UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL OCEAN SERVICE
Silver Spring, Maryland 20910

CRUISE REPORT[1]

VESSEL: *Hi'ialakai*, Cruise HA-09-03

CRUISE PERIOD: 15 April–7 May 2009

AREA OF OPERATION: Commonwealth of the Northern Mariana Islands (CNMI: Saipan, Sarigan, Pagan, Asuncion, Supply Reef, Farallon de Pajaros, Maug, Agrihan, Alamagan, Guguan, Zealandia, and Anatahan) (Fig. 1)

TYPE OF OPERATION: Personnel from the Coral Reef Ecosystem Division (CRED), Pacific Island Fisheries Science Center (PIFSC), National Marine Fisheries Service (NMFS), NOAA, and their partner agencies conducted coral reef assessment/monitoring and oceanographic studies in waters surrounding the Commonwealth of the Northern Mariana Islands.

ITINERARY:

15 April — In port Saipan Harbor. Commenced calibration dives for fish rapid ecological assessment (REA) divers and benthic tow team outside Saipan Harbor. This included divers that were aboard for HA-09-02 as well as divers that were embarking for the northern islands CNMI leg. Divers included: Robert Schroeder (Chief Scientist, REA Fish), Paula Ayotte (REA Fish), Valerie Brown (REA Fish), Kaylyn McCoy (REA Fish), Marc Nadon (REA Fish), Edmund Coccagna (Benthic Tow), Jason Helyer (Benthic Tow), and Jake Asher (Benthic Tow). (Note: fish tow team calibration dives were not possible due to lack of large fishes around Saipan.)

16 April — In port Saipan Harbor. Continued calibration dives for benthic REA team, two outside of Saipan Harbor. Divers included: Kerry Grimshaw, Laurie Raymundo, Cristi Richards, Jean Kenyon, Dave Burdick, and Bernardo Vargas-Angel.

17 April — In port Saipan Harbor. Teams worked independently on final pre-cruise logistical preparations, as remaining scientists arrived and settled into their berths.

[1] PIFSC Cruise Report CR-09-019
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18 April Start of cruise. Embarked Robert Schroeder (Chief Scientist, Fish REA), Florent Angly (Oceanography), Jake Asher (Tow Team), Paula Ayotte (Fish REA), James Bostick (Divemaster/Chamber Operator), Valerie Brown (Fish REA), Bonnie DeJoseph (Tow Team), Marie Ferguson (Education/Outreach, Fish REA) Kerry Grimshaw (Data Manager, Benthic REA), Jason Helyer (Tow Team), Jean Kenyon (Benthic REA), Kevin Lino (Oceanography), Frank Mancini (Oceanography), Danny Merritt (Oceanography), Marc Nadon (Fish REA), Russell Reardon (Benthic REA, Autonomous Reef Monitoring Structures [ARMS]), Benjamin Richards (Tow Team), Cristi Richards (Benthic REA), Stephanie Schopmeyer (Benthic REA), Molly Timmers (Benthic REA, ARMS), Bernardo Vargas-Angel (Benthic REA), and Chip Young (Oceanography). Conducted ship orientation and neurological exams for new scientists and conducted dive-safety briefing. Launched small boats for tow, oceanography, and REA fish and benthic teams; began research operations. The fish and benthic REA teams surveyed two established REA sites (SAI-06, and SAI-07). The independent fish and Line-Point Intercept (LPI) benthic REA teams surveyed three new sites (SAI-53, SAI-54, and SAI-55). The tow team completed 4.5 tows on the southwest and south sides of the island, covering 11 km. The oceanography team conducted 14 shallow-water conductivity-temperature-depth (CTD) casts, and collected six chlorophyll/nutrient water samples and one microbial sample. Total dives for all teams: 30.

19 April Continued operations at Saipan. The fish and benthic REA teams surveyed one established site and one new site (SAI-02 and SAI-09) along the east side. The independent fish and LPI benthic teams surveyed four new sites, two deep and two shallow (SAI-56, SAI-57, SAI-58, and SAI-59) along the northeast and east sides. The tow team completed four survey tows along the northeast and east sides of the island, covering 9 km. The oceanography team exchanged two ecological acoustic recorders (EARs) on the east side of the island, conducted eight shallow-water CTD casts, collected eight chlorophyll/nutrient water samples and one microbial sample. Total dives for all teams: 46.

20 April Continued operations at Saipan. The fish and benthic REA teams surveyed three established sites (SAI-02, SAI-03 and SAI-05) around the southeast side of the island. Three ARMS were deployed at site GUA-05. The independent fish and LPI benthic teams surveyed four new sites, two deep and two shallow (SAI-60, SAI-61, SAI-62, and SAI-63). The tow team completed six tows covering 14 km along the east and south sides of the island. The oceanography team recovered one wave and tide recorder (WTR), deployed one subsurface temperature recorder (STR), conducted eight shallow water CTD casts, and collected four chlorophyll/ nutrient water samples and one microbial sample. Total dives for all teams: 55.

21 April	Commenced operations at Sarigan. The fish and benthic REA teams surveyed three established sites (SAR-01, SAR-02 and SAR-03). The independent fish and LPI benthic teams surveyed four new sites, two deep and two shallow (SAR-50, SAR-51, SAR-52, and SAR-53). The tow team completed five survey tows and one calibration tow covering 14 km. The oceanography team conducted eleven CTD casts, collected four chlorophyll/nutrient samples, and collected one microbial sample. Nighttime oceanography operations consisted of one deepwater CTD and seven nutrient/chlorophyll samples. Total dives for all teams: 59.
22 April	Commenced operations at Pagan. The fish and benthic REA teams surveyed three established sites (PAG-02, PAG-03, and PAG-05). The independent fish and LPI benthic teams surveyed four new sites, two deep and two shallow (PAG-50, PAG-51, PAG-52 and PAG-53). The tow team completed six tows covering 14 km covering the north and northwest sides of the island. The oceanography team deployed one sea surface temperature (SST) buoy, deployed and recovered one STR, installed a land-based weather station, conducted eight shallow-water CTD casts, collected four nutrient/chlorophyll samples, and collected one microbial sample at REA site PAG-03. Nighttime oceanographic operations consisted of one deepwater CTD and five nutrient/chlorophyll samples. Total dives for all teams: 57.
23 April	Continued operations at Pagan. The fish and benthic REA teams surveyed three established sites (PAG-01, PAG-08 and PAG-13). The independent fish and benthic teams surveyed four new sites, two deep and two shallow (PAG-54, PAG-55, PAG-56 and PAG-57). The tow team completed six tows covering 13 km. The oceanography team deployed and recovered two STRs and deployed one new STR, conducted seven shallow water CTD casts, collected four nutrient/ chlorophyll samples, and collected one microbial sample. Nighttime oceanography operations consisted of one deepwater CTD and five nutrient/chlorophyll samples. Total dives for all teams: 62.
24 April	Continued operations at Pagan. The fish and benthic REA teams surveyed three established sites (PAG-06, PAG-09 and PAG-12). The independent fish and benthic teams surveyed four new sites, two deep and two shallow (PAG-58, PAG-59, PAG-60 and PAG-61). The tow team completed four tows covering 9 km. The oceanography team deployed one STR and one EAR, conducted eight shallow-water CTD casts, and collected eight nutrient/chlorophyll samples. Total dives for all teams: 54.
25 April	Commenced operations at Asuncion. The fish and benthic REA teams surveyed three established sites (ASC-01, ASC-02 and ASC-03). The independent fish and LPI benthic teams surveyed four new sites, two deep and two shallow (ASC-50, ASC-51, ASC-52 and ASC-53). The tow team

completed five tows covering 9 km. The oceanography team recovered one STR, deployed three STRs, conducted one shallow-water CTD cast, collected two nutrient/chlorophyll samples, and collected one microbial sample. Three fish collection dives yielded four specimens. Nighttime oceanographic operations consisted of one deepwater CTD and five nutrient/chlorophyll samples. Total dives for all teams: 60.

26 April Continued operations at Asuncion. The fish and benthic REA teams surveyed three new sites (ASC-04, ASC-05 and ASC-06). The independent fish and LPI benthic teams surveyed three new sites, one deep and two shallow (ASC-54, ASC-55, and ASC-56). The tow team completed four calibration tows covering 9.1 km. The oceanography team conducted 14 shallow water CTD casts, collected 4 nutrient/ chlorophyll samples, and collected 1 microbial sample. Fish collection free dives yielded 36 specimens. Nighttime oceanographic operations consisted of one deepwater CTD and five nutrient/chlorophyll samples. Total dives for all teams: 45.

27 April Commenced operations at Supply Reef. The oceanography team recovered and deployed one STR and recovered one WTR. Oceanographic operations also consisted of one deepwater CTD and seven nutrient/chlorophyll samples. Total dives for all teams: 5.

28 April Commenced operations at Farallon de Pajaros (Uracas). The fish and benthic REA teams surveyed three established sites (FDP-01, FDP-02 and FDP-04). The independent fish and LPI benthic teams surveyed four new sites, two deep and two shallow (FDP-50, FDP-51, FDP-52 and FDP-53). The tow team completed three survey tows and two calibration tows covering 10.4 km. The oceanography team recovered and deployed six STRs, conducted eight shallow-water CTD casts, collected four nutrient/ chlorophyll samples, and collected one microbial sample. Nighttime oceanographic operations consisted of one deepwater CTD and five nutrient/chlorophyll samples. Total dives for all teams: 57.

29 April Commenced operations at Maug. The fish and benthic REA teams surveyed three established sites (MAU-02, MAU-04 and MAU-12). The independent fish and LPI benthic teams surveyed four new sites, two deep and two shallow (MAU-50, MAU-51, MAU-52 and MAU-53). The tow team completed five tows covering 10 km. The oceanography team deployed one SST, three STRs and one EAR, conducted 17 shallow-water CTD casts, collected six nutrient/chlorophyll samples, and collected one microbial sample. Total dives for all teams: 62.

30 April Continued operations at Maug. The fish and benthic REA teams surveyed three established sites (MAU-01, MAU-10 and MAU-11). The independent fish and LPI benthic teams surveyed four new sites, two deep

and two shallow (MAU-54, MAU-55, MAU-56 and MAU-57). The tow team completed three survey and one calibration tows covering 8.6 km. The oceanography team deployed one EAR and one STR, deployed/retrieved three STRs, conducted one shallow-water CTD cast, and collected two nutrient/chlorophyll samples. Fish collection free dives yielded 22 specimens. Total dives for all teams: 54.

1 May Continued operations at Maug. The fish and benthic REA teams surveyed three established sites (MAU-03, MAU-06 and MAU-09). The independent fish and LPI benthic teams surveyed four new sites, two deep and two shallow (MAU-58, MAU-59, MAU-60 and MAU-61). The tow team completed two calibration tows covering 4.3 km. The oceanography team conducted four shallow-water CTD casts, collected eight nutrient/chlorophyll samples and collected one microbial sample. Fish collection free dives yielded 20 samples. Total dives for all teams: 60.

2 May Commenced operations at Agrihan. The fish and benthic REA teams surveyed three established sites (AGR-01, AGR-02 and AGR-06). The independent fish and LPI benthic teams surveyed four new sites, two deep and two shallow (AGR-50, AGR-51, AGR-52 and AGR-53). The tow teams completed six tows covering 13 km. The oceanography team deployed two STRs and recovered one STR, conducted 17 shallow water CTD casts, collected 10 nutrient/chlorophyll samples, and collected one microbial sample. Total dives for all teams: 59.

3 May Continued operations at Agrihan. The fish and benthic REA teams surveyed two established sites (AGR-04 and AGR-05) and one new site (AGR-07). The independent fish and LPI benthic teams surveyed four new sites, two deep and two shallow (AGR-54, AGR-55, AGR-56 and AGR-57). The tow team completed 5.5 tows covering 11 km. The oceanography team conducted one shallow water CTD cast, collected two nutrient/chlorophyll samples and collected one microbial sample. Fish collection free dives yielded four specimens. Total dives for all teams: 49.

4 May Commenced operations at Alamagan. The fish and benthic REA teams surveyed two established sites (ALA-02 and ALA-03). The independent fish and LPI benthic teams surveyed four new sites, two deep and two shallow (ALA-50, ALA-51, ALA-52 and ALA-53). The tow team completed six tows covering 13 km. The oceanography team deployed and recovered two STRs, conducted eighteen shallow-water CTD casts, collected six nutrient/chlorophyll samples, and collected one microbial sample. Total dives for all teams: 52.

5 May Commenced operations at Guguan. The fish and benthic REA teams surveyed three established sites (GUG-01, GUG-02 and ALA-03). The independent fish and LPI benthic teams surveyed three new sites, two

deep and one shallow (GUG-50, GUG-51, and GUG-52). The tow team completed four tows covering 8 km. The oceanography team deployed and recovered one STR, conducted twelve shallow-water CTD casts, collected six nutrient/chlorophyll samples, and collected one microbial sample. Total dives for all teams: 51.

6 May | Commenced operations at Zealandia Bank. The oceanography team recovered and deployed one STR and recovered one WTR. Total dives for all teams: 4.

Commenced operations at Anatahan. The oceanography team conducted five shallow-water CTD casts and collected four nutrient/chlorophyll samples. The Tow and REA teams conducted exploratory dives along the south and southwest coasts for qualitative observations on reef community recovery from multiple volcanic eruptions and ash deposition since early 2003. Total dives for all teams: 12.

7 May | Arrived at Saipan Harbor. Disembarked all scientists.

Table 1.--Cruise statistics for HA-09-03.

	Saipan	Sarigan	Pagan	Ascuncion	Supply Reef	Farallon de Pajaros	Maug	Agrihan	Alamagan	Guguan	Zealandia	Anatahan	CRUISE TOTALS
Towed-diver Habitat/Fish Surveys	21.5	5	15	5	0	3	8	11.5	6	4	0	0	79
Towed Diver Habitat Diver Calibration Tows/Dives	0	1	1	4	0	2	3	0	0	0	0	0	11
Combined tow lengths (km)	44	14	36	18.1	0	10.4	22.9	24	13	8	0	0	190.4
Fish Rapid Ecological Assessments	23	7	21	13	0	7	21	14	6	6	0	0	118
Benthic Rapid Ecological Assessments	23	7	21	13	0	7	20	14	6	6	0	0	117
Invertebrate Assessment/collection dives	7	3	6	5	0	3	6	6	2	3	0	0	41
ARMS deployed (3 per site)	2	0	3	0	0	0	3	0	0	0	0	0	8
SST buoys recovered	1	0	0	0	0	0	0	0	0	0	0	0	1
SST buoys deployed	1	0	1	0	0	0	1	0	0	0	0	0	3
STRs recovered	2	2	3	1	1	6	5	1	2	1	1	0	25
STRs deployed	3	2	5	3	1	6	6	2	2	1	1	0	32
SBE37 deployed	0	0	0	0	0	0	0	0	0	0	0	0	0
ADCP/Wave gauges deployed	0	0	0	0	0	0	0	0	0	0	0	0	0
EARs recovered	2	0	0	0	0	0	0	0	0	0	0	0	2
EARs deployed	2	0	1	0	0	0	2	0	0	0	0	0	5
WTRs recovered	1	0	0	0	1	0	0	0	0	0	1	0	3
WTRs deployed	0	0	0	0	0	0	0	0	0	0	0	0	0
Shallow water CTDs (oceanography team)	31	11	23	15	0	8	22	18	18	12	0	5	163
Nutrient and chlorophyll samples collected in conjunction with shallow water CTDs	20	4	16	6	0	4	16	12	6	6	0	4	94
Microbial Oceanography dives	4	1	2	2	0	1	2	2	1	1	0	0	16
Deepwater CTDs (from Hi'ialakai)	0	1	2	2	1	1	0	0	0	0	0	0	7
Nutrient and chlorophyll samples collected in conjunction with deep water CTDs	0	7	10	10	7	5	0	0	0	0	0	0	39
ADCP Transects (from Hi'ialakai, approx. km)	0	0	0	0	0	0	0	0	0	0	0	0	0
SCUBA dives	175	59	173	105	5	57	176	108	52	51	4	12	977

MISSIONS:

A. Conduct ecosystem monitoring of the species composition, abundance, percent cover, size distribution, and general health of the fishes, corals, other invertebrates, and algae of the shallow water (< 35 m) coral reef ecosystems of the northern islands of the Mariana Archipelago. In addition, this cruise included the establishment of new LPI benthic sites, new (total count, 15 m diameter) stationary-point-count (nSPC) fish sites, and the deployment of new ARMS.

B. Deploy new and maintain existing array of SST buoys, subsurface acoustic Doppler current profilers (ADCPs), subsurface wave gauges, and STRs to allow remote long-term monitoring of oceanographic and environmental conditions affecting these coral reef ecosystems.

C. Recover and replace existing environmental acoustic recorders and service existing array of SST buoys, subsurface ADCP, subsurface wave gauges, and STRs to allow remote long-term monitoring of oceanographic and environmental conditions affecting these coral reef ecosystems.

D. Collect deep (> 35 m) and shallow-water (< 35 m) samples for analysis of nutrient and chlorophyll levels to examine chemical and biological linkages supporting and maintaining these island ecosystems.

E. Conduct shipboard CTDs to a depth of 350 m, shallow-water CTDs from small boats to a depth of ~ 30 m, and shipboard ADCP surveys around reef ecosystems to examine physical and biological linkages supporting and maintaining these island and atoll ecosystems.

F. Collect ADCP data during all transits. The ADCP unit shall be configured to collect narrow-band data in 16-meter bins (deepwater mode).

G. Assist partner scientists with microbial oceanography sampling and invertebrate collections.

H. Conduct calibration dives to improve accuracy of data collected.

SCIENTIFIC PERSONNEL:

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DATA COLLECTED:

Digital images from photoquadrats
Algal voucher specimens necessary for algal species identification
Benthic Line Point Intercept data
Number of coral colonies, by species, within belt transects of known area, and overall coral colony density at each site
Qualitative assessment (DACOR) of coral species' relative abundance at each site
Size class distributions of corals (by species and overall) at each site
Digital images of diseased coral
Field notes on signs of coral bleaching or disease
Samples of diseased coral for histopathological analysis
Density counts of targeted organisms within belt transects
Urchin test size diameters
Installation of ARMS to eventually provide an index of biodiversity
Digital images of non-coral marine invertebrates
Samples of targeted species undergoing genetic connectivity work
Digital still photos of overall site character and typical benthos at each site
Belt-transect surveys of all diurnally active fish in 600 m^2 – identified to species and size estimated to nearest cm
Stationary Point Count (nSPC) surveys of all diurnally active fish in 707 m^2 – identified to species and size estimated to nearest cm

Fish species presence checklists for community diversity estimates at each site
Digital images of rare or interesting fish species
Digital images of the benthic habitat from towed-diver surveys
Macroinvertebrate counts from towed-diver surveys
Quantitative surveys of large reef fish (>50 cm Total Length) to species level from towed-diver surveys
Habitat lineation from towed-diver surveys
Benthic composition estimations from towed-diver surveys
Acoustic Doppler Current Profile data
Shipboard Conductivity, Temperature and Depth profiles to 350 m with fluorometer and dissolved oxygen sensor attached
Water Samples to 500 m: Chlorophyll and Nutrients 5 depths per cast
Shallow-water Conductivity, Temperature, Depth casts to 30 m (or water column depth with transmissometer and dissolved oxygen sensor attached
Shallow water samples (30 m): chlorophyll and nutrients 2 depths per cast
Shallow water microbial analysis samples
Sea surface and subsurface temperature at variable depths
Sea surface and subsurface salinity at variable depths
Spectral wave energy and tidal elevation
Moored Acoustic Doppler Current Profiler data
Solar radiation, air temperature, barometric pressure, wind speed and direction, and photosynethtic active radiation
Shipboard Surface Temperature and Salinity Gauge data
Shipboard Acoustic Doppler Current Profiler transects
Ecological Acoustic Recorder data

Submitted by: Robert E. Schroeder

Robert Schroeder, PhD
Chief Scientist

Approved by: Kacky Andrews

Kacky Andrews
Program Manager
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Attachments: Figure 1
Appendices A-M

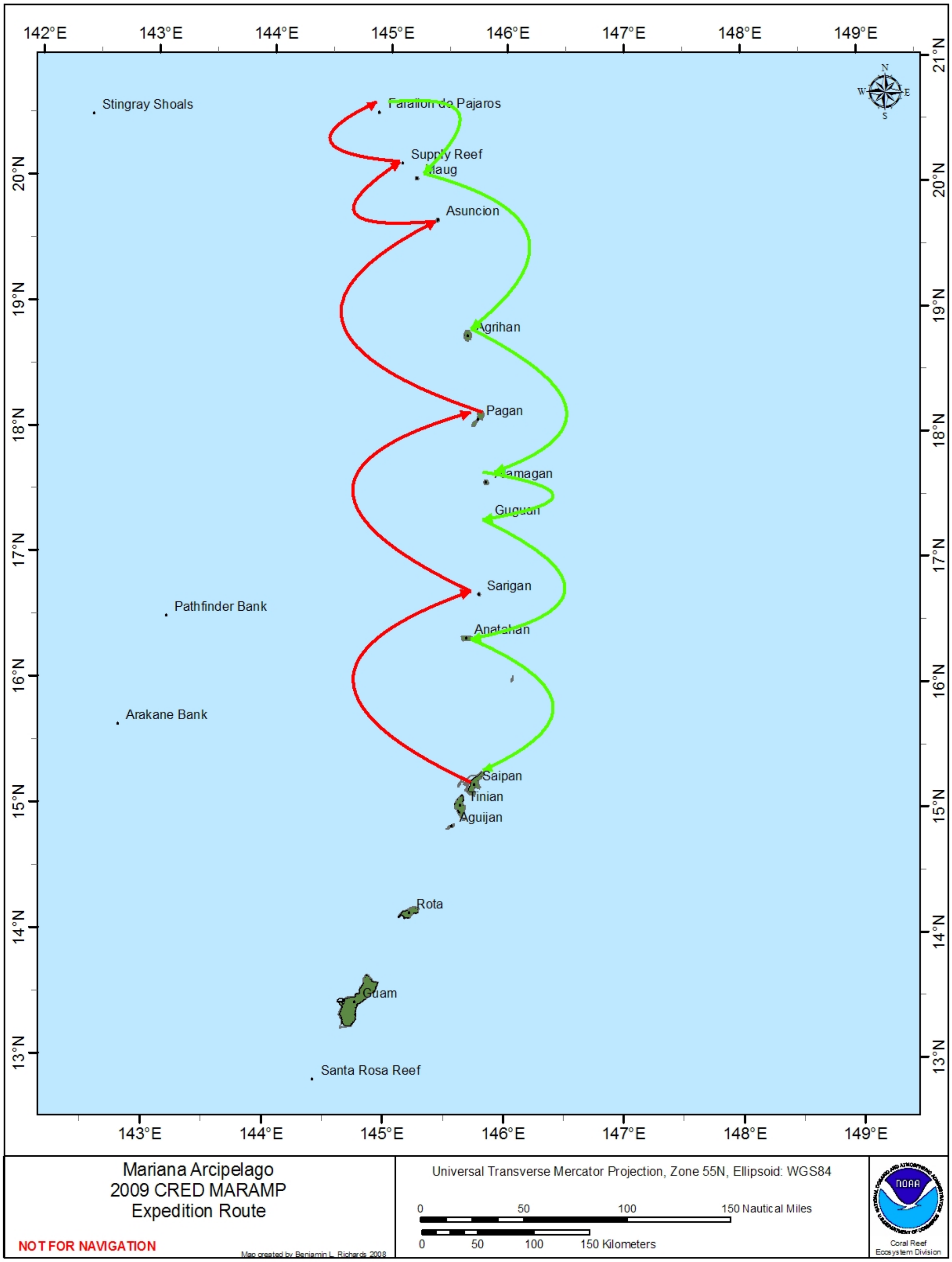


Figure 1.--Track of NOAA Ship *Hi'ialakai* during cruise HA0903, April 15–May 7, 2009.

Appendix A: Methods

A.1. Oceanography and Water Quality

(Danny Merritt, Frank Mancini, Chip Young, Kevin Lino and Florent Angly)

The Coral Reef Ecosystem Division (CRED) started conducting oceanographic research at U.S.-held islands in the tropical Pacific in 2001. CRED's on-location oceanographic investigations include in situ conductivity-temperature-depth (CTD) profiles; collecting water samples for the measurement of chlorophyll-a (chl-a), dissolved nutrient concentrations, microbial species identification, dissolved inorganic carbon (DIC), and salinity; and the deployment/replacement of instrument platforms used to measure physical and chemical parameters within the coral reef ecosystem. The list of deployed instrumentation includes:

- Sea Surface Temperature (SST) buoy: Measures and internally records high resolution surface water temperature and telemeters a subset of collected data in near real time.

- Wave and Tide Recorder (WTR): Measures surface gravity waves, tides and subsurface water temperature.

- Subsurface Temperature Recorder (STR): Measures high resolution subsurface water temperature.

- Ecological Acoustic Recorder (EAR): Records ambient subsurface sound.

Detailed in situ oceanographic and water quality surveys are accomplished through the following sampling techniques:

- Shallow-water CTD casts (max. depth 30 m) conducted from small boats at regularly spaced intervals around the 30-m bathymetry contour at each island/atoll/shoal. The CTD package includes a conductivity-temperature-depth sensor (SBE 19+), an auxiliary transmissometer (Wetlabs C-Star), and a dissolved oxygen sensor (SBE 43). Shallow vertical water profiles provide insight into water property structure and water mass interaction.

- Shallow-water samples for dissolved nutrient and chlorophyll-*a* analyses are taken at select rapid ecological assessment (REA) sites. Samples are collected at the surface-water interface and 1 m above the reef of select REA sites.

- Macro and microbiological coral reef ecosystem samples collected at select REA sites. Water samples are collected 0.5-1 m above the bottom in 1.75 liter Niskin bottles and later analyzed for: dissolved organic carbon (DOM); particulate organic material (POM); protist, microbial and viral abundance; and microbial community composition.

- Shipboard deepwater CTD casts conducted from the NOAA Ship *Hi'ialakai* with an SBE 911+ CTD package enhanced with a dissolved oxygen sensor (SBE 43) and a combination fluorometer and turbidity sensor (Wetlabs ECO-FLNTU). Shipboard CTD casts are conducted at sites 25 nm offshore from land masses to allow for satellite compatibility. Casts are to a maximum depth of 500 m. Water samples are collected from five Niskin bottles. Depths of water sample collections are chosen based on downcast fluorometer measurements regarding the chl-a maximum. Collections cover the entire range of values seen at each cast. Dissolved nutrient (NUT) and chlorophyll-a (chl-a) concentrations are analyzed post-cruise and chl-a values are used to calibrate the fluorometer.

- Surface and subsurface water temperatures are continuously recorded during all towed-diver operations. These data sets illustrate temperature variations over depth (see towed-diver section for further description of methods.)

- Shipboard meteorological observations including wind speed and direction, relative humidity, air temperature, and barometric pressure.

- Shipboard measurements of currents, using an acoustic Doppler current profiler (ADCP), sea surface temperature, and salinity.

A.1.1. Microbial and Water Chemistry Analysis

1.) Microscopy

Phages (viruses of Bacteria and Archaea) are the most abundant form of life in the ocean, ranging from 1×10^6 virus-like particles (VLPs) per ml of seawater in the open ocean to 1×10^8 VLPs per ml in more productive coastal waters. The number of microbial and protistan cells in seawater is typically 1×10^6 and 1×10^3 cells per ml, respectively. Microbial and viral loading and the dominance of heterotrophic bacteria in reef water are linked to coral disease (Dinsdale, et al., 2008). Trophic-level interactions among bacteria, phages, and protists also affect global nutrient and carbon cycling. The most direct method for assessing and monitoring changes in abundance of these microbiological components is by fluorescent microscopy using nucleic acid staining.

Enumeration of microbes and viruses: Five ml of water from each sample was fixed with paraformaldehyde, stained with the dsDNA stain SYBR-Gold, and filtered onto a 0.02um filter.

Enumeration of protists: Fifty ml of water from each sample was fixed with glutaraldehyde, stained with the dsDNA stain DAPI, and filtered onto a 0.8um black polycarbonate filter.

Frequency of dividing cells: Ten ml of water from each sample was fixed with glutaraldehyde, stained with the dsDNA stain DAPI, and filtered onto a 0.2um filter.

Enumeration of microbial components and quantification of actively dividing microbial cells will be counted using fluorescent microscopy at San Diego State University (SDSU). All filters will be stored at -20ºC for archival purposes.

2) Water chemistry

Spatial assessment of microbial, viral, and protist components with respect to dissolved organic carbon, nutrient levels, and particulate organics within coral reef ecosystems may identify important predictors of coral reef ecosystem degradation; information that may be essential for designing the most effective monitoring strategy possible.

Water samples were pushed through GF/F glass filters and the filtrate collected in pre-combusted glass bottles. Hydrochloric acid was added to each bottle to remove dissolved inorganic carbon and the bottles were stored upright at 4ºC. These samples will be analyzed for dissolved organic carbon levels at SDSU. The GF/F filters will be also be stored at -20ºC and analyzed for particulate organic carbon and stable isotopes of carbon and nitrogen at SDSU.

3) Archive microbial DNA samples

The structure of the uncultured microbial community will be assessed by metagenomic analysis. This involves collection of environmental DNA followed by 454 sequencing. Metagenomics is a powerful tool for studying environmental populations as less than 1% of all environmental microbial diversity is currently cultivable (Rappe and Giovannoni, 2003).

The collection of samples for the metagenomic analysis was performed by pushing 2l of seawater through a 20um pre-filter to remove large eukaryotic organisms. The 20um filtrate was then pushed through 0.22um Sterivex filters. The filters were stored at -20ºC. DNA isolation and metagenomic analysis will be completed at SDSU by extracting DNA and sequencing it.

4) Flow cytometry

Flow cytometry will be primarily used to characterize microbial community size structure. This technique will also provide complementary data for abundance counts, metagenomic analysis, and chlorophyll analysis.

Five ml of water from each site was pushed through a 20um filter. The filtrate was dispensed into 5 × 1ml cryovials, and glutaraldehyde added to each. Vials were inverted to mix, and incubated in the dark for 15 min. Glutaraldehyde preserved samples were flash frozen in liquid nitrogen contained in a dry shipper. The samples will be shipped on dry ice to SDSU for flow cytometry analysis.

A.2. Benthic REA Methods

(Bernardo Vargas-Angel, Jean Kenyon, Kerry Grimshaw (Alt.), *Stephanie Schopmeyer, Molly Timmers, Russell Reardon, and Cristi Richards)*

A.2.1. Algae

Using the line point-intercept (LPI) method, recorded were macroalgal species, algal functional group, coral species, non-coral invertebrate functional group, or substrate type at 20 cm (for permanent REA monitoring sites) and 50 cm (at new independent monitoring sites) intervals along two 25 m transect lines. Algal inventories and percent cover were generated from data collected at each site. Permanent historical records of benthic marine substrates at each permanent REA site were collected using a high resolution digital camera mounted on a 0.18 m^2 photoquadrat.

Additionally, when time permits, a roving diver swim at the end of the dive that covers a swath on 3 m on either side of the transect line is used to record algal species not observed along the transects themselves. Only one specimen of each species that cannot be identified in the field will be collected by hand and frozen. Ultimately, field-collected algal specimens will be critically analyzed in the laboratory to ensure positive species identification, catalogued, and subsequently placed in research institutions where they can be accessed by researchers interested in a suite of topics. After identification, provisions are made to ensure appropriate preservation and curation of each algal specimen, and provide a historical record that will be available to future researchers.

A.2.2. Corals

At each permanent REA monitoring site, two 25 m belt transects were laid out. Five 2.5 m segments were surveyed for each transect (beginning at points: 0, 5, 10, 15, and 20 m for a total of 25 m^2 per site). For each segment, all coral colonies whose center fell within 0.5 m of either side of the transect were identified to species and measured for size (maximum diameter and diameter perpendicular to the maximum diameter). In addition, the extent of mortality, both recent and long dead, was estimated for each colony. Observers paid special attention to identifying, as best as possible, the extent of the former live colony. When a coral colony exhibited signs of disease or compromised health, additional information was recorded including type of affliction (bleaching, skeletal growth anomaly, white syndrome, tissue loss other than white syndrome, trematodiasis, necrosis, other, pigmentation responses, algal overgrowth, and predation), severity of the affliction (mild, moderate, marked, severe, acute), as well as photographic documentation and sometimes tissue samples. Tissue samples were catalogued and fixed in buffered zinc-formalin solution for further histopathological analyses. Percent coral cover analysis was derived from the 20 cm LPI methods conducted by the algal divers.

The second team was deployed on a separate boat and surveyed new, randomly chosen sites that were situated in depth strata shallower (0 – 6m) or deeper (18-30 m) than the permanent REA sites. After settling on the bottom, a two person team laid a two 25 m transects and then performed the LPI as described above. Percent cover analysis was derived from the 50 cm LPI methods conducted by the additional benthic divers.

A.2.3. Non-coral Invertebrate Surveys

Quantitative counts and percent cover for specific target marine invertebrates are conducted along the two 25 m REA belt transects and the independent LPI transects at 5 m intervals. All invertebrates which fall within 1 m along either side of the transect are surveyed. Size frequency distribution of urchin species will be recorded for the first 25 individuals of each species. Based on data from previous rapid ecological assessments, a group of target species was chosen for quantitative counts. The species in this list have been shown to be common components of the reef habitats of the central and southern Pacific, and they are species that are generally visible (i.e., non-cryptic) and easily enumerated during the course of a single 50–60 min dive. Additionally, all species of urchins are counted and the test size diameter for the first 25 of all species present are measured and recorded.

Target species include:
CNIDARIA
- Octocorals – soft corals (*Sinularia, Cladiella, Lobophyton, Sarcophyton* etc)
- Zoanthids – rubber corals
- Actiniaria – Anemones (*Heteractis, Stichodactyla, Phymanthus* etc)

ECHINODERMS
- Echinoids – sea urchins
- Holothuroids – sea cucumbers
- Asteroids – sea stars

MOLLUSCA
- Bivalves – spondylid oysters, pearl oysters, tridacnid clams (Giant Clams)
- Large Gastropods – *Charonia* (Triton's Trumpet) and a species of *Lambis* (Spider Conch)
- Coralliophilidae gastropods
- Cephalopods - octopus

CRUSTACEA
- hermit crabs, lobsters, large crabs

A.2.3.1. Autonomous Reef Monitoring Systems (ARMS)
ARMS were deployed in eight forereef habitats (SAI-05, SAI-06, PAG-05, PAG-06, PAG-09, MAU-04, MAU-09, MAU-11) in the island systems. ARMS provide a mechanism to quantify marine invertebrates that are not easily identifiable or accountable on the transect lines. ARMS are installed on the benthos by pounding stainless steel rods by hand into bare substrate. They will remain on the benthos for 2 years enabling the recruitment and colonization of lesser known, cryptic marine invertebrates upon which time they will be collected and analyzed.

A.3. Fish Team Methods
(Marc Nadon, Paula Ayotte, Valerie Brown, Robert Schroeder, and Marie Ferguson [Alt.]*)*

The fish team, composed of four divers, conducted two types of surveys at preselected sites: Belt transects (BLT) and (new) Stationary Point Counts (nSPC). Two separate teams were deployed to conduct the surveys; each team consisted of two divers conducting either two nSPCs and two BLTs, or just two nSPCs.

The first team accompanied the Benthic REA team and surveyed previously visited sites. Surveys were performed using a 30-m line set along a single depth contour. As the line was set, two observers swam along either side of the line identifying, counting, and sizing all diurnally active, non-cryptic fish > 20 cm in total length (TL). Each diver counted and sized fish within an area 25 m long and 4 m wide. Afterwards, the divers returned along their respective sides of the line identifying, counting, and sizing all fishes ≤ 20 cm TL in a 2 m wide by 25 m long belt.

Once the belt transect was completed, the divers moved to the 7.5 m and 22.5 m marks on the transect line to start the (new) stationary point counts (7.5 m radius). For this method, each diver counted all diurnally active, non-cryptic fish in a cylindrical survey area by staying in the middle of their respective cylinders that had a 7.5 meter radius. During the first 5 min of the nSPC, the divers only recorded the presence of species within their survey areas. Afterwards, the divers proceeded down their respective species list, sizing and counting all individuals within their 7.5 m radius cylinder, one species at a time. Individuals from a single species were only recorded once. More sedentary species missed during the initial 5 min survey could still be added to the list. Once completed, the transect line was moved to another location 5-10 m away at the same depth stratum, and the procedure was repeated.

The second team was deployed on a separate boat and surveyed new, randomly chosen sites that were in an either shallow (0–6 m) or deep (18–30 m) depth stratum using the nSPC method. After settling on the bottom, a two person team laid a 30-m transect and then performed the nSPC as described above. Once completed, the transect line was moved to another location 5–10 m away at the same depth stratum, and the procedure was repeated.

Fishes observed off transect or after the initial 5 min of the nSPC were recorded for presence data. Limited collection efforts were made by the fish team during the survey period for orangespine unicornfish (*Naso lituratus*) and bridled parrotfish (*Scarus frenatus*).

(*Note: This SPC method, denoted in the database as nSPC for new, differs from the previous SPC surveys used in the Mariana (2003-2007), which employed a 10 m radius, but only recorded fish > 25 cm total length during 5min periods at four replicate sites around the belt-transect line.*)

A.4. Towed-diver Survey Methods

(Jacob Asher, Jason Helyer, Bonnie DeJoseph, and Benjamin Richards)

Shallow-water habitats around each island, bank, or reef were surveyed using pairs of divers towed 60 m behind a 19 ft SAFE Boat survey launch. In each towed-diver buddy team, one diver is tasked with quantifying the benthos while the other quantifies fish populations. Each towed-diver survey lasts 50 min, broken into ten 5-min segments, and covers approximately 2 km. A Global Positioning System (GPS) track of the survey launch track is recorded at 5 sec intervals using a Garmin GPS76Map GPS unit. A custom algorithm is used to calculate the track of the divers based on the track, speed, and course of the boat and depth of the diver. Each towboard is equipped with a precision temperature and depth recorder (Seabird SBE39) recording at 5 sec intervals. At the end of each day data are downloaded, processed and presented in ArcGIS and can be displayed in conjunction with IKONOS satellite imagery, NOAA chart data and/or other spatial data layers.

A.4.1. Benthic Towed-diver Methods

The benthic towboard is equipped with a downward high resolution digital still camera with dual strobes. The downward-looking camera is maintained 1–2 m off the bottom and is programmed to photograph benthic substrate every 15 sec, creating a permanent visual record to evaluate and track potential changes in the benthos between subsequent cruises. The diver on the benthic towboard also observes and records habitat composition (habitat complexity, prevalent habitats and substrate types, hard coral, stressed hard, soft coral, macroalgae, coralline algae, sand and rubble), and tallies conspicuous macroinvertebrates (crown-of-thorns starfish [COTS]), boring and free sea urchins, sea cucumbers, and giant clams) along a 10-m swath in 10 × 5-min time segments. Additional fields, including prevalent coral and algae genera (when applicable/time permitting) are also tracked. At the end of each day, the data are transcribed from field data sheets into a centralized MS Access database.

A.4.2. Fish Towed-diver Methods

The fish towboard is equipped with a forward-looking digital video camera which creates a visual archive of the survey track and can be used to evaluate changes in the reef environment, particularly following episodic events such as coral bleaching and vessel grounding. The diver on the fish towboard records, to species of lowest possible taxon, all fish greater than 50 cm total length (TL) along a 10-m swath in each time segment. Fish are recorded and length estimated in centimeters. Species of particular concern observed outside the survey swath are classified as presence/absence data and are recorded separately from the quantitative swath data. At the end of each day, the data are transcribed from field data sheets into a centralized MS-Access database. Biomass values are calculated using species specific length-weight parameters and are normalized by area (i.e., kg/100 m^2).

Appendix B: Saipan Results

B.1. Oceanography and Water Quality

Moorings recovered and replaced during HA0903 at Saipan included five subsurface temperature recorder (STR) deployments (one new), four STR recoveries, a sea surface temperature (SST) buoy replaced, two ecological acoustic recorder (EAR) replacements, and a wave and tide recorder (WTR) recovery. The WTR was originally deployed in 2007 by Coral Reef Ecosystem Division (CRED) for Professor Mark Merrifield from the University of Hawaii for a typhoon wave setup experiment (Table B. 1.1., Fig. B.1.1.) All the STRs show similar patterns and temperature ranges, with a clear annual fluctuation due to seasonal warming and cooling (Fig. B.1.2.). The warmest surface temperatures peaked at approximately 31^{o}C and occurred during the summer months of July to October. Winter temperatures reached lows of approximately 27.5^{o}C and occurred during November through June.

Four rapid ecological assessment (REA) sites (SAI-01, SAI-04, SAI-05 and SAI-07) were visited to collect water samples for microbiological, nutrient and chlorophyll analyses and five other REA sites (SAI-02, SAI-03, SAI-06, SAI-08 and SAI-09) were sampled for just nutrients and chlorophyll. Conductivity-temperature-depth (CTD) casts were done at these sites concurrently. Samples were obtained from the surface and approximately 1 m above the reef. Microbial water samples were taken using diver-deployable Niskin bottles to collect 8 liters of seawater (four bottles; 2 liters per bottle) at each study site. Chlorophyll samples were filtered and nutrient samples were frozen at -30^{o}C for post-cruise analysis. In addition, a total of 22 CTD casts were taken approximately every 3 km around the perimeter of Saipan at the 30 m depth contour. (Fig. B.1.1.)

Table B.1.1.--Saipan moorings.

Action	Mooring type	Serial number	Lat		Long		Depth (m)
Retrieval	EAR	9300312B028	15.25861393	N	145.8157331	E	16.5
Retrieval	EAR	9300412B007	15.17485131	N	145.7894801	E	19.5
Deployment	EAR	9300493B120	15.17485131	N	145.7894801	E	19.5
Deployment	EAR	9300495B103	15.25861393	N	145.8157331	E	16.5
Retrieval	SST	268004	15.17020069	N	145.6947845	E	0.3
Deployment	SST	DYK6U	15.17020069	N	145.6947845	E	0.3
Deployment	STR	39292520904	15.1561051	N	145.7696987	E	14.6
Deployment	STR	39327181112	15.17020069	N	145.6947845	E	16.8
Deployment	STR	39331791141	15.17485131	N	145.7894801	E	19.5
Deployment	STR	39331791142	15.23748055	N	145.7225488	E	5.8
Deployment	STR	39331791146	15.25861393	N	145.8157331	E	16.5
Retrieval	STR	39368591653	15.25861393	N	145.8157331	E	16.5
Retrieval	STR	39390381727	15.17020069	N	145.6947845	E	16.8
Retrieval	STR	39390381865	15.23748055	N	145.7225488	E	5.8
Retrieval	STR	39487873908	15.17485131	N	145.7894801	E	19.5
Retrieval	WTR	WTR1087(Merrifield)	15.15906634	N	145.7543837	E	11.9

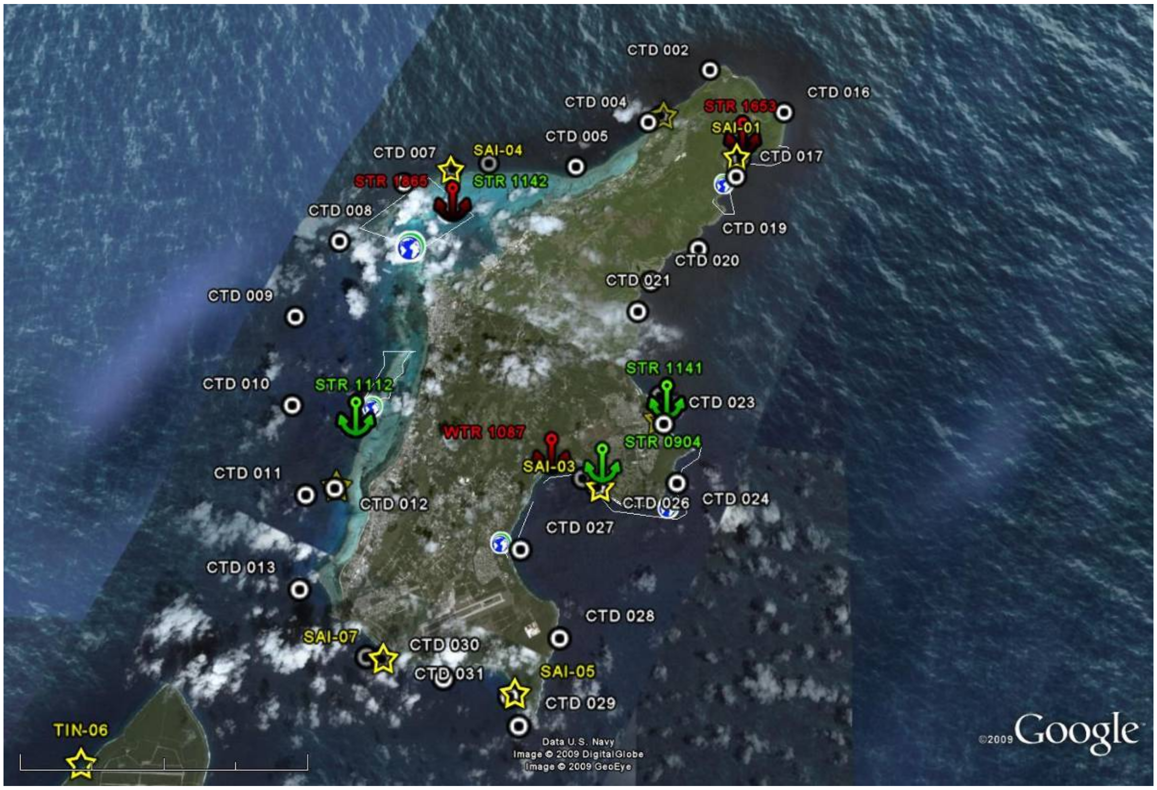


Figure B.1.1--Deployed and recovered instrument moorings and CTD and water sampling sites, Saipan, HA0903.

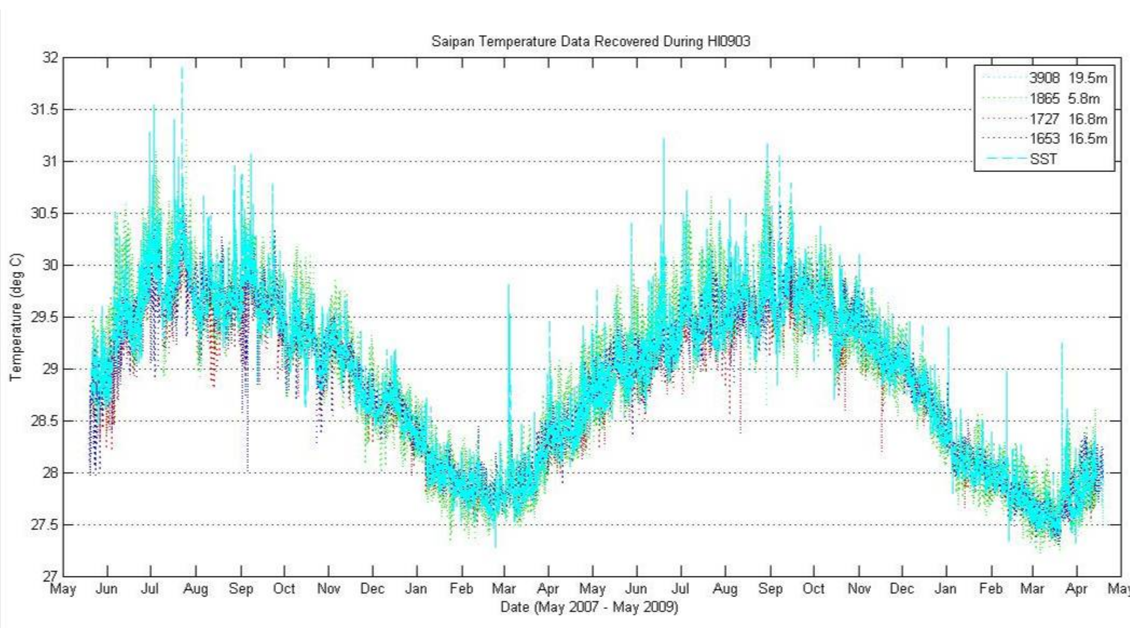


Figure B.1.2--Temperature time series from STR and SST moorings at Saipan.

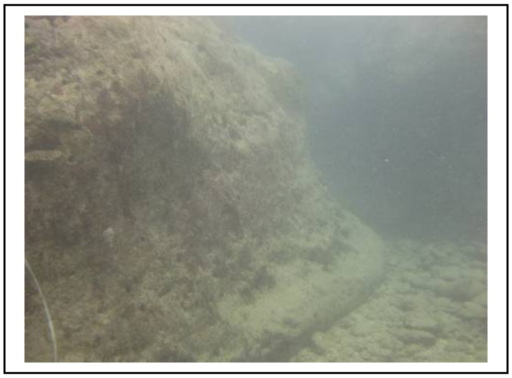
B.2. Rapid Ecological Assessment (REA) Site Descriptions

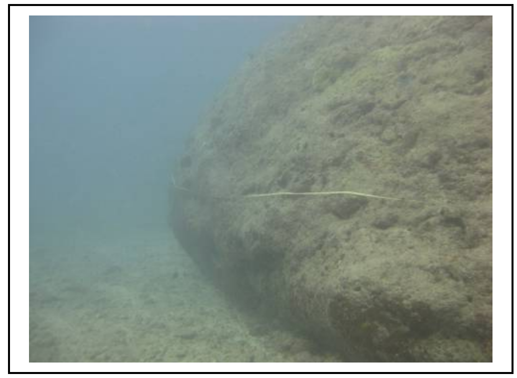
SAI-01
4/19/2009

E 145° 48.865
N 15° 15.533

Forereef
Mid

Depth: 11–12 m





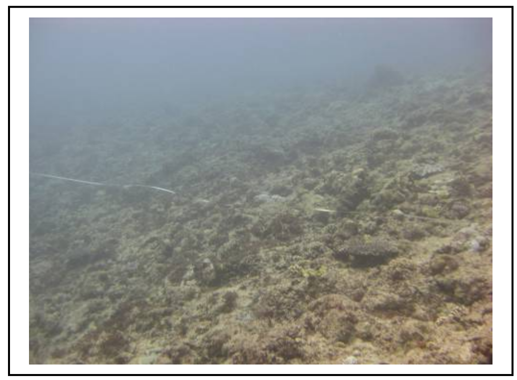
Site description: North side of Bird Island; high topographic complexity (boulder substrate); moderate coral and macroalgal cover; dominated by turf algae.

SAI-02
4/20/2009

E 145° 47.257
N 15° 10.561

Forereef
Mid

Depth: 15 m



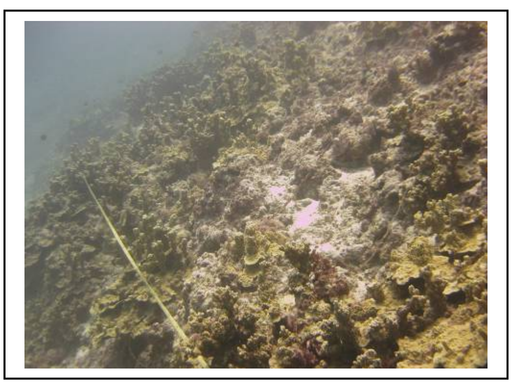
Site description: Southeastern region; low topographic complexity; moderate coral and macroalgal cover.

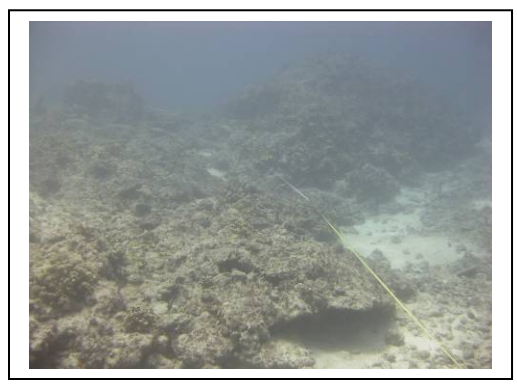
SAI-03
4/20/2009

E 145° 46.178
N 15° 09.360

Forereef
Mid

Depth: 14 m





Site description: Southwest region of Lau Lau (Forbidden); moderate topographic complexity; high coral cover; low macroalgal cover.

SAI-04
4/14/2009

E 145° 43.326
N 15° 15.320

Forereef
Mid

Depth: 11–12 m


Site description: Western outside reef north of Managaha marine protected area (MPA); low topographic complexity; moderate coral and macroalgal cover.

SAI-05
4/20/2009

E 145° 44.679
N 15° 05.917

Forereef
Mid

Depth: 14–15 m


Site description: Southeastern forereef; high topographic complexity; high coral cover dominated by a species of *Porite*; low macroalgal cover.

SAI-06
4/18/2009

E 145° 41.410
N 15° 09.396

Forereef
Mid

Depth: 10–12 m

Site description: Southwestern region; moderate topographic complexity; moderate coral cover; low macroalgal cover; dominated by CCA and turf algae.

SAI-07
4/18/2009

E 145° 42.376
N 15° 06.483

Forereef
Mid

Depth: 11–12 m

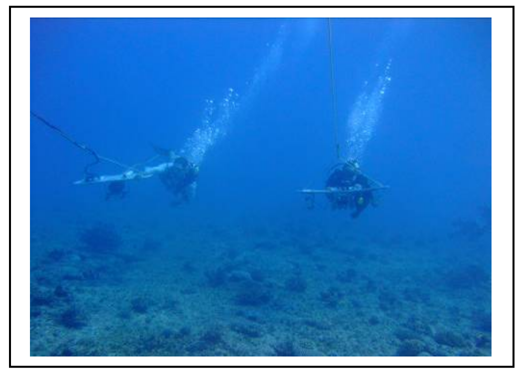
Site description: Southeastern region; moderate topographic complexity; gentle reef slope next to a sand/rubble channel; moderate coral cover; low macroalgal cover; dominated by turf algae.

SAI-08
4/14/2009

E 145° 47.473
N 15° 16.412

Forereef
Mid

Depth: 10–14 m



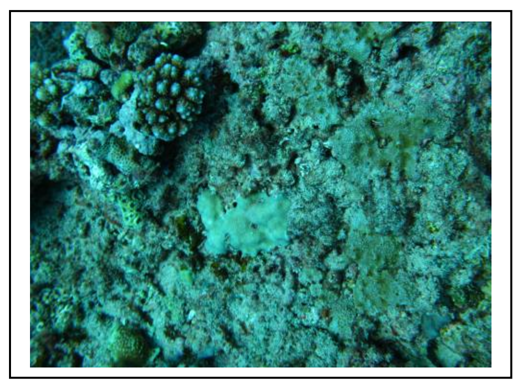
Site description: Northwestern region; Wing Beach; low togopraphic complexity; moderate coral and macroalgal cover.

SAI-09
4/19/2009

E 14.° 50.100
N 15° 15.400

Forereef
Mid

Depth: 12 m



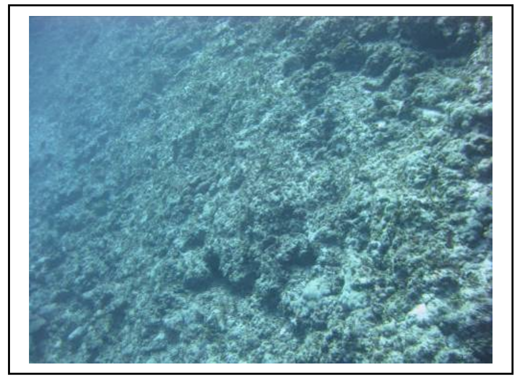
Site description: Northeastern region; gentle reef slope; low topographic complexity; moderate coral and macroalgal cover.

SAI-50
4/14/2009

E 145° 48.116
N 15° 16.955

Forereef
Deep

Depth: 24 m



Site description: Northwestern site; transects located at bottom of a small drop-off; low topographic complexity (scoured pavement); moderate coral and macroalgal cover.

SAI-51
4/14/2009

E 145° 45.106
N 15° 15.253

Forereef
Shallow

Depth: 3 m

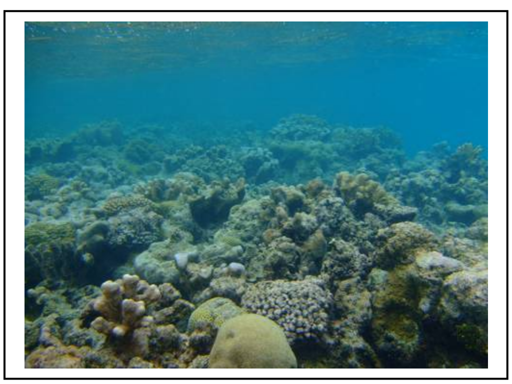
Site description: Shallow northwestern forereef; near lagoon; low topographic complexity (scoured pavement); low coral and macroalgal cover; dominated by turf algae.

SAI-52
4/14/2009

E 145° 42.109
N 15° 14.250

Backreef
Shallow

Depth: 1 m



Site description: Western backreef-side of the lagoon; low relief; high topographic complexity; high coral cover; low macroalgal cover.

SAI-53
4/18/2009

E 145° 41.651
N 15° 11.801

Forereef
Deep

Depth: 21–22 m

Site description: Southern region (south of harbor); low topographic complexity (large patch reefs surrounded by sand); moderate coral and macroalgal cover.

SAI-54
4/18/2009

E 145° 41.678
N 15° 09.715

Forereef
Shallow

Depth: 1 m

Site description: Southwestern region; low relief; moderate topographic complexity; high coral cover; low macroalgal cover.

SAI-55
4/18/2009

E 145° 41.127
N 15° 07.893

Forereef
Shallow

Depth: 2 m

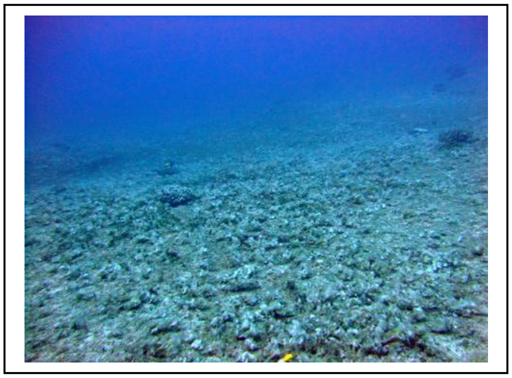
Site description: Southwestern region; moderate topographic complexity; high coral cover; low macroalgal cover.

SAI-56
4/19/2009

E 145° 49.931
N 15° 16.128

Forereef
Deep

Depth: 20–23 m



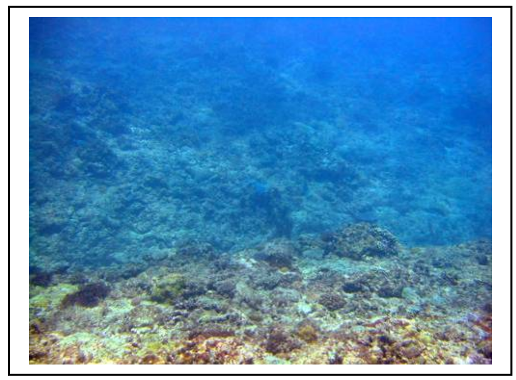

Site description: Northeastern region; low topographic complexity (scoured pavement); low coral cover; high macroalgal cover.

SAI-57
4/19/2009

E 145° 46.915
N 15° 11.167

Forereef
Mid

Depth: 7 m

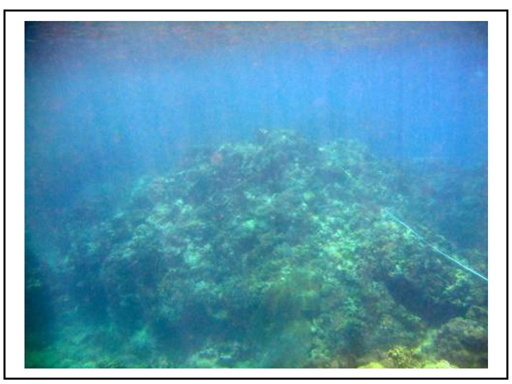
Site description: Shallow eastern region; moderate topographic complexity; high coral cover; low macroalgal cover.

SAI-58
4/19/2009

E 145° 45.800
N 15° 09.700

Forereef
Shallow

Depth: 1–3 m



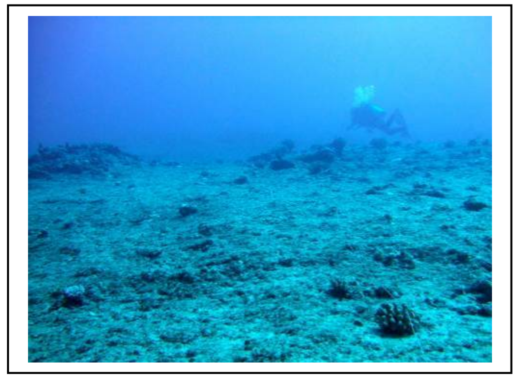

Site description: Shallow site in Lau Lau Bay; high topographic complexity; high coral cover; low macroalgal cover.

SAI-59
4/19/2009

E 145° 47.558
N 15° 09.495

Forereef
Deep

Depth: 20–22 m



Site description: Deep eastern site outside Lau Lau Bay; low topographic complexity (scoured pavement); moderate coral cover; low macroalgal cover.

SAI-60
4/20/2009

E 145° 45.007
N 15° 09.192

Forereef
Deep

Depth: 21 m

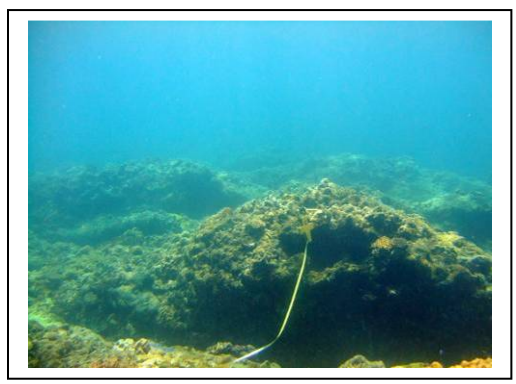
Site description: Eastern region of Lau Lau Bay; high topographic complexity; large spurs and grooves; moderate coral cover; high macroalgal cover.

SAI-61
4/20/2009

E 145° 44.925
N 15° 07.602

Forereef
Shallow

Depth: 4 m



Site description: Eastern region in Lau Lau Bay; high topographic complexity; high coral cover; low macroalgal cover.

SAI-62
4/20/2009

E 145° 44.734
N 15° 05.720

Forereef
Shallow

Depth: 3 m

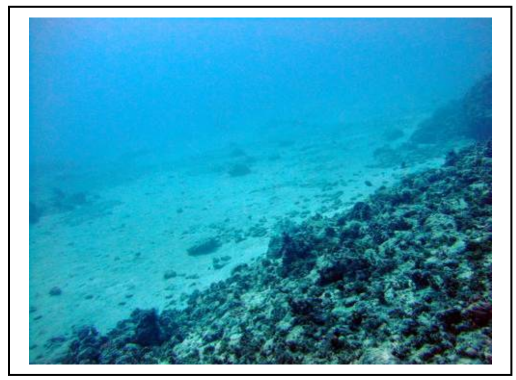
Site description: Southeastern region near airport; low topographic complexity; high coral cover; low macroalgal cover.

SAI-63
4/20/2009

E 145° 42.747
N 15° 06.269

Forereef
Deep

Depth: 19 m



Site description: Southern region; low topographic complexity; patch reefs intersperced with sand-covered pavement; moderate coral and macroalgal cover.

B.3. Benthic Environment

B.3.1. Algal Communities

During the Mariana Reef Assessment and Monitoring Program (MARAMP) 2009, nine permanent, long-term REA monitoring sites were surveyed around Saipan Island for percent benthic cover based on the 20-cm interval line point intercept (LPI) methodology. Benthic communities around Saipan were dominated by turf algae and scleractinian corals (Table B.3.1.1.). Turf algal percent cover exceeded that of other functional groups at seven of the nine sites surveyed with a percent cover range of 10% to 53.2% (Table B.3.1.1.). At site SAI-03, percent cover of turf algae, cyanobacteria, and scleractinian corals were approximately equal (27.2%, 24%, and 28%, respectively). At site SAI-05, scleractinian corals were the dominant functional group with 55.2% cover (Table B.3.1.1.). A combined total of 25 species of macroalgae were observed (14 chlorophytes, five ochrophytes, six rhodophytes) from the nine sites surveyed (Tables B.3.1.1., B.3.1.2.). The macroalgal communities around Saipan were diverse, and different species were the dominant cover at each site. *Caulerpella ambigua* was the dominant macroalga at sites SAI-01 and SAI-09 with percent cover of 5.6% and 4.4% (Table B.3.1.2.). *Asparagopsis taxiformis* dominated the macroalgal community at site SAI-02 with a percent cover of 8.4%, while the main macroalgae at site SAI-04 were species of *Halimeda* with 2.8% cover (Table B.3.1.3.). Site SAI-06 was dominated by *Lobophora variegata,* 3%, and the prominent macroalga at site SAI-08 was *Microdictyon setchellianum,* 4% cover (Table B.3.1.3.). Other sites had less than 1% macroalgal cover with the dominant functional group being turf algae.

Table B.3.1.1--Percent cover of algal functional groups at long-term monitoring sites at Saipan.

Site	Macroalgae	Turf Algae	Coralline red algae (crustose + upright)	Cyanobacteria	Scleractinian Coral	Octocoral
SAI-01	17.2%	53.2%	14.4%	4.8%	10.0%	-
SAI-02	20.8%	40.4%	7.6%	6.0%	24.0%	0.8%
SAI-03	0.4%	27.2%	18.8%	24.0%	28.0%	-
SAI-04	28.4%	43.2%	10.8%	1.2%	15.2%	-
SAI-05	2.0%	10.0%	17.2%	10.0%	55.2%	-
SAI-06	3.5%	50.5%	23.5%	1.5%	19.0%	-
SAI-07	8.8%	52.8%	22.0%	2.4%	13.6%	-
SAI-08	14.8%	53.2%	6.8%	6.4%	18.4%	-
SAI-09	25.6%	39.2%	11.2%	0.8%	23.2%	-

Table B.3.1.2--Additional macroalgal species recorded at each site around Saipan during roving diver surveys.

Site	**Chlorophyta**
SAI-04	*Boodlea* sp.
SAI-01	*Caulerpa microphysa*
SAI-04	*Caulerpa racemosa*
SAI-09	*Caulerpa serrulata*
SAI-04	*Halimeda* sp.
SAI-09	*Halimeda taenicola*
SAI-06	*Halimeda tuna*
SAI-02, SAI-04, SAI-07, SAI-09	*Neomeris* sp.
SAI-03	*Tydemania* sp.
SAI-03, SAI-06, SAI-09	*Valonia ventricosa*
	Ochrophyta
SAI-04	***Dictyota ceylanica***
SAI-02	***Dictyota* sp.**
SAI-05	***Lobophora variegata***
SAI-01, SAI-03, SAI-07, SAI-08	***Padina* sp.**
SAI-06	***Turbinaria ornata***

	Rhodophyta
SAI-01	***Amansia glomerata***
SAI-01	***Asparagopsis taxiformis***

Table B.3.1.3--Percent cover of macroalgal species at long-term monitoring sites around Saipan. Sum totals for each row equal the percent cover of macroalgae recorded in Table B.3.1.1.

Site	Caulerpa racemosa	Caulerpa serrulata	Caulerpella ambigua	Dictyosphaeria versluysii	Halimeda opuntia	Halimeda sp	Microdictyon setchellianum	Neomeris sp	Dictyota ceylanica	Dictyota sp	Lobophora variegata	Padina sp	Asparagopsis taxiformis	Galaxaura sp	Martensia sp	Peyssonnelia sp	Portieria hornemannii
SAI-01	-	1.2%	5.6%	-	-	-	-	0.8%	-	0.4%	-	-	-	0.4%	-	-	-
SAI-02	0.4%	-	1.6%	-	0.4%	-	-	-	0.4%	-	2.0%	-	8.4%	0.4%	-	-	0.4%
SAI-03	-	-	-	-	-	-	-	-	-	-	0.4%	-	-	-	-	-	-
SAI-04	-	-	-	1.2%	-	2.8%	-	-	-	-	-	1.2%	-	-	-	-	-
SAI-05	-	-	-	-	0.8%	-	-	-	-	-	-	-	-	-	-	-	-
SAI-06	-	-	-	-	-	-	-	-	-	-	3.0%	-	-	-	-	-	-
SAI-07	0.4%	0.4%	-	-	-	-	-	-	-	-	0.4%	-	-	-	-	-	-
SAI-08	-	0.4%	-	1.2%	-	-	4.0%	0.8%	-	-	0.4%	-	-	-	-	-	-
SAI-09	-	-	4.4%	-	2.0%	-	-	-	0.8%	-	3.2%	-	0.8%	3.2%	1.6%	2.8%	-

B.3.2. Coral Communities

B.3.2.1 Percent Benthic Cover

In 2009, percent benthic cover surveys around Saipan were conducted in concert with coral population, algae, and invertebrate REA surveys at nine permanent sites. Percent coral cover around Saipan derived from LPI surveys conducted at the permanent long-term REA sites yielded an island-wide mean of 21.7.8% (Fig. B.3.2.1.1). Percent coral cover was the greatest at SAI-07 and SAI-06, in the south and southwest area, respectively (Fig. B. 3.2.1.1).

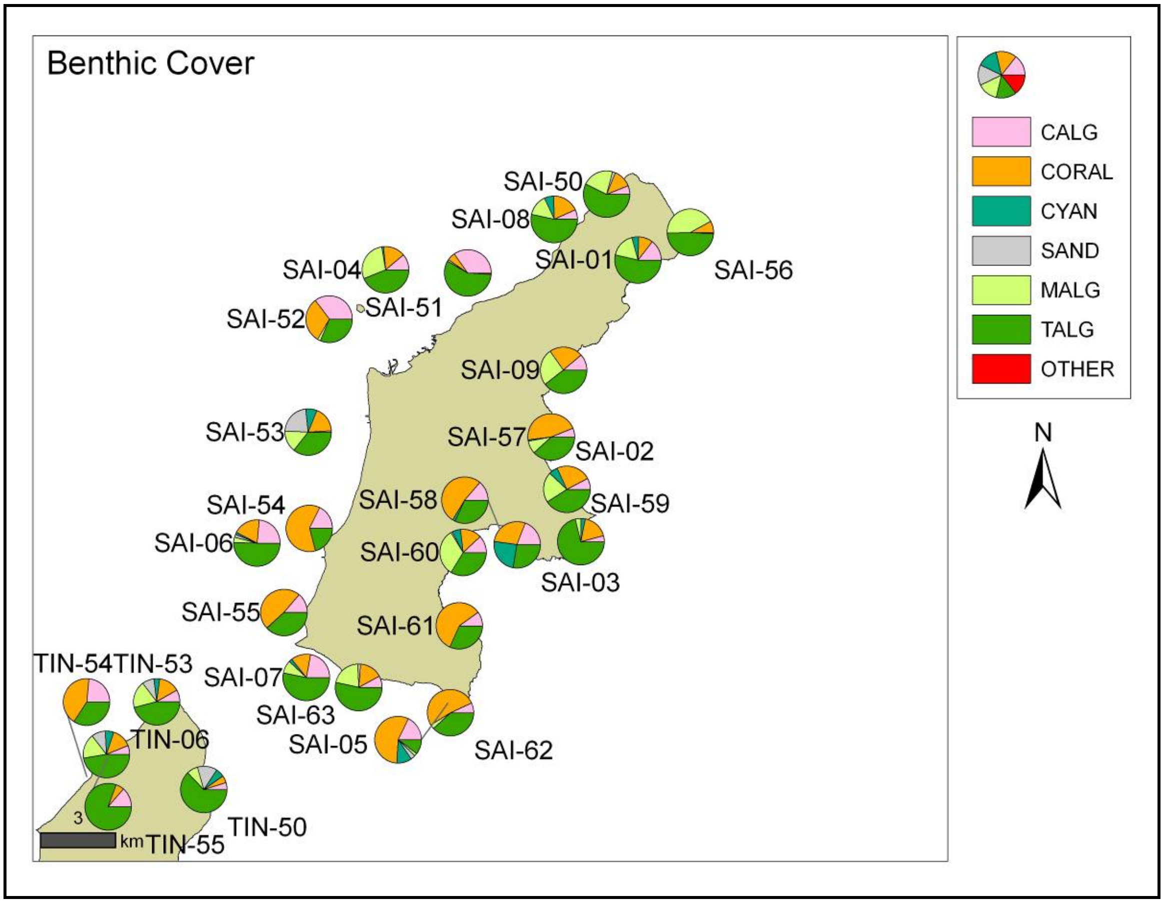


Figure B.3.2.1.1--Percent cover of benthic functional groups at the random stratified and permanent REA monitoring sites around Saipan during MARAMP 2009. CALG = crustose coralline red algae, CYAN = cyanobacteria, MALG = macroalgae, TALG = turf algae.

Fourteen additional stratified random REA sites were surveyed around Saipan for percent bethic cover (based on 50-cm interval LPI surveys) and generic diversity data in 2009. Results from the eight stratified random REA sites surveyed in 2009 yielded the following results: Benthic communities at six sites greater than 20 m depth were dominated by turf algal (49.03% $\pm$ 5.8), macroalgal (22.9% $\pm$ 5.4) and scleractinian coral (14.4% $\pm$ 1.5) functional groups (Fig. E). Eight shallow sites (<10 m depth) were dominated by scleractinian coral (43.7% $\pm$ 7.4), turf algal (34.5% $\pm$ 3.4), and calcareous algal (18.1% $\pm$ 4.0) functional groups (Fig. B.3.2.1.2). Coral generic diversity was highest at site SAI-53 with 29 different genera observed (Table

B.3.2.1.1). In contrast, site SAI-51 had the lowest generic diversity with nine different genera observed. The average number of coral genera recorded at each site was 20. Common genera observed at most sites included *Pocillopora, Montipora, Acropora, Favia,* and *Porites*. Macroalgal generic diversity was highest at sites SAI-60 and SAI-61 with 14 genera observed at both (Table B.3.2.1.2). Site SAI-51 had the lowest generic diversity with two genera observed. The average number of macroalgal genera recorded for each site was 11. Common macroalgae observed at most sites included *Halimeda*, and *Lobophora*.

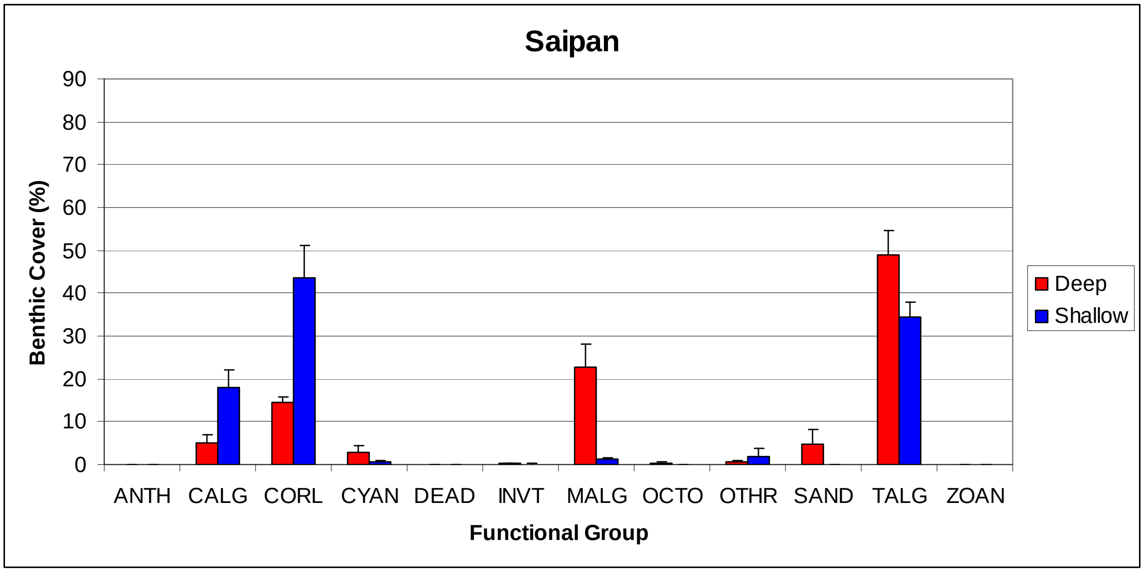


Figure B.3.2.1.2--Percent cover of functional groups at shallow and deep independent LPI monitoring sites established in 2009 at Saipan. ANTH = anthozoan, CALG = crustose coralline red algae, CORL = coral, CYAN = cyanobacteria, DEAD = dead coral, INVT = non-coral invertebrate, MALG = macroalgae, OCTO = octocoral, OTHER = other, TALG = turf algae, ZOAN = zoanthid.

Table B.3.2.1.1--Coral generic diversity of stratified random sites around Saipan.

	SAI-50	SAI-51	SAI-52	SAI-53	SAI-54	SAI-55	SAI-56	SAI-57	SAI-58	SAI-59	SAI-60	SAI-61	SAI-62	SAI-63
Acanthastrea	X		X	X	X			X	X		X	X	X	
Acropora	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Alveopora	X													
Astreopora	X		X	X			X	X		X	X	X		X
Cladiella*			X	X		X		X	X			X		
Corallimorph*											X			
Coscinarea	X							X	X	X				
Cyphastrea			X	X		X	X	X	X	X	X	X		X
Diploastrea														
Distichopora*	X			X	X	X	X		X		X		X	
Echinopora			X									X		
Euphyllia	X										X			
Favia	X	X	X	X	X	X		X	X	X	X	X	X	X
Favites					X							X		

	SAI-50	SAI-51	SAI-52	SAI-53	SAI-54	SAI-55	SAI-56	SAI-57	SAI-58	SAI-59	SAI-60	SAI-61	SAI-62	SAI-63
Fungia	X		X	X			X	X		X	X			X
Galaxea	X		X	X	X	X		X	X		X	X	X	X
Gardinoseris				X										
Goniastrea	X		X	X	X	X		X	X	X	X	X	X	X
Goniopora				X				X	X		X			X
Heliopora*			X					X						X
Herpolitha	X			X										
Hydnophora								X	X			X	X	
Isopora			X											
Leptastrea	X	X	X	X				X		X	X	X	X	X
Leptoria		X	X		X	X		X	X		X	X	X	
Leptoseris														
Lobophyllia			X		X				X					
Lobophytum*				X							X	X	X	
Merulina														
Millepora*	X	X		X	X	X	X	X	X			X	X	X
Montastrea		X		X	X	X		X	X	X		X	X	X
Montipora	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Ouphyllia			X	X				X			X			
Pachyseris														
Palythoa*										X				
Pavona	X		X	X	X	X		X		X	X	X	X	X
Platygyra		X	X	X	X	X		X				X	X	X
Pleisiastrea	X			X			X			X	X			
Plerogyra											X			
Pocillopora	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Porites	X		X	X	X		X	X	X	X	X	X	X	
Psammocora			X	X						X	X			X
Sarcophyton*														
Scapophyllia				X						X				X
Scolymia														
Seriatopora				X										
Sinularia*							X			X	X			X
Stylaster*														
Stylocoeniella			X	X							X		X	
Stylophora	X		X		X	X		X	X	X		X	X	X
Turbinaria	X			X			X			X	X			X
Wire Coral*	X													
Zoanthus*	X				X				X		X			
Total Genera per Site	23	9	24	29	18	15	12	24	20	20	27	22	19	21

* non-scleractinian genera

Table B.3.2.1.2--Macroalgal generic diversity of stratified random sites around Saipan.

	SAI-50	SAI-51	SAI-52	SAI-53	SAI-54	SAI-55	SAI-56	SAI-57	SAI-58	SAI-59	SAI-60	SAI-61	SAI-62	SAI-63
Amphiroa	X			X		X		X	X	X	X		X	
Asparagopsis								X				X		
Avrainvillea											X			
Boergesenia									X					
Boodlea					X									
Botrycladia							X							
Bryopsis										X		X		
Cladophora			X											
Caulerpa			X			X		X	X	X	X	X	X	
Chlorodesmis			X			X		X	X			X	X	
Crustose Coralline	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Cyanobacteria				X	X	X		X		X			X	X
Dichotomaria	X			X				X	X		X			
Dictyosphaeria			X		X	X								
Dictyota						X	X	X	X	X		X		
Galaxaura	X			X			X	X	X	X		X		
Gibsmithia	X						X							X
Halimeda	X	X	X	X			X	X	X		X	X	X	X
Halymenia														
Liagora							X	X						
Lobophora	X		X	X		X			X	X	X	X	X	
Microdictyon							X							X
Neomeris	X			X			X	X		X	X	X	X	X
Non-geniculate calcified branched			X	X	X	X		X	X		X	X	X	X
Padina	X			X			X			X	X	X		X
Peyssonnelia					X	X			X		X			
Portieria												X		
Rhipilia											X	X	X	
Turbinaria						X			X				X	
Tydemania														
Udotea				X										X
Valonia	X		X							X	X			X
Unknown	1					1					1			
Total Genera per site	11	2	9	11	6	12	10	13	13	11	14	14	11	10

B.3.2.2. Coral Populations

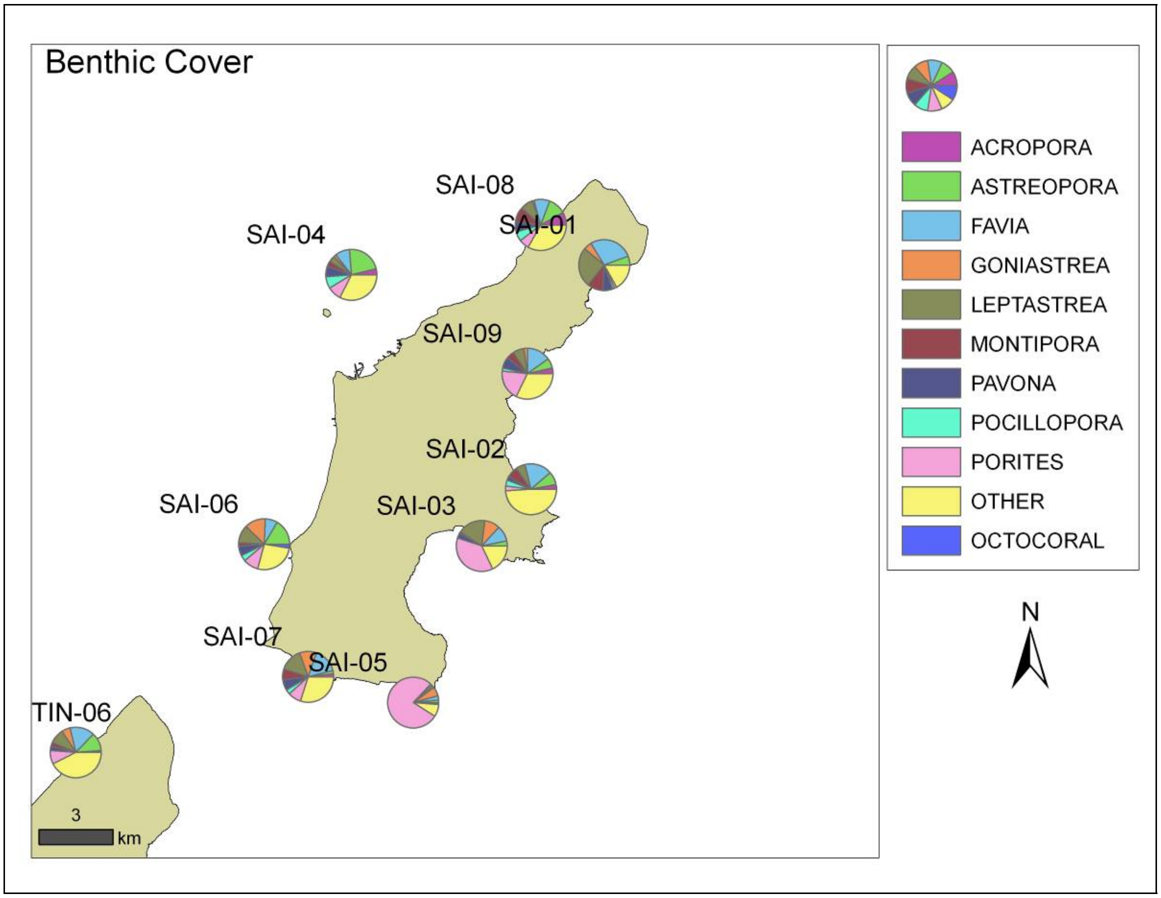
During MARAMP 2009, belt transect surveys were conducted at nine permanent, long-term REA sites around Saipan, covering a total reef area of nearly 165 m^2 and totaling 3202 anthozoan colonies enumerated. This translates to an estimated mean colony density of 17.5 colonies m^{-2}. Taxonomic richness varied between sites with 40 anthozoan genera (32 scleractinian, three octocoral, two hydrocorals, two zoanthids, and one corallimorph) being represented within belt transects (Table B.3.2.2.1). In order of decreasing importance, *Porites*, *Favia, Astreopora* and *Leptastrea* were the most abundant scleractinian genera, contributing

17.3% 11.9%, 11.3% and 10.8% of the total number of colonies enumerated island-wide. All other genera individually contributed less than 10% of the total number of colonies (Table B.3.2.2.1).

Table B.3.2.2.1--Relative abundance of anthozoan genera enumerated within belt transects around Saipan during MARAMP 2009.

Island	Genus	Relative abundance
Saipan	*Porites*	17.3
	Favia	11.9
	Astreopora	11.3
	Leptastrea	10.8
	Montastrea	6.5
	Galaxea	5.7
	Goniastrea	5.7
	Pavona	4.9
	Cyphastrea	4.6
	Montipora	4.4
	Stylophora	3.6
	Pocillopora	3.2
	Psammocora	3.1
	Acropora	2.2
	Platygyra	0.8
	Acanthastrea	0.5
	Leptoria	0.5
	Sinularia	0.4
	Stylocoeniella	0.4
	Hydnophora	0.3
	Turbinaria	0.3
	Distichopora	0.2
	Fungia	0.2
	Lobophytum	0.2
	Alveopora	0.1
	Cycloseris	0.1
	Goniopora	0.1
	Heliopora	0.1
	Echinopora	0.1
	Favites	0.1
	Oulophyllia	0.1
	Scolymia	0.1
	Zoanthus	0.1
	Echinophyllia	0.0
	Millepora	0.0
	Coscinaraea	0.0
	Leptoseris	0.0
	Lobophyllia	0.0
	Palythoa	0.0
	Rhodactis	0.0

Spatial patterns of generic relative abundance based on colony counts at nine long-term monitoring REA sites in 2009 are reflected in Figure B.3.2.2.1. Colonies of the genus *Porites* were particularly abundant at sites SAI-09, SAI-03 and SAI-05 on the east and southeast facing shores of the island. *Astreopora*, was the most numerically abundant coral at sites SAI-06, SAI-04, and SAI-08, along the west and southwest region of the islands, while *Favia* was dominant at sites SAI-07, SAI-01, and SAI-02 (Fig. B.3.2.2.1).



B.3.2.2.1--Relative abundance of coral genera from REA surveys around Saipan during MARAMP 2009.

B.3.3. Coral Health and Disease

During MARAMP 2009, the occurrence of disease, health impairments, and predation around Saipan was moderate, with a total of 104 cases of diseases and predation enumerated. A summary of disease occurrence and relative abundance is presented in Table B.3.3.1 The most numerically abundant type of lesions recorded on corals around Saipan was fungal infections, detected in relatively high numbers at SAI-09, SAI-07, and SAI-06, particularly on corals of the genus *Cyphastrea* (65% of cases). Hyperpigmented irritations were the second most numerically abundant type of affliction, with a total of 17 cases tallied island-wide. Lesions affecting coralline algae were not uncommon; a total of 18 cases were enumerated island-wide, with coralline lethal orange disease (CLOD) accounting for > 83% of cases.

Table B.3.3.1--Number of cases of scleractinian and coralline algal diseases and predation enumerated during REA surveys, around Saipan Island, MARAMP 2009. ALG: algal infections, BIN: barnacle infestation; BLE: bleaching; CYA: cyanophyte infections; DIS: discolorations other than bleaching; FUG: fungal infections; HYP: hyperpigmented irritations/pigmentation response; PRE: *Acanthaster*/*Drupella* predation scars; SGA: skeletal growth anomalies; TIN: tubeworm infestation; TLS: tissue loss; WSY: white syndrome; OTH: other diseases and lesions of unknown etiology; CLOD: coralline lethal orange disease; and CLD; coralline white band syndrome/lethal disease.

DZCode	SAI-01	SAI-02	SAI-03	SAI-04	SAI-05	SAI-06	SAI-07	SAI-08	SAI-09	Grand Total
ALG	7	1		1		4	1	1		15
BLE	5	2		2	1			2	2	14
CYA					1			2	1	4
DIS	2	1	1		1	3		1	1	10
FUG	9	2	2			4	5		1	23
HYP	1			9	2	1	1	1	2	17
SGA	2									2
TIN				1				1		2
TLS	3	1	1						1	6
WSY				1						1
OTH					5					5
PRE		2	1	2						5
TOTAL	**29**	**9**	**5**	**16**	**10**	**12**	**7**	**8**	**8**	**104**
CLD				1				14		15
CLOD			1		2					3

B.3.4. Macroinvertebrate Surveys (non-coral)

A total of 575 individuals of benthic invertebrate target species or taxa were enumerated from 23 belt transects at 13 sites. Non-cryptic macroinvertebrates were low around Saipan with the exception of the boring sea urchin, *Echinostrephus aciculatus.* The island density for *E. aciculatus* was 4.47 (SE 2.6) organisms 50 m^{-2}. Site SAI-01 had the greatest density with 14.56 organisms 50 m^{-2}. The sea cucumber, *Stichopus chlorontus*, was common at sites SAI-01 and SAI-02 with 0.72 organisms 50 m^{-2}. *Linckia multifora* were common at site SAI-03 with 1.98 organisms 50 m^{-2}. *Tridacna* clams were most abundant at sites SAI-03 and SAI-07 with 0.54 and 0.48 organisms 50 m^{-2}. *Acanthaster planci* was seen on a transect at SAI-09 in low numbers. *Calcinus* hermit crabs were common in coral heads at sites SAI-02 and SAI-03 and the coral crabs from the genus *Trapezia* were common at site SAI-07.

B.3.4.1. Urchin Measurements

Figure B.3.4.1.1--Average test diameter of urchins encountered at each site. Only sites where ≥ 5 measurements were recorded for a species are represented. *Echinostrephus aciculatus* is the only represented echinoid.

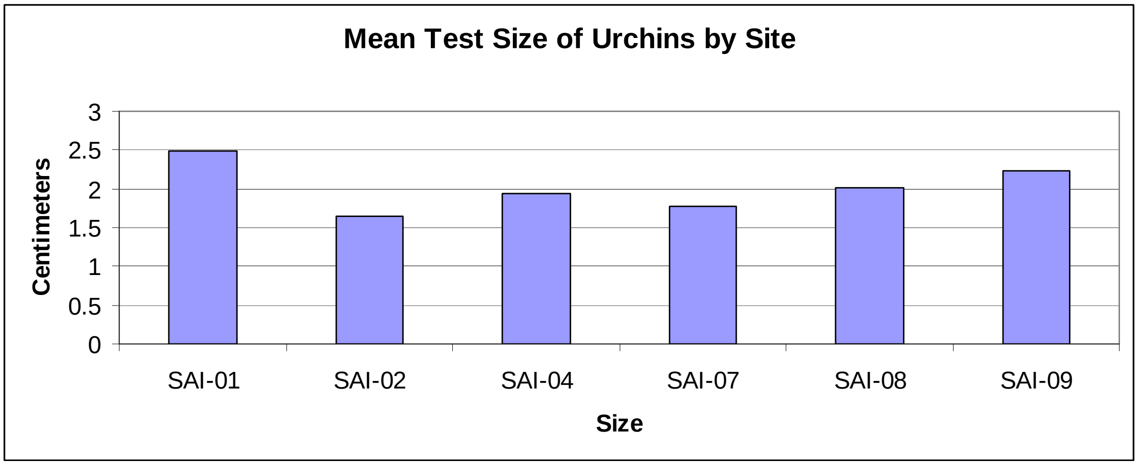


Figure B.3.4.1.1--Mean Test size of urchins by site.

B.3.4.2. Autonomous Reef Monitoring Systems (ARMS) Deployment
ARMS were deployed at the following REA sites around Saipan. Each site contains three ARMS (Table B.3.4.2.1.).

Table B.3.4.2.1--ARMS deployment locations around Saipan.

REA Site	Latitude	Longitude
SAI-08	15º 16.446 N	145º 47.463 E
SAI-06	15º 09.386 N	145º 41.401 E
SAI-05	15º 05.872 N	145º 44.604 E

B.3.5 Benthic Towed-diver Surveys
Eighteen benthic towed-diver surveys were completed around Saipan in 2009 (Fig. B.3.5.1.). Habitats covered during surveys varied with the majority of tow segments conducted over hard bottom (a mixture of continuous reef, continuous pavement, rock boulders, and ridges extending from shore creating steep drop-offs).

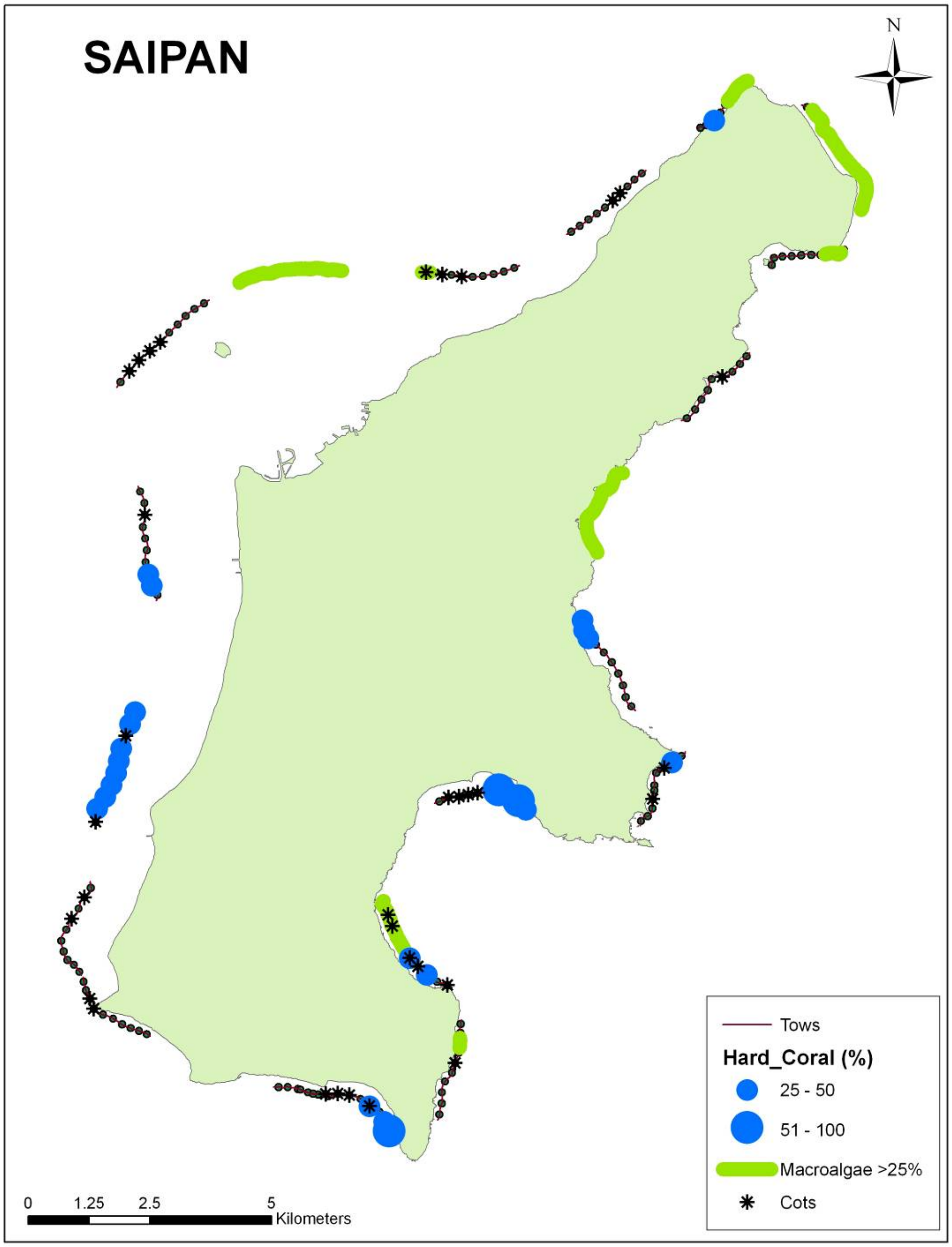


Figure B.3.5.1--Hard coral cover, elevated macroalgal cover (> 25%), and crown-of-thorn (COT) abundances during tow segments at Saipan 2009.

B.4 Fish Surveys

B.4.1 REA Fish Surveys

Stationary point count data (nSPC)

During the survey period, nSPC surveys were conducted at 23 sites around Saipan. Surgeonfish were the largest contributor to total biomass with 0.77 kg 100 m^{-2}. Parrotfish were the second largest contributor to total biomass with 0.30 kg 100 m^{-2}, followed by damselfish at 0.21 kg 100 m^{-2} (Fig. B.4.1.1).

Overall observations
A total of 234 fish species were observed by all divers during the survey period. The average total fish biomass around Saipan during the survey period was 2.1 kg 100 m^{-2} for the nSPC surveys (Table B.4.1.1.).

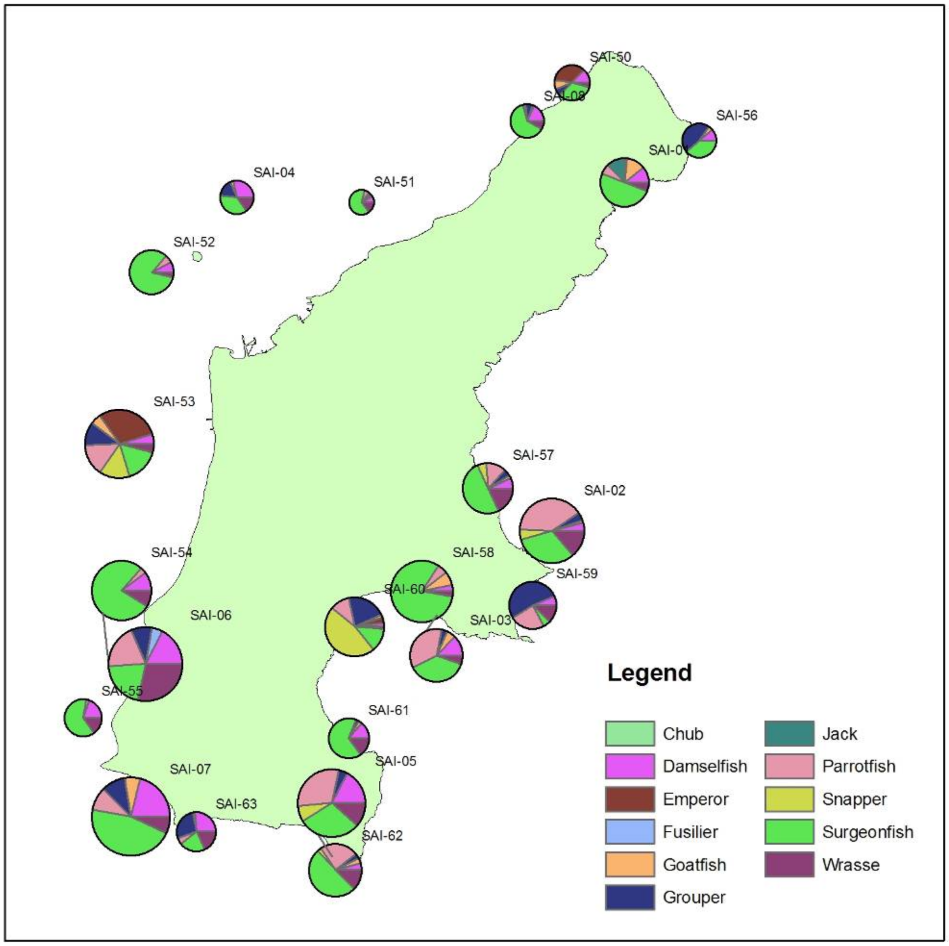


Figure B.4.1.1--Site location and distribution of total fish biomass by family. The sizes of the pie charts are proportional to fish biomass.

B.4.2 Towed-diver Surveys

During HA0903, the CRED towed-diver team completed 20 surveys at Saipan covering 43.6 km (43.6 ha) of ocean floor (Table B.4.2.1.). Mean survey length was 2.0 km with a maximum length of 2.8 km and a minimum of 1.4 km. Mean survey depth was 2.2 m with a maximum depth of 17.0 m and a minimum of 11.2 m. Mean temperature on these surveys was 28°C with a maximum temperature of 28.2°C and a minimum of 27.8°C.

Table B.4.2.1--Survey statistics for towed-diver sampling during HA0903.

Island/Reef	#	Length (km)					Depth (m)				Temperature (ºC)			
		Sum	Mean	Max	Min	SD	Mean	Max	Min	SD	Mean	Max	Min	SD
Saipan	20	43.6	2.2	2.7	1.2	0.4	14.4	17.0	11.2	1.4	28.0	28.2	27.8	0.1

Sixty-two individual large-bodied reef fish (> 50 cm TL) of 27 different species and 18 different families were encountered at Saipan (Table B.4.2.2.). Overall numeric density for this class of reef fishes was 0.14 #/100 m^2 (14.23 #/ha) with a biomass density of 1.74 kg/100 m^2 (0.17 t/ha). Numeric density was dominated by *Fistularia commersonii* while biomass density was dominated by *Aetobatus narinari.*

Table B.4.2.2--Species numeric and biomass density for large-bodied reef fishes (> 50 cm TL) observed at Saipan during HA0903 CRED towed-diver surveys.

Species	#	#/100 m^2	#/ha	Biomass (kg)	kg/100 m^2	t/ha
Aetobatus_narinari	5	0.01	1.15	202.88	0.47	0.05
Aluterus_scriptus	2	0.00	0.46	0.55	0.00	0.00
Aprion_virescens	2	0.00	0.46	6.70	0.02	0.00
Arothron_stellatus	2	0.00	0.46	22.30	0.05	0.01
Aulostomus_chinensis	2	0.00	0.46	0.84	0.00	0.00
Carangoides_orthogrammus	2	0.00	0.46	4.31	0.01	0.00
Caranx_ignobilis	1	0.00	0.23	20.69	0.05	0.00
Caranx_melampygus	3	0.01	0.69	7.73	0.02	0.00
Carcharhinus_melanopterus	1	0.00	0.23	25.22	0.06	0.01
Cheilinus_undulatus	4	0.01	0.92	97.23	0.22	0.02
Chlorurus_microrhinos	5	0.01	1.15	14.81	0.03	0.00
Diodon_hystrix	2	0.00	0.46	10.10	0.02	0.00
Fistularia_commersonii	6	0.01	1.38	1.62	0.00	0.00
Gymnosarda_unicolor	2	0.00	0.46	19.25	0.04	0.00
Gymnothorax_javanicus	1	0.00	0.23	6.13	0.01	0.00
Gymnothorax_meleagris	1	0.00	0.23	0.45	0.00	0.00
Himantura_fai	1	0.00	0.23	87.61	0.20	0.02
Hipposcarus_longiceps	1	0.00	0.23	3.29	0.01	0.00
Kyphosus_sp	5	0.01	1.15	14.48	0.03	0.00
Lutjanus_bohar	4	0.01	0.92	23.53	0.05	0.01
Naso_unicornis	1	0.00	0.23	2.57	0.01	0.00
Pastinachus_sephen	2	0.00	0.46	105.48	0.24	0.02
Plectorhinchus_gibbosus	1	0.00	0.23	2.44	0.01	0.00
Pseudobalistes_flavimarginatus	2	0.00	0.46	6.94	0.02	0.00
Scarus_rubroviolaceus	1	0.00	0.23	2.60	0.01	0.00
Taeniura_meyeni	2	0.00	0.46	33.03	0.08	0.01
Triaenodon_obesus	1	0.00	0.23	34.04	0.08	0.01
Grand Total	62	0.14	14.23	756.81	1.74	0.17
# of Species	27					

While overall numbers and biomass were low, a large number of fish families were encountered at Saipan compared to the northern islands. The most prevalent families in terms of numeric density were scarids (11%), carangids (10%), and lutjanids (10%) (Fig. B.4.2.1.), while biomass was dominated by dasyatids (30%) and myliobatids (27%) (Fig. B.4.2.2.) There was no clear pattern to the geographic distribution of large-bodied reef fish around the island. (Fig. B.4.2.3.).

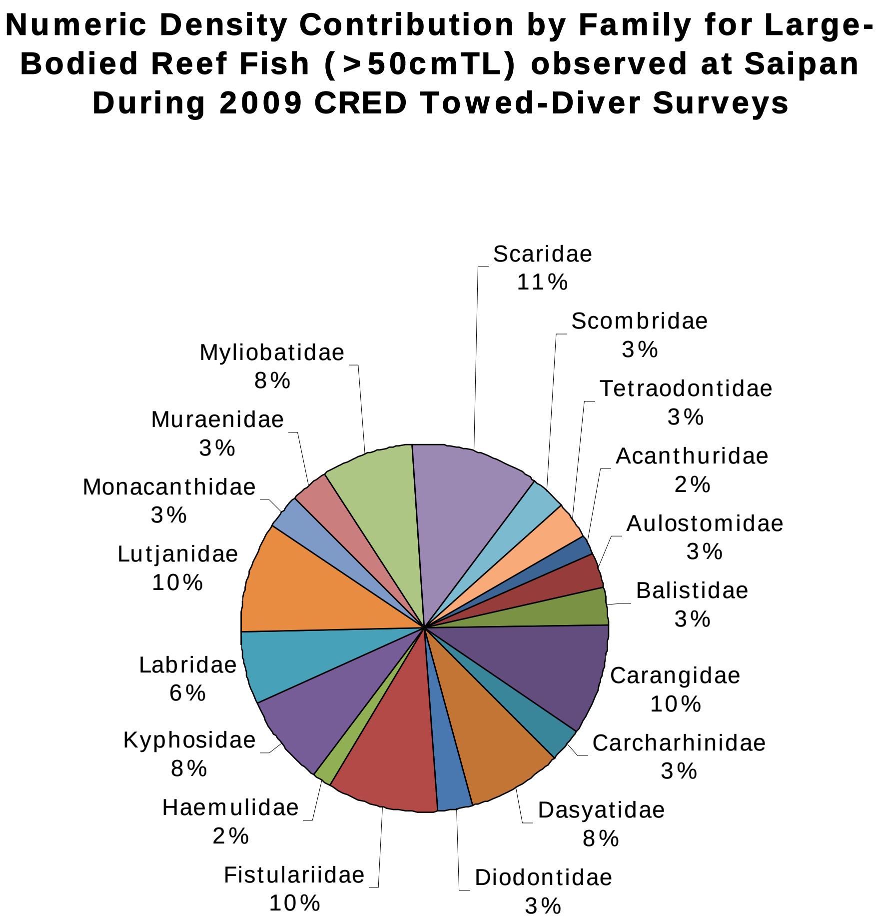


Figure B.4.2.1--Numeric density of fishes by family.

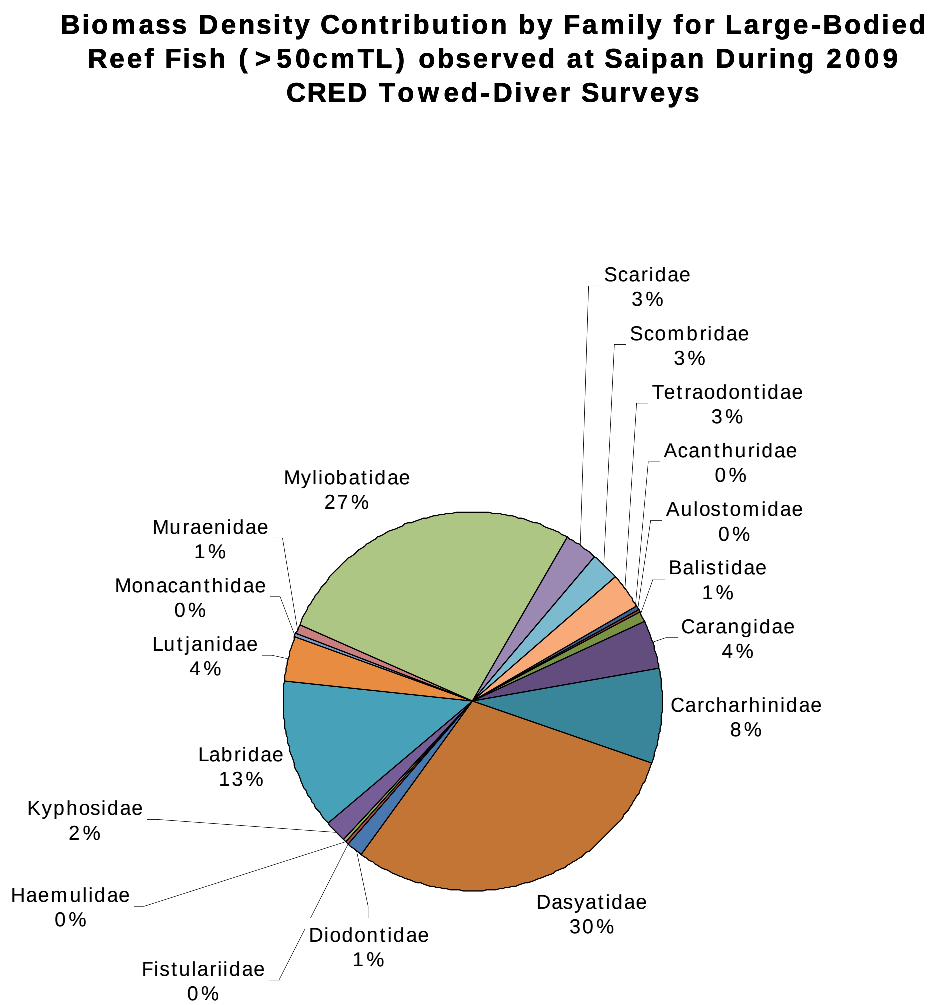


Figure B.4.2.2--Biomass density of fishes by family.

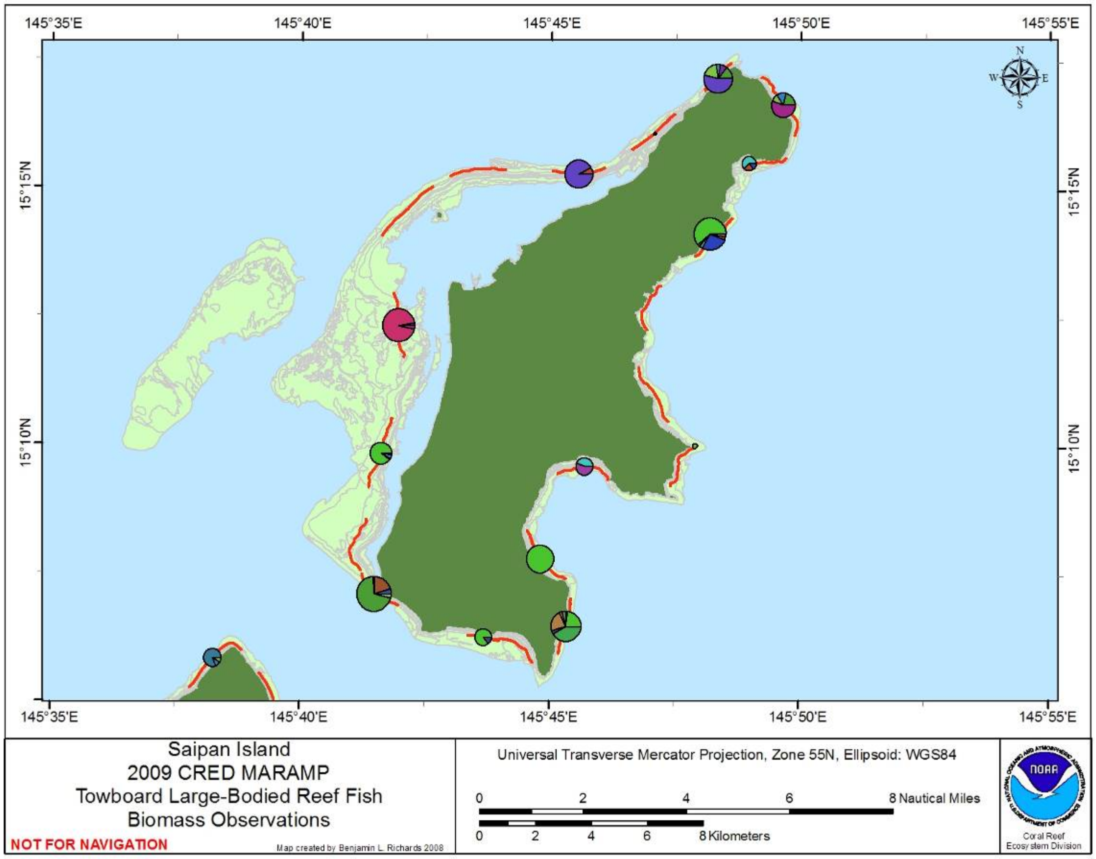


Figure B.4.2.3--Geographic distribution of biomass of fish species around Saipan. Each species is represented by a legend color. Diameter of pie chart is proportional to total biomass of all species encountered on the underlying survey.

Appendix C: Sarigan Results

C.1. Oceanography and Water Quality

Moorings recovered and replaced during HA0903 at Sarigan included two subsurface temperature recorders (STRs) (Table C.1.1., Fig. C.1.1.). Both STRs show similar patterns and temperature ranges, with a clear annual fluctuation due to seasonal warming and cooling (Fig. C.1.2.). Warmest temperatures peaked at approximately 31^{o}C and occurred during the summer months of July to October. Winter temperatures reached lows of about 27^{o}C and occurred during November through June.

One rapid ecological assessment (REA) site (SAR-04) was visited to collect water samples for microbiological, nutrient and chlorophyll analyses, and a second REA site (SAR-03) was sampled for just nutrients and chlorophyll. Samples were obtained from the surface and approximately 1 m above the reef. Microbial water samples were taken using diver-deployable Niskin bottles to collect 8 liters of seawater (four bottles; 2 liters per bottle). Chlorophyll samples were filtered, and nutrient samples were frozen at -30^{o}C for post-cruise analysis. Shallow-water conductivity-temperature-depth (CTD) casts were also conducted at these sites. In addition, nine CTD casts were taken every 1 km around the perimeter of Sarigan at the 30 m depth contour (Fig. C.1.1.).

Table C.1.1--Sarigan moorings.

Action	Mooring type	Serial number	Lat		Long		Depth (m)
Deployment	STR	39301590835	16.71059266	N	145.7678765	E	5.8
Deployment	STR	39327181048	16.69863235	N	145.788125	E	11.3
Retrieval	STR	39432363067	16.69863235	N	145.788125	E	11.3
Retrieval	STR	39443093483	16.71059266	N	145.7678765	E	5.8

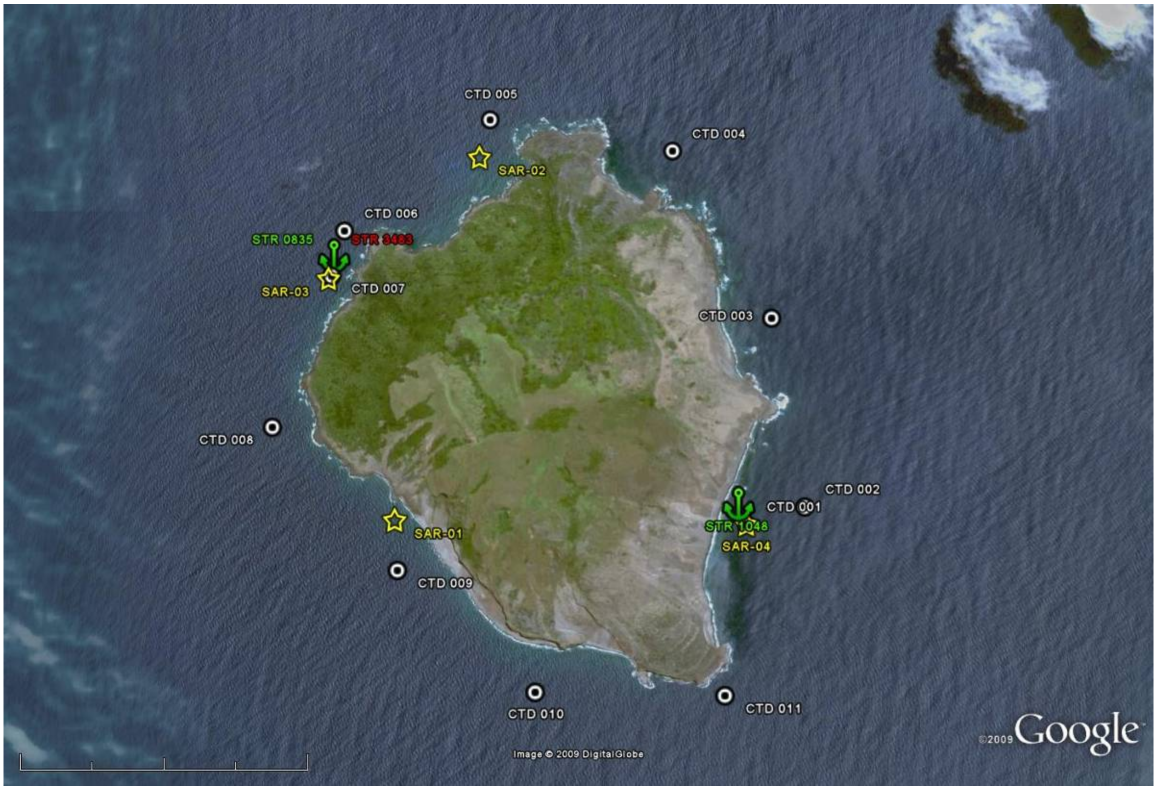


Figure C.1.1--Deployed and recovered instrument moorings and CTD and water sampling sites, Sarigan, HA0903.

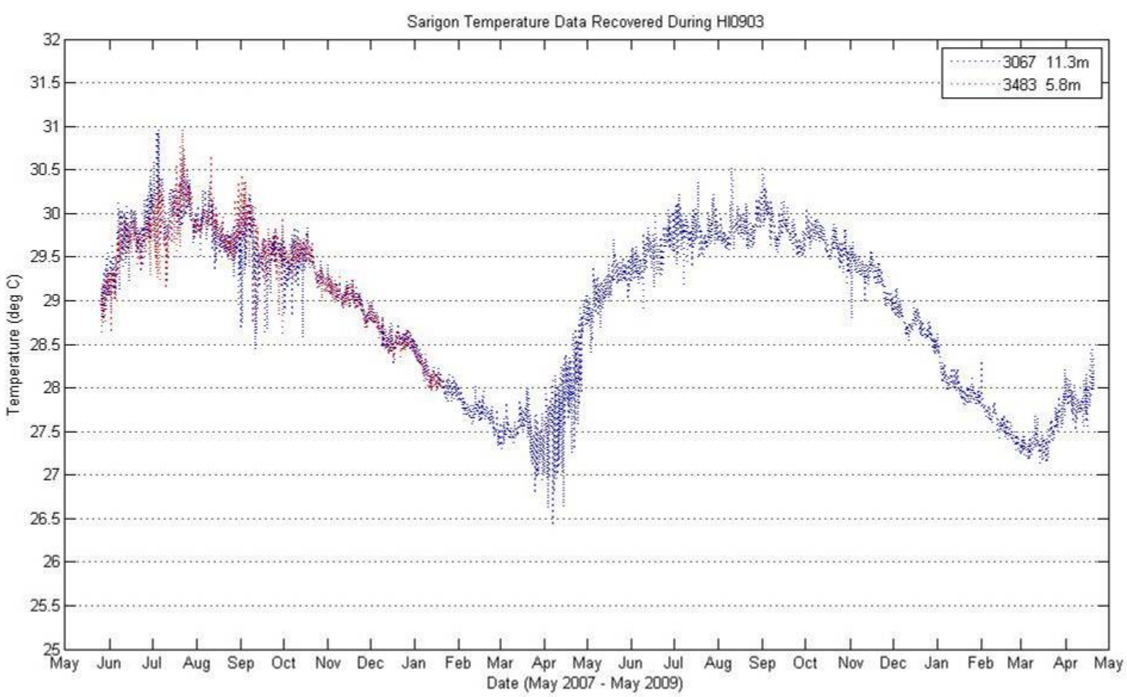


Figure C.1.2--Temperature time series from STR moorings at Sarigan.

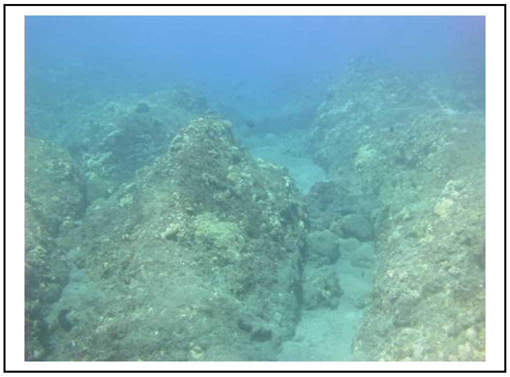
C.2. Rapid Ecological Assessment (REA) Site Descriptions

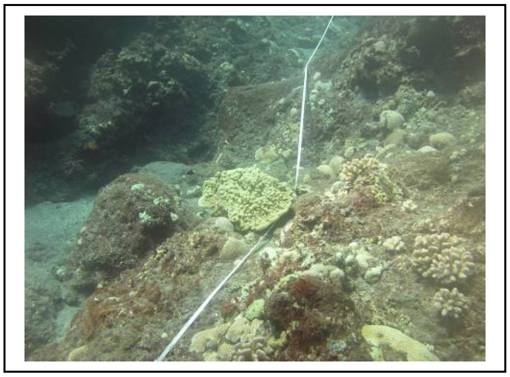
SAR-01
4/21/2009

E 145° 46.271
N 16° 41.930

Forereef
Mid

Depth: 12–14 m





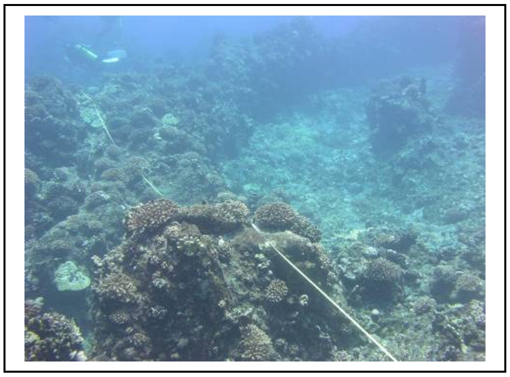
Site description: Southwestern region; site of rock slide; high topographic complexity; moderate/high coral cover; low macroalgal cover.

SAR-02
4/21/2009

E 145° 46.516
N 16° 42.984

Forereef
Mid

Depth: 12–13 m



Site description: Northwestern region; spur and groove reefs; high topographic complexity; high coral cover; low macroalgal cover.

SAR-04
4/21/2009

E 145° 47.316
N 16° 41.916

Forereef
Mid

Depth: 11–15 m

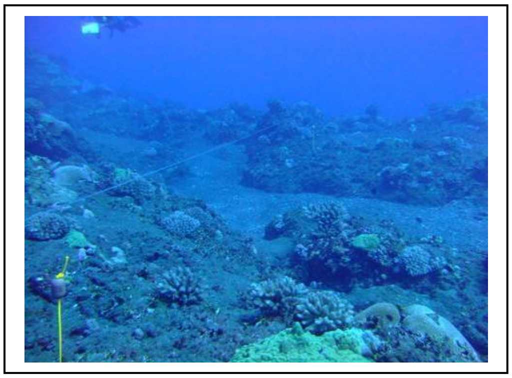
Site description: Southeastern region; moderate topographic complexity (boulders surrounded by sand); high coral cover; low macroalgal cover.

SAR-50
4/21/2009

E 145° 47.356
N 16° 42.519

Forereef
Deep

Depth: 22 m




Site description: Eastern region; moderate topographic complexity (rock formations surrounded by sand); moderate coral and macroalgal cover.

SAR-51
4/21/2009

E 145° 46.993
N 16° 42.881

Forereef
Shallow

Depth: 3 m


Site description: Eastern region; site in small cove; moderate topographic complexity (large boulders); low coral and macroalgal cover; dominated by turf algae.

SAR-52
4/21/2009

E 145° 45.984
N 16° 42.246

Forereef
Shallow

Depth: 2–3 m


Site description: Western region; shallow ledge near 6-8 m drop-off; moderate topographic complexity; low coral and macroalgal cover; dominated by turf algae.

SAR-53
4/21/2009

E 145° 46.439
N 16° 41.590

Forereef
Deep

Depth: 25 m

Site description: Western region; moderate slope and topographic complexity; high coral and macroalgal cover.

C.3. Benthic Environment

C.3.1. Algal Communities

During MARAMP 2009, three permanent, long-term REA monitoring sites were surveyed around Sarigan Island for percent benthic cover based on the 20-cm interval line point intercept (LPI) methodology. Benthic communities around Sarigan were dominated by turf algae and scleractinian corals (Table C.3.1.1). Turf algal percent cover exceeded that of other functional groups at site SAR-01 with a percent cover range of 58% (Table C.3.1.1). At sites SAR-02 and SAR-04, percent cover of turf algae and scleractinian corals were approximately equal (38.8% vs. 42% at SAR-02 and 38.4% vs. 36% at SAR-04, respectively). A combined total of 11 species of macroalgae were observed (9 chlorophytes, 1 ochrophyte, 1 rhodophyte) from the 3 sites surveyed (Tables C.3.1.2, C.3.1.3). *Lobophora variegata* was a prominent member of the macroalgal community; occurring at all three sites with a percent cover range of 0.8% to 1.6% (Table C.3.1.3). *Halimeda opuntia* dominated the macroalgal community at site SAR-02 with a percent cover of 2.4% (Table C.3.1.3).

Table C.3.1.1--Percent cover of algal functional groups at long-term monitoring sites at Sarigan.

Site	Macroalgae	Turf Algae	Coralline red algae (crustose + upright)	Cyanobacteria	Scleractinian Coral	Octocoral
SAR-01	3.2%	58.0%	4.0%	6.0%	22.4%	-
SAR-02	6.0%	38.8%	10.0%	0.8%	42.0%	-
SAR-04	6.0%	38.4%	4.8%	1.6%	36.0%	0.8%

Table C.3.1.2--Additional species recorded at each site at Sarigan during roving diver survey.

Site	Chlorophyta
SAR-04	*Halimeda taenicola*
SAR-01	*Halimeda tuna*
SAR-04	*Neomeris* sp.
SAR-01 SAR-04	*Valonia ventricosa*
	Rhodophyta
SAR-01	***Halymenia* sp.**

Table C.3.1.3--Percent cover of macroalgal species at long-term monitoring sites at Sarigan. Sum totals for each row equal the percent cover of macroalgae recorded in Table C.3.1.1.

Site	Caulerpa racemosa	Caulerpa serrulata	Caulerpella ambigua	Dictyosphaeria versluysii	Halimeda opuntia	Lobophora variegata
SAR-01	-	0.4%	-	0.4%	-	1.6%
SAR-02	0.4%	-	0.4%	-	2.4%	1.6%
SAR-04	-	-	-	0.4%	0.4%	0.8%

C.3.2. Coral Communities

C.3.2.1. Percent Benthic Cover

In 2009, percent benthic cover surveys around Sarigan were conducted in concert with coral population, algae, and invertebrate REA surveys at three permanent sites. Percent coral cover around Sarigan derived from LPI surveys conducted at the permanent long-term REA sites yielded an island-wide mean of 33.5.8% (Fig. C.3.2.1.1). Percent coral cover was the greatest at SAR-02 on the northern sector of the island, and the lowest at SAR-01 on the west-facing shore (Fig. C. 3.2.1.1).

Four additional stratified random REA sites were surveyed around Sarigan for percent bethic cover (based on 50-cm interval LPI surveys) and generic diversity data in 2009. Results from the four stratified random REA sites surveyed in 2009 yielded the following results: benthic communities surveyed at two sites greater than 20 m deep were dominated by macroalgal (34.3% $\pm$ 10.8), turf algal (31.8% $\pm$ 20.1) and scleractinian coral (27.5% $\pm$ 6.9) functional groups (Fig. C.3.2.1.2). Two shallow sites (< 10 m depth) were dominated by turf algal (57.4% $\pm$ 7.4) and calcareous algal (13.2% $\pm$ 11.3) functional groups (Fig. F). Coral generic diversity was highest at site SAR-53 with 25 different genera observed (Table C.3.2.1.2). In contrast sites SAI-51 and SAR-52 had the lowest generic diversity with 15 different genera observed at both. An average of 19 coral genera were recorded at each site. Common genera observed at most sites included *Porites*, *Pocillopora, Montipora*, *Acropora*, *Favia*, *Pavona*, *Platygyra* and *Leptastrea*. Macroalgal generic diversity was highest at sites SAR-51 and SAI-52 with 12 genera observed (Table C.3.2.1.2). Site SAI-53 had the lowest generic diversity with three genera observed. An average of 9 macroalgal genera were recorded for each site. Common macroalgae observed at most sites included *Halimeda*, *Bryopsis* and *Amphiroa*.

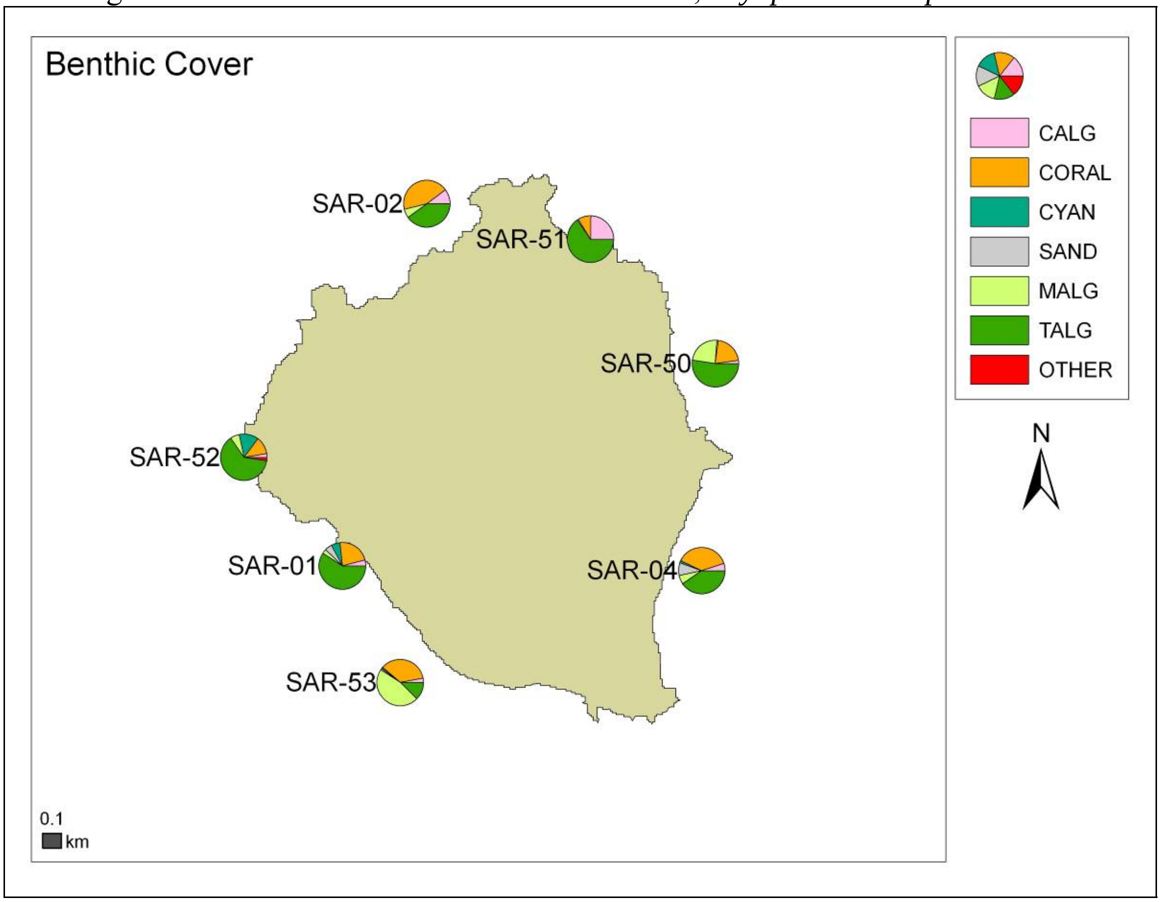


Figure C.3.2.1.1--Percent cover of benthic functional groups at the random stratified and permanent REA monitoring sites around Sarigan during MARAMP 2009. CALG = crustose coralline red algae, CYAN = cyanobacteria, MALG = macroalgae, TALG = turf algae.

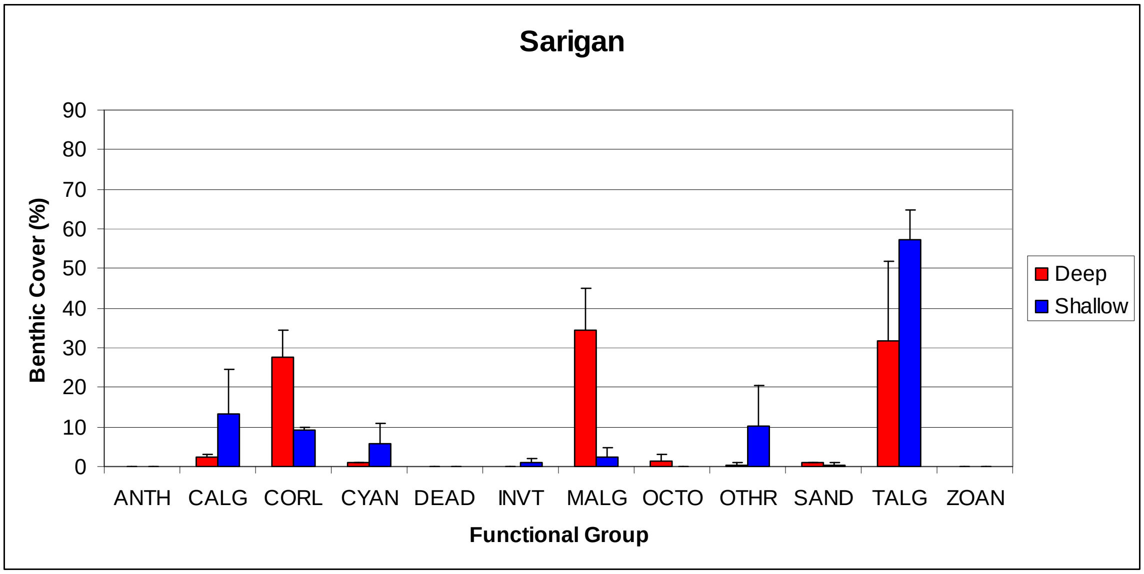


Figure C.3.2.1.2--Percent cover of functional groups at shallow and deep independent LPI monitoring sites established in 2009 at Sarigan. ANTH = anthozoan, CALG = crustose coralline red algae, CORL = coral, CYAN = cyanobacteria, DEAD = dead coral, INVT = non-coral invertebrate, MALG = macroalgae, OCTO = octocoral, OTHER = other, TALG = turf algae, ZOAN = zoanthid.

Table C.3.2.1.1--Coral generic diversity of stratified random sites around Sarigan.

	SAR-50	SAR-51	SAR-52	SAR-53
Acanthastrea		X	X	X
Acropora	X	X	X	X
Alveopora				
Astreopora	X			X
*Cladiella**		X	X	
*Corallimorph**				
Coscinarea				
Cyphastrea	X		X	X
Diploastrea				
*Distichopora**				
Echinopora				X
Euphyllia				
Favia	X	X	X	X
Favites		X		
Fungia	X			X
Galaxea	X			X
Gardinoseris				
Goniastrea	X	X		
Goniopora				X
*Heliopora**	X			X
Herpolitha				
Hydnophora				

	SAR-50	SAR-51	SAR-52	SAR-53
Isopora				
Leptastrea	X	X	X	X
Leptoria		X		
Leptoseris				
Lobophyllia				
Lobophytum*	X			X
Merulina				
Millepora*				X
Montastrea		X	X	
Montipora	X	X	X	X
Ouphyllia	X			X
Pachyseris				
Palythoa*	X	X	X	
Pavona	X	X	X	X
Platygyra	X	X	X	X
Pleisiastrea	X			X
Plerogyra				
Pocillopora	X	X	X	X
Porites	X	X	X	X
Psammocora	X		X	
Sarcophyton*				
Scapophyllia				X
Scolymia				
Seriatopora				
Sinularia*				X
Stylaster*				
Stylocoeniella				X
Stylophora	X		X	X
Turbinaria	X			X
Wire Coral*				
Zoanthus*				
Total Genera per Site	21	15	15	25

* non-scleractinian genera

Table C.3.2.1.2--Macroalgal generic diversity of stratified random sites around Sarigan.

	SAR-50	SAR-51	SAR-52	SAR-53
Amphiroa	X	X	X	
Asparagopsis	X			
Avrainvillea				
Boergesenia				
Boodlea		X	X	
Bryopsis	X		X	X
Caulerpa	X	X		
Chlorodesmis		X		
Crustose Coralline	X	X	X	
Cyanobacteria	X	X	X	X
Dichotomaria				
Dictyosphaeria		X	X	
Dictyota		X		
Galaxaura				
Gibsmithia	X			
Halimeda	X		X	X
Halymenia				
Lobophora		X	X	
Microdictyon				
Neomeris	X	X		
Non-geniculate calcified branched		X		
Padina				
Peyssonnelia				
Portieria			X	
Rhipilia				
Turbinaria				
Tydemania				
Udotea		X		
Valonia	X		X	
Unknown			2	
Total Genera per site	10	12	12	3

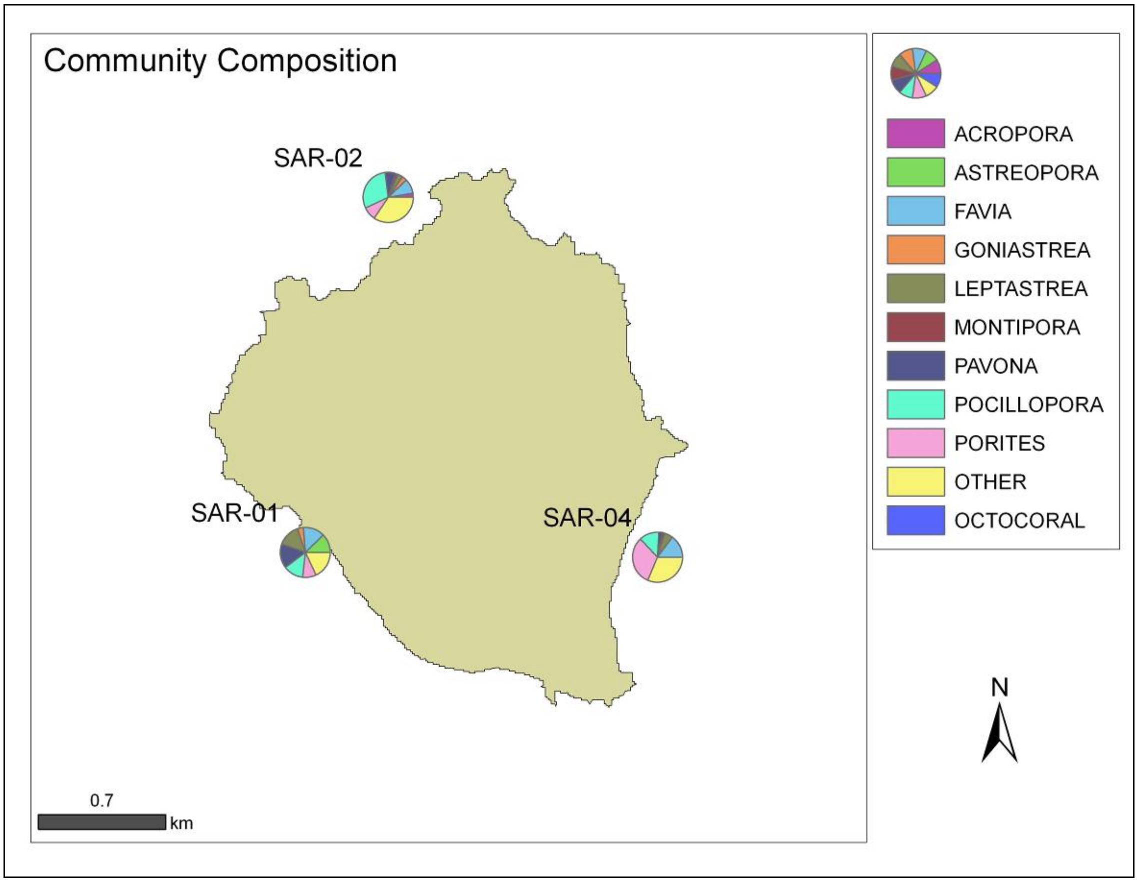
3.2.2. Coral Populations

During MARAMP 2009, belt transect surveys were conducted at three permanent, long-term REA sites around Sarigan covering a total reef area of nearly 63 m^2 and totaling 1170 anthozoan colonies enumerated. This translates to an estimated mean colony density of 18.7 colonies m^{-2}. Taxonomic richness varied between sites with 28 anthozoan genera (24 scleractinian, 2 octocoral, 1 hydrocoral, and 1 zoanthid) being represented within belt transects (Table C.3.2.2.1). Survey sites were made up of an amalgam of sand and basalt blocks, with coral colonies growing on the rocky boulders. In order of decreasing importance, *Pocillopora*, *Porites*, and *Favia* were the most abundant scleractinian genera, contributing 18% 15% and 12.8% of the total number of colonies enumerated island-wide. All other genera individually contributed less than 10% of the total number of colonies (Table C.3.2.2.1). Interestingly, Sarigan was perhaps the only island in the CNMI where *Pocillopora* was the most abundant scleractinian coral.

Table C.3.2.2.1--Relative abundance of anthozoan genera enumerated within belt transects around Sarigan during MARAMP 2009.

Island	Genus	Relative abundance
Sarigan	*Pocillopora*	18.0
	Porites	15.0
	Favia	12.8
	Cyphastrea	9.1
	Pavona	9.0
	Leptastrea	8.5
	Galaxea	5.7
	Astreopora	5.4
	Montastrea	4.0
	Goniastrea	2.5
	Platygyra	2.4
	Heliopora	1.0
	Montipora	1.0
	Psammocora	0.9
	Acropora	0.8
	Acanthastrea	0.6
	Favites	0.4
	Millepora	0.4
	Leptoseris	0.3
	Oulophyllia	0.3
	Stylocoeniella	0.3
	Stylophora	0.3
	Sinularia	0.3
	Plesiastrea	0.2
	Turbinaria	0.2
	Fungia	0.1
	Hydnophora	0.1
	Zoanthus	0.1

Spatial patterns of generic relative abundance based on colony counts at three long-term, monitoring REA sites in 2009 are reflected in Figure C.3.2.2.1. Colonies of the genus *Pocillopora* were particularly abundant at sites SAR-02 on the northern sector of the island. At site SAR-04, *Porites* was the most numerically abundant scleractinian coral genus.



C.3.2.2.1--Relative abundance of coral genera from REA surveys around Sarigan during MARAMP 2009.

C.3.3. Coral Health and Disease

During MARAMP 2009, the occurrence of disease, health impairments, and predation around Sarigan was moderately low, with a total of 61 cases of diseases and predation enumerated. A summary of disease occurrence and relative abundance is presented in Table C.3.3.1 The most numerically abundant type of lesions recorded on corals around Sarigan were fungal infections, detected in relatively high numbers at SAR-01 and SAR-04, particularly on corals of the genus *Cyphastrea* (63% of cases), as well as colonies of *Pavona varians* (23%). All other types of lesions, including algal infections and hyperpigmented irritations, were detected in relatively low numbers. No cases of coralline algae disease were enumerated around Sarigan.

Table C.3.3.1--Number of cases of scleractinian and coralline algal diseases and predation enumerated during REA surveys, around Sarigan Island, MARAMP 2009. ALG: algal infections, BIN: barnacle infestation; BLE: bleaching; CYA: cyanophyte infections; DIS: discolorations other than bleaching; FUG: fungal infections; HYP: hyperpigmented irritations/pigmentation response; PRE: *Acanthaster*/*Drupella* predation scars; SGA: skeletal growth anomalies; TIN: tubeworm infestation; TLS: tissue loss; WSY: white syndrome; OTH: other diseases and lesions of unknown etiology; CLOD: coralline lethal orange disease; and CLD; coralline white band syndrome/lethal disease.

Island	DZCode	SAR-01	SAR-02	SAR-04	Grand Total
Sarigan	ALG	4	2	1	7
	BLE			1	1
	CYA	1			1
	FUG	15		20	35
	HYP			6	6
	TIN	1			1
	TLS		4	2	6
	WSY		1		1
	OTH			1	1
	PRE		2		2
Grand Total		21	9	31	61

C.3.4. Macroinvertebrate Surveys (non-coral)

A total of 357 individuals of benthic invertebrate target species or taxa groups were enumerated from six belt transects at three sites. Non-cryptic macroinvertebrates were low around Sarigan. The boring sea urchin, *Echinostrephus aciculatus*, the sea star, *Linckia multifora*, and coral crabs from the genus *Trapezia* were the most abundant. The island density for *E. aciculatus* was 2.16 (SE 0.95) organisms 50 m^{-2}. Densities were highest at SAR-02 (3.68 organisms 50 m^{-2}). The island density for *L. multifora* was 2.32 (SE 1.81) organisms 50 m^{-2}. Densities were highest at site SAR-04 with 5.92 organisms 50 m^{-2}. The island density for species of *Trapezia* was 1.47 (SE 0.58) organisms 50 m^{-2} and was highest at site SAR-02 with 2.24 organisms 50 m^{-2}. Site SAR-02 had the greatest density of giant clams with 1.28 organisms 50 m^{-2}, and site SAR-02 had the greatest density of the coral eating snail, *Quoyula madreporarum* (1.76 organisms 50 m^{-2}). Holothuroids were exceptionally rare at Sarigan.

C.3.4.1. Urchin Measurements

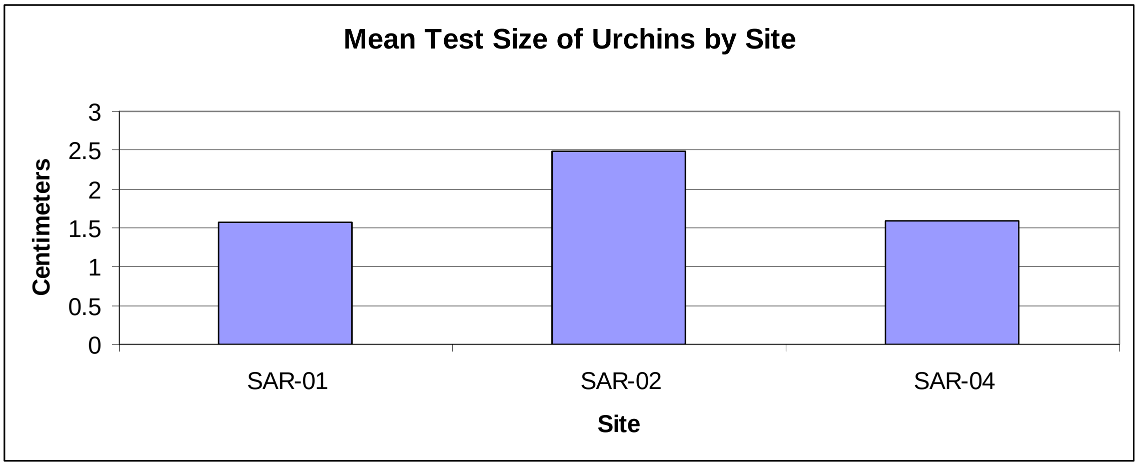


Figure C.3.4.1--Average test diameter of urchins encountered at each site. Only sites where ≥ 5 measurements were recorded for a species are represented. *Echinostrephus aciculatus* is the only represented echinoid.

C.3.5. Benthic Towed-diver Surveys

A total of five benthic towed-diver surveys were completed at Sarigan in 2009 (Fig. C.3.5.1.). One calibration tow was completed for the fish towed-diver team. Rock boulder habitat of medium to medium-high complexity was encountered along the middle of the leeward/western coast, heading south/counterclockwise along the forereef. Terrain shifted slightly to include moderate to moderate-high complexity steep pavement slopes and rock boulders with some pinnacles and sand channels rounding the southern portion of the island. Progressing along the windward/eastern side, terrain initially began as highly complex rock boulders, pinnacles, and ridges perpendicular to shore, before evolving into rock boulders, rock boulders/rubble flats, and continuous reef/sand flats. Approaching the northern part of the island, terrain consisted of pinnacles and rock boulders, moderate slope, and sand channels near the end. Rounding the northwest corner, habitat consisted primarily of medium-low to medium complexity continuous reef, shifting to continuous reef/rock boulders.

Benthic category	Mean ± SE
Hard coral	23.4 ± 1.4
Soft coral	1.8 ± 0.5
Sand	8.5 ± 1.2
Rubble	5.3 ± 1.5
Macroalgae	12.5 ± 1.4
Coralline algae	3.8 ± 0.5
COTs	0*
Free urchins	0*
Boring urchins	77*
Sea cucumbers	945*
Giant clams	116*

*Sum of observed individuals.

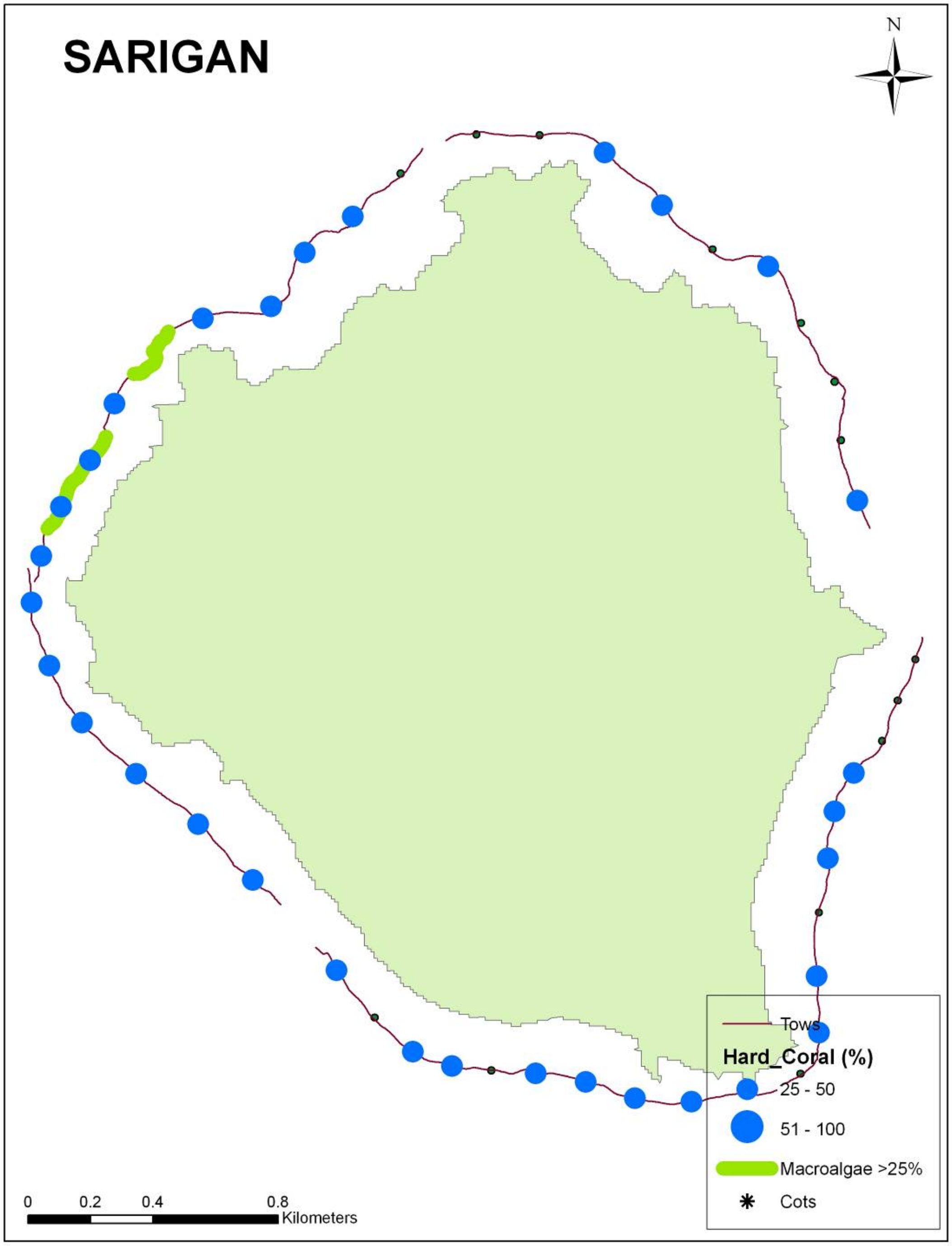


Figure C.3.5.1--Hard coral cover, elevated macroalgal cover (> 25%), boring urchin, sea cucumber abundance, and giant clam abundances during tow segments at Sarigan 2009.

Hard coral was the most abundant benthic feature, accounting for 23.4% of total benthic cover island-wide. Hard coral was most abundant along the windward/eastern side, where one survey recorded five out of ten time segments of 30.1–40% coverage. Other areas of high cover include the north/northwest side of the island, where three of six time segments (short-tow) recorded coral cover of 30.1–40%. However, many time segments around the island recorded elevated coral cover of 20.1–30%.

The dominant hard coral genera observed were *Porites* and *Pocillopora*, although the area was highly diverse. *Favites*, *Leptastrea purpurea*, *Cyphastrea*, and *Astreopora* were also prevalent in several sections. Encrusting species, in general, also appeared to be heavily represented. Increased numbers of large *Porites lobata* colonies were identified in one segment along the windward/eastern side. Less than 1% of corals appeared stressed throughout all surveys in 2009.

Octocorals averaged 1.8% island-wide with elevated numbers along the north/northwest side of the island. One area of interest was encountered along the northeastern corner of the island, where several high-density patches of *Junceela* were identified.

Macroalgae accounted for 12.5% of benthic cover island-wide. The greatest coverage occurred along the windward/eastern coastline, where several time segments recorded macroalgal cover of 30.1–40%. Species of *Halimeda*, along with *Asparagopsis taxiformis*, were common, with *Neomeris* being recorded in one isolated section. Coralline algal cover averaged 3.8% island-wide, and was observed in background levels with only several segments reaching 10.1–20% cover.

No crown-of-thorns seastars (COTS) or free sea urchins were observed around Sarigan. Boring urchins were relatively uncommon, with only 77 recorded island-wise. Sea cucumbers, on the other hand, had 945 recorded sightings. The highest number of sea cucumbers (*Stichopus chloronotus*) occurred during the shortest survey around the island, with three time segments = 101–250 individuals/average 175. Finally, a total of 116 giant clams were recorded around the island. The highest number of giant clams (68 per single survey; 14 per single time segment) was recorded along the windward/eastern towed-diver survey of the island.

C.4. Fish Surveys

C.4.1. REA Fish Surveys

Stationary point count data (nSPC)

During the survey period, nSPC surveys were conducted at seven sites around Sarigan. Surgeonfish were the largest contributor to total biomass with 0.95 kg 100 m^{-2}. Parrotfish were the second largest contributor to total biomass with 0.75 kg 100 m^{-2}, followed by snappers at 0.49 kg 100 m^{-2} (Fig. C.4.1.1.).

Overall observations

A total of 170 fish species were observed by all divers during the survey period. The average total fish biomass around Sarigan during the survey period was 3.65 kg 100 m^{-2} for the nSPC surveys (Table C.4.1.1.).

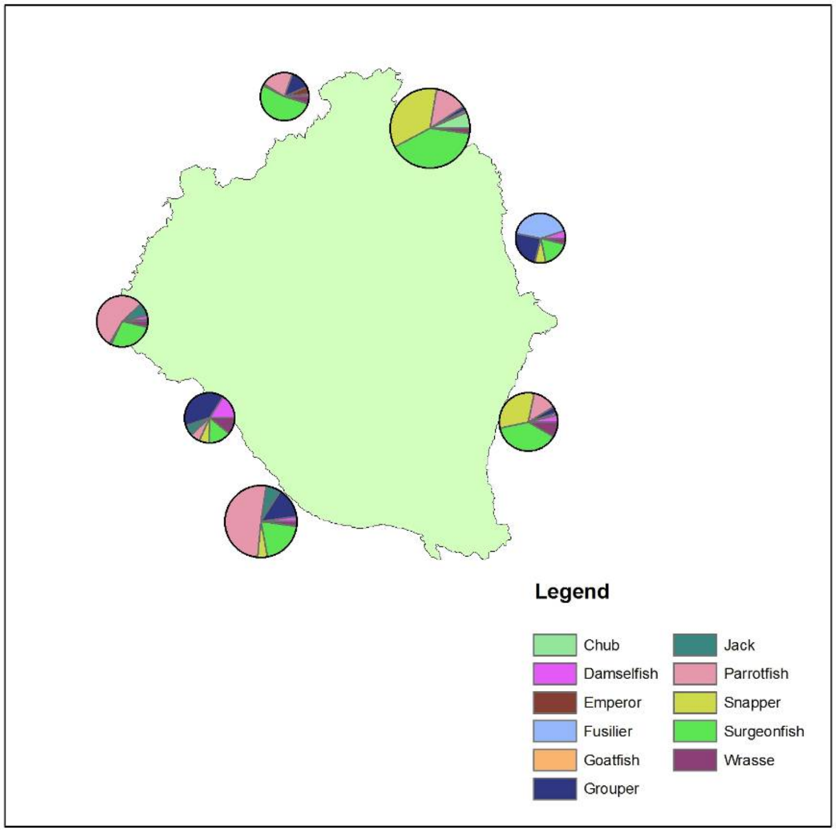


Figure C.4.1.1--Site location and distribution of total fish biomass by family. The sizes of the pie charts are proportional to fish biomass.

C.4.2. Towed-diver Surveys

During HA0903, the CRED towed-diver team completed six surveys at Sarigan covering 11.0 km (11.0 ha) of ocean floor (Table C.4.2.1.). Mean survey length was 1.8 km with a maximum length of 2.2 km and a minimum of 1.4 km. Mean survey depth was 14.6 m with a maximum depth of 18.0 m and a minimum of 12.4 m. Mean temperature on these surveys was 28°C with a maximum temperature of 28.3°C and a minimum of 27.9°C.

Table C.4.2.3--Survey statistics for towed-diver sampling during HA0903.

		Length (km)					Depth (m)				Temperature (ºC)			
Island/Reef	#	Sum	Mean	Max	Min	SD	Mean	Max	Min	SD	Mean	Max	Min	SD
Sarigan	6	11.0	1.8	2.2	1.4	0.3	14.6	18.0	12.4	1.9	28.0	28.3	27.9	0.2

One hundred fifty-two individual large-bodied reef fish (> 50 cm TL) of 21 different species and 11 different families were encountered at Sarigan (Table C.4.2.2.). Overall numeric density for this class of reef fishes was 1.39 #/100 m^2 (138.69 #/ha) with a biomass density of 9.45 kg/100 m^2 (0.95 t/ha). Numeric density was dominated by *Sphyraena qenie* while biomass density was dominated by *Nebrius ferrugineus.*

Table C.4.2.2. Species numeric and biomass density for large-bodied reef fishes (> 50 cm TL) observed at Sarigan during HA0903 CRED towed-diver surveys.

Species	#	#/100 m^2	#/ha	Biomass (kg)	kg/100 m^2	t/ha
Aprion_virescens	1	0.01	0.91	4.86	0.04	0.00
Caranx_ignobilis	1	0.01	0.91	12.75	0.12	0.01
Caranx_melampygus	1	0.01	0.91	2.12	0.02	0.00
Carcharhinus_amblyrhynchos	35	0.32	31.93	179.49	1.64	0.16
Cheilinus_undulatus	3	0.03	2.74	88.46	0.81	0.08
Chlorurus_microrhinos	3	0.03	2.74	7.79	0.07	0.01
Diodon_hystrix	1	0.01	0.91	3.06	0.03	0.00
Gymnosarda_unicolor	1	0.01	0.91	4.75	0.04	0.00
Lutjanus_bohar	24	0.22	21.90	72.06	0.66	0.07
Lutjanus_monostigma	1	0.01	0.91	1.97	0.02	0.00
Macolor_macularis	2	0.02	1.82	4.22	0.04	0.00
Macolor_niger	2	0.02	1.82	3.63	0.03	0.00
Naso_brachycentron	1	0.01	0.91	3.81	0.03	0.00
Naso_hexacanthus	6	0.05	5.47	12.73	0.12	0.01
Naso_tonganus	8	0.07	7.30	30.02	0.27	0.03
Naso_unicornis	2	0.02	1.82	5.13	0.05	0.00
Nebrius_ferrugineus	3	0.03	2.74	386.04	3.52	0.35
Plectorhinchus_gibbosus	1	0.01	0.91	2.44	0.02	0.00
Scomberoides_lysan	1	0.01	0.91	1.00	0.01	0.00
Sphyraena_qenie	50	0.46	45.62	143.36	1.31	0.13
Triaenodon_obesus	5	0.05	4.56	66.31	0.61	0.06
Grand Total	152	1.39	138.69	1036.00	9.45	0.95
# of Species	21					

The most prevalent families in terms of numeric density were Sphyraenids (32%), Carcharhinids (26%), and Lutjanids (20%) (Fig. C.4.2.1.). The most prevalent families in terms of biomass density were Ginglymostomaids (37%), Carcharhinids (24%), and Sphyraenids (14%) (Fig. C.4.2.2.). There was no clear pattern to the geographic distribution of large-bodied reef fishes around the island. (Fig. C.4.2.3.).

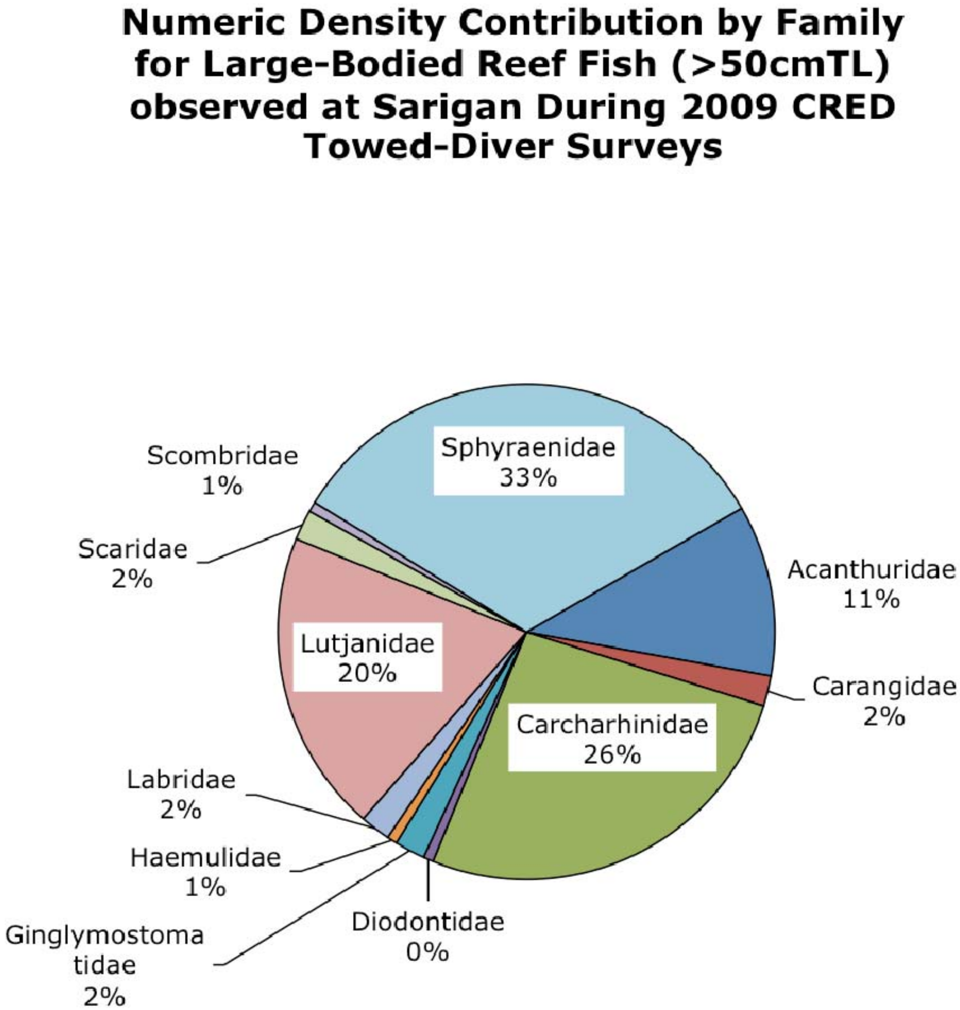


Figure C.4.2.1--Numeric density of fishes by family.

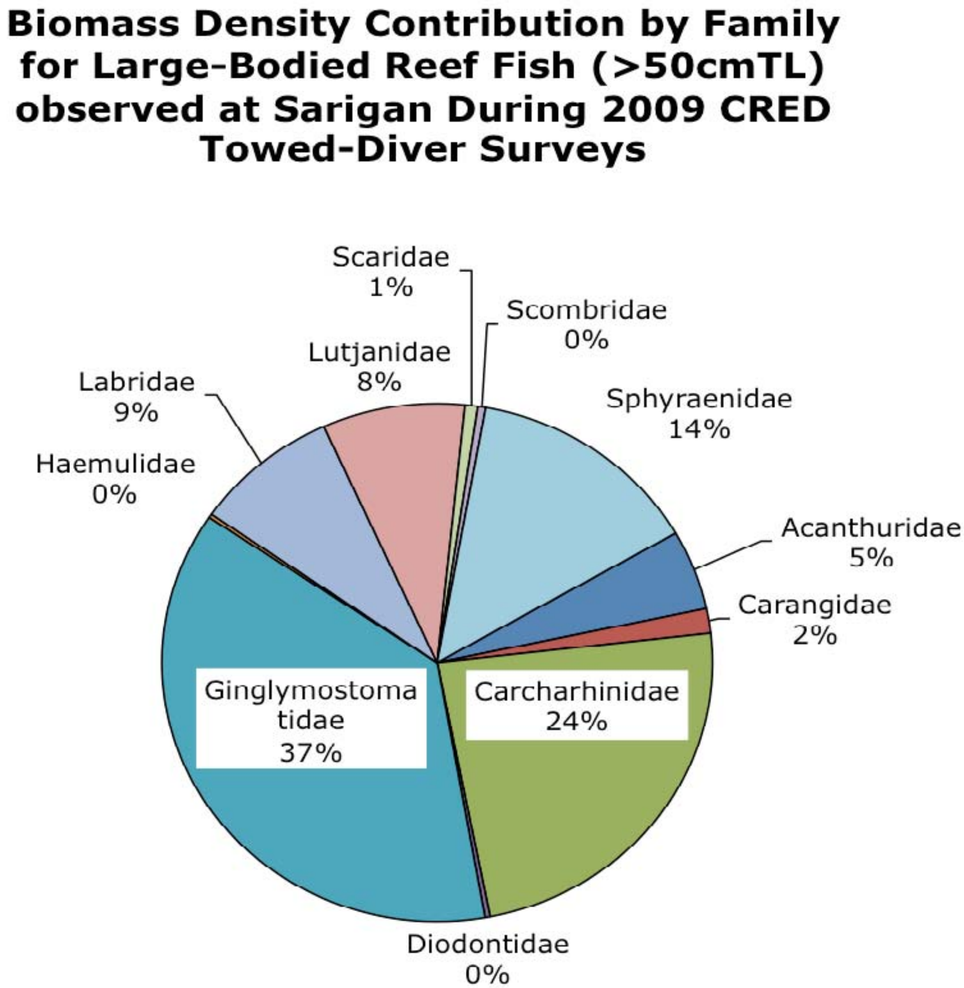


Figure C.4.2.2--Biomass density of fishes by family.

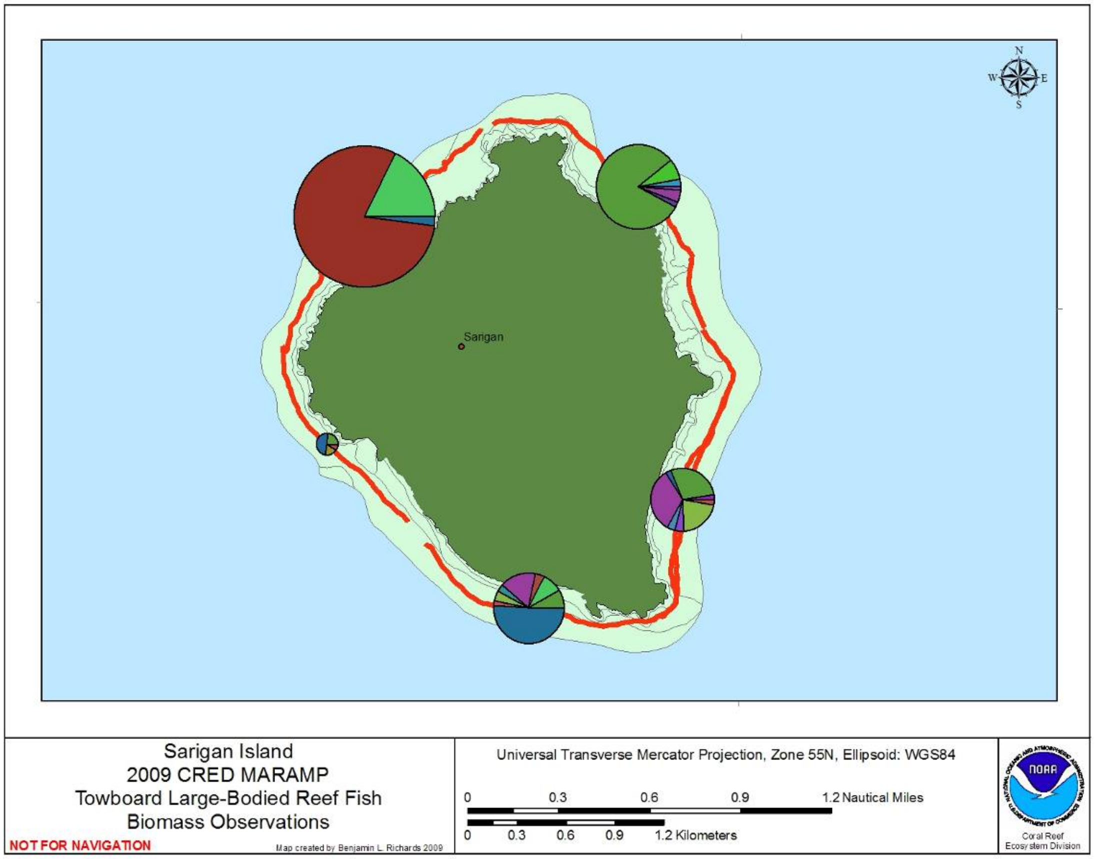


Figure C.4.2.3--Geographic distribution of fish biomass around Sarigan. Each species is represented by a legend color. Diameter of pie chart is proportional to total biomass of all species encountered on the underlying survey.

Appendix D: Pagan Results

D.1. Oceanography and Water Quality

Moorings recovered and replaced during HA0903 at Pagan included five subsurface temperature recorders (STRs) deployed (two new, one at a possible vent site), three STRs recovered, a sea surface temperature (SST) buoy deployed (original broke free from mooring approximately 1 month prior to cruise arrival) and a new ecological acoustic recorder (EAR) (Table D.1.1., Fig. D.1.1.). All the STRs show similar patterns and temperature ranges, with a clear annual fluctuation due to seasonal warming and cooling (Fig. D.1.2.). Warmest temperatures peaked at approximately 32°C and occurred during the summer months of July to October. Winter temperatures reached lows of approximately 26.5°C and occurred during November through June.

In addition to the normal suite of oceanographic instruments, the Coral Reef Ecosystem Division (CRED) collaborated with the NOAA National Weather Service (NWS) to attempt to fix a shore based weather station. The station was successfully located, and an electronics control unit and solar charging unit were replaced. The station was also inspected for any obvious damage (none found), a global positioning system (GPS) point was recorded, and the platform was thoroughly photo documented. Unfortunately, bigger problems exist with the system and the CRED team was unable to get the station fixed with the tools and expertise on hand.

Two rapid ecological assessment REA sites (PAG-01 and PAG-05) were visited to collect water samples for microbiological, nutrient and chlorophyll analyses, and six additional REA sites (PAG-02, PAG-03, PAG-05, PAG-06, PAG-08 and PAG-09) were sampled for just nutrients and chlorophyll. Samples were obtained from the surface and approximately 1 m above the reef. Microbial water samples were taken using diver-deployable Niskin bottles to collect 8 liters of seawater (four bottles; 2 liters per bottle) at each study site. Chlorophyll samples were filtered, and nutrient samples were frozen at -30°C for post-cruise analysis. Shallow-water conductivity temperature and depth (CTD) casts were also conducted at these sites. In addition, 12 CTD casts were taken every 3 km around the perimeter of Pagan at the 30 m depth contour and a CTD was taken in the brackish water lake near the village at Pagan.

Table D.1.1--Pagan moorings.

Action	Mooring type	Serial number	Lat		Long		Depth (m)
Deployment	EAR	9300505B072	18.12017731	N	145.7546457	E	17.4
Deployment	SST	W5KMW	18.12726455	N	145.757517	E	0.3
Deployment	STR	39327181069	18.10293071	N	145.767849	E	0.9
Deployment	STR	39331791187	18.09634656	N	145.7648454	E	14.3
Deployment	STR	39331791193	18.04578566	N	145.7219793	E	19.5
Deployment	STR	39331791369	18.12017731	N	145.7546457	E	17.4
Retrieval	STR	39368591566	18.12726455	N	145.757517	E	6.1
Retrieval	STR	39368591643	18.09634656	N	145.7648454	E	14.3
Retrieval	STR	39368591674	18.10293071	N	145.767849	E	0.9
Deployment	STR	39390381724	18.12726455	N	145.757517	E	6.1

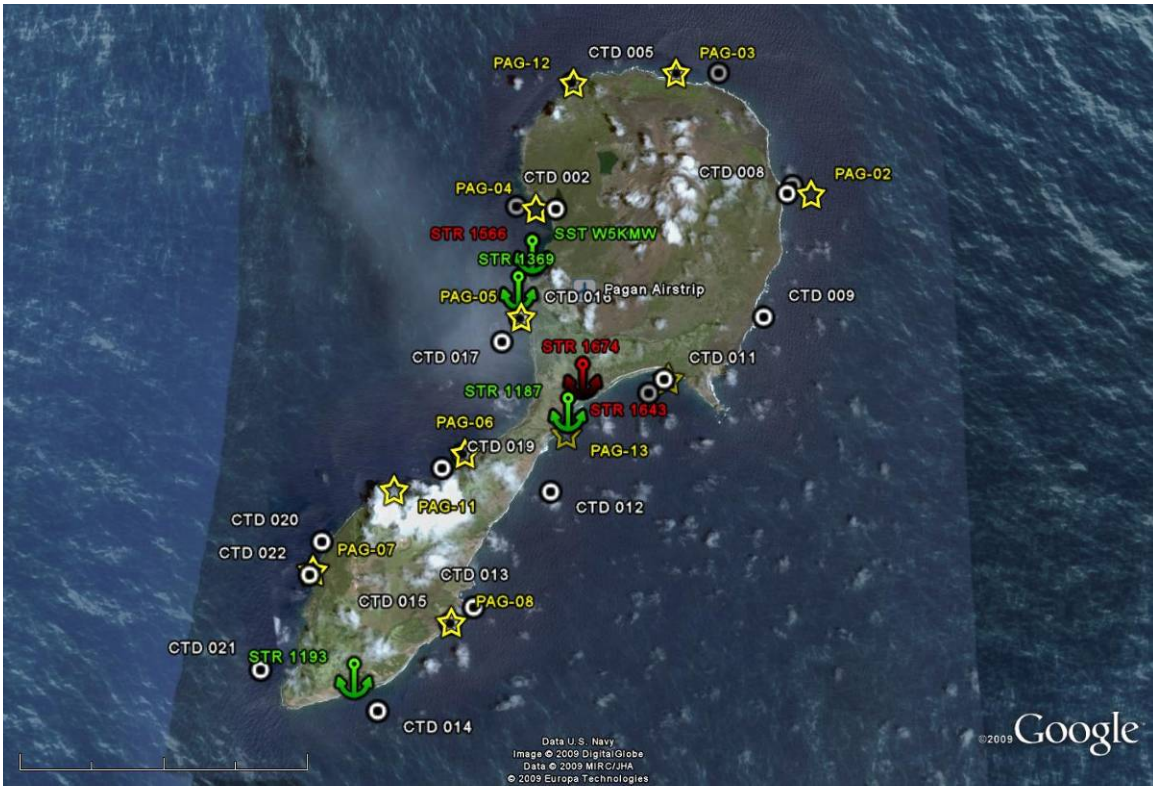


Figure D.1.1--Deployed and recovered instrument moorings and CTD and water sampling sites, Pagan, HA0903.

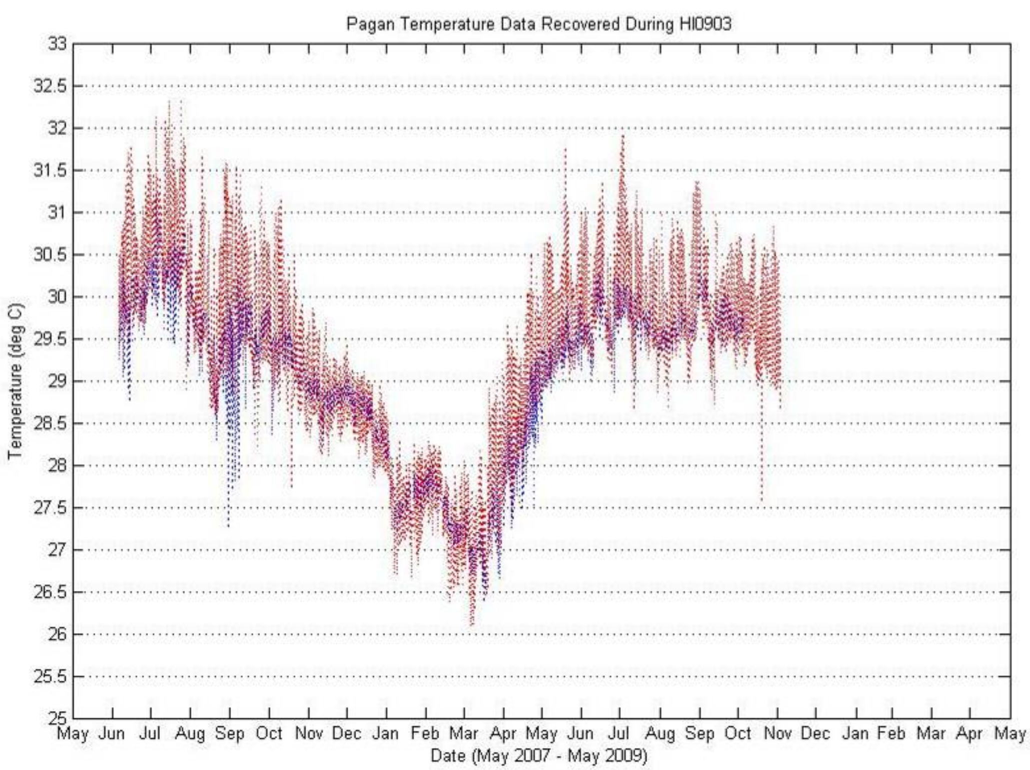


Figure D.1.2--Temperature time series from STR moorings at Pagan.

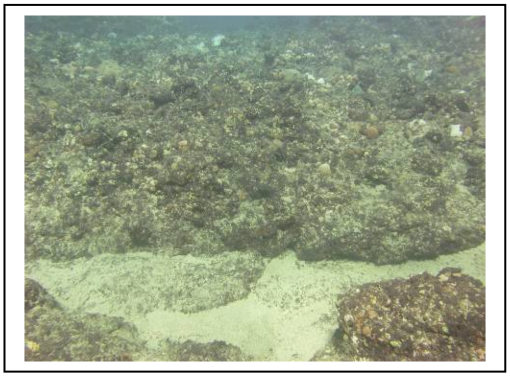
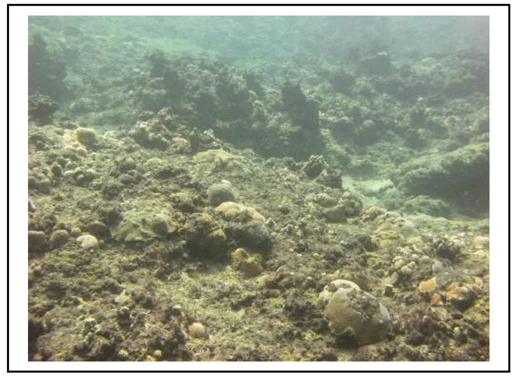
D.2. Rapid Ecological Assessment (REA) Site Descriptions

PAG-01
4/23/2009

E 145° 47.146
N 18° 06.433

Forereef
Mid

Depth: 10–12 m

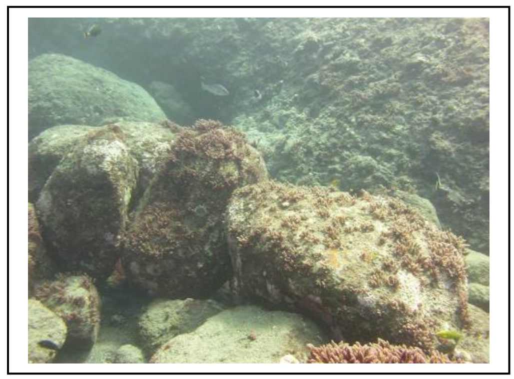
Site description: Southeastern region; low/moderate topographic complexity; sand channels; moderate coral cover; low macroalgal cover; dominated by cyanobacteria.

PAG-02
4/22/2009

E 145° 48.954
N 18° 08.638

Forereef
Mid

Depth: 12–14 m

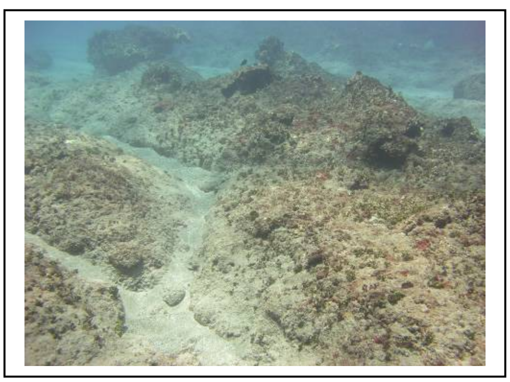
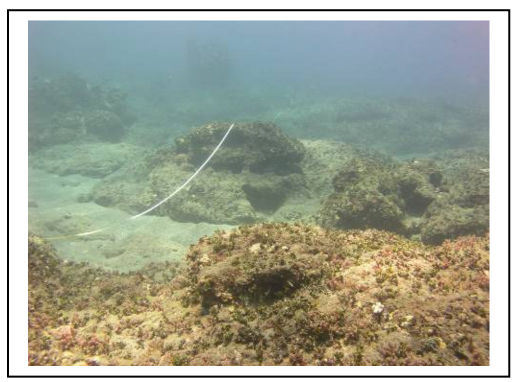
Site description: Northeastern region; moderate topographic complexity (boulders); moderate coral and macroalgal cover; dominated by turf algae.

PAG-03
4/22/2009

E 145° 47.277
N 18° 10.099

Forereef
Mid

Depth: 12 m

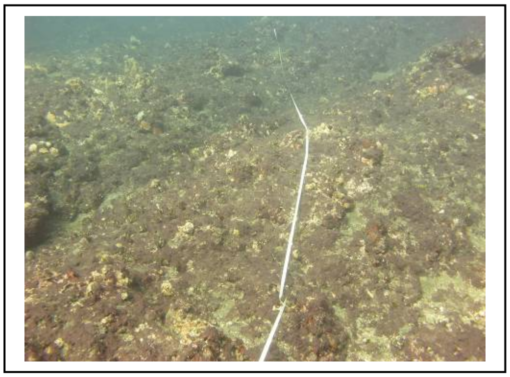
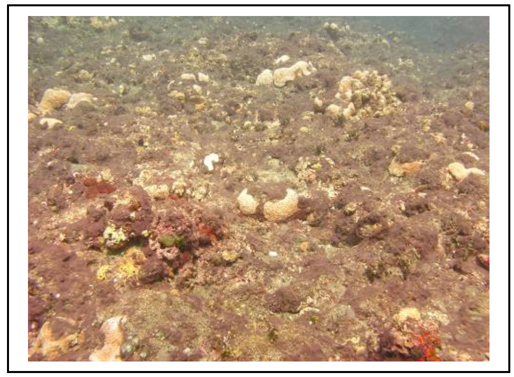
Site description: Northern tip; low/moderate topographic complexity (some sand channels); low coral cover; moderate macroalgal cover; dominated by turf algae.

PAG-05
4/22/2009

E 145° 45.340
N 18° 07.167

Forereef
Mid

Depth: 11 m

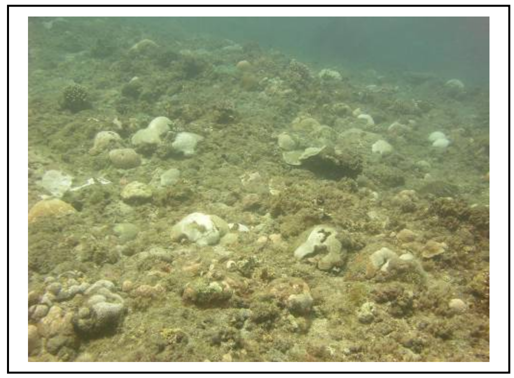
Site description: Western region; low topographic complexity; low coral and macroalgal cover; dominated by cyanobacteria.

PAG-06
4/23/2009

E 145° 44.653
N 18° 05.575

Forereef
Mid

Depth: 13–15 m

Site description: Southwestern region; low/moderate topographic complexity; moderate coral and macroalgal cover; dominated by turf algae.

PAG-08
4/23/2009

E 145° 44.503
N 18° 03.642

Forereef
Mid

Depth: 10–11 m

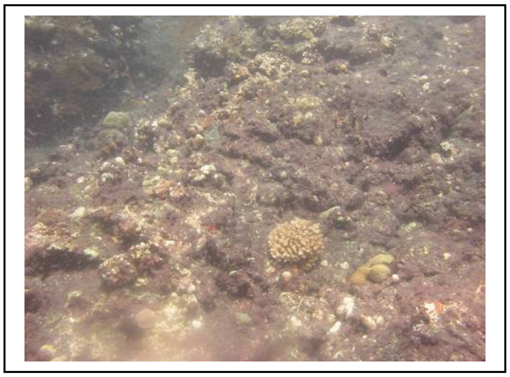

Site description: Southeastern region; high topographic complexity (boulders); low coral cover; moderate macroalgal cover; dominated by turf algae.

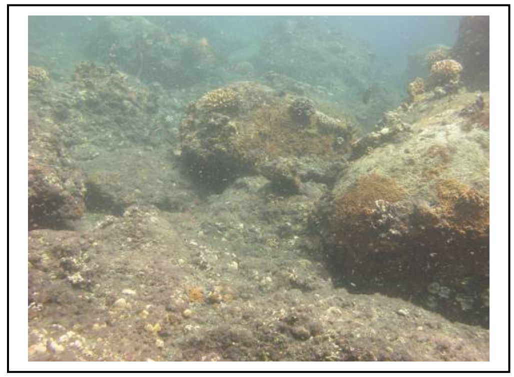
PAG-09
4/24/2009

E 145° 42.818
N 18° 04.241

Forereef
Mid

Depth: 10–14 m





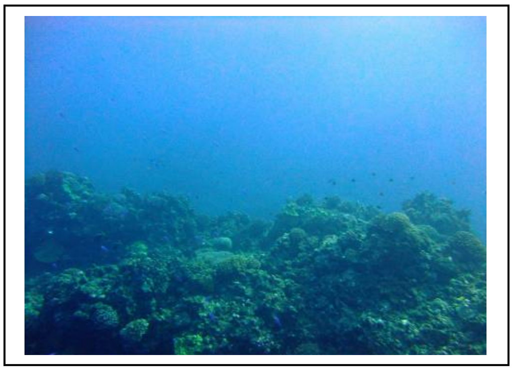
Site description: Southwestern region; moderate topographic complexity (boulders); moderate coral and macroalgal cover.

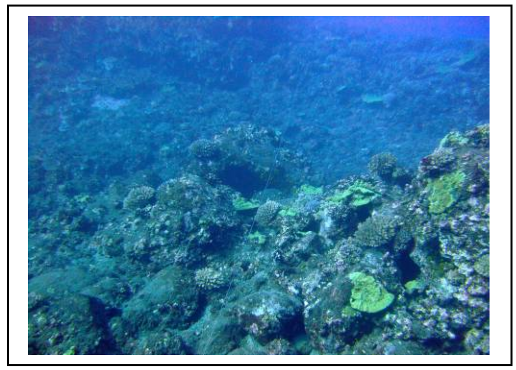
PAG-12
4/23/2009

E 145° 45.988
N 18° 09.994

Forereef
Mid

Depth: 14–15 m





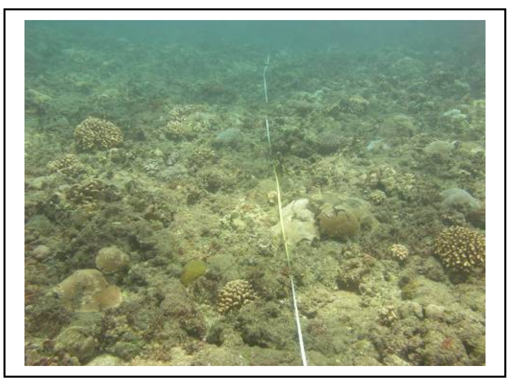
Site description: Northeastern region; moderate complexity; spur and groove; moderate coral cover; low macroalgal cover; dominated by turf algae.

PAG-13
4/23/2009

E 145° 45.894
N 18° 05.799

Forereef
Mid

Depth: 13–14 m



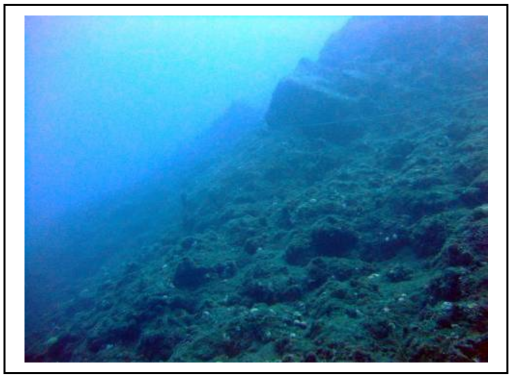
Site description: Southeastern region; moderate topographic complexity; moderate coral and macroalgal cover.

PAG-50
4/22/2009

E 145° 45.549
N 18° 07.964

Forereef
Deep

Depth: 21–22 m




Site description: Northwestern bay region; moderate slope and topographic complexity; moderate coral cover; low macroalgal cover; dominated by cyanobacteria.

PAG-51
4/22/2009

E 145° 45.524
N 18° 09.621

Forereef
Shallow

Depth: 5–6 m


Site description: Northeastern region; moderate topographic complexity (boulders); low coral and macroalgal cover; dominated by turf algae.

PAG-52
4/22/2009

E 145° 46.847
N 18° 10.171

Forereef
Shallow

Depth: 2–5 m

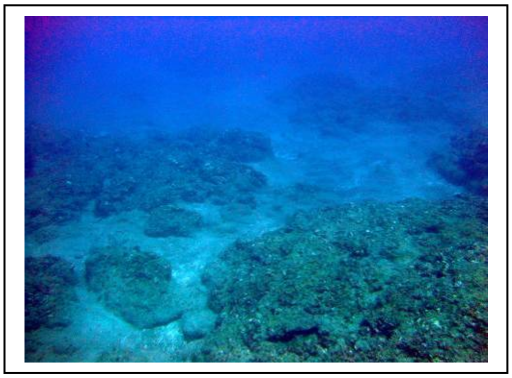

Site description: Shallow northwestern region; moderate topographic complexity (boulders and large rock formations); moderate coral cover; low macroalgal cover; dominated by turf algae.

PAG-53
4/22/2009

E 145° 48.539
N 18° 09.571

Forereef
Deep

Depth: 22 m



Site description: Northeastern region; low topographic complexity; patch reefs surrounded by sand channels; low coral cover; moderate macroalgal cover; dominated by turf algae.

PAG-54
4/23/2009

E 145° 48.311
N 18° 07.299

Forereef
Deep

Depth: 19–20 m

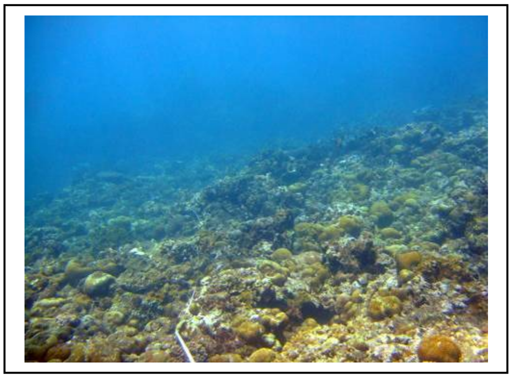
Site description: Northeastern region; moderate topographic complexity (boulders surrounded by sand channels); moderate coral and macroalgal cover; dominated by turf algae.

PAG-55
4/23/2009

E 145° 46.452
N 18° 06.301

Forereef
Shallow

Depth: 3–6 m



Site description: Eastern region in large bay; moderate topographic complexity; high coral cover; low macroalgal cover; massive *Porites* colony slightly offshore from transects.

PAG-56
4/23/2009

E 145° 45.211
N 18° 04.945

Forereef
Shallow

Depth: 4–5 m

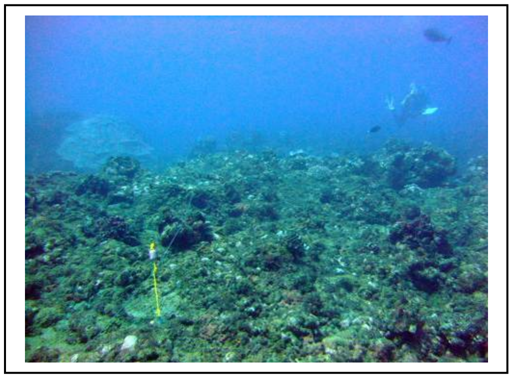
Site description: Southeastern region; moderate topographic complexity; high coral cover; low macroalgal cover.

PAG-57
4/23/2009

E 145° 43.615
N 18° 02.798

Forereef
Deep

Depth: 19 m



Site description: Deep southeastern region site; moderate topographic complexity; low coral cover; moderate macroalgal cover; dominated by cyanobacteria; massive *Porites* colony near transect.

PAG-58
4/24/2009

E 145° 45.206
N 18° 06.356

Forereef
Deep

Depth: 23 m

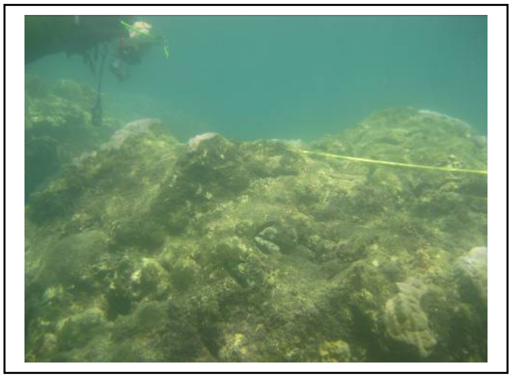
Site description: Western region; high topographic complexity; reticulated reef habitat and drop-offs; moderate/high coral cover; low macroalgal cover; dominated by turf algae.

PAG-59
4/24/2009

E 145° 43.366
N 18° 04.945

Forereef
Shallow

Depth: 2 m



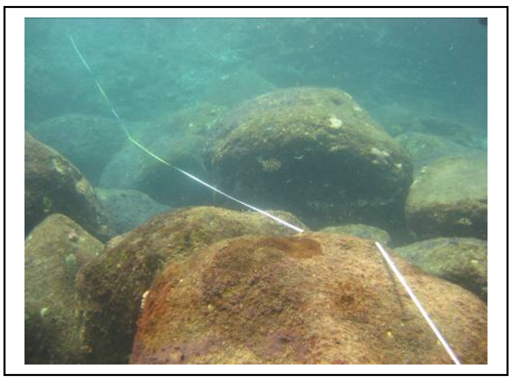

Site description: Southwestern region; potential naval training site; moderate topographic complexity (pavement intermixed w/ large coral bommies); high coral cover; low macroalgal cover; dominated by cyanobacteria.

PAG-60
4/24/2009

E 145° 45.480
N 18° 07.446

Forereef
Shallow

Depth: 4 m



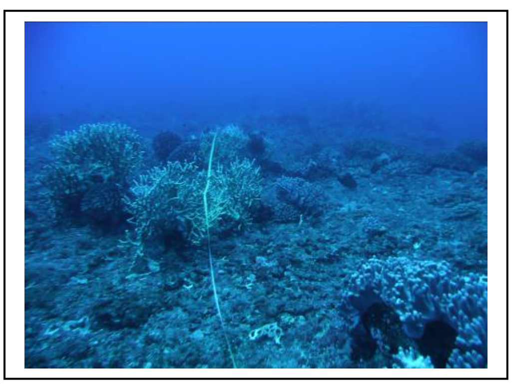
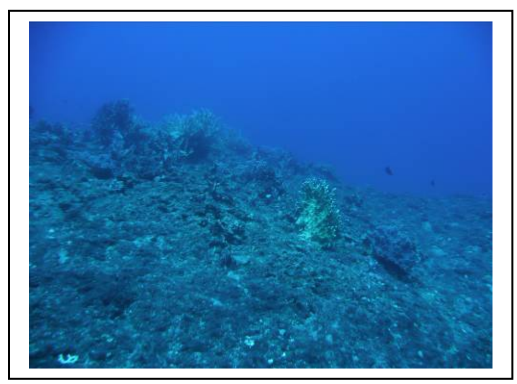

Site description: Northwestern region; moderate topographic complexity (boulders); low coral and macroalgal cover; dominated by turf algae.

PAG-61
4/24/2009

E 145° 42.404
N 18° 03.479

Forereef
Deep

Depth: 23 m

Site description: Southwestern region; gradual slope; moderate topographic complexity; spur & groove; moderate coral cover; low macroalgal cover; dominated by cyanobacteria.

D.3. Benthic Environment

D.3.1. Algal Communities

During the Mariana Reef Assessment and Monitoring Program (MARAMP) 2009, nine permanent, long-term REA monitoring sites were surveyed around Pagan Island for percent benthic cover based on the 20-cm interval line point intercept (LPI) methodology. Benthic communities around Pagan were dominated by cyanobacteria and turf algae (Table D.3.1.1). Turf algal percent cover exceeded that of other functional groups at five of the nine sites surveyed with a range of 8.8% to 53.2% cover (Table D.3.1.1). Cyanobacteria were the dominant cover at sites PAG-01 and PAG-05 with 43.2% and 56% cover, respectively (Table D.3.1.1). At site PAG-09, percent cover of macro-, turf, and crustose coralline algae, cyanobacteria and scleractinian corals were approximately equal (12%, 15.2%, 16.4%, 16.8%, and 15.2%, respectively). At site PAG-13, macro- and turf algal percent covers were approximately equal, 30% and 28%, and exceeded that of all other functional groups. A combined total of 21 species of macroalgae were observed (13 chlorophytes, four ochrophytes, four rhodophytes) from the nine sites surveyed (Tables D.3.1.2 and D.3.1.3). *Lobophora variegata* dominated the macroalgal community at four of the nine sites with a percent cover range of 0.4% to 7.6% (Table D.3.1.3). *Asparagopsis taxiformis* also dominated the macroalgal community at four of the nine sites with a percent cover range of 0% to 22.8% (Table D.3.1.3). *Caulerpa serrulata* was the most prevalent macroalgal species at site PAG-09 with a percent cover of 2.4% (Table D.3.1.3).

Table D.3.1.1--Percent cover of algal functional groups at long-term monitoring sites at Pagan.

Site	Macroalgae	Turf Algae	Coralline red algae (crustose + upright)	Cyanobacteria	Scleractinian Coral	Octocoral
PAG-01	8.4%	12.8%	7.2%	43.2%	14.4%	0.0%
PAG-02	29.2%	41.6%	8.0%	2.4%	17.2%	0.0%
PAG-03	24.8%	50.4%	1.6%	7.2%	4.4%	0.0%
PAG-05	11.6%	8.8%	4.4%	56.0%	11.6%	0.0%
PAG-06	20.0%	53.2%	10.4%	3.2%	12.0%	0.4%
PAG-08	23.2%	44.8%	0.8%	16.4%	8.0%	0.4%
PAG-09	12.0%	15.2%	16.4%	16.8%	15.2%	0.4%
PAG-12	12.0%	40.8%	18.8%	3.2%	23.2%	0.0%
PAG-13	30.0%	28.0%	10.8%	2.8%	23.6%	1.6%

Table D.3.1.2--Additional species recorded at each site at Pagan during roving diver survey.

Site	**Chlorophyta**
PAG-13	*Boodlea* sp.
PAG-02	*Caulerpa filicoides*
PAG-03, PAG-08	*Caulerpa racemosa*
PAG-05, PAG-06, PAG-08	*Caulerpa serrulata*
PAG-13	*Caulerpa sertularioides*

PAG-03, PAG-09	*Caulerpa webbiana*
PAG-02, PAG-03	*Dictyosphaeria versluysii*
PAG-12	*Halimeda opuntia*
PAG-02, PAG-03, PAG-06, PAG-08, PAG-09, PAG-13	*Neomeris* sp.
PAG-06	*Tydemania* sp.
PAG-06	*Udotea* sp.
PAG-01, PAG-02, PAG-03, PAG-05, PAG-06, PAG-12	*Valonia ventricosa*
	Ochrophyta
PAG-03, PAG-05	***Dictyota* sp.**
PAG-01, PAG-02, PAG-03, PAG-13	***Padina* sp.**
	Rhodophyta
PAG-06	*Asparagopsis taxiformis*
PAG-08	*Ganonema* sp.
PAG-13	*Portieria* sp.
PAG-03	*Wrangelia* sp.

Table D.3.1.3--Percent cover of macroalgal species at long-term monitoring sites at Pagan. Sum totals for each row equal the percent cover of macroalgae recorded in Table D.3.1.1.

Site	Caulerpa racemosa	Caulerpa serrulata	Caulerpa webbiana	Dictyosphaeria cavernosa	Dictyosphaeria versluysii	Halimeda opuntia	Neomeris sp	Dictyota ceylanica	Dictyota sp	Lobophora variegata	Asparagopsis taxiformis	Portieria hornemannii
PAG-01	-	0.8%	-	-	0.4%	-	0.4%	-	-	1.2%	0.4%	-
PAG-02	0.4%	0.8%	-	-	-	-	-	-	0.4%	1.6%	22.8%	0.4%
PAG-03	-	-	-	-	-	0.8%	-	-	-	0.4%	8.0%	0.8%
PAG-05	-	-	-	0.8%	-	-	0.4%	-	-	1.2%	-	-
PAG-06	-	-	-	-	-	-	-	-	0.4%	6.4%	0.8%	-
PAG-08	-	-	-	-	0.4%	2.0%	-	-	-	1.2%	15.6%	-
PAG-09	-	2.4%	-	-	-	-	-	-	-	0.8%	-	-
PAG-12	-	1.6%	0.4%	-	-	-	-	0.4%	1.6%	7.6%	-	-
PAG-13	0.4%	0.8%	-	-	0.4%	-	-	-	-	1.2%	11.6%	-

D.3.2. Coral Communities

D.3.2.1. Percent Benthic Cover

In 2009, percent benthic cover surveys around Pagan were conducted in concert with coral population, algae, and invertebrate REA surveys at nine permanent sites. Coral cover around Pagan derived from LPI surveys conducted at the permanent long-term REA sites yielded an island-wide mean of 14.4.8% (Fig. D.3.2.1.1). Percent coral cover was the greatest at PAG-12 and PAG-13, on the north and eastern regions. The lowest percent coral cover was detected at the north-facing site PAG-03 (Fig. D. 3.2.1.1).

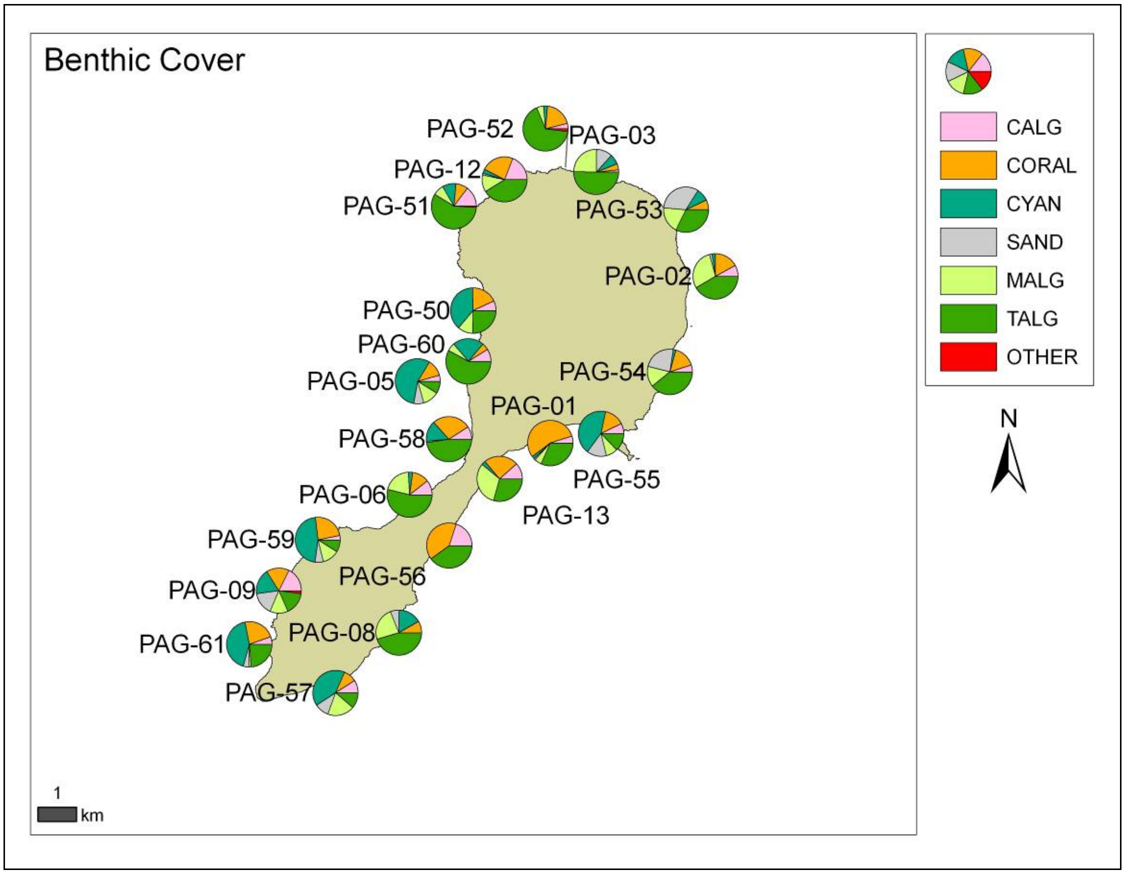


Figure D.3.2.1.1--Percent cover of benthic functional groups at the random stratified and permanent REA monitoring sites around Pagan during MARAMP 2009. CALG = crustose coralline red algae, CYAN = cyanobacteria, MALG = macroalgae, TALG = turf algae.

Twelve additional stratified random REA sites were surveyed around Pagan for percent bethic cover (based on 50-cm interval LPI surveys) and generic diversity data in 2009. Results from these 12 stratified random REA surveys yielded the following results: Benthic communities at six sites greater than 20 m depth were dominated by turf algal (29.3% $\pm$ 5.3), cyanobacterial (23.5% $\pm$ 6.9) and scleractinian coral (16.3% $\pm$ 3.1) functional groups (Fig. D.3.2.1.2). Six shallow sites (< 10 m deep) were dominated by turf algal (43.6% $\pm$ 8.8) and scleractinian coral (25.2% $\pm$ 7.7) functional groups (Fig. D.3.2.1.2). Coral generic diversity was highest at site PAG-54 with 30 different genera observed (Table D.3.2.1.1). In contrast. site PAG-51 had the lowest generic diversity with 12 different genera observed. The average number of coral genera recorded at each site was 22. Common genera observed at most sites included *Porites, Favia, Pocillopora, Pavona, Goniastrea, Cyphastrea* and *Astreopora*. Macroalgal generic diversity was highest at site PAG-54 with 14 genera observed (Table D.3.2.1.2). Sites PAG-56 and PAG-61 had the lowest generic diversity with seven genera observed at both. The average number of macroalgal genera recorded for each site was 11. Common macroalgae observed at most sites included *Dictyota* and *Halimeda*.

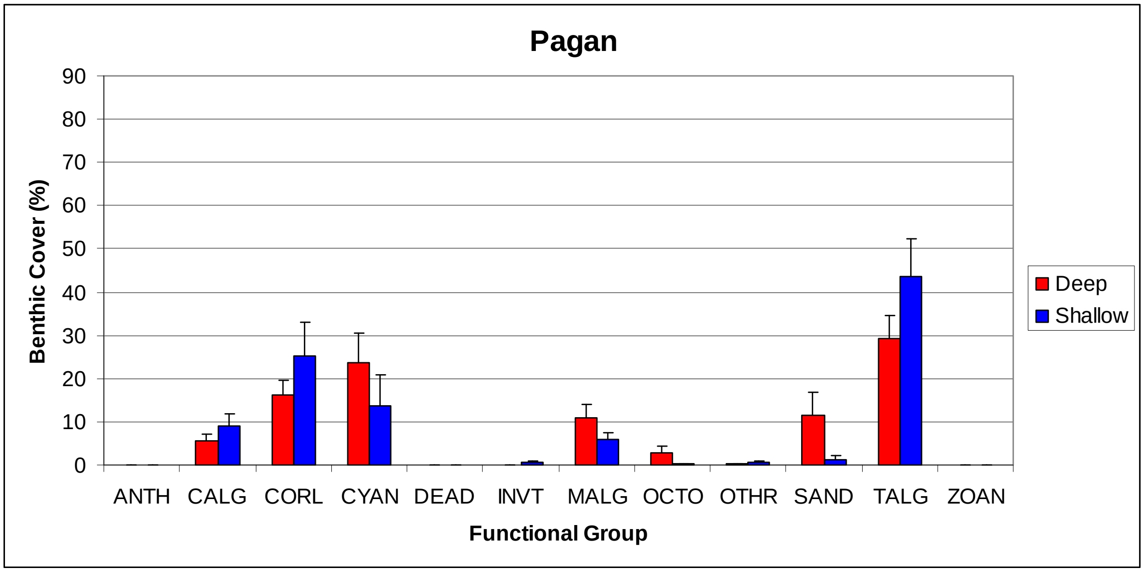


Figure D.3.2.1.2--Percent cover of functional groups at shallow and deep independent LPI monitoring sites established in 2009 at Pagan Island. ANTH = anthozoan, CALG = crustose coralline red algae, CORL = coral, CYAN = cyanobacteria, DEAD = dead coral, INVT = non-coral invertebrate, MALG = macroalgae, OCTO = octocoral, OTHER = other, TALG = turf algae, ZOAN = zoanthid.

Table D.3.2.1.1--Coral generic diversity of stratified random sites around Pagan.

	PAG-50	PAG-51	PAG-52	PAG-53	PAG-54	PAG-55	PAG-56	PAG-57	PAG-58	PAG-59	PAG-60	PAG-61
Acanthastrea	X	X	X			X	X	X		X		X
Acropora	X	X	X		X	X	X			X	X	
Alveopora	X								X		X	
Astreopora	X		X	X	X	X	X	X	X	X	X	X
Cladiella*	X		X		X	X	X	X		X		
Corallimorph*												
Coscinarea						X	X		X	X		
Cyphastrea	X	X	X	X	X	X	X	X		X	X	X
Diploastrea												
Distichopora*			X		X							
Echinopora					X	X	X		X			
Euphyllia									X			
Favia	X	X	X	X	X	X	X	X	X	X	X	X

	PAG-50	PAG-51	PAG-52	PAG-53	PAG-54	PAG-55	PAG-56	PAG-57	PAG-58	PAG-59	PAG-60	PAG-61
Favites			X		X	X	X	X				X
Fungia	X			X	X			X	X			X
Galaxea	X		X		X	X	X	X	X	X		X
Gardinoseris									X			X
Goniastrea	X	X	X	X	X	X	X	X	X	X	X	
Goniopora	X			X	X	X	X		X	X	X	
Heliopora*			X		X	X		X				X
Herpolitha	X								X			X
Hydnophora			X									
Isopora					X							
Leptastrea	X	X			X	X			X	X	X	X
Leptoria			X			X	X			X		
Leptoseris	X				X				X		X	X
Lobophyllia	X				X				X			X
Lobophytum*	X		X	X	X	X		X		X	X	X
Merulina												
Millepora*			X					X				X
Montastrea		X	X	X	X	X	X	X		X	X	
Montipora	X	X	X	X		X			X			X
Ouphyllia					X	X		X				
Pachyseris												
Palythoa*						X	X		X		X	
Pavona	X	X	X	X	X	X	X	X	X		X	X
Platygyra			X		X	X	X	X			X	
Pleisiastrea	X			X				X				
Plerogyra	X											
Pocillopora	X	X	X	X	X		X	X	X	X	X	X
Porites	X	X	X	X	X	X	X	X	X	X	X	X
Psammocora	X			X	X			X			X	X
Sarcophyton*												
Scapophyllia					X			X				X
Scolymia		X	X		X				X		X	
Seriatopora												
Sinularia*				X			X	X	X		X	X
Stylaster*												
Stylocoeniella	X				X							X
Stylophora				X	X	X	X	X				
Turbinaria	X			X	X			X	X		X	X
Wire Coral*	X											
Zoanthus*			X							X		X
Total Genera per Site	26	12	23	17	30	24	21	24	23	17	20	25

* non-scleractinian genera

Table D.3.2.1.2--Macroalgal generic diversity of stratified random sites around Pagan.

	PAG-50	PAG-51	PAG-52	PAG-53	PAG-54	PAG-55	PAG-56	PAG-57	PAG-58	PAG-59	PAG-60	PAG-61
Amphiroa	X	X	X		X			X	X	X		X
Asparagopsis			X	X	X	X	X	X		X		
Avrainvillea												
Boergesenia												
Boodlea						X				X		
Bryopsis		X		X	X			X				
Caulerpa	X		X		X	X		X			X	X
Chlorodesmis												
Crustose Coralline	X	X	X	X	X	X	X	X	X	X	X	X
Cyanobacteria	X	X	X	X	X	X		X	X	X	X	X
Dichotomaria					X	X					X	
Dictyosphaeria	X	X	X		X				X	X	X	
Dictyota	X	X	X	X	X	X	X	X	X	X	X	X
Galaxaura		X	X								X	
Gibsmithia		X		X								X
Halimeda	X	X	X	X		X	X	X		X	X	
Halymenia												
Lobophora	X	X	X	X	X	X		X	X		X	
Microdictyon												
Neomeris	X		X	X	X	X		X	X	X	X	
Non-geniculate calcified branched							X					
Padina				X					X			
Peyssonnelia												
Portieria			X		X	X	X	X		X	X	
Rhipilia					X							
Turbinaria		X										
Tydemania									X			
Udotea	X									X		
Valonia	X	X			X	X		X	X	X	X	X
Unknown						1	1				1	
Total Genera per site	11	12	12	10	14	13	7	12	10	12	13	7

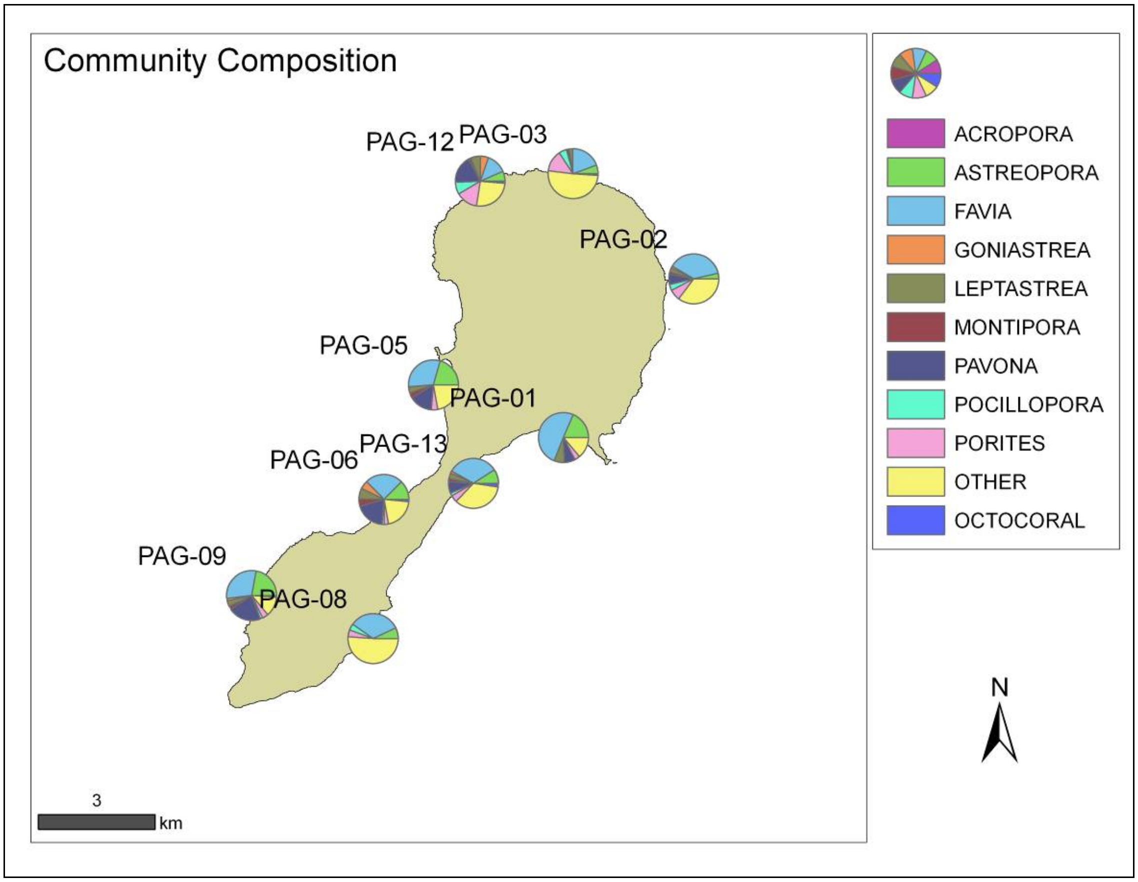
D.3.2.2. Coral Populations

During MARAMP 2009, belt transect surveys were conducted at nine permanent, long-term REA sites around Pagan, covering a total reef area of 212 m^2 and totaling 3,572 anthozoan colonies enumerated. This translates to an estimated mean colony density of 16.8 colonies m^{-2}. Taxonomic richness varied between sites with a total of 39 anthozoan genera (33 scleractinian, three octocoral, one hydrocorals, two zoanthids) being represented within belt transects (Table D.3.2.2.1). In order of decreasing importance, *Favia*, *Cyphastrea*, *Astreopora,* and *Pavona* were the most abundant scleractinian genera, contributing 30.9% 15.4%, 12% and 10.8% of the total number of colonies enumerated island-wide. All other genera individually contributed less than 10% of the total number of colonies (Table D.3.2.2.1).

Table D.3.2.2.1--Relative abundance of anthozoan genera enumerated within belt transects around Pagan during MARAMP 2009.

Island	Genus	Relative abundance
Pagan	*Favia*	30.9
	Cyphastrea	15.4
	Astreopora	12.0
	Pavona	10.8
	Porites	6.1
	Leptastrea	4.4
	Montastrea	3.5
	Pocillopora	2.9
	Galaxea	2.4
	Montipora	1.9
	Goniastrea	1.8
	Psammocora	1.0
	Stylophora	0.8
	Scolymia	0.8
	Platygyra	0.7
	Turbinaria	0.6
	Acanthastrea	0.6
	Goniopora	0.5
	Lobophytum	0.5
	Sinularia	0.5
	Palythoa	0.3
	Stylocoeniella	0.3
	Alveopora	0.2
	Favites	0.2
	Heliopora	0.1
	Leptoria	0.1
	Echinophyllia	0.1
	Fungia	0.1
	Plesiastrea	0.1
	Echinopora	0.1
	Euphyllia	0.1
	Millepora	0.1
	Acropora	0.0
	Leptoseris	0.0
	Merulina	0.0
	Montipora/Astreopora	0.0
	Mycedium	0.0
	Symphillia	0.0
	Zoanthus	0.0

In addition, spatial patterns of generic relative abundance based on colony counts at nine long-term monitoring REA sites in 2009 are reflected in Figure D.3.2.2.1. The genus *Favia* contributed more than 25% of the total number colonies at over 75% of sites surveyed, with the greatest relative abundances (> 38%) recorded at PAG-01 and PAG-02 (eastern region). The greatest numerical abundance of colonies of were recorded at site PAG-12 (Fig. D.3.2.2.1).



D.3.2.2.1--Relative abundance of coral genera from REA surveys around Pagan during MARAMP 2009.

D.3.3. Coral Health and Disease

During MARAMP 2009, the occurrence of disease, health impairments, and predation around Pagan was moderately low, with a total of 83 cases of diseases and predation enumerated. A summary of disease occurrence and relative abundance is presented in Table D.3.3.1. The most numerically abundant type of lesions recorded on corals around Pagan was fungal infections, which accounted for nearly 75% of cases, detected in high numbers at PAG-03 and PAG-05. *Cyphastrea* and *Pavona* were the two scleractinian genera exhibiting the greatest number of cases of this kind of affliction (62% and 31% of cases, respectively). All other types of lesions, including algal infections, hyperpigmented irritations, and predation were detected in relatively low numbers. No cases of coralline algae disease were enumerated around Pagan.

Table D.3.3.1--Number of cases of scleractinian and coralline algal diseases and predation enumerated during REA surveys, around Pagan Island, MARAMP 2009. ALG: algal infections, BIN: barnacle infestation; BLE: bleaching; CYA: cyanophyte infections; DIS: discolorations other than bleaching; FUG: fungal infections; HYP: hyperpigmented irritations/pigmentation response; PRE: *Acanthaster*/*Drupella* predation scars; SGA: skeletal growth anomalies; TIN: tubeworm infestation; TLS: tissue loss; WSY: white syndrome; OTH: other diseases and lesions of unknown etiology; CLOD: coralline lethal orange disease; and CLD; coralline white band syndrome/lethal disease.

Island	DZCode	PAG-01	PAG-02	PAG-03	PAG-05	PAG-06	PAG-08	PAG-09	PAG-12	PAG-13	Grand Total
Pagan	BIN								3		3
	BLE				1	1					2
	CYA				2						2
	DIS		2							1	3
	FUG		2	34	20	1	2	1		1	61
	HYP			1							1
	TLS	2							1		3
	WSY					1					1
	PRE	1				3			3		7
Grand Total		**3**	**4**	**35**	**23**	**6**	**2**	**1**	**7**	**2**	**83**

D.3.4. Macroinvertebrate Surveys (non-coral)

A total of 908 individuals of benthic invertebrate target species or taxa groups were enumerated from 12 belt transects at six sites. Due to Autonomous Reef Monitoring Systems (ARMS) deployment, the invertebrate surveys were not conducted at sites PAG-05, PAG-06, and PAG-09. However, at site PAG-06, a 25 m by 12 m transect was conducted to survey *Acanthaster planci* abundance. Thirty-three *A. planci* were counted giving a density of 0.11 organisms 300 m^{-2}. This density does not meet the density of 40 starfish per hectare (1.2 organisms 300 m^{-2}) which is considered indicative of crown-of-thorns outbreaks following Moran and De'ath (1992) for scuba surveys. Although this area may not define an outbreak, coral damage was apparent from this *A. planci* aggregation (See Coral section).

Pagan was the most diverse island for targeted non-cryptic macroinvertebrates. Four species of sea urchins were enumerated: *Echinostrephus aciculatus, Echinometra mathaei, Echinothrix calamaris,* and *Echinothrix diadema.* The rock boring urchin, *Echinostrephus aciculatus,* was the most abundant sea urchin at Pagan. The island density was 7.06 (SE 2.70) organisms 50 m^{-2}. Site PAG-13 had the greatest density with 19.2 organisms 50 m^{-2} followed by site PAG-02 with 13.36 organisms 50 m^{-2}. Species of *Echinothrix* were most prevalent at site PAG-03 with 1.84 organisms 50 m^{-2}.

Three species of sea cucumbers were abundant: *Holothuria atra, Stichopus chloronotus,* and *Actinopyga mauritana.* However, *Actinopyga* was seen only at site PAG-13 with a density of 0.72 organisms 50 m^{-2} and *Holothuria atra* at sites PAG-13 and PAG-12 with a density of 0.56 and 0.16 organisms 50 m^{-2}. *Sticopus chloronotus* was the most common and had the greatest island density with 0.50 organisms 50 m^{-2}. Site PAG-12 had the greatest *Stichopus* density with 1.36 organisms 50 m^{-2} followed by PAG-01 with 0.96 organisms 50 m^{-2}.

Tridacna clams had an island density of 0.24 organisms 50 m^{-2}. Site PAG-01 had the greatest density with 1.04 organisms 50 m^{-2}. Coral crabs, from the genus *Trapezia* and hermit crabs from the genus *Calcinus,* were common within coral heads only at site PAG-12 with a density of 2.16 and 1.44 organisms 50 m^{-2}.

D.3.4.1. Urchin Measurements

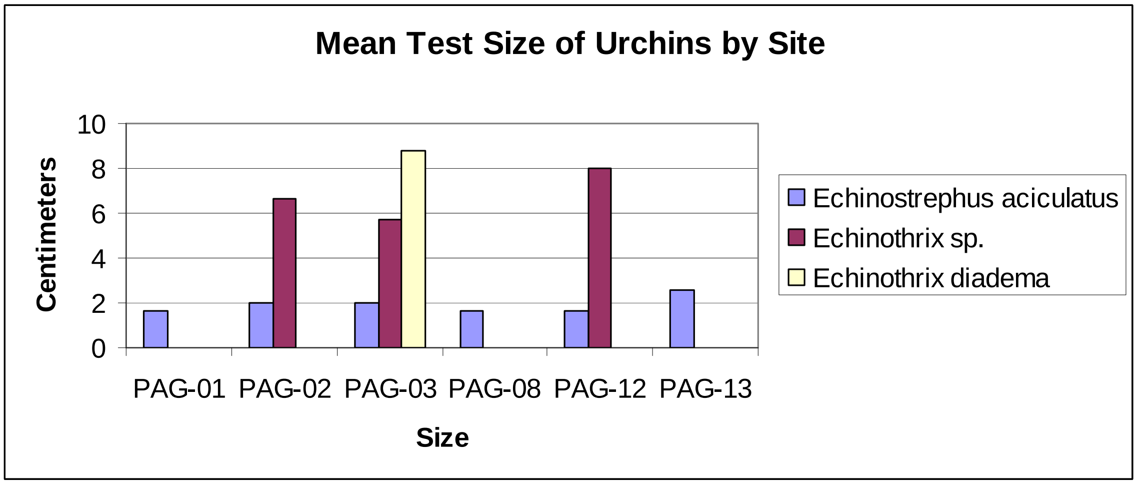


Figure D.3.4.1--Average test diameter of urchins encountered at each site. Only sites where ≥ 5 measurements were recorded for a species are represented.

D.3.4.2. ARMS Deployment

ARMS were deployed at the following REA sites around Maug (Table D.3.4.2.1.). Each site contains three ARMS.

Table D.3.4.2.1--ARMS deployment locations around Pagan.

REA Site	Latitude	Longitude
PAG-05	18º 07.168 N	145º 45.333 E
PAG-06	18º 05.546 N	145º 44.622 E
PAG-09	18º 04.243 N	145º 42.826 E

D.3.4.3 Invertebrate Collections

Twenty-three *Linckia multifora* arms, 36 *Acanthaster planci* arms and one juvenile *Pearsonothuria graeffei* were collected at Pagan.

D.3.5. Benthic Towed-diver Surveys

A total of 15 benthic towed-diver surveys were completed at Pagan in 2009 (Fig. D.3.5.1.). One benthic calibration tow was also completed. Benthic habitats along the western/northwestern forereef were characterized by continuous reef/shallow spur and groove, switching to continuous reef, sand flats, pavement and rock boulders as surveys progressed north. Approaching the northwest side of the island, habitat consisted of medium to medium-high continuous reef, rubble flats, and pinnacles.

Benthic category	Mean ± SE
Hard coral	13.3 ± 0.7
Soft coral	2.6 ± 0.3
Sand	15.2 ± 2.0
Rubble	2.8 ± 0.4
Macroalgae	9.9 ± 0.9
Coralline algae	8.4 ± 0.6
COTS	211*
Free urchins	343*
Boring urchins	4439*
Sea cucumbers	5469*
Giant clams	123*

* Sum of observed individuals

The north coast was characterized by moderately complex rock boulders and slope mixed in with continuous hard bottom. Rounding the corner in the northeast, habitat was composed of low complexity pavement with sand flats/patches, giving way to moderate complexity continuous reef/rock boulders.

Along the windward/eastern coastline, terrain was generally composed of medium complexity rock boulders, medium complexity reef, and medium high rock boulders/continuous reef interspersed with ridges perpendicular to shore, progressing into low rock boulders and pavement, and changing again into spur-and-groove style reef and finally, sand flats. Approaching the southeast side of the island, terrain consisted of sand flats with rock boulders and low-moderate relief continuous reef. Finally, along the southwest side of the island, terrain consisted primarily of medium-low to medium complexity continuous reef, with ridges extending from shore and areas of rock boulders.

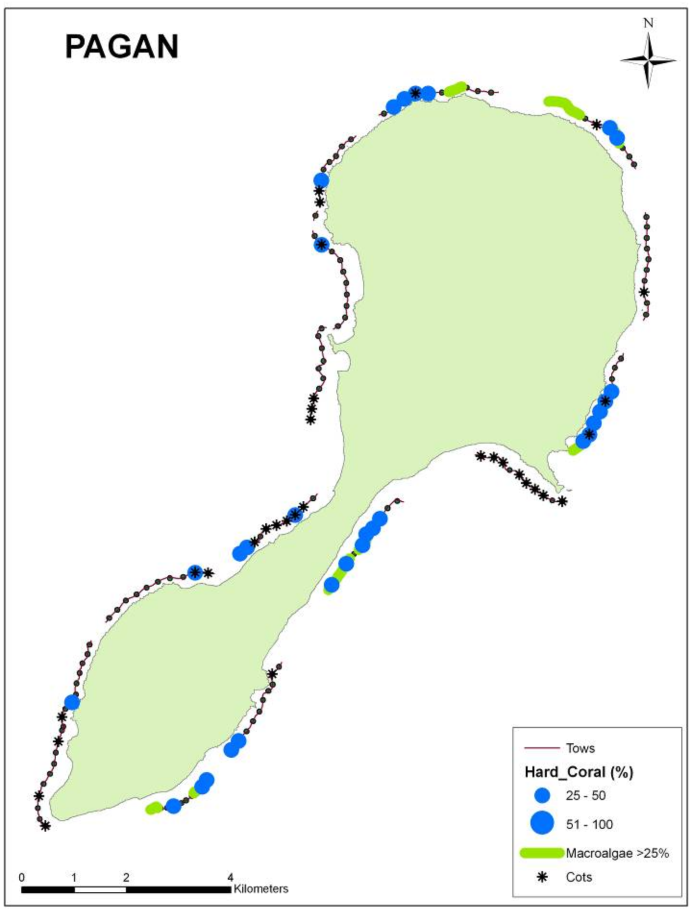


Figure D.3.5.1--Hard coral cover, elevated macroalgal cover (> 25%), and crown-of-thorn (COT) abundances during tow segments at Pagan 2009.

Hard coral was the most abundant (biotic) benthic feature, accounting for 13.3 ± 0.7 % of total benthic cover island-wide. Hard coral was most abundant along the northeast coast/northeast of Toagri Rock where one survey recorded up to 30.1–40% cover (two time segments). Other areas of high cover included the survey along the windward/east side, paralleling Maru and Togari Mountains, with one segment recording from 30.1–40% cover. There were many areas where, aside from the more gregarious species of *Pocillopora* and *Porites*, patches of other genera/species were noted. These included *Euphyllia ancora*, species of *Galaxea Goniopora*, *Montipora*, *Astreopora*, *Diploastrea heliopora*, and *Stylophora*. Low levels of coral stress (mean 0.8 ± 0.2) were observed throughout all surveys in 2009. A singular exception was observed along the west side of the island, near where the isthmus joins with the southwest lobe of Pagan. Coral stress was recorded at 10.1–20%, in a large part due to elevated COT numbers recorded during a single time segment (36 COTS).

Octocorals averaged 2.6 ± 0.3% island-wide; few areas were recorded with elevated coverage. The highest soft coral cover was recorded during a tow in the northeast/northeast of Togari Rock, in the vicinity of Unairikiki (3 segments @ 10.1 – 20%).

Macroalgae accounted for 9.9 ± 0.9% of benthic cover island-wide. The greatest coverage was readily apparent on the windward/east side, with several segments recording 40.1–50% cover (e.g., near Togari Point in the east, and past Tagari Mountain in the northeast). In contrast, the vast majority of time segments on the leeward/west side recorded < 5% macroalgae. *Asparagopsis taxiformis* and species of *Halimeda* and *Caulerpa* were the more obvious macroalgal components. The highest cover was seen in the northeast, northeast of Togari Rock, in the vicinity of Unairikiki, with three time segments recording 20.1–30% and one time segment recording 30.1–40% coralline algal cover.

Unlike the previous visits to Pagan, dark-green cyanobacteria were prevalent island-wide on all types of substrate (rock boulders, sand, continuous reef), with several areas (e.g., northwest) recording near 100% cover. Fragments of cyanobacteria were readily found suspended in the water column along the southeast side of the island, moving south to north along a relatively slow-moving current, indicating fragmentation and transport potential to other areas of the island. Several time segments also recorded cyanobacteria actively growing over (live) coral and macroalgae, indicating that the cyanobacteria were more aggressive in certain areas.

A total of 211 COTS were recorded island-wide, with the largest aggregation occurring along the west side of the island in an area previously described. A total of 343 free sea urchins were recorded island-wide, along with 4439 boring sea urchins. The highest concentration of free urchins was recorded in the north bordering either side of Tarago, with two separate surveys recording 37 in one time segment. The highest number of boring sea urchins (one time segment recording an average of 375 urchins; one time segment recording 175 urchins; several segments recording an average of 75 urchins) was noted for the area northeast, northeast of Togari Rock, in the vicinity of Unairikiki. A total of 5,469 sea cucumbers, mostly belonging to *Stichopus Chloronotus*, were recorded for 2009, with the largest concentration focused around the southeast part of the island. Two separate surveys recorded a single time segment of an average of 375 sea cucumbers, in the area between Pariyaaru and Periiruu. Finally, a total of 123 giant clams were recorded during 2009 surveys. The highest number of giant clams (9 in one time segment) was recorded off the east side near Degusa.

D.4. Fish Surveys

D.4.1. REA Fish Surveys

Stationary point count data (nSPC)

During the survey period, nSPC surveys were conducted at 21 sites around Pagan. Snappers were the largest contributor to total biomass with 1.3 kg 100 m^{-2}. Surgeonfish were the second largest contributor to total biomass with 1.2 kg 100 m^{-2}, followed by parrotfish at 0.8 kg 100 m^{-2} (Fig. D.4.1.1.).

Overall observations

A total of 222 fish species were observed by all divers during the survey period. The average total fish biomass around Pagan during the survey period was 5.8 kg 100 m^{-2} for the nSPC surveys (Table D.4.1.1.).

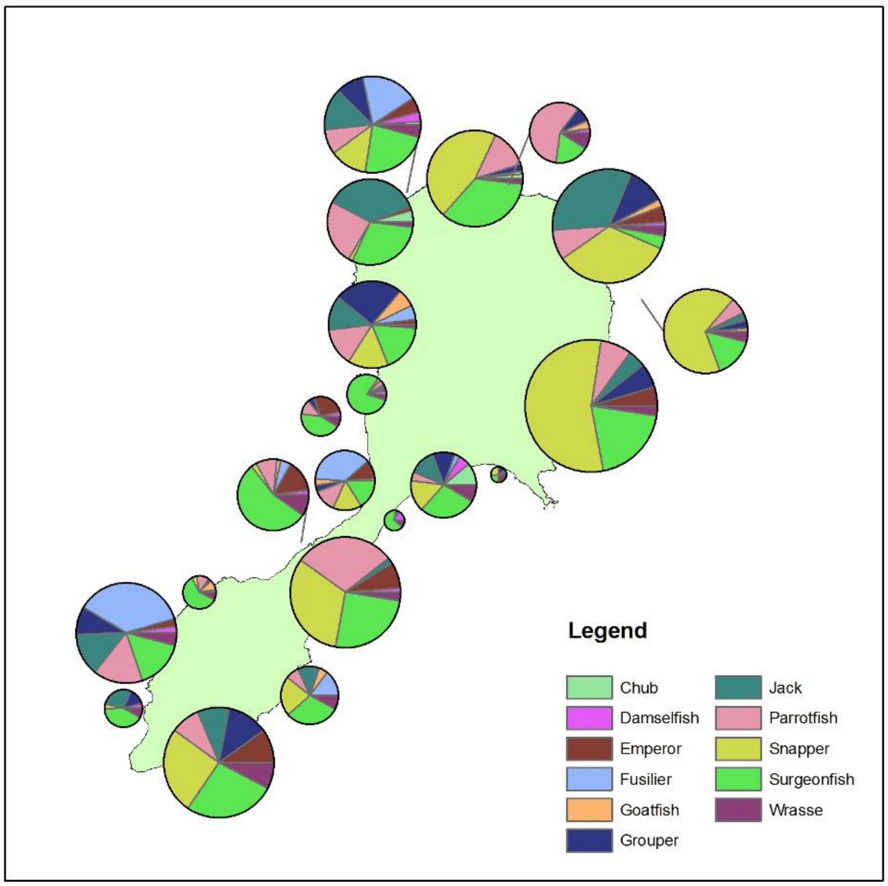


Figure D.4.1.1--Site location and distribution of total fish biomass by family. The sizes of the pie charts are proportional to fish biomass.

D.4.2. Towed-diver Surveys

During HA0903, the CRED towed-diver team completed 16 surveys at Pagan covering 34.8 km (34.8 ha) of ocean floor (Table D.4.2.1.). Mean survey length was 2.2 km with a maximum length of 2.5 km and a minimum of 1.4 km. Mean survey depth was 14.5 m with a maximum depth of 15.8 m and a minimum of 12.5 m. Mean temperature on these surveys was 28.4°C with a maximum temperature of 28.6°C and a minimum of 28.2°C.

Table D.4.2.1--Survey statistics for towed-diver sampling during HA0903.

Island/ Reef	#	Length (km)					Depth (m)				Temperature (ºC)			
		Sum	Mean	Max	Min	SD	Mean	Max	Min	SD	Mean	Max	Min	SD
Pagan	16	34.8	2.2	2.5	1.4	0.2	14.5	15.8	12.5	1.0	28.4	28.6	28.2	0.1

One hundred ninty-five individual large-bodied reef fish (> 50 cm TL) of 15 different species and 14 different families were encountered at Pagan (Table D.4.2.2.). Overall numeric density for this class of reef fishes was 0.56 #/100 m^2 (56.02 #/ha) with a biomass density of 3.50 kg/100 m^2 (0.35 t/ha). Numeric density was dominated by *Lutjanus bohar,* while biomass density was dominated by *Lutjanus bohar.*

Table D.4.2.2--Species numeric and biomass density for large-bodied reef fishes (> 50 cm TL) observed at Pagan during HA0903 CRED towed-diver surveys.

Species	#	#/100 m^2	#/ha	Biomass (kg)	kg/100 m^2	t/ha
Aprion_virescens	3	0.01	0.86	12.83	0.04	0.00
Arothron_stellatus	2	0.01	0.57	18.95	0.05	0.01
Carangoides_orthogrammus	6	0.02	1.72	13.65	0.04	0.00
Caranx_ignobilis	1	0.00	0.29	20.69	0.06	0.01
Caranx_melampygus	7	0.02	2.01	15.54	0.04	0.00
Caranx_sexfasciatus	1	0.00	0.29	3.11	0.01	0.00
Caranx_sp	1	0.00	0.29	2.35	0.01	0.00
Carcharhinus_amblyrhynchos	3	0.01	0.86	31.40	0.09	0.01
Chlorurus_microrhinos	3	0.01	0.86	7.79	0.02	0.00
Diodon_hystrix	2	0.01	0.57	7.87	0.02	0.00
Gymnosarda_unicolor	5	0.01	1.44	42.24	0.12	0.01
Lutjanus_bohar	52	0.15	14.94	193.52	0.56	0.06
Macolor_niger	7	0.02	2.01	12.69	0.04	0.00
Naso_brachycentron	1	0.00	0.29	3.81	0.01	0.00
Naso_hexacanthus	25	0.07	7.18	53.03	0.15	0.02
Naso_tonganus	3	0.01	0.86	8.48	0.02	0.00
Nebrius_ferrugineus	3	0.01	0.86	149.61	0.43	0.04
Oplegnathus_punctatus	1	0.00	0.29	2.54	0.01	0.00
Plectorhinchus_gibbosus	6	0.02	1.72	18.10	0.05	0.01
Scarus_rubroviolaceus	6	0.02	1.72	15.62	0.04	0.00
Sphyraena_qenie	29	0.08	8.33	162.40	0.47	0.05
Taeniura_meyeni	14	0.04	4.02	246.13	0.71	0.07
Triaenodon_obesus	13	0.04	3.73	174.93	0.50	0.05
Variola_louti	1	0.00	0.29	2.08	0.01	0.00
Grand Total	195	0.56	56.02	1219.35	3.50	0.35
# of Species	15					

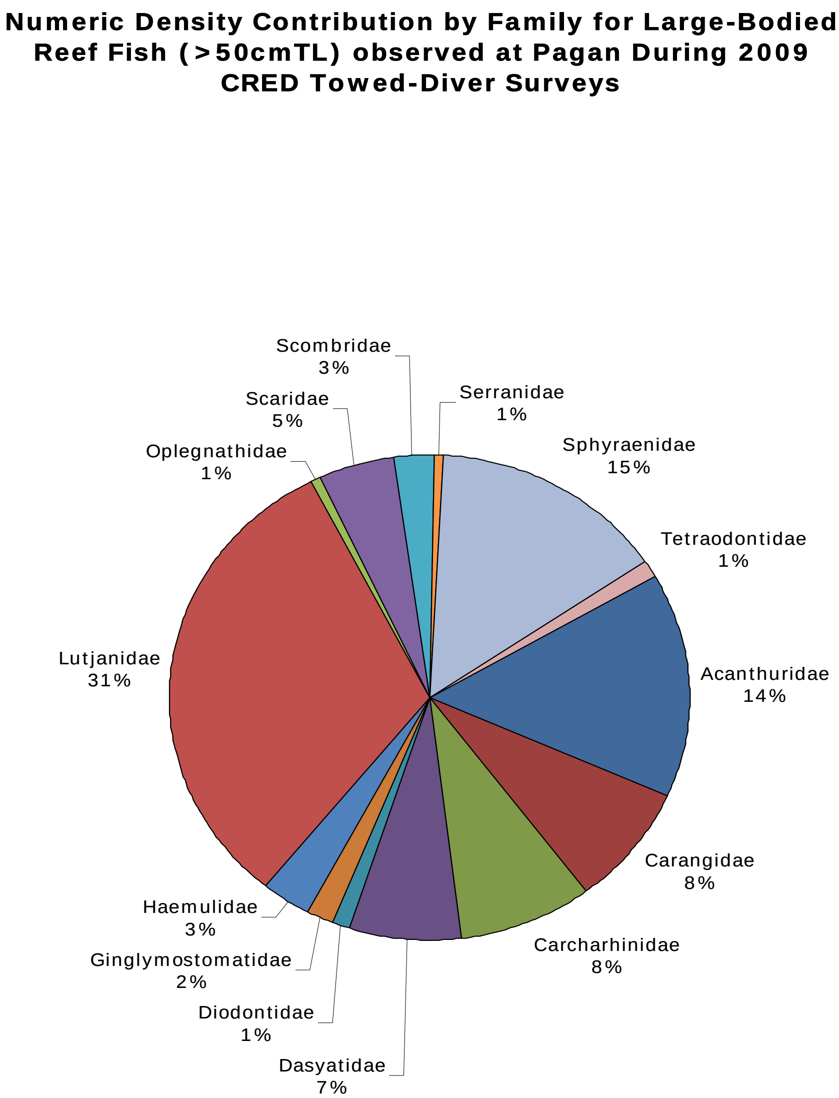


Figure D.4.2.1--Numeric density of fishes by family.

The most prevalent families in terms of numeric and biomass density were lutjanids (ND = 31%, BD = 18%), sphyraenids (ND = 15%, BD = 13%), and acanthurids (ND = 14%, BD = 5%) (Fig. D.4.2.1., D.4.2.2.). There was no clear pattern to the geographic distribution of large-bodied reef fish around the island. (Fig. D.4.2.3.).

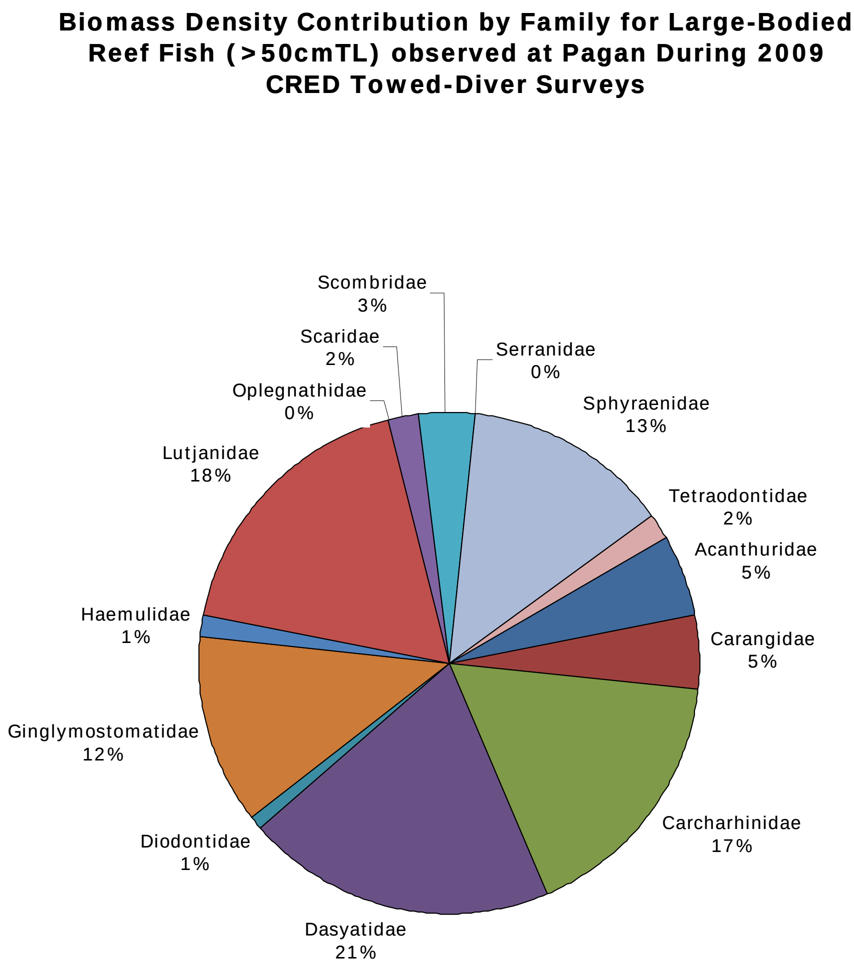


Figure D.4.2.2--Biomass density of fishes by family.

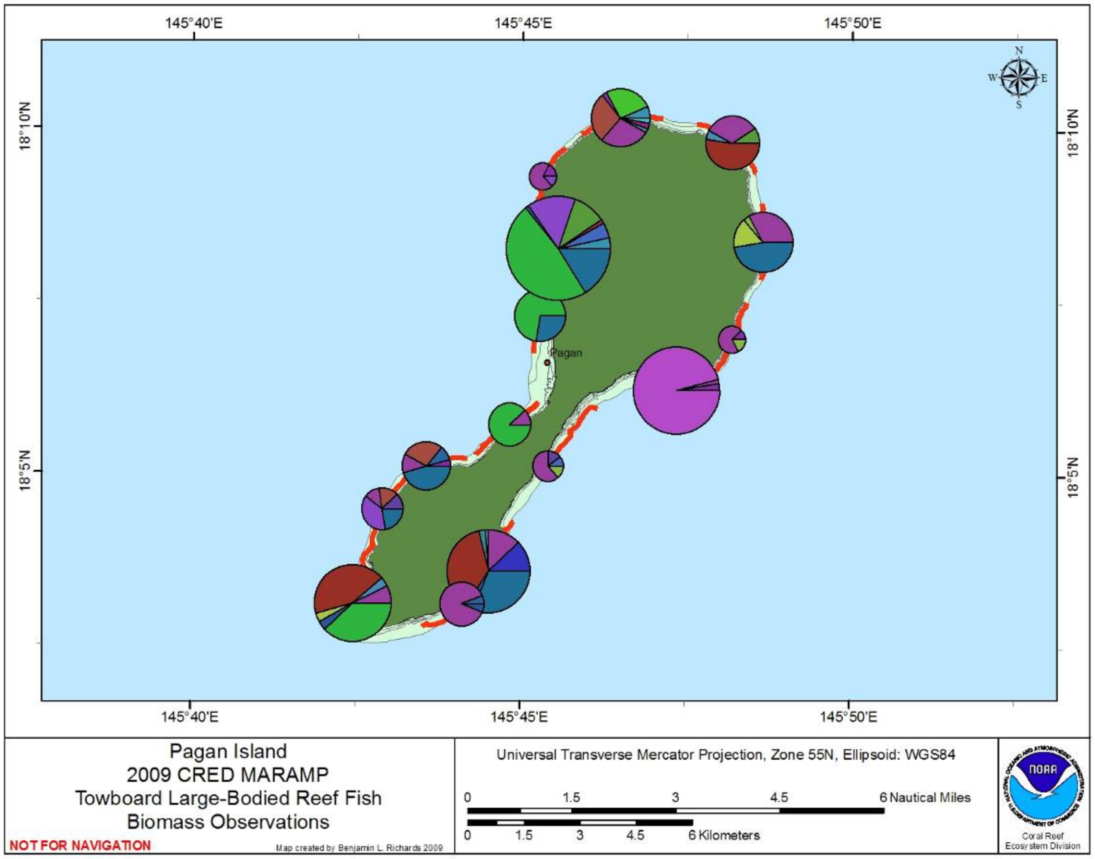


Figure D.4.2.3--Geographic distribution of fish biomass around Pagan. Each species is represented by a legend color. Diameter of pie chart is proportional to total biomass of all species encountered on the underlying survey.

Appendix E: Asuncion Results

E.1. Oceanography and Water Quality

Moorings recovered and replaced during HA0903 at Asuncion included one subsurface temperature recorder (STR) recovered and replaced and two new STRs deployed as a depth transect at approximately 10 m and 30 m on the northeast side of the island. (Table E.1.1., Fig. E.1.1.). The STR shows a clear annual fluctuation due to seasonal warming and cooling (Fig. E.1.2.). Warmest temperatures peaked at about 31^{o}C and occurred during the summer months of July to October. Winter temperatures reached lows of approximately 25^{o}C and occurred during November through June.

One rapid ecological assessment (REA) site (ASC-01) was visited to collect water samples for microbiological, nutrient and chlorophyll analyses, and the two long-term monitoring sites (ASC-02 and ASC-03) were sampled for just nutrients and chlorophyll. Samples were obtained from the surface and approximately 1 m above the reef. Microbial water samples were taken using diver-deployable Niskin bottles to collect 8 liters of seawater (4 bottles; 2 liters per bottle) at each study site. Chlorophyll samples were filtered, and nutrient samples were frozen at -30^{o}C for post-cruise analysis. Shallow-water conductivity-temperature-depth (CTD) casts were also conducted at these sites. In addition, 12 CTD casts were taken every 1 km around the perimeter of Asuncion at the 30 m depth contour.

Table E.1.1--Asuncion moorings.

Action	Mooring type	Serial number	Lat		Long		Depth (m)
Deployment	STR	39301590842	19.69955728	N	145.4185619	E	29.3
Deployment	STR	39331791151	19.69982215	N	145.4175904	E	12.2
Deployment	STR	39331791370	19.6934043	N	145.3897302	E	3.7
Retrieval	STR	39368591646	19.6934043	N	145.3897302	E	3.7

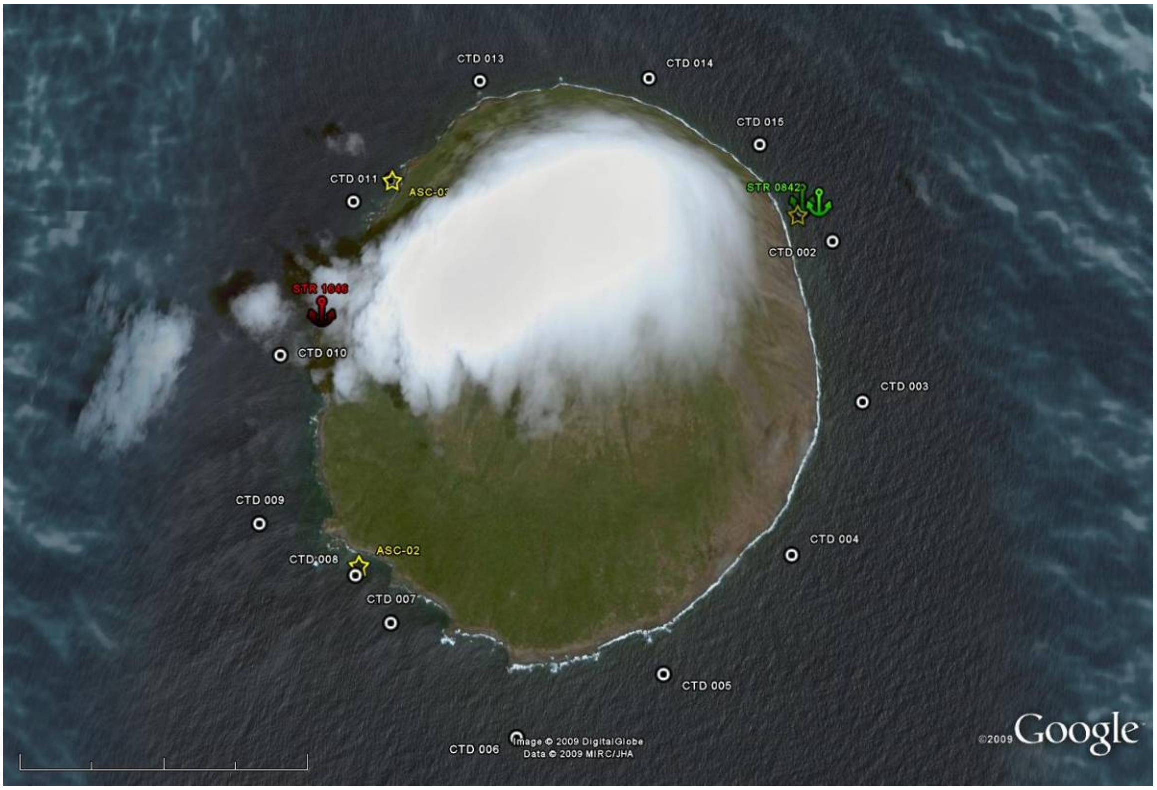


Figure E.1.1--Deployed and recovered instrument moorings and CTD and water sampling sites, HA0903.

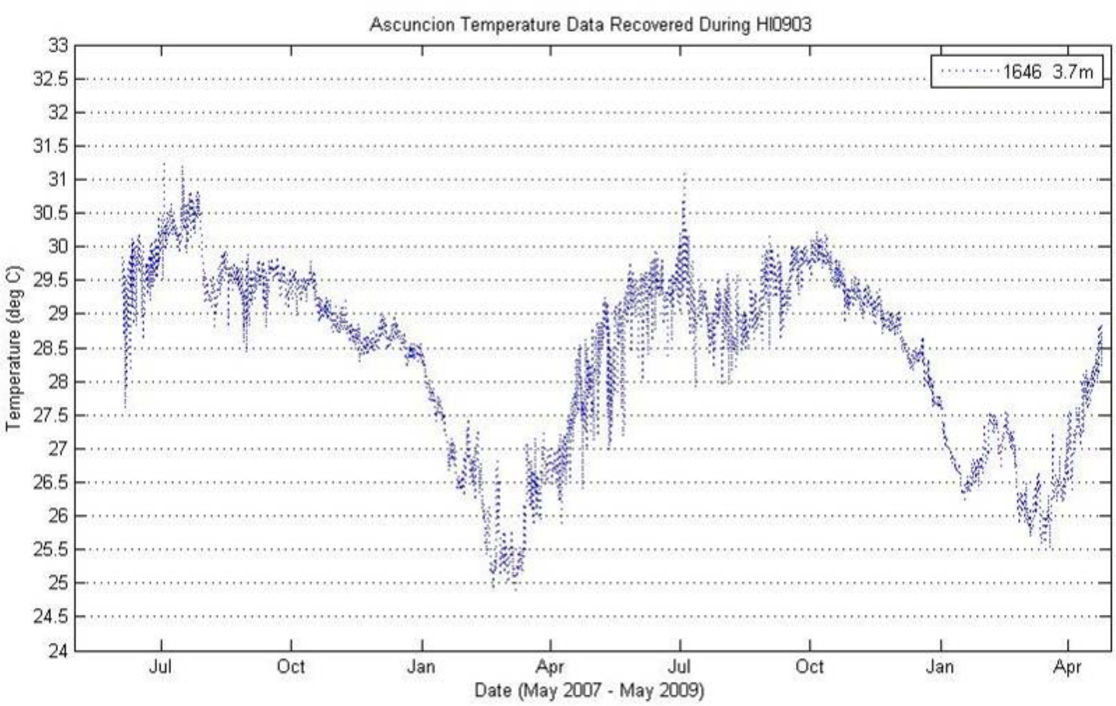


Figure E.1.2--Temperature time series from STR moorings at Asuncion.

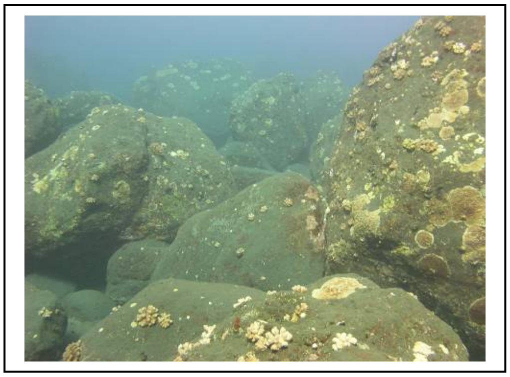
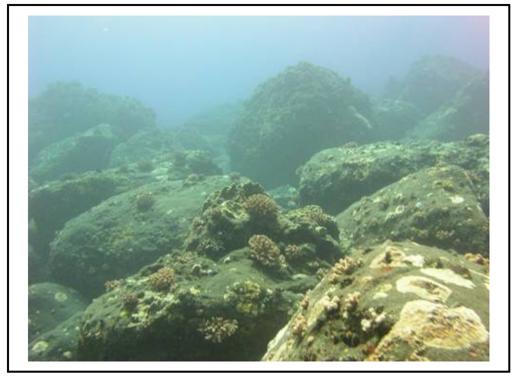
E.2. Rapid Ecological Assessment (REA) Site Descriptions

ASC-01
4/25/2009

E 145° 25.044
N 19° 41.986

Forereef
Mid

Depth: 11–17 m

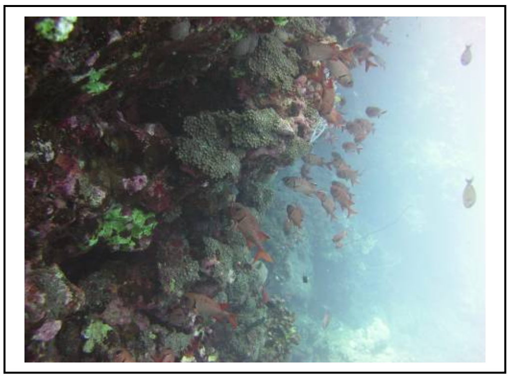
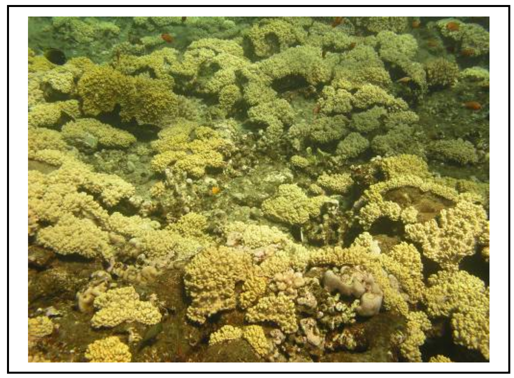
Site description: Northeastern region; moderate topographic complexity (boulders); high coral cover; low macroalgal cover; dominated by turf algae.

ASC-02
4/25/2009

E 145° 23.535
N 19° 40.843

Forereef
Mid

Depth: 9–14 m

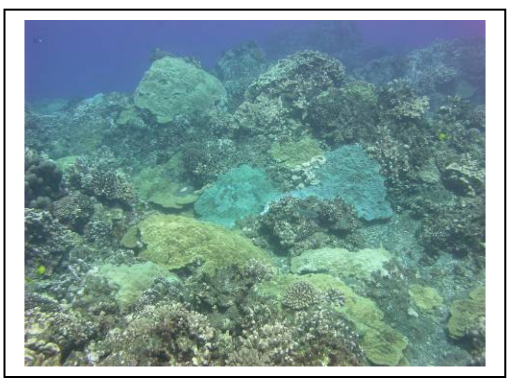
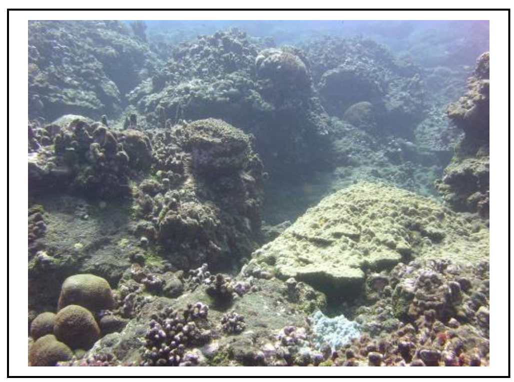
Site description: Southwestern region; high topographic complexity; wall environment; high coral cover; low macroaglal cover; high crustose coralline algae cover.

ASC-03
4/25/2009

E 145° 23.619
N 19° 42.102

Forereef
Mid

Depth: 14–18 m

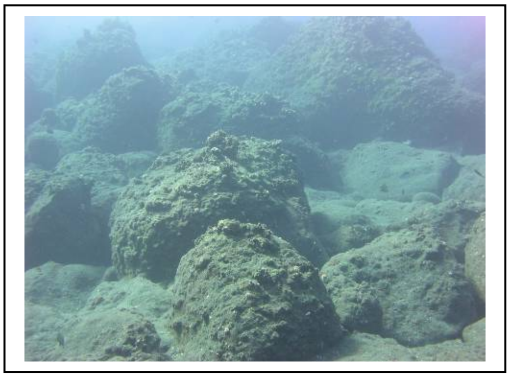
Site description: Northwestern region; high topographic complexity; high coral and macroalgal cover.

ASC-04
4/26/2009

E 19.° 42.505
N 14° 24.183

Forereef
Mid

Depth: 11–12 m



Site description: Northern region; moderate topographic complexity (boulders); low coral cover; moderate macroalgal cover; dominated turf algae.

ASC-05
4/26/2009

E 19.° 40.682
N 14° 24.706

Forereef
Mid

Depth: 11 m

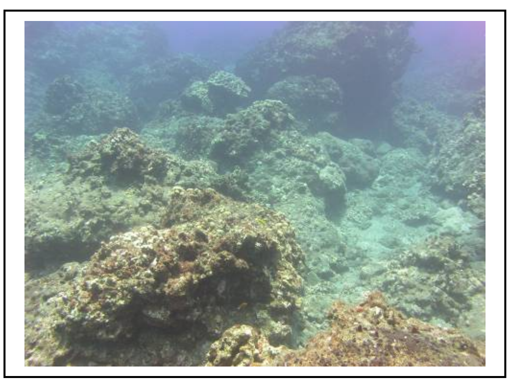
Site description: Southeasten region; moderate topographic complexity (boulders surrounded by sand); moderate coral cover; low macroalgal cover; dominated by turf algae.

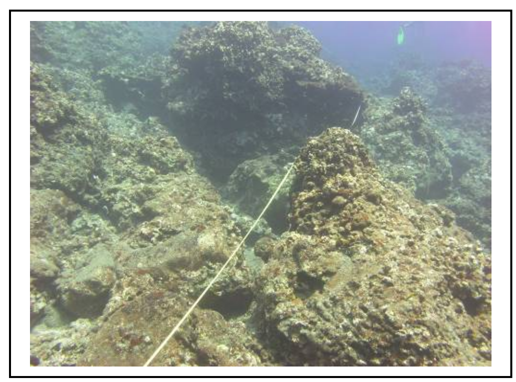
ASC-06
4/26/2009

E 19.° 47.917
N 14° 28.300

Forereef
Mid

Depth: 12 m





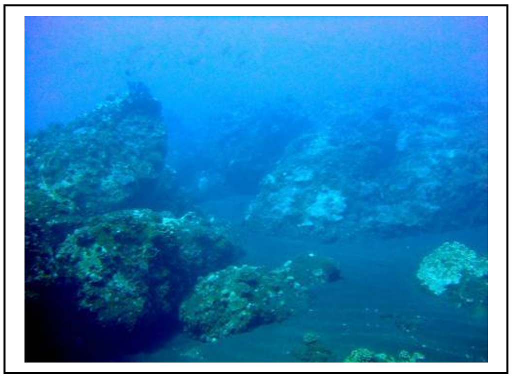
Site description: Southwestern region; moderate topographic complexity; low coral cover; moderate macroalgal cover; dominated by turf algae and *Lobophora variegata*.

ASC-50
4/25/2009

E 145° 25.222
N 19° 41.476

Forereef
Deep

Depth: 23 m



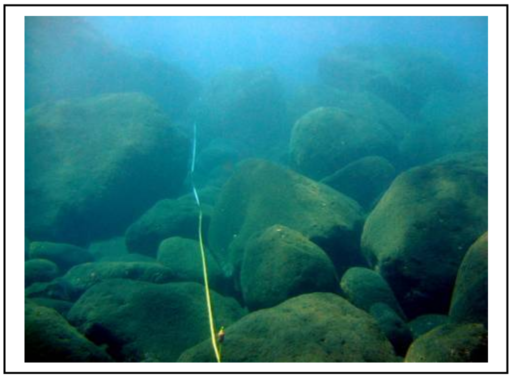

Site description: Eastern region; moderate topographic complexity (non-continuous forereef with pinnacles); high coral cover; moderate macroalgal cover.

ASC-51
4/25/2009

E 145° 24.815
N 19° 42.204

Forereef
Shallow

Depth: 5 m



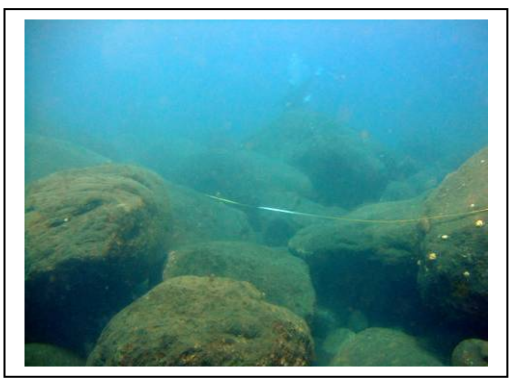
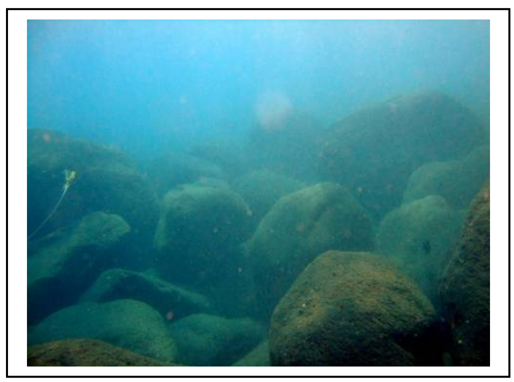

Site description: Northeastern region; moderate topographic complexity (boulders); very low coral and macroalgal cover; dominated by turf algae.

ASC-52
4/25/2009

E 145° 24.346
N 19° 42.451

Forereef
Shallow

Depth: 5–6 m

Site description: Northern shallow site; moderate topographic complexity (boulders); low coral and macroalgal cover; dominated by turf algae.

ASC-53
4/25/2009

E 145° 23.352
N 19° 41.659

Forereef
Deep

Depth: 22 m

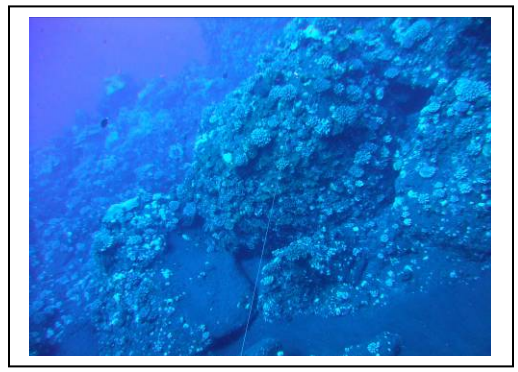
Site description: Western deep site; moderate topographic complexity (patch reefs interspersed with small sand patches); high coral cover; moderate macroalgal cover.

ASC-54
4/26/2009

E 145° 24.951
N 19° 40.856

Forereef
Deep

Depth: 23 m



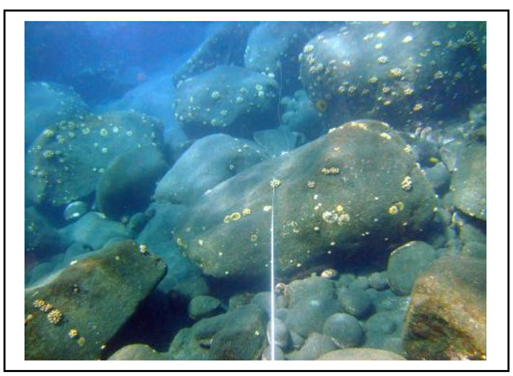
Site description: Western deep forereef; high topographic complexity; high coral cover; low macroalgal cover.

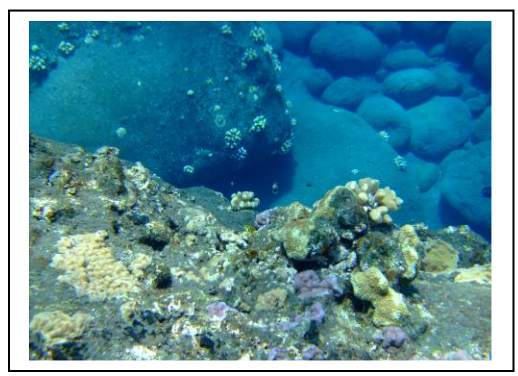
ASC-55
4/26/2009

E 145° 23.950
N 19° 40.598

Forereef
Shallow

Depth: 5 m





Site description: Southern shallow site; moderate topographic complexity (boulders); moderate coral cover; low macroalgal cover; dominated by turf algae.

ASC-56
4/26/2009

E 145° 23.315
N 19° 41.085

Forereef
Shallow

Depth: 3 m

Site description: Southwest shallow forereef; moderate topographic complexity; high coral cover; low macroalgal cover.

E.3. Benthic Environment

E.3.1. Algal Communities

During the Mariana Reef Assessment and Monitoring Program (MARAMP) 2009, six permanent, long-term REA monitoring sites were surveyed around Pagan Island for percent benthic cover based on the 20-cm interval line point intercept (LPI) methodology. Benthic communities around Asuncion were dominated by turf algae, scleractinian corals, and macroalgae (Table E.3.1.1). Turf algal percent cover exceeded that of other functional groups at four of the six sites surveyed with a percent cover range of 16% to 58.4% cover across all sites. Scleractinian corals were the dominant cover at site ASC-02 with 46.5% cover (Table E.3.1.1). At site ASC-03, percent cover of macroalgae and scleractinian corals were approximately equal (29.2% and 30.4%, respectively). A combined total of nine species of macroalgae were observed (6 chlorophytes, 3 ochrophytes) from the six sites surveyed (Tables E.3.1.2 and E.3.1.3). *Lobophora variegata* dominated the macroalgal community at five of the six sites with a percent cover range of 1.6% to 25.6% (Table E.3.1.3). *L. variegata* and species of *Dictyota* had equal percent covers of 1.6% at site ASC-05 (Table E.3.1.3).

Table E.3.1.1--Percent cover of algal functional groups at long-term monitoring sites at Asuncion.

Site	Macroalgae	Turf Algae	Coralline red algae (crustose + upright)	Cyanobacteria	Scleractinian Coral	Octocoral
ASC-01	3.2%	56.8%	3.6%	0.8%	31.2%	0.8%
ASC-02	8.6%	16.0%	28.4%	-	46.5%	-
ASC-03	29.2%	20.8%	15.2%	0.4%	30.4%	1.6%
ASC-04	21.2%	54.0%	12.8%	1.2%	8.4%	-
ASC-05	3.2%	58.4%	4.0%	0.4%	16.8%	-
ASC-06	28.8%	40.4%	11.2%	4.4%	9.2%	-

Table E.3.1.2--Additional species recorded at each site at Asuncion during roving diver survey.

Site	Chlorophyta
ASC-05	*Caulerpa filicoides*
ASC-01 ASC-02	*Dictyosphaeria cavernosa*
ASC-04	*Halimeda opuntia*
ASC-05	*Halimeda* sp.
ASC-01 ASC-04 ASC-05	*Neomeris* sp.
ASC-06	*Valonia ventricosa*
	Ochrophyta
ASC-05	*Padina* sp.

Table E.3.1.2--Percent cover of macroalgal species at long-term monitoring sites at Asuncion. Sum totals for each row equal the percent cover of macroalgae recorded in Table E.3.1.1.

Site	Caulerpa serrulata	Halimeda opuntia	Dictyota sp.	Lobophora variegata	Padina sp.
ASC-01	-	-	-	2.8%	-
ASC-02	2.5%	-	-	4.9%	-
ASC-03	2.8%	2.8%	-	6.4%	-
ASC-04	0.4%	-	0.4%	8.8%	3.2%
ASC-05	-	-	1.6%	1.6%	-
ASC-06	2.0%	1.2%	-	25.6%	-

E.3.2. Coral Communities

E.3.2.1. Percent Benthic Cover

During MARAMP 2009, percent benthic cover REA surveys conducted around Asuncion Island at six permanent, long-term sites yielded an island-wide mean of 23.8% (Fig. E.3.2.1.1). Percent coral cover was the greatest at ASC-02 on the southwestern region where it amounted to 47%. Contrastingly, the lowest percent coral cover was detected at an exposed, north-facing shore site, PAG-03, where it amounted to 8% (Fig. E. 3.2.1.1).

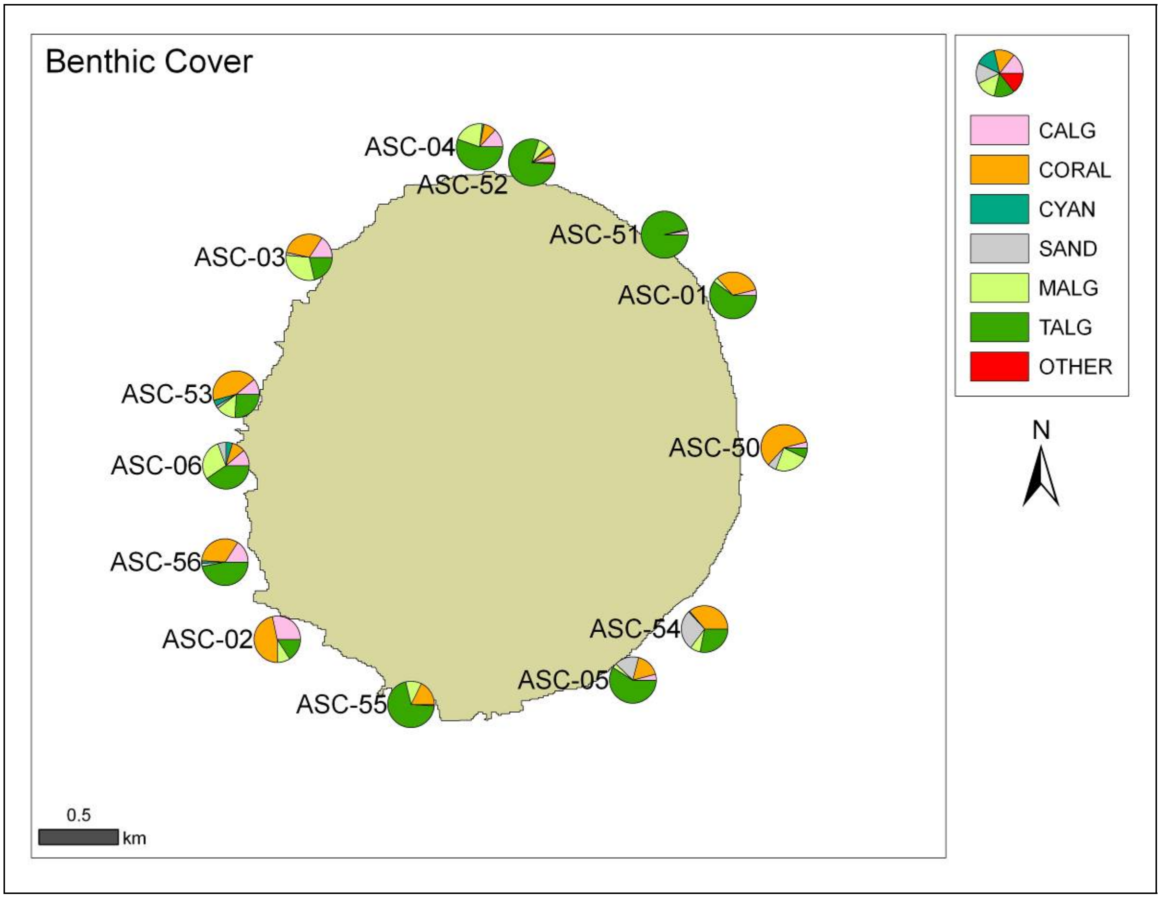


Figure E.3.2.1.1--Percent cover of benthic functional groups at the random stratified and permanent REA monitoring sites around Asuncion during MARAMP 2009. CALG = crustose coralline red algae, CYAN = cyanobacteria, MALG = macroalgae, TALG = turf algae.

Seven additional stratified random REA sites were surveyed around Asuncion for percent benthic cover (based on 50-cm interval LPI surveys; Fig. F.3.2.1.1) and generic diversity data in 2009. Benthic communities at three sites greater than 20 m deep were dominated by scleractinian coral (44.8% $\pm$ 6.0), turf algal (19.9% $\pm$ 6.6) and macroalgal (14.7% $\pm$ 4.8) functional groups (Fig. E.3.2.1.2). Four shallow sites (< 10 m depth) were dominated by turf algal (78.1% $\pm$ 10.1) and scleractinian coral (14.0% $\pm$ 7.1) functional groups (Fig. E.3.2.1.2). Coral generic diversity was highest at site ASC-53 with 33 different genera observed (Table E.3.2.1.2). In contrast site ASC-51 had the lowest generic diversity with seven different genera observed at both. An average of 21 coral genera were recorded at each site. Common genera observed at most sites included *Pocillopora, Favia, Platygyra, Acanthastrea, Porites, Pavona, Goniastrea,* and *Cyphastrea.* Macroalgal generic diversity was highest at site ASC-56 with 12 genera observed (Table E.3.2.1.2). Sites ASC-51 and ASC-54 had the lowest generic diversity with four genera observed at both. An average of 7 macroalgal genera were recorded for each site. Common macroalgae observed at most sites included *Dictyota* and *Lobophora*.

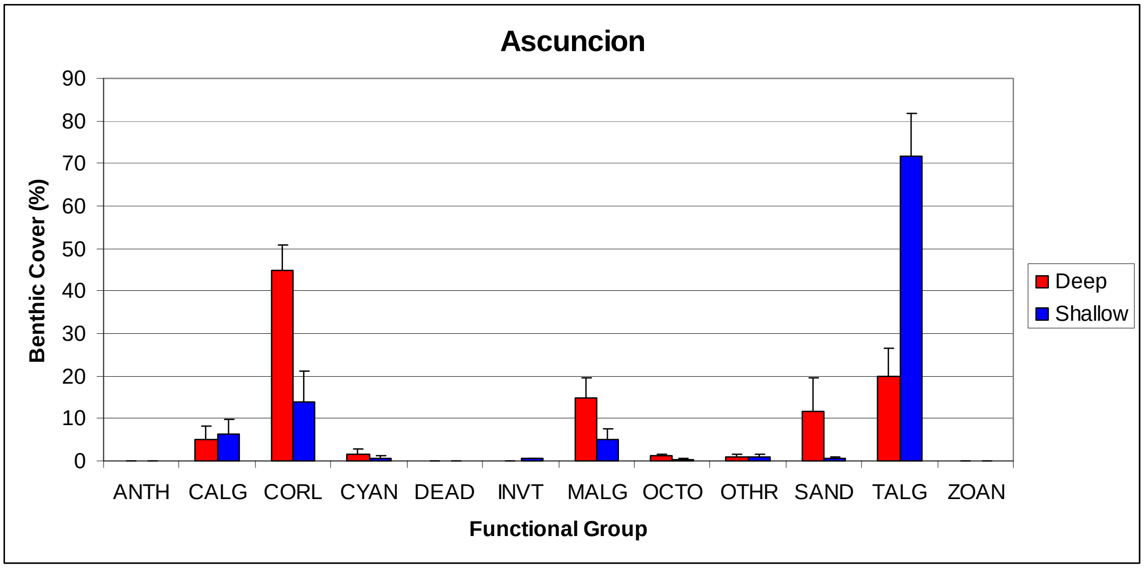


Figure E.3.2.1.2--Percent cover of functional groups at shallow and deep independent LPI monitoring sites established in 2009 around Asuncion Island. ANTH = anthozoan, CALG = crustose coralline red algae, CORL = coral, CYAN = cyanobacteria, DEAD = dead coral, INVT = non-coral invertebrate, MALG = macroalgae, OCTO = octocoral, OTHER = other, TALG = turf algae, ZOAN = zoanthid.

Table E.3.2.1.1--Coral generic diversity of stratified random sites around Asuncion.

	ASC-50	ASC-51	ASC-52	ASC-53	ASC-54	ASC-55	ASC-56
Acanthastrea	X	X	X	X	X	X	X
Acropora	X				X	X	X
Alveopora							
Astreopora	X		X	X	X	X	
Cladiella*							X
Corallimorph*				X			
Coscinarea				X			X
Cyphastrea		X	X	X	X	X	X
Diploastrea							
Distichopora*				X			
Echinopora				X			
Euphyllia				X			
Favia	X	X	X	X	X	X	X
Favites	X						
Fungia					X		
Galaxea				X	X		X
Gardinoseris				X	X		
Goniastrea	X		X	X	X	X	X
Goniopora	X			X	X		
Heliopora*	X			X	X		X
Herpolitha							
Hydnophora	X						

	ASC-50	ASC-51	ASC-52	ASC-53	ASC-54	ASC-55	ASC-56
Isopora				X			
Leptastrea	X		X		X	X	X
Leptoria	X	X	X			X	X
Leptoseris					X		
Lobophyllia	X			X	X		
Lobophytum*	X			X	X		
Merulina							
Millepora*	X			X	X		X
Montastrea	X			X	X		X
Montipora	X			X	X	X	X
Ouphyllia	X			X			
Pachyseris							
Palythoa*			X	X	X	X	
Pavona	X		X	X	X	X	X
Platygyra	X	X	X	X	X	X	X
Pleisiastrea				X	X		
Plerogyra	X			X	X		
Pocillopora	X	X	X	X	X	X	X
Porites		X	X	X	X	X	X
Psammocora	X		X		X		
Sarcophyton*					X		
Scapophyllia				X	X		
Scolymia							
Seriatopora							
Sinularia*	X			X	X		
Stylaster*	X						
Stylocoeniella				X	X		
Stylophora			X	X	X		
Turbinaria	X			X	X		
Wire Coral*	X						
Zoanthus*							X
Total Genera per Site	26	7	14	33	32	14	19

* non-scleractinian genera

Table E.3.2.1.2--Macroalgal generic diversity of stratified random sites around Asuncion.

	ASC-50	ASC-51	ASC-52	ASC-53	ASC-54	ASC-55	ASC-56
Amphiroa							X
Asparagopsis							
Avrainvillea							
Boergesenia							
Boodlea							
Bryopsis	X			X	X		X
Caulerpa	X			X	X	X	X
Chlorodesmis							
Crustose Coralline	X	X	X	X	X	X	X
Cyanobacteria			X	X			X
Dichotomaria	X						
Dictyosphaeria							X
Dictyota		X	X	X		X	X
Galaxaura							
Gibsmithia							
Halimeda			X	X		X	
Halymenia							
Liagora		X					
Lobophora		X	X	X	X	X	X
Microdictyon							
Neomeris			X			X	
Non-geniculate calcified branched				X			X
Padina			X				
Peyssonnelia							
Portieria							
Rhipilia							
Turbinaria							X
Tydemania							
Udotea							X
Valonia	X						X
Unknown							
Total Genera per site	5	4	7	8	4	6	12

E.3.2.2 Coral Populations

During MARAMP 2009, belt transect surveys were conducted at six long-term REA sites around Asuncion, covering a total reef area of 124.2 m^2 and totaling 2540 anthozoan and hydrozoan colonies enumerated. Taxonomic richness varied between sites with 35 anthozoan genera (31 scleractinian, 2 octocoral, 2 zoanthid) and two hydrozoan genera being represented within belt transects (Table E.3.2.2.1). *Pocillopora* was the most abundant scleractinian genus, contributing 33.7% of the total number of colonies enumerated island-wide. All other genera individually contributed less than 10% of the total number of colonies.

Table E.3.2.2.1--Relative abundance of anthozoan and hydrozoan genera enumerated within belt transects around Asuncion during MARAMP 2009.

Island	Genus	Relative abundance
Asuncion	*Pocillopora*	33.66
	Pavona	8.11
	Porites	7.95
	Cyphastrea	7.80
	Montastrea	4.29
	Goniastrea	4.02
	Favia	3.62
	Zoanthus	3.19
	Platygyra	2.99
	Tubastrea	2.83
	Astreopora	2.60
	Plerogyra	2.52
	Palythoa	2.44
	Heliopora	2.28
	Leptastrea	2.13
	Galaxea	1.57
	Montipora	1.34
	Leptoria	1.30
	Psammocora	0.75
	Acanthastrea	0.71
	Lobophytum	0.63
	Acropora	0.59
	Leptoseris	0.43
	Millepora	0.43
	Stylocoeniella	0.43
	Stylophora	0.39
	Favites	0.35
	Alveopora	0.12
	Echinophyllia	0.12
	Lobophyllia	0.08
	Sinularia	0.08
	Echinopora	0.04
	Fungia	0.04
	Hydnophora	0.04
	Plesiastrea	0.04
	Scolymia	0.04
	Turbinaria	0.04

The highest relative abundance of *Pocillopora* (> 74% of number of colonies) was found at site ASC-04 on the north side of the island (Fig. E.3.2.2.1).

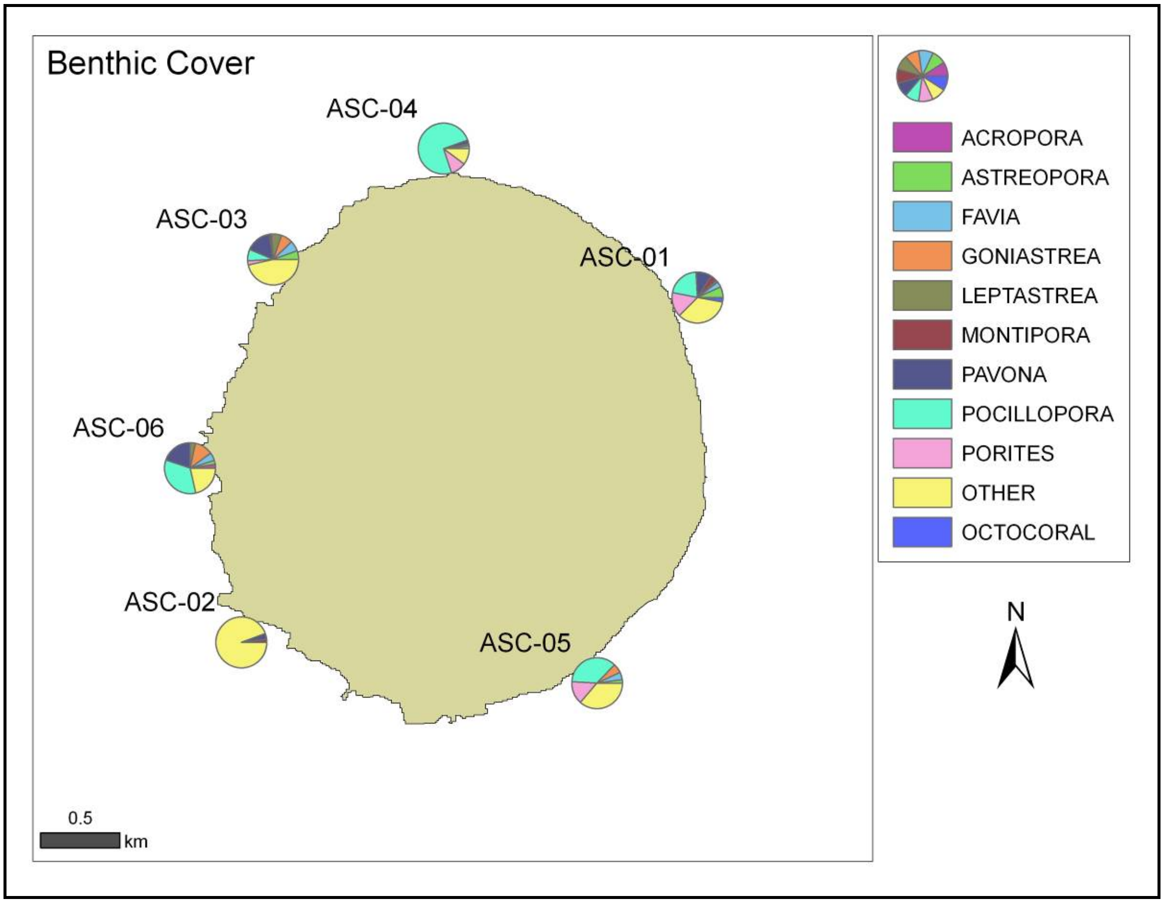


Figure E.3.2.2.1--Relative abundance of coral genera from REA surveys around Asuncion during MARAMP 2009.

E.3.3. Coral Health and Disease

During MARAMP 2009, the occurrence of disease, predation, and other health impairments around Asuncion was moderate, with a total of 49 cases enumerated. A summary of lesion occurrence and relative abundance is presented in Table E.3.3.1. The most numerically abundant type of lesion was due to fungal infections. These were detected primarily in *Cyphastrea* (29 cases), but also noted in *Psammocora, Pocillopora,* and *Pavona varians*. Bleaching was the next most numerically abundant type of affliction, observed in six genera. Four cases of predation were detected, all in *Pocillopora*. A single case of skeletal growth anomaly was observed, in *Porites lobata*. Lesions affecting coralline algae were rare, with only one case of coralline lethal disease (CLD) observed island-wide.

Table E.3.3.1--Number of cases of scleractinian and coralline algal diseases and predation enumerated during REA surveys around Asuncion, MARAMP 2009. BLE: bleaching; FUG: fungal infections; PRE: *Acanthaster*/*Drupella* predation scars; SGA: skeletal growth anomalies; CLD; coralline white band syndrome/lethal disease.

DZCode	ASC-01	ASC-02	ASC-03	ASC-04	ASC-05	ASC-06	Grand Total
BLE		1	1	1	5	2	10
FUG	11		1	1	21		34
PRE				3	1		4
SGA				1			1
Total	**11**	**1**	**2**	**6**	**27**	**2**	**49**
CLD		1					1

E.3.4. Macroinvertebrate Surveys (non-coral)

A total of 1,102 individuals of benthic invertebrate target species or taxa groups were enumerated from 12 belt transects at six sites. The sea star, *Linckia multifora*, was the most abundant non-cryptic invertebrate on transect. The island density for *L. multifora* was 8.82 (SE 3.0) organisms 50 m^{-2}. Densities were highest at ASC-01, ASC-04, and ASC-05 (9.84, 20.72 and 12.96 organisms 50 m^{-2}, respectively). Sea urchins were relatively low in abundance with the exception of the rock boring urchin, *Echinostrephus aciculatus.*

The island density for *E. aciculatus* was 4.0 (SE 2.85) organisms 50 m^{-2}. Densities were highest at ASC-04 (15.36 organisms 50 m^{-2}) followed by ASC-06 (2.25 organisms 50 m^{-2}). Coral crabs from the genus *Trapezia* and hermit crabs from the genus *Calcinus* were common within coral heads. Densities of *Trapezia* and *Calcinus* were greatest at site ASC-04 (2.88 and 1.6 organisms 50 m^{-2}, respectively). Site ASC-03 had the greatest density of giant clams with 0.72 organisms 50 m^{-2}, and the crab *Percnon planissimum* was common at both ACS-01 and ACS-05, with a density of 0.32 organisms 50 m^{-2}. Holothuroids were exceptionally rare.

E.3.4.1.--Urchin Measurements

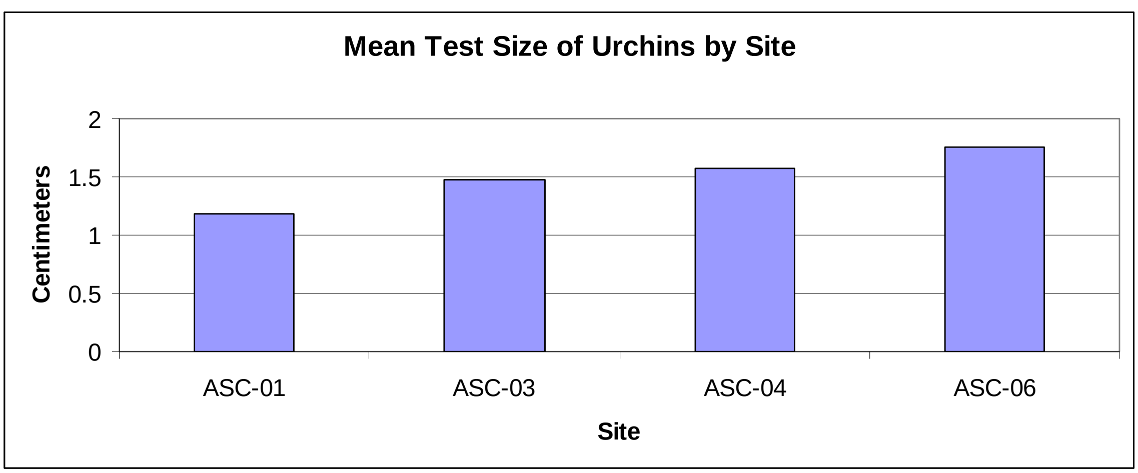


Figure E.3.4.1.1--Average test diameter of urchins encountered at each site. Only sites where ≥ 5 measurements were recorded for a species are represented. *Echinostrephus aciculatus* is the only represented echinoid.

E.3.4.2. Invertebrate Collections
Sixty-two *Linckia multifora* arms were collected at Asuncion

E.3.5. Benthic Towed-diver Surveys
A total of five benthic towed-diver surveys were completed at Asuncion in 2009 (Fig. E.3.5.1.). Two benthic calibration surveys and two fish calibration surveys were also completed.

Benthic category	Mean ± SE
Hard coral	18.5 ± 1.1
Soft coral	4.9 ± 0.5
Sand	19.7 ± 2.3
Rubble	3.1 ± 0.9
Macroalgae	8.1 ± 0.8
Coralline algae	3.1 ± 0.6
COTs	1
Free urchins	0
Boring urchins	591
Sea cucumbers	17
Giant clams	66

* Sum of observed individuals

Terrain was composed primarily of medium to medium-high complexity rock boulders, interspersed with sand flats/channels. Many segments of the tow also had rock ridges and spur-and-groove type terrain running perpendicular from shore, increasing habitat complexity.

Hard coral was the most abundant biotic benthic feature, accounting for 18.5 ± 1.1% of total benthic cover island-wide. Hard coral was most abundant in three time segments along the western/windward coastline, and four time segments along the northeastern coast (all registering 30.1–40% cover). In the north, species of *Porites* and *Pocillopora* were the most gregarious. Large *Isopora* fields, covering up to 100% of the bottom, were noted for parts of northern segments. Coral cover was also notably elevated along the rock ridges running perpendicular to the shoreline. In a portion of one northern survey, there was an area which marked a drastic reduction in coral cover (5.1-10%), with the reef appearing as though a die-off had occurred at some point in the past (many dead colonies covered by turf).

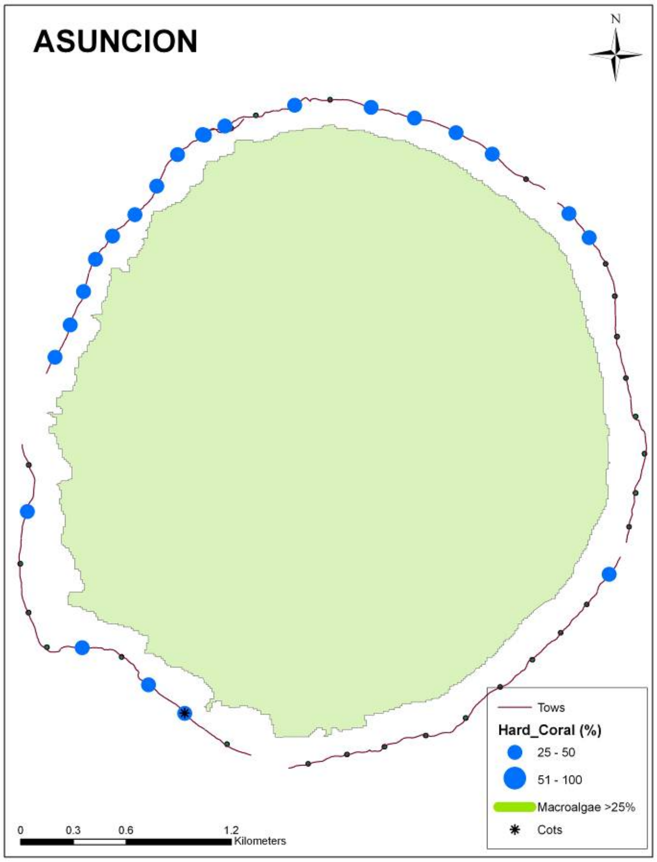


Figure E.3.5.1--Hard coral cover, elevated macroalgal cover (> 25%), and crown-of-thorn (COT) abundances during tow segments at Asuncion 2009.

Octocorals averaged 4.9 ± 0.5%, but reached as high as 10.1–20% along several segments in the east/north. Several genera were represented. In addition, *Palythoa* was very prevalent along several sections of the windward/eastern coastline.

Macroalgae accounted for 8.1 ± 0.8% of benthic cover island-wide. The highest macroalgal cover was recorded at 20.1–30% in several sections island-wide. Gregarious species included *Caulerpa filicoides*, *Padina*, and *Halimeda*.

Macroinvertebrates, in general, were low around Asuncion. Only one COT was recorded, and no free urchins were observed. Boring urchin numbers remained generally low, with the highest concentration seen located along one segment of the northern coastline (average 175/time segment). Sea cucumbers never exceeded 7/single time segment. A total of 66 giant clams were observed island-wide, with the highest numbers located along the leeward/western coastline (8/single time segment).

E.4. Fish Surveys

E.4.1. REA Fish Surveys

Stationary point count data (nSPC)

During the survey period, nSPC surveys were conducted at 13 sites around Asuncion. Snappers were the largest contributor to total biomass with 2.10 kg 100 m^{-2}. Surgeonfish were the second largest contributor to total biomass with 2.1 kg 100 m^{-2}, followed by chubs at 0.69 kg 100 m^{-2} (Fig. E.4.1.1.).

Overall observations

A total of 195 fish species were observed by all divers during the survey period. The average total fish biomass around Asuncion during the survey period was 8.7 kg 100 m^{-2} for the nSPC surveys (Table E.4.1.1.).

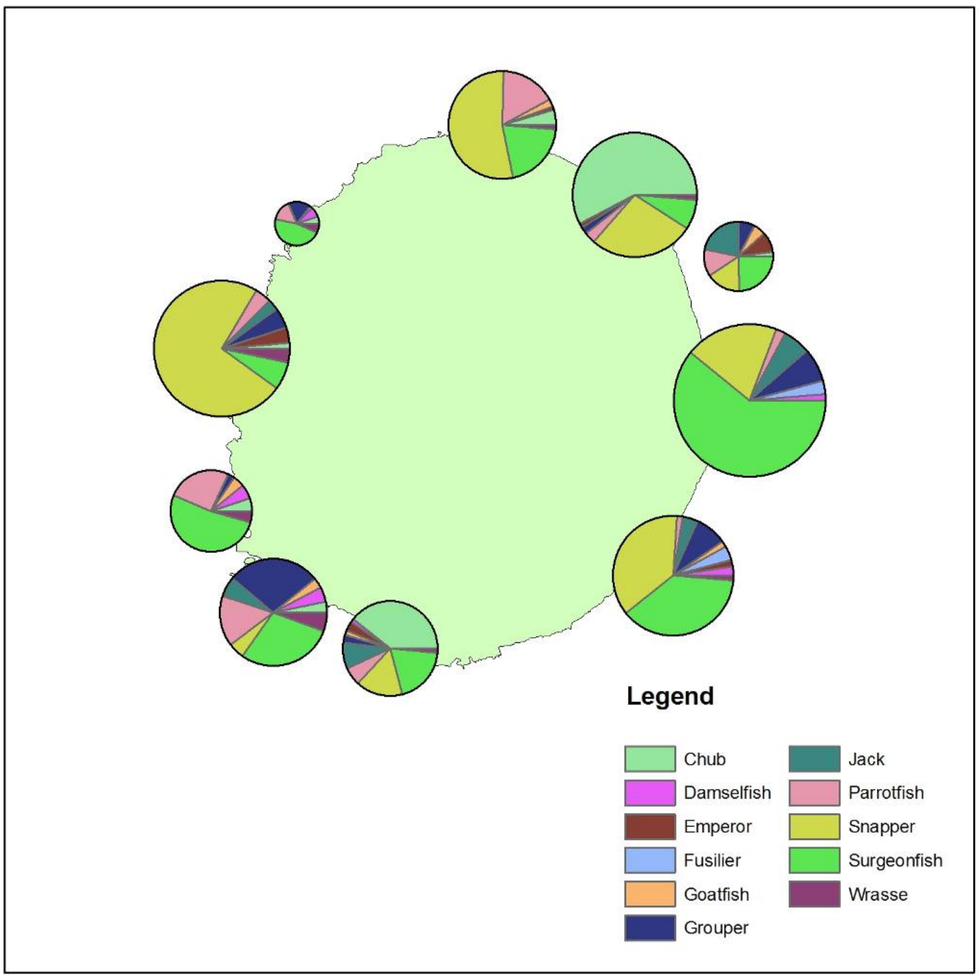


Figure E.4.1.1--Site location and distribution of total fish biomass by family. The sizes of the pie charts are proportional to fish biomass.

E.4.2. Towed-diver Surveys

During HA0903, the Coral Reef Ecosystem Division's (CRED) towed-diver team completed nine surveys at Asuncion covering 20.2 km (20.2 ha) of ocean floor (Table E.4.2.1.). Mean survey length was 2.3 km with a maximum length of 2.6 km and a minimum of 1.9 km. Mean survey depth was 13.5 m with a maximum depth of 14.3 m and a minimum of 12.1 m. Mean temperature on these surveys was 28.1°C with a maximum temperature of 28.4°C and a minimum of 27.8°C.

Table E.4.2.4--Survey statistics for towed-diver sampling during HA0903.

		Length (km)					Depth (m)				Temperature (ºC)			
Island/ Reef	**#**	**Sum**	**Mean**	**Max**	**Min**	**SD**	**Mean**	**Max**	**Min**	**SD**	**Mean**	**Max**	**Min**	**SD**
Asuncion	9	20.2	2.3	2.6	1.9	0.2	13.5	14.3	12.1	1.0	28.1	28.4	27.8	0.3

Eighty individual large-bodied reef fish (> 50 cm TL) of 16 different species and 10 different families were encountered at Asuncion (Table E.4.2.2.). Overall numeric density for this class of reef fishes was 0.40 #/100 m^2 (39.55 #/ha) with a biomass density of 2.92 kg/100 m^2 (0.29 t/ha). Numeric density was dominated by *Lutjanus bohar,* while biomass density was dominated by *Nebrius ferrugineus*..

Table E.4.2.5--Species numeric and biomass density for large-bodied reef fishes (> 50 cm TL) observed at Guam during HA0903 CRED towed-diver surveys.

Species	#	#/100 m2	#/ha	Biomass (kg)	kg/100 m2	t/ha
Naso hexacanthus	1	0.00	0.49	2.12	0.01	0.00
Naso tonganus	1	0.00	0.49	2.83	0.01	0.00
Balistoides viridescens	2	0.01	0.99	6.56	0.03	0.00
Caranx ignobilis	1	0.00	0.49	17.76	0.09	0.01
Caranx melampygus	1	0.00	0.49	2.12	0.01	0.00
Carcharhinus amblyrhynchos	6	0.03	2.97	95.45	0.47	0.05
Triaenodon obesus	1	0.00	0.49	18.50	0.09	0.01
Taeniura meyeni	5	0.02	2.47	62.50	0.31	0.03
Diodon hystrix	1	0.00	0.49	3.06	0.02	0.00
Nebrius ferrugineus	3	0.01	1.48	221.00	1.09	0.11
Aprion virescens	2	0.01	0.99	13.08	0.06	0.01
Lutjanus bohar	38	0.19	18.78	108.27	0.54	0.05
Macolor macularis	6	0.03	2.97	11.47	0.06	0.01
Macolor niger	10	0.05	4.94	18.72	0.09	0.01
Sphyraenidae sp	1	0.00	0.49	8.14	0.04	0.00
Arothron stellatus	1	0.00	0.49	3.17	0.02	0.00
Grand Total	80	0.40	39.55	591.58	2.92	0.29
# of Species	16					

The most prevalent families in terms of numeric density were the lutjanids (ND = 69%), carcharhinids (ND = 9%), and dasyatids (ND = 6%), while ginglymostomatids (BD = 37%), lutjanids (BD = 25%), and carcharhinids (BD = 19%) were most abundant in terms of biomass (Figs. E.4.2.1., E.4.2.2.). There was no clear pattern to the geographic distribution of large-bodied reef fish around the island (Fig. E.4.2.3.).

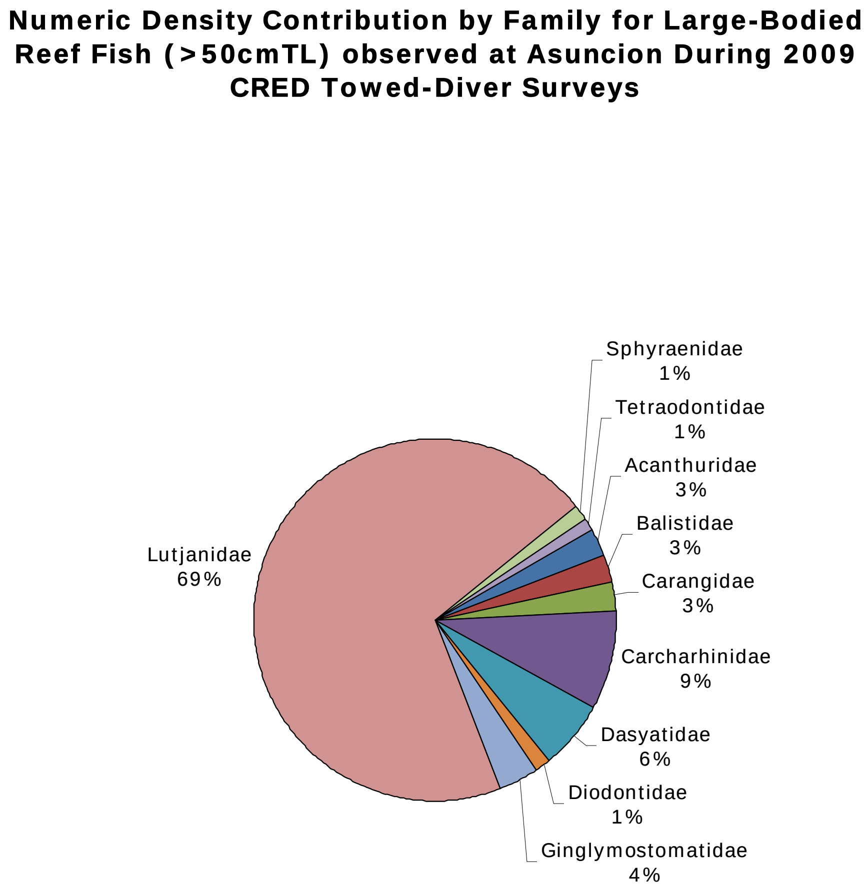


Figure E.4.2.1--Numeric density of fishes by family.

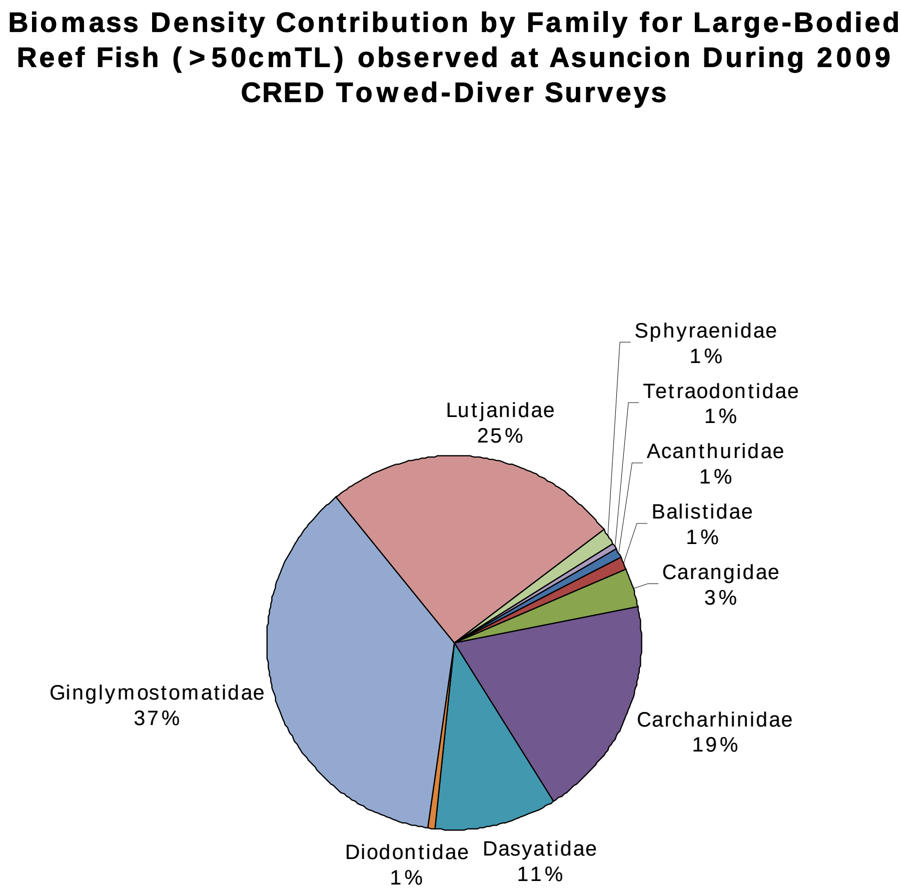


Figure E.4.2.2--Biomass density of fishes by family.

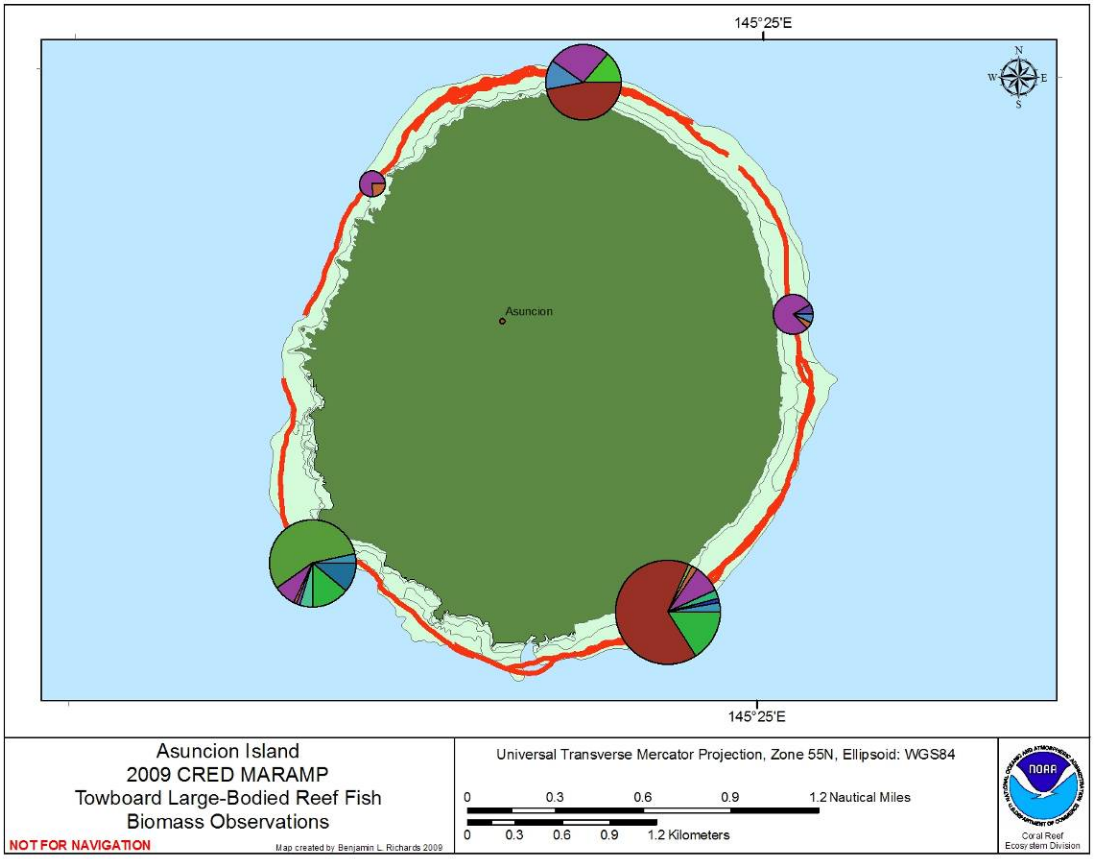


Figure E.4.2.3--Geographic distribution of fish biomass around Asuncion. Each species is represented by a legend color. Diameter of pie chart is proportional to total biomass of all species encountered on the underlying survey.

Appendix F: Supply Reef Results

F.1. Oceanography and Water Quality

A wave and tide recorder (WTR) was recovered during HA0903 at Supply Reef and a subsurface temperature recorder (STR) was recovered and replaced. The STR shows a clear annual fluctuation due to seasonal warming and cooling (Table F.1.1., Fig. F.1.1.). Also evident are large temperature fluctuations (4^{o}C) over very short time scales during the months between April and October. Warmest temperatures peaked at about 30^{o}C and occurred during the summer months of July to October. Winter temperatures reached lows of about 24.5^{o}C and occurred during November through June.

Table F.1.1--Supply reef moorings.

Action	Mooring type	Serial number	Lat		Long		Depth (m)
Deployment	STR	39331791150	20.14002697	N	145.0986096	E	27.4
Retrieval	STR	39368591645	20.14002697	N	145.0986096	E	27.4
Retrieval	WTR	26P368591032	20.14002697	N	145.0986096	E	27.4

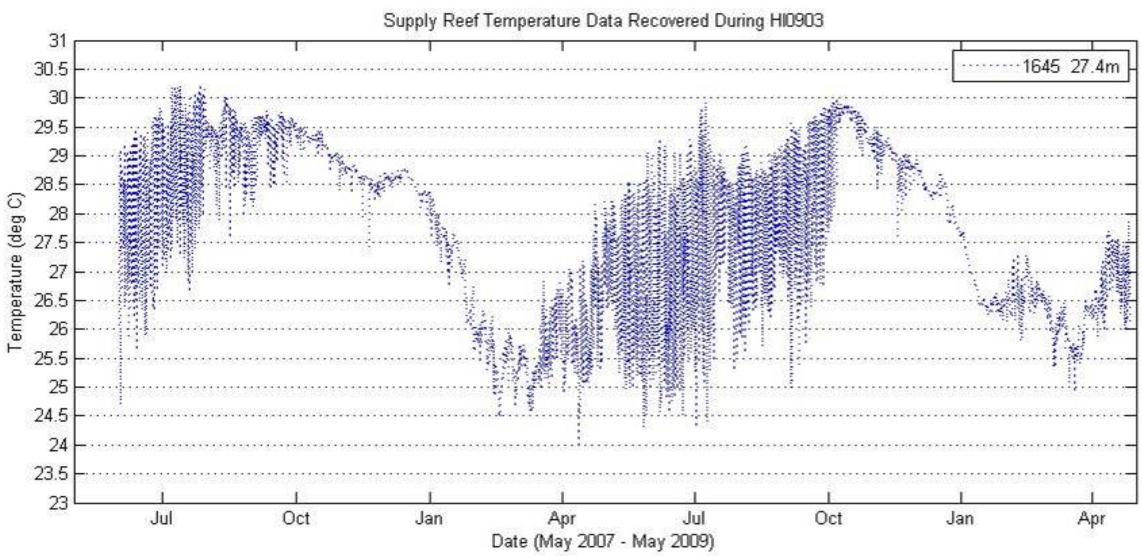


Figure F.1.1--Temperature time series from STR mooring at Supply Reef.

Appendix G: Farallon de Pajaros Results

G.1. Oceanography and Water Quality

Moorings recovered and replaced during HA0903 at Farallon de Pajaros included six subsurface temperature recorders (STRs) (Table G.1.1., Fig. G.1.1.). All the STRs show similar patterns and temperature ranges, with a clear annual fluctuation due to seasonal warming and cooling (Figs. G.1.2., G.1.3.). Additionally, the two STRs deployed at approximately 30 m deep showed very large (7°C) short-term fluctuations between the months of May and October that are at times larger than the seasonal variability with the coldest temperatures dropping below the coldest winter temperatures. Warmest surface temperatures peaked at approximately 31°C and occurred during the summer months of July to October. Winter surface temperatures reached lows of 25°C and occurred during November through June.

One rapid ecological assessment (REA) site (FDP-02) was visited to collect water samples for microbiological, nutrient and chlorophyll analyses, and REA site FDP-01 was sampled for just nutrients and chlorophyll. Samples were obtained from the surface and approximately 1 m above the reef. Microbial water samples were taken using diver-deployable Niskin bottles to collect 8 liters of seawater (four bottles; 2 liters per bottle) at each study site. Chlorophyll samples were filtered, and nutrient samples were frozen at -30°C for post-cruise analysis. Shallow-water conductivity temperature and depth (CTD) casts were also conducted at these sites. In addition, six CTD casts were taken every 1 km around the perimeter of Farallon de Pajaros at the 30 m depth contour.

Table G.1.1--FDP moorings.

Action	Mooring type	Serial number	Lat		Long		Depth (m)
Deployment	STR	39301590836	20.53722289	N	144.9002347	E	32.0
Retrieval	STR	39368591568	20.53789261	N	144.898612	E	11.6
Retrieval	STR	39368591641	20.54522728	N	144.8853457	E	31.7
Retrieval	STR	39368591642	20.54505285	N	144.8857954	E	12.5
Retrieval	STR	39368591647	20.53722289	N	144.9002347	E	32.0
Retrieval	STR	39368591650	20.53755817	N	144.8994852	E	17.4
Retrieval	STR	39368591654	20.54513684	N	144.8855898	E	18.9
Deployment	STR	39390381871	20.53755817	N	144.8994852	E	17.4
Deployment	STR	39390383004	20.53789261	N	144.898612	E	11.6
Deployment	STR	39432363073	20.54513684	N	144.8855898	E	18.9
Deployment	STR	39432363084	20.54505285	N	144.8857954	E	12.5
Deployment	STR	39432363244	20.54522728	N	144.8853457	E	31.7

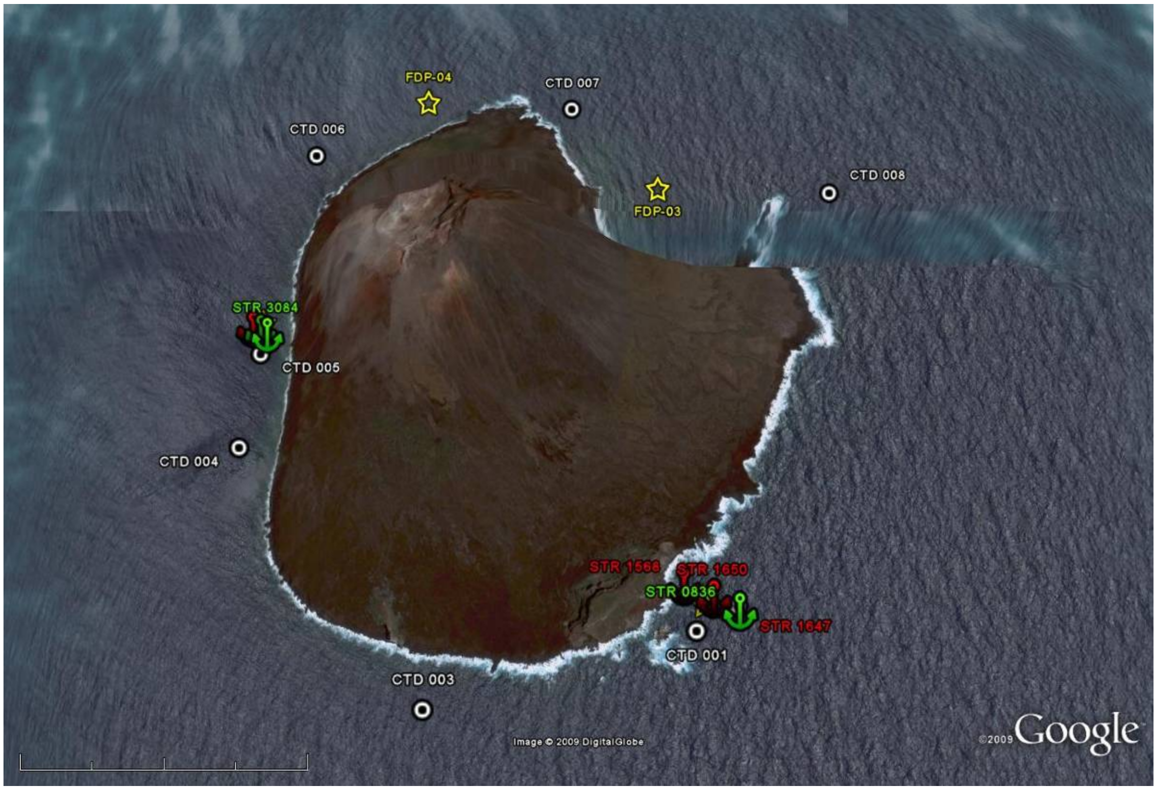


Figure G.1.1--Deployed and recovered instrument moorings and CTD and water sampling sites, Farallon de Pajaros, HA0903.

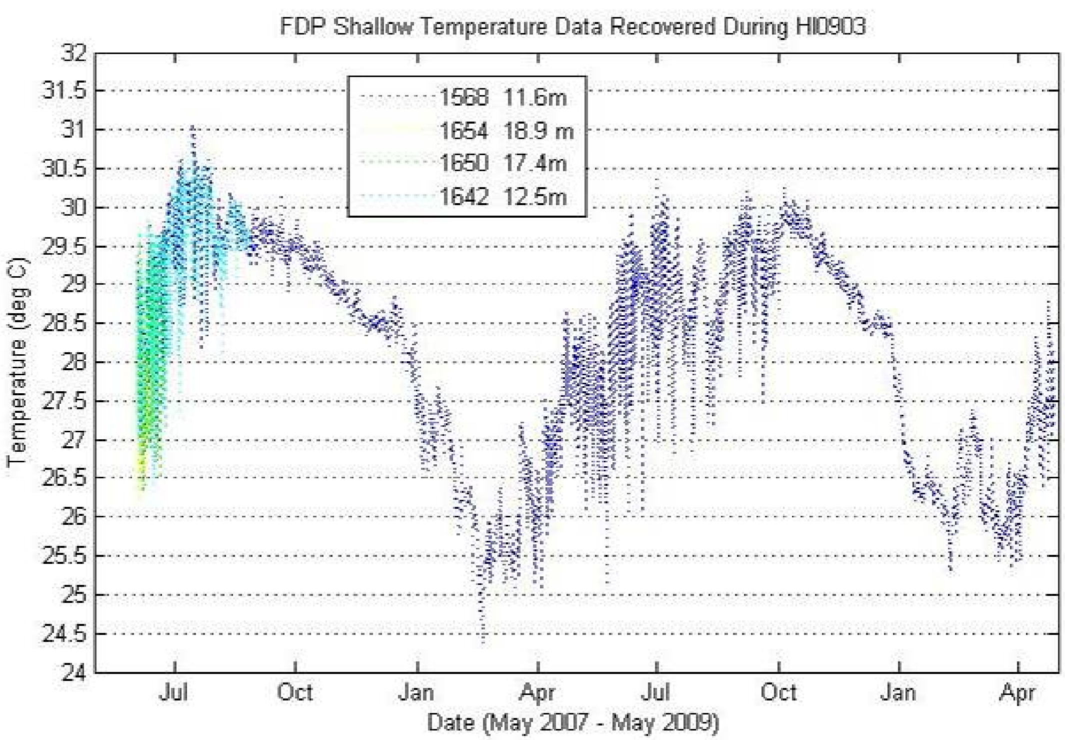


Figure G.1.2--Temperature time series from STR moorings at Farallon de Pajaros.

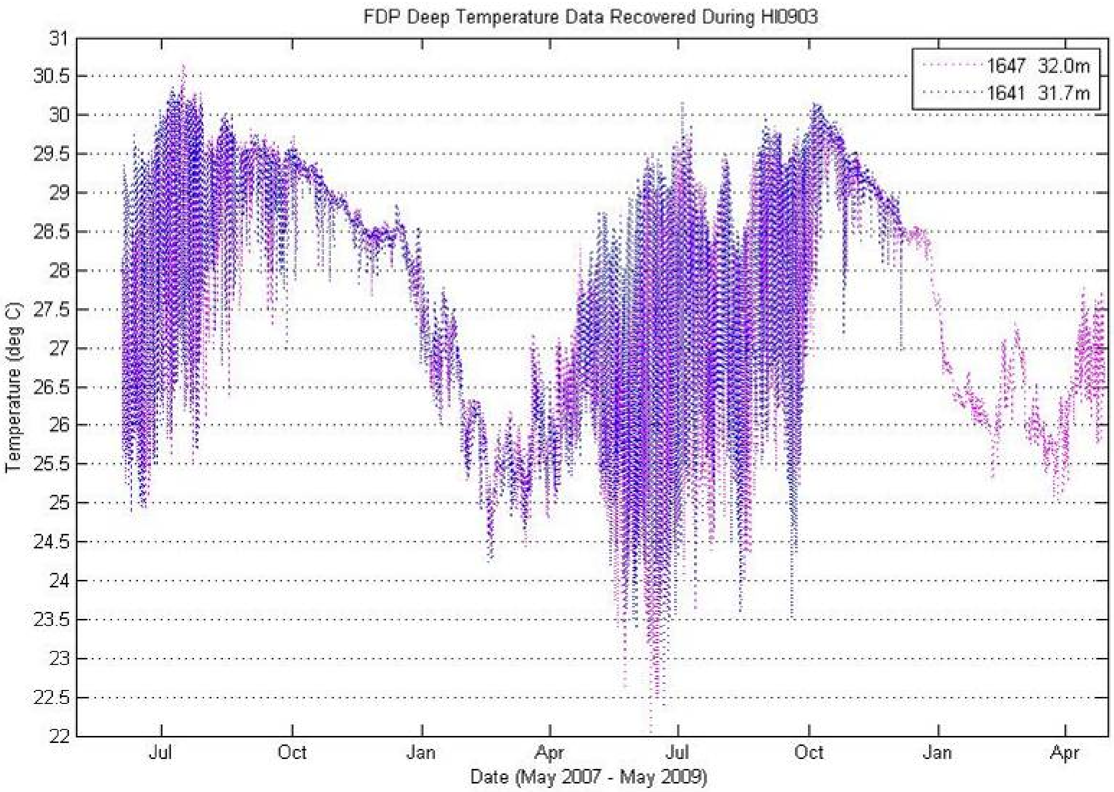


Figure G.1.3--Temperature time series from 30-m STR moorings at Farallon de Pajaros.

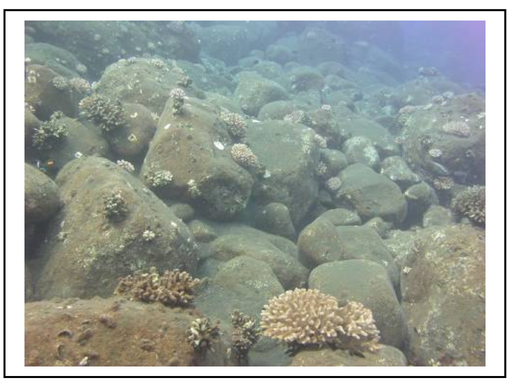
G.2. Rapid Ecological Assessment (REA) Site Descriptions

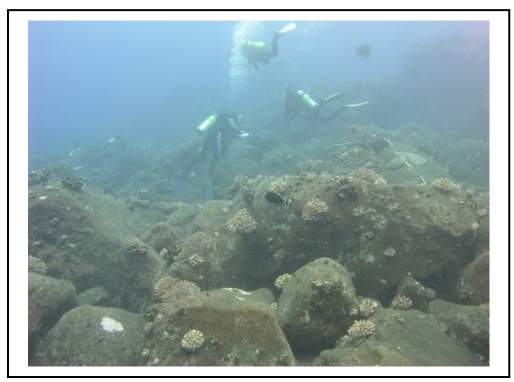
FDP-01
4/28/2009

E 144° 53.139
N 20° 32.762

Forereef
Mid

Depth: 14–15 m





Site description: Western region; moderate topographic complexity (boulders); moderate coral cover; high macroalgal (*Lobophora variegata*); and turf algal cover.

FDP-02
4/28/2009

E 144° 53.956
N 20° 32.280

Forereef
Mid

Depth: 12–16 m

Site description: Southeastern region; low/moderate topographic complexity (boulders); moderate coral and macroalgal cover; dominated by turf algae.

FDP-04
4/28/2009

E 144° 53.433
N 20° 33.192

Forereef
Mid

Depth: 14–16 m

Site description: Northwestern region; moderate topographic complexity (boulders); moderate coral cover; high macroalgal cover (*Lobophora variegata*).

FDP-50
4/28/2009

E 144° 54.306
N 20° 32.735

Forereef
Deep

Depth: 23 m

Site description: Deep western site; low topographic complexity (flat sand with a few boulders and hard pavement patches); moderate coral cover; low macroalgal cover; dominated by sand.

FDP-51
4/28/2009

E 144° 53.172
N 20° 32.800

Forereef
Shallow

Depth: 4–5 m

Site description: Shallow eastern site; moderate topographic complexity (boulders); low coral and macroalgal cover; dominated by turf algae.

FDP-52
4/28/2009

E 144° 53.761
N 20° 33.030

Forereef
Shallow

Depth: 5 m

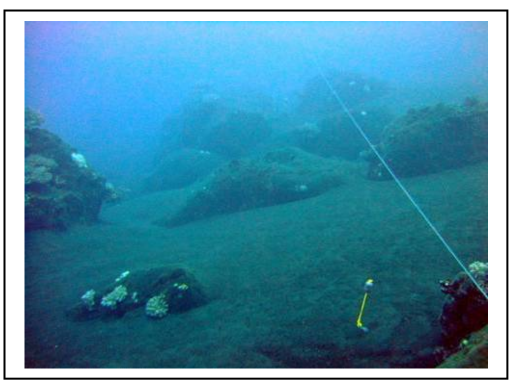
Site description: Shallow eastern site; moderate topographic complexity (boulders); low coral and macroalgal cover; dominated by turf.

FDP-53
4/28/2009

E 144° 53.134
N 20° 32.537

Forereef
Shallow

Depth: 5 m



Site description: Deep eastern site; low topographic complexity (boulders surrounded by sand on a steep slope); low coral and macroalgal cover; dominated by turf algae.

G.3. Benthic Environment

G.3.1. Algal Communities

During the Mariana Reef Assessment and Monitoring Program (MARAMP) 2009, three permanent, long-term REA monitoring sites were surveyed around Farallon de Pajaros for percent benthic cover based on 20-cm interval line point intercept (LPI) methodology. Benthic communities around Farallon de Pajaros were dominated by turf and macroalgae (Table

G.3.1.1). Turf algal percent cover exceeded that of other functional groups at sites FDP-01 with 39.6% cover and FDP-02 with 45.2% cover. Macroalgae were the dominant cover at site FDP-04 with 48.8% cover (Table G.3.1.1). A combined total of five species of macroalgae were observed (three chlorophytes, two ochrophytes) from the three sites surveyed (Tables G.3.1.2 and G.3.1.3). *Lobophora variegata* dominated the macroalgal community at all three sites with a percent cover range of 16.8% to 48.4% (Table G.3.1.3).

Table G.3.1.1--Percent cover of algal functional groups at long-term monitoring sites at Farallon de Pajaros.

Site	Macroalgae	Turf Algae	Coralline red algae (crustose + upright)	Cyanobacteria	Scleractinian Coral	Octocoral
FDP-01	32.4%	39.6%	3.2%	0.8%	13.2%	-
FDP-02	23.2%	45.2%	3.2%	0.4%	14.0%	-
FDP-04	48.8%	27.2%	0.8%	0.0%	20.8%	-

Table G.3.1.2--Additional species recorded at each site at Farallon de Pajaros during roving diver survey.

Site	**Chlorophyta**
FDP-02	*Dictyosphaeria cavernosa*
FDP-01 FDP-04	*Neomeris* sp.
	Ochrophyta
FDP-04	*Padina* sp.

Table G.3.1.3--Percent cover of macroalgal species at long-term monitoring sites at Farallon de Pajaros. Sum totals for each row equal the percent cover of macroalgae recorded in Table G.3.1.1.

Site	Dictyosphaeria cavernosa	Halimeda opuntia	Lobophora variegata
FDP-01	-	-	32.0%
FDP-02	-	0.8%	16.8%
FDP-04	0.4%	-	48.4%

G.3.2. Coral Communities

G.3.2.1. Percent Benthic Cover

During MARAMP 2009, percent benthic cover REA surveys conducted around Farallon de Pajaros at three permanent, long-term sites yielded an island-wide mean of 16% (Fig. G.3.2.1.1). The greatest coral cover recorded at site FDP-04 located on the northern region, where coral cover amounted to nearly 21%. The lowest percent coral cover was detected at west-facing site, FDP-01, where it amounted to 13% (Fig. G. 3.2.1.1).

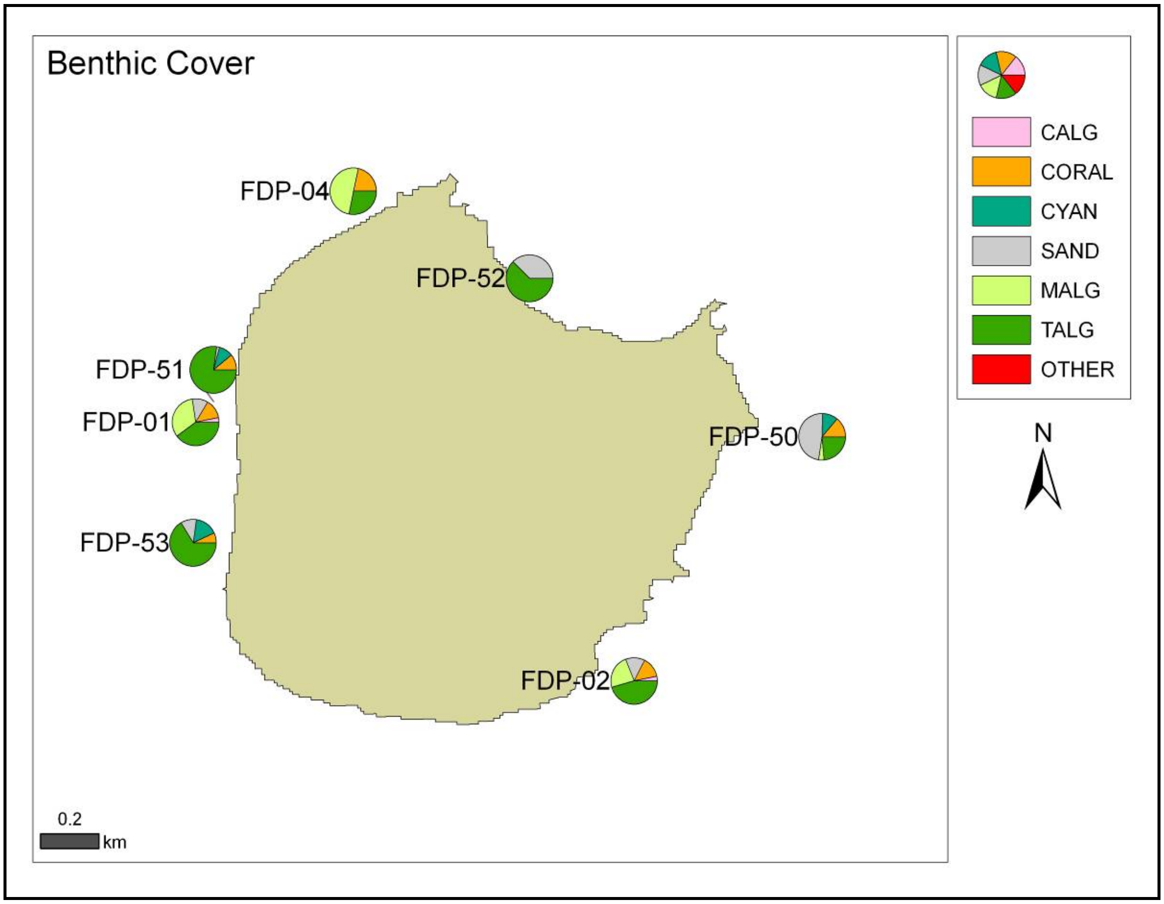


Figure G.3.2.1.1--Percent cover of benthic functional groups at the random stratified and permanent long-term REA monitoring sites around Farallon de Pajaros during MARAMP 2009. CALG = crustose coralline red algae, CYAN = cyanobacteria, MALG = macroalgae, TALG = turf algae.

Four additional stratified random REA sites were surveyed around Asuncion for percent benthic cover (based on 50-cm interval LPI surveys) and generic diversity data in 2009. Benthic communities at two sites greater than 20 m depth were dominated by scleractinian coral (44.8% ± 6.0), turf algal (19.9% ± 6.6) and macroalgal (14.7% ± 4.8) functional groups (Fig. G.3.2.1.2). Two shallow sites (< 10 m depth) were dominated by turf algal (78.1% ± 10.1) and scleractinian coral (14.0% ± 7.1) functional groups (Fig. G.3.2.1.2). Coral generic diversity was highest at site FDP-53 with 13 different genera observed (Table G.3.2.1.1). In contrast, site FDP-50 had the lowest generic diversity with eight different genera observed at both. An average of 10 coral genera were recorded at each site. Common genera observed at most sites included *Pocillopora, Favia, Porites, Pavona,* and *Cyphastrea.* Macroalgal generic diversity was highest at site FDP-50 with six genera observed (Table G.3.2.1.2). Sites FDP-51 and FDP-53 had the lowest generic diversity with five genera observed at both. An average of 5 macroalgal genera were recorded for each site. Common macroalgae observed at most sites included *Lobophora* and *Neomeris.*

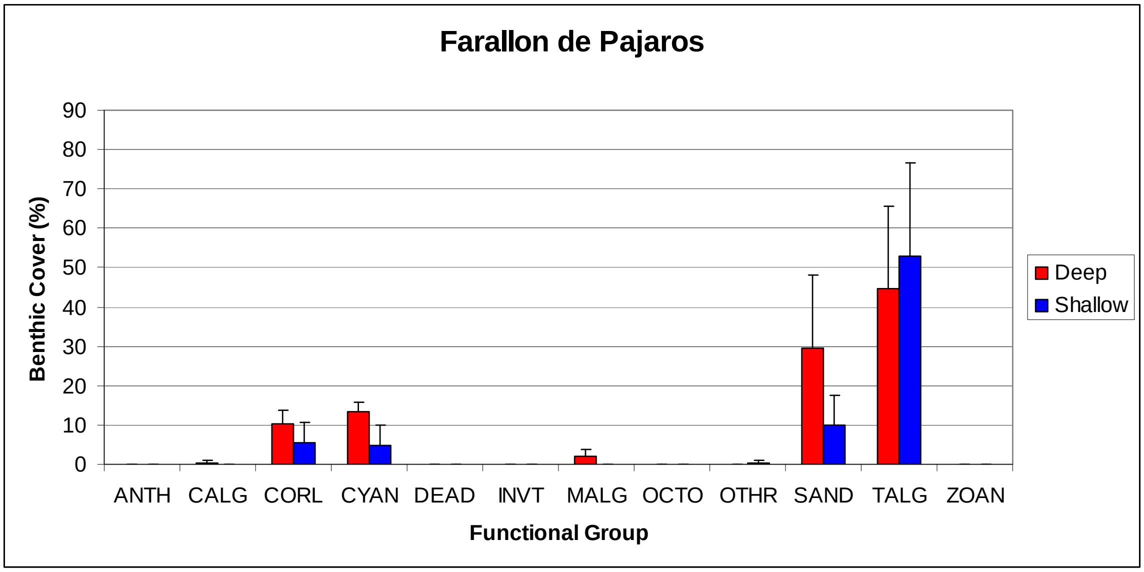


Figure G.3.2.1.2--Percent cover of functional groups at shallow and deep independent LPI monitoring sites established in 2009 around Farallon de Pajaros. ANTH = anthozoan, CALG = crustose coralline red algae, CORL = coral, CYAN = cyanobacteria, DEAD = dead coral, INVT = non-coral invertebrate, MALG = macroalgae, OCTO = octocoral, OTHER = other, TALG = turf algae, ZOAN = zoanthid.

Table G.3.2.1.1--Coral generic diversity of stratified random sites around Farallon de Pajaros.

	FDP-50	FDP-51	FDP-52**	FDP-53
Acanthastrea		X		X
Acropora		X		
Alveopora				
Astreopora	X	X		
Cladiella*				
Corallimorph*				
Coscinarea				
Cyphastrea	X	X		X
Diploastrea				
Distichopora*				X
Echinopora				
Euphyllia				
Favia	X	X		X

	FDP-50	FDP-51	FDP-52**	FDP-53
Favites				
Fungia				X
Galaxea				
Gardinoseris				
Goniastrea				
Goniopora				
Heliopora*				
Herpolitha				
Hydnophora				
Isopora				
Leptastrea		X		X
Leptoria				
Leptoseris				X
Lobophyllia				
Lobophytum*				
Merulina				
Millepora*				
Montastrea				
Montipora	X			X
Ouphyllia				
Pachyclavularia*				
Pachyseris				
Palythoa*		X		
Pavona	X	X		X
Platygyra				
Pleisiastrea				
Plerogyra				X
Pocillopora	X	X		X
Porites	X	X		X
Psammocora	X			
Sarcophyton*				
Scapophyllia				
Scolymia				
Seriatopora				
Sinularia*				
Stylaster*				
Stylocoeniella				
Stylophora				X
Turbinaria				
Wire Coral*				
Zoanthus*				
Total Genera per site	8	10	0	13

* non-scleractinian genera, **no benthic surveys conducted

Table G.3.2.1.2--Macroalgal generic diversity of stratified random sites around Farallon de Pajaros.

	FDP-50	FDP-51	FDP-52**	FDP-53
Amphiroa				
Asparagopsis				
Avrainvillea				
Boergesenia				
Boodlea				
Bryopsis				
Caulerpa	X			
Chlorodesmis				
Crustose Coralline	X	X		X
Cyanobacteria		X		X
Dichotomaria				
Dictyosphaeria	X	X		
Dictyota				
Galaxaura				
Gibsmithia				
Halimeda	X			X
Halymenia				
Lobophora	X	X		X
Microdictyon				
Neomeris	X	X		X
Non-geniculate calcified branched				
Padina				
Peyssonnelia				
Portieria				
Rhipilia				
Turbinaria				
Tydemania				
Udotea				
Valonia				
Unknown				
Total Genera per site	6	5	0	5

**no benthic surveys conducted

G.3.2.2 Coral Populations

During MARAMP 2009, belt transect surveys were conducted at three long-term REA sites around Farallon de Pajaros, covering a total reef area of 71.7 m^2 and totaling 1366 anthozoan and hydrozoan colonies enumerated. Taxonomic richness varied between sites with 19 anthozoan genera (18 scleractinian, 1 zoanthid) and 1 hydrozoan genus being represented within belt transects (Table G.3.2.2.1). *Pocillopora* and *Porites* were the most abundant scleractinian genera, contributing 58.4% and 20.8% of the total number of colonies enumerated island-wide. All other genera individually contributed less than 10% of the total number of colonies.

Table G.3.2.2.1--Relative abundance of anthozoan and hydrozoan genera enumerated within belt transects around Farallon de Pajaros during MARAMP 2009.

Island	Genus	Relative abundance
Farallon de Pajaros	*Pocillopora*	58.42
	Porites	20.79
	Favia	4.61
	Montastrea	4.39
	Pavona	3.29
	Astreopora	2.12
	Leptastrea	1.24
	Palythoa	1.02
	Goniastrea	0.81
	Psammocora	0.73
	Montipora	0.59
	Acropora	0.37
	Scolymia	0.29
	Acanthastrea	0.22
	Cyphastrea	0.22
	Hydnophora	0.22
	Millepora	0.22
	Stylophora	0.22
	Platygyra	0.15
	Leptoria	0.07

Relative abundance of colonies of the genus *Pocillopora* was particularly high at site FDP-02 on the southwest facing shores of the island, while relative abundance of *Porites* was greatest at site FDP-04 on the northwest facing shore (Fig. G.3.2.2.1).

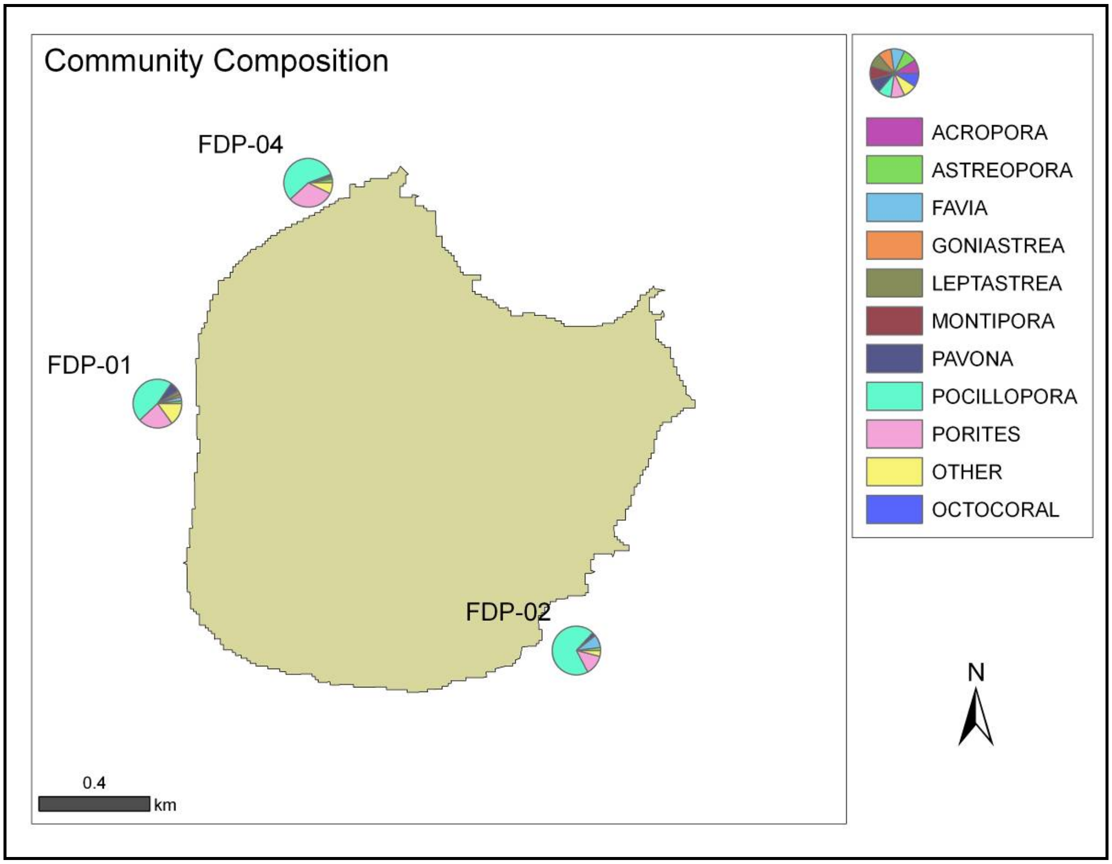


Figure G.3.2.2.1--Relative abundance of coral genera from REA surveys around Farallon de Pajaros during MARAMP 2009.

G.3.3. Coral Health and Disease

During MARAMP 2009, the occurrence of disease, predation, and other health impairments around Farallon de Pajaros was low, with a total of 12 cases enumerated. A summary of lesion occurrence and relative abundance is presented in Table G.3.3.1. The most numerically abundant type of lesion was bleaching, which was detected in *Pocillopora meandrina* (three cases), *Montastrea valenciennesi* (one case) and *Leptastrea* (one case). Predation was the next most abundant lesion, with all cases observed in *P. meandrina*. Two cases of fungal infection were detected on *Porites*. One case each of barnacle infestation and tissue discoloration were observed on *M. valenciennesi* and *P. meandrina*, respectively.

Table G.3.3.1--Number of cases of scleractinian and coralline algal diseases and predation enumerated during REA surveys around Farallon de Pajaros, MARAMP 2009. BIN: barnacle infestation; BLE: bleaching; DIS: discolorations other than bleaching; FUG: fungal infections; PRE: *Acanthaster*/*Drupella* predation scars.

Island	DZCode	FDP-01	FDP-02	FDP-04	Grand Total
Farallon de Pajaros	BIN			1	1
	BLE	2	1	2	5
	DIS			1	1
	FUG			2	2
	PRE			3	3
Grand Total		**2**	**1**	**8**	**12**

G.3.4. Macroinvertebrate Surveys (non-coral)

A total of 133 individuals of benthic invertebrate target species or taxa groups were enumerated from six belt transects at three sites. Due to an illness, the REA invertebrate diver was unable to survey these sites. However, a replacement quantified urchins and sea stars along the transects. The island density for *L. multifora* was 2.45 (SE 0.33) organisms 50 m^{-2}. Densities were highest at FDP-04 (3,12 organisms 50 m^{-2}). The island density for *E. aciculatus* was 1.09 (SE 1.09) organisms 50 m^{-2}. *E. aciculatus* was seen only at site FDP-02 with a density of 3.28 organisms 50 m^{-2}.

G.3.4.1. Urchin Measurements

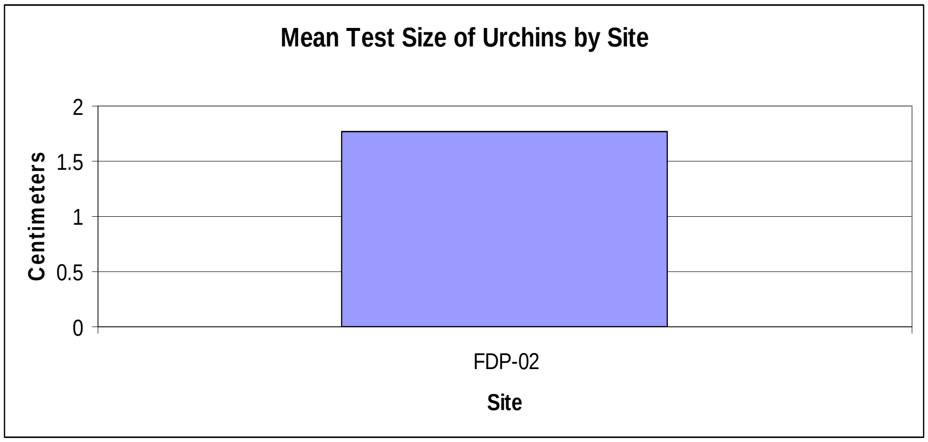


Figure G.3.4.1-Average test diameter of urchins encountered at each site. Only sites where ≥ 5 measurements were recorded for a species are represented. *Echinostrephus aciculatus* is the only represented echinoid.

G.3.5. Benthic Towed-diver Surveys

A total of three benthic towed-diver surveys were completed at Farallon de Pajaros in 2009 (Fig. G.3.5.1.). One benthic calibration survey and one fish calibration survey were also completed. Terrain was composed primarily of medium-complexity terrain consisting of rock boulders interspersed with sand patches, and some small stretches of continuous reef broken up by pinnacle formations.

Benthic category	Mean ± SE
Hard coral	10.5 ± 1.1
Soft coral	0.02 ± 0.01
Sand	8.9 ± 1.9
Rubble	0.5 ± 0.1
Macroalgae	0.04 ± 0.02
Coralline algae	2.8 ± 0.5
COTs	0
Free urchins	1
Boring urchins	2716
Sea cucumbers	0
Giant clams	26
* Sum of observed individuals	

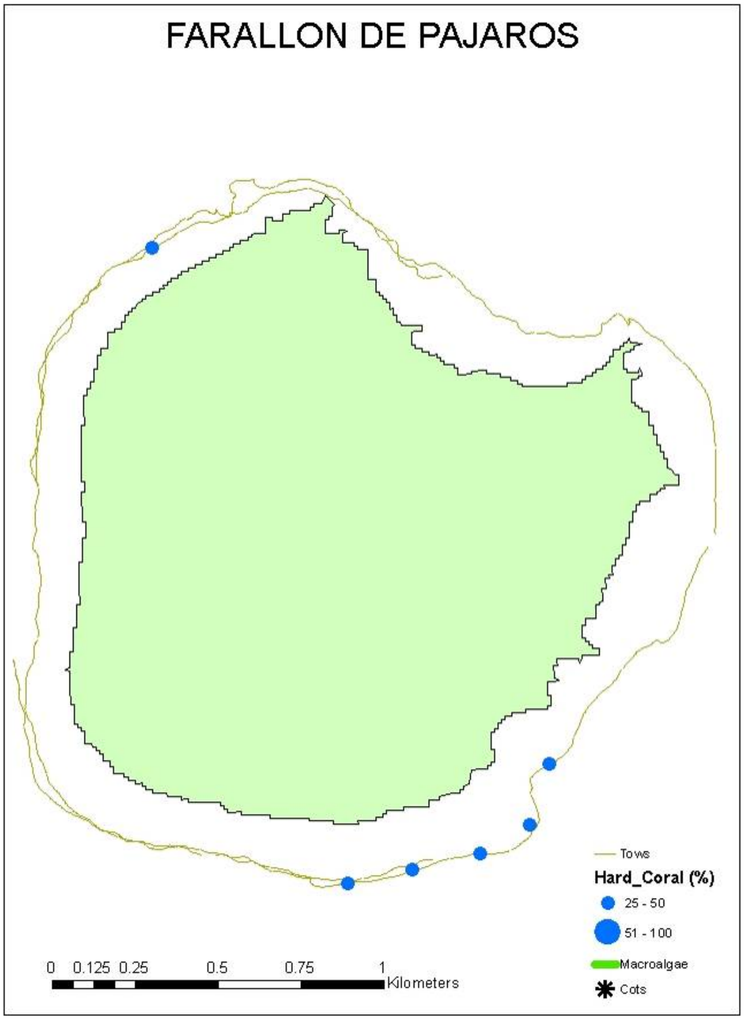


Figure G.3.5.1--Hard coral cover, elevated macroalgal cover (> 25%), and crown-of-thorn (COT) abundances during tow segments at Asuncion 2009.

Hard coral averaged 10.5 ± 1.1%, and was characterized by species of *Pocillopora* as the most gregarious genera encountered. Coral cover reached as high as 10.1–20% in several sections along the southeast corner of the island. Ridges that were encountered during the tow had elevated coral cover and diversity.

Octocorals averaged 0.02 ± 0.01% and was generally low island-wide. Similarly, macroalgae were recorded at 0.04 ± 0.02%, and were generally not a major visible/gregarious part of the benthos.

Finally, macroinvertebrate counts were also low, with no COTS, one free urchin, and no sea cucumbers being reported. A total of 2716 boring urchins and 26 giant clams were reported, with the vast majority located along the southeast corner of the island.

G.4. Fish Surveys

G.4.1. REA Fish Surveys

Stationary point count data (nSPC)

During the survey period, nSPC surveys were conducted at seven sites around Farallon de Pajaros. Snappers were the largest contributor to total biomass with 1.3 kg 100 m^{-2}. Surgeonfish were the second largest contributor to total biomass with 1.1 kg 100 m^{-2}, followed by jacks at 0.38 kg 100 m^{-2} (Fig. G.4.1.1.).

Overall observations

A total of 146 fish species were observed by all divers during the survey period. The average total fish biomass around Farallon de Pajaros during the survey period was 6.9 kg 100 m^{-2} for the nSPC surveys (Table G.4.1.1.).

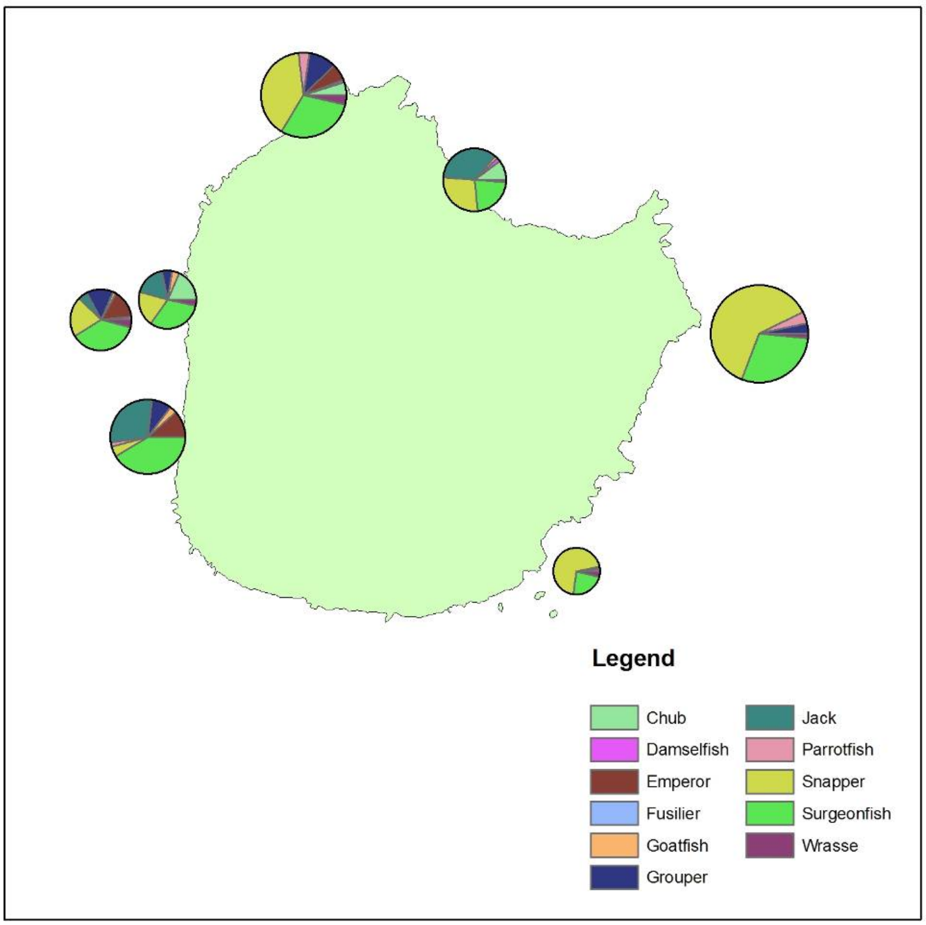


Figure G.4.1.1--Site location and distribution of total fish biomass by family. The sizes of the pie charts are proportional to fish biomass.

G.4.2. Towed-diver Surveys

During HA0903, the CRED towed-diver team completed five surveys at Farallon de Pajaros covering 10.4 km (10.4 ha) of ocean floor (Table G.4.2.1.). Mean survey length was 2.1 km with a maximum length of 2.5 km and a minimum of 1.6 km. Mean survey depth was 13.3 m with a maximum depth of 15.1 m and a minimum of 12.3 m. Mean temperature on these surveys was 27.5°C with a maximum temperature of 27.7°C and a minimum of 27.2°C.

Table G.4.2.1.--Survey statistics for towed-diver sampling during HA0903.

		Length (km)					Depth (m)				Temperature (ºC)			
Island/Reef	**#**	**Sum**	**Mean**	**Max**	**Min**	**SD**	**Mean**	**Max**	**Min**	**SD**	**Mean**	**Max**	**Min**	**SD**
Farallon de Pajaros	5	10.4	2.1	2.5	1.6	0.3	13.3	15.1	12.3	1.2	27.5	27.7	27.2	0.2

Two-hundred individual large-bodied reef fish (> 50 cm TL) of 14 different species and seven different families were encountered at Farallon de Pajaros (Table G.4.2.2.). Overall numeric density for this class of reef fishes was 1.92 #/100 m^2 (191.75 #/ha) with a biomass density of 12.78 kg/100 m^2 (1.28 t/ha). Numeric density was dominated by *Caranx sexfasciatus,* while biomass density was dominated by *Nebrius ferrugineus.*

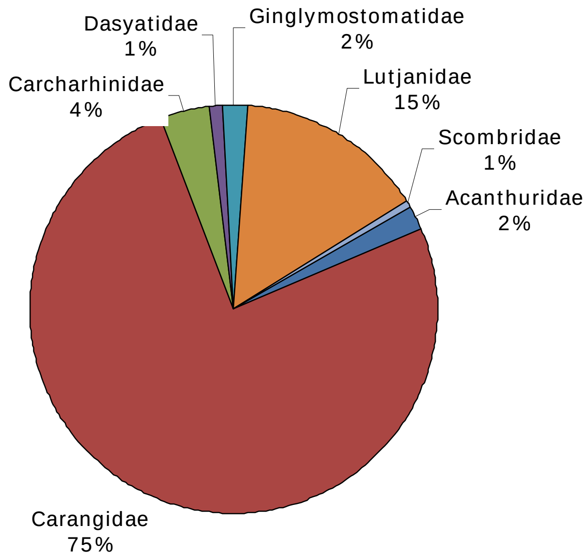
Table G.4.2.2--Species numeric and biomass density for large-bodied reef fishes (> 50 cm TL) observed at Guam during HA0903 CRED towed-diver surveys.

Species	#	#/100 m^2	#/ha	Biomass (kg)	kg/100 m^2	t/ha
Naso brevirostris	1	0.01	0.96	10.26	0.10	0.01
Naso hexacanthus	2	0.02	1.92	4.24	0.04	0.00
Naso unicornis	1	0.01	0.96	7.13	0.07	0.01
Caranx sexfasciatus	150	1.44	143.82	351.46	3.37	0.34
Scomberoides lysan	1	0.01	0.96	2.68	0.03	0.00
Carcharhinus amblyrhynchos	6	0.06	5.75	104.23	1.00	0.10
Triaenodon obesus	2	0.02	1.92	33.16	0.32	0.03
Taeniura meyeni	2	0.02	1.92	47.21	0.45	0.05
Nebrius ferrugineus	4	0.04	3.84	589.29	5.65	0.56
Aprion virescens	2	0.02	1.92	8.78	0.08	0.01
Lutjanus bohar	24	0.23	23.01	81.33	0.78	0.08
Macolor macularis	3	0.03	2.88	5.44	0.05	0.01
Macolor niger	1	0.01	0.96	1.81	0.02	0.00
Gymnosarda unicolor	1	0.01	0.96	85.82	0.82	0.08
Grand Total	200	1.92	191.75	1332.86	12.78	1.28
# of Species	14					

The most prevalent families in terms of numeric density were carangids (ND = 75%), lutjanids (ND = 15%), and carcharhinids (ND = 4%); whereas, ginglymostomatids (BD = 44%), carangids (BD = 27%), and carcharhinids (BD = 10%) were the most prevalent in terms of biomass density (Fig. G.4.2.1., G.4.2.2.).

Being that Farallon de Pajaros is such a small island, although there appears to be a concentration of biomass along the western portion of the island, patterns of geographic distribution are not strong (Fig. G.4.2.3.).

Numeric Density Contribution by Family for Large-Bodied Reef Fish (>50cmTL) observed at Faralon de Pajaros During 2009 CRED Towed-Diver Surveys



G.4.2.1--Numeric density of fishes by family.

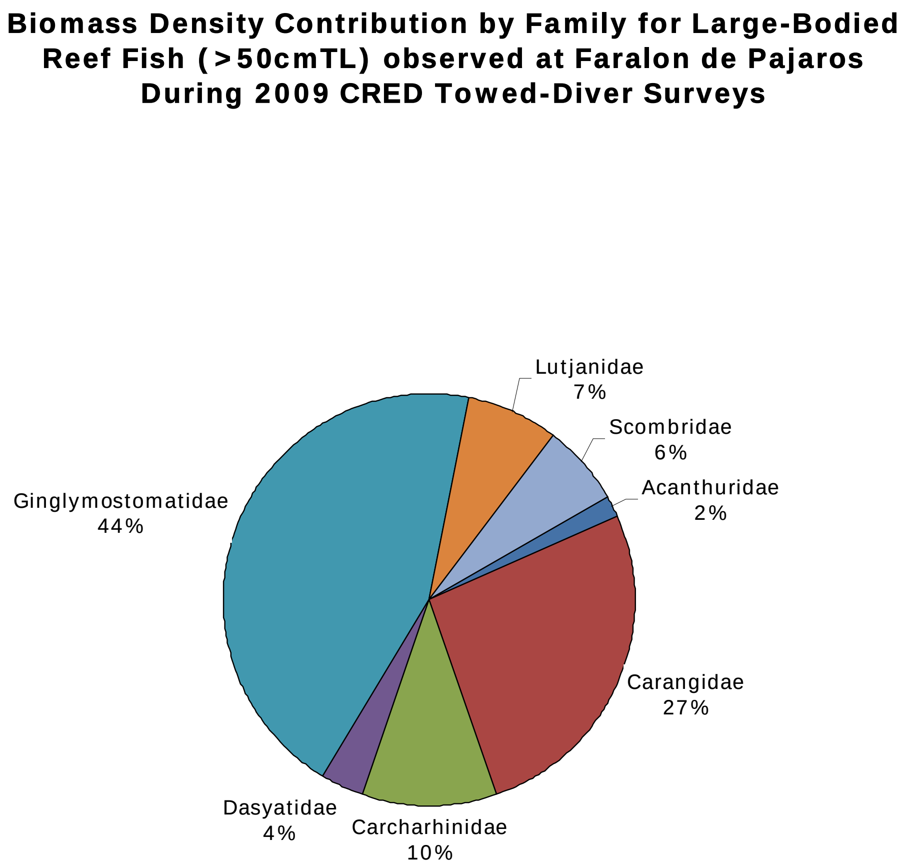


Figure G.4.2.2--Biomass density of fishes by family.

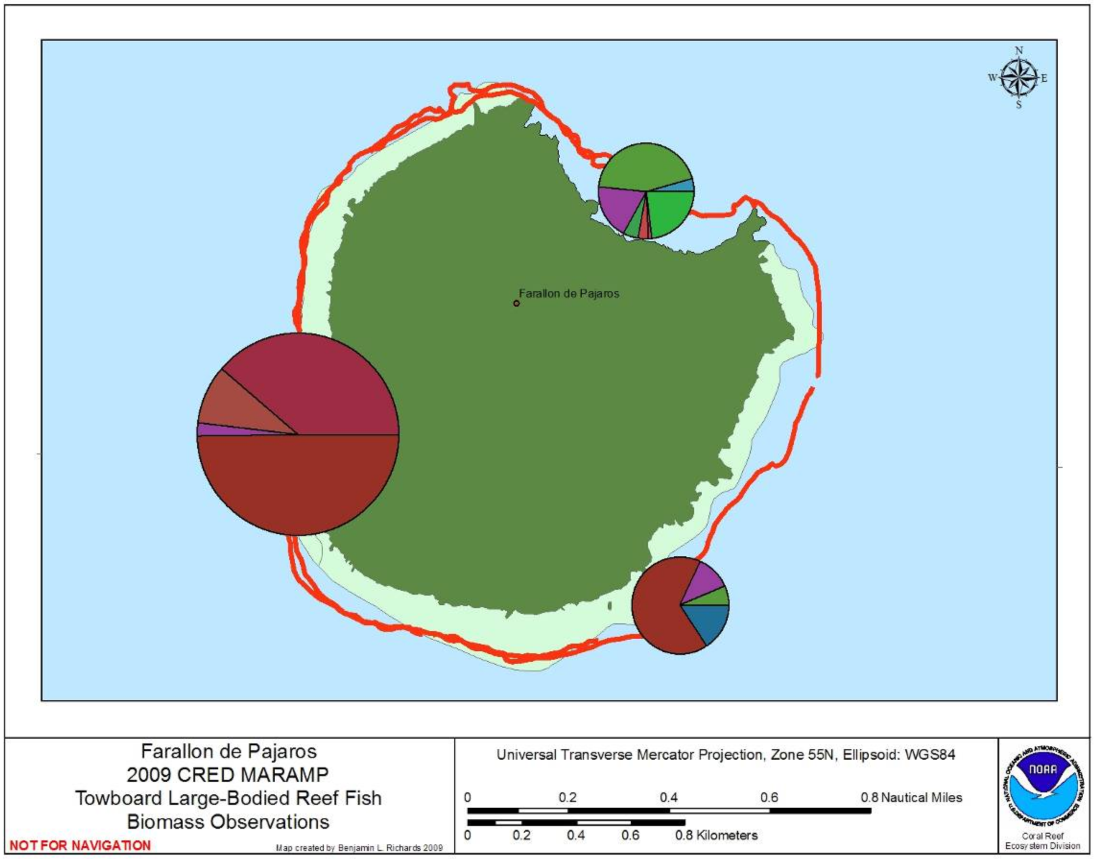


Figure G.4.2.3--Geographic distribution of fish biomass around Farallon de Pajaros. Each species is represented by a legend color. Diameter of pie chart is proportional to total biomass of all species encountered on the underlying survey.

Appendix H: Maug Results

H.1. Oceanography and Water Quality

Five subsurface temperature recorder (STRs) were recovered and replaced during HA0903 at Maug. Additionally, a sea surface temperature (SST) buoy was redeployed after the old one had broken free, and two new ecological acoustic recorders (EARs) with STRs attached were also deployed (Table H.1.1., Fig. H.1.1.). All the STRs show similar patterns and temperature ranges, with a clear annual fluctuation due to seasonal warming and cooling (Figs. H.1.2., H.1.3). Also evident are large short-term temperature changes at the approximately 30 m depth STR. Warmest surface temperatures peaked at 30.5°C and occurred during the summer months of July to October. Winter temperatures reached lows of about 25°C and occurred during November through June.

Two rapid ecological assessment (REA) sites (MAU-02, MAU-05) were visited to collect water samples for microbiological, nutrient and chlorophyll analyses, and five of the REA sites (MAU-01, MAU-06, MAU-10, MAU-11 and MAU-12) along with the vent site on the west side of the east island were sampled for just nutrients and chlorophyll. Samples were obtained from the surface and approximately 1 m above the reef. Microbial water samples were taken using diver-deployable Niskin bottles to collect 8 liters of seawater (four bottles; 2 liters per bottle) at each study site. Chlorophyll samples were filtered, and nutrient samples were frozen at -30°C for post-cruise analysis. Shallow-water conductivity temperature and depth (CTD) casts were also conducted at these sites. In addition, 11 CTD casts were taken every 1 km around the perimeter of Maug, and 3 CTDs were conducted inside the caldera at the 30 m depth contour.

Table H.1.1--Maug moorings.

Action	Mooring type	Serial number	Lat		Long		Depth (m)
Deployment	EAR	9300464B015	20.02331726	N	145.207497	E	17.1
Deployment	EAR	9300506B073	20.01395317	N	145.2272835	E	13.4
Deployment	SST	EYVYD	20.02909239	N	145.2319558	E	0.3
Deployment	STR	39301590839	20.02334761	N	145.2297646	E	8.8
Retrieval	STR	39301590841	20.01794807	N	145.2071486	E	32.3
Deployment	STR	39331791149	20.01772041	N	145.2077188	E	2.4
Retrieval	STR	39368591563	20.02334761	N	145.2297646	E	8.8
Retrieval	STR	39368591567	20.02909239	N	145.2319558	E	12.5
Deployment	STR	39368591669	20.01766727	N	145.2072534	E	10.4
Retrieval	STR	39432363062	20.01766727	N	145.2072534	E	10.4
Deployment	STR	39432363068	20.01395317	N	145.2272835	E	13.4
Retrieval	STR	39432363080	20.01772041	N	145.2077188	E	2.4
Deployment	STR	39432363246	20.02331726	N	145.207497	E	17.1
Deployment	STR	39443093476	20.01794807	N	145.2071486	E	31.4
Deployment	STR	39510234397	20.02909239	N	145.2319558	E	12.5

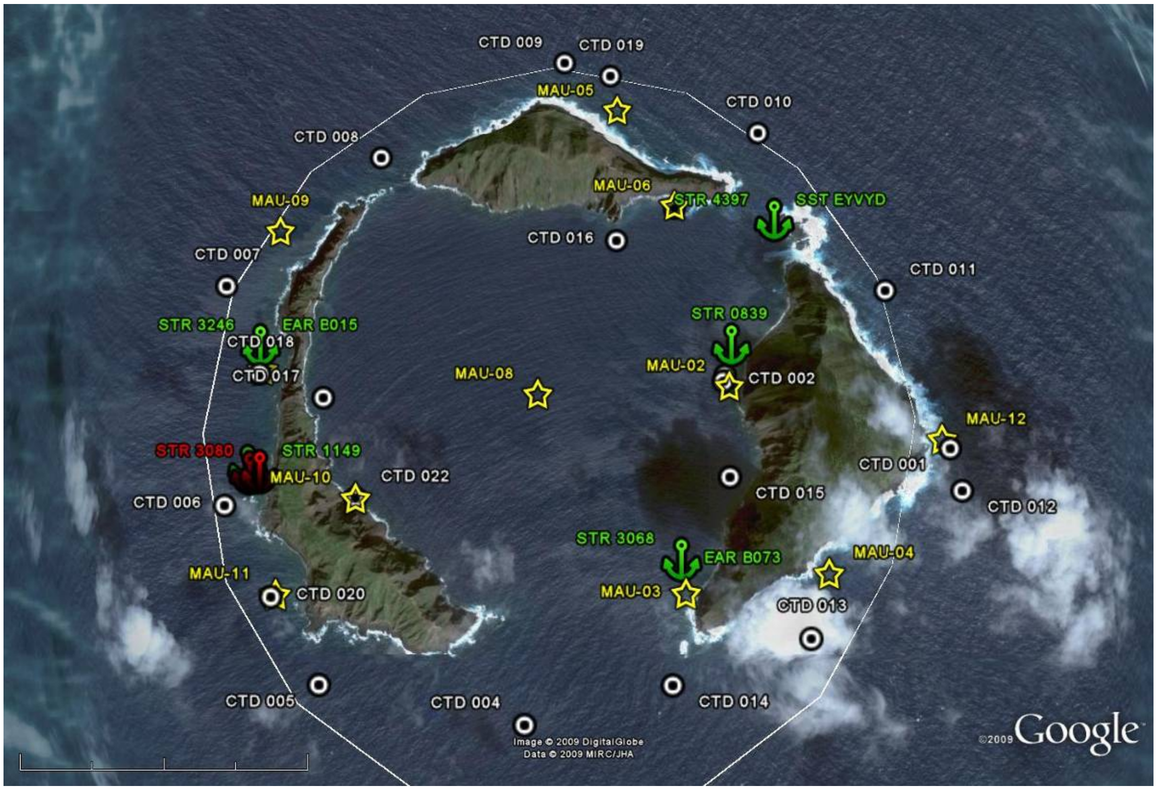


Figure H.1.1--Deployed and recovered instrument moorings and CTD and water sampling sites, Maug, HA0903.

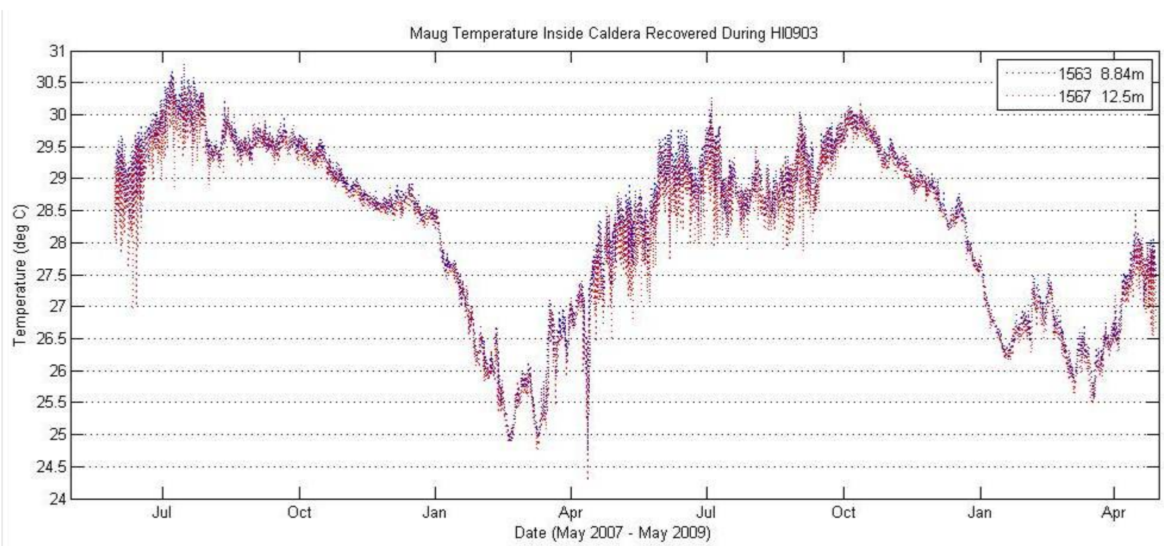


Figure H.1.2--Temperature time series from STR moorings inside the caldera at Maug.

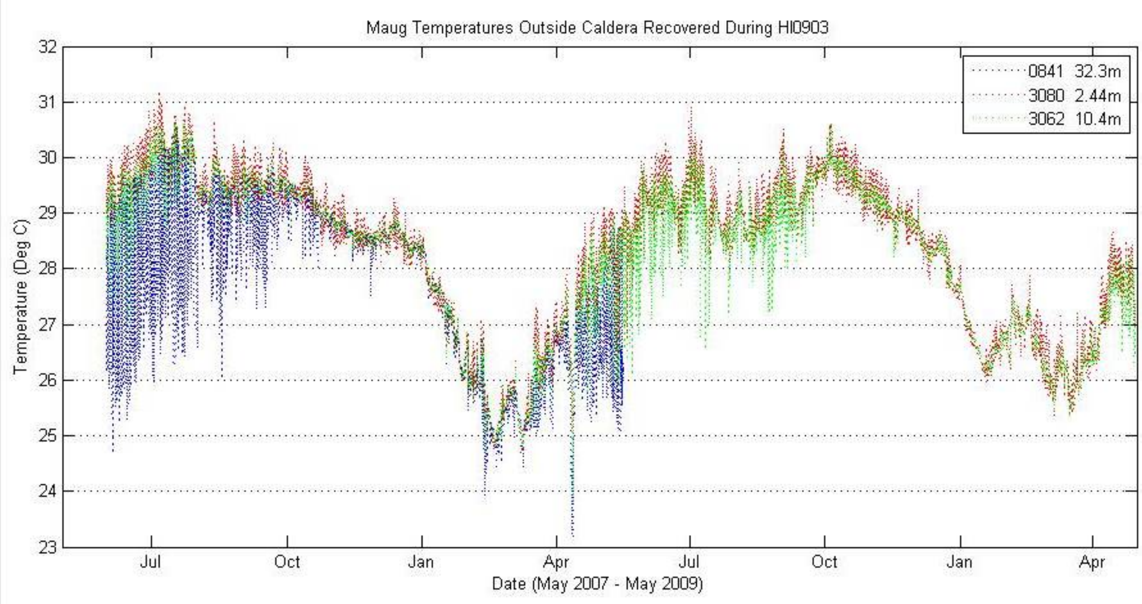


Figure H.1.3--Temperature time series from STR moorings outside the caldera at Maug.

H.2. Rapid Ecological Assessment (REA) Site Descriptions

MAU-01
4/30/2009

E 145° 12.462
N 20° 01.397

Forereef
Mid

Depth: 14–18 m

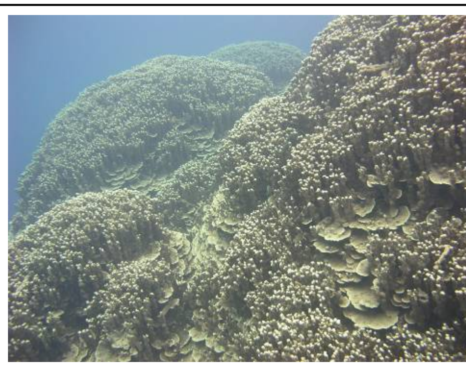
Site description: Western forereef; high topographic complexity; spur and groove; high coral cover; low macroalgal cover.

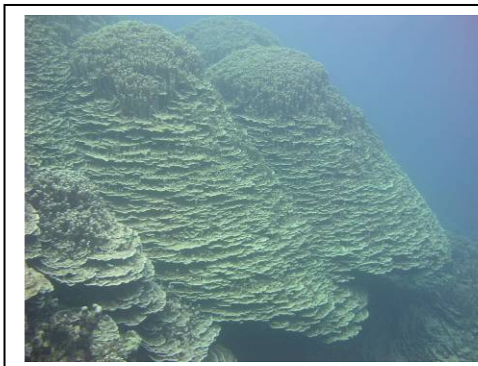
MAU-02
4/29/2009

E 145° 13.785
N 20° 01.354

Forereef
Mid

Depth: 14 m





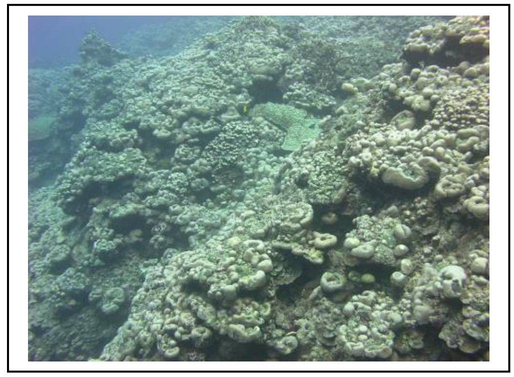
Site description: Inner reef on east island; high topographic complexity; steep slope; high coral cover (dominated by *Porites rus*); low macroalgal cover; turf algae present on dead coral.

MAU-03
5/1/2009

E 145° 13.655
N 20° 00.813

Forereef
Mid

Depth: 12–13 m



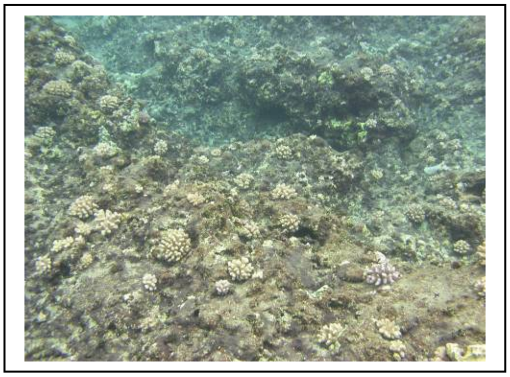
Site description: Inner reef slope on east island; high topographic complexity; dominated by high coral cover (*Goniastrea* sp.); low macroalgal cover.

MAU-04
4/29/2009

E 145° 14.051
N 20° 00.864

Forereef
Mid

Depth: 11–14 m



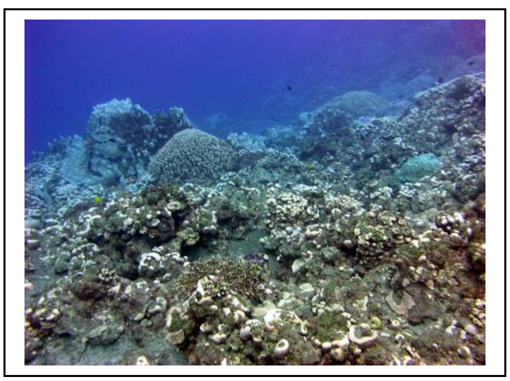
Site description: Outside reef on east island; moderate/high topographic complexity; moderate coral cover; high macroalgal cover.

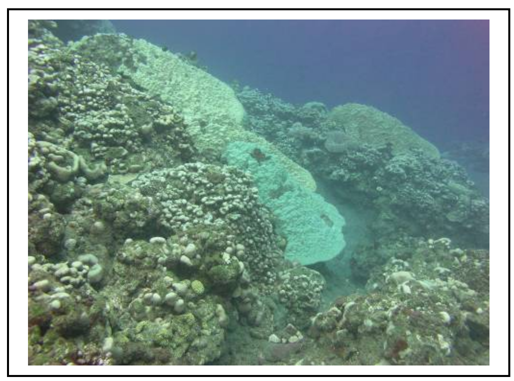
MAU-06
5/1/2009

E 145° 13.636
N 20° 01.851

Forereef
Mid

Depth: 10–18 m





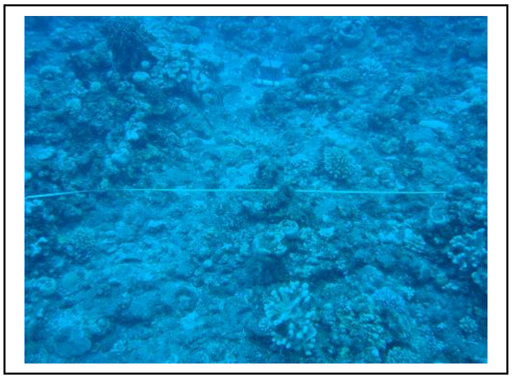
Site description: Inner reef on north island; high topographic complexity (reef formations interspersed with sand channels); high coral cover; low macroalgal cover; dominated by turf algae.

MAU-09
5/1/2009

E 145° 12.497
N 20° 01.778

Forereef
Mid

Depth: 14–17 m

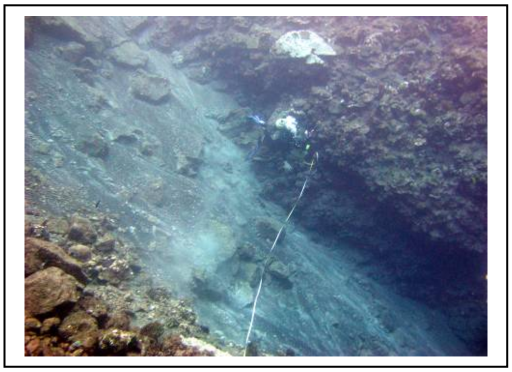
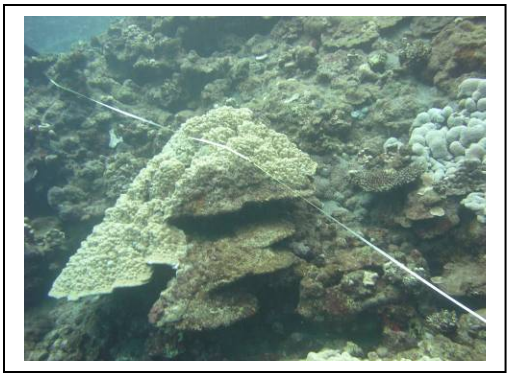
Site description: Outer reef on northern tip of west island; moderate topographic complexity; high coral and macroalgal cover.

MAU-10
4/30/2009

E 145° 12.743
N 20° 01.056

Forereef
Mid

Depth: 12–13 m

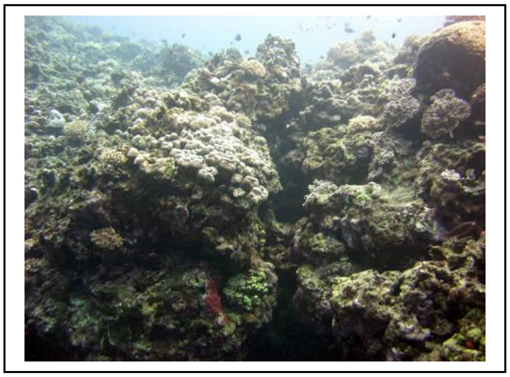
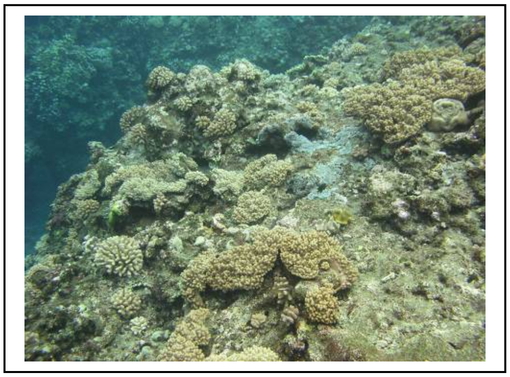
Site description: Inner reef slope on west island; high topographic complexity; steep slope; high coral cover; low macroalgal cover; dominated by turf algae.

MAU-11
4/30/2009

E 145° 12.524
N 20° 00.809

Forereef
Mid

Depth: 9–13 m

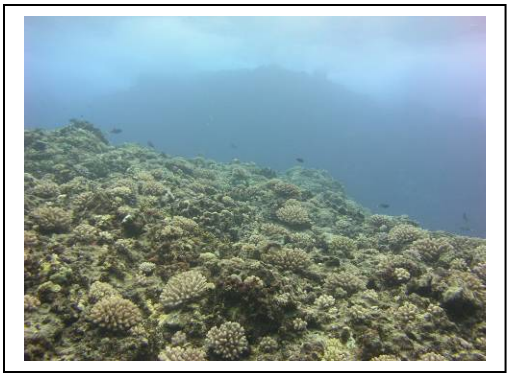
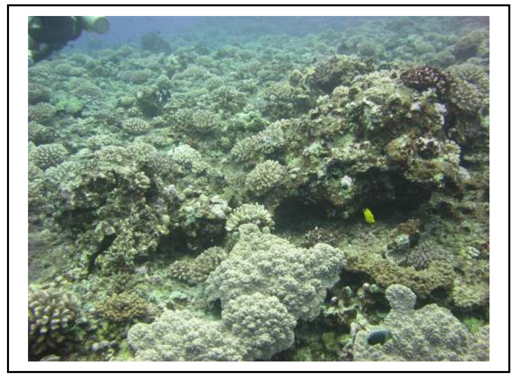
Site description: Outer reef slope in southern region of west island; high topographic complexity; spur & groove; high coral cover; low macroalgal cover.

MAU-12
4/29/2009

E 145° 14.380
N 20° 01.213

Forereef
Mid

Depth: 13 m

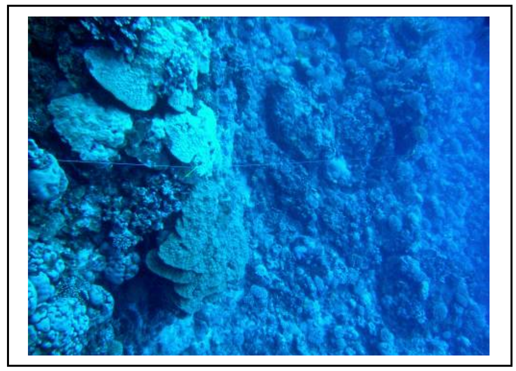
Site description: Outer reef slope on east island; moderate topographic complexity; moderate coral cover; high macroalgal cover.

MAU-50
4/29/2009

E 145° 14.271
N 20° 01.477

Forereef
Deep

Depth: 19 m

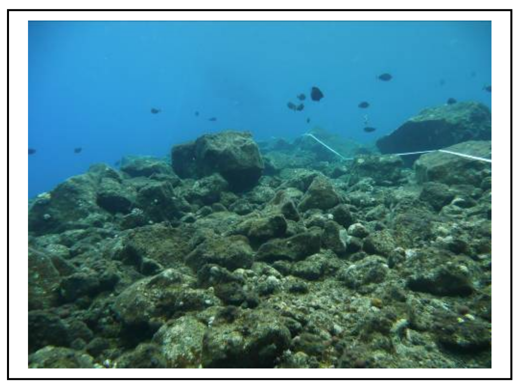
Site description: Outer reef slope in northern region of east island; moderate topographic complexity; high coral cover; moderate macroalgal cover.

MAU-51
4/29/2009

E 145° 13.790
N 20° 01.062

Forereef
Mid

Depth: 9 m

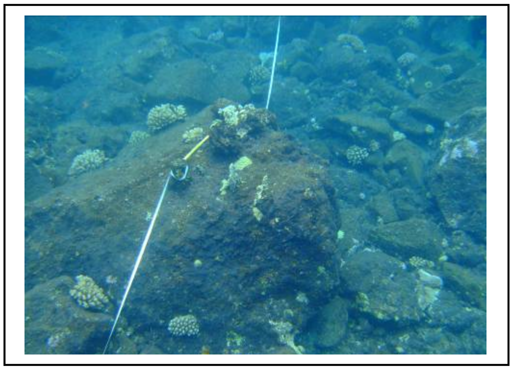
Site description: Inner site in southwestern region on east island; low/moderate topographic complexity (boulders); moderate coral cover; low macroalgal cover; dominated by turf algae.

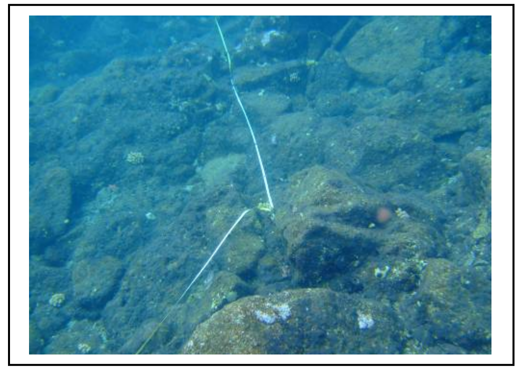
MAU-52
4/29/2009

E 145° 13.757
N 20° 01.377

Forereef
Shallow

Depth: 5 m





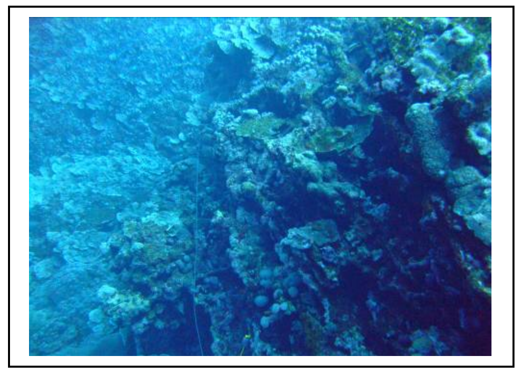
Site description: Inner site in northwestern region on east island;low topographic complexity (rocks and boulders); low coral and macroalgal cover.

MAU-53
4/29/2009

E 145° 13.765
N 20° 01.381

Forereef
Deep

Depth: 21 m



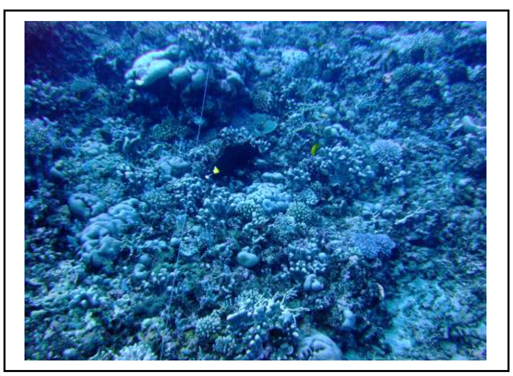
Site description: Inner reef slope in northwestern region of east island; high topographic complexity; very high coral cover; low macroalgal cover.

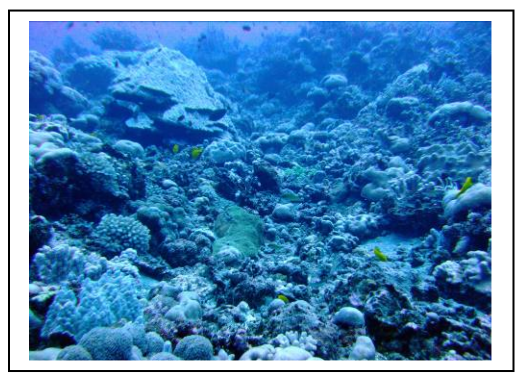
MAU-54
4/30/2009

E 145° 12.498
N 20° 01.802

Forereef
Deep

Depth: 22 m





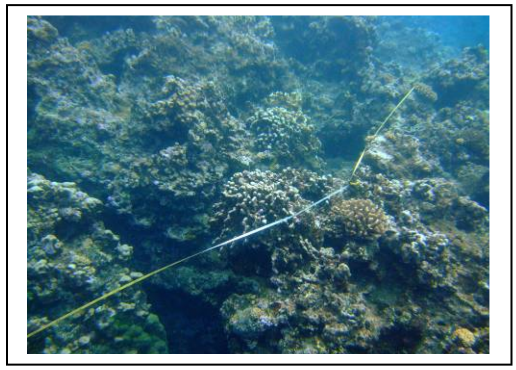
Site description: Western outer reef slope; moderate topographic complexity; very high coral cover; low macroalgal cover.

MAU-55
4/30/2009

E 145° 12.527
N 20° 01.469

Forereef
Shallow

Depth: 5 m

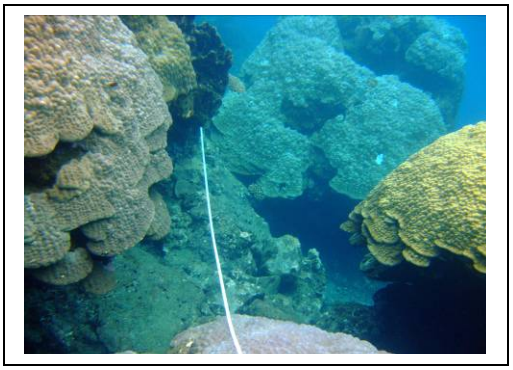
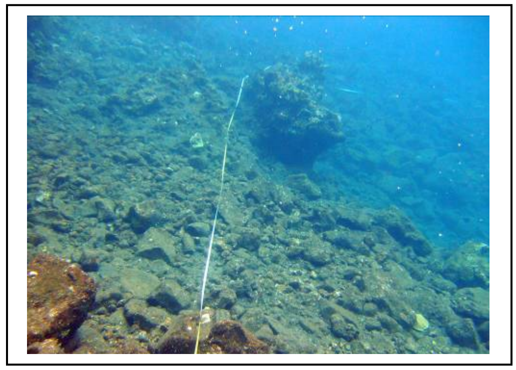
Site description: Outer shallow western forereef site; moderate topographic complexity (boulders on 1st transect); moderate coral cover; low macroalgal cover; dominated by turf algae.

MAU-56
4/30/2009

E 145° 12.872
N 20° 00.960

Forereef
Shallow

Depth: 3 m

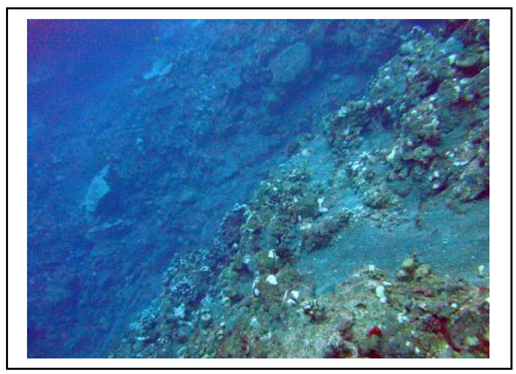
Site description: Inner shallow western site; moderate topographic complexity; moderate coral cover; low macroalgal cover; dominated by turf algae.

MAU-57
4/30/2009

E 145° 12.653
N 20° 01.192

Forereef
Deep

Depth: 21 m

Site description: Inner deep western site; moderate topographic complexity; steep slope (sand, rocks and sparse reef formations); moderate coral cover; low macroalgal cover; dominated by turf algae.

MAU-58
5/1/2009

E 145° 12.756
N 20° 01.774

Forereef
Deep

Depth: 18 m

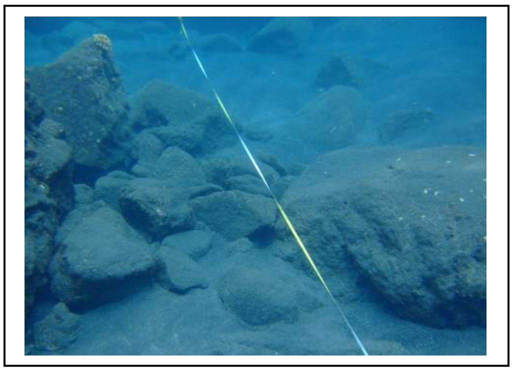
Site description: Inner northwestern deep site; moderate topographic complexity (reef formations surrounded by sand channels); moderate slope; moderate coral cover; low macroalgal cover; dominated by sand.

MAU-59
5/1/2009

E 145° 13.502
N 20° 01.830

Forereef
Shallow

Depth: 3 m



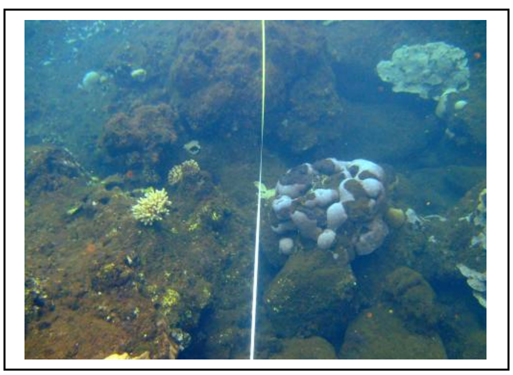
Site description: Shallow inner site on north island; moderate topographic complexity (medium boulders on 1st transect; 2nd transect along wall); moderate coral cover; low macroalgal cover; dominated by turf algae.

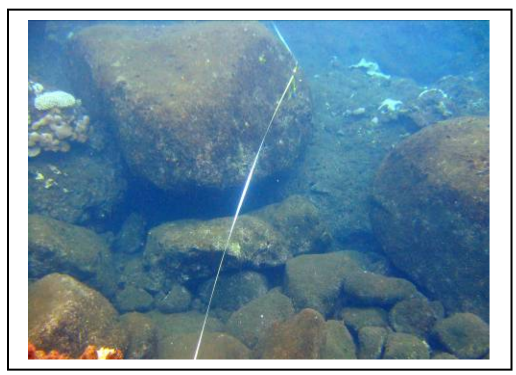
MAU-60
5/1/2009

E 145° 13.038
N 20° 01.843

Forereef
Shallow

Depth: 4 m





Site description: Shallow inner shallow site on north island; low topographic complexity (medium/large boulders intermixed with pavement); moderate coral cover; low macroalgal cover; dominated by turf algae.

MAU-61
5/1/2009

E 145° 13.153
N 20° 01.797

Forereef
Deep

Depth: 21 m

Site description: Deep inner site on north island; moderate topographic complexity; steep slope; no benthic surveys conducted.

H.3. Benthic Environment

H.3.1. Algal Communities

During the Mariana Reef Assessment and Monitoring Program (MARAMP) 2009, nine permanent, long-term REA monitoring sites were surveyed around Maug for percent benthic cover based on the 20-cm interval line point intercept (LPI) methodology. Benthic communities around Maug were dominated by scleractinian corals, turf, and macroalgae (Table H.3.1.1). Scleractinian coral percent cover exceeded that of other functional groups at five of the nine sites surveyed with a percent cover range of 17.2% to 63.2% (Table H.3.1.1). Turf and macroalgae were each the dominant cover at two of the nine sites (Table H.3.1.1). A combined total of 20 species of macroalgae were observed (12 chlorophytes, 5 ochrophytes, 3 rhodophytes) from the 9 sites surveyed (Tables H.3.1.2 and H.3.1.3). *Lobophora variegata* dominated the macroalgal community at six of the nine sites with a percent cover range of 0.4% to 23.2% (Table H.3.1.3). Species of *Neomeris, Dictyosphaeria cavernosa, and Asparagopsis taxiformis* each dominated the macroalgal community at one site with percent covers of 1.2%, 4%, and 7.6%, respectively (Table H.3.1.3).

Table H.3.1.1--Percent cover of algal functional groups at long-term monitoring sites at Maug.

Site	Macroalgae	Turf Algae	Coralline red algae (crustose + upright)	Cyanobacteria	Scleractinian Coral	Octocoral
MAU-01	8.8%	17.2%	21.2%	1.6%	48.8%	0.8%
MAU-02	4.4%	28.4%	4.0%	0.0%	63.2%	0.0%
MAU-03	2.0%	23.2%	9.2%	6.4%	55.6%	1.2%
MAU-04	31.6%	24.4%	6.0%	18.0%	17.2%	0.0%
MAU-06	6.4%	43.6%	6.8%	6.4%	24.0%	0.4%
MAU-09	27.2%	15.2%	14.4%	0.0%	42.4%	0.0%
MAU-10	7.6%	46.8%	3.6%	8.0%	24.0%	1.2%
MAU-11	13.6%	21.6%	12.8%	4.4%	44.0%	2.4%
MAU-12	33.2%	18.8%	2.8%	14.0%	24.4%	6.4%

Table H.3.1.2--Additional species recorded at each site at Maug during roving diver survey.

Site	**Chlorophyta**
MAU-06, MAU-10	*Caulerpa filicoides*
MAU-02, MAU-04	*Dictyosphaeria cavernosa*
MAU-06	*Halimeda opuntia*
MAU-09	*Halimeda tuna*
MAU-06, MAU-10, MAU-12	*Neomeris* sp.
MAU-03	*Tydemania* sp.
MAU-04	*Udotea* sp.
MAU-02	*Valonia* sp.
MAU-01, MAU-02, MAU-03 MAU-06, MAU-09, MAU-10, MAU-11	*Valonia ventricosa*
	Ochrophyta
MAU-06, MAU-10	*Padina* sp.
LAN-07	*Lobophora variegata*
MAU-04, MAU-12	*Padina* sp.
MAU-04, MAU-10, MAU-12	*Turbinaria ornata*
	Rhodophyta
MAU-02	*Amphiroa* sp.
MAU-09	*Asparagopsis taxiformis*
MAU-09, MAU-10	*Ganonema* sp.

Table H.3.1.3--Percent cover of macroalgal species at long-term monitoring sites at Maug. Sum totals for each row equal the percent cover of macroalgae recorded in Table H.3.1.1.

Site	Caulerpa racemosa	Caulerpa serrulata	Dictyosphaeria cavernosa	Dictyosphaeria versluysii	Halimeda opuntia	Neomeris sp	Dictyota sp	Lobophora variegata	Turbinaria ornata	Asparagopsis taxiformis
MAU-01	-	-	-	-	0.8%	-	-	7.2%	0.4%	-
MAU-02	0.4%	-	-	0.8%	-	-	0.4%	2.4%	-	-
MAU-03	-	0.4%	-	-	-	1.2%	-	0.4%	-	-
MAU-04	0.4%	-	-	-	-	0.4%	-	6.8%	-	7.6%
MAU-06	-	-	4.0%	-	-	-	0.4%	0.8%	0.4%	-
MAU-09	-	-	-	-	4.0%	-	-	23.2%	-	-
MAU-10	-	-	0.8%	-	-	-	-	4.4%	-	-
MAU-11	-	-	-	-	-	-	-	13.6%	-	-
MAU-12	-	-	-	-	0.8%	-	-	20.4%	-	-

H.3.2. Coral Communities

H.3.2.1. Percent Benthic Cover

During MARAMP 2009, percent benthic cover REA surveys conducted around Maug at nine permanent, long-term sites yielded an island-wide mean coral cover of 38.2 % (Fig. H.3.2.1.1.). The highest values for coral cover were recorded at sites MAU-02 and MAU-03 located on the inner side of the East Island (56% and 63%, respectively). The lowest levels of coral cover were detected at site MAU-04 on the west-facing side of East Island, where percent coral cover amounted to 17% (Fig. H.3.2.1.1.)

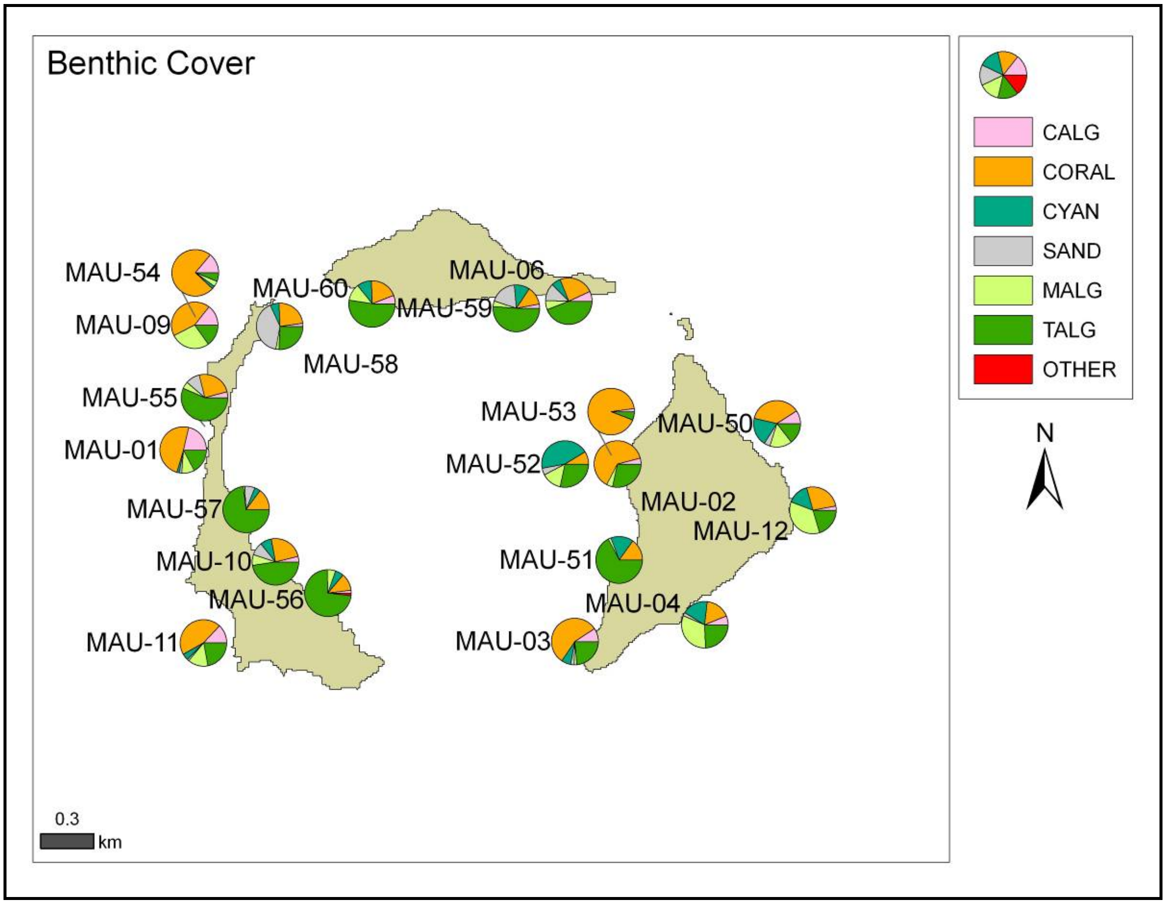


Figure H.3.2.1.1--Percent cover of benthic functional groups at the long-term and stratified random REA monitoring sites around Maug during MARAMP 2009. CALG = crustose coralline red algae, CYAN = cyanobacteria, MALG = macroalgae, TALG = turf algae.

Eleven additional stratified random REA sites were surveyed around Maug for percent benthic cover (based on 50-cm interval LPI surveys; Fig H.3.2.1.1.) and generic diversity data in 2009. Benthic communities surveyed at five sites greater than 20 m deep were dominated by scleractinian coral (47.5% $\pm$ 14.7) and turf algal (24.5% $\pm$ 12.3) functional groups (Fig. H.3.2.1.2.). Six shallow sites (< 10 m deep) were dominated by turf algal (54.1% $\pm$ 6.0), cyanobacterial (15.0% $\pm$ 6.2), and scleractinian coral (14.7% $\pm$ 2.6) functional groups (Fig. H.3.2.1.2.). Coral generic diversity was highest at site MAU-50 with 29 different genera observed (Table H.3.2.1.1.). In contrast, site MAU-51 had the lowest generic diversity with 13 different genera observed at both. An average of 20 coral genera were recorded at each site. Common genera observed at most sites included *Pocillopora, Porites, Pavona, Goniastrea, Acropora*, and *Astreopora.* Macroalgal generic diversity was highest at sites MAU-55 and MAU-60 with 11 genera observed (Table H.3.2.1.2.). Site MAU-54 had the lowest generic diversity with three genera observed. An average of 8 macroalgal genera were recorded at each site. Common macroalgae observed at most sites included *Lobophora* and *Neomeris*.

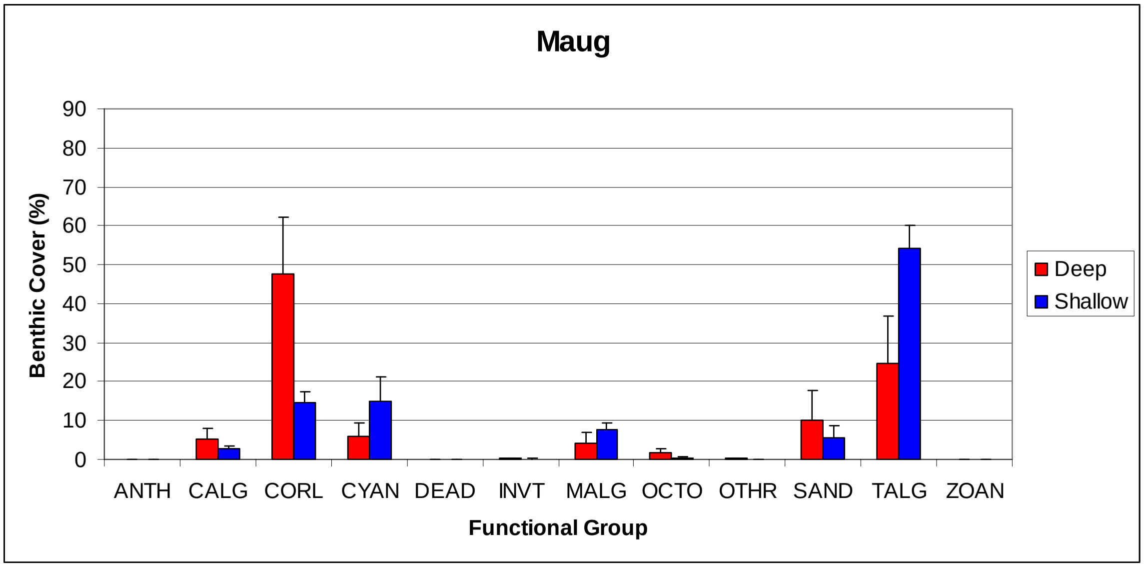


Figure H.3.2.1.2--Percent cover of functional groups at shallow and deep independent LPI monitoring sites established in 2009 at Maug. ANTH = anthozoan, CALG = crustose coralline red algae, CORL = coral, CYAN = cyanobacteria, DEAD = dead coral, INVT = non-coral invertebrate, MALG = macroalgae, OCTO = octocoral, OTHER = other, TALG = turf algae, ZOAN = zoanthid.

Table H.3.2.1.1--Coral generic diversity of stratified random sites around Maug.

	MAU-50	MAU-51	MAU-52	MAU-53	MAU-54	MAU-55	MAU-56	MAU-57	MAU-58	MAU-59	MAU-60	MAU-61**
Acanthastrea	X		X			X	X	X			X	
Acropora	X	X	X	X	X	X	X	X	X	X	X	
Alveopora												
Astreopora	X	X	X	X	X	X	X	X	X	X	X	
*Cladiella**												
*Corallimorph**				X								
Coscinarea	X			X	X	X		X				
Cyphastrea	X	X		X	X	X	X	X		X		
Diploastrea												
*Distichopora**												
Echinopora	X			X			X		X			
Euphyllia					X				X			
Favia	X	X	X	X	X	X		X	X	X	X	
Favites	X			X		X		X				
Fungia												
Galaxea	X	X		X	X	X	X	X	X	X	X	
Gardinoseris	X											
Goniastrea	X	X	X	X	X	X	X	X	X	X	X	
Goniopora	X	X		X	X			X	X		X	
*Heliopora**	X		X		X	X						
Herpolitha					X							

	MAU-50	MAU-51	MAU-52	MAU-53	MAU-54	MAU-55	MAU-56	MAU-57	MAU-58	MAU-59	MAU-60	MAU-61**
Hydnophora	X					X						
Isopora					X							
Leptastrea	X	X	X	X		X	X	X	X	X	X	
Leptoria			X			X						
Leptoseris												
Lobophyllia				X	X							
Lobophytum*	X				X		X					
Merulina												
Millepora*	X		X		X	X	X			X	X	
Montastrea	X	X	X		X	X	X	X	X	X	X	
Montipora	X	X	X		X	X	X	X	X	X		
Ouphyllia							X					
Oxypora								X	X			
Pachyclavularia*	X				X			X	X			
Pachyseris												
Palythoa*												
Pavona	X	X	X	X	X	X	X	X	X	X	X	
Platygyra	X				X	X	X			X	X	
Pleisiastrea	X										X	
Plerogyra				X				X	X			
Pocillopora	X	X	X	X	X	X	X	X	X	X	X	
Porites	X	X	X	X	X	X	X	X	X	X	X	
Psammocora	X			X	X	X		X	X			
Sarcophyton*						X						
Scapophyllia												
Scolymia												
Seriatopora												
Sinularia*	X				X	X		X		X	X	
Stylaster*	X											
Stylocoeniella				X			X			X	X	
Stylophora	X				X							
Turbinaria						X					X	
Wire Coral*				X				X				
Zoanthus*												
Total Genera per site	29	13	14	20	25	24	18	22	18	16	18	

* non-scleractinian genera, **no benthic surveys conducted

Table G.3.2.1.2.--Macroalgal generic diversity of stratified random sites around Maug.

	MAU-50	MAU-51	MAU-52	MAU-53	MAU-54	MAU-55	MAU-56	MAU-57	MAU-58	MAU-59	MAU-60	MAU-61**
Amphiroa		X									X	
Asparagopsis	X								X			
Avrainvillea												
Boergesenia												
Boodlea												
Bryopsis												
Caulerpa			X			X	X		X	X	X	
Chlorodesmis												
Crustose Coralline	X	X	X	X	X	X	X	X	X	X	X	
Cyanobacteria	X	X	X	X		X	X	X	X	X		
Dichotomaria												
Dictyosphaeria		X	X			X				X	X	
Dictyota		X	X			X	X			X		
Galaxaura												
Ganonema			X			X						
Gibsmithia												
Halimeda	X		X		X	X	X		X		X	
Halymenia												
Lobophora	X	X		X	X	X	X	X		X	X	
Microdictyon											X	
Neomeris	X	X	X			X	X	X	X	X	X	
Non-geniculate calcified branched	X											
Padina			X				X				X	
Peyssonnelia												
Portieria												
Rhipilia												
Turbinaria		X	X							X		
Tydemania				X				X				
Udotea						X						
Valonia	X	X		X		X	X	X	X	X	X	
Unknown											1	
Total Genera per site	8	9	10	5	3	11	9	6	7	9	11	

**no benthic surveys conducted

G.3.2.2 Coral Populations

During MARAMP 2009, belt transect surveys were conducted at nine long-term REA sites around Maug, covering a total reef area of 151.4 m^2 and totaling 2795 anthozoan and hydrozoan colonies enumerated. Taxonomic richness varied between sites with 34 anthozoan (32 scleractinian, 1 octocoral, 1 corallimorph) and 2 hydrozoan genera being represented within belt transects (Table H.3.2.2.1). *Goniastrea*, *Pocillopora*, and *Pavona* were the most abundant scleractinian genera, contributing 16.0%, 14.8%, and 11.8% of the total number of colonies enumerated island-wide. All other genera individually contributed less than 10% of the total number of colonies.

Table H.3.2.2.1--Relative abundance of anthozoan and hydrozoan genera enumerated within belt transects around Maug during MARAMP 2009.

Island	Genus	Relative abundance
Maug	*Goniastrea*	15.96
	Pocillopora	14.81
	Pavona	11.81
	Astreopora	9.23
	Favia	9.23
	Montastrea	8.37
	Montipora	4.94
	Galaxea	4.44
	Porites	4.19
	Heliopora	2.25
	Cyphastrea	2.11
	Goniopora	2.08
	Leptastrea	1.86
	Lobophytum	1.29
	Sinularia	1.18
	Acropora	1.04
	Millepora	0.72
	Alveopora	0.64
	Psammocora	0.61
	Isopora	0.47
	Stylocoeniella	0.47
	Acanthastrea	0.39
	Pachyclavularia	0.36
	Coralimorphia	0.32
	Stylophora	0.29
	Echinophyllia	0.25
	Platygyra	0.21
	Turbinaria	0.11
	Echinopora	0.07
	Favites	0.07
	Scapophyllia	0.07
	Coscinaraea	0.04
	Fungia	0.04
	Leptoseris	0.04
	Oxypora	0.04
	Plesiastrea	0.04

The highest relative abundance of *Goniastrea* (> 25% of total number of colonies) was found at sites MAU-01 and MAU-09 on the western outer reef. The highest relative abundance of *Pocillopora* (> 38% of total number of colonies) was found at sites MAU-04 and MAU-12 on the eastern outer reef. The highest relative abundance of *Pavona* (> 23 of total number of colonies) was found at sites MAU-03 and MAU-11 (Fig. H.3.2.2.1).

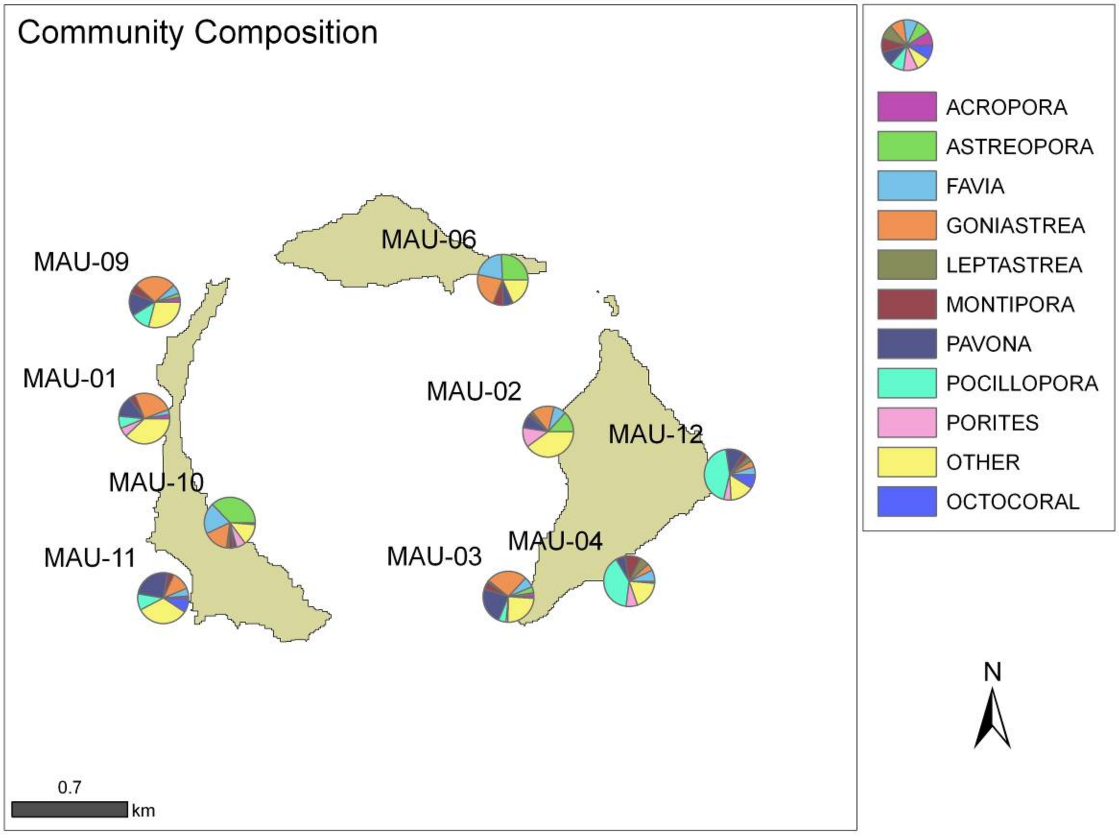


Figure H.3.2.2.1--Relative abundance of coral genera from REA surveys around Maug during MARAMP 2009.

H.3.3. Coral Health and Disease

During MARAMP 2009, the occurrence of disease, predation, and other health impairments around Maug was moderate, with a total of 50 cases enumerated. A summary of lesion occurrence and relative abundance is presented in Table H.3.3.1. The most numerically abundant type of lesion was predation by *Acanthaster* or *Drupella*; such predation scars were observed in *Goniastrea*, *Astreopora,* and *Porites*. Tissue loss and fungal infections were the second and third most numerically abundant type of afflictions, with a total of nine and eight cases tallied island-wide, respectively. Tissue loss was detected only on *Goniastrea* colonies, while discoloration from fungal infections was detected only on *Pavona varians*. Two types of coralline algal diseases were observed: coralline orange lethal disease (CLOD) and the coralline white band syndrome (CLD), of which the former was the more common.

Table H.3.3.1--Number of cases of scleractinian and coralline algal diseases and predation enumerated during REA surveys around Maug, MARAMP 2009. BIN: barnacle infestation; BLE: bleaching; CYA: cyanophyte infections; FUG: fungal infections; PRE: *Acanthaster*/*Drupella* predation scars; TLS: tissue loss; CLOD: coralline lethal orange disease; and CLD; coralline white band syndrome/lethal disease.

DZCode	MAU-01	MAU-02	MAU-03	MAU-04	MAU-06	MAU-09	MAU-10	MAU-11	MAU-12	Grand Total
BIN								1	1	2
BLE			2		1					3
CYA						1				1
FUG				3	2	2		1		8
PRE	2		15			1	2			20
TLS			9							9
Total	**2**	**0**	**26**	**3**	**3**	**4**	**2**	**2**	**1**	**43**
CLD	1									1
CLOD	3		2					1		6

H.3.4. Macroinvertebrate Surveys (non-coral)

A total of 438 individuals of benthic invertebrate target species or taxa groups were enumerated from 14 belt transects at 9 sites. Due to an illness with the REA invertebrate diver, only urchins and giant clams were enumerated at sites MAU-02 and MAU-12. Due to autonomous reef monitoring systems (ARMS) deployment, no invert surveys were conducted at site MAU-04 and only one transect was surveyed at sites MAU-11 and MAU-09. Non-cryptic macroinvertebrates were low around Maug with the exception of a species of *Tridacna* (giant clam), and the rock boring urchin *E. aciculatus.* Maug had the greatest island density of *Tridacna* in the Mariana with 1.84 (SE 0.75) organisms 50 m^{-2}. Densities were greatest at MAU-06 and MAU-10 with 5.84 and 3.68 organisms 50 m^{-2}. The island density of *E. aciculatus* was 1.51 (SE 0.89) organisms 50 m^{-2}. Site MAU-12 had the greatest density with 7.44 organisms 50 m^{-2}. Site MAU-01 had the greatest density of coral crabs with 1.84 organisms 50 m^{-2} and for the coral eating snail, *Quoyula madreporarum*, with 0.48 organisms 50 m^{-2}. Holothuroids were rare on transect. Off transect in the eastern lagoon, *Synapta maculata* and *Holothuria fuscopunctata,* were common. *Acanthaster planci* was seen off transect at site MAU-06.

H.3.4.1.--Urchin Measurements

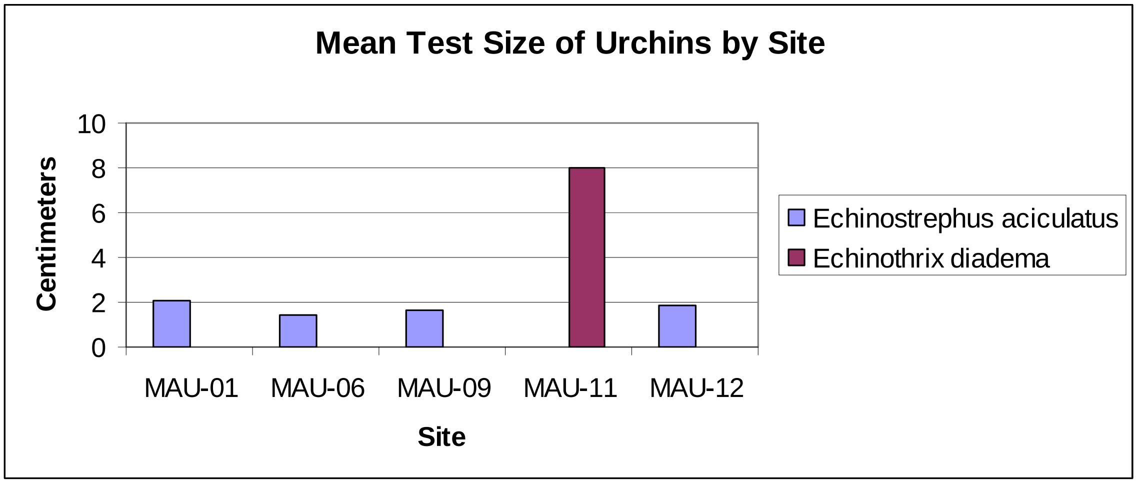


Figure H.3.4.1.1--Average test diameter of urchins encountered at each site. Only sites where ≥ 5 measurements were recorded for a species are represented.

H.3.4.2. ARMS Deployment
ARMS were deployed at the following REA sites around Maug (Table H.3.4.2.1.). Each site contains three ARMS.

Table H.3.4.2.1--ARMS deployment locations around Maug.

REA site	Latitude	Longitude
MAU-04	20º 00.836 N	145º 14.059 E
MAU-11	20º 00.799 N	145º 12.539 E
MAU-09	20º 01.791 N	145º 12.505 E

H.3.4.3. Invertebrate Collections
Thirty-two *Linckia multifora* arms, seven *Acanthaster planci* arms, and five *Ophiocoma pica* arms were collected at Maug.

H.3.5. Benthic Towed-diver Surveys
A total of eight benthic towed-diver surveys were completed at Maug in 2009 (Fig. H.3.5.1.). Two benthic calibration surveys and one fish calibration surveys were also completed.

Terrain was mixed between the forereef outside of caldera/eastern, northern, and western islands, vs. the interior caldera forereef. Along the outside of the caldera, habitat was primarily composed of medium-low to medium-high complexity continuous reef, interspersed with rock boulders and several walls with dramatic drops in depth sometimes > 30 m. Increased habitat complexity along the continuous reef habitats were noted near the channels as well. Within the interior of the caldera, habitats were largely composed of continuous reef/walls of medium high complexity, switching to medium-complexity continuous reefs, rock boulders, and the occasional large sand flat.

Benthic category	Mean ± SE
Hard coral	28.6 ± 1.4
Soft coral	3.4 ± 0.4
Sand	6.8 ± 1.5
Rubble	1.5 ± 0.2
Macroalgae	3.1 ± 0.4
Coralline algae	7.3 ± 0.7
COTS	84
Free urchins	103
Boring urchins	3377
Sea cucumbers	80
Giant clams	546
* Sum of observed individuals	

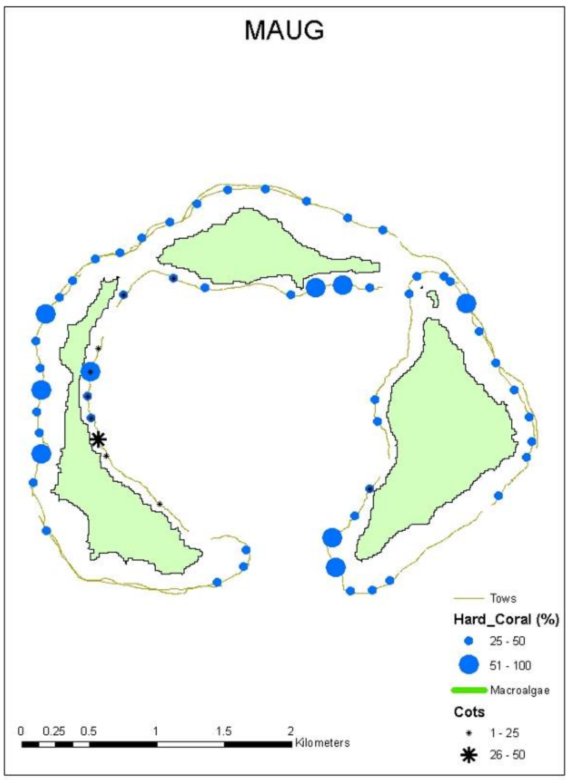


Figure H.3.5.1--Hard coral cover, elevated macroalgal cover (> 25%), and crown-of-thorn (COT) abundances during tow segments at Maug 2009.

Hard coral was the most abundant benthic feature, recording an average of 28.6 ± 1.4% island-wide. Coral cover was noted as high as 50.1-62.5% in several time segments along the western coastline/outer reef of West Island, while one singular time segment along the outer forereef of East Island approaching the southern channel recorded a time segment with 62.5-75% cover. Species of *Porites*, *Pocillopora*, *Galaxea*, *Pavona*, *Favia*, *Goniastrea*, *Isopora*, *Acropora*, and

Millepora were more gregarious than most other genera and often had localized spikes in cover/dominance along the outside of the caldera (e.g., extensive swaths of *Goniastrea*, large *Porites* colonies approaching 9–10 m, etc.).

Coral stress was generally low around Maug. However, species of *Astreopora* appeared pale/bleached in patchy areas inside of the caldera along the forereef bordering North Island (inside of the caldera), with no apparent causation (stress recorded up to 5.1-10%). As surveys continued around the interior towards the (inner) forereef of the caldera bordering West Island, elevated COT counts were noted along with stress levels of 5.1–10% (2 segments) and 10.1–20% (1 segment), suggesting that localized coral stresses may have been linked to predation events.

Octocorals averaged 3.4 ± 0.4% island-wide. The highest octocoral coverage was noted during a time segment recorded during a northern forereef survey, where 20.1–30% cover was noted.

Macroalgae accounted for 3.1 ± 0.4% of the benthic cover, and were generally low island-wide. Several segments reached 10.1–20%, but generally most observations fell below 10%. Species of *Halimeda*, *Neomeris*, and *Asparagopsis* were noted. Similar to Pagan, divers noted dark-green cyanobacteria growing on the reefs of Maug, although not in the same concentrations. The highest benthic cover of cyanobacteria noted during towed-diver surveys reached 10.1–20% along the eastern/outer forereef. It is important to note that several segments in that region also mentioned cyanobacteria in the water column, suggesting fragmentation and potential transport to other parts of the island.

A total of 84 COTS were reported island-wide. The highest concentration occurred during a time segment within the caldera, along the inner forereef bordering West Island. A total of 27 COTS and 15 COTS were reported in two consecutive time segments along the forereef, with associated coral stresses (COT scars) also being reported in the same area.

A total of 103 free urchins were recorded around Maug, and appeared in higher concentrations along the outer eastern forereef, and along the southern tip of West Island. A total of 3377 boring urchins were reported, with the highest concentrations found along the outer/eastern and northern forereef habitats. None were noted for the interior caldera. A total of 80 sea cucumbers were observed by divers and appeared to be evenly distributed along the outer forereef/inner caldera habitats. Finally, 546 giant clams were reported (the highest number counted for all surveys in the Mariana Archipelago), with the highest concentrations centered around the outer/western forereef bordering West Island and the southern channel entrance/southern corner of West Island.

H.4. Fish Surveys

H.4.1. REA Fish Surveys

Stationary point count data (nSPC)

During the survey period, nSPC surveys were conducted at 21 sites around Maug. Surgeonfish were the largest contributor to total biomass with 1.4 kg 100 m^{-2}. Snappers were the second largest contributor to total biomass with 0.9 kg 100 m^{-2}, followed by parrotfish at 0.54 kg 100 m^{-2} (Fig. H..4.1.1.).

Overall observations
A total of 193 fish species were observed by all divers during the survey period. The average total fish biomass around Maug during the survey period was 5.3 kg 100 m^{-2} for the nSPC surveys (Table H..4.1.1.).

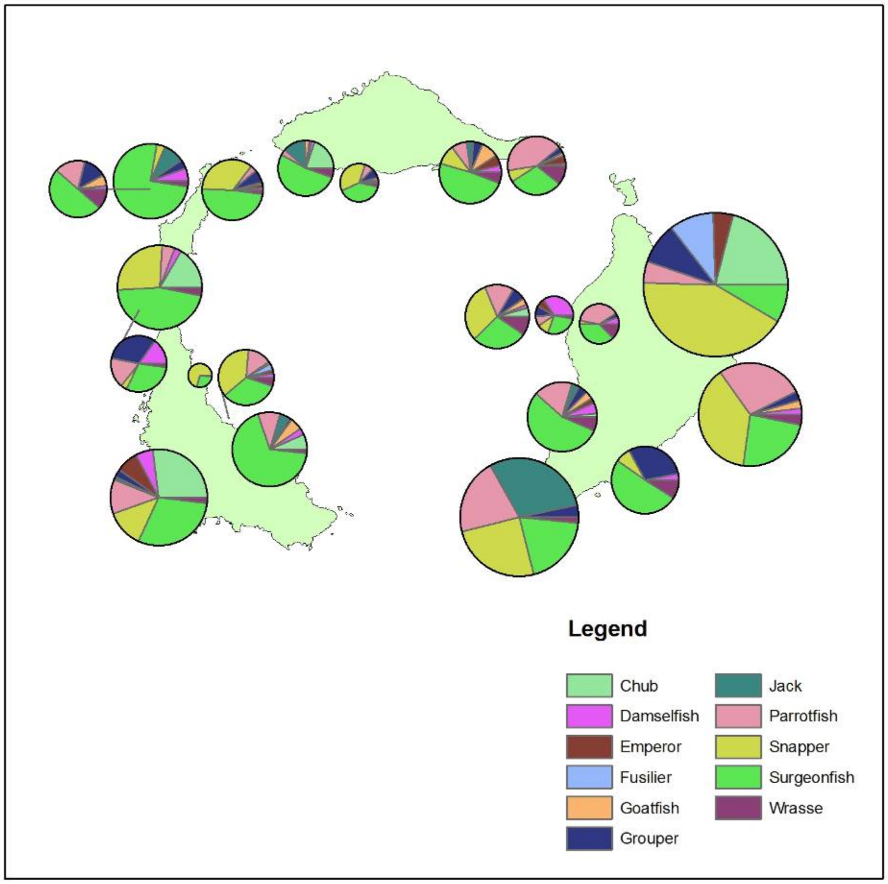


Figure H.4.1.1--Site location and distribution of total fish biomass by family. The sizes of the pie charts are proportional to fish biomass.

H.4.2. Towed-diver Surveys

During HA0903, the CRED towed-diver team completed 11 surveys at Maug covering 23.1 km (23.1 ha) of ocean floor (Table H.4.2.1.). Mean survey length was 2.1 km with a maximum length of 2.5 km and a minimum of 1.8 km. Mean survey depth was 14.7 m with a maximum depth of 17.2 m and a minimum of 13.1 m. Mean temperature on these surveys was 27.2°C with a maximum temperature of 27.6°C and a minimum of 26.6°C.

Table H.4.2.1--Survey statistics for towed-diver sampling during HA0903.

		Length (km)					Depth (m)				Temperature (ºC)			
Island/Reef	**#**	**Sum**	**Mean**	**Max**	**Min**	**SD**	**Mean**	**Max**	**Min**	**SD**	**Mean**	**Max**	**Min**	**SD**
Maug	11	23.1	2.1	2.5	1.8	0.2	14.7	17.2	13.1	1.2	27.2	27.6	26.6	0.3

One hundred twenty-seven individual large-bodied reef fishes (> 50 cm TL) of 12 different species and seven different families were encountered at Maug (Table H.4.2.2.). Overall numeric density for this class of reef fishes was 0.55 #/100 m^2 (54.91 #/ha) with a biomass density of 2.02 kg/100 m^2 (0.20 t/ha). Numeric density was dominated by *Caranx sexfasciatus* while biomass density was dominated by *Triaenodon obesus.*

Table H.4.2.2--Species numeric and biomass density for large-bodied reef fishes (> 50 cm TL) observed at Maug during HA0903 CRED towed-diver surveys.

Species	#	#/100 m^2	#/ha	Biomass (kg)	kg/100 m^2	t/ha
Naso annulatus	1	0.00	0.43	2.71	0.01	0.00
Naso hexacanthus	13	0.06	5.62	27.58	0.12	0.01
Balistoides viridescens	1	0.00	0.43	3.28	0.01	0.00
Caranx melampygus	2	0.01	0.86	4.24	0.02	0.00
Caranx sexfasciatus	32	0.14	13.83	78.37	0.34	0.03
Carcharhinus amblyrhynchos	2	0.01	0.86	20.23	0.09	0.01
Triaenodon obesus	9	0.04	3.89	147.76	0.64	0.06
Lutjanus bohar	41	0.18	17.73	122.34	0.53	0.05
Macolor macularis	6	0.03	2.59	10.88	0.05	0.00
Macolor niger	14	0.06	6.05	25.38	0.11	0.01
Chlorurus microrhinos	4	0.02	1.73	10.38	0.04	0.00
Gymnosarda unicolor	2	0.01	0.86	14.47	0.06	0.01
Grand Total	127	0.55	54.91	467.61	2.02	0.20
# of Species	12					

The most prevalent families in terms of numeric and biomass density were lutjanids (ND = 47%, BD = 34%), carangids (ND = 27%, BD = 18%), and acanthurids (ND = 11%, BD = 6%) (Figs. H.4.2.1., H.4.2.2.). While there appeared to be an area of elevated biomass along the northeastern section of the island complex, overall there was no clear pattern to the geographic distribution of large-bodied reef fishes around the islands. (Fig. H.4.2.3.).

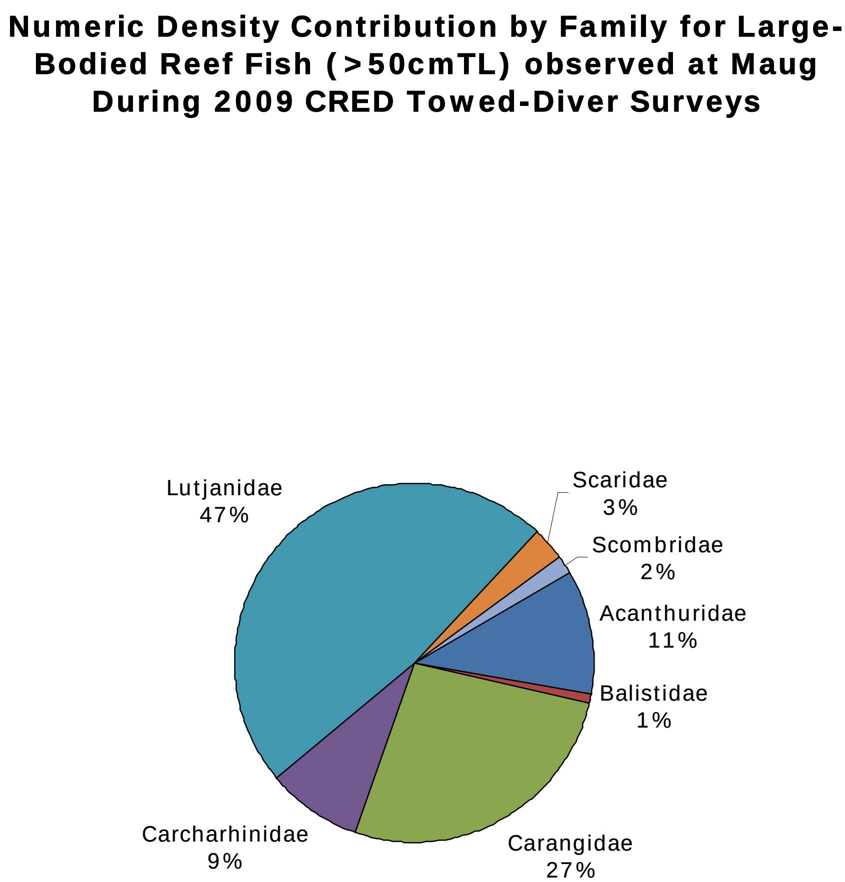


Figure H.4.2.1--Numeric density of fishes by family..

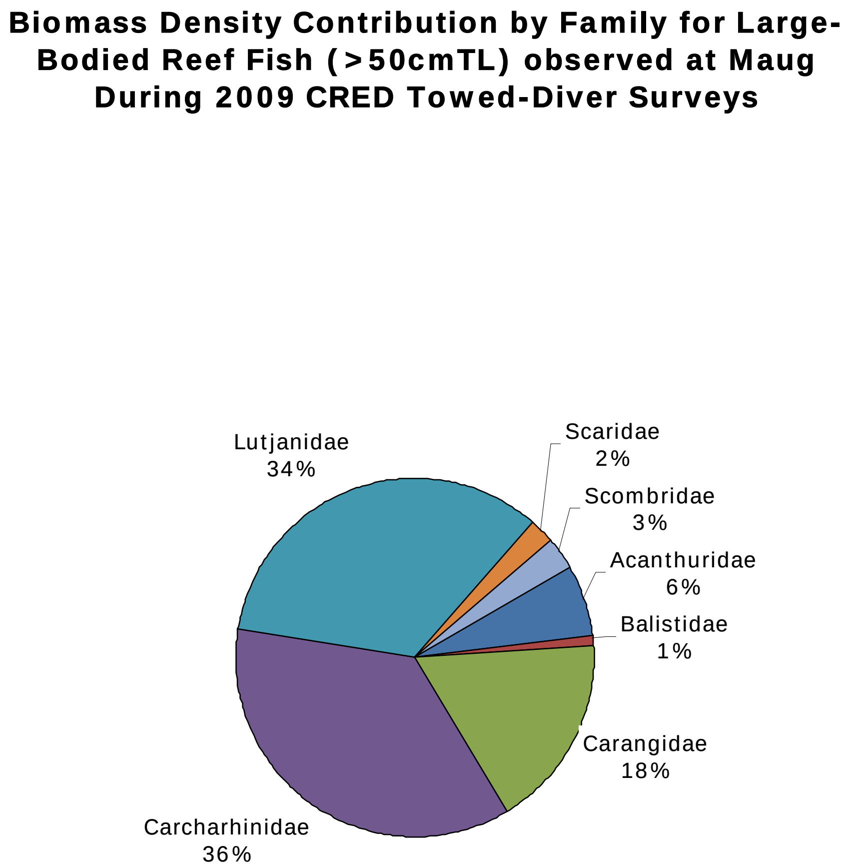


Figure H.4.2.2--Biomass density of fishes by family..

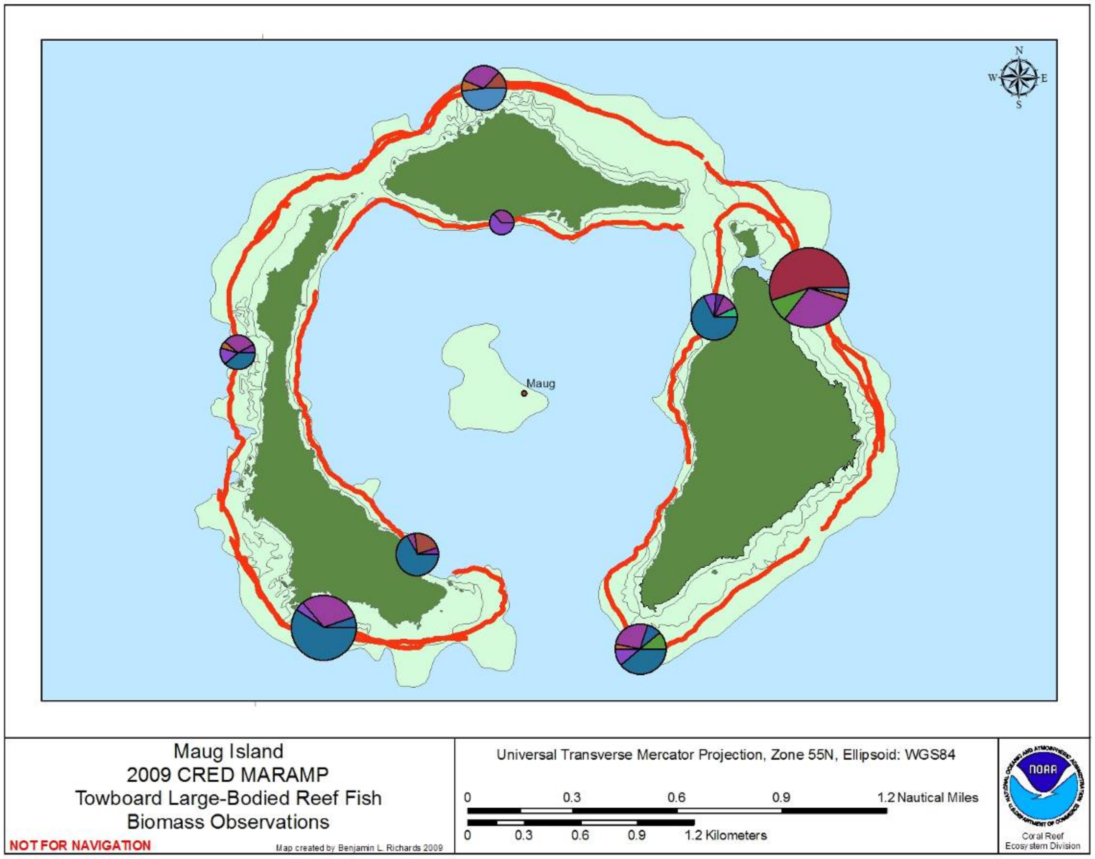


Figure H.4.2.3--Geographic distribution of fish biomass around Maug. Each species is represented by a legend color. Diameter of pie chart is proportional to total biomass of all species encountered on the underlying survey.

Appendix I: Agrihan Results

I.1. Oceanography and Water Quality

One subsurface temperature recorder (STR) was recovered, and two new STRs were deployed at REA sites (AGR-02, AGR-04) during HA0903 at Agrihan (Table I.1.1., Fig. I.1.1.). The STR recovered shows a clear annual fluctuation due to seasonal warming and cooling (Fig. I.1.2.). Warmest surface temperatures peaked at 32°C and occurred during the summer months of July to October. Winter temperatures reached lows of 26°C and occurred during November through June.

Two rapid ecological assessment (REA) sites (AGR-02, AGR-07) were visited to collect water samples for microbiological, nutrient and chlorophyll analyses and three REA sites (AGR-01, AGR-04, AGR-06) were sampled for just nutrients and chlorophyll. Samples were obtained from the surface and approximately 1 m above the reef. Microbial water samples were taken using diver-deployable Niskin bottles to collect 8 liters of seawater (four bottles; 2 liters per bottle) at each study site. Chlorophyll samples were filtered and nutrient samples were frozen at - 30°C for post-cruise analysis. Shallow-water conductivity temperature and depth (CTD) casts were also conducted at these sites. In addition, 12 CTD casts were taken every 2 km around the perimeter of Agrihan at the 30 m depth contour.

Table I.1.1--Agrihan moorings.

Action	Mooring type	Serial number	Lat		Long		Depth (m)
Retrieval	STR	39240220358	18.76657376	N	145.6382238	E	2.7
Deployment	STR	39390383054	18.72671211	N	145.6631728	E	10.1
Deployment	STR	39432363079	18.80750687	N	145.6487061	E	14.3

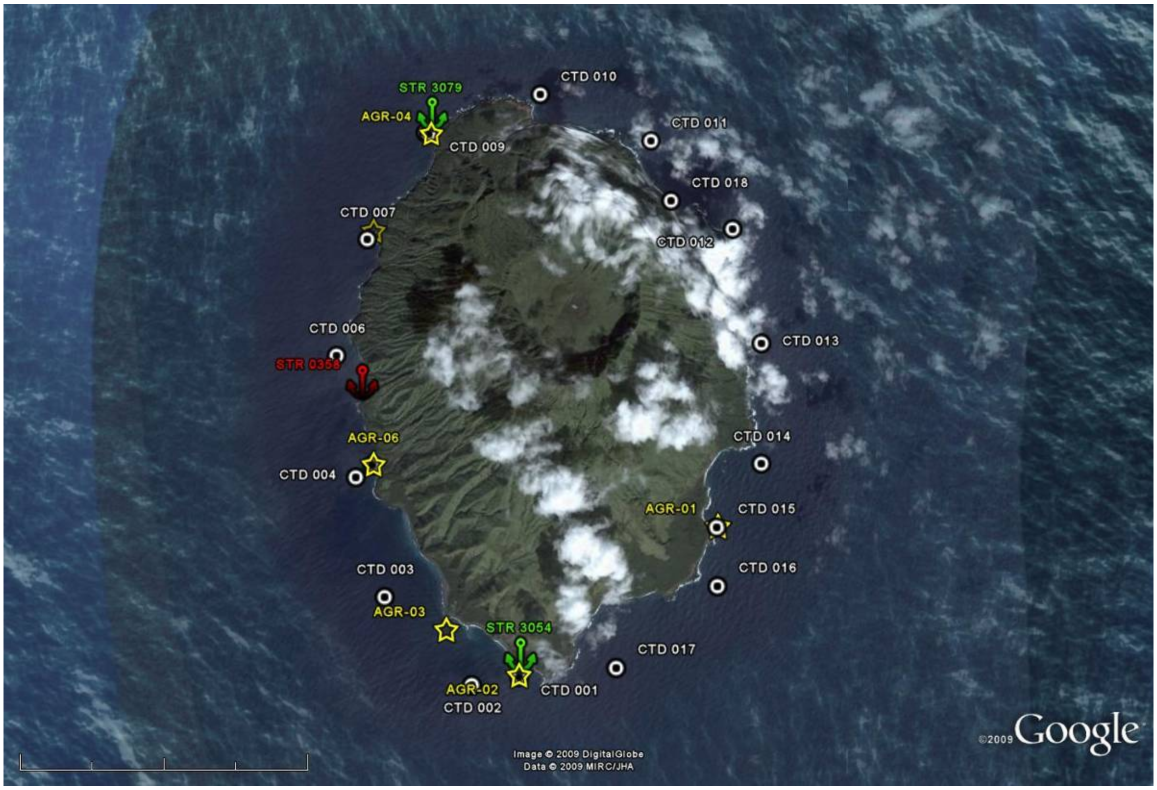


Figure I.1.1--Deployed and recovered instrument moorings and CTD and water sampling sites, Agrihan, HA0903.

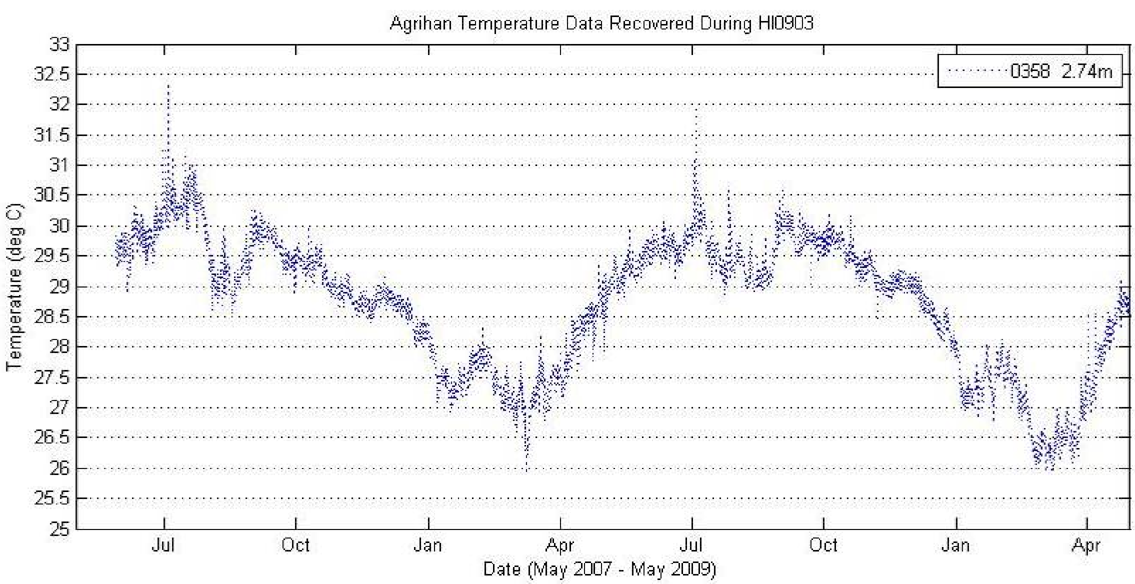


Figure I.1.2--Temperature time series from STR mooring at Agrihan.

I.2. Rapid Ecological Assessment (REA) Site Descriptions

AGR-01
5/2/2009

E 145° 41.646
N 18° 44.891

Forereef
Mid

Depth: 13 m


Site description: Southeastern region; moderately topographic complexity; high coral cover; low macroalgal cover.

AGR-02
5/2/2009

E 145° 39.793
N 18° 43.604

Forereef
Mid

Depth: 13 m

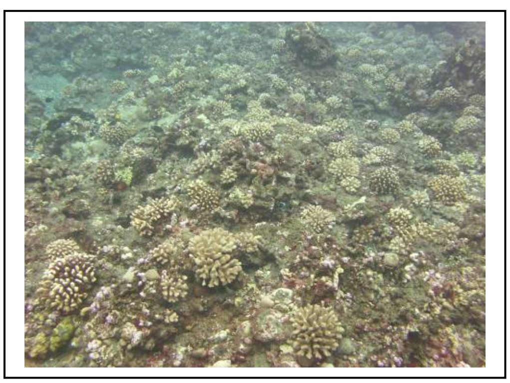
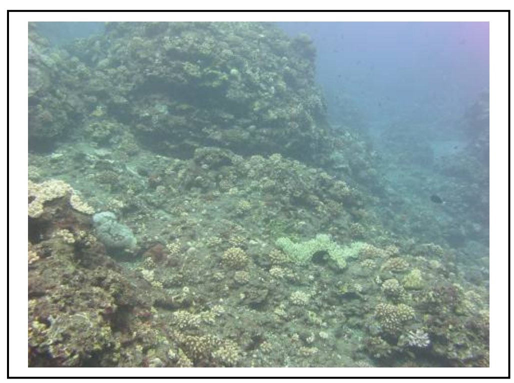

Site description: Site on southern tip; high topographic complexity; complex substrate on a shallow wall; high coral cover; low macroalgal cover.

AGR-04
5/3/2009

E 145° 38.929
N 18° 48.448

Forereef
Mid

Depth: 12–14 m

Site description: Northwestern region; moderate topographic complexity; high coral cover; moderate macroalgal cover; dominated by turf algae.

AGR-05
5/3/2009

E 145° 38.389
N 18° 47.547

Forereef
Mid

Depth: 12–13 m

Site description: Northwestern region; low relief; moderate topographic complexity; high coral cover; moderate macroalgal cover; dominated by turf algae.

AGR-06
5/2/2009

E 145° 38.420
N 18° 45.441

Forereef
Mid

Depth: 12–13 m

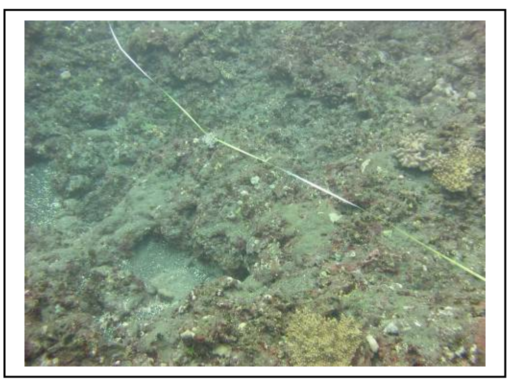
Site description: Southwestern region; moderate topographic complexity (boulders); low coral cover; high macroalgal and turf algal communities.

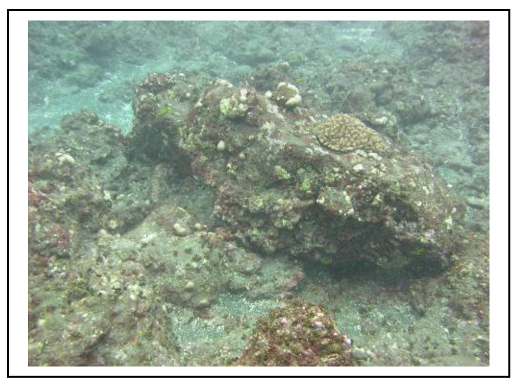
AGR-07
5/3/2009

E 145° 45.316
N 18° 01.433

Forereef
Mid

Depth: 13 m





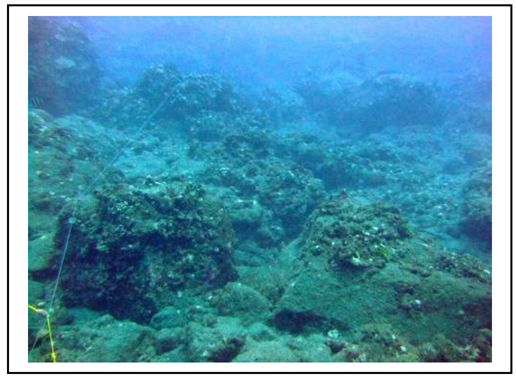
Site description: Northeastern region; low/moderate topographic complexity; low coral cover; high macroalgal cover.

AGR-50
5/2/2009

E 145° 42.012
N 18° 46.309

Forereef
Deep

Depth: 24 m



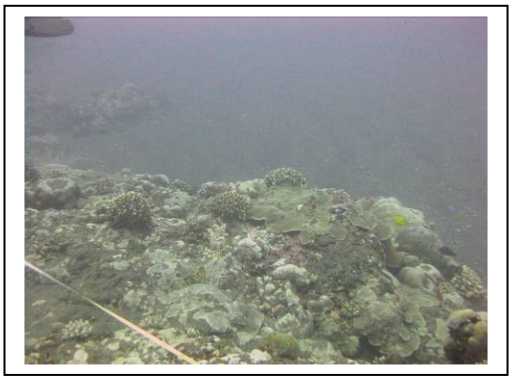
Site description: Deep eastern site; moderate topographic complexity; moderate slope; high coral cover; low macroalgal cover.

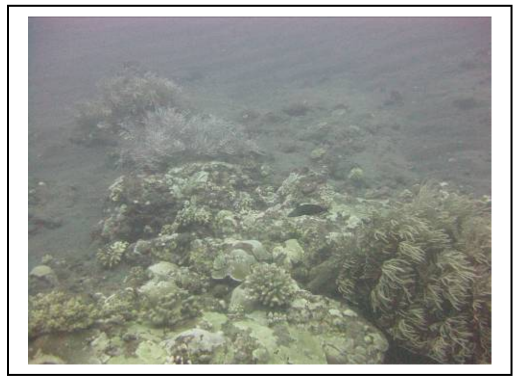
AGR-51
5/2/2009

E 145° 40.185
N 18° 43.514

Forereef
Deep

Depth: 19 m





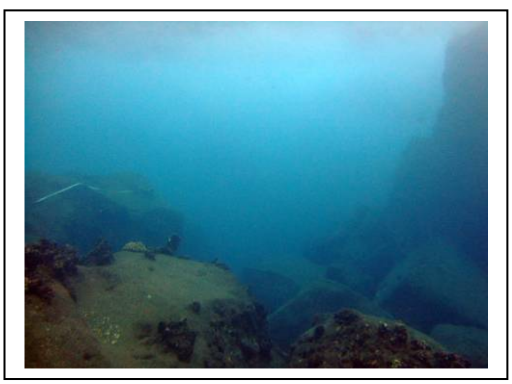
Site description: Deep southern site; low topographic complexity (patch reefs surrounded by black sand); high coral cover (gorgonians present); low macroalgal cover.

AGR-52
5/2/2009

E 145° 38.368
N 18° 45.640

Forereef
Shallow

Depth: 5 m



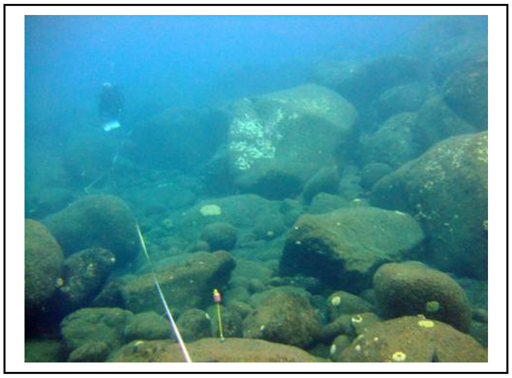
Site description: Shallow southwestern site; moderate topgraphic complexity (boulders); moderate coral cover; low macroalgal cover; dominated by turf algae.

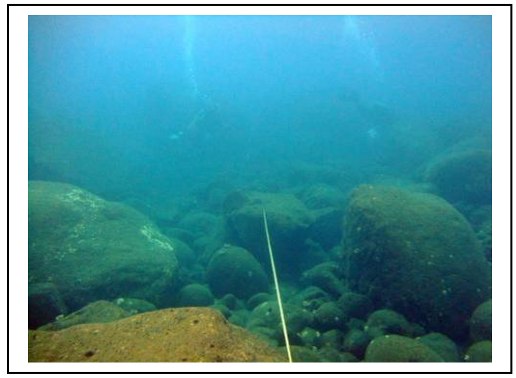
AGR-53
5/2/2009

E 145° 38.292
N 18° 46.225

Forereef
Shallow

Depth: 5 m





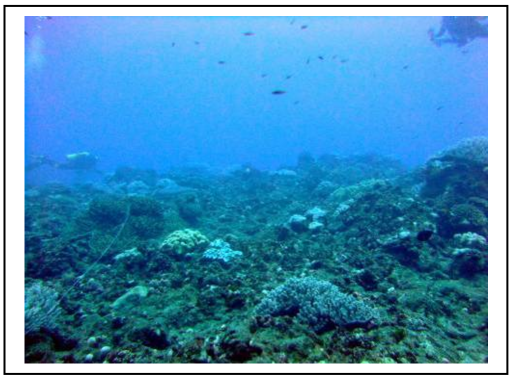
Site description: Shallow southwestern site; moderate topographic complexity (boulders); moderate coral cover; low macroalgal cover; dominated by turf algae.

AGR-54
5/3/2009

E 145° 40.606
N 18° 48.673

Forereef
Deep

Depth: 23 m



Site description: Deep northern site; moderate topographic complexity; high coral cover; moderate macroalgal and turf algal cover.

AGR-55
5/3/2009

E 145° 38.905
N 18° 48.179

Forereef
Shallow

Depth: 3–4 m

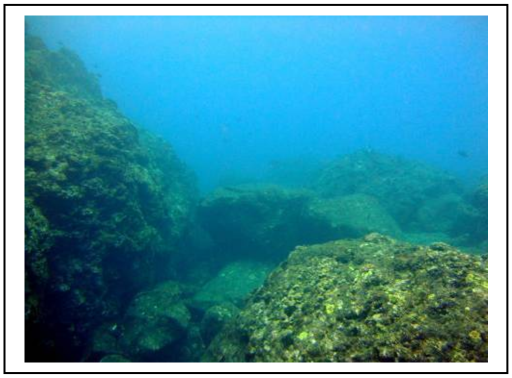
Site description: Shallow northwestern site; moderate topographic complexity (boulders); moderate coral cover; low macroalgal cover; dominated by turf algae.

AGR-56
5/3/2009

E 145° 38.226
N 18° 46.742

Forereef
Shallow

Depth: 5 m




Site description: Shallow western site; moderate topographic complexity (reef ledge near drop-off); moderate coral and macroalgal cover.

AGR-57
5/3/2009

E 145° 38.083
N 18° 46.603

Forereef
Deep

Depth: 25 m


Site description: Deep western site; moderate topgraphic complexity; moderate slope located near a 20-foot drop-off; crevice filled with large fish; moderate coral cover; low macroalgal cover; dominated by cyanobacteria.

I.3. Benthic Environment

I.3.1. Algal Communities

During the Mariana Reef Assessment and Monitoring Program (MARAMP) 2009, six permanent, long-term REA monitoring sites were surveyed around Agrihan Island for percent benthic cover based on the 20-cm interval line point intercept (LPI) methodology**.** Benthic communities around Agrihan were dominated by scleractinian coral, turf, and macroalgal functional groups (Table I.3.1.1.). Scleractinian coral percent cover exceeded that of other functional groups at sites AGR-01 and AGR-02 (38.4% and 60%, respectively), while turf algae was the dominant cover at sites AGR-04 and AGR-05 (41.6%, 38%; Table I.3.1.1.). At sites AGR-06 and AGR-07, macroalgal percent cover exceeded that of all other functional groups (42%, 36%). A combined total of 13 species of macroalgae were observed (6 chlorophytes, 3 ochrophytes, 4 rhodophytes) from the 6 sites surveyed (Tables I.3.1.2. and Table I.3.1.3.). *Lobophora variegata* dominated the macroalgal community at all of the sites surveyed with a percent cover range of 3.6% to 41.6% (Table I.3.1.3.).

Table I.3.1.1--Percent cover of algal functional groups at long-term monitoring sites at Agrihan

Site	Macroalgae	Turf Algae	Coralline red algae (crustose + upright)	Cyanobacteria	Scleractinian Coral	Octocoral
AGR-01	8.8%	26.8%	6.8%	4.4%	38.4%	7.2%
AGR-02	4.4%	20.4%	9.2%	5.2%	60.0%	0.4%
AGR-04	15.2%	41.6%	7.2%	1.2%	34.4%	-
AGR-05	14.8%	38.0%	8.0%	8.8%	29.6%	-
AGR-06	42.0%	40.8%	2.4%	6.0%	6.8%	-
AGR-07	36.0%	23.6%	21.2%	0.4%	8.0%	4.4%

I.3.1.2--Additional species recorded at each site at Agrihan during roving diver survey.

Site	**Chlorophyta**
AGR-02	*Boodlea* sp.
AGR-02	*Caulerpa racemosa*
AGR-06	*Dictyosphaeria versluysii*
AGR-01, AGR-04, AGR-07	*Neomeris* sp.
AGR-04	*Udotea* sp.
AGR-02, AGR-04, AGR-05, AGR-06	*Valonia ventricosa*
	Ochrophyta
AGR-05	*Dictyota* sp.
AGR-01, AGR-02, AGR-05, AGR-07	*Padina* sp.
	Rhodophyta
AGR-04	*Dichotomaria* sp.
AGR-02	*Martensia* sp.

Table I.3.1.3--Percent cover of macroalgal species at long-term monitoring sites at Agrihan. Sum totals for each row equal the percent cover of macroalgae recorded in Table I.3.1.1.

Site	Caulerpa racemosa	Neomeris sp	Dictyota sp	Lobophora variegata	Asparagopsis taxiformis	Peyssonnelia sp
AGR-01	-	-	-	3.6%	0.8%	-
AGR-02	-	-	0.8%	3.6%	-	-
AGR-04	-	-	-	14.4%	-	0.4%
AGR-05	0.4%	-	-	10.4%	-	0.8%
AGR-06	-	0.4%	-	41.6%	-	-
AGR-07	-	-	0.4%	8.4%	2.4%	0.8%

I.3.2. Coral Communities

I.3.2.1. Percent Benthic Cover

During MARAMP 2009, percent benthic cover REA surveys conducted around Agrihan at six permanent, long-term sites yielded an island-wide mean coral cover of 29.5% (Fig. I.3.2.1.1.), with the highest value recorded at site AGR-02 located in the protected southwestern shore (60%). The lowest levels of coral cover coral cover were detected at site AGR-06 and AGR-07 on the northeast and southwestern regions where coral percent cover attained values of 7% and 8%, respectively (Fig. I.3.2.1.1.)

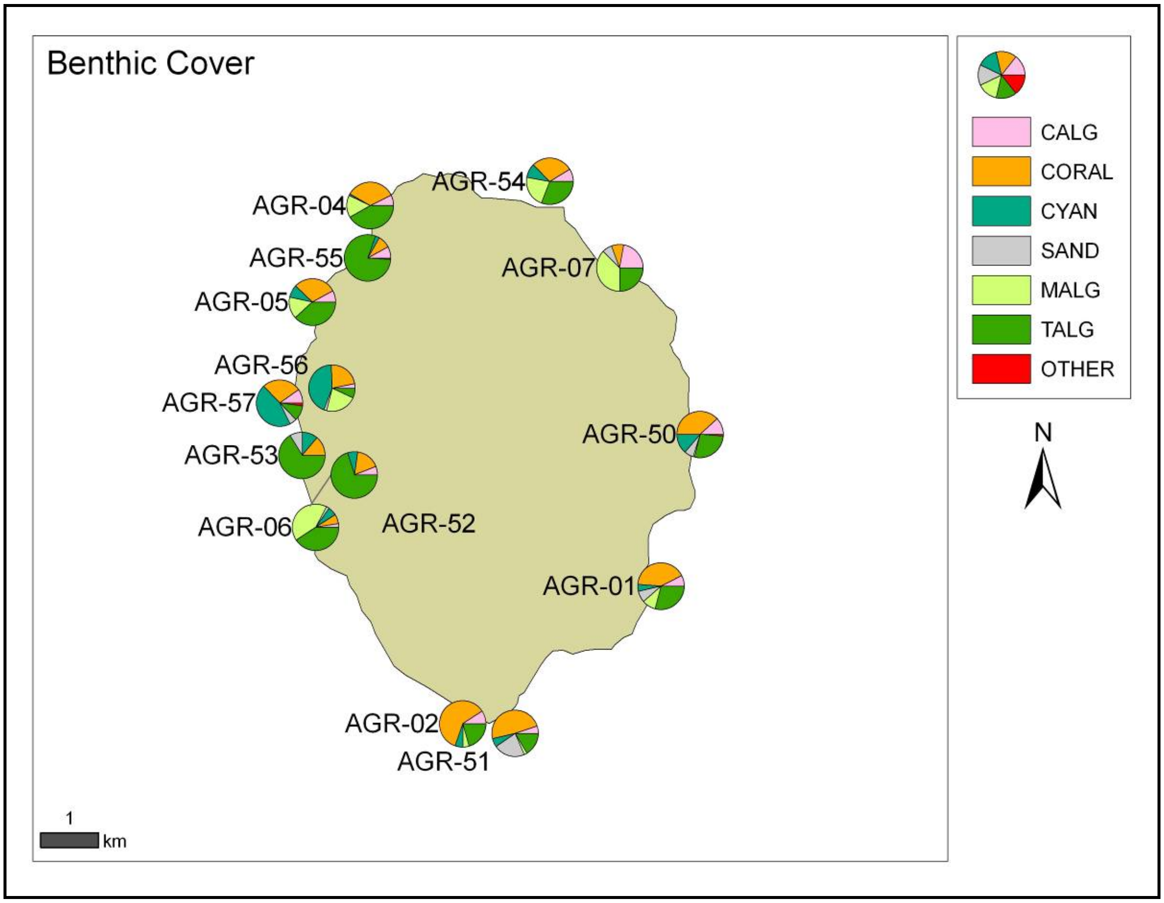


Figure I.3.2.1.1--Percent cover of benthic functional groups at the long-term and stratified random REA monitoring sites around Agrihan during MARAMP 2009. CALG = crustose coralline red algae, CYAN = cyanobacteria, MALG = macroalgae, TALG = turf algae.

Eight additional stratified random REA sites were surveyed around Agrihan for percent benthic cover (based on 50-cm interval LPI surveys; Fig H.3.2.1.1) and generic diversity data in 2009. Benthic communities surveyed at four sites greater than 20 m deep were dominated by turf algal (32.4% $\pm$ 11.7), scleractinian coral (25.5% $\pm$ 4.5) and cyanobacterial (19.6% $\pm$ 8.6) functional groups (Fig. H.3.2.1.2). Four shallow sites (<10 m deep) were dominated by turf algal (42.9% $\pm$ 18.5), scleractinian coral (23.5% $\pm$ 8.0) and cyanobacterial (14.7% $\pm$ 9.5) functional groups (Fig. H.3.2.1.2). Coral generic diversity was highest at site AGR-51 with 28 different genera observed (Table H.3.2.1.1). In contrast, sites AGR-53 and AGR-55 had the lowest generic diversity with 13 different genera observed at both. An average of 21 coral genera were recorded at each site. Common genera observed at most sites included *Pocillopora, Porites, Favia, Montastrea, Acanthastrea*, and *Stylophora.* Macroalgal generic diversity was highest at site AGR-56 with 11 genera observed (Table I.3.2.1.2.). Site AGR-55 had the lowest generic diversity with four genera observed. An average of 7 macroalgal genera were recorded for each site. Common macroalgae observed at most sites included *Lobophora, Dictyota,* and *Neomeris.*

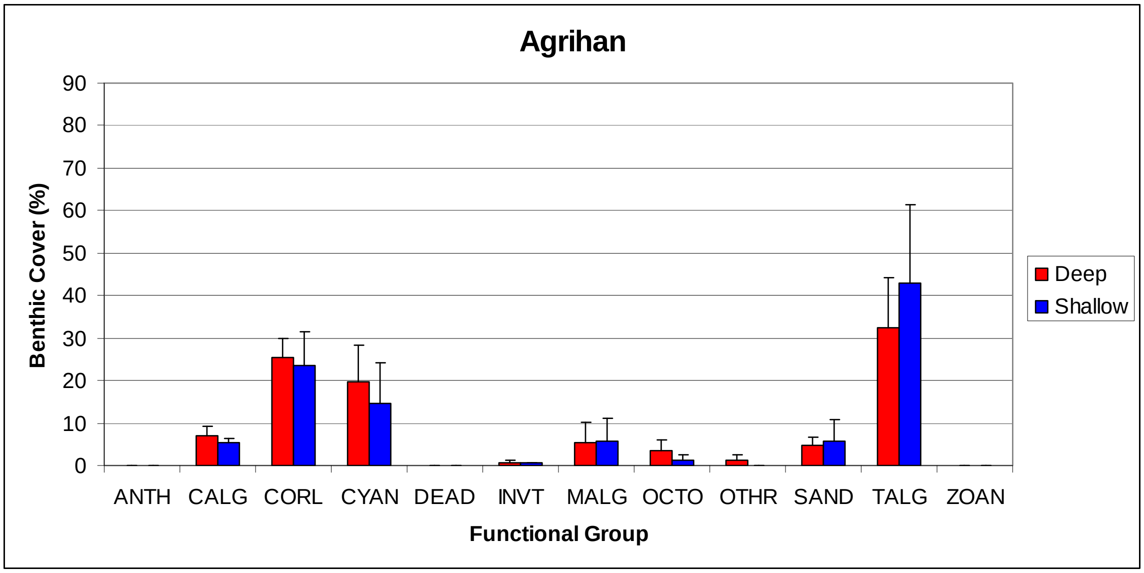


Figure I.3.2.1.2--Percent cover of functional groups at shallow and deep independent LPI monitoring sites established in 2009 at Agrihan. ANTH = anthozoan, CALG = crustose coralline red algae, CORL = coral, CYAN = cyanobacteria, DEAD = dead coral, INVT = non-coral invertebrate, MALG = macroalgae, OCTO = octocoral, OTHER = other, TALG = turf algae, ZOAN = zoanthid.

Table I.3.2.1.1--Coral generic diversity of stratified random sites around Agrihan.

	AGR-50	AGR-51	AGR-52	AGR-53	AGR-54	AGR-55	AGR-56	AGR-57
Acanthastrea	X	X	X	X	X	X	X	X
Acropora		X	X	X	X	X	X	
Alveopora								
Astreopora	X	X	X	X	X		X	X
Cladiella*								
Corallimorph*								
Coscinarea								
Cyphastrea	X	X	X	X	X	X	X	
Diploastrea								
Distichopora*								
Echinopora	X	X		X	X			X
Euphyllia								
Favia	X	X	X	X	X	X	X	X
Favites			X				X	
Fungia		X			X			X
Galaxea	X	X	X		X			X
Gardinoseris	X				X			
Goniastrea	X	X	X	X	X	X		X
Goniopora	X	X			X			X
Gorgonian - other*		X						X
Heliopora*	X	X			X			X
Herpolitha								X

	AGR-50	AGR-51	AGR-52	AGR-53	AGR-54	AGR-55	AGR-56	AGR-57
Hydnophora								
Isopora	X							X
Leptastrea	X	X	X			X	X	X
Leptoria	X				X	X	X	
Leptoseris					X			X
Lobophyllia	X	X						X
Lobophytum*		X			X			
Merulina								
Millepora*					X			
Montastrea	X	X	X	X	X	X	X	X
Montipora	X	X	X		X		X	X
Ouphyllia								
Pachyclavularia*								
Pachyseris								
Palythoa*	X	X			X			
Pavona	X	X	X	X		X	X	X
Platygyra	X	X		X	X	X	X	X
Pleisiastrea	X	X			X			X
Plerogyra								
Pocillopora	X	X	X	X	X	X	X	X
Porites	X	X	X	X	X	X	X	X
Psammocora	X	X			X			X
Sarcophyton*	X	X						
Scapophyllia					X			X
Scolymia								
Seriatopora								
Sinularia*	X	X			X			X
Stylaster*								
Stylocoeniella					X		X	X
Stylophora	X	X	X	X	X	X	X	X
Turbinaria								
Wire Coral*								
Zoanthus*		X						
Total Genera per site	26	28	15	13	28	13	16	27

* non-scleractinian genera

Table I.3.2.1.2--Macroalgal generic diversity of stratified random sites around Agrihan.

	AGR-50	AGR-51	AGR-52	AGR-53	AGR-54	AGR-55	AGR-56	AGR-57
Amphiroa	X							
Asparagopsis								
Avrainvillea								
Boergesenia								
Boodlea			X				X	
Bryopsis								
Caulerpa					X			
Chlorodesmis								
Crustose Coralline	X	X	X	X	X	X	X	X
Cyanobacteria		X		X	X		X	X
Dichotomaria					X			
Dictyosphaeria			X	X		X	X	
Dictyota	X	X	X		X	X	X	X
Galaxaura								
Gibsmithia								
Halimeda		X			X			
Halymenia								
Lobophora	X	X	X	X	X	X	X	X
Microdictyon								
Neomeris	X	X	X	X	X		X	X
Non-geniculate calcified branched								
Padina	X		X	X			X	
Peyssonnelia								
Portieria								
Rhipilia								
Turbinaria							X	
Tydemania								
Udotea							X	
Valonia	X	X	X	X	X		X	X
Unknown								
Total Genera per site	7	7	8	7	9	4	11	6

I.3.2.2. Coral Populations

During MARAMP 2009, belt transect surveys were conducted at six long-term REA sites around Agrihan, covering a total reef area of 100 m^2 and totaling 2205 anthozoan and hydrozoan colonies enumerated. Taxonomic richness varied between sites with 34 anthozoan genera (30 scleractinian, 3 octocoral, 1 zoanthid) and 2 hydrozoan genera being represented within belt transects (Table I.3.2.2.1.). *Pavona*, *Goniastrea*, *Favia*, and *Pocillopora* were the most abundant scleractinian genera, contributing 17.1% 16.6%, 11.4%, and 11.0% of the total number of colonies enumerated island-wide. All other genera individually contributed less than 10% of the total number of colonies.

Table I.3.2.2.1--Relative abundance of anthozoan genera enumerated within belt transects around Agrihan during MARAMP 2009.

Island	Genus	Relative abundance
Agrihan	Pavona	17.10
	Goniastrea	16.64
	Favia	11.38
	Pocillopora	10.98
	Cyphastrea	8.89
	Astreopora	4.90
	Montastrea	4.40
	Stylophora	3.85
	Montipora	3.58
	Porites	3.49
	Galaxea	3.17
	Leptastrea	2.04
	Sarcophyton	2.04
	Heliopora	1.32
	Lobophytum	1.22
	Platygyra	1.04
	Acanthastrea	1.00
	Sinularia	0.59
	Palythoa	0.50
	Acropora	0.32
	Goniopora	0.32
	Psammocora	0.32
	Alveopora	0.09
	Echinophyllia	0.09
	Echinopora	0.09
	Favites	0.09
	Lobophyllia	0.09
	Mycedium	0.09
	Leptoria	0.05
	Leptoseris	0.05
	Plesiastrea	0.05
	Scapophyllia	0.05
	Scolymia	0.05
	Stylaster	0.05
	Stylocoeniella	0.05
	Turbinaria	0.05

The highest relative abundance of *Pavona* (> 30% of number of colonies) was found at sites AGR-02 and AGR-04 on the south and north side of the island, respectively. The highest relative abundance of *Goniastrea* (> 26% of number of colonies) was found at sites AGR-05 and AGR-06 on the west side of the island. The highest relative abundance of *Favia* (18% of number of colonies) was found at site AGR-06 on the west side of the island. The highest relative abundance of *Pocillopora* (22% of number of colonies) was found at AGR-04 on the north side. (Fig. I.3.2.2.1.).

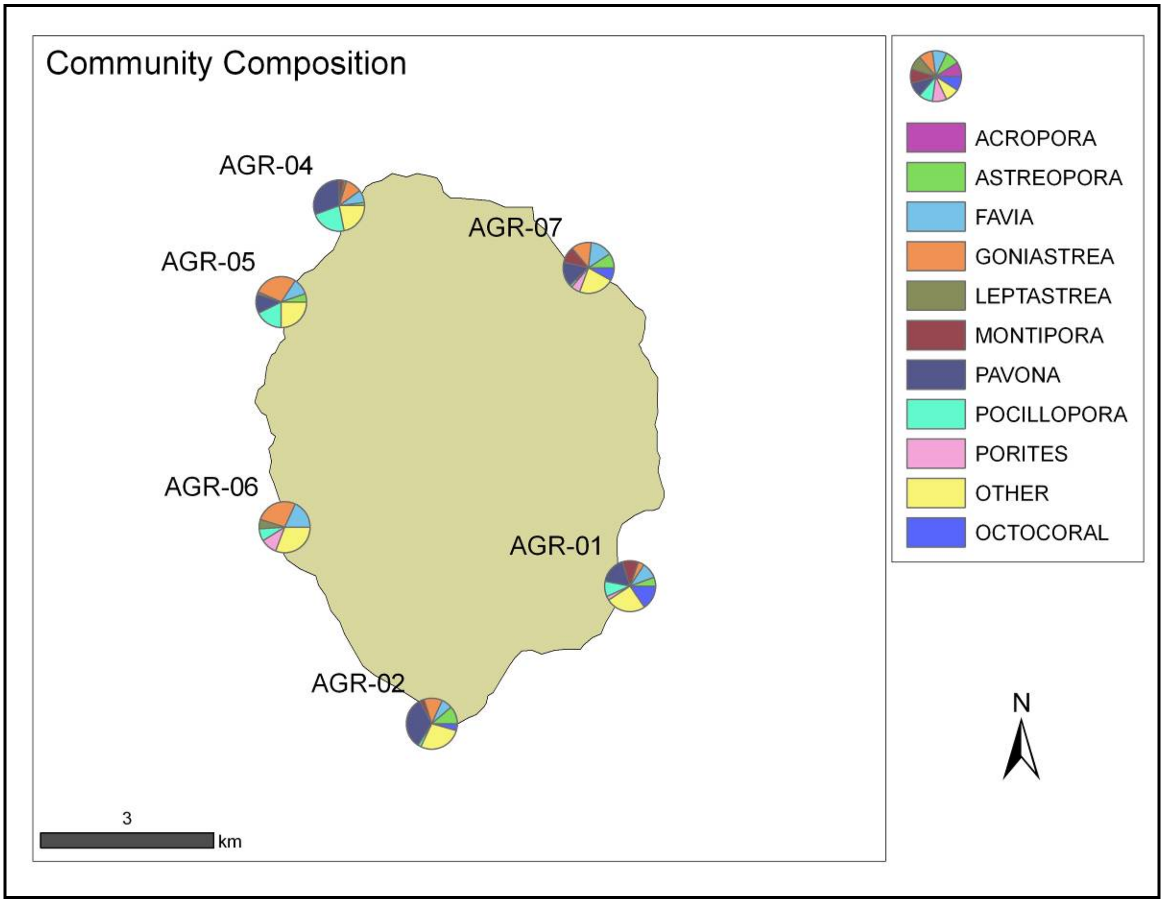


Figure I.3.2.2.1--Relative abundance of coral genera from REA surveys around Agrihan during MARAMP 2009.

I.3.3. Coral Health and Disease

During MARAMP 2009, the occurrence of disease, predation, and other health impairments around Agrihan was low, with a total of 18 cases enumerated. A summary of lesion occurrence and relative abundance is presented in Table I.3.3.1. The most numerically abundant type of lesion was due to predation. These were detected in *Goniastrea reniformis* and *Astreopora myriophthalma*. Fungal infections, bleaching, and barnacle infestations were the next most numerically abundant type of afflictions, with three cases of each type of condition tallied island-wide. Two cases of cyanophyte infection were detected. Lesions affecting coralline algae were rare, with only one case of coralline lethal orange disease (CLOD) observed island-wide.

Table I.3.3.1--Number of cases of scleractinian and coralline algal diseases and predation enumerated during REA surveys around Agrihan, MARAMP 2009. BIN: barnacle infestation; BLE: bleaching; CYA: cyanophyte infections; FUG: fungal infections; PRE: *Acanthaster*/*Drupella* predation scars; TLS: tissue loss; CLOD: coralline lethal orange disease.

DZCode	AGR-01	AGR-02	AGR-04	AGR-05	AGR-06	AGR-07	Grand Total
BIN	2		1				3
BLE			2	1			3
CYA	2						2
FUG		2			1		3
PRE		6					6
TLS	1						1
Total	**5**	**8**	**3**	**1**	**1**	**0**	**18**
CLOD		1					1

I.3.4. Macroinvertebrate Surveys (non-coral)

A total of 871 individuals of benthic invertebrate target species or taxa groups were enumerated from 12 belt transects at six sites. Non-cryptic macroinvertebrates were low around Agrihan with the exception of the boring sea urchin, *Echinostrephus aciculatus*, and the sea star, *Linckia multifora.* The island density for *E. aciculatus* was 5.81 (SE 2.51) organisms 50 m^{-2}. Densities were highest at AGR-01, AGR-04 and AGR-05 (4.48, 11.2 and 15.44 organisms 50 m^{-2}, respectively). The island density for *L. multifora* was 3.4 (SE 0.68) organisms 50 m^{-2}. Densities were relatively high at all sites; the greatest being at AGR-01, AGR-02, and AGR-07 (5.12, 4.64 and 4.72 organisms 50 m^{-2}, respectively).

Coral crabs from the genus *Trapezia*, hermit crabs from the genus *Calcinus,* and the coral eating snail, *Quoyula madreporarum* were common within coral heads. Densities of *Trapezia* were greatest at sites AGR-02 and AGR-03 (2.32 and 2.16 organisms 50 m^{-2}, respectively). Densities of *Calcinus* were greatest at sites AGR-04 and AGR-05 (1.2 and 1.92 organisms 50 m^{-2}, respectively), and densities of *Quoyula madreporarum* were greatest at site AGR-07 with 0.72 organisms 50 m^{-2}. *Tridacna* clams were not abundant. Site AGR-05 had the greatest density with 0.24 organisms 50 m^{-2}. Holothuroids were exceptionally rare.

I.3.4.1--Urchin Measurements

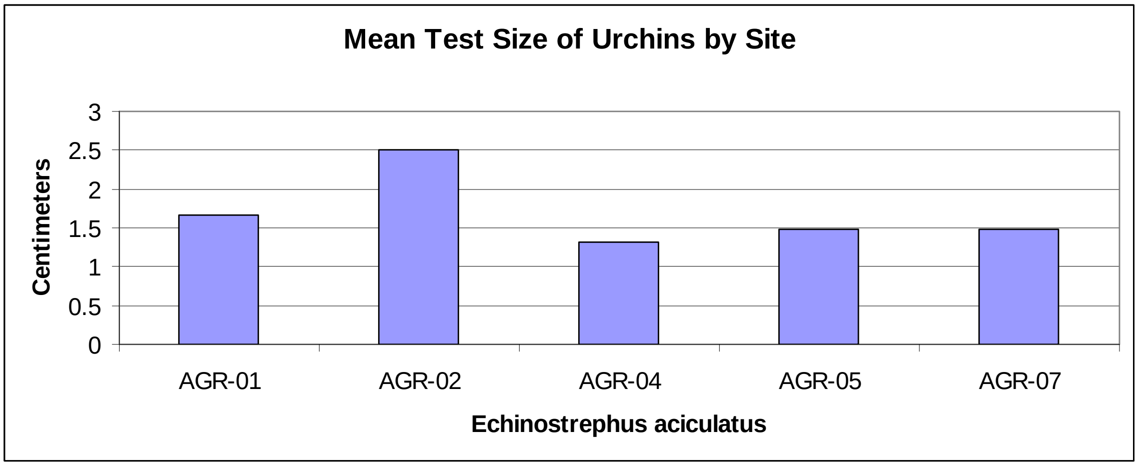


Figure I.3.4.1.1--Average test diameter of urchins encountered at each site. Only sites where ≥ 5 measurements were recorded for a species are represented. *Echinostrephus aciculatus* is the only represented echinoid.

I.3.4.2. Invertebrate Collections

Seventy five *Linckia multifora* arms and three asterinids were collected at Agrihan.

I.3.5. Benthic Towed-diver Surveys

Eleven benthic towed-diver surveys were completed at Agrihan in 2009 (Fig. I.3.5.1.). Habitats covered during surveys varied with the majority of tow segments conducted over hard bottom (a mixture of continuous pavement reefs and pavement separated by thin sand channels). Extensive sand flats were encountered during one tow off the village in the southwest region of the island.

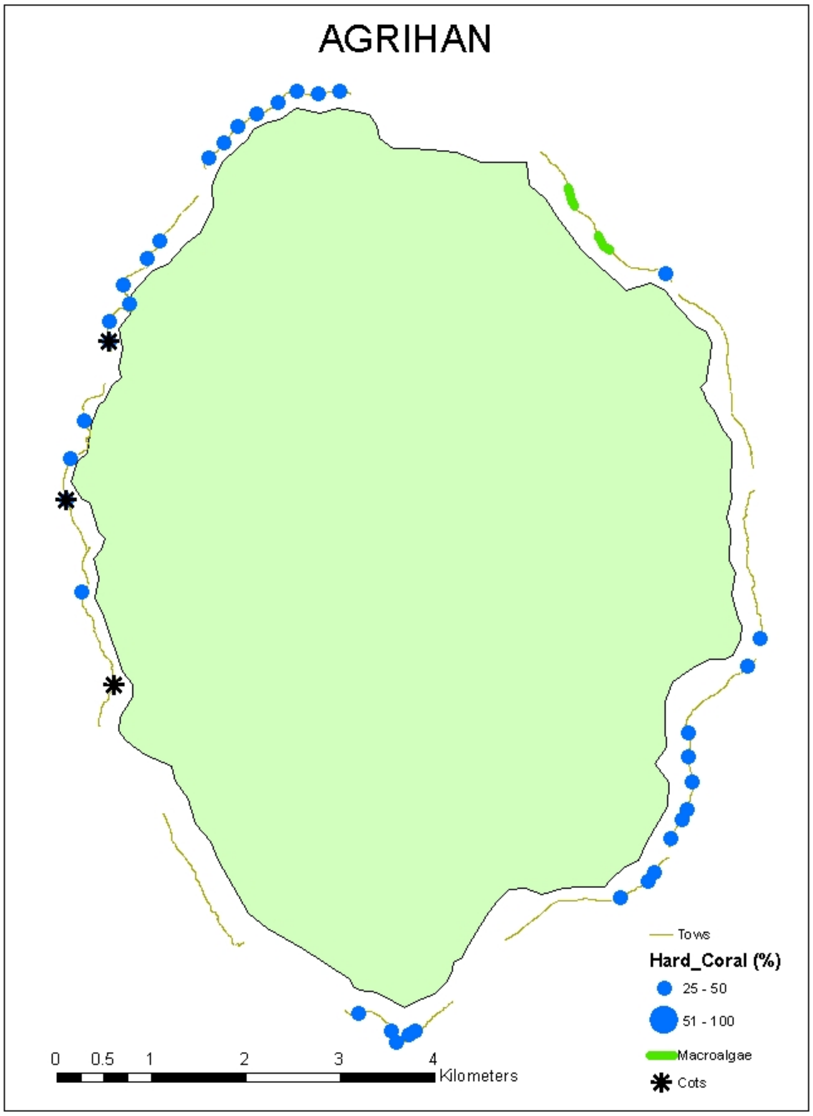


Figure I.3.5.1--Hard coral cover, elevated macroalgal cover (> 25%), and crown-of-thorn (COT) abundances during tow segments at Agrihan 2009.

Hard coral constituted the highest cover of the biotic categories observed at Agrihan, and some spatial patterns were observed with higher cover noted on the northwestern and eastern coasts. Common coral genera observed included *Pocillopora*, *Astreopora*, and localized *Pavona*, *Galaxea*, and *Goniopora*. Some areas of elevated soft coral were also noted, mostly *Sinularia* and *Sarcophyton*.

Macroalgal cover was surprisingly low for most tow segments with the exception of two localized areas in the northeast where *Halimeda* and *Asparagopsis* were the most gregarious genera observed.

Few COTs were observed at Agrihan while the most abundant macroinvertebrates were boring urchins. Giant clams were common but in low densities with occasional individuals noted in most tows.

Benthic category	Mean ± SE
Hard coral	16 ± 1.2
Soft coral	5.5 ± 0.7
Macroalgae	3.2 ± 0.7
Coralline algae	5.6 ± 0.5
Sand	16.6 ± 2.9
Rubble	1.9 ± 0.3
COTs	5
Free urchins	7
Boring urchins	5796
Sea cucumbers	11
Giant clams	84
* Sum of observed individuals	

I.4. Fish Surveys

I.4.1. REA Fish Surveys

Stationary point count data (nSPC)

During the survey period, nSPC surveys were conducted at 14 sites around Agrihan. Surgeonfish were the largest contributor to total biomass with 1.4 kg 100 m^{-2}. Snapper were the second largest contributor to total biomass with 0.7 kg 100 m^{-2}, followed by parrotfish at 0.6 kg 100 m^{-2} (Fig. I.4.1.1.).

Overall observations

A total of 183 fish species were observed by all divers during the survey period. The average total fish biomass around Agrihan during the survey period was 5.9 kg 100 m^{-2} for the nSPC surveys (Table I.4.1.1.).

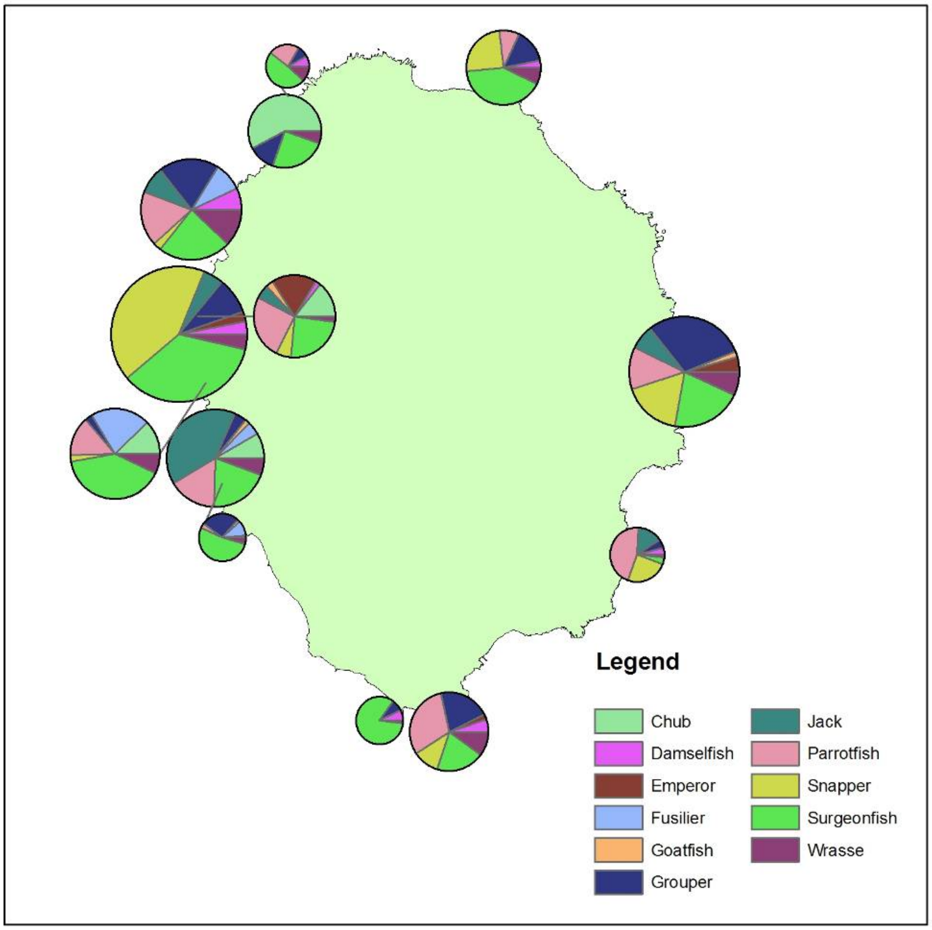


Figure I.4.1.1--Site location and distribution of total fish biomass by family. The sizes of the pie charts are proportional to fish biomass.

I.4.2. Towed-diver Surveys

During HA0903, the CRED towed-diver team completed 11 surveys at Agrihan covering 23.6 km (23.6 ha) of ocean floor (Table I.4.2.1.). Mean survey length was 2.1 km with a maximum length of 2.5 km and a minimum of 1.7 km. Mean survey depth was 15.0 m with a maximum depth of 18.5 m and a minimum of 13.6 m. Mean temperature on these surveys was 28.3°C with a maximum temperature of 28.5°C and a minimum of 28.1°C.

Table I.4.2.6.--Survey statistics for towed-diver sampling during HA0903.

		Length (km)					Depth (m)				Temperature (ºC)			
Island/Reef	#	Sum	Mean	Max	Min	SD	Mean	Max	Min	SD	Mean	Max	Min	SD
Agrihan	11	23.6	2.1	2.5	1.7	0.3	15.0	18.5	13.6	1.4	28.3	28.5	28.1	0.1

One hundred ninty-two individual large-bodied reef fishes (> 50 cm TL) of 23 different species and 14 different families were encountered at Agrihan (Table I.4.2.2.). Overall numeric density for this class of reef fishes was 0.81 #/100 m^2 (81.42 #/ha) with a biomass density of 2.29 kg/100 m^2 (0.23 t/ha). Numeric and biomass density were both dominated by *Carcharhinus amblyrhynchos*.

Table I.4.2.7--Species numeric and biomass density for large-bodied reef fishes (> 50 cm TL) observed at Guam during HA0903 CRED towed-diver surveys.

Species	#	#/100 m^2	#/ha	Biomass (kg)	kg/100 m^2	t/ha
Naso hexacanthus	19	0.08	8.06	41.68	0.18	0.02
Naso tonganus	1	0.00	0.42	2.83	0.01	0.00
Balistoides viridescens	3	0.01	1.27	9.84	0.04	0.00
Caranx lugubris	1	0.00	0.42	2.48	0.01	0.00
Caranx melampygus	14	0.06	5.94	33.37	0.14	0.01
Carangoides orthogrammus	3	0.01	1.27	6.46	0.03	0.00
Caranx sexfasciatus	25	0.11	10.60	58.58	0.25	0.02
Carcharhinus amblyrhynchos	34	0.14	14.42	202.27	0.86	0.09
Triaenodon obesus	2	0.01	0.85	31.42	0.13	0.01
Taeniura meyeni	4	0.02	1.70	73.58	0.31	0.03
Diodon hystrix	1	0.00	0.42	7.03	0.03	0.00
Fistularia commersonii	1	0.00	0.42	0.62	0.00	0.00
Nebrius ferrugineus	1	0.00	0.42	57.54	0.24	0.02
Plectorhinchus gibbosus	1	0.00	0.42	2.44	0.01	0.00
Aprion virescens	1	0.00	0.42	10.04	0.04	0.00
Lutjanus bohar	26	0.11	11.03	84.20	0.36	0.04
Macolor macularis	4	0.02	1.70	8.57	0.04	0.00
Macolor niger	26	0.11	11.03	47.13	0.20	0.02
Chlorurus microrhinos	11	0.05	4.66	29.38	0.12	0.01
Scarus rubroviolaceus	3	0.01	1.27	7.81	0.03	0.00
Gymnosarda unicolor	3	0.01	1.27	23.81	0.10	0.01
Sphyraena qenie	6	0.03	2.54	33.60	0.14	0.01
Arothron stellatus	2	0.01	0.85	27.03	0.11	0.01
Grand Total	192	0.81	81.42	540.18	2.29	0.23
# of Species	23					

The most prevalent families in terms of numeric and biomass density were lutjanids (ND = 29%, BD = 19%), carangids (ND = 21%, BD = 13%), and carcharhinids (ND = 19%, BD = 29%) (Fig. I.4.2.1., I.4.2.2.). There was no clear pattern to the geographic distribution of large-bodied reef fishes around the island. (Fig. I.4.2.3.).

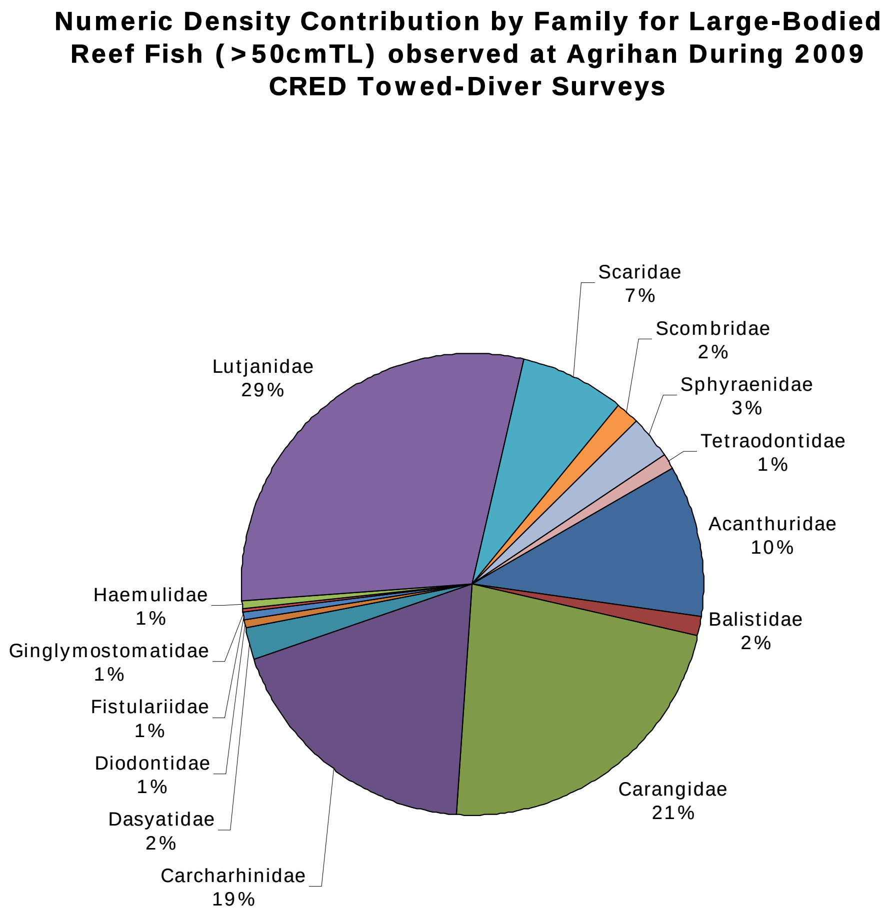


Figure I.4.2.1--Numeric density of fishes by family.

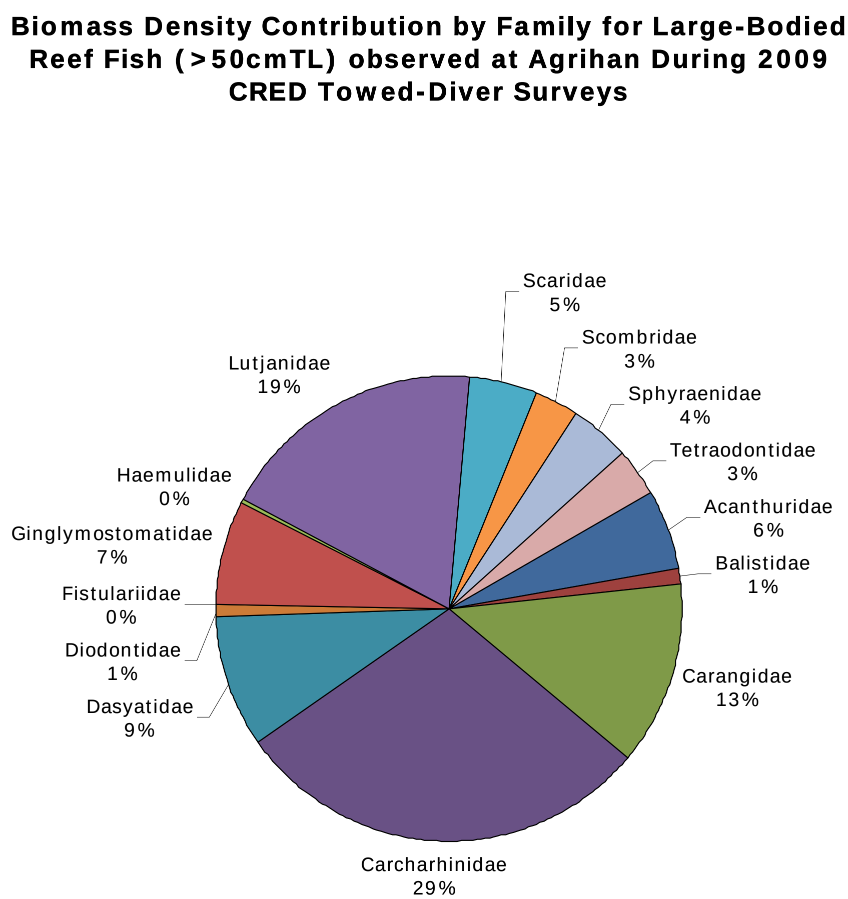


Figure I.4.2.2--Biomass density of fishes by family.

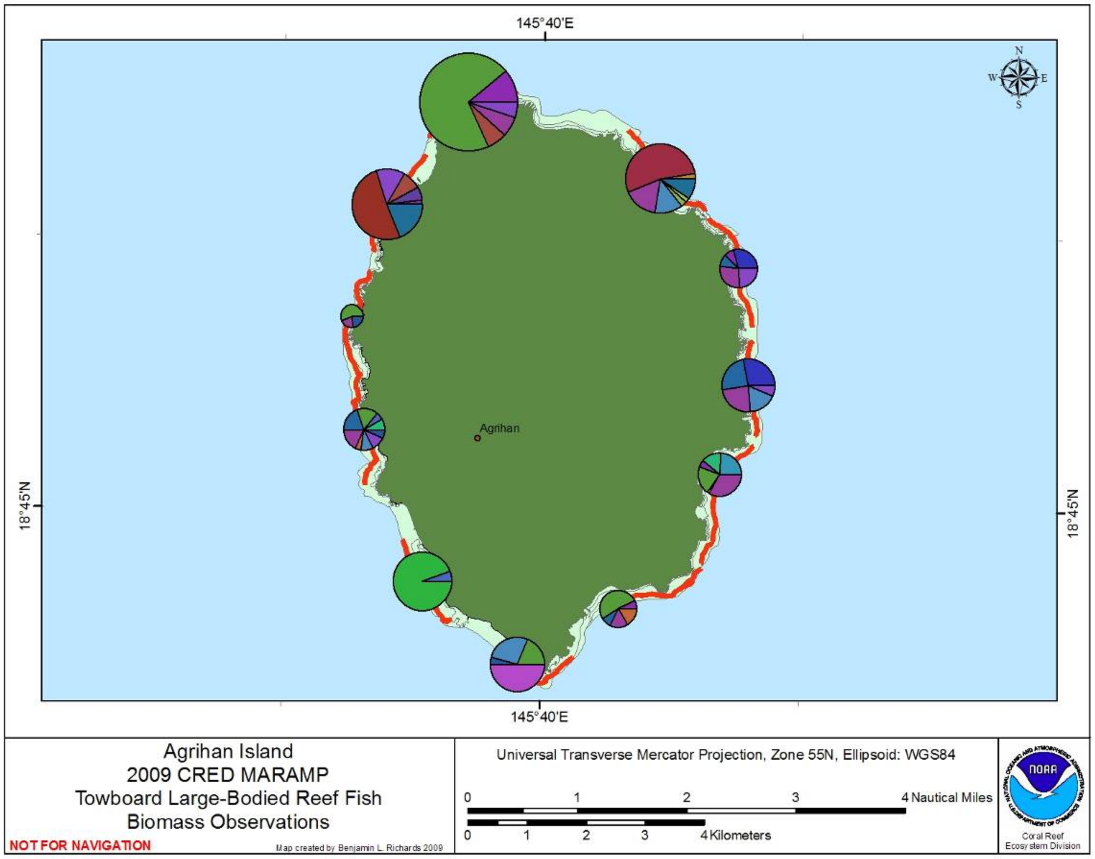


Figure I.4.2.3--Geographic distribution of fish biomass around Agrihan. Each species is represented by a legend color. Diameter of pie chart is proportional to total biomass of all species encountered on the underlying survey.

Appendix J: Alamagan Results

J.1. Oceanography and Water Quality

Two subsurface temperature recorders (STRs) were recovered and replaced at Alamagan during HA0903 (Table J.1.1., Fig. J.1.1.). Both STRs show similar patterns and temperature ranges, with a clear annual fluctuation due to seasonal warming and cooling (Fig. J.1.2.). Warmest temperatures peaked at about 31^{o}C and occurred during the summer months of July to October. Winter temperatures reached lows of approximately 26^{o}C and occurred during November through June.

One rapid ecological assessment (REA) site (ALA-01) was visited to collect water samples for microbiological, nutrient and chlorophyll analyses, and the remaining two REA sites (ALA-02 and ALA-03) were sampled for just nutrients and chlorophyll. Samples were obtained from the surface and approximately 1 m above the reef. Microbial water samples were taken using diver-deployable Niskin bottles to collect 8 liters of seawater (four bottles; 2 liters per bottle) at each study site. Chlorophyll samples were filtered, and nutrient samples were frozen at -30^{o}C for post-cruise analysis. Shallow-water conductivity temperature and depth (CTD) casts were also conducted at these sites. In addition, 15 CTD casts were taken every 1 km around the perimeter of Alamagan at the 30 m depth contour.

Table J.1.1--Alamagan moorings.

Action	Mooring type	Serial number	Lat		Long		Depth (m)
Deployment	STR	39240220358	17.61488409	N	145.8425208	E	16.5
Retrieval	STR	39368591651	17.58746102	N	145.8187342	E	7.0
Retrieval	STR	39390381811	17.61488409	N	145.8425208	E	16.5
Deployment	STR	39432363080	17.58746102	N	145.8187342	E	7.0

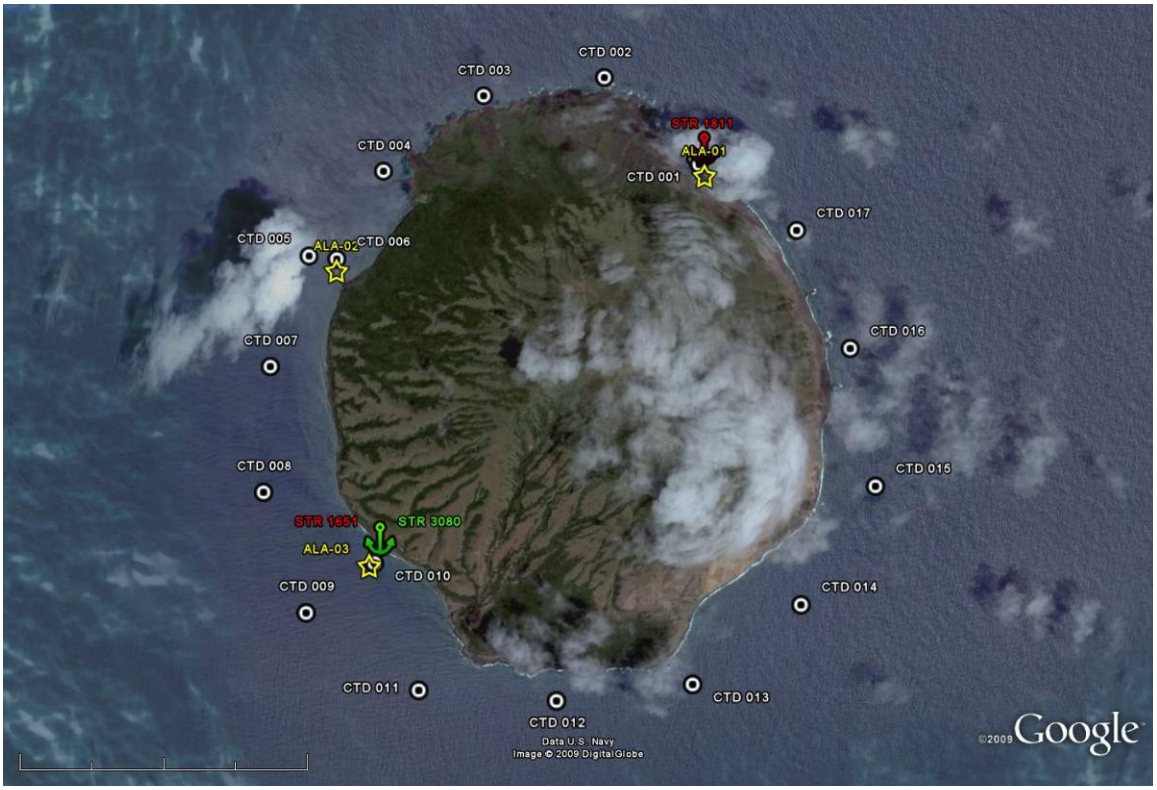


Figure J.1.1--Deployed and recovered instrument moorings and CTD and water sampling sites, Alamagan, HA0903.

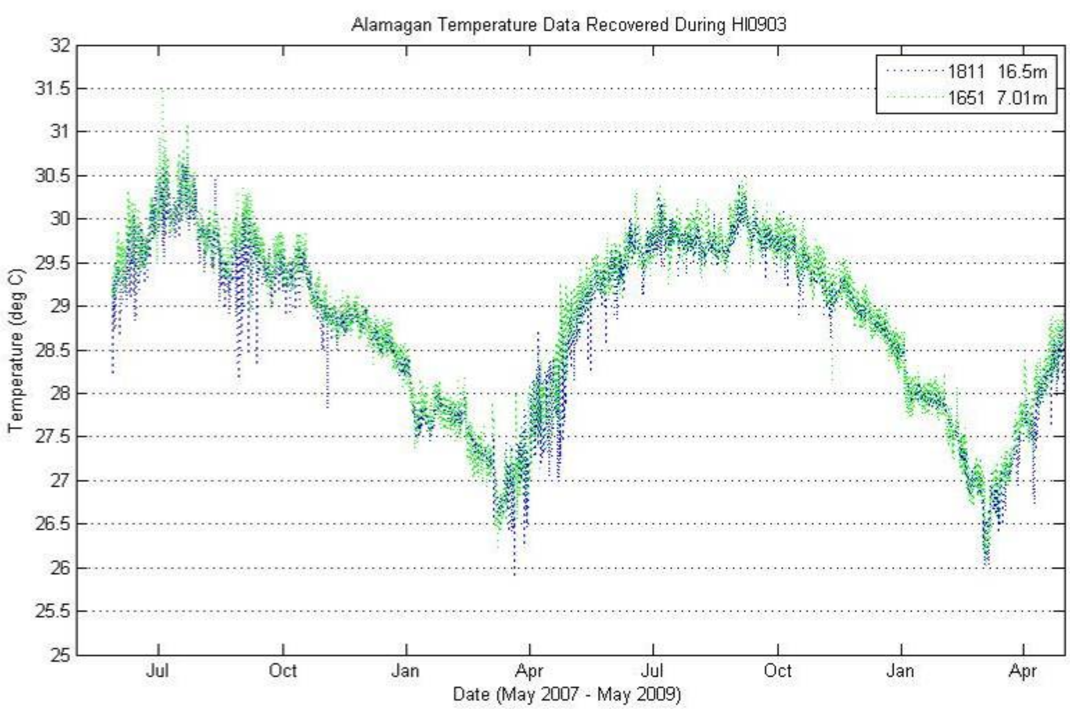


Figure J.1.2--Temperature time series from STR moorings at Alamagan.

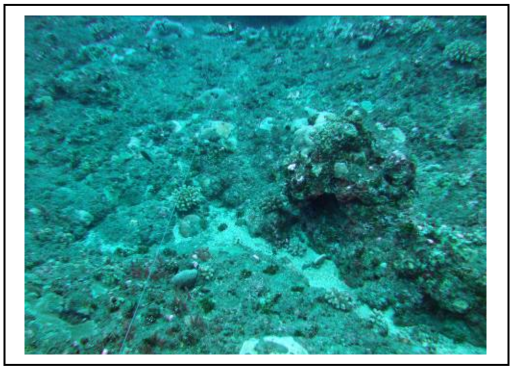
J.2. Rapid Ecological Assessment (REA) Site Descriptions

ALA-02
5/4/2009

E 145° 48.918
N 17° 36.452

Forereef
Mid

Depth: 11–15 m



Site description: Northwestern site; low topographic complexity (low relief); high coral and macroalgal cover.

ALA-03
5/4/2009

E 145° 49.085
N 17° 35.216

Forereef
Mid

Depth: 11–17 m

Site description: Southwestern site; moderate topographic complexity (low relief); high coral cover; moderate macroalgal cover; dominated by turf algae.

ALA-50
5/4/2009

E 145° 51.175
N 17° 36.140

Forereef
Deep

Depth: 25 m

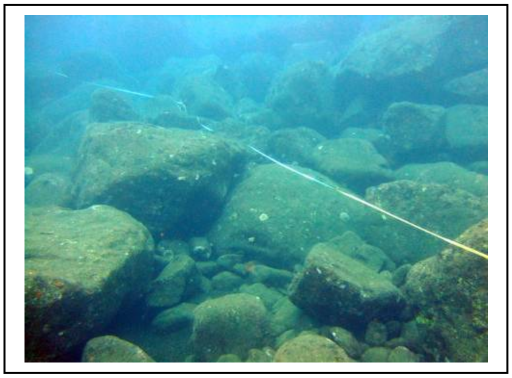
Site description: Eastern deep site; moderate topographic complexity; 40 degree slope; high coral and macroalgal cover.

ALA-51
5/4/2009

E 145° 49.216
N 17° 36.771

Forereef
Shallow

Depth: 5 m




Site description: Shallow northwestern site; moderate topographic complexity (boulders); moderate coral cover; low macroalgal cover; dominated by turf algae.

ALA-52
5/4/2009

E 145° 48.859
N 17° 35.877

Forereef
Shallow

Depth: 2 m

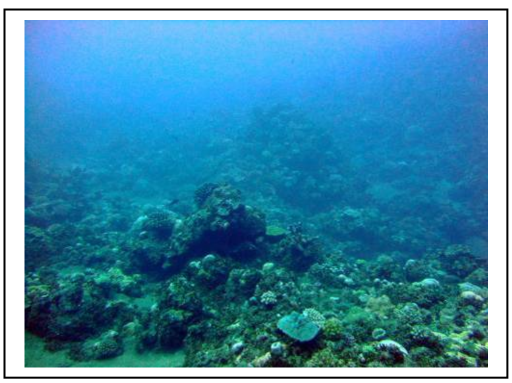
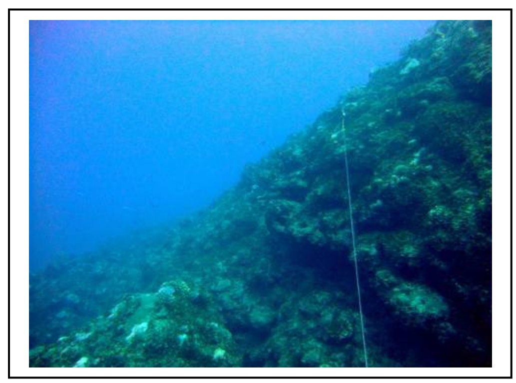

Site description: Shallow western site, moderate topographic complexity; spur and groove habitat creating deep channels; moderate coral cover; low macroalgal cover; dominated by turf algae.

ALA-53
5/4/2009

E 145° 50.149
N 17° 34.712

Forereef
Deep

Depth: 21 m

Site description: Deep southern site; high topographic complexity; 45 degree slope; ledges and drop-offs; high coral and macroalgal cover.

J.3. Benthic Environment

J.3.1. Algal Communities

During the Mariana Reef Assessment and Monitoring Program (MARAMP) 2009, two permanent, long-term REA monitoring sites were surveyed around Alamagan Island for percent benthic cover based on the 20-cm interval line point intercept (LPI) methodology. Benthic communities at sites surveyed around Alamagan were dominated by macroalgae, scleractinian corals, and turf algae (Table J.3.1.1.). Turf algal percent cover exceeded that of other functional groups at site ALA-03 with 41.2% cover. At site ALA-02, percent cover of macroalgae and scleractinian corals were approximately equal (30.8% and 33.6%, respectively). A combined total of 7 species of macroalgae were observed (4 chlorophytes, 1 ochrophytes, 2 rhodophytes) from the 2 sites surveyed (Tables J.3.1.2. and Table J.3.1.3.). *Asparagopsis taxiformis* dominated the macroalgal community at site ALA-02 with a percent cover range of 12.8% (Table J.3.1.3.). *Halimeda opuntia* and *Lobophora variegata* were found with equal percent covers of 0.8% at site ALA-03 (Table J.3.1.3.).

Table J.3.1.1--Percent cover of algal functional groups at long-term monitoring sites at Alamagan.

Site	Macroalgae	Turf Algae	Coralline red algae (crustose + upright)	Cyanobacteria	Scleractinian Coral	Octocoral
ALA-02	30.8%	22.8%	8.0%	0.4%	33.6%	0.4%
ALA-03	18.8%	41.2%	9.6%	2.0%	25.6%	0.8%

Table J.3.1.2--Additional species recorded at each site at Alamagan during roving diver survey.

Site	Chlorophyta
ALA-02	*Caulerpa serrulata*
ALA-02	*Neomeris* sp.
ALA-02 ALA-03	*Valonia ventricosa*
	Rhodophyta
ALA-02	*Amphiroa* sp.

Table J.3.1.3--Percent cover of macroalgal species at long-term monitoring sites at Alamagan. Sum totals for each row equal the percent cover of macroalgae recorded in Table J.3.1.1.

Site	Halimeda opuntia	Lobophora variegata	Asparagopsis taxiformis
ALA-02	1.6%	2.4%	12.8%
ALA-03	0.8%	0.8%	-

J.3.2. Coral Communities

J.3.2.1. Percent Benthic Cover

During MARAMP 2009, percent benthic cover REA surveys conducted around Alamagan at two permanent, long-term sites yielded an island-wide mean of 29.6% (Fig. J.3.2.1.1.), with the highest value recorded at site ALA-02 located in the protected southwestern shore (33.6%) (Fig. J.3.2.1.1.).

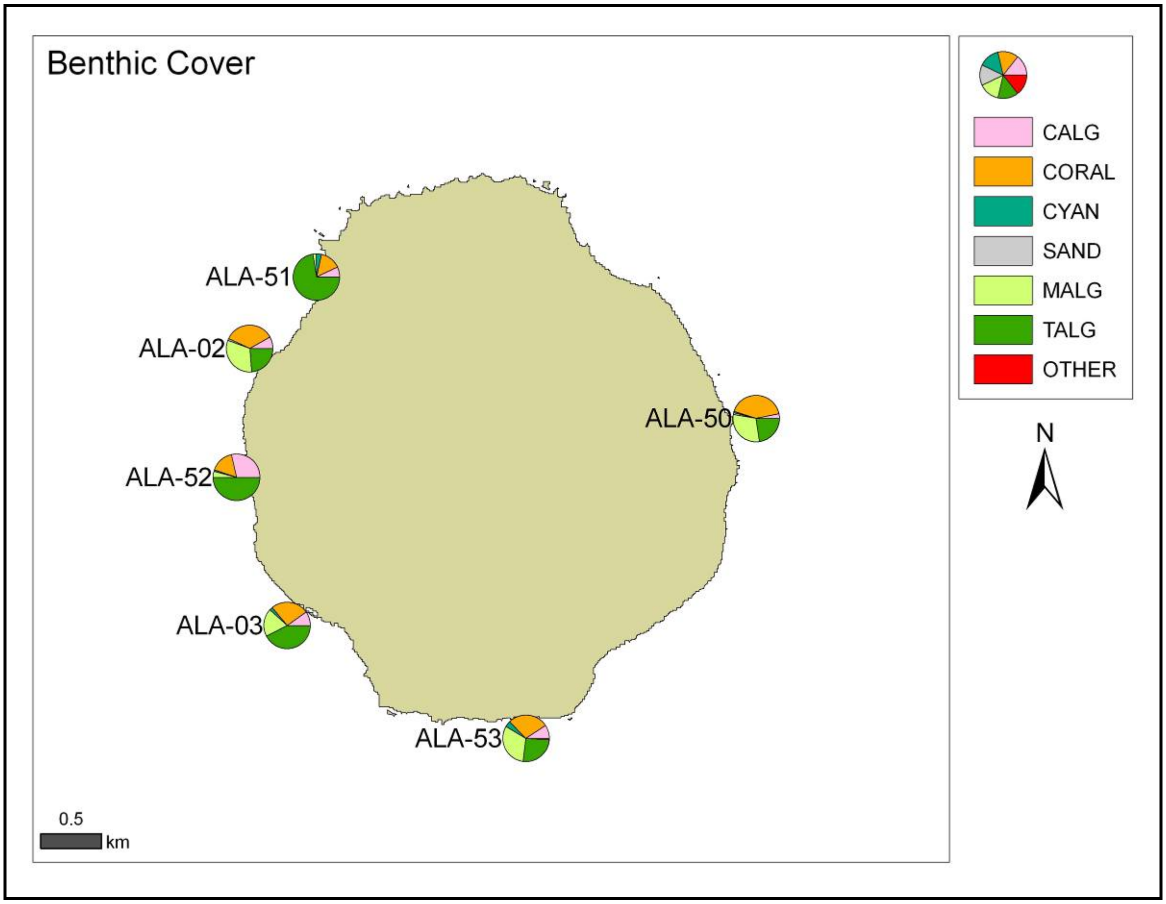


Figure J.3.2.1.1--Percent cover of benthic functional groups at the long-term and stratified random REA monitoring sites around Alamagan during MARAMP 2009. CALG = crustose coralline red algae, CYAN = cyanobacteria, MALG = macroalgae, TALG = turf algae.

Four additional stratified random REA sites were surveyed around Alamagan for percent benthic cover (based on 50-cm interval LPI surveys; Fig. J.3.2.1.1.) and generic diversity data in 2009. Benthic communities surveyed at two sites greater than 20 m deep were dominated by scleractinian coral (32.4% $\pm$ 5.9), macroalgal (28.4% $\pm$ 1.0) and turf algal (22.5% $\pm$ 2.0) functional groups (Fig. I.3.2.1.2). Two shallow sites (< 10 m deep) were dominated by turf algal (60.3% $\pm$ 12.3), calcareous algal (17.2% $\pm$ 10.3) and scleractinian coral (15.2% $\pm$ 0.5) functional groups (Fig. I.3.2.1.2). Coral generic diversity was highest at site ALA-53 with 32 different genera observed (Table J.3.2.1.1.). In contrast, site ALA-51 had the lowest generic diversity with 13 different genera observed at both. An average of 25 coral genera were recorded at each site. Common genera observed at most sites included *Pocillopora, Porites, Pavona, Favia, Leptastrea, Goniastrea*, and *Astreopora.* Macroalgal generic diversity was highest at sites ALA-52 and ALA-53 with 10 genera observed at both locations (Table J.3.2.1.2.). Site ALA-50 had the lowest generic diversity with five genera observed. An average of 8 macroalgal genera were recorded for each site. Common macroalgae observed at most sites included *Caulerpa, Halimeda,* and *Dictyota.*

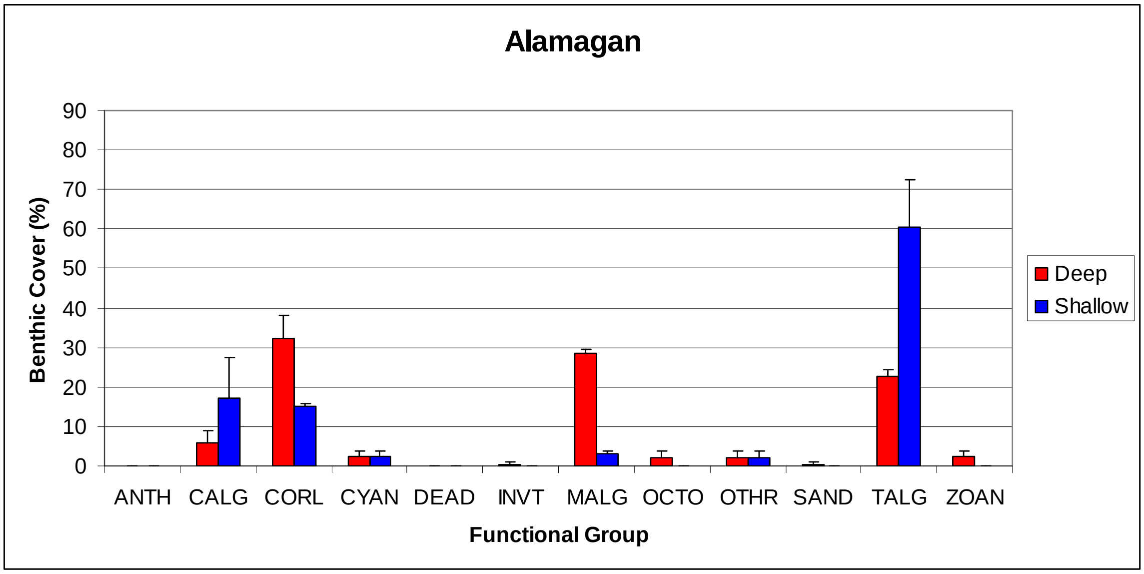


Figure J.3.2.1.2.--Percent cover of functional groups at shallow and deep independent LPI monitoring sites established in 2009 at Alamagan. ANTH = anthozoan, CALG = crustose coralline red algae, CORL = coral, CYAN = cyanobacteria, DEAD = dead coral, INVT = non-coral invertebrate, MALG = macroalgae, OCTO = octocoral, OTHER = other, TALG = turf algae, ZOAN = zoanthid.

Table J.3.2.1.1--Coral generic diversity of stratified random sites around Alamagan.

	ALA-50	ALA-51	ALA-52	ALA-53
Acanthastrea	X	X	X	X
Acropora		X	X	
Alveopora				
Astreopora	X	X	X	X
*Cladiella**			X	
*Corallimorph**				
Coscinarea	X			X
Cyphastrea	X	X	X	X
Diploastrea				
*Distichopora**				
Echinopora	X			
Euphyllia				
Favia	X	X	X	X
Favites		X	X	
Fungia				X
Galaxea	X		X	X
Gardinoseris	X			
Goniastrea	X	X	X	X
Goniopora	X		X	X
*Heliopora**	X		X	X
Herpolitha				X
Hydnophora	X		X	

	ALA-50	ALA-51	ALA-52	ALA-53
Isopora				X
Leptastrea	X	X	X	X
Leptoria		X	X	
Leptoseris	X			X
Lobophyllia	X			
Lobophytum*	X			X
Merulina				
Millepora*				X
Montastrea	X		X	X
Montipora	X		X	X
Ouphyllia	X			X
Pachyclavularia*				X
Pachyseris				
Palythoa*	X			
Pavona	X	X	X	X
Platygyra	X	X	X	X
Pleisiastrea	X			X
Plerogyra				
Pocillopora	X	X	X	X
Porites	X	X	X	X
Psammocora	X		X	X
Sarcophyton*				
Scapophyllia	X			X
Scolymia				
Seriatopora				
Sinularia*	X		X	X
Stylaster*	X			X
Stylocoeniella				
Stylophora	X			X
Turbinaria	X			
Wire Coral*				X
Zoanthus*				X
Total Genera per site	31	13	22	32

* non-scleractinian genera

Table J.3.2.1.2--Macroalgal generic diversity of stratified random sites around Alamagan.

	ALA-50	ALA-51	ALA-52	ALA-53
Amphiroa			X	
Asparagopsis			X	
Avrainvillea				
Boergesenia				
Boodlea		X	X	
Bryopsis				
Caulerpa	X	X	X	X
Chlorodesmis		X	X	
Crustose Coralline	X	X	X	X
Cyanobacteria				
Dichotomaria				
Dictyosphaeria		X	X	
Dictyota		X	X	X
Galaxaura				
Gibsmithia				
Halimeda	X	X	X	X
Halymenia				
Lobophora	X	X		
Microdictyon				
Neomeris		X		
Non-geniculate calcified branched				
Padina				
Peyssonnelia				
Portieria		X		
Rhipilia				
Turbinaria				
Tydemania				X
Udotea				
Valonia	X			X
Unknown			1	
Total Genera per site	5	10	10	6

I.3.2.2 Coral Populations

During MARAMP 2009, belt transect surveys were conducted at two long-term REA sites around Alamagan, covering a total reef area of 38.7 m^2 and totaling 927 anthozoan and hydrozoan colonies enumerated. Taxonomic richness varied between sites with 23 anthozoan genera (20 scleractinian, 2 octocoral, 1 zoanthid) and 1 hydrozoan genus being represented within belt transects (Table J.3.2.2.1.). *Favia*, *Astreopora*, and *Pavona* were the most abundant scleractinian genera, contributing 23.5% 16.1%, and 13.4% of the total number of colonies enumerated island-wide. All other genera individually contributed less than 10% of the total number of colonies.

Table J.3.2.2.1--Relative abundance of anthozoan and hydrozoan genera enumerated within belt transects around Alamagan during MARAMP 2009.

Island	Genus	Relative abundance
Alamagan	*Favia*	23.52
	Astreopora	16.07
	Pavona	13.38
	Pocillopora	9.82
	Cyphastrea	7.66
	Montipora	7.34
	Leptastrea	5.07
	Porites	3.78
	Goniopora	1.73
	Lobophytum	1.62
	Goniastrea	1.51
	Heliopora	1.51
	Montastrea	1.51
	Galaxea	0.97
	Psammocora	0.97
	Platygyra	0.86
	Alveopora	0.76
	Sinularia	0.76
	Echinopora	0.32
	Palythoa	0.32
	Mycedium	0.22
	Acanthastrea	0.11
	Hydnophora	0.11
	Stylocoeniella	0.11

Astreopora was the dominant genus at site ALA-02, contributing 18.6% of the total number of colonies enumerated at the site, while *Favia* was the dominant genus at site ALA-03, contributing 25.2% of the total number of colonies enumerated at the site (Fig. J.3.2.2.1.).

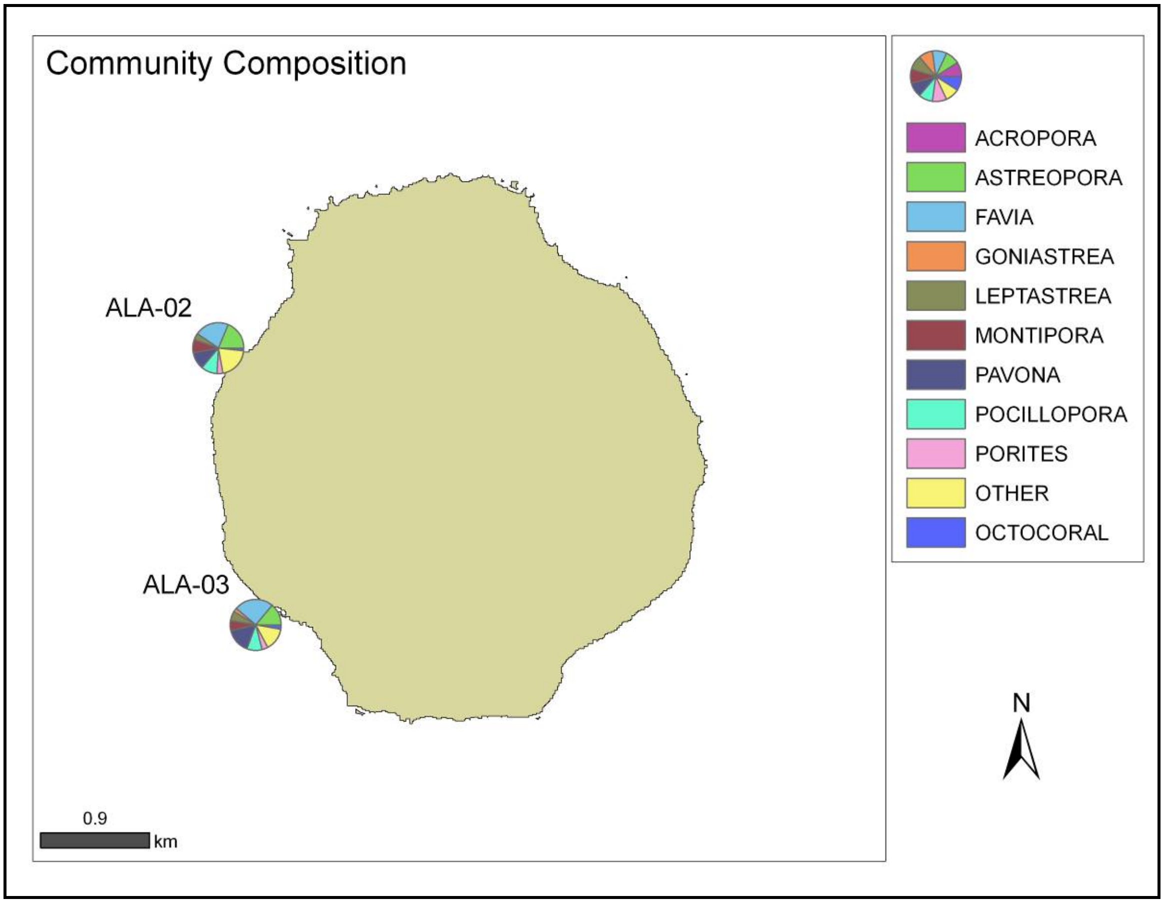


Figure J.3.2.2.1--Relative abundance of coral genera from REA surveys around Alamagan during MARAMP 2009.

J.3.3. Coral Health and Disease

During MARAMP 2009, the occurrence of disease, predation, and other health impairments around Alamagan was low, with a total of 13 cases enumerated. A summary of lesion occurrence and relative abundance is presented in Table J.3.3.1. The most numerically abundant type of lesion was due to fungal infections. These were detected in *Pavona varians, Cyphastrea*, and *Pocillopora*. Two cases of cyanophyte infections and one case of bleaching were also noted.

Table J.3.3.1--Number of cases of scleractinian diseases enumerated during REA surveys around Alamagan, MARAMP 2009. BLE: bleaching; CYA: cyanophyte infections; FUG: fungal infections.

DZCode	ALA-02	ALA-03	Grand Total
BLE		1	1
CYA	1	1	2
FUG	9	1	10
Total	**10**	**3**	**13**

J.3.4. Macroinvertebrate Surveys (non-coral)

A total of 396 individuals of benthic invertebrate target species or taxa groups were enumerated from four belt transects at two sites. Non-cryptic macroinvertebrates were low around Alamagan with the exception of the boring sea urchin, *Echinostrephus aciculatus*, and coral crabs from the genus *Trapezia*. The island density for *E. aciculatus* was 11.36 (SE 4) organisms 50 m^{-2}. Densities were highest at ALA-02 (15.36 organisms 50 m^{-2}). The island density for species of *Trapezia* was 2.24 (SE 0.08) organisms 50 m^{-2} and was highest at site ALA-02 with 2.32 organisms 50 m^{-2}. Site ALA-03 had the greatest density of giant clams with 0.24 organisms 50 m^{-2} and *Calcinus* hermit crabs (0.88 organisms 50 m^{-2}). With the exception of *E. aciculatus* and a rare species of *Echinothrix*, echinoderms (holothuroids, ophiouroids, asteroids, and echinoids) were exceptionally rare at Alamagan.

J.3.4.1. Urchin Measurements

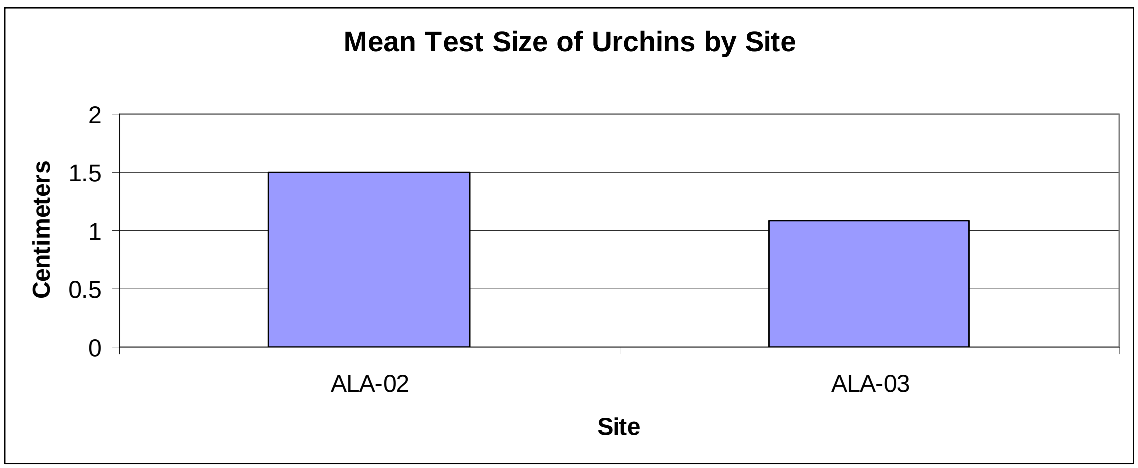


Figure J.3.4.1.1--Average test diameter of urchins encountered at each site. Only sites where ≥ 5 measurements were recorded for a species are represented. *Echinostrephus aciculatus* is the only represented echinoid.

J.3.5. Benthic Towed-diver Surveys

Five benthic towed-diver surveys were completed at Alamagan in 2009 (Fig. J.3.5.1.). Habitats covered during the surveys varied with the majority of tow segments conducted over hard bottom (a mixture of continuous reef, rock boulders, drop-offs, and ridges extending from shore creating steep drop-offs).

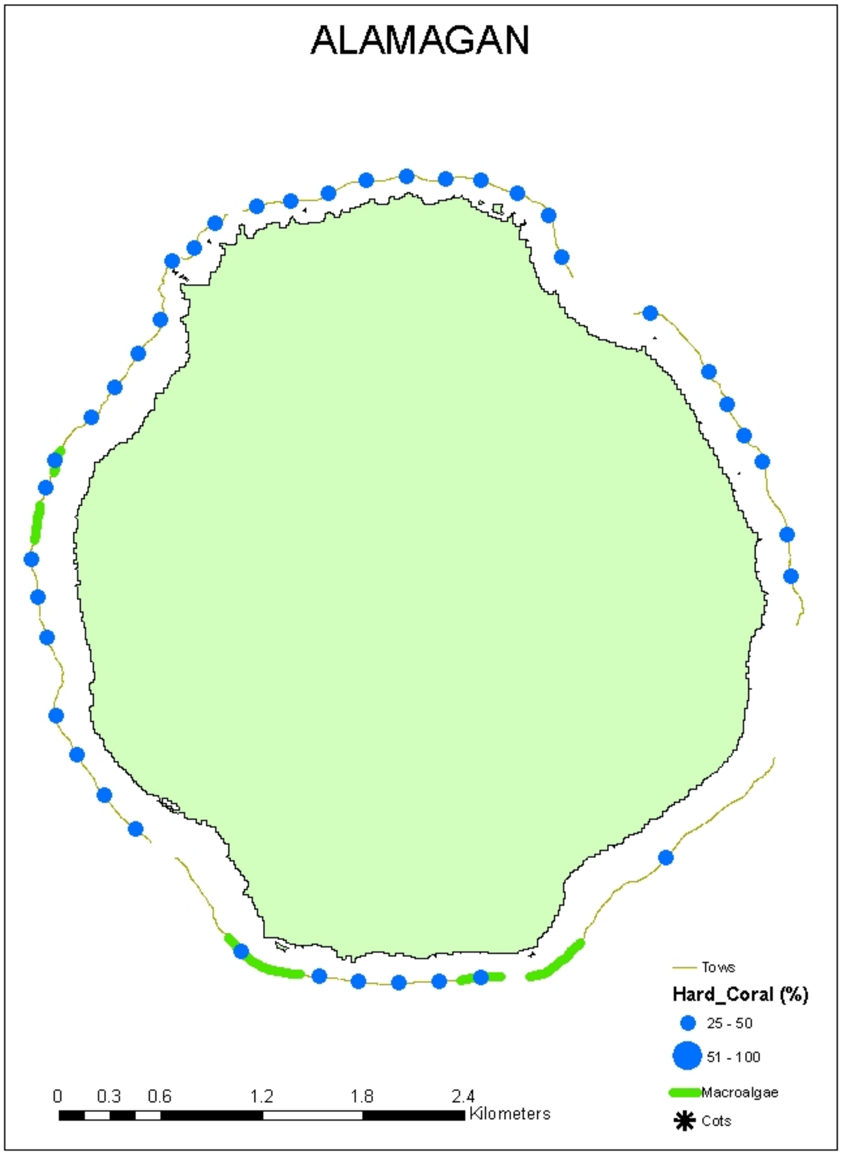


Figure J.3.5.1--Hard coral cover, elevated macroalgal cover (> 25%), and crown-of-thorn (COT) abundances during tow segments at Alamagan 2009.

Hard coral cover was relatively high in most regions of Alamagan with the exception of a small area in the southeast. Coral communities were variable with some sections of reef dominated by *Goniopora*, while *Pocillopora* and massive *Porites* were common elsewhere. Macroalgal cover was moderately high with *Halimeda* and *Asparagopsis* being the most common genera seen.

Boring urchins were the most abundant macroinvertebrates being common in most tows, while giant clams were relatively common although in low densities. Few other macroinvertebrates were observed with no COTs observed.

Benthic category	Mean ± SE
Hard coral	23.3 ± 1.1
Soft coral	1.8 ± 0.3
Macroalgae	15.5 ± 1.6
Coralline algae	5.3 ± 0.7
Sand	5.4 ± 1.8
Rubble	0.9 ± 0.2
COTs	0
Free urchins	1
Boring urchins	1877
Sea cucumbers	6
Giant clams	173

* Sum of observed individuals

J.4. Fish Surveys

J.4.1. REA Fish Surveys

Stationary point count data (nSPC)

During the survey period, nSPC surveys were conducted at six sites around Alamagan. Snappers were the largest contributor to total biomass with 4.4 kg 100 m^{-2}. Surgeonfish were the second largest contributor to total biomass with 3.0 kg 100 m^{-2}, followed by wrasses at 2.1 kg 100 m^{-2} (Fig. J.4.1.1.).

Overall observations

A total of 164 fish species were observed by all divers during the survey period. The average total fish biomass around Alamagan during the survey period was 16.6 kg 100 m^{-2} for the nSPC surveys (Table J.4.1.1.).

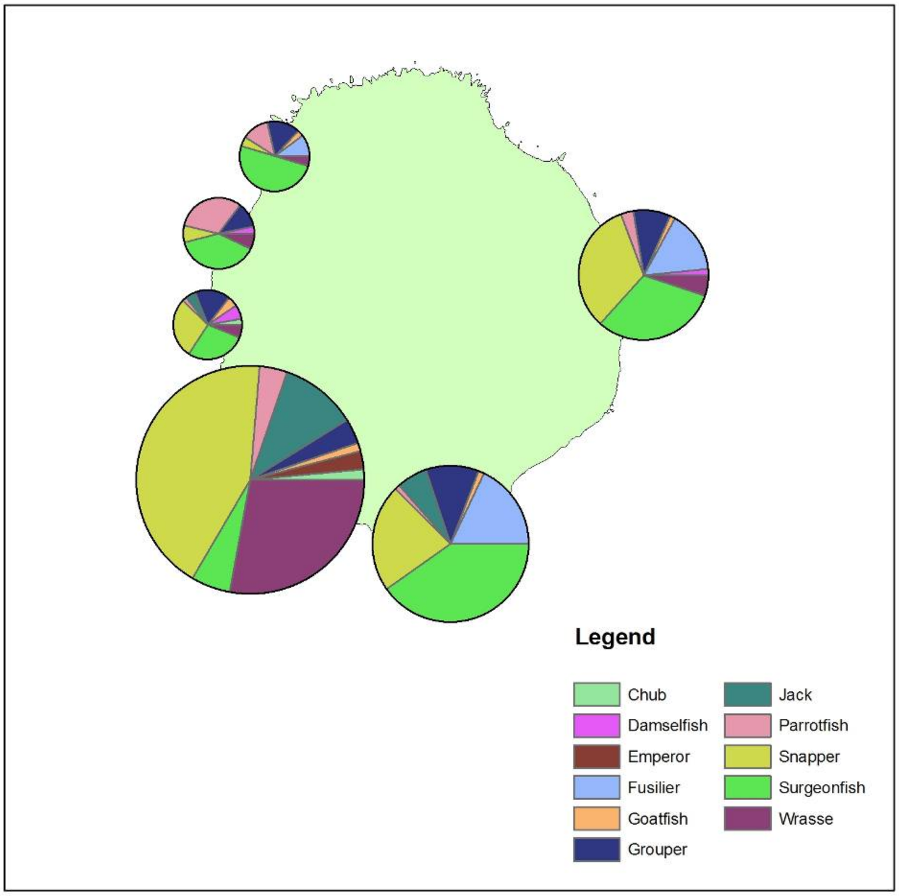


Figure J.4.1.1--Site location and distribution of total fish biomass by family. The sizes of the pie charts are proportional to fish biomass.

J.4.2. Towed-diver Surveys

During HA0903, the CRED towed-diver team completed six surveys at Alamagan covering 13.4 km (13.4 ha) of ocean floor (Table J.4.2.1.). Mean survey length was 2.2 km with a maximum length of 2.5 km and a minimum of 2.0 km. Mean survey depth was 14.1 m with a maximum depth of 15.4 m and a minimum of 12.8 m. Mean temperature on these surveys was 28.3°C with a maximum temperature of 28.6°C and a minimum of 27.9°C.

Table J.4.2.1.--Survey statistics for towed-diver sampling during HA0903.

		Length (km)					Depth (m)				Temperature (ºC)			
Island/Reef	#	Sum	Mean	Max	Min	SD	Mean	Max	Min	SD	Mean	Max	Min	SD
Alamagan	6	13.4	2.2	2.5	2.0	0.2	14.1	15.4	12.8	1.0	28.3	28.6	27.9	0.3

Seventy-nine individual large-bodied reef fishes (> 50 cm TL) of 21 different species and 13 different families were encountered at Alamagan (Table J.4.2.2.). Overall numeric density for this class of reef fishes was 0.59 #/100 m^2 (58.91 #/ha) with a biomass density of 3.73 kg/100 m^2 (0.37 t/ha). Numeric density was dominated by *Naso hexacanthus,* while biomass density was dominated by *Triaenodon obesus.*

Table J.4.2.8. Species numeric and biomass density for large-bodied reef fishes (> 50 cm TL) observed at Alamagan during HA0903 CRED towed-diver surveys.

Species	#	#/100 m^2	#/ha	Biomass (kg)	kg/100 m^2	t/ha
Naso hexacanthus	17	0.13	12.68	39.51	0.29	0.03
Balistoides viridescens	1	0.01	0.75	3.28	0.02	0.00
Caranx ignobilis	3	0.02	2.24	50.93	0.38	0.04
Caranx lugubris	1	0.01	0.75	2.48	0.02	0.00
Caranx melampygus	2	0.01	1.49	5.74	0.04	0.00
Caranx sexfasciatus	10	0.07	7.46	23.43	0.17	0.02
Carcharhinus amblyrhynchos	3	0.02	2.24	43.69	0.33	0.03
Triaenodon obesus	12	0.09	8.95	193.97	1.45	0.14
Taeniura meyeni	2	0.01	1.49	18.77	0.14	0.01
Fistularia commersonii	1	0.01	0.75	0.17	0.00	0.00
Nebrius ferrugineus	2	0.01	1.49	64.57	0.48	0.05
Plectorhinchus gibbosus	1	0.01	0.75	2.44	0.02	0.00
Aprion virescens	2	0.01	1.49	14.90	0.11	0.01
Lutjanus bohar	11	0.08	8.20	33.86	0.25	0.03
Macolor niger	1	0.01	0.75	2.41	0.02	0.00
Aluterus scriptus	1	0.01	0.75	0.28	0.00	0.00
Chlorurus microrhinos	2	0.01	1.49	5.19	0.04	0.00
Scarus ghobban	1	0.01	0.75	2.42	0.02	0.00
Scarus rubroviolaceus	4	0.03	2.98	10.42	0.08	0.01
Gymnosarda unicolor	1	0.01	0.75	18.97	0.14	0.01
Arothron stellatus	1	0.01	0.75	9.38	0.07	0.01
Grand Total	79	0.59	58.91	500.14	3.73	0.37
# of Species	21					

The most prevalent families in terms of numeric density were acanthurids (22%), carangids (20%), and carcharhinids (19%) (Fig. J.4.2.1.). The most prevalent families in terms of biomass density were carcharhinids (44%), carangids (16%), and ginglymostomatids (12%) (Fig. J.4.2.2.). There was no clear pattern to the geographic distribution of large-bodied reef fishes around the island (Fig. J.4.2.3.).

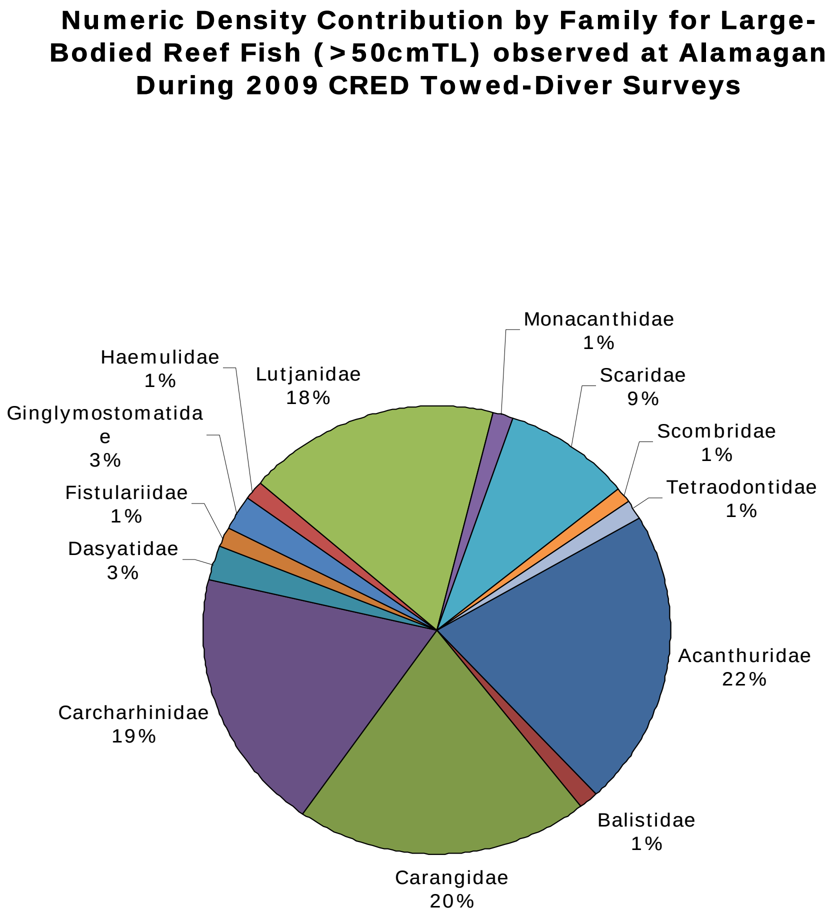


Figure J.4.2.1--Numeric density of fishes by family.

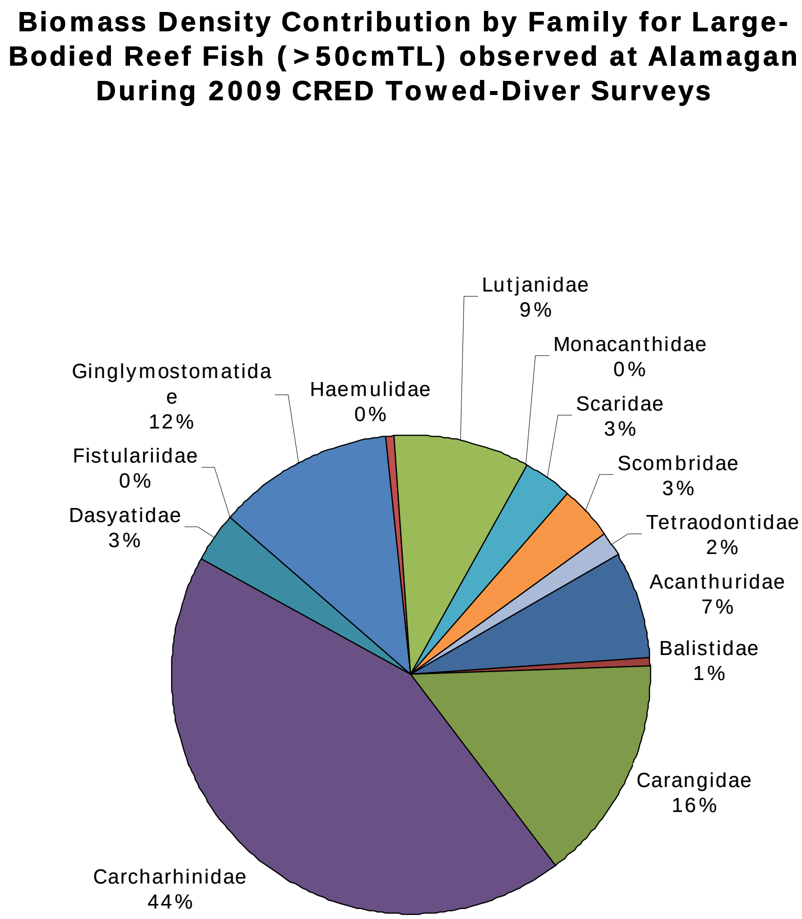


Figure J.4.2.2--Biomass density of fishes by family.

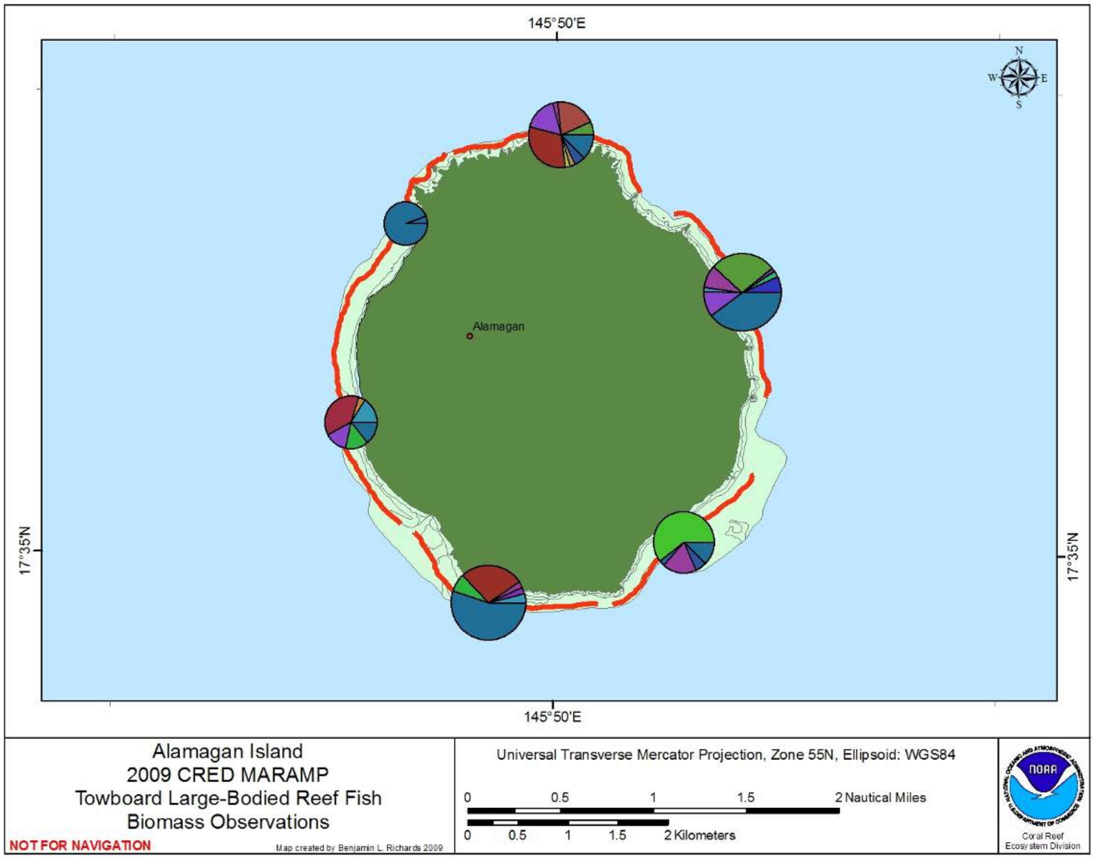


Figure J.4.2.3--Geographic distribution of fish biomass around Alamagan. Each species is represented by a legend color. Diameter of pie chart is proportional to total biomass of all species encountered on the underlying survey.

Appendix K: Guguan Results

K.1. Oceanography and Water Quality

One subsurface temperature recorder (STR) was recovered and replaced at Guguan during HA0903 (Fig. K.1). The STR shows a clear annual fluctuation due to seasonal warming and cooling (Fig. K.2). Warmest temperatures peaked at approximately 31°C and occurred during the summer months of July to October. Winter temperatures reached lows of about 26.5°C and occurred during November through June.

One rapid ecological assessment REA site (GUG-01) was visited to collect water samples for microbiological, nutrient and chlorophyll analyses, and the remaining two REA sites (GUG-02, GUG-03) were sampled for just nutrients and chlorophyll. Samples were obtained from the surface and approximately 1 m above the reef. Microbial water samples were taken using diver-deployable Niskin bottles to collect 8 liters of seawater (4 bottles; 2 liters per bottle) at each study site. Chlorophyll samples were filtered, and nutrient samples were frozen at -30°C for post-cruise analysis. Shallow-water conductivity temperature and depth (CTD) casts were also conducted at these sites. In addition, 9 CTD casts were taken every 1 km around the perimeter of Guguan at the 30 m depth contour.

Table K.1--Guguan moorings.

Action	Mooring type	Serial number	Lat		Long		Depth (m)
Retrieval	STR	39331791192	17.30733077	N	145.8314279	E	6.7
Deployment	STR	39368591670	17.30733077	N	145.8314279	E	6.7

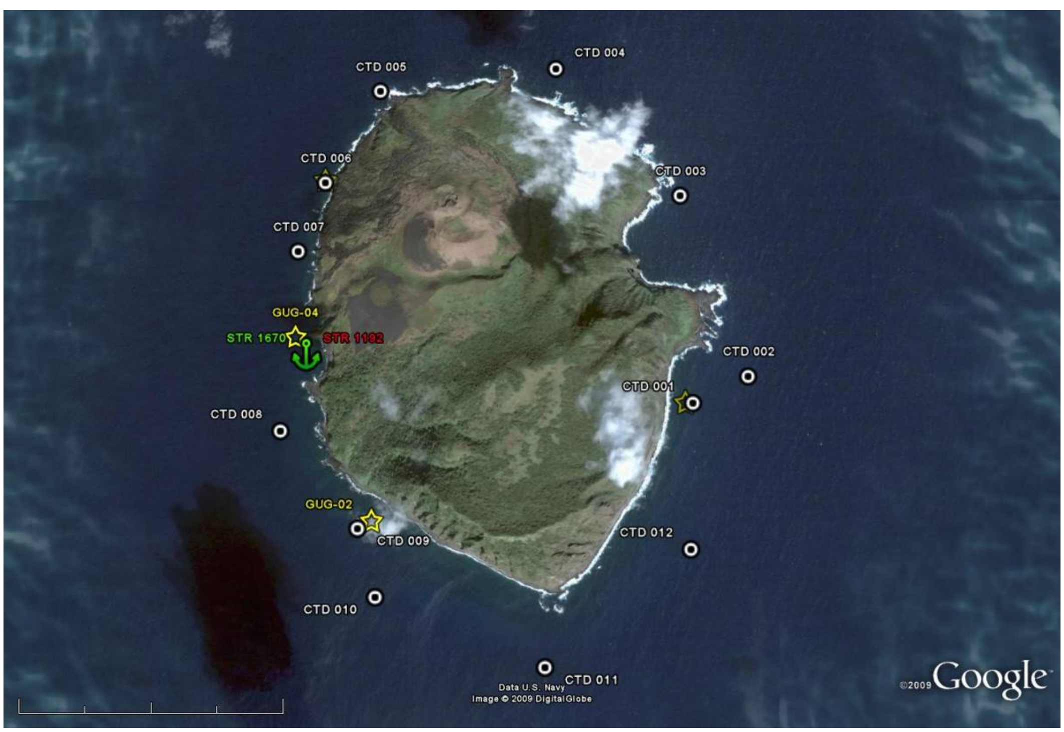


Figure K.1--Deployed and recovered instrument moorings and CTD and water sampling sites, Guguan, HA0903.

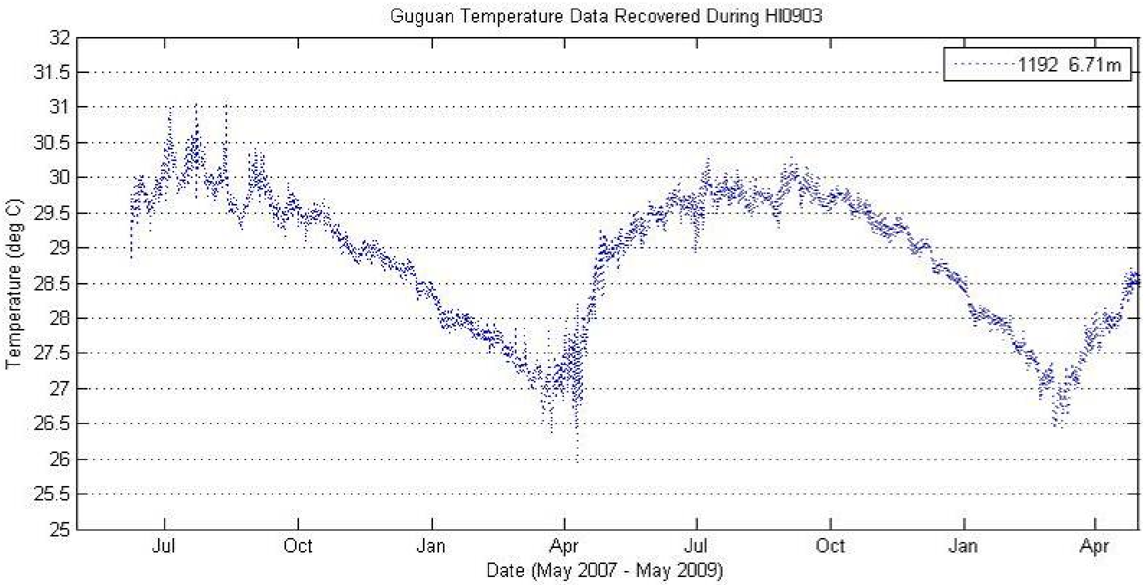


Figure K.2--Temperature time series from STR mooring at Guguan.

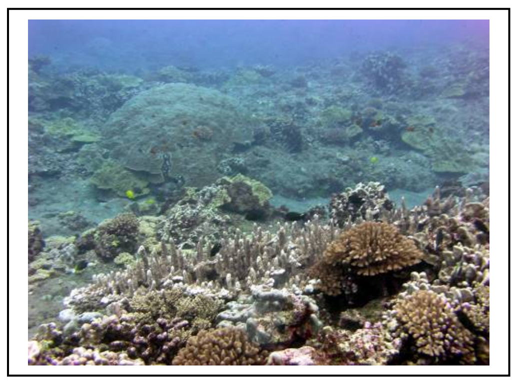
K.2. Rapid Ecological Assessment (REA) Site Descriptions

GUG-01
5/5/2009

E 145° 51.056
N 17° 18.350

Forereef
Mid

Depth: 11–15 m



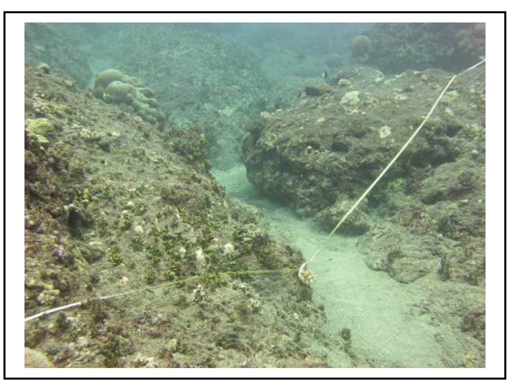
Site description: Southeastern site; moderate topographic complexity; high coral cover (*Lobophora variegata* present); moderate macroalgal cover.

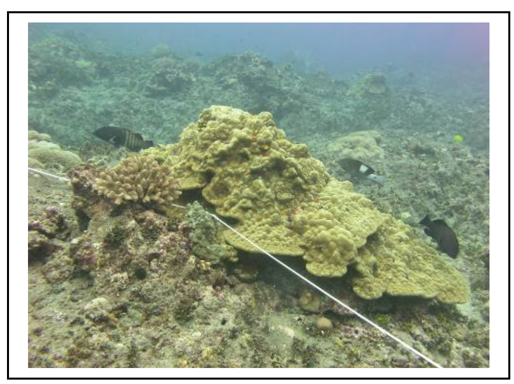
GUG-02
5/5/2009

E 145° 50.097
N 17° 18.009

Forereef
Mid

Depth: 11–13 m





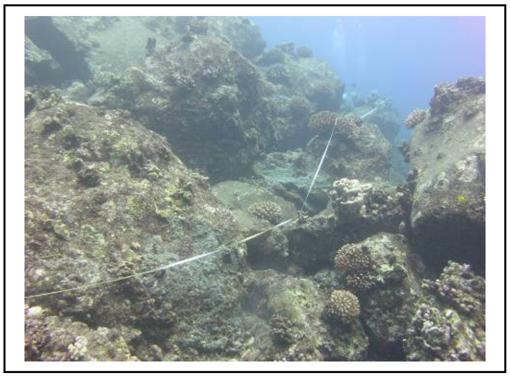
Site description: Southwestern site; moderate topographic complexity; moderate coral and macroalgal cover; dominated by turf algae.

GUG-03
5/5/2009

E 145° 49.940
N 17° 19.017

Forereef
Mid

Depth: 10–12 m



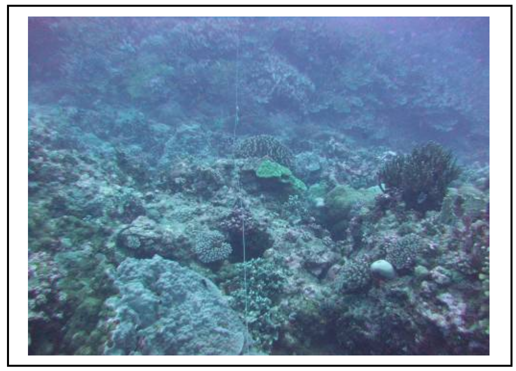
Site description: Northwestern site; moderate topographic complexity (boulders); moderate coral and macroalgal cover; moderate cover by CCA, turf algae, and an encrusting species of sponge.

GUG-50
5/5/2009

E 145° 51.048
N 17° 18.902

Forereef
Deep

Depth: 21 m



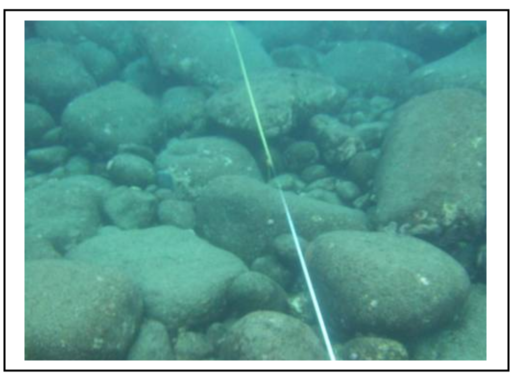
Site description: Northeastern deep site; moderate topographic complexity (boulders); 40 degree slope; very high coral cover; low macroalgal cover.

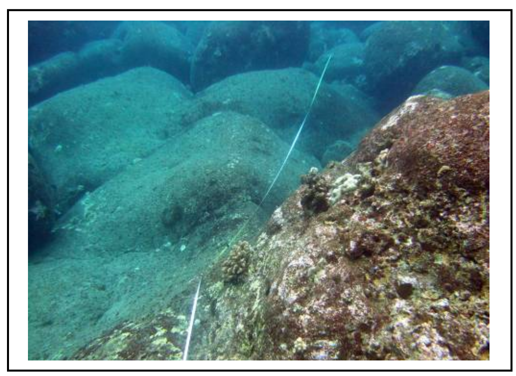
GUG-51
5/5/2009

E 145° 49.930
N 17° 18.485

Forereef
Shallow

Depth: 5 m





Site description: Western shallow site; moderate topographic complexity (boulders); low coral and macroalgal cover; dominated by turf algae.

GUG-52
5/5/2009

E 145° 50.357
N 17° 19.352

Forereef
Deep

Depth: 21 m

Site description: Northern deep site; moderate/high topographic complexity (boulders with sand intermixed); 45 degree slope; high coral and macroalgal cover.

K.3. Benthic Environment

K.3.1. Algal Communities

During the Mariana Reef Assessment and Monitoring Program (MARAMP) 2009, three permanent, long-term REA monitoring sites were surveyed around Guguan Island for percent benthic cover based on the 20-cm interval line point intercept (LPI) methodology. Benthic communities around Guguan were dominated by scleractinian corals and turf algae (Table K.3.1.1.). Turf algal percent cover exceeded that of other functional groups at two of the three sites surveyed with a range of 23.2% to 42.4% cover (Table K.3.1.1.). At site GUG-01, scleractinian coral percent cover was 33.6% and exceeded that of all other functional groups. A combined total of 16 species of macroalgae were observed (11 chlorophytes, 3 ochrophytes, 2 rhodophytes) from the three sites surveyed (Tables K.3.1.2. and Table K.3.1.3.). *Lobophora variegata* dominated the macroalgal community at all sites with a percent cover range of 2.4% to 12.4% (Table K.3.1.3.). Species of *Caulerpa, Halimeda and Dictyosphaeria* were also documented during the LPI survey.

Table K.3.1.1--Percent cover of algal functional groups at long-term monitoring sites at Guguan.

Site	Macroalgae	Turf Algae	Coralline red algae (crustose + upright)	Cyanobacteria	Scleractinian Coral	Octocoral
GUG-01	11.2%	23.2%	18.8%	3.6%	33.6%	0.8%
GUG-02	18.0%	42.4%	8.0%	3.6%	17.6%	0.0%
GUG-03	12.8%	32.4%	17.2%	0.4%	22.4%	0.8%

Table K.3.1.2--Additional species recorded at each site at Guguan during roving diver survey.

Site	Chlorophyta
GUG-02, GUG-03	*Caulerpa filicoides*
GUG-02	*Caulerpa serrulata*
GUG-01, GUG-03	*Halimeda tuna*
GUG-02, GUG-03	*Neomeris* sp.
GUG-03	*Rhipilia* sp.
GUG-03	*Tydemania* sp.
GUG-02	*Udotea* sp.
GUG-02, GUG-03	*Valonia ventricosa*
	Ochrophyta
GUG-02, GUG-03	*Dictyota* sp.
GUG-01	*Turbinaria ornate*`
	Rhodophyta
GUG-01	*Amphiroa* sp.
GUG-02	*Dichotomaria* sp.

Table K.3.1.3--Percent cover of macroalgal species at long-term monitoring sites at Guguan. Sum totals for each row equal the percent cover of macroalgae recorded in Table K.3.1.1.

Site	Caulerpa webbiana	Dictyosphaeria versluysii	Halimeda opuntia	Lobophora variegata
GUG-01	0.8%	-	0.4%	2.4%
GUG-02	-	0.8%	0.4%	3.2%
GUG-03	0.4%	-	-	12.4%

K.3.2. Coral Communities

K.3.2.1. Percent Benthic Cover

During MARAMP 2009, percent benthic cover REA surveys conducted around Guguan at three permanent, long-term sites yielded an island-wide mean of 24.5% (Fig. K.3.2.1.1.), with the highest value recorded at site GUG-01 located in the protected southeastern embayment. The two other survey sites exhibited coral percent cover values ranging between 17 and 22% (Fig. K.3.2.1.1.).

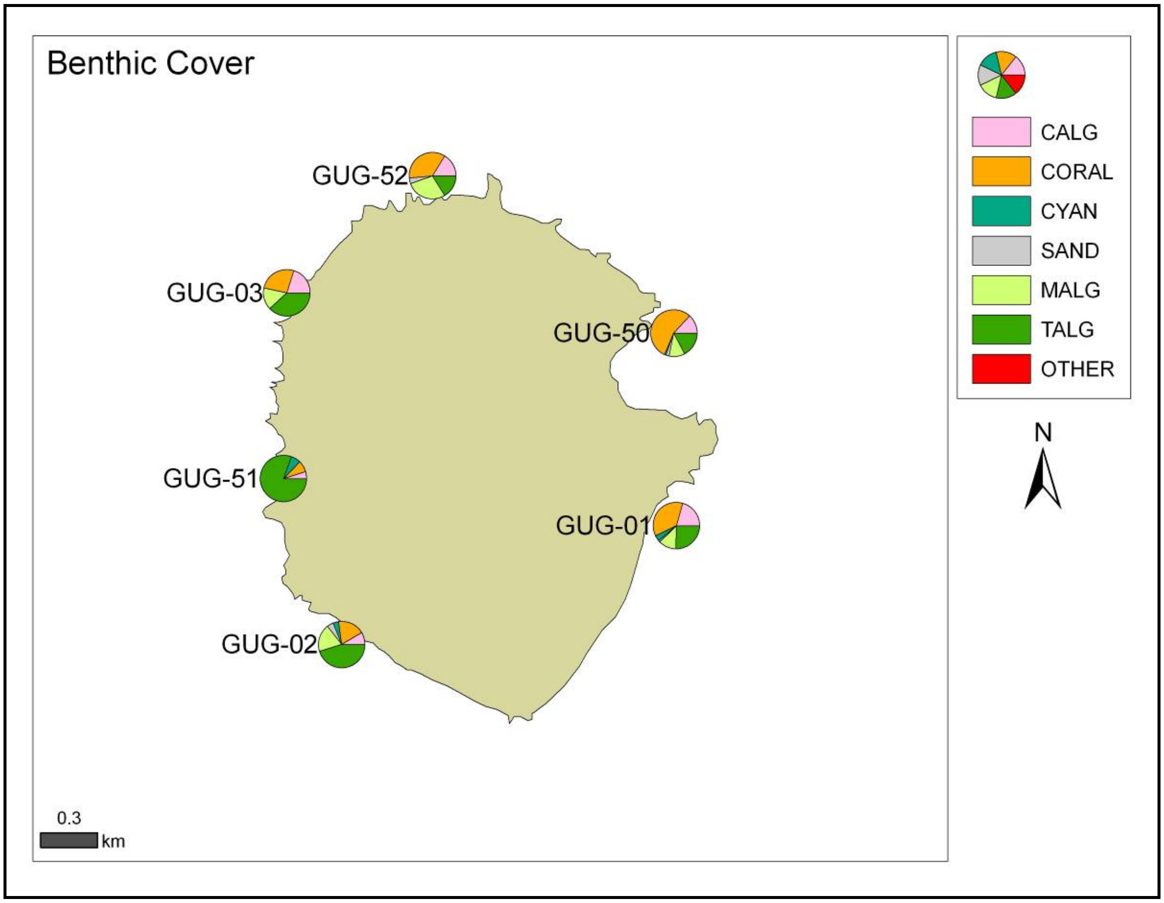


Figure K.3.2.1.1--Percent cover of benthic functional groups at the long-term and stratified random REA monitoring sites around Guguan during MARAMP 2009. CALG = crustose coralline red algae, CYAN = cyanobacteria, MALG = macroalgae, TALG = turf algae.

Three additional stratified random REA sites were surveyed around Guguan for percent benthic cover (based on 50-cm interval LPI surveys; Fig K.3.2.1.1.) and generic diversity data in 2009. Benthic communities surveyed at two sites greater than 20 m deep were dominated by scleractinian coral (42.2% + 7.8), macroalgal (18.6% + 8.8), turf algal (15.7% + 0.0) and calcareous algal (13.7% + 1.9) functional groups (Fig. J.3.2.1.2.). One shallow site (< 10 m deep) was dominated by the turf algal (80.4% + 0.0) functional group (Fig. K.3.2.1.2.). Coral generic diversity was highest at site GUG-50 with 27 different genera observed (Table K.3.2.1.1.). In contrast, site GUG-51 had the lowest generic diversity with 14 different genera observed at both. An average of 22 coral genera were recorded at each site. Common genera observed at most sites included *Pocillopora, Porites, Pavona, Favia, Leptastrea, Goniastrea*, and *Cyphastrea.* Macroalgal generic diversity was highest at site GUG-50 with 9 genera observed (Table K.3.2.1.2.). Sites GUG-51 and GUG-52 had the lowest generic diversity with 7 genera observed at both. An average of 8 macroalgal genera were recorded for each site. Common macroalgae observed at most sites included *Caulerpa,* and *Halimeda.*

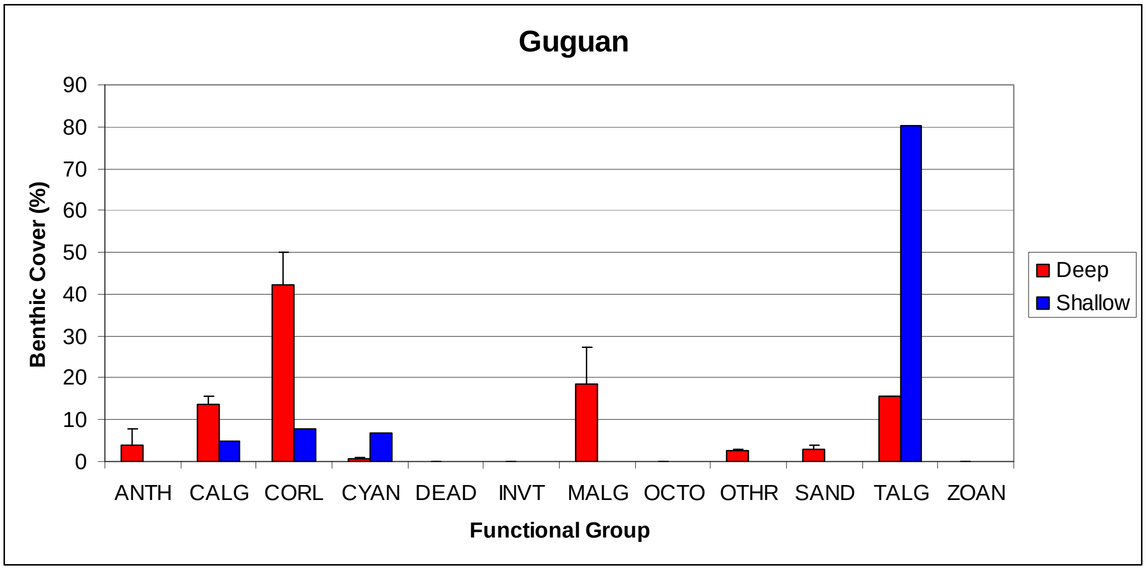


Figure K.3.2.1.2--Percent cover of functional groups at shallow and deep independent LPI monitoring sites established in 2009 at Guguan. ANTH = anthozoan, CALG = crustose coralline red algae, CORL = coral, CYAN = cyanobacteria, DEAD = dead coral, INVT = non-coral invertebrate, MALG = macroalgae, OCTO = octocoral, OTHER = other, TALG = turf algae, ZOAN = zoanthid.

Table K.3.2.1.1--Coral generic diversity of stratified random sites around Guguan.

	GUG-50	GUG-51	GUG-52
Acanthastrea			X
Acropora	X	X	
Alveopora	X		
Astreopora			X
Cladiella*			
Corallimorph*	X		
Coscinarea			
Cyphastrea	X	X	X
Diploastrea			
Distichopora*	X		
Echinopora	X		X
Euphyllia			
Favia	X	X	X
Favites		X	
Fungia	X		X
Galaxea	X	X	X
Gardinoseris	X		
Goniastrea	X	X	X
Goniopora	X		X
Heliopora*	X		X
Herpolitha			

	GUG-50	GUG-51	GUG-52
Hydnophora			
Isopora	X	X	
Leptastrea	X	X	X
Leptoria		X	
Leptoseris			X
Lobophyllia	X		X
Lobophytum*			X
Merulina			
Millepora*			X
Montastrea			X
Montipora		X	X
Ouphyllia	X		
Pachyseris			
Palythoa*			
Pavona	X	X	X
Platygyra	X	X	X
Pleisiastrea			
Plerogyra			
Pocillopora	X	X	X
Porites	X	X	X
Psammocora	X		X
Sarcophyton*	X		
Scapophyllia			X
Scolymia			
Seriatopora			
Sinularia*	X		
Stylaster*	X		X
Stylocoeniella			X
Stylophora	X		X
Turbinaria			
Wire Coral			
Zoanthus*	X		
Total Genera per site	27	14	26

* non-scleractinian genera

Table K.3.2.1.2--Macroalgal generic diversity of stratified random sites around Guguan.

	GUG-50	GUG-51	GUG-52
Amphiroa			
Asparagopsis			
Avrainvillea			
Boergesenia			
Boodlea			
Bryopsis	X		
Caulerpa	X	X	X
Chlorodesmis			
Crustose Coralline	X	X	X
Cyanobacteria		X	
Dichotomaria			
Dictyosphaeria			
Dictyota	X	X	
Galaxaura			
Gibsmithia			X
Halimeda	X	X	X
Halymenia			
Lobophora	X		X
Microdictyon			
Neomeris		X	
Non-geniculate calcified branched			
Padina			
Peyssonnelia			
Portieria			
Rhipilia	X		X
Turbinaria			
Tydemania	X		X
Udotea			
Valonia	X	X	
Unknown			
Total Genera per site	9	7	7

J.3.2.2 Coral Populations

During MARAMP 2009, belt transect surveys were conducted at three long-term REA sites around Guguan, covering a total reef area of 64 m^2 and totaling 1052 anthozoan and hydrozoan colonies enumerated. Taxonomic richness varied between sites with 27 anthozoan genera (22 scleractinian, 3 octocoral, 1 zoanthid, and 1 corallimorph) and 1 hydrozoan genus being represented within belt transects (Table K.3.2.2.1.). *Pavona*, *Favia*, and *Pocillopora* were the most abundant scleractinian genera, contributing 22.6% 17.8%, and 14.8% of the total number of colonies enumerated island-wide. All other genera individually contributed less than 10% of the total number of colonies.

Table K.3.2.2.1--Relative abundance of anthozoan and hydrozoan genera enumerated within belt transects around Guguan during MARAMP 2009.

Island	Genus	Relative abundance
Guguan	*Pavona*	22.62
	Favia	17.78
	Pocillopora	14.83
	Leptastrea	7.41
	Montipora	5.42
	Cyphastrea	5.23
	Porites	4.75
	Goniastrea	4.28
	Astreopora	2.95
	Montastrea	2.95
	Platygyra	2.66
	Lobophytum	2.28
	Echinopora	1.24
	Galaxea	1.24
	Hydnophora	0.95
	Acanthastrea	0.57
	Heliopora	0.57
	Psammocora	0.57
	Acropora	0.29
	Goniopora	0.29
	Coralimorphia	0.19
	Leptoseris	0.19
	Palythoa	0.19
	Sarcophyton	0.19
	Isopora	0.10
	Mycedium	0.10
	Sinularia	0.10
	Stylocoeniella	0.10

The highest relative abundance of *Pavona* (> 26% of total number of colonies) was found at site GUG-03 on the western outer reef. The highest relative abundance of *Favia* (> 21% of total number of colonies) was found at site GUG-02 on the southwestern outer reef. The highest relative abundance of *Pocillopora* (> 19% of total number of colonies) was found at site GUG-03 (Fig. K.3.2.2.1.).

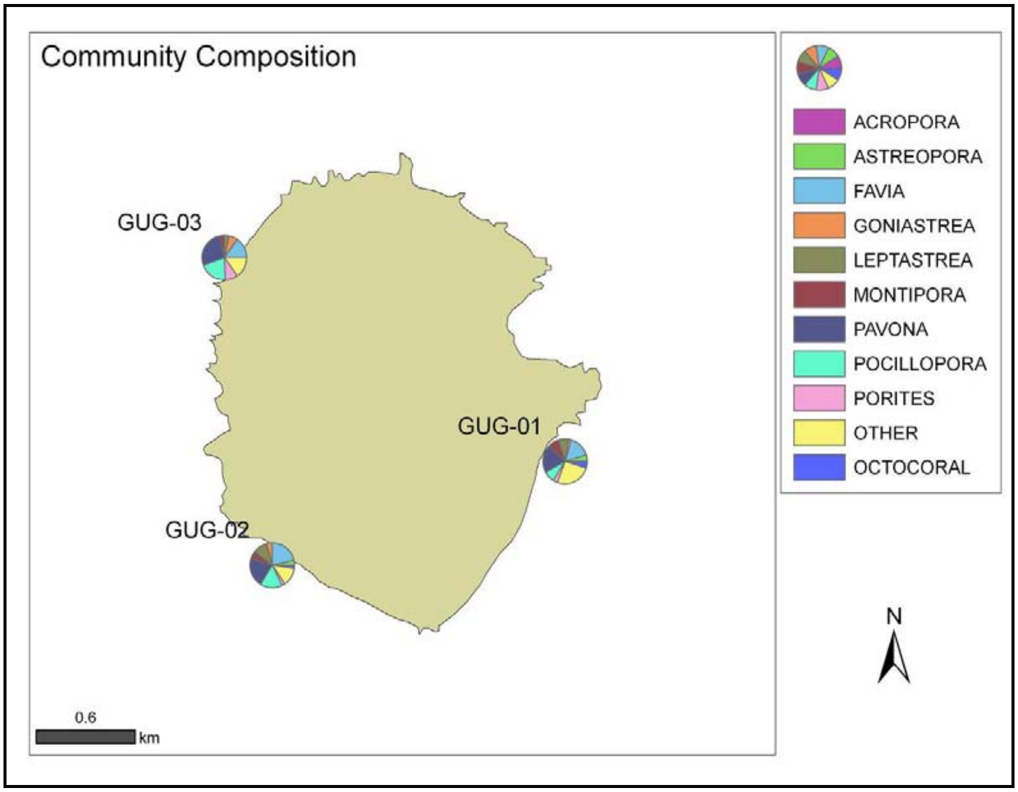


Figure K.3.2.2.1--Relative abundance of coral genera from REA surveys around Guguan during MARAMP 2009.

K.3.3. Coral Health and Disease

During MARAMP 2009, the occurrence of disease, predation, and other health impairments around Guguan was low, with a total of 11 cases enumerated. A summary of lesion occurrence and relative abundance is presented in Table K.3.3.1. The most numerically abundant type of lesion was fungal infection, which was detected in *Pavona varians*. Subacute tissue loss was the second most numerically abundant type of affliction, with two cases detected in *Porites lobata*. One case each of bleaching and predation was observed in *Pocillopora*. Three lesions of unknown etiology were detected in *Galaxea*, *Platygyra*, and *Pavona varians*.

Table K.3.3.1--Number of cases of scleractinian and coralline algal diseases and predation enumerated during REA surveys around Guguan, MARAMP 2009. BLE: bleaching; FUG: fungal infections; PRE: *Acanthaster*/*Drupella* predation scars; TLS: tissue loss; OTH: other diseases and lesions of unknown etiology; CLOD: coralline lethal orange disease.

DZCode	GUG-01	GUG-02	GUG-03	Grand Total
BLE	1			1
FUG		3	1	4
OTH			3	3
PRE			1	1
TLS	2			2
Total	**3**	**3**	**5**	**11**
CLOD	1			1

K.3.4. Macroinvertebrate Surveys (non-coral)

A total of 412 individuals of benthic invertebrate target species or taxa groups were enumerated from 6 belt transects at 3 sites. Non-cryptic macroinvertebrates were low around Guguan with the exception of the boring sea urchin, *Echinostrephus aciculatus*, and coral crabs from the genus *Trapezia*. The island density for *E. aciculatus* was 7.01 (SE 3.7) organisms 50 m^{-2}. Densities were highest at GUG-01 (12.8 organisms 50 m^{-2}) and GUG-02 (8.16 organisms 50 m^{-2}). The island density for species of *Trapezia* was 1.28 (SE 0.58) organisms 50 m^{-2} and was highest at site GUG-03 with 2.4 organisms 50 m^{-2}. Site GUG-02 had the greatest density of giant clams with 1.76 organisms 50 m^{-2}, and site GUG-01 had the greatest density of *Calcinus* hermit crabs (1.12 organisms 50 m^{-2}). *Linckia multifora* were most abundant at site GUG-02 at 1.28 organisms 50 m^{-2}. Holothuroids were exceptionally rare at Guguan.

K.3.4.1. Urchin Measurements

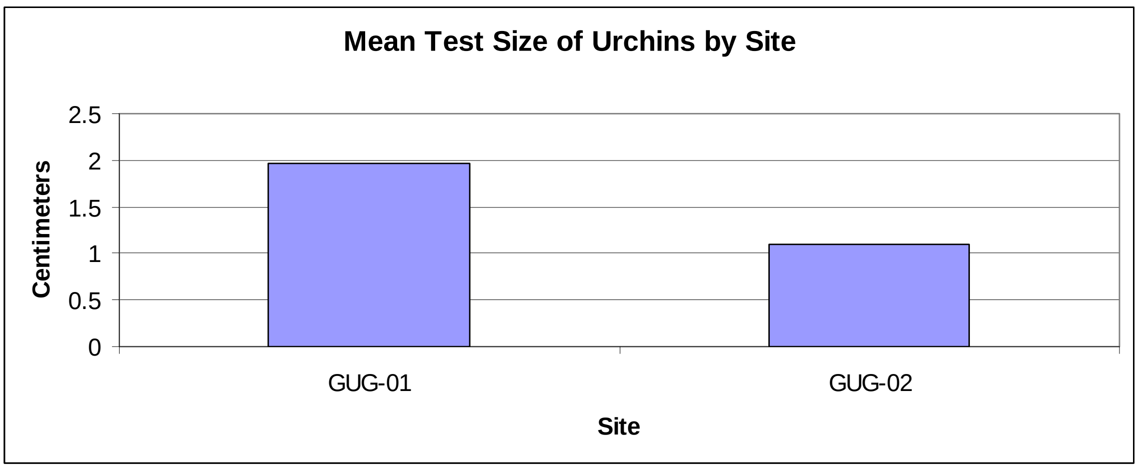


Figure K.3.4.1.1--Average test diameter of urchins encountered at each site. Only sites where ≥ 5 measurements were recorded for a species are represented. *Echinostrephus aciculatus* is the only represented echinoid.

K.3.4.2. Invertebrate Collections

Twenty-nine *Linckia multifora* arms were collected at Guguan.

K.3.5. Benthic Towed-diver Surveys

Four benthic towed-diver surveys were completed at Guguan in 2009 (Fig. K.3.5.1.). Habitats covered during surveys varied with the majority of tow segments conducted over hard bottom (a mixture of continuous reef, rock boulders, drop-offs, and ridges extending from shore creating steep drop-offs).

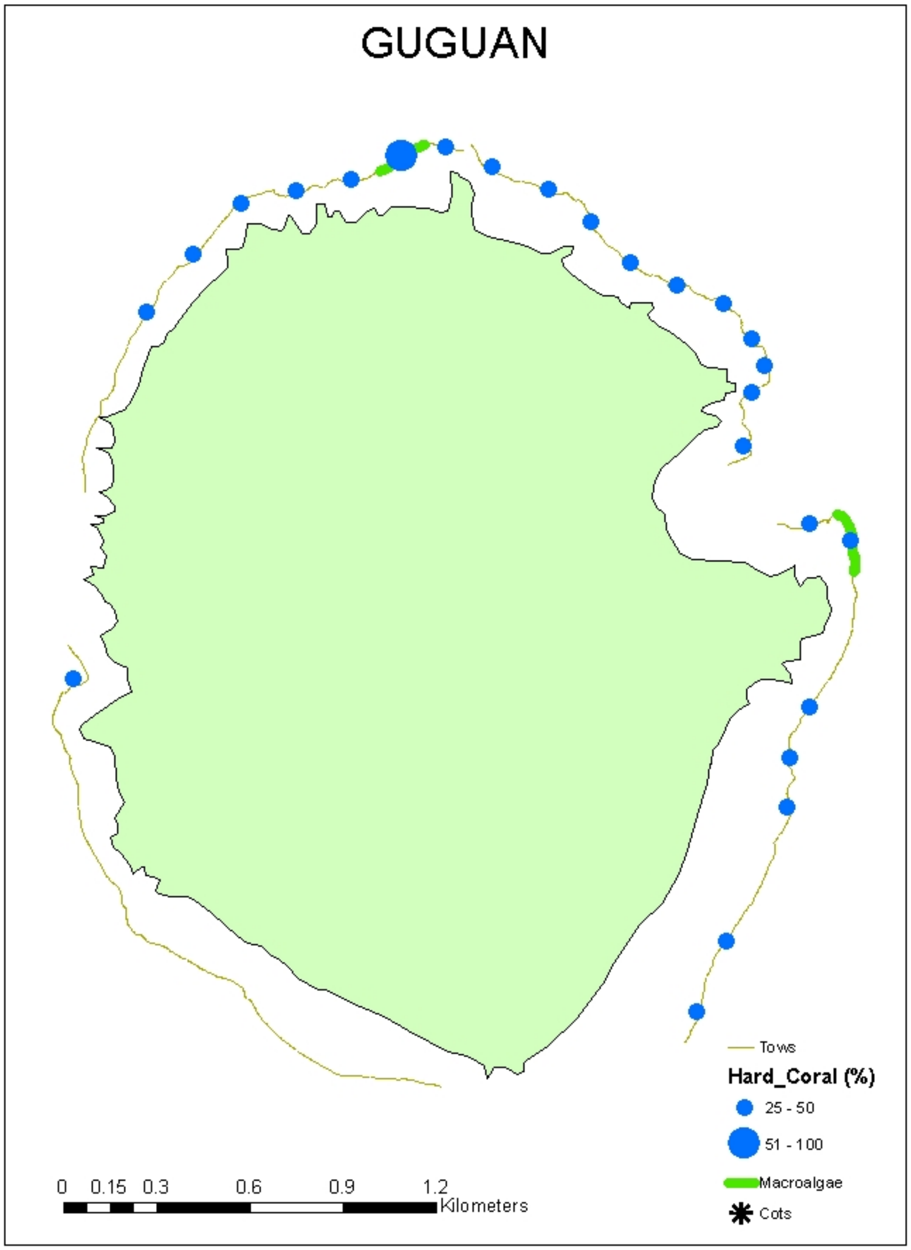


Figure K.3.5.1--Hard coral cover, elevated macroalgal cover (> 25%), and crown-of-thorn (COT) abundances during tow segments at Guguan 2009.

Hard coral cover was the most abundant benthic feature at Guguan although cover was highest in the northern and northeastern region where *Porites rus, Goniopora*, and *Pocillopora* were the most common corals. Macroalgal cover was moderate but few areas of elevated cover were encountered. Coralline algae cover at Guguan was higher than most other islands in the archipelago.

Similar to the other islands, boring urchins were the most abundant macroinvertebrates, with giant clams also being common although in low densities.

Benthic category	Mean ± SE
Hard coral	25 ± 1.8
Soft coral	0.9 ± 0.2
Macroalgae	17 ± 1.4
Coralline algae	14.6 ± 1.8
Sand	3.3 ± 1.1
Rubble	1.3 ± 0.2
COTs	0
Free urchins	0
Boring urchins	1876
Sea cucumbers	19
Giant clams	113
* Sum of observed individuals	

K.4. Fish Surveys

K.4.1.REA Fish Surveys

Stationary point count data (nSPC)

During the survey period, nSPC surveys were conducted at six sites around Guguan. Surgeonfish were the largest contributor to total biomass with 3.4 kg 100 m^{-2}. Snappers were the second largest contributor to total biomass with 1.7 kg 100 m^{-2}, followed by fusiliers at 1.5 kg 100 m^{-2} (Fig. K.4.1.1.).

Overall observations

A total of 157 fish species were observed by all divers during the survey period. The average total fish biomass around Guguan during the survey period was 14.1 kg 100 m^{-2} for the nSPC surveys (Fig. K.4.1.1.).

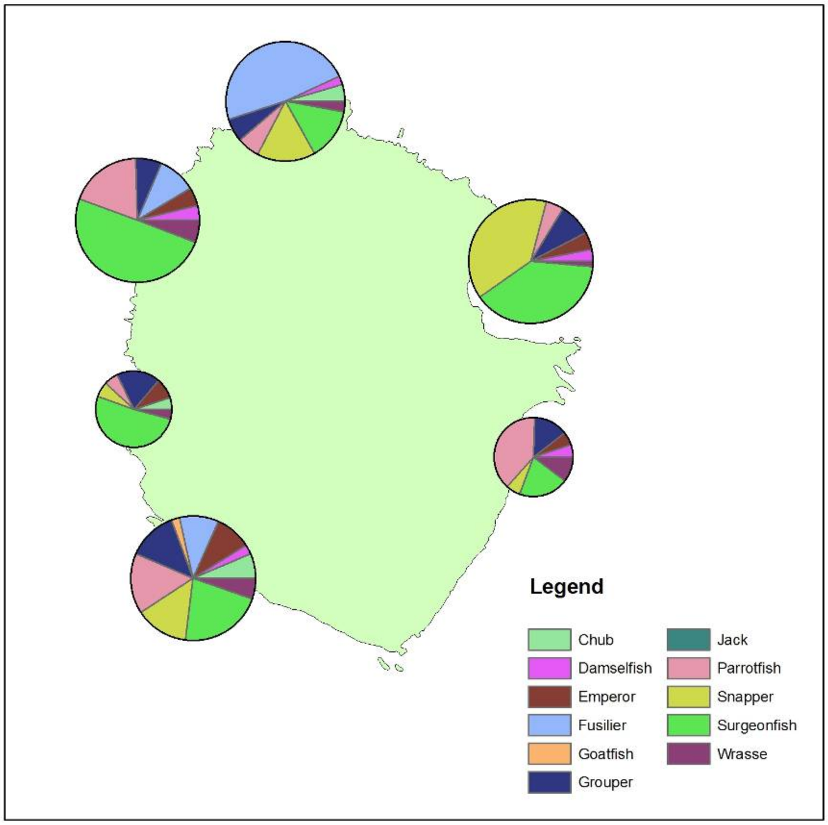


Figure K.4.1.1--Site location and distribution of total fish biomass by family. The sizes of the pie charts are proportional to fish biomass.

K.4.2 Towed-diver Surveys

During HA0903, the CRED towed-diver team completed four surveys at Guguan covering 8.1 km (8.1 ha) of ocean floor (Table K.4.2.1.). Mean survey length was 2.0 km with a maximum length of 2.3 km and a minimum of 1.8 km. Mean survey depth was 15.0 m with a maximum depth of 16.3 m and a minimum of 13.3 m. Mean temperature of these surveys was 28.4°C with a maximum temperature of 28.5°C and a minimum of 28.3°C.

Table K.4.2.1--Survey statistics for towed-diver sampling during HA0903.

		Length (km)					Depth (m)				Temperature (ºC)			
Island/Reef	#	Sum	Mean	Max	Min	SD	Mean	Max	Min	SD	Mean	Max	Min	SD
Guguan	4	8.1	2.0	2.3	1.8	0.2	15.0	16.3	13.3	1.3	28.4	28.5	28.3	0.1

One hundred-four individual large-bodied reef fishes (> 50 cm TL) of 13 different species and 9 different families were encountered at Guguan (Table K.4.2.2.). Overall numeric density for this class of reef fishes was 1.28 #/100 m^2 (127.92 #/ha) with a biomass density of 5.79 kg/100 m^2 (0.58 t/ha). Numeric density was dominated by *Caranx sexfasciatus,* while biomass density was dominated by *Himantura fai.*

Table K.4.2.2--Species numeric and biomass density for large-bodied reef fishes (> 50 cm TL) observed at Guguan during HA0903 CRED towed-diver surveys.

Species	#	#/100 m^2	#/ha	Biomass (kg)	kg/100 m^2	t/ha
Naso hexacanthus	25	0.31	30.75	53.03	0.65	0.07
Balistoides viridescens	1	0.01	1.23	3.28	0.04	0.00
Caranx sexfasciatus	32	0.39	39.36	74.98	0.92	0.09
Scomberoides lysan	3	0.04	3.69	3.98	0.05	0.00
Carcharhinus amblyrhynchos	2	0.02	2.46	15.46	0.19	0.02
Himantura fai	1	0.01	1.23	185.09	2.28	0.23
Fistularia commersonii	2	0.02	2.46	1.46	0.02	0.00
Lutjanus bohar	9	0.11	11.07	22.95	0.28	0.03
Macolor macularis	8	0.10	9.84	14.50	0.18	0.02
Macolor niger	11	0.14	13.53	19.94	0.25	0.02
Chlorurus microrhinos	2	0.02	2.46	5.19	0.06	0.01
Scarus rubroviolaceus	2	0.02	2.46	5.21	0.06	0.01
Gymnosarda unicolor	6	0.07	7.38	65.69	0.81	0.08
Grand Total	104	1.28	127.92	470.75	5.79	0.58
# of Species	13					

The most prevalent families in terms of numeric density were carangids (33%), lutjanids (27%), and acanthurids (24%) (Fig. K.4.2.1.). The most prevalent families in terms of biomass density were dasyatids (40%), carangids (17%), and scombrids (14%) (Fig. K.4.2.2.). While it is hard to discuss geographic distribution on such a small island, biomass appears to be slightly higher in the north and western sections of the island (Fig. K.4.2.3.).

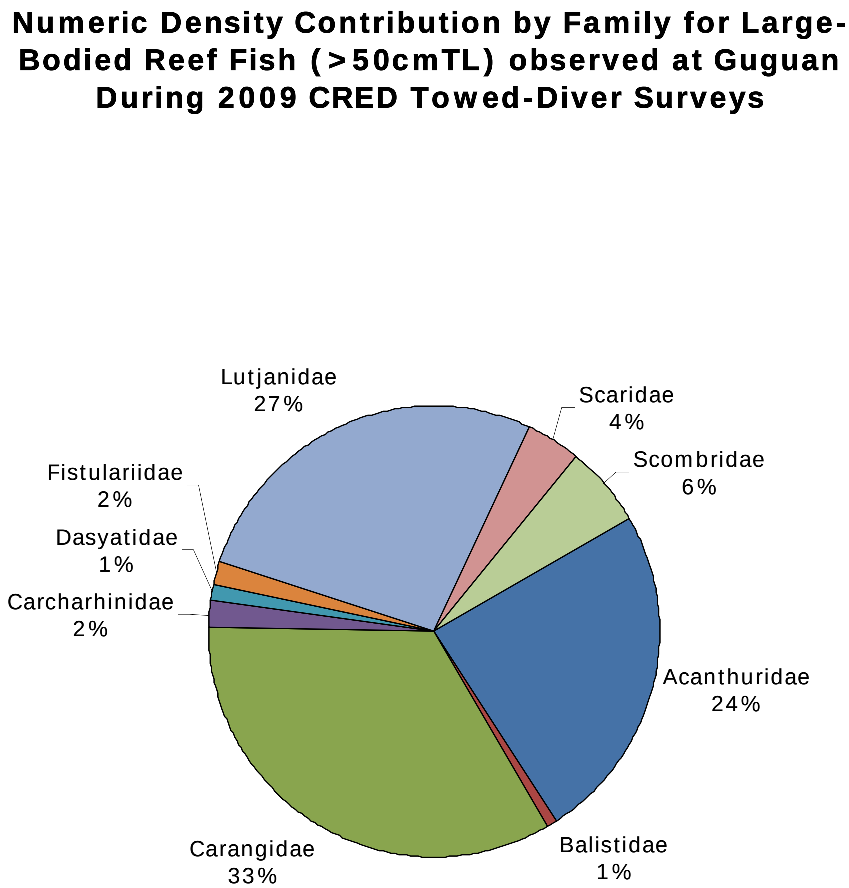


Figure K.4.2.1--Numeric density of fishes by family.

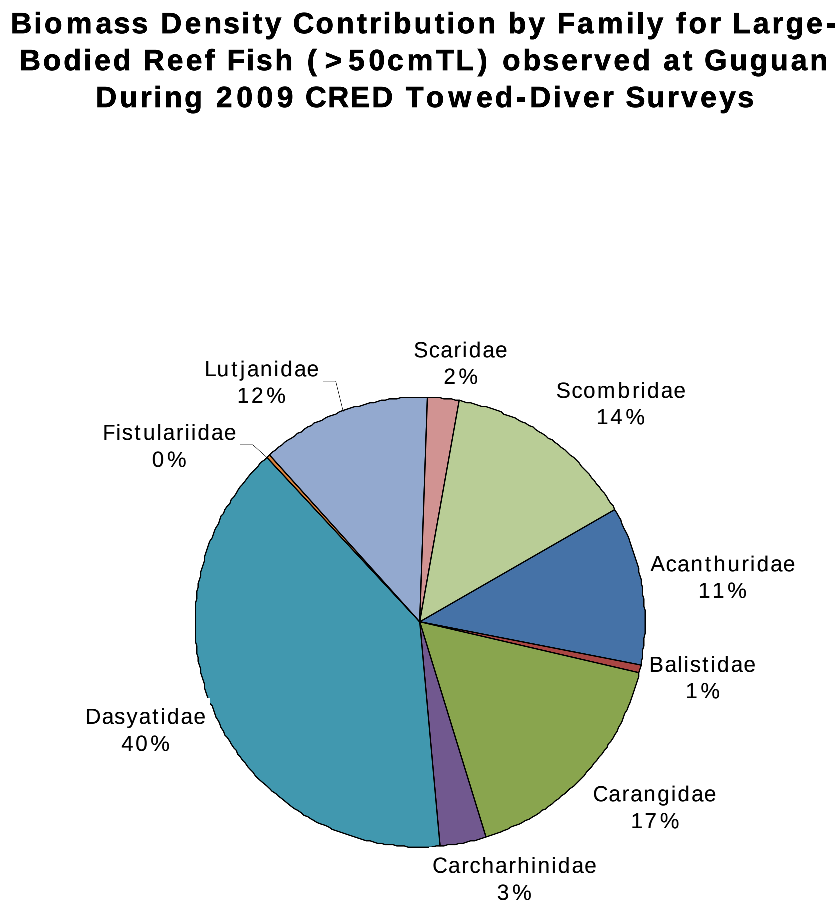


Figure K.4.2.2--Biomass density of fishes by family.

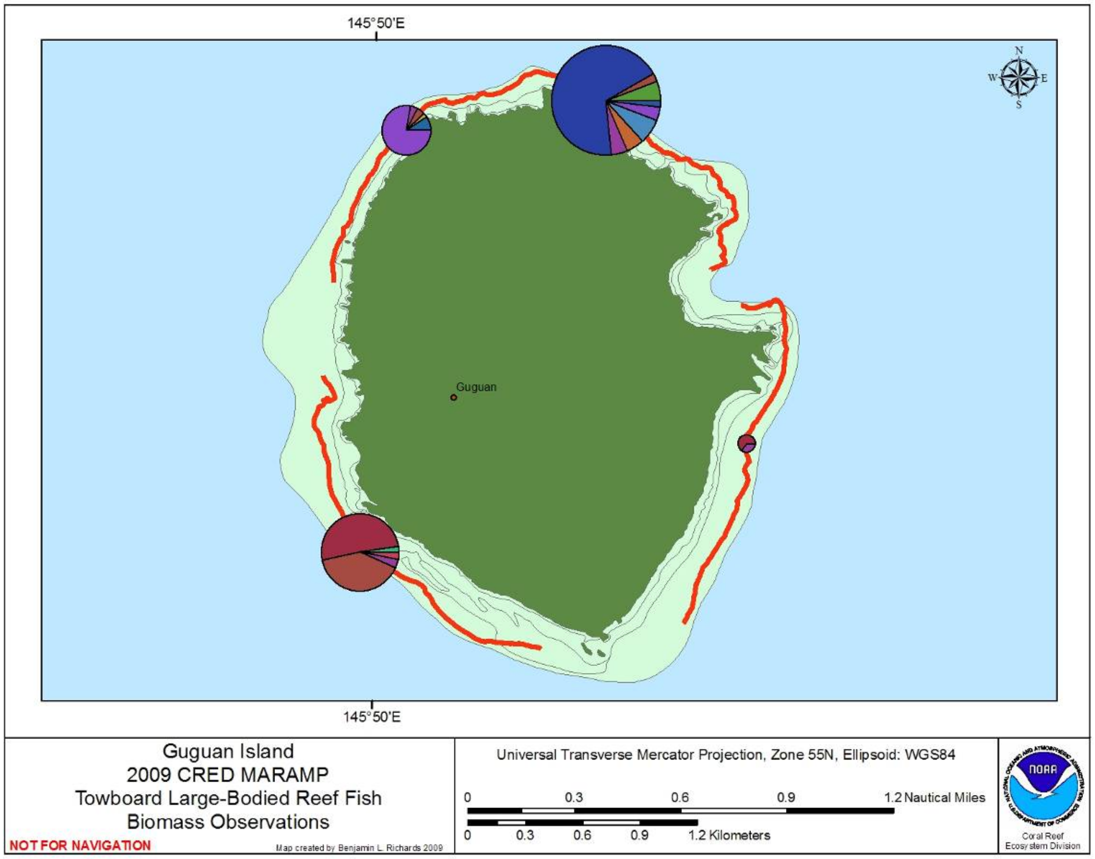


Figure K.4.2.3--Geographic distribution of fish biomass around Guguan. Each species is represented by a legend color. Diameter of pie chart is proportional to total biomass of all species encountered on the underlying survey.

Appendix L: Zealandia Bank Results

L.1. Oceanography and Water Quality

One wave and tide recorder (WTR) was recovered and one subsurface temperature recorder (STR) was recovered and replaced at Zealandia Bank during HA0903. The STRs show a clear annual fluctuation due to seasonal warming and cooling and large short-term fluctuations between the months of April through October (Table L.1.1., Fig. L.1.1.). Warmest temperatures peaked at approximately 30.5^{o}C and occurred during the summer months of July to October. Winter temperatures reached lows of nearly 26^{o}C and occurred during November through June.

Table L.1.1--Zealandia moorings.

Action	Mooring type	Serial number	Lat		Long		Depth (m)
Retrieval	STR	39207070160	16.89744322	N	145.853452	E	25.0
Deployment	STR	39327181049	16.89744322	N	145.853452	E	25.0
Retrieval	WTR	26P368591030	16.89744322	N	145.853452	E	25.0

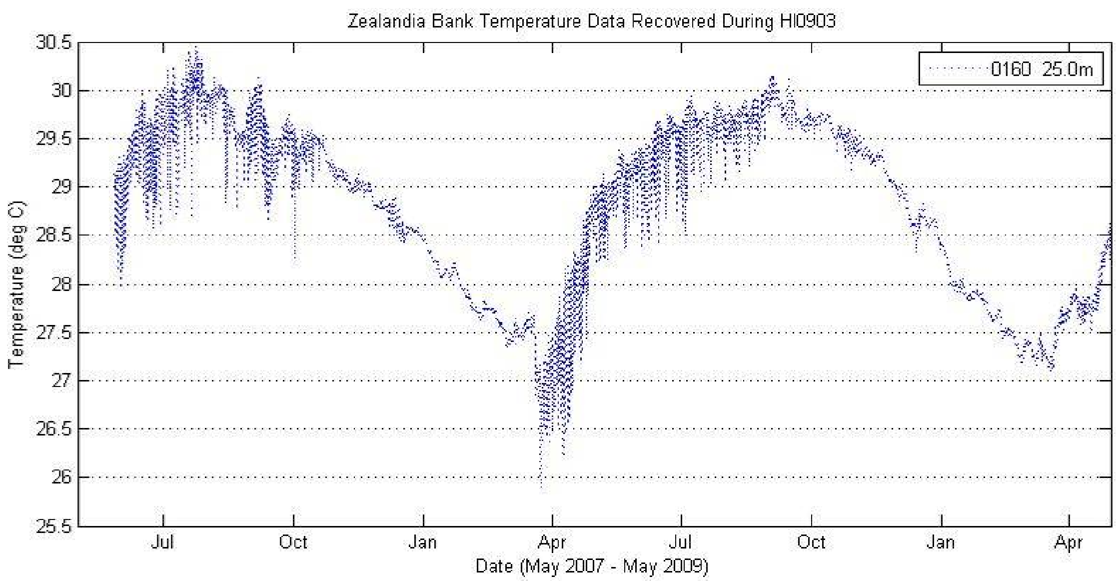


Figure L.1.1--Temperature time series from STR mooring at Zealandia.

Appendix M: Anatahan Results

M.1. Oceanography and Water Quality

One subsurface temperature recorder (STR) was recovered and replaced during HA0903 at Anatahan. In 2003, an STR was deployed but subsequently not found/recovered due to multiple ongoing eruptions since that time (Table M.1.1., Fig. M.1.1.). The STR shows a clear annual fluctuation due to seasonal warming and cooling (Fig. M.1.2.). Warmest temperatures peaked at approximately 31°C and occurred during the summer months of July to October. Winter temperatures reached lows of almost 27°C and occurred during November through June.

Two sites at Anatahan were sampled for nutrients and chlorophyll (STR site, ANA-03). Samples were obtained from the surface and approximately 1 m above the reef. Chlorophyll samples were filtered, and nutrient samples were frozen at -30°C for post-cruise analysis. Shallow-water conductivity temperature and depth (CTD) casts were also conducted at these sites. In addition, three CTD casts were taken along the south shore of Anatahan at the 30 m depth contour.

Table M.1.1--Anatahan moorings.

Action	Mooring type	Serial number	Lat		Long		Depth (m)
Deployment	STR	39432363086	16.33289119	N	145.7026963	E	4.0
Retrieval	STR	39443093484	16.33289119	N	145.7026963	E	4.0

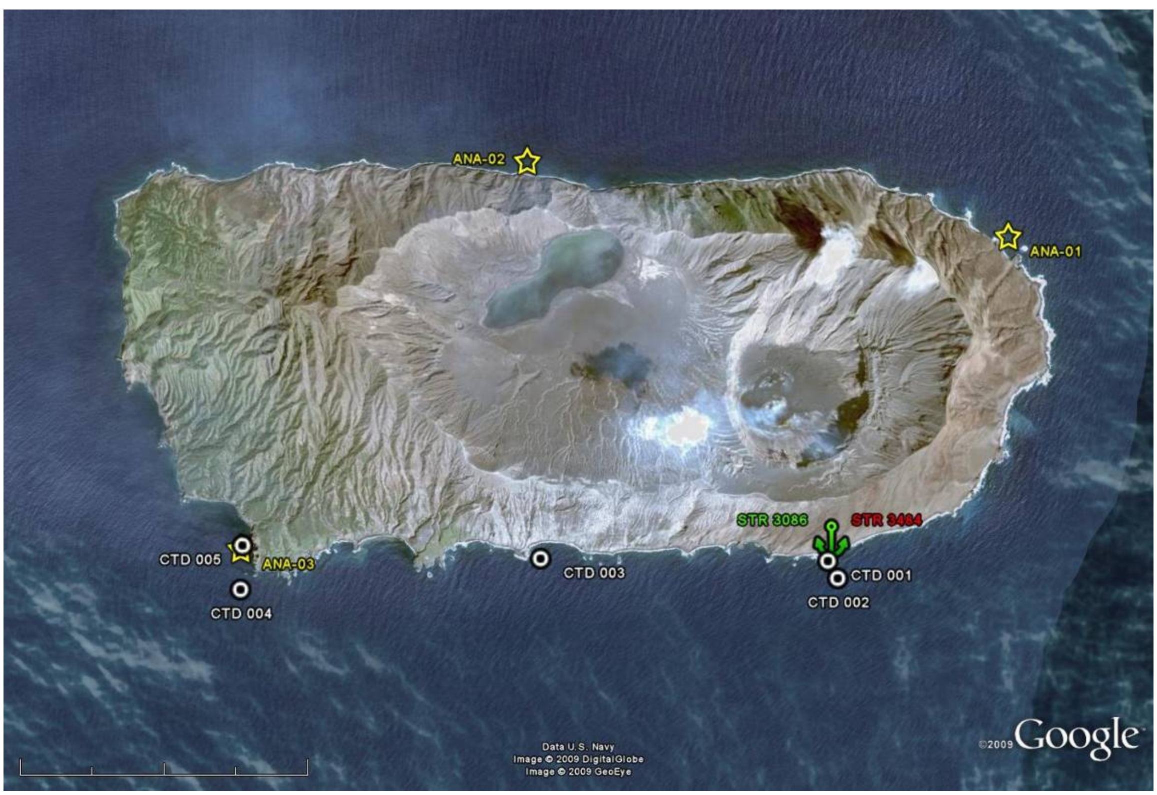


Figure M.1.1--Deployed and recovered instrument moorings and CTD and water sampling sites, Anatahan, HA0903.

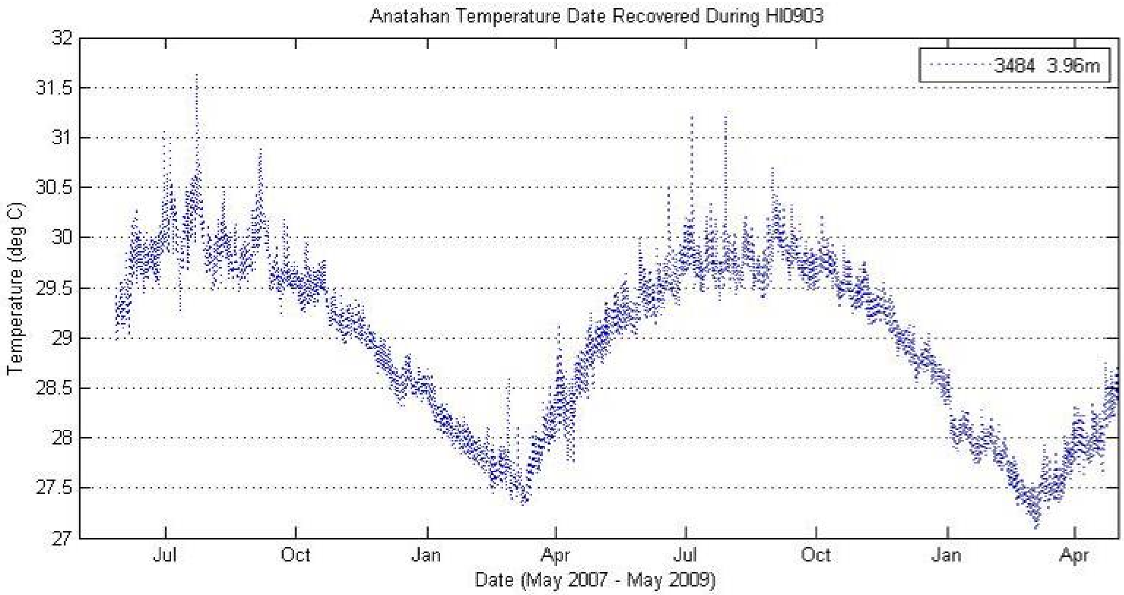


Figure M.1.2--Temperature time series from STR mooring at Anatahan.

M.2. Rapid Ecological Assessment (REA) General Site Descriptions

As only a few hours were available, REA scientists conducted qualitative survey dives, 2-20 m deep along the southwest side of the island. Deep layers of volcanic ash still buried most of the coral reef. Visibility was low (~ 3 m) in waters shallower than 12 m deep. Small recently recruited coral colonies dotted the large basalt boulders on a deep bed of dark gray ash. In waters deeper than 15 m, visibility improved to ~ 10 m. Many of the same fishes were seen that were common around the other northern (unimpacted) islands (e.g., jacks, schools of juvenile snapper, anthias). Some interesting forms of algae and invertebrates were also observed.

Macroinvertebrates: Invertebrates sighted between depths of 5 and 12 m included the following: exposed and prevalent on the boulders were a species of *Clathria* (sponge), a hydroid *Macrorhynchia philippina,* an unidentified hydroid, and the gastropod families, Conidae, Mitridae, and Buccinidae. A few *Diadema sauvigni* and *Echinostrephus aciculatus* were found burrowed within the holes and crevices of boulders. However, sea urchins from the genera *Echinothrix*, *Diadema*, *Echinometra*, *Echinostrephus* and *Eucidaris* were prevalent under large rocks when flipped over. They were all free-living and exposed underneath these rocks, possibly due to the lack of calcium carbonate to burrow into and/or available holes and crevices as refuges, considering the ash covered the boulder habitat. Brittle stars and cowries were also prevalent underneath turned rocks on the benthos. A few *Euapta godeffroyi* sea cucumbers were seen, and an unidentified species of *Stichopus* was sighted and collected. In general, it appeared that the macroinvertebrates at these sites were unusually exposed due to a lack of reef structure from the ash and boulder benthos.

Numerous documentary photos were taken of the preliminary recovery of the coral reef community at Anatahan, in spite of heavy ash still dominating most of the substrate (examples follow).