Stephen

I attach my report on the Dollar et al study. As you see, I think it is extremely good, but needs a couple of amplifications and presentation improvements.

Regarding the fee, please send it to Professor Charles Sheppard at Department of Biological Science, Warwick University, CV4 7AL, UK. Thank you.

And thank you for the opportunity to see this. Many consultancy reports are, by comparison, very lacking in both scientific rigor and data!
Best wishes
Charles

Professor Charles Sheppard
Dept Biological Sciences
University of Warwick
Coventry, CV4 7AL,
UK
charles.sheppard@warwick.ac.uk
tel (44) (0) 2476 524975

Review of Dollar et al, study on Apra Harbor.

Prof Charles Sheppard
11 August 2009.

This is a study of a tropical coastal area, whose benthic substrata are a mixture of coral, algal habitat and soft substrate habitat. The study is more than sufficiently detailed to obtain a very good characterisation of the area. One important stated purpose is for input into Habitat Equivalency Analyses (HEA), and it is more than sufficient for this.

It does more than this: it provides a good model for future surveys of this kind.

Some small points, mainly of presentation:

Introduction

In the Introduction, I suggest you supply a good map of the wider area. The several maps at the end do not include any map other than of the same, smaller work site.

Methods

For both the benthic survey and the spectral reflectance aspects, the work is appropriate and well explained, in fact extremely good.

There is a little bit of repetition and redundancy in the Methods write-up, especially in the early sections, but the Methods used are very clear, comprehensive for the task, and will permit repetition of the work. The methods used from small scale to broader scale are skilfully integrated (i.e. the diver studies, both photo-quadrats and optical studies, and those using remote sensing). This is a scientifically very good study. If anything, the site of interest as described is not a particularly complex one, so the number and extent of methods and statistical analyses applied to it are more than sufficient. Certainly it is sufficient for HEA.

Results

As a scientist, this is all interesting and understandable. I suspect, however, that if other non-scientists need to read this, some of the descriptions such as of Principal Components, might be too difficult to follow. However, I accept that such readers may limit their attention to the Summary.

Conclusions and Discussion

The discussion is clear. But I think a paragraph or two summing up the Conclusions are necessary. This is mostly a lot of general discussion, which is fine, but they aren't the conclusions of your study. This would, I suspect, be largely a repetition of the Exec Summary.

Figures

I would hope that these figures will appear in the body of the text, each at the appropriate place, rather than as a bunch at the end. Some should also be place (repeated if necessary) in the text of the Summary.

<u>Summary</u>. Care should be taken with this section, as it probably will be the only part read by some. It should contain several of the illustrations. It should contain a non-technical précis of the results. I suggest this is looked at again with a view to explaining in lay language some of the methods and results. Some of its described methods may be too complex for a non-scientific reader. Finally, the point of the study should be made clear, namely general survey for generating data suitable for HEA, for example. The changes made would actually be fairly small as the material seems to me to be all there, but just modified for a possibly broader audience than the main text.

<u>General</u>

The purpose of the study seems to be to provide the data for HEA. The study certainly produces the data, but does not very well address the issue of which data, and how. A section is needed to explain how the present results can be used specifically for HEA.

Your specific questions:

Questions

1. Do the methods used in this study provide data to make reasonable conclusions about the status of the coral reef habitat under study?

Yes. With the imagery, the whole area is sufficiently mapped biologically.

2. Does the accuracy rate for the remote sensing map created from sea-truth data meet scientific rigor for acceptance as a viable means for extrapolation to the greater area?

Yes, some methods are standard, while others appear to take them on a bit further, very successfully.

3. Do the methods used have the capability to provide replicate data that is testable for ensuring valid and unbiased results?

Yes.

4. Do the results of this report represent a reasonable and cost effective characterization of the affected coral reef habitat?

I have no idea what the cost of the survey was! From the point of view of cost in terms of effort, then the field sampling effort was pretty much optimal.

5. How would you define and measure coral reef ecosystem function?

My own definition is probably irrelevant! But a definition must include the following: for reef habitat itself, provision of a good 3-dimensional, complex cover of corals over the hard substrate, consequent provision of healthy, actively growing corals (ie not bleached, diseased or too obviously stressed). High diversity is often chosen as a requirement too, but sometimes erroneously – many areas naturally will have a low diversity (as seems to be the case here), in which case they may form a near 'monoculture' over wide areas (as also seems to be the case here)..

6. Would application of the data derived from this study provide the necessary input to a habitat equivalency analysis (HEA) model to meet accepted scientific standards for assessing direct physical impacts (dredging) to coral reefs?

Yes, but see note above on HEA.

-----Original Message-----
From: Peter Vroom [mailto:Peter.Vroom@noaa.gov]
Sent: Tuesday, August 11, 2009 10:59
To: Jameson, Stephen C CIV NAVFAC Pacific, EV2
Cc: Jean.Kenyon@noaa.gov; Rusty Brainard; Hesse, JT T CIV NAVFAC PAC, EV2; Pepi, Vanessa E CIV NAVFAC PAC ; Rosen, Liane K CIV NAVFAC PAC
Subject: Re: Guam CVN Marine Assessment - Peer Review Request

Dear Stephen,

Please find my review for the study titled "Assessment of benthic community structure in the vicinity of the proposed turning basin and berthing area for carrier vessels nuclear (CVN) Apra Harbor, Guam"
attached to this e-mail. Let me know if you have any questions, comments, or concerns.

Best wishes,
Peter Vroom.

Dear reviewers:

This is a review for Dollar and Hochberg "Assessment of benthic community structure in the vicinity of the proposed turning basin and berthing area for carrier vessels nuclear (CVN) Apra Harbor, Guam."

Dredging of Apra Harbor is slated to occur, and surveys were conducted to examine the types of benthic communities found in areas to be impacted in order to conduct habitat equivalency analyses. I was impressed regarding the degree of background information provided to insure that readers clearly understood how sampling points were chosen, how data were collected, as well as inherent issues with the study (e.g. discussion of the relatively small geographic area sampled). I also liked that multiple images of each survey site were supplied in the appendices so that readers could rapidly gain understanding of benthic community attributes. Overall, I think this study was well orchestrated, and data were analyzed appropriately.

In answer to your specific questions:

1. Do the methods used in this study provide data to make reasonable conclusions about the status of the coral reef habitat under study?

> Yes. The study provides good insight into the major types of benthic communities existing in and around areas to be dredged. Although it is possible that additional types of benthic communities may occur in areas that were not sampled with transect surveys, the stratified random design utilized to determine sampling sites provides confidence that the vast majority of dominant communities were sampled. The types of statistical analyses performed to analyze percent cover determined from the transect surveys data are standard and other studies using these methods have undergone rigorous peer review in the literature. Similarly, the methodologies employed to collect remote sensing, coral stress and size-frequency, invertebrate community, and sediment composition data have all been used in past studies and are accepted by the scientific community.

2. Does the accuracy rate for the remote sensing map created from sea-truth data meet scientific rigor for acceptance as a viable means for extrapolation to the greater area?

> I'm a bit confused by data presented. Table 7 is missing from the document, and Table 6 doesn't seem to correspond to descriptions in the text. Did an error occur? I think Table 6 might actually be Table 7. Seeing the missing table would help answer your question.
>
> As for whether the accuracy rate meets scientific rigor, it would be helpful to know what your agency considers acceptable. For some people, 75% accuracy (such as found in this study) would be considered good. However, considering that reef communities will be destroyed by dredging activities, other agencies might want to see improved accuracy to insure adequate mitigation efforts.

3. Do the methods used have the capability to provide replicate data that is testable for ensuring valid and unbiased results?

Yes, methods used are repeatable, and it would be expected that they would provide similar results within a certain range of confidence.

4. Do the results of this report represent a reasonable and cost effective characterization of the affected coral reef habitat?

Yes. As stated by the authors of the report, it is impossible to survey the entire benthic substratum of the area that will be impacted by dredging. The stratified random points selected provide an adequate characterization of the seafloor considering time and cost constraints. However, coarse level manta tows may still be useful in addition to the already completed field surveys to determine whether any unusual habitats exist that may not have been sampled, or if any historically significant artifacts might exist in areas to be dredged (e.g. shipwrecks).

5. How would you define and measure coral reef ecosystem function?

I would compare and contrast the following parameters from healthy reefs and impacted reefs to create a health index:

(1) The amount of carbonate sediment produced by algal and coral constituents of the reef over time.
(2) Typical “chlorophyll a” concentration as determined from satellite imagery over time.
(3) Total biodiversity.

I would consider a reef’s function to be lost if it produced a diminished amount of carbonate sediments, had either too much or too little chlorophyll a (signifying a lack of photosynthetic organisms, or overgrowth of coral by invasive algae), and could no longer support a diverse array of organisms.

6. Would application of the data derived from this study provide the necessary input to a habitat equivalency analysis (HEA) model to meet accepted scientific standards for assessing direct physical impacts (dredging) to coral reefs?

Yes. This study found thriving coral and algal dominated systems at many of the survey sites, which is expected for this area. If similar acreage that contains equivalent habitats that support similar coral and algal communities, and contain similar associated macroinvertebrate communities and similar levels of coral disease can be conserved, it would be a step towards mitigating the effects of dredging.

Appendix J
Supplemental Aircraft Carrier Marine Surveys

8. Quantitative Assessment of Reef Fish Communities in Apra Harbor Guam (Draft). August 7, 2009.

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Quantitative Assessment of the Reef Fish Communities in Apra Harbor, Guam

7 August, 2009

Prepared by

Brett M. Taylor, Andrew Halford,

Alyssa L. Marshell, and Mark A. Priest

University of Guam Marine Laboratory

University of Guam

Mangilao, Guam

Prepared for

Naval Facilities Engineering Command Pacific

Pearl Harbor, Hawaii

Executive Summary

This report represents a quantitative assessment of the reef fish communities within Apra Harbor, Guam, in response to the Department of Navy's proposal to construct a pier for the mooring of a nuclear aircraft carrier (CVN). Underwater visual surveys were conducted to quantify species richness, abundance, and biomass of reef fish communities within and adjacent to the proposed project area. A total of 119 species representing 28 families were recorded. Multivariate analyses indicated that fish assemblages largely grouped along a depth/habitat gradient and diversity and biomass were greatest at sites of high coral cover. It is apparent that most low diversity sites will be directly impacted, while 50% of sites dominated by coral and having the most significant fish assemblages will also be directly affected. On average, the families Acanthuridae, Caesionidae, Lutjanidae, Scaridae, and Lethrinidae had the highest biomass per transect, and commercially important groupers of the family Serranidae were more common than anticipated, yet still rare. Given the magnitude of the proposed dredging project, there will undoubtedly be major impacts on the reef fish communities present. However, of particular concern is the fate of sites which will be indirectly impacted, as some of these contain diverse fish assemblages.

Introduction

Reef fish assemblages vary considerably over multiple spatial scales. This 'patchy' nature of most reef fish communities is easily explained by the variability in environmental parameters, such as nutrient availability, water quality, and most importantly habitat structure. Habitat structure plays a very important role in structuring reef fish communities because many species are dependent on certain habitats at both small and large spatial scales.

Predicting the response of reef fish communities to habitat disturbance, however, is much more complicated. Such predictions rely on the magnitude of environmental impact and the mobility and site-fidelity of particular species. Reef fish are arguably less affected than other reef organisms to many physical disturbances. However, there are many species which are highly site attached and remain within a very small home range throughout their entire lives.

This report represents a quantitative assessment of the reef fish communities within Apra Harbor, Guam, in response to the Department of Navy's proposal to construct a pier for the mooring of a nuclear aircraft carrier (CVN). This will require an area of ~100 acres to be greater than 51.5 feet in depth and will be accomplished by seafloor dredging. Therefore, this report summarizes baseline information on fish communities and the potential threats to these communities, be they direct or indirect, from the proposed project as part of a pre-impact Environmental Impact Assessment.

Methods

Underwater visual surveys were conducted to quantify species richness, abundance, and size structure of fish communities at 58 randomly selected sites in Apra Harbor. These sites lie within the proposed dredge project area of the CVN pier, turning basin, and entrance channel (Figure 1). The original 67 sites were reduced to 58 in this study as sites extremely close together were grouped in order to eliminate spatial autocorrelation (e.g., sites 1 and 2, 4 and 5, 11 and 12, 15 and 16, 29 and 30, and 37 and 38). In addition, sites 44, 56, and 66 were not completed because visibility at these sites remained too poor for visual census throughout the duration of the survey period. Depths of sites ranged from <1 to 18 meters, which is where the majority of any potential impacts resulting from the dredge project are anticipated to occur. Sites were stratified by slope (0-15° and >15°) and by anticipated project impact (direct impact – dredging, or indirect impact - project related risk).

At each site, a team of two divers swam along three 25 meter transects. All transects followed the pre-determined depth contour of the respective site. The divers swam side by side along each transect, with one diver recording all species from those families heavily targeted by fishing, i.e., Acanthuridae, Caesionidae, Carangidae, Labridae, Lethrinidae, Lutjanidae, Haemulidae, Mullidae, Scaridae, Serranidae, and Siganidae, and the other diver recording non-target species from the following familes: Aulostomidae, Balistidae, Blennidae, Chaetodontidae, Cirrhitidae, Diodontidae, Fistularidae, Gerreidae, Microdesmidae, Monacanthidae, Mugilidae, Nemipteridae, Ophichthidae, Pomacanthidae, Pomacentridae, Synodontidae, and Tetraodontidae. Highly cryptic species from families such as the Apogonidae and Holocentridae were not counted. Both divers estimated size of each fish (total length) to the nearest 5 cm.

As well as fish abundance and size structure the observers recorded the dominant habitat type at each site as either coral-dominated, macroalgae-dominated, rubble-dominated, or sand-dominated. A more detailed assessment of the benthic habitat was performed by another survey team. There was one additional site unique to all others which we referred to as a 'dump site' as the benthic habitat at this site was comprised entirely of cinder blocks that had been deposited onto the seafloor, creating an artificial habitat.

Analysis

Univariate measures of mean density and biomass were calculated for each family at each site, along with species richness and measures of diversity. Differences in mean biomass between direct and indirect impact sites were assessed for each family using Kruskal-Wallis tests. Fish community patterns were assessed through clustering and ordination of the Sites x Species data matrix. Prior to analysis the data was ln(x+1) transformed to help normalize the distribution of the data and to weight less-abundant species more heavily thereby emphasizing community dynamics over the dynamics of the most abundant species in the dataset. The Bray-Curtis measure of similarity was applied to the transformed data matrix which was then subject to ordination through nonMetric Multidimensional Scaling. All analyses were done using the Community Analysis Package in PRIMER 6.0.

Results & Discussion

We recorded 119 species across 28 families during our surveys although the actual number was slightly higher as we grouped some species that were hard to differentiate in low visibility conditions. The acanthurids *Ctenochaetus striatus* and *Acanthurus nigrofuscus* were grouped, as were *A. nigricauda* and *A. blochii*. A number of similar looking *Pomacentrus* spp. from the Pomacentridae were also grouped as were all *Halichoeres* spp. from the family Labridae. From the 119 species recorded, this was reduced to 65 for multivariate analysis. The 54 species removed were extremely rare and would only contribute extra noise to the analysis.

We tabulated abundance and biomass data for all species into 15 and 13 families and/or family groupings respectively (Tables 1 & 2). Biomass estimates were obtained using length-weight relationships extracted from Fishbase (Froese & Pauly 2009) for each species. The most numerically dominant families were Pomacentridae, Scaridae, Caesionidae, and Acanthuridae (Table 1). On average, the acanthurids had the highest mean biomass per transect (871 g ±219), followed by the caesionids (394 g ±147), the lutjanids (371 g ±106), the scarids (341 g ±61), and the lethrinids (261 g ±39) (Table 2). Members of the family Serranidae (commercially important groupers) were more common than originally expected. These were most abundant and speciose at sites with high coral cover. Unfortunately, sites with the highest grouper density and biomass will be directly impacted.

The multivariate analyses indicate fish assemblages are largely grouping out along a depth/habitat gradient with those sites dominated by coral having the most speciose and abundant fish assemblages (Figure 2A, B, & D). Biomass of commercially important species is highest at the coral-dominated sites while those sites dominated by sand have depauperate fish communities (Figure 3). When analyses were performed with depth as a factor, there was a strong grouping among sites below 12 meters. The greater variability in fish assemblages among sites within the depth range 12-18 meters is likely explained by previous dredging of many of these sites. When sites were coded for their location with respect to future direct or indirect impacts of dredging (Figure 2C) it can be seen that many of the low diversity sites will be directly affected. However, 50% (9 of 18) of those sites dominated by coral will also be directly affected and these sites have the most significant fish assemblages. We also found that for eight of eleven commercially important fish categories, mean biomass per transect was greater for sites with direct project impacts anticipated. However, because of high variability in the data, these differences were only significant for the lutjanids (Kruskal-Wallis $H = 4.5$, $P < 0.05$) while the scarids had a significantly greater mean biomass in sites that will be indirectly affected (Kruskal-Wallis $H = 9.0$, $P < 0.05$).

Among the major habitat types, those dominated by coral and sand had the least similar fish communities, which is not surprising given that coral-dominated sites have high habitat complexity while sand-dominated sites naturally lack fish habitat. Sites dominated by coral were generally the most speciose and diverse whereas the opposite was true for sand-dominated sites (Figure 3). The species most responsible for this difference were *Amblyglyphidodon curacao* and *Chlorurus sordidus*, whose abundance increased by an order of magnitude in coral-dominated sites, and *Chrysiptera cyanea*, whose abundance was greater in sand dominated sites. In general, the vast majority of species recorded increased in abundance at coral-dominated sites.

The lone 'dump site' (site 42) stood out as a unique site with a high mean dissimilarity value compared with other habitats. This was driven by an unusually high abundance of *Cheilinus fasciatus*, *Caranx papuensis*, and *Lutjanus fulvus* which apparently favored the artificial habitat, and a very low abundance of pomacentrid species (*Amblyglyphidodon curacao*, *Chrysiptera cyanea*, and *Chromis viridus*) that are very common in most other habitats. Such pomacentrids are closely associated with benthic habitats which were apparently not available at the artificial reef.

Conclusions

Given the magnitude of the proposed dredging project, there will be major impacts on the reef fish communities present. Site attached species such as those from the families Pomacentridae and Chaetodontidae will be heavily influenced by changes in habitat structure. In fact, pomacentrids are commonly used to measure community change across sites because of their high abundance, small home ranges, and site specificity. In this study, they represented over 60% of the total fish abundance across sites. However, this does not imply that more mobile species will not be unaffected by the same factors, but their mobility potentially enables them to be less influenced by small-scale changes. Nevertheless, the nature of the proposed dredging project will create both small- and large-scale changes in benthic habitat across the study area.

Of particular concern are the high-diversity, high biomass sites which will be directly impacted. Sites of interest include 4 and 10 near the entrance of the channel east of Western Shoals (WS; Figure 1). These coral-rich sites contain a high biomass of commercially important species, including serranid species which are now rare on Guam. Other notable sites which will be directly impacted are 21, 25, 26, 31, 33, 34, 35, 49, and 59 most located within the channel. Perhaps the most important consideration is the fate of sites which will be indirectly impacted as some of these sites contain diverse fish assemblages and attract SCUBA divers. Predicting the impact on the fish communities at these sites is difficult because it will be highly dependent on the impact to the benthic habitat at these sites. Sites in close proximity to dredging will likely suffer more than others, although the effect on highly mobile species could be variable.

The major source of bias in the quantification of fish communities among sites was the variability in water visibility. Many sites within the channel and near the Navy dry dock (DD; Figure 1) had poor visibility. Three sites (56, 44, and 66) had to be removed from the study because visibility was too poor to see anything beyond ~1.5 meters after two attempts on separate days. Poor visibility at a given site would have a negative influence on the estimated abundance of highly mobile species, while the influence on site attached species would be considerable but of lesser concern. Therefore, it is likely that water visibility had a significant effect on the reported richness and abundance of species at many sites.

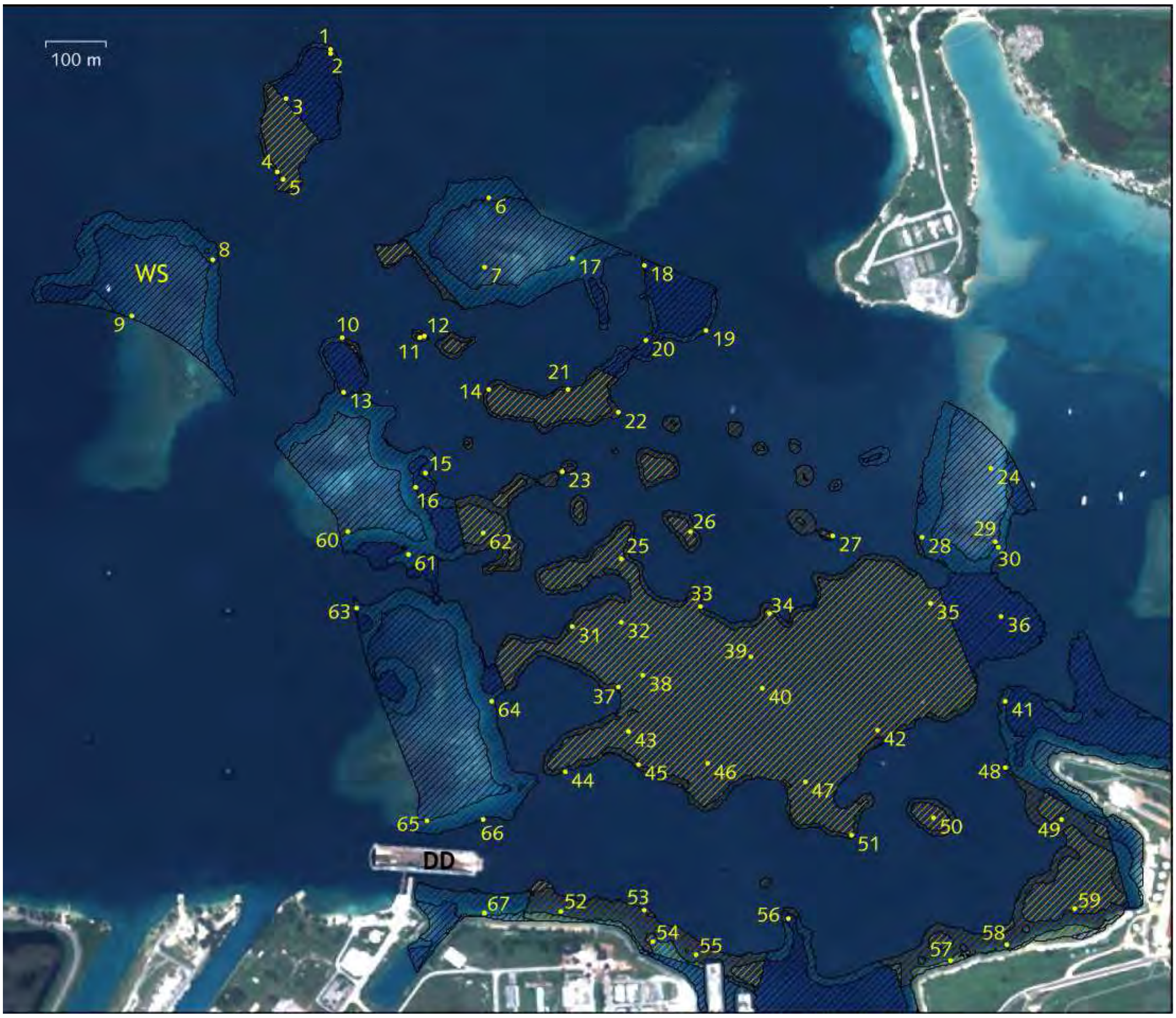

Figure 1. Map of 67 original survey sites within the proposed dredging impact area in Apra Harbor, Guam. Hatched areas are shallower than 18 meters and comprised the survey area. WS = Western Shoals, DD = Navy Dry Dock.

Table 1. Mean density per transect of major fish categories at each site organized by dominant habitat type. Shaded sites represent those with an anticipated direct impact from dredging.

Habitat	Site	*Acanthuridae*	*Caesionidae*	*Carangidae*	*Chaetodontidae*	*Labridae*	*Lethrinidae*	*Lutjanidae*	*Mullidae*	*Other*	*Pomacanthidae*	*Pomacentridae*	*Scaridae*	*Serranidae*	*Siganidae*	*Tetra-odontiformes*
CORAL	1	14.3	63.3	-	5.3	5.7	1.0	0.3	1.0	22.3	-	122.3	8.7	0.3	-	0.7
CORAL	4	15.7	52.7	-	7.7	8.0	-	2.3	0.3	3.7	-	174.0	33.7	0.7	-	1.0
CORAL	6	8.3	-	-	10.7	3.3	-	-	0.3	1.7	-	33.3	14.0	-	-	-
CORAL	8	20.7	-	0.3	8.7	8.0	-	2.3	-	56.7	-	1146.7	4.3	0.7	-	2.3
CORAL	9	9.7	-	-	8.7	10.7	-	-	1.0	30.3	-	222.0	10.3	-	0.7	1.3
CORAL	10	10.0	21.3	-	9.0	6.0	1.0	0.7	0.7	11.0	-	90.3	10.3	2.0	-	0.7
CORAL	25	9.7	27.3	0.3	8.0	5.3	1.7	19.7	0.3	10.3	-	63.0	15.3	0.3	8.3	5.7
CORAL	26	4.0	10.7	-	3.0	3.7	1.7	3.0	0.3	1.7	-	11.3	3.0	0.3	-	0.7
CORAL	28	4.7	-	-	9.0	6.7	-	1.0	-	0.7	-	109.3	19.7	-	-	-
CORAL	29	4.0	-	-	4.7	2.3	1.7	-	-	1.0	-	17.0	21.3	-	-	1.7
CORAL	35	5.0	-	-	3.7	3.3	0.7	3.3	-	-	-	14.0	1.0	-	0.3	-
CORAL	36	2.3	0.7	-	5.0	3.0	0.7	5.3	0.3	0.7	-	15.3	0.3	-	0.7	0.3
CORAL	49	1.7	-	-	5.3	0.7	0.3	1.7	-	-	-	47.0	8.7	-	-	-
CORAL	55	13.7	51.7	0.3	6.0	3.7	0.3	-	-	9.0	-	215.3	1.3	-	-	1.0
CORAL	59	4.3	-	-	1.3	5.0	0.7	1.0	2.0	5.3	-	27.0	9.0	-	-	1.0
CORAL	61	8.3	1.3	-	8.3	3.3	0.3	-	-	1.0	-	40.3	2.3	-	-	0.7
CORAL	62	2.3	0.3	-	2.7	2.0	0.7	-	-	27.3	-	31.3	2.7	-	-	0.7
CORAL	63	16.7	1.3	-	6.7	2.0	2.0	3.7	-	1.3	0.3	13.7	1.3	-	-	0.7
DUMP	42	2.7	6.0	5.3	4.0	15.0	-	5.0	-	1.3	-	-	-	-	0.3	0.3
MAC	7	2.3	-	-	3.0	3.7	1.0	-	-	0.7	-	6.3	70.7	-	0.3	-
MAC	11	-	21.3	-	-	0.3	0.7	-	0.3	-	-	27.7	-	-	-	-
MAC	14	1.0	-	-	0.3	0.3	-	-	-	2.0	-	5.3	0.7	-	-	0.3
MAC	16	8.0	10.3	-	6.3	5.0	0.7	1.0	0.3	0.7	-	55.7	11.3	-	1.0	0.7
MAC	18	2.0	2.3	-	1.7	0.7	0.7	-	-	1.3	-	2.7	0.3	0.3	-	-
MAC	19	1.3	-	-	-	-	-	-	-	0.3	-	2.0	-	-	-	-
MAC	20	2.0	1.0	-	1.7	0.7	-	-	-	1.0	-	0.7	1.0	-	-	-
MAC	21	2.7	18.0	-	1.7	4.0	1.0	10.0	1.0	1.3	-	41.7	4.7	0.7	2.0	0.7
MAC	22	2.3	-	-	1.3	1.0	0.3	-	-	0.7	-	0.3	4.0	-	-	1.0
MAC	23	5.0	17.0	-	3.7	0.7	0.3	7.7	0.7	0.7	-	92.0	0.7	-	1.7	0.7
MAC	27	0.3	-	-	0.7	-	-	-	-	-	-	1.3	-	-	-	-
MAC	33	4.0	2.0	-	1.0	0.3	1.3	5.0	1.0	3.0	-	17.0	1.0	-	0.3	-
MAC	34	0.7	0.3	12.3	2.0	1.3	1.7	2.3	0.3	1.0	-	28.3	2.3	-	0.7	0.3
MAC	39	13.3	1.7	-	7.0	3.3	0.3	5.0	-	0.7	-	52.3	3.0	-	-	-

Table 1. Continued…

Habitat	Site	*Acanthuridae*	*Caesionidae*	*Carangidae*	*Chaetodontidae*	*Labridae*	*Lethrinidae*	*Lutjanidae*	*Mullidae*	*Other*	*Pomacanthidae*	*Pomacentridae*	*Scaridae*	*Serranidae*	*Siganidae*	*Tetraodontiformes*
MAC	40	-	-	-	1.7	-	-	1.3	0.3	-	-	10.0	-	-	-	-
MAC	45	3.0	1.7	-	2.7	1.0	0.7	3.7	-	1.0	-	11.3	12.3	-	-	-
MAC	46	2.3	-	-	2.3	2.3	0.7	1.0	-	1.0	-	21.3	4.7	-	-	-
MAC	50	3.0	-	0.3	5.3	3.3	2.0	8.0	-	6.0	-	17.3	2.7	-	0.7	-
MAC	60	11.7	-	-	2.7	7.3	-	-	-	2.3	-	20.7	21.7	-	2.3	1.0
MAC	65	17.0	-	0.3	5.0	3.0	2.0	-	0.3	18.3	-	11.3	21.0	-	1.0	1.0
RUBBLE	3	1.7	1.7	-	5.7	3.0	0.7	-	-	1.0	-	15.3	3.3	0.3	-	0.3
RUBBLE	13	6.0	-	-	2.0	2.3	-	-	-	8.3	-	13.3	1.3	0.3	-	1.3
RUBBLE	17	4.3	-	-	2.3	1.3	-	-	-	5.0	-	72.0	75.0	-	-	0.3
RUBBLE	24	4.7	-	-	2.3	4.3	2.0	-	0.7	1.7	-	1.7	32.3	-	0.7	0.7
RUBBLE	41	0.3	-	-	1.0	1.7	0.7	2.7	-	3.0	-	1.3	-	0.3	-	0.7
RUBBLE	52	1.7	-	-	1.3	0.3	2.3	0.7	0.3	17.0	-	11.3	2.7	-	-	1.3
RUBBLE	54	5.0	0.3	1.0	2.0	2.0	0.3	-	-	3.3	-	65.3	2.3	-	-	2.0
RUBBLE	57	3.0	-	3.0	1.3	1.7	0.7	-	-	1.0	-	5.3	22.0	-	0.3	0.7
RUBBLE	58	4.0	-	-	2.0	1.7	0.7	-	-	0.7	-	23.3	5.3	-	-	2.3
RUBBLE	67	19.3	-	-	4.7	3.0	2.0	-	0.7	2.3	-	5.0	11.7	-	-	-
SAND	31	9.3	9.7	-	1.7	1.3	1.0	4.7	0.7	1.3	-	58.0	0.3	-	-	0.7
SAND	32	2.0	-	-	-	-	-	0.7	-	-	-	9.0	-	-	-	-
SAND	37	0.3	-	-	0.3	0.3	-	-	-	-	-	8.7	-	-	0.7	-
SAND	43	-	-	-	-	-	-	-	-	0.3	-	0.3	-	-	-	-
SAND	47	-	0.3	0.3	-	-	0.3	-	-	-	-	5.7	-	-	-	-
SAND	48	-	-	0.7	1.3	-	0.3	0.7	-	-	-	1.3	-	-	-	-
SAND	51	-	-	-	-	-	-	-	-	-	-	4.7	-	-	-	-
SAND	53	0.3	-	1.3	-	-	1.7	0.3	-	-	-	2.7	-	-	-	-
SAND	64	0.7	-	-	0.3	1.3	-	-	-	0.3	-	8.7	1.3	-	-	0.3

Table 2. Mean biomass (g) per transect of commercially important fish categories at each site organized by habitat type. Shaded sites represent an anticipated direct impact from dredging.

Habitat	Site	*Acanthuridae*	*Caesionidae*	*Carangidae*	*Haemulidae*	*Labridae*	*Lethrinidae*	*Lutjanidae*	*Mullidae*	*Other*	*Scaridae*	*Serranidae*	*Siganidae*	*Tetra-odontiformes*
CORAL	1	6696	6080	-	-	1374	801	344	12	-	848	38	-	398
CORAL	4	8587	5056	-	-	677	-	3352	57	-	2157	422	-	749
CORAL	6	90	-	-	-	144	-	-	23	-	1377	-	-	-
CORAL	8	4271	-	236	-	775	-	409	-	-	947	499	-	712
CORAL	9	397	-	-	-	315	-	-	19	-	463	-	28	104
CORAL	10	1135	2091	-	-	1198	304	477	552	-	704	1619	-	398
CORAL	25	1243	2601	137	-	852	946	2641	30	-	725	126	1732	1896
CORAL	26	872	231	-	-	120	781	579	1	-	54	74	-	368
CORAL	28	97	-	-	-	456	-	223	-	-	356	-	-	-
CORAL	29	166	-	-	-	84	261	-	-	-	856	-	-	320
CORAL	35	293	-	-	-	185	215	358	-	-	13	-	8	-
CORAL	36	148	107	-	-	309	294	860	30	-	64	-	49	135
CORAL	49	46	-	-	-	1	54	142	-	-	207	-	-	-
CORAL	55	4107	-	71	-	108	360	-	-	-	103	-	-	424
CORAL	59	154	-	-	956	502	109	132	30	-	1167	-	-	8
CORAL	61	107	60	-	-	121	95	-	-	-	93	-	-	15
CORAL	62	213	9	-	-	326	597	-	-	-	99	-	-	65
CORAL	63	3324	128	-	-	427	740	811	-	-	24	-	-	241
DUMP SITE	42	449	1824	1485	-	1226	-	595	-	-	-	-	112	-
MAC	7	84	-	-	-	51	237	-	-	-	1329	-	8	-
MAC	11	-	341	-	-	52	941	-	0	-	-	-	-	-
MAC	14	10	-	-	-	5	-	-	-	-	12	-	-	26
MAC	16	290	992	-	-	651	355	541	57	-	588	-	40	259
MAC	18	150	224	-	-	6	109	-	-	-	8	126	-	-
MAC	19	19	-	-	-	-	-	-	-	-	-	-	-	-
MAC	20	635	-	-	-	10	-	-	-	-	398	-	-	-
MAC	21	602	1728	-	-	252	506	4459	337	-	408	147	215	368
MAC	22	794	-	-	-	85	448	-	-	-	219	-	-	326
MAC	23	1027	-	-	-	38	299	1131	29	-	91	-	149	436
MAC	27	1	-	-	-	-	-	-	-	-	-	-	-	-
MAC	33	3553	128	-	-	21	323	872	130	130	141	-	25	-
MAC	34	81	9	9941	-	27	457	171	23	-	150	-	2	135
MAC	39	1797	115	-	-	68	107	592	-	-	96	-	-	-

Table 2. Continued…

Habitat	Site	*Acanthuridae*	*Caesionidae*	*Carangidae*	*Haemulidae*	*Labridae*	*Lethrinidae*	*Lutjanidae*	*Mullidae*	*Other*	*Scaridae*	*Serranidae*	*Siganidae*	*Tetra-odontiformes*
MAC	40	-	-	-	-	-	-	149	12	-	-	-	-	-
MAC	45	37	41	-	-	5	374	199	-	-	115	-	-	-
MAC	46	63	-	-	-	66	77	324	-	-	135	-	-	-
MAC	50	201	-	1404	-	206	963	951	-	-	132	-	45	-
MAC	60	488	-	-	-	11	-	-	-	-	452	-	50	129
MAC	65	1603	-	137	-	67	724	-	23	-	1020	-	30	129
RUBBLE	3	79	160	-	-	197	374	-	-	-	293	214	-	135
RUBBLE	13	420	-	-	-	37	-	-	-	-	127	197	-	142
RUBBLE	17	63	-	-	-	103	-	-	-	-	1091	-	-	-
RUBBLE	24	151	-	-	-	5	316	-	7	-	1147	-	28	91
RUBBLE	41	8	-	-	-	161	162	271	-	-	-	126	-	163
RUBBLE	52	134	-	-	-	5	751	44	1	132	5	-	-	118
RUBBLE	54	964	32	278	-	295	54	-	-	-	263	-	-	162
RUBBLE	57	16	-	81	-	66	109	-	-	401	155	-	2	2
RUBBLE	58	316	-	-	-	167	109	-	-	-	266	-	-	96
RUBBLE	67	1537	-	-	-	768	528	-	15	-	892	-	-	-
SAND	31	2874	928	-	-	83	269	706	-	-	6	-	-	820
SAND	32	76	-	-	-	-	-	153	-	-	-	-	-	-
SAND	37	1	-	-	-	6	-	-	-	-	-	-	10	-
SAND	43	-	-	-	-	-	-	-	-	-	-	-	-	-
SAND	47	-	9	97	-	-	23	-	-	-	-	-	-	-
SAND	48	-	-	194	-	-	107	45	-	-	-	-	-	-
SAND	51	-	-	-	-	-	-	-	-	-	-	-	-	-
SAND	53	29	-	388	-	-	887	7	-	-	-	-	-	-
SAND	64	38	-	-	-	29	-	-	-	-	17	-	-	26

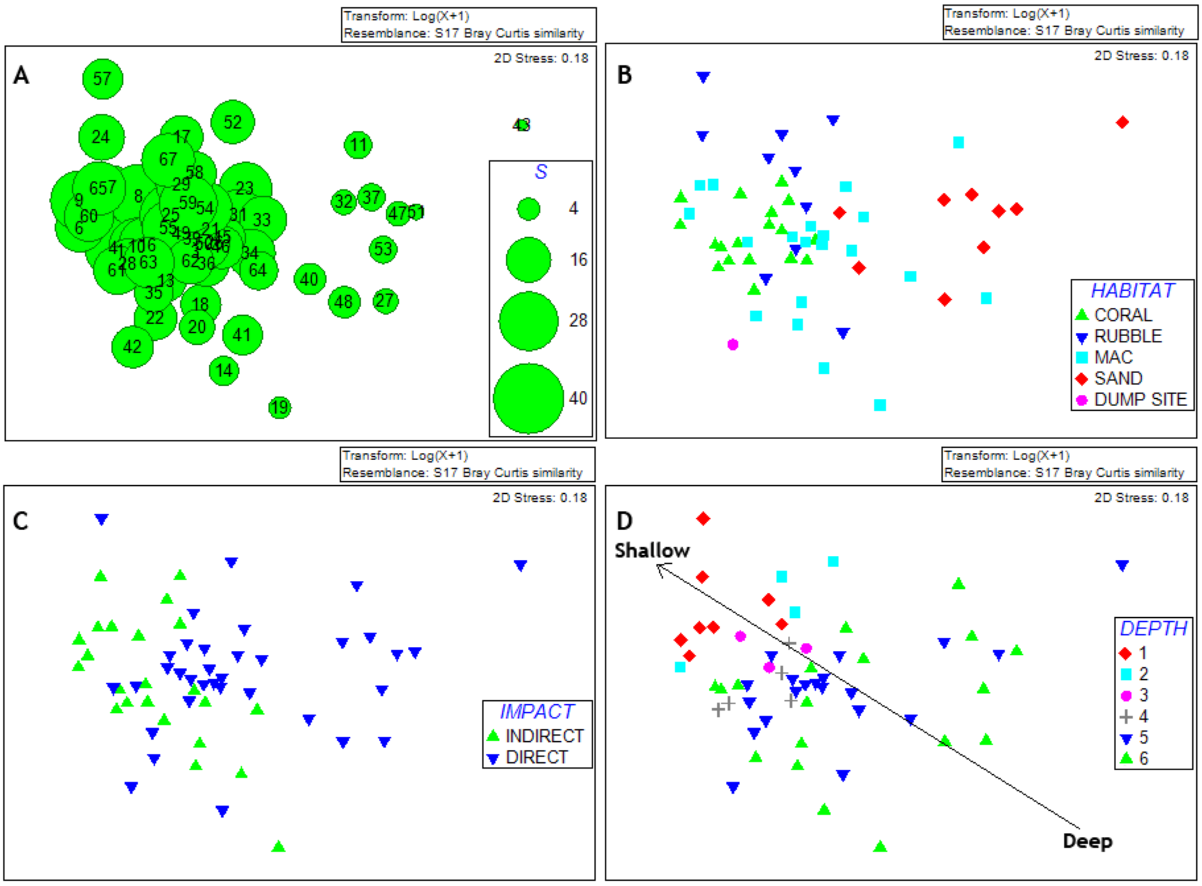

Figure 2. The nMDS plots showing the spatial similarity of reef fish assemblages from all surveyed sites at the species level with A) bubble size representing species richness with site numbers labeled, B) dominant habitat type overlaid, C) type of anticipated impact from CVN dredging project overlaid, and D) depth overlaid. In D, depth **1** represents depths <10 ft, **2** = 11-20 ft, **3** = 21-30 ft, **4** = 31-40 ft, **5** = 41-50 ft, and **6** = 51-60 ft.

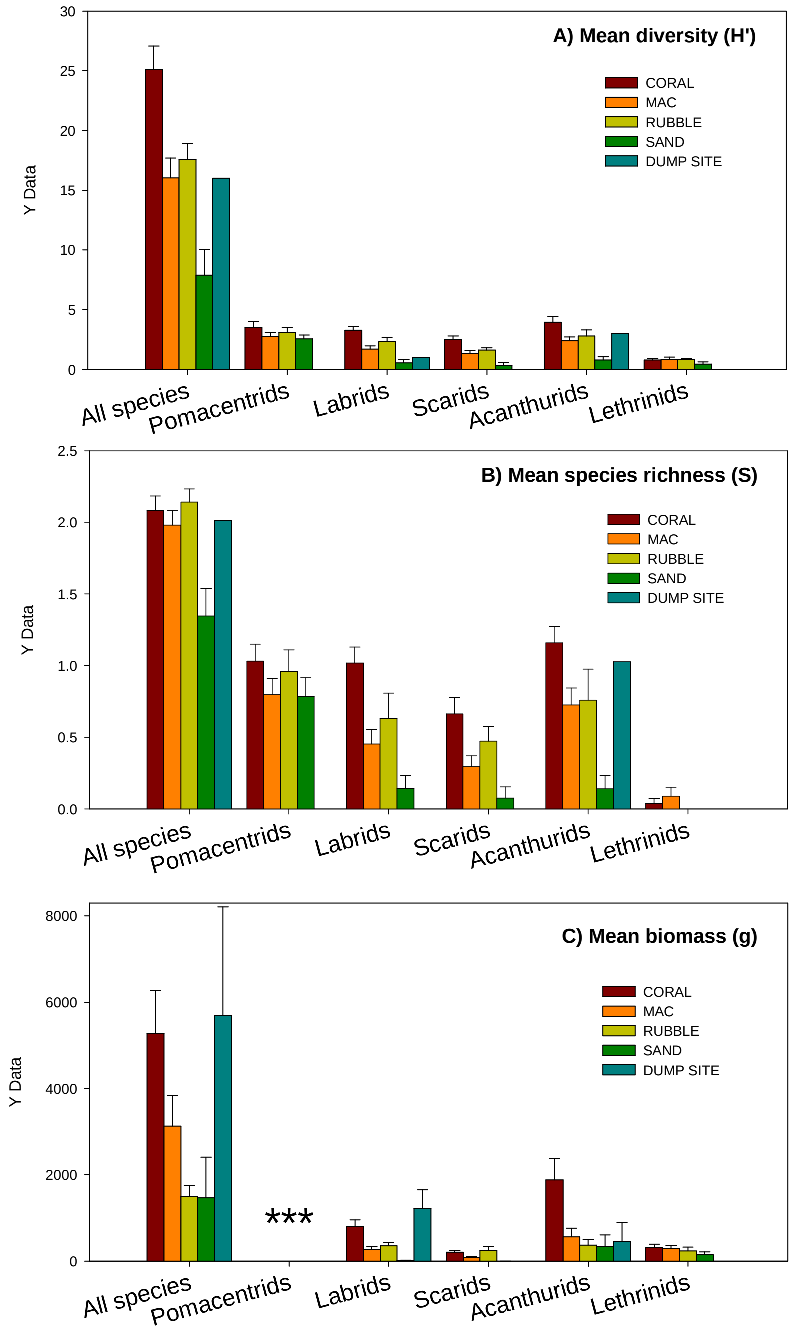

Figure 3. Histograms showing A) the mean diversity value (Shannon diversity H'), B) the mean species richness (total number of species S), and C) the mean biomass in grams for all fish and the most common families by habitat type. *** Biomass was not estimated for the family Pomacentridae.

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Appendix J
Supplemental Aircraft Carrier Marine Surveys

9. Cover letter and Scope of Work for Marine Surveys for the CVN Project Area and Potential Mitigation Sites, and Habitat Equivalency Analysis. May and June 2010.

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DEPARTMENT OF THE NAVY

THE ASSISTANT SECRETARY OF THE NAVY
(ENERGY, INSTALLATIONS & ENVIRONMENT)
1000 NAVY PENTAGON
WASHINGTON DC 20350-1000

Mr. Jared Blumenfeld
Regional Administrator
U.S. EPA Pacific Southwest Region
75 Hawthorne Street
San Francisco, CA 94105

MAY 26 2010

Dear Mr. Blumenfeld,

The purpose of this letter is to memorialize our recent agreement that the Department of the Navy will voluntarily collect additional coral reef functional assessment data for the Carrier Vessel Nuclear (CVN) Berthing Project in Apra Harbor, Guam. We will implement the attached scope of work developed by U.S. Fish and Wildlife (USFWS), National Oceanic and Atmospheric Administration (NOAA), and EPA to augment data already collected for the Guam and CNMI Military Relocation Project Draft Environmental Impact Statement.

This work will provide additional information to assess coral reef conditions in Apra Harbor and baseline conditions at potential compensatory mitigation sites for the functional assessment requirements of the EPA/Army Corps of Engineers 2008 Compensatory Mitigation Rule. This information will also be incorporated into project-specific National Environmental Policy Act documentation prepared for Clean Water Act permitting.

I understand that this additional work will adequately address any concerns raised by EPA and other resource agencies regarding coral and mitigation data for site selection and permitting of a CVN transient berthing facility on Guam. I look forward to working with EPA and our other federal partners in finalizing the scope of work and completing this effort.

Thank you for your continued involvement on this matter.

Sincerely,

Jackalyne Pfannenstiel
Assistant Secretary of the Navy
Installations and Environment

Attachment:
Scope of Work for Marine Surveys of the CVN Project Area and Potential Mitigation Sites, and a Habitat Equivalency Analysis

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June 25, 2010

Final Scope of Work Elements
for
Marine Surveys of the CVN Project Area and Potential Mitigation Sites, and Habitat Equivalency Analysis

I. OBJECTIVES/GOALS

a) Develop a Statement of Work (SOW) to collect additional marine resource data to augment existing Department of Navy (DoN) surveys of biological resources within Apra Harbor to further inform the selection of the transient aircraft carrier nuclear (CVN) berthing and mitigation sites and support required National Environmental Policy Act (NEPA) analysis, and United States Army Corps of Engineers (USACE) permitting actions under the Clean Water Act (CWA), and the Rivers and Harbors Act of 1899 (R&HA). Additional marine resource data will also support compliance with Essential Fish Habitat coordination with NOAA-National Marine Fisheries Service (NOAA) under the Magnuson-Stevens Fishery and Conservation Management Act, and compliance with the Coral Reef Protection Executive Order 13089.

b) Additional data will supplement baseline CVN information to assist USACE with the evaluation of marine resources Projects and identification of potential mitigation sites by: (1) providing a description and baseline of the affected environment at proposed transient CVN berth and mitigation sites ; (2) provide input into a Habitat Equivalency Analysis (HEA) or equivalent functional assessment tool; and (3) provide additional data for USACE consideration regarding the functional assessment requirements of the USACE/EPA 2008 Compensatory Mitigation Rule.

c) Incorporate additional data into DON's application for USACE CWA Sec 404 and R&HA Sec 10 Permit and, if required, supporting NEPA analysis for the construction of a transient berthing facility and to further analyze potential environmental mitigation Projects resulting from the proposed site selection for the CVN transient berthing project.

II. PLAN OF ACTION

Coordination with Stakeholders

The DoN will hold periodic meetings with the federal and local resource agencies for the purpose of providing information and oversight of this data collection effort. If needed, the Navy will engage the U.S. Institute for Environmental Conflict Resolution (USIECR) to facilitate mediation among federal and local resource agencies with the goal of achieving agreement on issues in dispute. The parties may include DoN, USACE, EPA, NOAA, USFWS, Guam EPA, Guam Division of Aquatic and Wildlife Resources, and the Guam Coastal Management Program.

Variables/Metrics

The variables listed in Table 1 are recommended by the Resource Agencies (RA) for collection at all sites. These data will be obtained for all sites either from existing data (if present and appropriate to use) or through in-field data collection.

Project Phases

Phase 1: Site Assessment and Reporting

Surveys have been completed by DoN on 67 sites in Apra Harbor within the CVN project area. Thirty of these 67 sites were resurveyed, and additional data collected by the RAs, to include all of the variables listed in Table 1. In addition to these existing 67 sites, surveys of an additional 35 sites are proposed, giving a total of 102 survey sites within the project proposed CVN access channel, turning basin, and waterfront (i.e. Project Area). Surveys will include completing data collection of all Table 1 variables at the 37 DoN sites that were not previously resurveyed by the RAs, and collection of all Table 1 variables at the 35 proposed sites (locations to be determined).

Phase 2: Preliminary Mitigation Site Assessment and Reporting

Numerous potential mitigation projects/locations exist. The preliminary Final EIS for the Guam and CNMI Military Relocation Project includes a discussion of thirteen (13) potential mitigation options (an output of a CEQ-led coral assessment/mitigation group) for CVN. Options include watershed restoration, coral transplantation, coral reef restoration (on DoD as well as non-DoD submerged lands), aquaculture and artificial reefs among others. DoN has already conducted a preliminary assessment of mitigation potential for four watersheds. Using the DoN work as a starting point, additional surveys of potential mitigation locations will be conducted. The survey will look at both in-water and upland locations. The survey will then allow subsequent efforts (Phase 3) to focus mitigation planning on a few locations, thus optimizing time and resources. At each potential mitigation location that involves in-water data collection, data will be collected at 3-5 sites using the same methods as those employed within the CVN Project Area (Table 1). These "pilot" data will aid with development of a statistically rigorous sampling plan for Phase 3. The output of Phase 2 includes a recommended work plan/scope of work for Phase 3 efforts.

Phase 3: Mitigation Site Assessment and Reporting

In-water mitigation sites selected for additional survey work in Phase 2 will be investigated using the same survey methods (i.e. sample size/design) employed within the CVN Project Area. The time required to survey each location will depend on the number of sites selected, their size, and their specific location. This work will be conducted under separate contract from Phases 1 and 2. Phase 3 will also investigate potential upland watershed restoration locations and make detailed recommendations for watershed improvements (tree planting, erosion control, etc.). The output of Phase 3 is a detailed assessment of mitigation options that can be used by DoN to develop a detailed compensatory mitigation plan for follow-on permitting and, if required, supplemental NEPA.

Table 1. RA preferred list of variable/metrics selected for data retrieval/collection as part of the marine resource surveys of Apra Harbor to support the CVN Project. Variables/metrics are presented in no particular order.

Coral Data

Variable	Metric
Algae Abundance by species (or lowest possible taxonomic level)	Percent of bottom covered
Coral colony abundance: density of colonies by species (or lowest possible taxonomic level) and morphological form	# of colonies/m^2
Coral colony size	Length of longest axis in centimeters
Coral Fragments	To be determined
Partial coral colony mortality	% mortality on colonies with complete fission
Occurrence of gross growth anomalies and/or anomalous patterns of tissue loss by species (or lowest possible taxonomic level)	% of colonies showing the described condition[1]

[1] Photographs of affected colonies will be sent to a coral disease expert for identification and data be presented by the identified name.

Other Biological Data

Variable	Metric
Mobile macro-invertebrate density by species (or lowest possible taxonomic level)	# of individuals/m^2
Sessile Macro-invertebrate (especially sponges) abundance by species (or lowest possible taxonomic level)	Percent of bottom covered or other relevant measure (e.g., for sponges)
Fish abundance and diversity by species (or lowest possible taxonomic level)	# of individuals/m^2 or # of individuals/minute
Individual fish size	Length in centimeters
Occurrence of protected species (e.g. sea turtles)	Presence-absence/site
Rugosity	Rugosity index

Phase 4: Habitat Equivalency Analysis (HEA) or Equivalent Functional Assessment Tool

A HEA (or equivalent functional assessment tool), conducted by a mutually agreed qualified party, will be developed to propose the scale of the mitigation, for the USACE to consider, at each selected mitigation site. The HEA (or equivalent) will use the relevant data collected at the CVN Project Area as well as for each proposed mitigation site. The HEA (or equivalent) will also be conducted under separate contract from Phases 1 and 2.

Methods and Survey Design

The final survey methods and sampling design will be developed by a mutually agreed third party in coordination with DoN, USFWS, NOAA, EPA and USACE and the results will be detailed in a Survey Methods and Sampling Plan. This plan will include, at minimum, a detailed description of the methods used to collect the data for each variable and a statistically valid sampling design. An estimate of the sampling design's statistical rigor will also be provided (*e.g.*, variability estimates for the proposed data).

A statistically rigorous sampling design cannot be completed without the following information, which the DoN will supply:

1) ArcGIS files for the habitat map generated by DoN contractors for the Draft Environmental Impact Statement.
2) ArcGIS digital elevation model (DEM) created from the LIDAR data and relevant products (e.g., habitat layer, "landscape rugosity", etc.) derived from this data.

Personnel

Due to the taxonomic specialization necessary to complete this type of work, this project will be undertaken by mutually agreed third parties with scientific/taxonomic expertise in the following areas: hard coral, marine fish, marine algae, non-coral invertebrates. Further, preference shall be given, but not limited to those third parties that have previous experience conducting dive surveys of the data specified in Table 1 for projects in Guam or the Marianas Islands. The third party who performs this work must have an approved DoN dive safety plan that complies with DoN requirements (EM-385, 1-1).

III. REPORTS

The following products will be provided by the mutually agreed third party:

1) Survey Methods and Sampling Plan. This plan will include a detailed description of the methods used to collect the data for each variable and a statistically valid sampling design.
2) Reports. All reports will include the following standard sections: (a) introduction with project background and review of relevant literature, (b) methods, (c) results, (d) discussion of survey, (e) references, and (f) appendices of all raw data. Draft reports will be released to all partners for review and comment.
3) Final Reports. Final reports will address comments received by the reviewers on draft reports. Electronic copies of final reports shall be submitted on CD-R, and shall include the source files (*e.g.*, Microsoft Word for Windows 2000).
4) Final Data. Any generated maps shall be on paper and in digital format (submitted on CD-R) compatible with ArcGIS version 9.X with associated attribute tables of GPS data (in UTM,

WGS 84 Zone 55N, Meters). As appropriate, the maps will depict the locations, areas, or resources and/or habitats that are deemed particularly sensitive to the proposed action and may incorporate or enhance previously collected geospatial data. Data collected shall be compliant with SDSFIE (Spatial Data Standards for Facilities, Infrastructure and Environment).

Time Line

If construction for the CVN project is to begin in late 2012, field surveys should commence no later than July 2010 to allow sufficient time to complete the SOW elements and CWA and R&HA permitting processes. Flexibility will be given to accommodate work constrained by weather and ocean conditions. Surveys conducted within Apra Harbor can occur at any time during the year. However, any surveys conducted outside Apra Harbor may be restricted to summer months when weather and sea conditions are conducive to in-water work. To support required field work it is important that funding agreements with the DoN and the mutually agreed third party be finalized as soon as possible to allow for maximum flexibility in scheduling field work to ensure that project deadlines can be met. The approximate timeline to complete this work is 9-12 months.

Table 2 contains a breakdown of the proposed timeline. In general, all phases need to be conducted sequentially, not concurrently.

Table 2. Survey Project timeline.

Date	Event/Task
NTP	Funding documents put in place
NTP+14 days	Phase 1: Submission of the Survey Methods and Sampling Plan
NTP+24	Phase 1:Review/concurrence by federal agencies and Final Plan submitted
NTP+50 days	Phase 1: Complete Field Work
NTP+78 days	Phase 1: Complete data processing
NTP+106 days	Phase 1: Draft Report delivered to DoN
14 days after receipt of DoN comments	Phase 1: Final Report and electronic data files delivered to DoN
Note2	Phase 2: Notification from DoN of Sites to be surveyed
Note2+20 days	Phase 2: Complete Field Work (includes planning time)
Note2+30 days	Phase 2: Complete data processing
Note2+44 days	Phase 2: Final Report delivered to DoN (no draft necessary)
Note3	Phase 3: Notification from DoN of Sites to be surveyed
*	Phase 3: Submission of the Survey Methods and Sampling Plan
*	Phase 3: Complete Field Work
*	Phase 3: Complete Data processing
*	Phase 3: Draft Report delivered to DoN
14 days after receipt of DoN comments	Phase 3: Final Report and electronic data files delivered to DoN
Note4	Phase 4: All relevant data received (*e.g.*, Project, Project reduction and recovery potential data by category)
**	Phase 4: Complete data sorting for scaling
**	Phase 4: Complete HEA Scaling and Functional Trade-offs Analysis

**	Phase 4: Completed Draft Report(s) delivered to DoN
14 days after receipt of DoN comments	Phase 4: Final Report and electronic data files delivered to DoN

NTP=Notice To Proceed, contract term for start date.
*Survey time will varying depending upon sites selected. To be determined once selection is made.
** Timing will vary depending on number and types of mitigation projects selected for analysis.

IV. STIPULATIONS AND RESTRICTIONS

A third party contractor agreed to by DoN, USFWS, NOAA, and EPA will be used to collect, analyze, and report on the surveys described herein. A final work plan will be submitted by a third party contractor to DoN before any field work is conducted. DoN will share the work plan with the USFWS, NOAA, EPA, and USACE and obtain written agreement from USFWS, NOAA, and EPA before any surveys begin.

USFWS and NOAA will contribute expertise in the form of training and technical support to any third party contractor selected, prior to conduct of the assessments. As one element of this support, NOAA and USFWS staff will accompany the contractor during the first week of assessments to preclude confusion in regard to the application of the methods defined in the contractor scope of work. If any significant issues are identified, they will be addressed through DoN as the manager of the contract. In addition, NOAA and USFWS will coordinate with the Navy to accompany the contractor in the field during later phases of the surveys, in order to familiarize NOAA and USFWS with work being performed, and as an aid to subsequent data analysis.

Appendix 1. Proposed methods for CVN surveys

Coral Methods
Coral surveys will be conducted by mutually agreed third party divers with preference given to those with taxonomic expertise in Mariana Islands coral reefs pursuant to the Survey Methods and Sampling Plan.

Algae and sessile non-coral invertebrates methods
Divers, with preference given to those with taxonomic expertise in Mariana Islands benthic communities will collect benthic composition data pursuant to the Survey Methods and Sampling Plan.

Mobile non-coral invertebrates methods
Non-coral invertebrate surveys will conducted by divers with preference given to those with taxonomic expertise and experience with Mariana Islands invertebrate fauna pursuant to the Survey Methods and Sampling Plan.

Fish[1]
Fish surveys will be conducted by divers with preference given to those with taxonomic expertise in Mariana Islands coral reef pursuant to the Survey Methods and Sampling Plan.

Incidental sightings of marine mammals and reptiles
Incidental sightings of marine mammals and reptiles will be noted at all survey sites and while in the vicinity of the study areas. Where possible, the location of the observation will be taken using a Garmin 76CSX Global Positioning System unit and the mammals or reptiles will be photographed.

[1] Prior to finalizing fish methods for this project, the methods used by the UoG researchers for previous survey work in the CVN area will be reviewed. The methods for this proposed project will be modified as necessary to ensure that all data is comparable.

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