

Chapter 2 Program Design, Operational Background, Data Collection, and Processing Methodologies

The Pacific Reef Assessment and Monitoring Program (RAMP) field collection methodologies produce a series of integrated, comprehensive, and multidisciplinary ecosystem observations for the ~ 50 islands, atolls, and shallow-water banks of the United States (U.S.)-affiliated Pacific Islands. The data collections are designed to characterize the spatial and temporal variability of the distribution, abundance, and diversity of fish, corals, other invertebrates, and algae in the context of their benthic and oceanographic habitats. Though most of the ecological and oceanographic observations are collected every 2 years during Pacific RAMP research cruises, time series observations of key environmental conditions influencing reef processes are also made continuously by an array of moored oceanographic and bioacoustic instruments deployed and maintained as part of the National Oceanic and Atmospheric Administration (NOAA) Coral Reef Watch (CRW) program. These biological and environmental observations are further complemented by a suite of benthic habitat mapping products produced collaboratively by the NOAA Pacific Islands Fisheries Science Center (PIFSC) Coral Reef Ecosystem Division (CRED) and the Center for Coastal Monitoring and Assessment (CCMA) Biogeography Program of the NOAA National Centers for Coastal Ocean Science. Collectively, CRED's Pacific RAMP, CRW, and benthic habitat mapping are part of the NOAA Coral Reef Conservation Program's (CRCP's) Coral Reef Ecosystem Integrated Observing System (CREIOS) in the Pacific Islands.

The primary objectives of these CRED-led activities in the U.S.-affiliated Pacific Islands are:

- To conduct benthic habitat mapping of reefs and submerged banks using ship- and launch-based multibeam echosounders, underwater towed-camera systems, and towed-diver surveys for characterizing the benthic environments that provide habitat and shelter for reef biota;
- To conduct near and offshore oceanographic and water quality surveys and deploy a variety of surface and subsurface oceanographic and bioacoustic instruments, to quantify, assess, and gain a better understanding of the overall hydrographic and bioacoustic environments (e.g., water temperature, salinity, nutrients, waves, tides, currents, and ambient sound levels) influencing reef biota;
- To employ complementary and overlapping methods, collectively referred to as Rapid Ecological Assessment (REA) surveys to assess and monitor species composition, abundance, percent cover, size distribution, diversity, and general health of fish, corals, other invertebrates, and algae in shallow-water (< 35 m) habitats;
- To monitor coral and coralline algal diseases in conjunction with continued long-term monitoring of fish, coral, invertebrates, and algae;
- To conduct broad-scale towed-diver surveys that provide a spatial assessment of the composition and condition of shallow-water benthic habitats, and general distribution and abundance patterns of ecologically and/or economically important macroinvertebrates and reef fish (> 50 cm total length); and
- To ascertain the existence of threats to the health of coral reef resources from natural and/or anthropogenic sources.

Ecosystem observations and monitoring of this scope and detail are unprecedented and unequalled in the waters of American Samoa. As such, the initial years of these multidisciplinary Pacific RAMP research expeditions were exploratory in nature, often providing the first-ever baseline assessments of reef resources in these mostly remote and uninhabited regions of the Pacific. As the analyses of initial baseline assessments have progressed, the program has shifted from an assessment phase to a long-term ecosystem monitoring phase. With this shift, the suite of methods used by the program has slowly evolved to continually improve the quality of the data and ability to detect temporal changes in ecosystem processes and community structure.

To qualify the nature and temporal variation of the data gathered during Pacific RAMP cruises and to provide a context for how surveys were performed, the operational background of the three American Samoa RAMP (ASRAMP) cruises conducted to date and details on the suite of assessment and monitoring methods employed are presented in the following sections.

2.1 Operational Background

As part of the Pacific-wide monitoring effort, CRED conducted its first ASRAMP cruise in 2002 with subsequent cruises in 2004 and 2006. Partners from the local management agencies, including the scientists and managers from American Samoa's Department of Marine and Wildlife Resources (DMWR), the Department of Commerce (DOC), the National Park of American Samoa (NPAS), and NOAA's Fagatele Bay National Marine Sanctuary (FBNMS) worked alongside CRED scientists to plan the surveys, determine and establish monitoring sites, and conduct surveys. Specific individuals from American Samoa who participated in the planning and/or implementation of ASRAMP cruises included:

- 2002: Tony Beeching (DMWR), Dr. Andrew Cornish (DMWR), Dr. Peter Craig (NPAS), Nancy Daschbach (FBNMS), Gene Brighthouse (DOC), Eva Pasko-DiDonato (NPAS), Dr. Douglas Wilson (DMWR), Joshua Seamon (DMWR), Saifoi Fa'aumu (DMWR), Dr. Ray Tulafono (DMWR), Lelei Peau (DOC), Wallace Thompson (Swains Island Representative)
- 2004: Dr. Douglas Fenner (DMWR), Dr. Peter Craig, Christopher Hawkins (DOC), Nancy Daschbach, Gene Brighthouse, Dr. Ray Tulafono, Lelei Peau, Fatima Sauafea (DMWR), Francesca Riolo (DMWR), Wallace Thompson, Penekosova Peau (student)
- 2006: Dr. Douglas Fenner, Dr. Peter Craig, Nancy Daschbach, Gene Brighthouse, Dr. Karl Brookins (DMWR), Dr. Ray Tulafono, Lelei Peau, Wallace Thompson, Merideth Speicher (DOC), Dr. Bill Keine (FBNMS), Fatima Sauafea



Figure 2.1a. The NOAA ships used to conduct ASRAMP cruises in 2002, 2004, and 2006. From left to right: *Townsend Cromwell*, *Oscar Elton Sette*, and the *Hi'ialakai*. (Photographs provided by NOAA PIFSC CRED)

The first three ASRAMP expeditions were conducted from the NOAA Ships *Townsend Cromwell* between February 9 and March 3, 2002, *Oscar Elton Sette* between February 3 and 26, 2004, and *Hi`ialakai* between February 9 and March 10, 2006 (Fig. 2.1a). Each of these research vessels, as well as their officers and crews, had different capabilities and limitations. In its 39th year of service supporting NOAA missions, the aging *Townsend Cromwell* was significantly smaller (50 m) than the other two vessels (69 m). The smaller size restricted the vessel's ability to carry, launch, and recover small boats and also limited the maximum scientific complement to 12 scientists. With the addition of the larger *Oscar Elton Sette* in 2003, the capacity to support Pacific RAMP requirements increased significantly. The *Oscar Elton Sette* can accommodate a complement of 20 scientists and has the ability to carry and deploy larger small boats. The addition of the *Hi`ialakai* in 2005 increased the maximum complement to 22 scientists and significantly improved the ability of CRED to conduct benthic habitat mapping missions because of the ship's hull-mounted shallow- and deep-water multibeam systems and the ability to carry CRED's 8-m multibeam survey launch R/V *Acoustic Habitat Investigator (AHI)*. The *Hi`ialakai* is also equipped with diesel-powered 8-m and 10-m small boats, a cascade Nitrox compressor system, and a permanently installed diving recompression chamber.

Concurrent with changes in vessels from 2002 to 2006, CRED increased its small-boat and dive-support capabilities with the addition of two 6-m SAFEboats and a portable cascade Nitrox compressor system. During this period, support of diving operations was enhanced as the NOAA Dive Center endorsed the transition from exclusive use of decompression tables to the standard use of dive computers and began providing a portable recompression chamber aboard the *Oscar Elton Sette* during cruises requiring extensive diving operations.

2.2 Benthic Habitat Mapping

Accurate, high-resolution benthic habitat maps are essential tools for the effective conservation and management of coral reef ecosystems. CRED, through its Pacific Islands Benthic Habitat Mapping Center (PIBHMC), supports mapping operations during dedicated mapping cruises, combined RAMP/mapping cruises, and cruises with other missions on which mapping is piggybacked. The data collected during these missions were used to create a set of comprehensive map products that are available to resource management agencies, researchers, and the general public.

High-resolution multibeam echosounder bathymetric data serve as the primary base layer for CRED's benthic habitat mapping. The highly accurate and detailed maps generated from these data are useful for a number of management and research applications. Maps illustrating or highlighting other seafloor characteristics, including slope, rugosity (a measure of topographic roughness and convolutedness), and bathymetric position index structures and zones, are derived from the bathymetric data.

In addition to bathymetric and derived data products, modern multibeam echosounders produce backscatter intensity data which provide an indication of the acoustic roughness and/or hardness of the seafloor. Used in various combinations, depth, slope, rugosity, and backscatter intensity can yield significant information about seafloor characteristics that

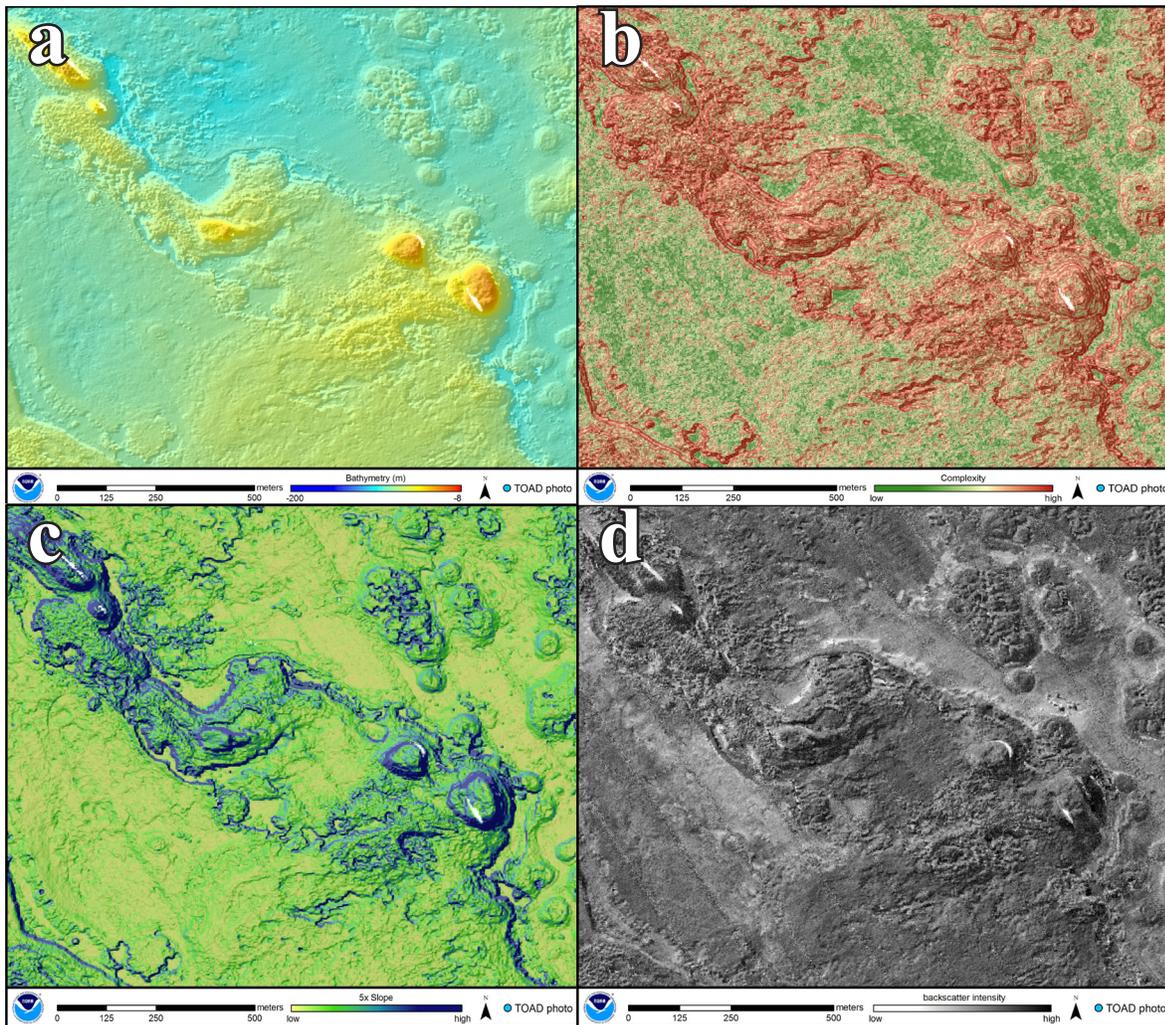


Figure 2.2a. Multibeam bathymetry (a), slope (b), rugosity (c), and multibeam backscatter (d) data provide valuable information about seafloor characteristics.

are important to specific groups of organisms and can be used to identify and delineate the benthic habitats they use (Fig. 2.2a).

To fully interpret and understand the wealth of data from multibeam echosounders, additional optical data are needed to validate (ground-truth) interpretations of the acoustically derived information. Towards this end, towed-camera surveys using a Towed Optical Assessment Device (TOAD) and towed-diver habitat surveys were routinely conducted to collect observations, still photographs, and video imagery of the seafloor. Towed-camera systems covered depths between 20 and 150 m and towed-diver surveys covered depths between 3 and 30 m.

2.2.1 Operational Background and Logistics

In *The National Action Plan to Conserve Coral Reefs*, the U.S. Coral Reef Task Force identified mapping of all U.S. coral reef habitats as one of their highest priorities. The NOAA CRCP established a goal to map all U.S. coral reef areas to support conservation and management of U.S. coral reefs. In support of these goals, CRED and the CCMA Biogeography Program have been leading efforts to produce benthic habitat maps of coral

reef areas from the shoreline to moderate depths (≤ 1000 m). The Biogeography Program has been leading collaborative efforts to develop shallow-water benthic habitat maps using aerial and satellite-based methods. As a result of visibility constraints, these techniques are best suited for shallow-water habitats (≤ 20 m deep). CRED has been leading efforts using multibeam acoustic echosounders and optical assessment technologies to extend the existing shallow-water maps to moderate depths (~ 20 – 1000 m) where aerial- and satellite-based techniques are less suitable.

As stated above, three different NOAA ships were used to support mapping operations in American Samoan waters between 2002 and 2006. These include the NOAA Ships *Townsend Cromwell* (2002), *Oscar Elton Sette* (2004), and the *Hi`ialakai* (2006). In addition, the CRED R/V *AHI*, an 8-m survey launch, was deployed in 2004 and 2006 to conduct shallow-to-moderate depth habitat mapping.

A variety of operational scenarios have been developed to optimize the efficiency of mapping operations. During cruises aboard the *Hi`ialakai*, shipboard multibeam mapping surveys were conducted primarily during nighttime hours to avoid interfering with daytime reef ecosystem monitoring and nearshore oceanographic surveys requiring small boat and diver-based operations. R/V *AHI*-based mapping operations were conducted during daylight hours to perform multibeam surveys in shallow, nearshore waters inaccessible to the *Hi`ialakai*.

During previous cruises aboard the *Townsend Cromwell* and *Oscar Elton Sette*, optical validation data were typically collected using a towed camera sled deployed from the ships in deeper waters (20–150 m) during nighttime hours and by towed-diver surveys in shallower waters (3–30 m) during daylight hours.

Operationally, depth limitations existed for both multibeam surveying and optical data collection. As a general rule, multibeam surveys by CRED have focused on collecting data at depths between approximately 20 and 1000 m. The 20-m inshore limit is based on: (1) safety concerns relating to increased risks in shallow water as a result of possible groundings and/or breaking waves, and (2) significant decreases in mapping efficiencies because the area mapped decreases proportionally to water depth. Combined, these factors meant that survey work in waters shallower than 20 m would have required increasingly larger amounts of time that were spent working in potentially dangerous conditions, particularly in areas with steep forereef slopes.

Similarly, ship-based towed-camera optical data collection has been limited to depths between approximately 20 and 150 m based on the depth limitations of the instruments. Towed-diver surveys provide optical data to about a 30-m maximum depth. Below this depth, the divers would be subject to increased risk of decompression sickness. Ship- and launch-based multibeam surveying, as well as towed-camera and towed-diver optical assessment data collection procedures adhere strictly to NOAA safety policies applicable to ship, small boat, and scuba diving operations.

2.2.2 Acoustic Mapping

Equipment

Aboard the *Townsend Cromwell*, acoustic mapping was conducted using a Simrad EQ-50 (50 kHz) single-beam echosounder that was integrated with a Quester Tangent Corporation (QTC) View data acquisition and bottom classification system. This system was subsequently transferred to the *Oscar Elton Sette*, where the QTC View was interfaced to one quadrant of a 38 kHz split-beam transducer used in conjunction with a Simrad EK-60 echosounder. Acoustic seafloor classification systems such as QTC are best used in reasonably flat areas such as the continental shelf off the eastern seaboard of the continental U.S. It was found that in areas where the seafloor is quite steep, including much of the seafloor around the islands of American Samoa, classification results are not very reliable. For this and other reasons, acoustic surveying transitioned to multibeam echosounder technology at the earliest opportunity.

The *Hī ialakai* is equipped with two multibeam sonars: a Kongsberg 300 kHz EM3002 multibeam echosounder that can map at depths between roughly 20 and 150 m, and a Kongsberg 30 kHz EM300 multibeam that is capable of mapping in depths ranging from about 50 to 3000 m. The *AHI* is equipped with a 240 kHz RESON 8101ER multibeam echosounder capable of mapping at depths between approximately 10 and 250 m. When used in conjunction with the *Hī ialakai*, the *AHI* can be deployed and recovered in locations far from sheltered harbors, allowing shallow-water surveys to be conducted throughout the remote U.S.-affiliated Pacific Island areas (Fig. 2.2.2a).

Survey Design

The quality and geographic coverage of existing bathymetric data, as well as consultation with key resource managers and stakeholders, were used to determine survey priorities. Data collected on previous cruises were typically combined with existing datasets, allowing the mapping team to develop survey plans to most effectively target gaps in the bathymetry coverage.



Figure 2.2.2a. Survey launch R/V *AHI* and NOAA Ship *Hī ialakai* are outfitted with three multibeam echosounders that facilitate mapping in depths ranging from ~ 20 to 3000 m. (Photograph provided by NOAA PIFSC CRED)

Prior to 2002, only a few, limited shallow- and moderate-depth bathymetry datasets existed for the nearshore waters of American Samoa. Existing nautical charts of Tutuila Island showed surrounding banks (0–60 m) with an area of approximately 300 km², but little was known about the coral reef and other shallow habitats that existed on these banks. Almost no shallow bathymetric information

existed around Ofu, Olosega, Ta`u, and Swains Islands or Rose Atoll. Aside from nautical charts, the available limited data (Wright, 2002) served as the primary base for the 2004 planning process.

In early 2004, shallow-water multibeam surveying was conducted around Tutuila and the Manu`a Islands using the R/V *AHI*. During the ASRAMP 2004 cruise, the *AHI* operated independently of the *Oscar Elton Sette* and was based out of Pago Pago Harbor and the Ofu small boat harbor. During that deployment, the shallow waters surrounding Ofu, Olosega and Ta`u were completely surveyed, as were approximately 60% of the banks surrounding Tutuila. Substantial amounts of deeper multibeam data were collected in American Samoan waters during a variety of academic research deployments between 2004 and 2006. These datasets were collated in the online Seamount Catalog (<http://earthref.org>), and also incorporated more recent data obtained from NOAA and University of Hawaii (UH) research activities aboard the R/V *Kilo Moana* and the R/V *Kaimi`kai O Kanaloa*. These data, combined with multibeam data collected from previous CRED cruises, formed the base for the 2006 survey planning. In 2006, the *AHI* was deployed from the *Hi`ialakai* and surveyed the shallow waters surrounding Rose and Swains while the ship surveyed the deeper flanks. Surveys of the banks surrounding Tutuila were completed by a combination of the two vessels.

Data Collection and Processing

Though the QTC habitat classification system can be used with a variety of sonar systems and different frequencies, data collected at different sonar frequencies or transmission characteristics cannot be easily integrated. Unfortunately, this meant that QTC classifications acquired during the 2002 surveys aboard the *Townsend Cromwell* could not be compared with QTC classifications acquired during the 2004 surveys aboard the *Oscar Elton Sette*. Nevertheless, the spatial variability of the habitat classifications, rather than the classifications themselves, was determined to be a good predictor of bottom type for use in targeting areas for optical ground-truth surveys.

Since 2004, the R/V *AHI* and *Hi`ialakai* have been the exclusive platforms for CRED multibeam mapping missions. Real-time data acquisition and processing often occurred concurrently and involved several processing steps and software packages. See the Documentation section of PIBHMC's web site (<http://www.soest.hawaii.edu/pibhmc>) for more details.

Data Acquisition

Multibeam data were collected using the ISS-2000 collection module. Sensors were interfaced to the system through a software module called a Data Transaction Center (DTC) that was used to set sensor settings, calibration parameters, quality control parameters, input formats, and output file formats. Each of the DTC modules stored the data from its corresponding sensor in the appropriate file formats and assigned the appropriate names to each file. Most data were ASCII text files, but binary Generic Sensor Format (GSF; Ferguson and Chayes, 1995; SAIC, 2007) were used specifically for multibeam data. Each filename was unique and based on the sensor collecting the data, the collection date, and a sequential extension.

A benefit of ISS-2000 was that all echosounder correctors were applied in real-time during data collection. All data were displayed in real-time for quality control purposes and for guidance of the progress of the survey. Each GSF echosounder file not only stored all information necessary to provide the depth for each beam, but each file also contained a record of every

action taken on the data file.

Data Processing

Data collected using the ISS-2000 software were fully corrected for ship's motion, navigation, sound velocity, and predicted tides (if selected). Predicted tidal correctors were applied (using data from the NOAA Center for Operational Oceanographic Products and Services) to multibeam data during collection to minimize apparent errors which may be caused by tide offsets or other system problems. Using Science Applications International Corporation's (SAIC's) compatible Survey Analysis and area Based EditoR (SABER) processing package, many of these corrections can be reapplied or changed, if desired. The following four processing steps were needed for the majority of multibeam bathymetric data collected:

- The application of alternate sound velocity profiles to a limited number of multibeam swath files;
- The application of corrected tides (if available and/or needed) to some or all multibeam swath files to replace the predicted tides applied in real-time;
- The visual editing of individual multibeam swath data files in GSF; and
- The assembly of all data in a given area within a Pure File Magic (PFM) grid and visual editing using an area-based editor.

After edits were made to the PFM grid the data were downloaded back to the GSF files, where flags were set to indicate the edits. These processed GSF files were used for data synthesis work at PIBHMC and were documented with metadata; the GSF files with metadata were sent to the NOAA National Geophysical Data Center on a cruise-by-cruise basis.

After the grid editing was complete, the PFM grid was downloaded to ASCII, Cartesian or other grid formats, or the original GSF files were regrided and output to these formats. The GSF files, ASCII, Cartesian, and/or grid files were then transferred to other data processing and visualization packages, including:

- MBSystem: an open-source software package for the processing and display of bathymetry and backscatter imagery data derived from multibeam, interferometry, and sidescan sonars (<http://www.mbari.org/data/mbsystem/>). MBSystem is supported by the National Science Foundation (NSF); and
- Generic Mapping Tools (GMT): GMT is an open-source collection of about 60 tools for manipulating geographic and Cartesian datasets and producing output in the encapsulated postscript format. It is supported by the NSF (<http://www.soest.hawaii.edu/gmt/>).

2.2.3 Optical Validation Surveys

TOAD

CRED's initial TOAD integrated a digital still camera, an underwater video camera, lights, and parallel scaling lasers on a Guideline Minibat tow body (Fig. 2.2.3a). The Minibat design allowed limited control of the vehicle's position while towing by changing the angle of the Minibat wings. The TOAD operator entered the estimated layback distance into the Minibat software, which integrated it with the ship's position to provide an estimated position of the

tow body along the survey track. Estimated positional accuracies using this method were on the order of 50 m. Various operational scenarios were tested, including towing the TOAD at speeds of 1 to 3 kn and using it in a drift mode. After several cruises, it was determined that the drift technique was most effective and presented the least overall risk to both the tow body and shipboard personnel operating the winch, particularly over high relief terrain.

Seafloor videography collected during TOAD deployments were analyzed using a series of five small circles extending in a straight horizontal line marked on a video monitor screen. The types of substrate (sand, rock, etc.) and living cover (macroalgae, scleractinian coral, hydrocorals or other benthic fauna, etc.) that fell within these circles were identified at 20-m or 30-sec increments along the camera's trackline. Other biologically relevant observations were made as well. The full listing of benthic habitat classifications is shown in Appendix I, Table I. i. TOAD habitat classifications are incorporated in attribute tables associated with Arc© shapefiles that show the location of TOAD tracks over the seafloor.

Towed-diver Benthic Habitat Characterization

Data characterizing the benthic habitats around American Samoa in depths between 3 and 30 m were collected during towed-diver surveys. These benthic habitat characterizations provide background for analyses of biological data collected during the towed-diver surveys and also can be used to validate (ground-truth) habitat maps created by acoustic and/or satellite-derived information. The benthic characterization data collected during benthic towed-diver surveys are discussed in Section 2.4.2, Towed-diver Surveys. Only a brief overview of towed-diver surveys and details on the benthic habitat categories used to make habitat characterization maps are presented in this section.

The towed-diver methodology involved towing two divers/observers approximately 60 m behind a small boat while they each maneuver their towboard to maintain their position about 1 m above the bottom. A typical survey covered approximately 2 linear km of habitat and lasted about 50 min. Surveys were divided into ten 5-min segments (~ 200 m in length) during which the benthic diver/observer recorded visual estimates of habitat complexity and benthic substrate cover within a 10-m swath (5 m on either side of the tow line). In addition to visual estimates of benthic cover, continuous video imagery of the benthos was collected in 2002 and still camera photographs of the benthos were taken at 15-sec intervals in 2004 and 2006. The photos and video imagery have been archived for future analyses.

Classification of habitat complexity was a subjective assessment of topographical diversity and complexity over a large scale (~ 2000 m²) based on six categories: low, medium-low, medium, medium-high, high, and very high. For example, a sandy bottom with scattered macroalgae has low habitat complexity. In contrast, a shallow reef with numerous



Figure 2.2.3a. TOAD. (Photograph provided by NOAA PIFSC CRED)

growth forms of corals and three-dimensional structure providing shelter for reef fish of various size categories would be rated medium-high to very high. See Figure 2.4.2b in Section 2.4.2: Towed-diver Surveys for visual examples of each complexity category.

Benthic cover was estimated for four different types of substrate: hard substrate/pavement, sand, rubble, and live hard (scleractinian) coral. A description of each substrate type is given in Table 2.2.3a. It is important to note that in 2006 the definition of rubble changed to include only unconsolidated fragments of coral skeleton or reef rock not visibly encrusted by fleshy or calcareous algae or corals. Also in 2006, the hard substrate/pavement category was not recorded. All other benthic substrate definitions remained the same for towed-diver surveys from 2002 to 2006.

Towed-diver benthic data were used to make habitat characterization maps for complexity, sand, hard substrate/pavement, rubble, and live hard (scleractinian) coral. For each habitat characterization map, estimates of respective benthic features were plotted in ArcGIS 9.2 using the midpoint of each 5-min towed-diver segment. Results from the 2002, 2004, and 2006 surveys were combined and then an inverse distance weighting (IDW) interpolation function (ArcGIS 9.2) was applied to the combined dataset. The IDW function produced a continuous plot of the salient benthic features around each island.

Table 2.2.3a. Benthic cover categories used to create habitat characterization products from towed-diver surveys, 2002-2006 (Kenyon et al., 2006a).

Benthic Cover Category	Description
Live Hard Coral	Colonies or portions of colonies, of live pigmented tissue.
Sand	Unconsolidated sediment, ranging in texture and size from fine to coarse. Origins are both inorganic (eroded rock) and organic (eroded fragments of calcareous organisms).
Rubble*	Unconsolidated fragments of coral skeleton or reef rock whose sizes are larger than sand.
Hard Substrate/ Pavement**	Consolidated substrate, typically composed of calcareous and/or basaltic elements that have become cemented together by biogenic and physical processes.

* In 2006 the definition changed to include only rubble that was not visibly encrusted by macroalgae, calcareous algae or corals.

** In 2006 the hard substrate/pavement category was not recorded.

2.3 Oceanography and Water Quality

Knowledge of local oceanographic processes and water quality parameters is fundamental to understanding the natural dynamics and anthropogenic influences controlling many environmental aspects of coral reef ecosystems, including organism distribution, abundance, and biodiversity; biological productivity; larval dispersal and recruitment; localized and large-scale patterns of coral bleaching and disease; and degrees of disturbance from episodic storms and human-related activities. To assess the oceanographic and water quality conditions influencing the environmental aspects of coral reef ecosystems in American Samoa, CRED collected and integrated five key data streams, including: (1) deep-water oceanographic

surveys characterizing prevailing water properties and ocean currents around the islands of American Samoa; (2) intensive closely spaced nearshore oceanographic and water quality surveys conducted concurrently with REA and towed-diver biological surveys; (3) an array of surface and subsurface moored instruments providing continuous, high-resolution time series observations; (4) satellite remote sensing products providing spatial time series observations of key oceanographic properties (e.g., sea surface temperature [SST], sea surface height, surface winds, chlorophyll-a, and other derived products), and (5) numerical models (e.g., Wave Watch III) providing spatial and temporal estimates of various oceanographic parameters.

2.3.1 Operational Background and Survey Design

CRED has used a diverse array of data collection methodologies to monitor and assess local oceanographic and water quality conditions, including in situ telemetered surface and subsurface moored instruments, shipboard and nearshore spatial hydrographic surveys performed during research cruises, and bioacoustic surveys. Oceanographic equipment and instrument specifications are detailed in Appendix I, Table I. ii. Shipboard surveys were conducted by the three different NOAA ships (discussed in Section 2.1: Operational Background), and nearshore surveys and instrument deployment/retrievals were accomplished by small boats deployed from these ships.

The monitoring sites were selected to characterize the prevailing climatic and oceanographic conditions by spatially and temporally quantifying key physical forcing mechanisms pertinent to biological processes (e.g., temperature, salinity, currents, wave energy, ultraviolet [UV] radiation, nutrients, chlorophyll, dissolved oxygen, and dissolved inorganic carbon) over seasonal, interannual, and decadal time scales. By so doing, CRED is generating a baseline for long-term observation of environmental conditions influencing reef ecosystems that are particularly important in aiding efforts to understand and predict the ecological impacts of climate change.

2.3.2 Shipboard Surveys

Shipboard deep-water (500 m) conductivity, temperature, and depth (CTD) casts with simultaneous water sample collection were conducted to determine prevailing water property profiles surrounding the islands and atolls of American Samoa. These deep-water casts provide high-resolution vertical profiles of conductivity (salinity), temperature, dissolved oxygen, and chlorophyll-a concentration versus depth. In addition, shipboard acoustic Doppler current profiler (ADCP) transects were conducted



Figure 2.3.2a. Deep-water CTD (SBE 911*plus*) with rosette and Niskin water bottles being deployed from ship. (Photograph provided by NOAA PIFSC CRED)

in the deep-water regions around each of the islands and atolls to examine the horizontal and vertical structure of the prevailing ocean currents (Lumpkin and Pazon, 2005).

Deep-water CTD Surveys

A Sea-Bird Electronics, Inc. (SBE) SBE 911*plus* CTD with a SBE 43 dissolved oxygen sensor and Wetlabs ECO FLNTU fluorescence and turbidity sensors was used to collect vertical profiles of water properties from the surface to 500 m deep in offshore environments around each island/atoll surveyed. In addition, a rosette with multiple 5-l Niskin bottles (Fig. 2.3.2a) was used to collect water samples at selected depths for chlorophyll-a and nutrient analyses. Data from the deep-water CTD casts are presented in the archipelago chapter of this report (Chapter 8, Section 8.4.2: Seasonal Variation).

Shipboard ADCPs

Transects of ocean current velocity profiles were collected using shipboard ADCPs during ASRAMP cruises in 2002, 2004, and 2006. During the 2002 cruise aboard the *Townsend Cromwell*, the surveys were conducted using a hull-mounted 153-kHz RD Instruments (RDI) narrow beam ADCP, which collected current profiles in 8-m sampling bins over depths between 20 and approximately 250 m, averaged into over 5-min ensembles. During the 2004 and 2006 cruises aboard the *Oscar Elton Sette* and *Hi'ialakai*, the surveys were conducted using hull-mounted 75 kHz RDI Ocean Surveyor instruments. These systems were configured with an 8-m pulse length which typically collects current profiles in 16-m depth bins between depths ranging from 25 to about 600 m averaged into 15-min ensembles. The actual depth range depended on the density and abundance of scattering material in the water column. In addition to dedicated ADCP transect grids around the islands data were generally collected continuously while the vessels were underway. Data from the shipboard ADCPs are not presented in this report.

2.3.3 Nearshore Spatial Surveys



Figure 2.3.3a. SBE 19*plus* shallow-water CTD used for nearshore profiling of salinity, temperature and pressure-based depth. (Photograph provided by NOAA PIFSC CRED)

Closely spaced nearshore CTD surveys were conducted throughout the shallow-water environments around each of the islands, atolls, and reefs surveyed during all of the ASRAMP cruises. The distance between adjacent casts ranged from 0.25 to 2.0 km, depending on the size of the area being sampled with each cast typically being conducted approximately 30 m deep. These surveys were conducted to characterize the spatial structure of the physical and chemical properties of the ocean environment influencing the living coral reef resources observed during REA and towed-diver surveys. Water samples were collected at a subset of the shallow-water CTD sites to examine nearshore water quality.

Shallow-water CTD Surveys

The shallow-water CTD surveys provided vertical profiles of conductivity and temperature versus depth using an SBE 19*plus* CTD. Beam transmission data were

collected concurrently using a Wetlabs C-Star Transmissometer. The CTD profiles were collected by hand-lowering the CTD profiler (Fig. 2.3.3a) from a small boat at a descent rate of approximately 0.5 to 0.75 m s⁻¹ to a 30-m maximum depth. The shallow-water CTD observations around each island/atoll are presented as vertical cross-section plots generated using Ocean Data View software (<http://odv.awi.de>). Subsets of the data representing the same oceanographic parameters at a 20-m depth are presented to further illustrate their spatial structure around each of the islands and atolls of American Samoa.

Seawater Laboratory Analyses

Water samples were collected at a subset of the shallow- and deep-water CTD sites. During the shallow-water CTD surveys, a daisy chain of 1.75- and 5-l Niskin bottles were lowered to collect water samples at various depths (1, 10, 20, and 30 m) by triggering the bottles to close shut using a trip weight (messenger) sent down the line. These water samples were preserved for laboratory analyses of water quality including levels of: chlorophyll-a, nitrates, nitrites, phosphates, silicates, total nitrogen, partial pressure of carbon dioxide ($p\text{CO}_2$), and/or alkalinity. Chlorophyll-a water samples were processed by Dr. Paul Bienfang of Analytical Services, Inc., Honolulu, Hawaii. Nutrients, $p\text{CO}_2$, and alkalinity were processed at the NOAA Pacific Marine Environmental Laboratory in the nutrient laboratory of Dr. Calvin Mordy and in the carbon chemistry laboratory of Dr. Richard Feely.

2.3.4 Surface Moorings

As a key component of CREIOS, buoys were moored in shallow-water environments at many U.S.-affiliated Pacific Islands. These buoys provide near real-time observations of key oceanographic conditions influencing coral reef ecosystem processes to managers, stakeholders, and the public. These surface observations were transmitted via satellite for daily dissemination at the CRED website <http://www.pifsc.noaa.gov/cred/>.

Coral Reef Early Warning System (CREWS) Buoys

CREWS buoys are sea surface moorings that telemeter in situ observations of atmospheric and oceanographic parameters influencing reef conditions (Fig. 2.3.4a). CREWS buoys have been providing near real-time observations of high-resolution SST and surface conductivity (or salinity) at a 1-m depth, air temperature, barometric pressure, and wind velocity. Enhanced versions additionally provide photosynthetically available radiation (PAR) and UV radiation. All data were sampled at 30-min intervals and internally recorded. Subsets of data have been transmitted daily via satellite telemetry to provide near real-time updates of changing environmental conditions. The sensors used to collect and record the data include an SBE 37 MicroCAT conductivity and temperature recorder, an RM Young WS425 air temperature sensor, a Heise Instruments DXD barometric pressure sensor and a Vaisala Instruments acoustic wind velocity sensor. Enhanced versions of the CREWS buoys also include Biospherical Instrument's



Figure 2.3.4a. CREWS buoys relay oceanographic and meteorological data via satellite telemetry. (Photograph provided by NOAA PIFSC CRED)



Figure 2.3.4b. OTR SB200 SST buoy. (Photograph provided by NOAA PIFSC CRED)



Figure 2.3.4c. SOSI Model SST-001 SST buoy. (Photograph provided by NOAA PIFSC CRED)

PAR and UV radiation sensors. Data from the CREWS buoy at Rose are presented in Chapter 6, Section 6.3.2: Habitat Characterization.

SST Buoys

SST buoys are sea surface moorings that telemeter in situ observations of high-resolution SST in near real-time. Data are recorded internally and transmitted, via satellite, at 1-hour intervals. The two types of buoys, an Ocean Trek Research (OTR) SB200 solar rechargeable buoy and the battery-powered Sound Ocean Systems, Inc. (SOSI) Model SST-001 use a SBE 39 temperature recorder for SST measurements.

Images of the two types of SST buoys can be seen in Figures 2.3.4b and 2.3.4c. Data from the SST buoys are presented in the respective island/atoll chapters of this report.

2.3.5 Subsurface Moorings

Ocean data platforms (ODPs), wave and tide recorders (WTRs), subsurface temperature recorders (STRs), and Aanderaa current meters are subsurface moorings deployed at selected locations and configured to continuously record important oceanographic parameters that influence reef conditions. These moorings were recovered on a periodic basis and replaced with refurbished units to maintain a continuous time series of data at each location. ODPs record observations of ocean current profiles, wave energy, temperature, and salinity;

WTRs record observations of sea level height, wave energy, and temperature; STRs record observations of subsurface temperature; and Aanderaa current meters record observations of

ocean current velocity (at a fixed depth) and temperature.

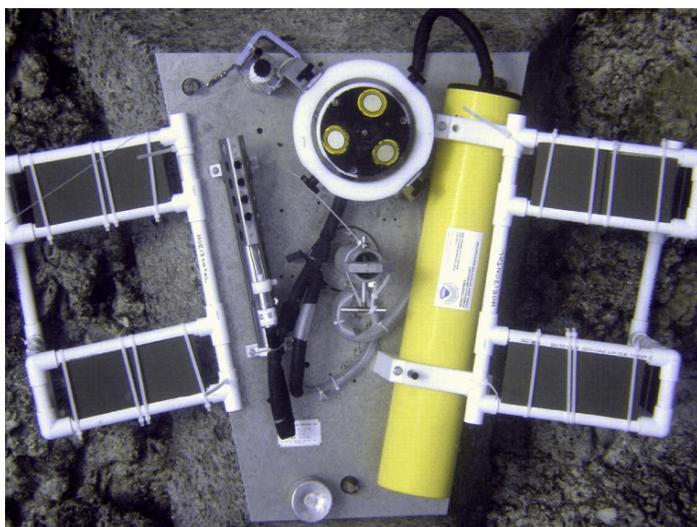


Figure 2.3.5a. ODP mooring. (Photograph provided by NOAA PIFSC CRED)

ODPs

ODPs recorded directional current profiles and wave spectra using a Sontek 1000-kHz ADCP, and high-resolution ocean temperature and salinity using a SBE 37 MicroCAT conductivity and temperature recorder (Fig. 2.3.5a).

Sample intervals for current and wave data varied depending on duration of deployment;

temperature and salinity were sampled at 30-min intervals. Deployment depths typically ranged from 15 to 35 m. Data were internally recorded and retrieved from platforms during subsequent ASRAMP cruises. Data from the ODPs are not presented in this report.

WTRs

WTRs are subsurface moored instruments consisting of an SBE 26*plus* SEAGAUGE WTR that records observations of high-resolution pressure (wave height and tides) and temperature. Data were internally recorded with sample intervals determined by duration of deployment. Deployment depths typically ranged from 10 to 25 m.

STRs

STRs are subsurface moored instruments consisting of SBE 39 temperature recorders, which are physically attached to reef structures to record observations of high-resolution temperature influencing the corals and other benthic biota. Unlike CREWS buoys, SST buoys, and satellite observations of SST, STRs record the actual temperatures at the depth of the corals living near their point of deployment. These observations are particularly important during calm conditions conducive to coral bleaching. At these times, the water column is often well-stratified, meaning that many of the corals may not be subjected to the warmer temperatures at the surface, thereby potentially lessening the likelihood of bleaching. STRs have been deployed in a variety of locations and habitats throughout the coral reef ecosystems of American Samoa, particularly those considered most prone to coral bleaching.

Aanderaa RCM 9 Recording Current Meter (RCM)

The Aanderaa RCM 9 current meter is an autonomous subsurface mooring used to record observations of the speed and direction of ocean currents at a specific depth. Data were internally recorded with sample intervals determined by duration of the deployment.

Ecological Acoustic Recorders (EARs)

EARs (Fig. 2.3.9a) are passive acoustic recording devices developed specifically for monitoring fish, invertebrates, and human activity in marine habitats (Lammers et al., in press). The EAR is a digital, low-power system based on a Persistor CF2 microprocessor and a 16-bit analog-to-digital converter that records ambient sounds up to 30 kHz on a programmable schedule for up to 1 to 2 years. The EAR also responds to transient acoustic events that meet specific criteria, such as cetaceans or motorized vessels passing nearby. A total of eight EARs were deployed in American Samoa during ASRAMP 2006. Deployment depths typically ranged from 10 to 25 m. Four EARs were retrieved and their data (only for Tutuila) are presented in this report.

2.3.6 Oceanographic Equipment Deployment

Oceanographic instrumentation has been deployed across the American Samoa Archipelago since 2002. These deployments, accompanied by successive retrievals for specific devices, are summarized in Table 2.3.6a. At each island and atoll in the archipelago, important oceanographic features were evaluated and specific management concerns were addressed by selecting pertinent monitoring locations and using appropriate instrumentation. These instruments and the data they have collected are described in the oceanography and water quality sections of each island/atoll chapter.

Table 2.3.6a. Number of oceanographic instruments deployed (Dep) and retrieved (Ret) by year in the American Samoa region. Instrument Types: CREWS buoy, EAR, ODP, RCM, STR, SST buoy, and WTR.

Instrument Type	2002		2004		2005		2006		Lost	CURRENT
	Dep	Ret	Dep	Ret	Dep	Ret	Dep	Ret		
CREWS	1	0	1	1	0	0	1	1	0	1
EAR	0	0	0	0	0	0	4	0	0	4
ODP	1	0	0	1	0	0	0	0	0	0
RCM	2	0	0	2	0	0	0	0	0	0
STR	0	0	17	1	4	0	27	17	3	27
SST	8	4	5	5	3	2	5	3	2	5
WTR	0	0	2	0	1	1	2	2	0	2
TOTAL	12	4	25	10	8	3	39	23	5	39

2.3.7 Satellite Remote Sensing and Ocean Modeling

Satellite Remote Sensing

All satellite-derived data products presented in this report are produced and distributed publicly by various government and private organizations. Brief summaries of data providers and any further analyses performed by CRED are outlined below.

- NOAA AVHRR Pathfinder 5.0 SST (Casey, 2006)
 - <http://www.nodc.noaa.gov/sog/pathfinder4km/>
 - Infrared Radiometer SST from NOAA polar orbiter satellites
 - 4-km resolution grid
 - Climatology: Produced by National Oceanographic Data Center (NODC) using data from 1985 to 2001
 - Time series plots: Pathfinder 5.0 weekly data and climatology time series plots are based on data extracted from $1^\circ \times 1^\circ$ latitude-longitude boxes surrounding the area of interest
- National Aeronautics and Space Administration (NASA) Quikscat Scatterometer Winds
 - <http://winds.jpl.nasa.gov/missions/quikscat/index.cfm>
 - Microwave scatterometer that measures near-surface wind speed and direction
 - 0.25-degree resolution grid
 - Climatology: Produced by CRED and NODC for OceanEye project using data from 2000 to 2003
- NASA SeaWiFS imager
 - <http://oceancolor.gsfc.nasa.gov/SeaWiFS/>
 - Measures bio-optical properties of the ocean, including a calculation of chlorophyll-a levels
 - 9-km resolution grid
 - Climatology: Produced by CRED and NODC for OceanEye project using data from 1998 to 2003

Ocean Modeling: Bleaching Threshold

As early as 1997, the NOAA National Environmental Satellite, Data, and Information Service began producing near real-time, web accessible, satellite-derived SST products to monitor

conditions conducive to coral bleaching from thermal stress around the globe. This activity evolved into a crucial part of CRW in 2000 (<http://coralreefwatch.noaa.gov/satellite/index.html>).

The Bleaching Threshold, developed by CRW (<http://www.coralreefwatch.noaa.gov>), serves as a general indicator for coral bleaching and is defined by 1°C above the maximum monthly climatological SST value for a particular geographic area.

CRED generated SST and wave height time series around the islands and atolls of American Samoa between January 2002 and April 2006. Remotely sensed data (SST Climatology and weekly Pathfinder-derived SST) and modeled significant wave height derived from Wave Watch III were overlaid with CRED in situ observations from various locations around each island and atoll in the archipelago, with indicators for each region's bleaching threshold and ASRAMP cruise dates. In situ and telemetered data were used to produce the time series record for each island or atoll, as shown in the respective oceanography and water quality sections of each island/atoll chapter.

Ocean Modeling: Wave Watch III

Wave Watch III is a third-generation full spectral ocean wind-wave model which provides historical and near real-time open-ocean, deep-water modeled spectral wave data (height, period, and direction). Three hourly forecasts of wave conditions, up to 144 hours (6 days) in advance, are generated twice daily.

Wave Watch III solves the spectral action density balance equation for the wave number-direction spectra. The implicit assumption of this equation is that properties of medium (water depth and current) as well as the wave field itself vary on time and space scales that are much larger than the variation scales of a single wave. A further constraint is that the parameterizations of physical processes included in the model do not address conditions where the waves are strongly depth-limited. These two basic assumptions imply that the model can generally be applied on spatial scales (grid increments) larger than 1 to 10 km, and outside the surf zone (<http://polar.ncep.noaa.gov/waves/wavewatch/wavewatch.html>). Additional information can be referenced in Tolman (1999; 2002).

2.3.8 Surface Drifters

Satellite-tracked Lagrangian surface drifting buoys, commonly called drifters, measure SST and mixed layer currents in the upper ocean. As part of the World Ocean Circulation Experiment's (WOCE) Surface Velocity Program (SVP), drifters are designed with a surface buoy attached by a thin tether to a subsurface holey-sock drogue or sea anchor, centered at 15 m beneath the sea surface. Twenty-five SVP-compliant drifters (Lumpkin and Pazos, 2005) have been deployed in the American Samoa region during ASRAMP research cruises since 2002 (Table 2.3.8a). Two drifter models have been used: the ClearSat-15 with on-board global positioning system (GPS) navigation manufactured by Clearwater Instrumentation and the WOCE SVP drifting buoys with on-board GPS navigation manufactured by Technocean. GPS data (including date, time [accurate to ± 1.0 sec] and location [accurate to $\pm 0.0001^\circ$]), SST, drogue presence and battery level are transmitted daily via satellite telemetry to the satellite-based Argos data collection system and delivered to CRED periodically by e-mail.

Table 2.3.8a. Number of WOCE SVP drifter buoys deployed by year and location in the American Samoa Archipelago (Lumpkin and Pazos, 2005).

Deployment Year	Drifter Manufacturer	Drifter Model	Tutuila	Manu`a Islands	Rose	Swains
2002	Technocean	GPS, drogue at 15 m	4	1	1	1
2003	Clearwater	ClearSat-15 GPS	3	1	0	1
2004	Clearwater	ClearSat-GPS-HP	3	1	1	1
2006	Clearwater	ClearSat-GPS-HP	3	1	2	0

2.3.9 Bioacoustic Surveys



Figure 2.3.9a. An EAR secured to a concrete anchor ready for deployment. (Photograph provided by NOAA PIFSC CRED)

Understanding the biological interactions in coral reef ecosystems requires long-term observations of inter- and intraspecies relationships and their environments. While existing monitoring instruments are capable of measuring long-term physical environmental trends, they currently lack the ability to observe most biological processes. The sounds present in marine habitats can be an effective indicator of many biological processes such as spawning events, courtship behavior, feeding, and competition among

many species of fish, invertebrates, and aquatic mammals. Acoustic monitoring of marine habitats is a promising means of tracking biological activity and detecting ecological responses to changing environmental conditions. In addition to tracking biological activity, acoustic monitoring can also be an effective tool for detecting human activities in the marine habitat, such as vessel traffic and fishing using explosives. This application is of particular use in areas where traditional monitoring methods are difficult or impossible to implement, such as remote islands and atolls. Long-term acoustic monitoring can provide a cost-effective means of logging the human presence at a particular location and thus help gauge the effectiveness of management practices.

CRED explored the benefits of bioacoustic surveys by collaboratively developing and deploying EARs with Drs. Marc Lammers and Whitlow Au of UH's Hawaii Institute of Marine Biology. Refer to Section 2.3.5: Subsurface Moorings for additional information.

2.4 Reef Benthic (Coral, Algae, Macroinvertebrate) and Fish Surveys

Information on the condition, abundance, diversity, and distribution of biological communities is vital to the effective management of coral reef resources. To provide resource managers with such information, CRED has supported two biological assessment teams focused on collecting reef fish and benthic community datasets. An REA team conducted fine-scale assessments at specific reef sites (~ 300 m²), while a team of towed divers conducted broad-scale surveys (~ 15 000–25 000 m² per survey) around the islands and atolls of American Samoa. The two assessment teams collected complementary data relating to four ecological disciplines: coral, algae, other macroinvertebrates, and reef fish (Table 2.4a). An overview of each assessment team and its sampling design, operational description, and methods is presented in the following sections.

Table 2.4a. Overview of the biological data collected by the REA and towed-diver assessment teams presented in this report.

Survey Results Presented in Report		
Discipline	REA	Towed-diver
Coral	<ul style="list-style-type: none"> • Coral community composition and generic richness • Percent live coral cover • Coral density (# colonies m⁻²) • Scleractinian (stony) coral size class distribution • Coral disease distribution and prevalence 	<ul style="list-style-type: none"> • Percent live scleractinian (stony) coral cover • Percent dead/stressed coral cover
Algae	<ul style="list-style-type: none"> • Algae percent occurrence by genera/functional group • Coralline algae disease distribution and density 	<ul style="list-style-type: none"> • Percent fleshy/macroalgae cover • Percent coralline algae cover
Other Macroinvertebrate	<ul style="list-style-type: none"> • Macroinvertebrate species presence • Macroinvertebrate species richness 	<ul style="list-style-type: none"> • Crown-of-thorns seastar (COTS), giant clam, sea cucumber, and sea urchin distribution and abundance
Reef Fish	<ul style="list-style-type: none"> • Reef fish community composition and species richness • Reef fish biomass 	<ul style="list-style-type: none"> • Large fish (> 50 cm) biomass • Large fish species composition

Within this report, summary statistics are presented as either standard deviation of the mean (SD) or the estimated standard deviation of the error (SE), depending on the variable being analyzed. SD quantifies how much values vary from one another. SE quantifies precision within the true mean of the population, factoring in both sample size and SD. Results from both REA and towed-diver surveys primarily include SE summary statistics because of the variations in the number and location of sites visited within and between years caused by environmental conditions (e.g., higher number of REA surveys along leeward versus windward sides). Data analyzed within ArcGIS from towed-diver surveys (e.g., depth data) include SD summary statistics primarily because of the inability of the software to directly calculate SE at the time of this report.

2.4.1 REA Surveys

REA surveys are investigations that provide a high degree of taxonomic resolution for coral, algae, other macroinvertebrate, and reef fish communities. The surveys were conducted using a combination of dive teams which generally included a two- to three-person fish team, a two-person coral/coral disease team, and a combined team of two algae biologists and a single macroinvertebrate biologist. The majority of REA surveys were conducted along the forereef slopes of individual islands at depths between 10 and 20 m. However, additional surveyed habitats included lagoonal patch reefs at Rose and a shallow offshore oceanic bank near Tutuila.

Selection of Sampling Sites and Transect Locations

The selection of REA sites in 2002 was not made randomly in close consultation with Dr. Andy Cornish, the coral reef monitoring coordinator for American Samoa's Coral Reef Advisory Group (CRAG). Factors considered during REA site selection included: (1) ensuring a range of sample sites representative of the benthic and reef fish habitats around each island; (2) selecting a mixture of sites within and outside of marine protected areas; (3) selecting a mixture of both 'impacted' and 'least impacted' sites; (4) selecting some sites adjacent to local villages, and (5) selecting a number of sites that could be compared to and complement previous assessment and monitoring work done by Drs. Alison Green, Charles Birkeland, and Peter Craig, as well as future coral reef monitoring proposed by CRAG. It is important to note that access to REA sites can be limited by wave exposure, weather conditions, and other environmental factors such as currents, which can affect the ability to resurvey sites between years.

The nonrandom nature of site selection places limits on the degree to which biotic metrics such as percent cover, density, diversity, and coral/coralline algal disease prevalence can be extrapolated through statistic inference to the larger population constituted by each island/atoll. It nonetheless remains statistically appropriate to examine differences among the same sites sampled over different years, which is the priority of CRED's long-term monitoring efforts.

An additional caveat in tracking temporal changes in relatively immobile resources (e.g., coral, algae) versus mobile resources (e.g., schools of fish) is that benthic spatial plots may accrue cumulative, temporally non-independent impacts over a succession of surveys depending on the type of impact (e.g., successive years of bleaching versus singular hurricane events), whereas mobile schools of fish would be re-randomizing themselves in space when surveys

are conducted over time in the same sites.

At each site, transects were deployed by the fish REA survey team, whose members were the first to enter the water. Transect placement was guided by: (1) a focus on hard-bottom communities; (2) deploying lines along an isobath to the extent possible at each site, and (3) laying the transect lines into the prevailing current. The latter was an important safety consideration to facilitate divers working against the current at the start of each dive but swimming with the current towards the end of each dive when they were more fatigued. The placement of transects by the fish team, rather than the benthic team, also helped reduce bias in the selection of specific benthic habitat that might otherwise be inadvertently introduced. Each benthic sub-discipline (e.g., corals, coral disease, algae, other macroinvertebrates) used survey protocols driven by: (1) accepted methods within the sub-discipline, and (2) the number of divers available and the need to choreograph each dive so as to stay within NOAA safety guidelines (e.g., proximity to a buddy). All sub-disciplines used the two transect lines as the geographical reference by which their selection of point, area, or quadrat placement was guided. Both random numbers and fixed intervals, which were used by the algal and macroinvertebrate researchers for quadrat placement, are commonly used sampling methods; both methods reduce observer bias by forcing scientists to sample pre-set areas.

Operational Description

During REA surveys, biological assessment teams follow highly structured protocols that are repeated at each REA site. Upon arrival at an REA site, three teams of divers enter the water over spaced time intervals. The first team to enter the water is the fish team, which consists of two to three investigators. The fish team deploys a 25-m transect line and two of the divers begin to survey along that transect while the remaining fish diver begins stationary point count assessments in the general vicinity. After approximately 20 min, the two-person coral team enters the water and begins to work along the first transect line. By this time the fish team has deployed and begun surveys along a second 25-m transect. About 10 min later, the algal/invertebrate team, consisting of two to three investigators, enters the water and begins surveying the first transect. In total, the fish team surveys three transects at each site (transects 1, 2, and 3), and the coral and algal/invertebrate teams survey transects 1 and 2 (Fig. 2.4.1a). The sampling effort takes between 60 and 80 min to complete.

REA Disciplines and Methods

The biological assessment teams used specific methodologies targeting their respective biological communities. These methodologies overlapped and complemented each other to ensure that collected data were representative of the biological state at each REA site. A timeline of methods development for each discipline is displayed in Tables 2.4.1a and 2.4.1b, and the methods used by each assessment team are discussed in the following paragraphs.

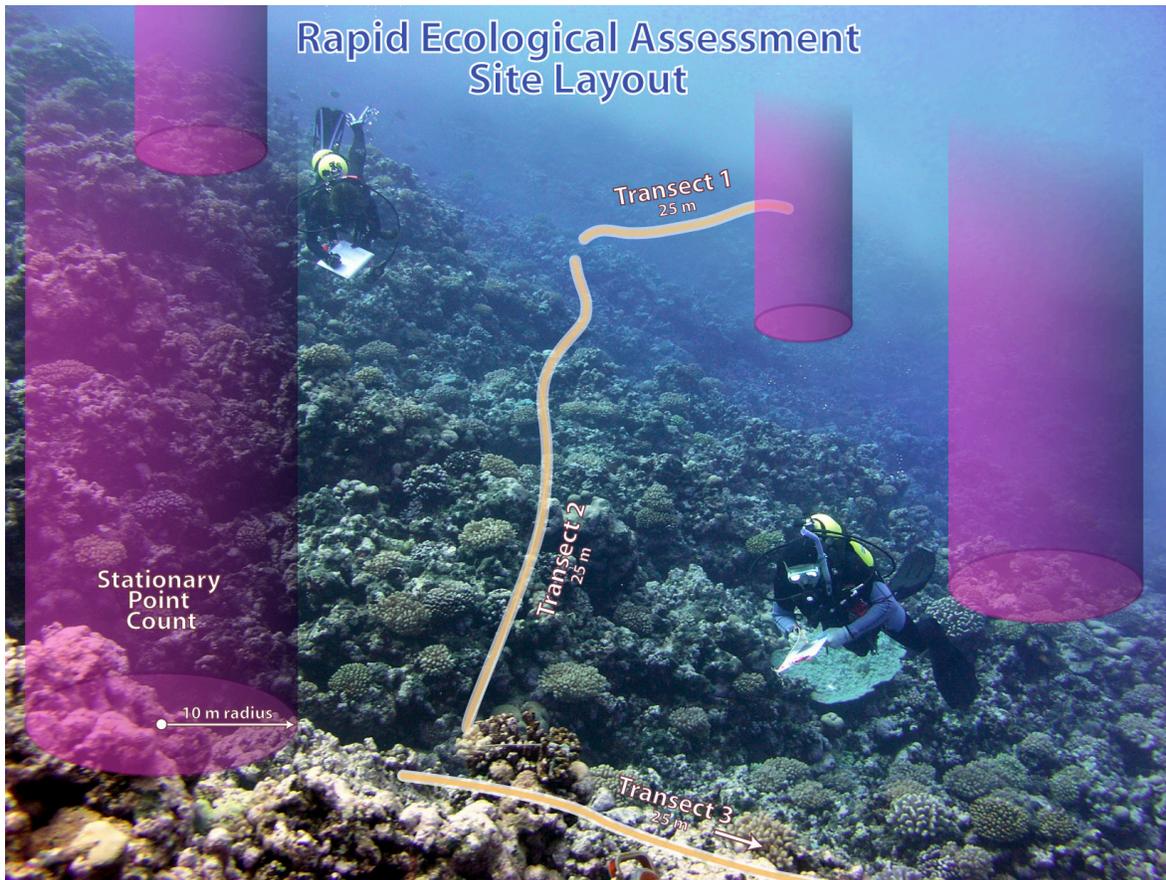


Figure 2.4.1a. Schematic of REA site layout. The reef fish assessment team surveys transects 1, 2, and 3 and conducts four stationary point count surveys. The coral/coral disease and algae/macrobenthos teams each survey transects 1 and 2. (Photograph provided by NOAA PIFSC CRED; J. Kenyon, JIMAR)

Table 2.4.1a. Timeline of methods development for each of the REA disciplines. Each REA discipline is separated by the various measured parameters.

REA Disciplines							
Coral and Coral Disease						Algae	
Year	Generic richness/composition	Percent live cover	Colony density (# colonies m ⁻²)	Size class	Disease prevalence	Percent occurrence (Genera)	Species presence
2002	MD	—	—	—	—	MD	—
2004	BLT	VE	BLT	BLT	—	QS, PQS	VS
2006	BLT	LPI	BLT	BLT	BLT	QS, PQS	VS

Method Acronyms: BLT = Belt Transect, LPI = Line Point Intercept, MD = Methods Development, PQS = Photoquadrat Survey, QS = Quadrat Survey, VE = Visual Estimate, VS = Voucher Specimen.

Table 2.4.1b. Timeline of methods development for each of the REA disciplines. Each REA discipline is separated by the various measured parameters.

REA Disciplines					
Macroinvertebrates			Reef Fish		
Year	Species presence	Species richness	Total fish biomass (all sizes)	Fish biomass (> 25 cm)	Species richness
2002	MD	—	—	—	BLT, RDS
2004	BLT, RDS	BLT, RDS	BLT, RDS	SPC	BLT, RDS
2006	BLT, QS	—	BLT, RDS	SPC	BLT, RDS

Method Acronyms: BLT = Belt Transect, MD = Methods Development, QS = Quadrat Survey, RDS = Roving-diver Survey, SPC = Stationary Point Count.

2.4.1.1 Coral and Coral Disease

The coral community at each REA site was assessed to quantify the diversity, abundance, density, and size class distribution of the anthozoan and hydrozoan¹ corals. The methods employed by the coral assessment team in American Samoa were different in all survey years. These methods included several complementary and noninvasive underwater survey techniques, e.g., visual estimate, line point intercept, and belt-transect; all of which provide viable and complementary datasets for quantitative and descriptive analyses (Kenyon et al., 2006a). Details on each method are discussed below including a description of the development of coral methods during 2002 REA surveys (*Coral Methods Development*). The temporal variation of coral sampling methodologies is summarized in Table 2.4.1a. A common name index of American Samoan coral species can be found in Appendix I, Table I. iii.

Coral Methods Development

The REA coral surveys during ASRAMP 2002 were the first surveys conducted in American Samoa by CRED. As such, the methods employed varied between sites and were mostly qualitative and exploratory in nature. Tested methods included: (1) relative abundance estimates of coral by species or genus using a semiquantitative DACOR (dominant, abundant, common, occasional, and rare) protocol (Maragos et al., 2004); (2) visual estimates of the percent coral cover at each REA site; (3) belt transects consisting of a coral biologist swimming along as many transect lines as bottom time permitted identifying coral species (or genus, when species identification in the field was ambiguous) occurring within approximately 0.5 m of each side of the transect lines; each colony was assigned to one of seven size classes (≤ 5 , 6–10, 11–20, 21–40, 41–80, 81–160 or > 160 cm) based on a visual estimate of the maximum colony diameter; (4) wide-angle photo-documentation of the benthos using a Nikon RS camera with a 13-mm lens, and (5) video documentation of the three 25-m transects using a Sony PC digital PC100 camcorder in a Gates underwater housing while slowly swimming about 1 m above the seafloor along the length of each transect.

¹ Anthozoan = Any of the Cnidarian class Anthozoa, such as the corals and sea anemones, that have radial segments and grow singly or in colonies. Hydrozoan = Any of the Cnidarian class Hydrozoa, such as the colonial hydrocorals, that secrete a calcium carbonate skeleton.

Visual Estimates

Percent live coral cover was recorded at REA sites in 2004 using visual estimates. Estimation of coral cover was a subjective, qualitative assessment in which the coral biologist estimated (by eye) the percentage of benthic substrate that was covered by live coral in the general area traversed by the transect lines.

Line Point Intercepts

The line point intercept technique was used to quantitatively assess average percent live coral cover and other benthic substrates at REA sites during ASRAMP 2006 (Hill and Wilkinson, 2004). A coral biologist swam along two 25-m transect lines recording all benthic elements falling directly underneath the transect line at 50-cm intervals. Benthic elements were recorded as one of nine benthic categories: live coral, dead coral, carbonate pavement, coralline algae, macroalgae, coral rubble, sand, rock, and other benthic sessile invertebrates. Living benthic elements (e.g., coral, algae, and other invertebrates) were identified to the lowest taxonomic level possible.

Belt Transects

Colony density and size classes of each coral colony were quantitatively assessed using belt-transect surveys (Fig. 2.4.1.1a). At the beginning of each dive, subjective perceived colony density dictated the belt width: 1-m width was used in high density areas, while 2-m width was used in low density areas. The coral biologist surveyed two 25-m transect lines, recording the maximum diameter of all coral colonies whose centers fell within 0.5 to 1 m (depending on density) on either side of the transect line. Colonies were recorded to the genus level and assigned, by visual estimation, to one of seven size classes: ≤ 5 , 6–10, 11–20, 21–40, 41–80, 81–160, and > 160 cm (binning of coral colony size classes based on Mundy [1996]). Estimation of individual coral colony boundaries in the field can be complicated especially for species with life history strategies involving clonal propagation (e.g., *Acropora formosa*) or fissioning (e.g., *Porites lobata*). When estimating coral colony boundaries, consideration was given to tissue color, interfaces (e.g., skeletal ridges) with neighboring colonies of the same species, and variations in growth form. If determinations of individual colony boundaries could not be made on these criteria alone, conspecific areas of live tissue separated by more than 10 cm were considered to be separate colonies.

Results from 2004 and 2006 coral surveys were used to calculate generic richness, percent live coral cover, coral density (# colonies m^{-2}), and size class distributions of scleractinian corals for each REA site. Generic richness was computed as the maximum number of coral genera recorded within belt transects at a site. Coral community composition values were calculated from the relative percentages of coral genera observed during belt-transect surveys. Percent live coral was calculated from the raw site estimates of coral cover during ASRAMP 2004 and the average of the line point intercept results from each 25-m transect during ASRAMP 2006. Coral size class histograms were created by calculating the relative frequencies of all scleractinian corals in each of the seven size classes recorded during belt-transect surveys.

Coral and coralline algal diseases and predation scars were quantified at each REA site to assess the health and viability of the coral reef populations in the nearshore waters. Coral and coralline algal diseases and predation were first surveyed during ASRAMP 2006 using belt transects.

Coral disease and predation assessments were conducted along two 25-m belt transects during which each affected coral colony was identified to the lowest taxonomic level possible. The width of belt transects varied depending on diver's bottom time, but was generally conducted within 3 to 5 m perpendicular to each transect line (~300–400 m² per site). For each affected coral the following information was recorded: colony size,



Figure 2.4.1.1a. A coral assessment diver conducting a belt-transect survey. (Photograph provided by NOAA PIFSC CRED; J. Kenyon, JIMAR)

type of affliction, area affected, percent live/dead, and severity of the affliction (mild = 1–10%, moderate = 11–25%, marked = 26–50%, severe = 51–75%, acute = 76–100%). Coral afflictions were classified into one of six general categories (following Willis et al., 2004) including: bleaching, tissue loss, black band disease, skeletal growth anomaly, predation, and other lesions. This latter category included algal overgrowth, as well as unidentified syndromes causing deterioration of scleractinian corals. Afflictions to coralline algae were also enumerated based on the high incidence of lesions found in American Samoa. Coralline algae afflictions were classified into three general categories: coralline lethal orange disease (CLOD), coralline fungal disease, and unidentified coralline discoloration. Photographic records and tissue samples of select diseased colonies were also collected for future laboratory analysis. Descriptions of coral and coralline algae disease states are listed below.

Bleaching

Coral bleaching was characterized by a reduction in intensity or the complete absence of coloration within living coral as a result of loss of pigmentation and/or expulsion of the endosymbiotic zooxanthellae. The tissue of bleached corals can be transparent, making the coral appear white because of the skeleton of the coral (Fig. 2.4.1.1b[a]). However, coral tissue of corals can also appear pale, pinkish or bluish when bleaching occurs. Patterns of bleaching can vary, with only the upper surface or lower surface of the colony being affected and can also appear patchy or mottled or as a circular blotch, ring or wedge.

Tissue Loss

Losses of coral tissue were characterized by coral lesions of sharp, clean bands appearing where tissue was completely removed from the skeleton. The clean band of exposed skeleton is sometimes coupled with a region of filamentous and turf algae (Fig. 2.4.1.1b[b]). Tissue loss is sometimes also referred to as white syndrome and is distinguished from feeding scars by the narrow width of the zone of recently exposed white skeleton and the relatively regular appearance of the tissue front. These features contrast with the wide zone of white skeleton commonly exposed following COTS (*Acanthaster planci*) predation or the scalloped or

irregular tissue front produced by the thaidinae gastropod *Drupella* (Willis et al., 2004).

Black Band Disease

Black band disease was characterized by a black mat, about 0.5 to 4 cm wide, moving across the living coral tissue and leaving behind bare white skeleton, while unaffected coral tissue remains normal in color and morphology (Fig. 2.4.1.1b[c]). The major component of the black mat is *Phormidium corallyticum*, a photosynthesizing cyanobacterium. Other microorganisms, including marine fungi, heterotrophic bacteria, sulfur-oxidizing bacteria (*Beggiatoa*), and sulfate-reducing bacteria (*Desulfovibrio*), are present in the black mat and also contribute to the loss of coral tissue (Ducklow and Mitchell, 1997; Richardson, 1996).

Skeletal Growth Anomaly

Skeletal growth anomalies were characterized by changes in the shape or form of coral skeletons resulting in unusual lumps and protuberances associated with an abnormal deposition of calcium carbonate (Fig. 2.4.1.1b[d]). Skeletal growth anomalies are caused by changes in the coral cells that deposit the carbonate skeleton. The two most common types of skeletal growth anomalies are hyperplasia, a process that leads to an increase in the number of cells in a tissue or organ, thereby increasing the bulk of the tissue or the organ, and neoplasia, a pathologic process that results in the formation and growth of an undifferentiated mass of cells.

Other Lesions and Pigmentation Response

Some reef corals, such as *Porites*, *Montipora*, and *Astreopora*, appear to respond to a variety of allopathic and parasitic interactions by producing a hyperpigmentation of polyps in contact with or adjacent to areas of interaction. These interactions sometimes result in impairment or inhibition of normal coral function (e.g., growth, calcification, and reproduction) and may take on the character of a disease (Willis et al., 2004). Pigmentation responses are often launched by the coral along adherent edges involved in interactions with algae, but also with cyanobacteria, polychaetes, molluscs, trematodes, etc. The range of pigmentation responses vary for each coral genera ranging from pink to light blue in *Astreopora*, from pink to purple but also blue to brown in *Montipora* (Fig. 2.4.1.1b[e]), and from pink to purple but also accompanied by swelling or enlargement of the affected polyps in *Porites*. These pigmentation responses, together with other unidentified cases of disease, were grouped under “*other lesions*” during coral disease surveys.

Predation

Coral predators often leave scars devoid of tissue which may lead to decreased health status and increased susceptibility to algal overgrowth, invasion by other pathogens or lower reproductive output. The pattern of tissue loss from predation often differs from tissue loss patterns stemming from other causes. Predation scars were characterized by wide zones of exposed coral skeleton commonly seen following predation by the COTS, *Acanthaster planci* (Fig. 2.4.1.1b[f]) or by scalloped or irregular tissue fronts that are often produced by the thaidinae gastropod, *Drupella* (Willis et al., 2004).

CLOD

CLOD was characterized by a band of bright orange slimy material spreading across the algal surface, leaving behind the bare skeletal carbonate remains of the coralline algae (Fig. 2.4.1.1c[a]). When this material reaches the margin of the algal thallus, it forms upright

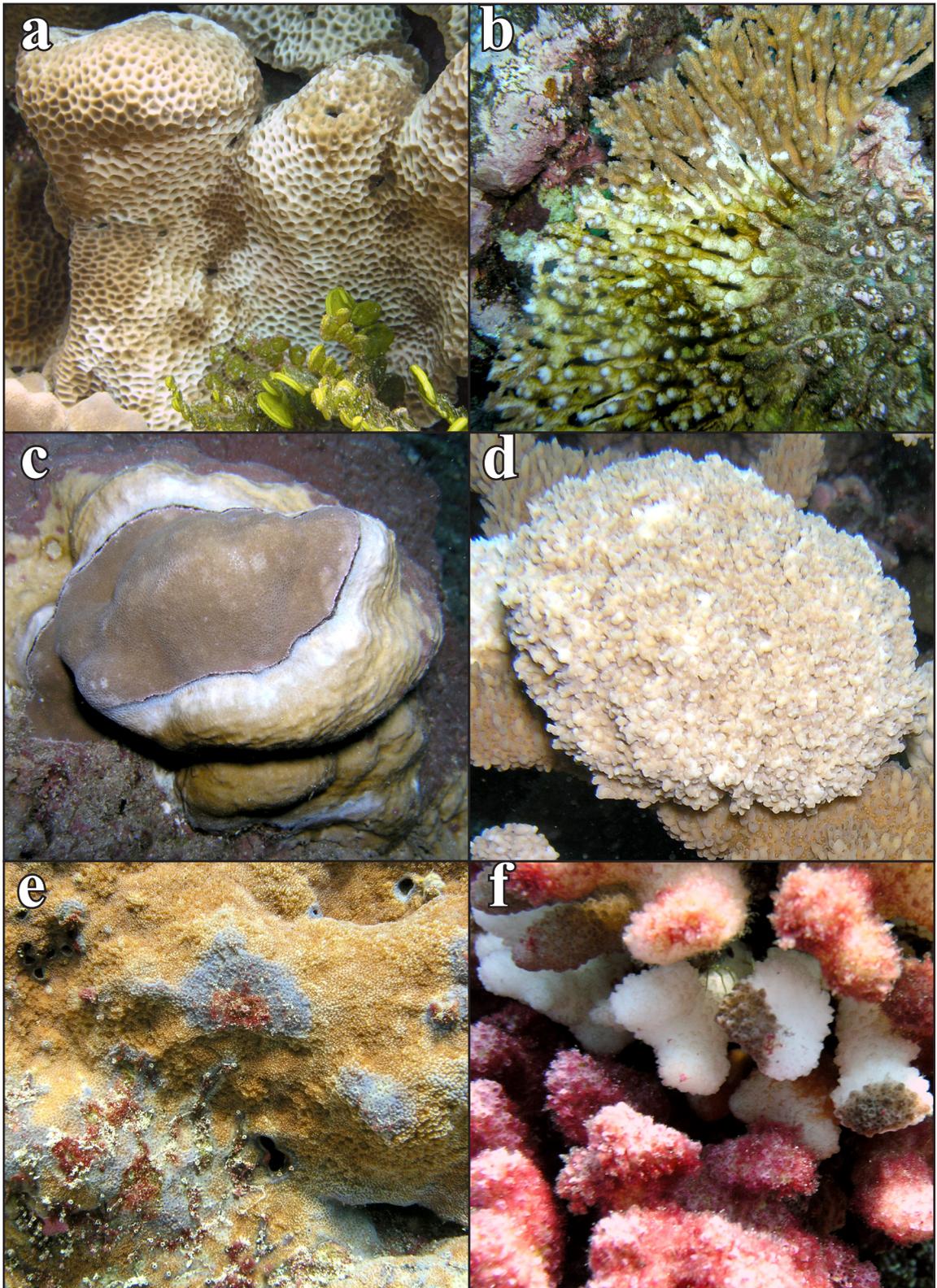


Figure 2.4.1.1b. Coral Diseases. Underwater photographs illustrating the field appearance of lesions affecting scleractinian corals in the American Samoa Archipelago during ASRAMP 2006. **(a)** bleaching on *Gardineroseris planulata*; **(b)** tissue loss on *Acropora cytherea*; **(c)** black band disease on *Porites*; **(d)** skeletal growth anomalies on *Acropora abrontanoides*; **(e)** pigmentation response on *Montipora* sp. (Note blue pigmentation surrounding areas of allopathic interaction); **(f)** predation lesions on *Pocillopora*, probably caused by the corallivorous snail *Drupella*; also, note algal overgrowth on old dead colony surfaces. (Photographs by NOAA PIFSC CRED; B. Vargas-Angel, JIMAR)

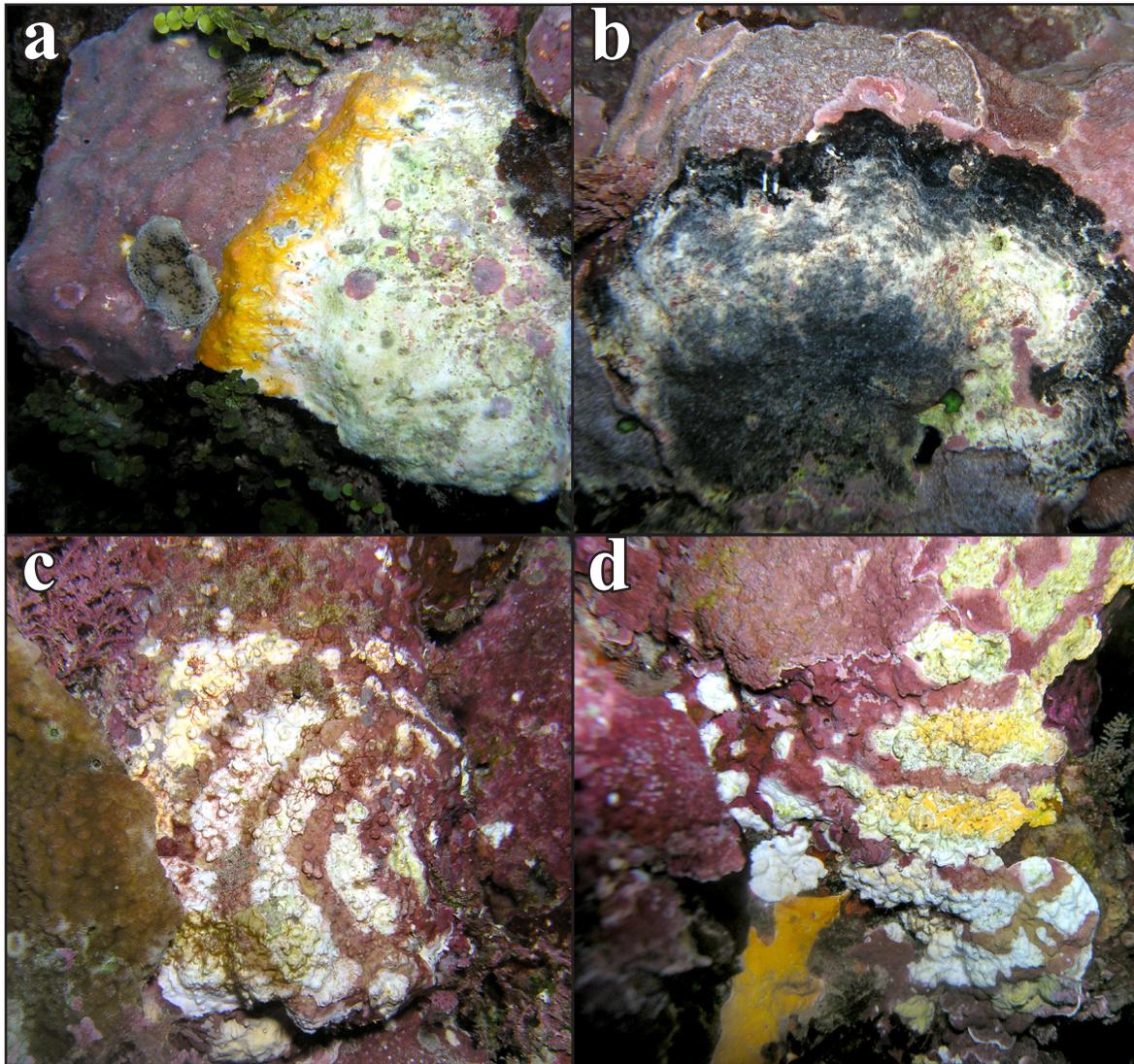


Figure 2.4.1.1c. Underwater photographs illustrating the field appearance of diseases affecting crustose coralline algae in the American Samoa Archipelago, 2006. **(a)** CLOD; **(b)** coralline fungal disease; **(c)** and **(d)** unidentified coralline discoloration. (Photographs provided by NOAA PIFSC CRED; B. Vargas-Angel, JIMAR)

filaments and globules, similar to those formed by terrestrial slime molds. The globules can be caught by waves and easily spread to nearby corallines. Microscopic examination of the orange material revealed motile gliding rods of a colonial bacterium in a mucilaginous matrix. The orange globules can be experimentally transferred to other coralline algae and cause the same disease and loss of algal tissue. Additional studies of this bacterium associated with CLOD are underway (Littler and Littler, 1998).

Coralline Fungal Disease

This disease is characterized by a 1 to 5 cm black mat, moving across the surface of the coralline algae and leaving behind bare white carbonate skeleton (Fig. 2.4.1.1c[b]). Coralline fungal disease was discovered in 1996 by Diane and Mark Littler who observed abundant populations of this undescribed fungal disease in both calm and exposed coral reef environments in American Samoa (Littler and Littler, 2003).

Unidentified Coralline Discoloration

Discolored (light yellow, green or white) bands, measuring 0.5 to 3 cm in width, which spread across the algal surface leaving behind the bare skeletal carbonate remains of the coralline algae were characterized as unidentified coralline discoloration (Figs. 2.4.1.1c [c] and 2.4.1.1c[d]). In some cases discolorations appeared as concentric, annular or horse-shoe shaped bands radiating from a focal point (Littler and Littler, 2003). In other cases, discoloration appeared as wide, irregular, white bands along adherent edges.

Results of coral and coralline algae surveys were used to calculate prevalence values for coral disease and density values for coralline algae disease. Coral disease prevalence was computed as the percentage of diseased colonies (counts) out of the total estimated number of colonies within the survey area. The estimated number of colonies within the survey area was calculated by multiplying the coral density (# colonies m⁻²) value obtained from the coral belt transect by the total area covered in the disease survey at each site (Prevalence = [No. cases within the area surveyed for disease × 100] ÷ [colony density × area surveyed for presence of disease]). The relative abundance of coralline algal diseases per site was calculated by adding the total number of cases over the two transects and dividing by the total area surveyed for each site. Coral disease results are presented within the coral section of each island while coralline algae disease results are discussed within the algae section.

2.4.1.2 Algae

Algal populations were surveyed to assess the relative abundance and species diversity of algae in the American Samoa Archipelago. Algal survey methods in 2002 differed from methods employed in 2004 and 2006. Underwater survey methods included quadrat surveys, photoquadrat surveys, and voucher specimen surveys. Details on each method are discussed below including a description of the development of algal methods during 2002 REA surveys (*Algal Methods Development*). Temporal sampling variation is detailed in Table 2.4.1a.

Algal Methods Development

REA algae surveys in 2002 were the first surveys conducted in American Samoa by CRED. As such, the methods employed were mostly qualitative and exploratory in nature. Methods included collecting samples of algae and qualitative observations of the algal populations at each REA site.

Quadrat Surveys

Quadrat surveys were employed to document the relative abundance of macroalgal genera in the field. At each REA site, 12 sample 0.18-m² quadrats were surveyed along two 25-m transects. Six quadrats were located at randomly selected points along each transect (three per transect), and six other quadrats were located at points 3 m perpendicular from each random point in the direction of shallower water (Preskitt et al., 2004; Vroom et al., 2005a). Macroalgae were identified to genus level in the field, whereas crustose-coralline red algae, branched coralline red algae, turf algae and cyanophytes were lumped into functional group categories. In addition, each genus or functional group found in each quadrat was assigned a rank based on its relative abundance in the quadrat (1 being the most abundant, 2 being the next most abundant, etc.). All ranked data for a given survey year were collected by the same individual, minimizing the effects of observer bias.

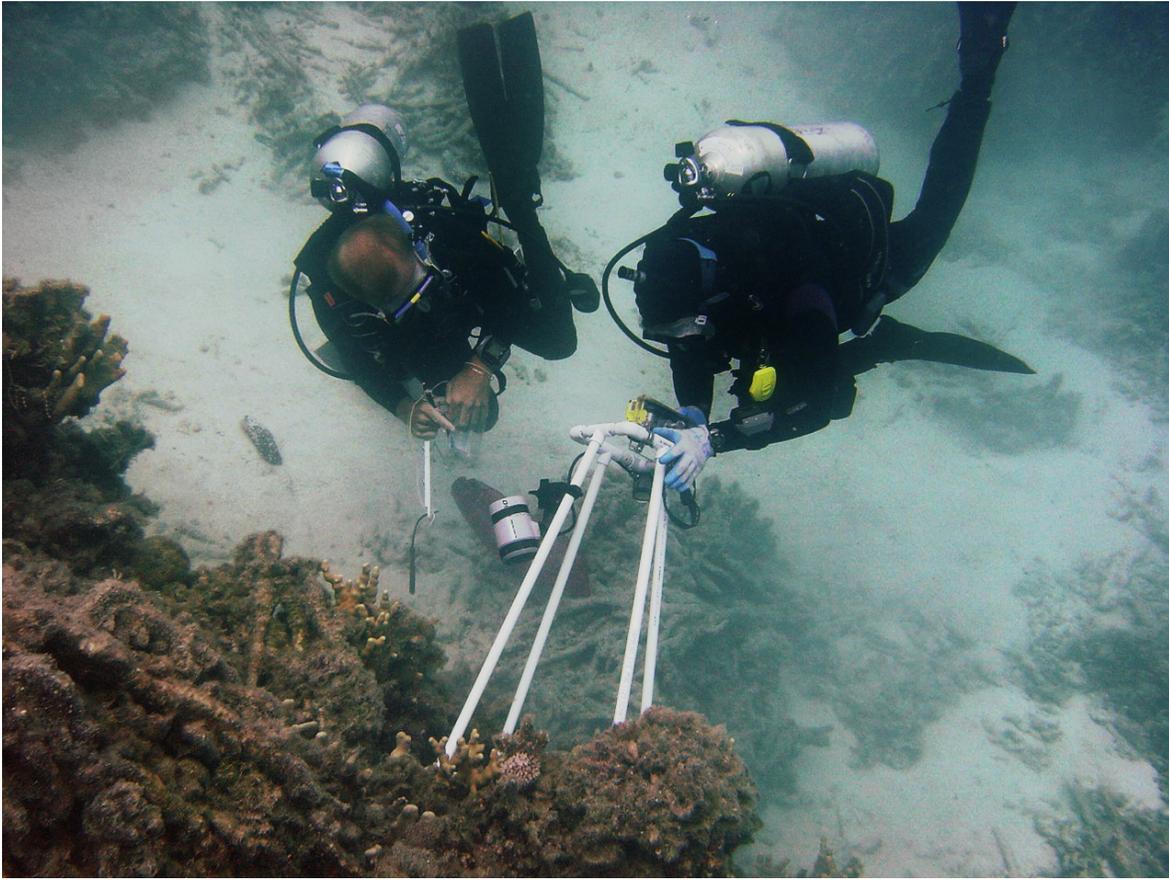


Figure 2.4.1.2a. The algal assessment team conducting photoquadrat surveys. (Photograph provided by NOAA PIFSC CRED; J. Kenyon, JIMAR)

Photoquadrat Surveys

During quadrat surveys, photographic documentation of each 0.18-m² quadrat assessed was recorded to provide a quantitative dataset for further in-depth, algae species-level percent cover analyses. Twelve photos were taken at each site using either a Sony DSC P-9 or an Olympus C-4040 digital still camera and an Ikelite substrobe DS-50 (Fig. 2.4.1.2a). Photographs are being analyzed using Coral Point Count with Excel extensions (Kohler and Gill, 2006) to determine percent cover of benthic organisms at the species level (when possible).

Voucher Specimen Surveys

Algal voucher specimens were collected from a 2-m swath on either side of the same two 25-m transects surveyed during the quadrat surveys. Samples were brought back to the laboratory for qualitative species identification at the microscopic level to assemble comprehensive species lists for each site. Voucher specimen surveys were conducted at all sites, even when environmental conditions (e.g., strong currents or surge) did not allow for the quantitative photoquadrat protocol to be completed.

Algae diver observation results from quadrat surveys were used to calculate percent occurrence of algae genera/functional groups for each REA site. Percent occurrence values were calculated by summing the number of quadrats in which each algal genus/functional group was observed and dividing by the total number of quadrats surveyed at the site (12). Percent occurrence results were then used to create distributional maps of algal abundance for each island/atoll. In addition, algal composition results by island/atoll were calculated

by summing the percent occurrence values for each algal genus/functional group and then dividing the respective occurrence values by the sum.

2.4.1.3 Other Macroinvertebrates

Macroinvertebrate surveys were focused on quantifying the noncoral invertebrates that are common to the reef habitats of American Samoa. Several different survey techniques were used in each of the survey years to quantify the diverse communities. These methods included belt-transect, roving-diver, and quadrat surveys. The development of REA macroinvertebrate survey methods and the details of each are described below (*Macroinvertebrate Methods Development*). Temporal sampling variation is detailed in Table 2.4.1b.

It should be noted that in situ methods record invertebrate species that are generally noncryptic (i.e., visible) and easily enumerated during the course of a single scuba dive. Therefore, the marine invertebrate species recorded and identified during the course of these observations only represent the noncryptic fauna of the reef habitat and should not be considered the only species present at each site. It should also be noted that many invertebrate species are nocturnal and therefore unlikely to be observed during the daylight surveys conducted during Pacific RAMP.

Macroinvertebrate Methods Development

REA macroinvertebrate surveys in 2002 were the first surveys conducted in American Samoa by CRED. As such, the methods employed were mostly qualitative and exploratory in nature, aimed at collecting baseline data that would be used to refine methodologies for subsequent surveys. Two separate 50-m transect lines were surveyed using a zigzag search pattern that extended roughly 2 m on either side of each transect line. In addition, a roving-swim survey was conducted to survey a larger area and account for macroinvertebrate species not found in the transect area. During both surveys, species of macroinvertebrates were recorded and assigned a qualitative abundance ranking using the DACOR method (Maragos et al., 2004).

Belt-transect Surveys

Quantitative invertebrate counts were recorded along two 25-m belt transects in 2004 and 2006. Highly detailed invertebrate observations (the target species list is presented in Appendix III) were recorded within 2 m on either side of each transect (total area = 100 m²) in 2004. During ASRAMP 2006, the target list of macroinvertebrates (Appendix IV) became more general, although the quantitative count methodology remained the same.

Roving-swim Surveys

In 2004 and 2006, a 500-m (10 × 50 m) roving-swim survey was conducted with the goal of quantifying larger invertebrates such as COTS and Tritons Trumpet molluscs which may not be seen during belt-transect surveys. The roving swim was accomplished by swimming a zigzag pattern extending 5 m to either side of both 25-m transect lines.

Quadrat Surveys

In 2006 quadrat surveys were used to quantify the smaller, more cryptic macroinvertebrates which were sometimes overlooked or too numerous to count during belt-transect surveys. Ten 0.25-m² quadrats were laid out at 2-m intervals along two of the 25-m transects (total

area = 5 m²). For each quadrat the percent cover of sponges, octocorals (e.g., *Sarcophyton*, *Lobophytum*, *Sinularia* or *Cladiella*) and zoanthids was recorded, as well as all of the *Echinostrephus* spp. and *Echinometra* spp. urchins, hermit crabs of the genus *Calcinus*, trapezid crabs, and coralliophilid snails.

Macroinvertebrate results were used to calculate presence/absence data for each REA site. Presence data are only presented for ASRAMP 2004 and 2006 surveys and results from all survey methods employed during a respective year were used to calculate presence data. In addition, results from the 2004 macroinvertebrate surveys were used to calculate species richness values. Species richness values are not presented for 2006 as a result of the abbreviated target species list.

2.4.1.4 Reef Fish

Three complementary methods were used to catalog the diversity (species richness) and abundance (numeric density [# fish 100 m⁻²] and biomass density [kg 100 m⁻²]) of diurnally active reef fish assemblages including belt-transect, stationary point count, and roving-diver surveys. The methods remained the same for all survey years with the exception of stationary point counts which were first used in 2004. For all methods, fish were identified at the species level, when possible, and assigned to a size bin ranging from 1 to 200 cm based on a visual estimate of total fish length. The temporal variation of reef fish sampling is detailed in Table 2.4.2b.

Belt-transect Surveys

The entire diurnal fish community (all size classes) was quantified using belt-transect surveys. At each site, three 25-m lines were surveyed. Two fish biologists swam side-by-side along a transect, each recording all fish larger than 20 cm observed within a 4-m wide belt perpendicular to their respective side of the transect (200 m² area per line, 100 m² per diver). Then the fish biologists made a second pass along each transect recording all fish less than 20 cm observed within a 2-m wide belt (100 m² area per line, 50 m² per diver). The survey of large fish took approximately 5 min to complete while the survey of smaller fish took about 10 min to complete. All reef-associated fish, including those in the water column (including planktivores), were counted. Any coastal pelagic species (e.g., clupeids [sardines], belonids [beakfish], antherinids [silversides]) seen near the surface were not recorded.

Stationary Point Count Surveys

Quantification of larger, more mobile reef fish species that can be missed on belt-transect surveys was performed using the stationary point count method (Bohnsack and Bannerot, 1986). For each stationary point count survey, the fish biologist swam approximately 15 m away from a transect line concurrently being surveyed by the other fish biologists. The stationary point count biologist then recorded all fish greater than 25 cm in length that passed within a visually estimated 20-m diameter cylinder centered on the diver's fixed position (10-m radius, total area = 314 m²). The survey time for each stationary point count survey was 5 min and a total of four stationary point count surveys were conducted at each REA site. The method for counting fish was the same as the method used in belt-transect surveys as described above.

Roving-diver Surveys

Following belt-transect and stationary point count surveys, and as diver bottom time permitted, the fish assessment team conducted random swim surveys throughout the REA site area, recording, to the species level or the lowest recognizable taxon, the presence of reef fish not encountered during previous methods.

Results from REA reef fish surveys were used to calculate biomass estimates. Fish counts from belt-transect surveys were converted to biomass estimates ($\text{kg } 100 \text{ m}^{-2}$) using published length-weight relationships for individual species (Kulbicki et al., 2005). Total fish biomass at each REA site was calculated by combining fish biomass from the 100-m^2 belt transects (small fish) with the biomass from the 200-m^2 belt transects (larger fish). Biomass estimates were summed by fish families and used to create biomass totals by site and year as well as fish family composition graphs, which represent the biomass percent breakdown by fish family. In addition to total fish biomass estimates, data collected from belt-transect surveys were used to calculate species richness ($\# \text{ species } 100 \text{ m}^{-2}$) values at each site. Stationary point count and roving-diver survey results are not presented in this report.

2.4.2 Towed-diver Surveys

Towed-diver surveys were used to characterize benthic habitats and to quantify the abundance and spatial distributions of ecologically and economically important fish, coral, and macroinvertebrate taxa over a much broader area than is possible using REA techniques. While typical REA surveys provided species level documentation of marine organisms over spatial areas of approximately 300 m^2 , towed-diver surveys documented patterns of habitat condition and distributions of larger marine organisms over areas ranging from $15\,000$ to $25\,000 \text{ m}^2$. In addition, towed-diver surveys were able to access exposed coasts (e.g., windward-facing shores and high swell conditions) not surveyed by stationary REA surveys, which are fundamentally limited to survey areas with more favorable environmental conditions (e.g., lower currents or lower surge/wave action).

The broad-scale nature of towed-diver surveys has helped to increase the breadth of the ecological benthic data collected by CRED and to improve the program's ability to investigate and quantify large-scale environmental stresses, such as bleaching events (Kenyon et al., 2006c) and COTS outbreaks. Towed-diver surveys were likewise tasked with recording unusual or important sightings which included significant biological or habitat gradients, derelict fishing gear or other types of marine debris, shipwrecks, and unexploded ordinance located on the seafloor.

This method also allowed for "snapshot assessments" of larger fish (e.g., sharks, jacks, and barracudas), and schools of various species whose range and abundance may be underestimated during area-limited REA surveys. Finally, other "species of concern" (e.g., sea turtles, cetaceans, and pinnipeds) not normally observed or examined by REA scientists were also recorded during towed-diver surveys.

Sampling Design

Towed-diver surveys were typically completed along the outer reef slopes and forereefs of individual islands/atolls, with additional surveys completed along backreefs, lagoons, and/or

offshore banks. Towed-diver survey tracks were intended to cover as many habitat types (e.g., slope, forereef, backreef, lagoon, and bank) and as much of a complete revolution around each island or atoll as time allowed while surveying along a relatively constant isobath (typically targeted at 15 to 20 m).

Towed-diver surveys typically completed circumnavigations around each of the islands and atolls of American Samoa, with most individual surveys covering linear distances between 1.5 and 2.5 km along relatively fixed isobaths (10–20 m). For the smaller islands and atolls, such as Swains and Rose, multiple circumnavigations were conducted targeting different isobath depths (e.g., 5, 15, and 25 m).

Operational Description

Towed-diver surveys were conducted by teams of four scientists who alternated between data gathering and boat handling responsibilities. Surveys consisted of towing two divers approximately 60 m behind a small boat with one diver tasked with benthic composition and macroinvertebrate data collection while the other collected data on fish species larger than 50 cm total length (Fig. 2.4.2a). Each diver made observations over a 10-m swath (5 m to each side of their respective tow lines, which act as transect lines). The diver/observers attempted to maintain their position approximately 1 m above the seafloor, while being towed at an average speed of 0.5 to 1.3 m s⁻¹ (1–2.5 kn). Each survey took approximately 50 min with four to six surveys completed each field day.

To geo-reference all data collected during a tow, a GPS receiver located on the towboat was programmed to record longitude and latitude coordinates every 5 sec. When the divers were ready to begin recording data, an acoustic signal from the fish towed diver was sent to the towboat coxswain via telegraph. The coxswain would mark a waypoint indicating the start point of the towed-diver survey. The coxswain followed along a predetermined depth contour using a bathymetric chart, a singlebeam echosounder, and shoreline features (when present) as a guide while maintaining speed. Additional “o.k.” signals were sent to the towboat every 5 min to inform the coxswain of the diver’s status, while “mark” signals were sent to record any sites of interest (natural or anthropogenic). At the end of the survey, prior to beginning an ascent to the safety stop, another coded signal was sent to the towboat to record the end-position of the survey.



Figure 2.4.2a. Towed divers conducting a survey in American Samoa. (Photograph provided by NOAA PIFSC CRED)

In the years following the initial towed-diver surveys in 2002, specific routes were pre-programmed into the GPS prior to initiating field activities. This was done to: (1) transition from assessment to monitoring, and obtain as much track and area overlap with previous years as possible, and (2) coincide with logistical challenges associated with operating remote field operations involving several disciplines (REA, mapping, oceanography).

A byproduct of repeating previous towed-

diver survey tracks is that in certain areas it results in an inherent sampling bias assigned to nonrandomized route selection and the subsequent survey analyses including biological estimates generated. Some locations (e.g., Tutuila) have considerable portions of coastline that cannot be surveyed repeatedly due to operational, logistical, budgetary, and/or environmental constraints. The consequence is that certain abiotic and biotic metrics (e.g., concatenated habitat complexity from GIS IDW analyses) have to be inferred based on the results from surrounding survey areas. In addition, biological estimates of other metrics (e.g., macroinvertebrate populations) remain unknown for areas not surveyed. This is in contrast to smaller islands/atolls (e.g., Swains), where the entire island can be easily circumnavigated.

Following each day of field operations, GPS waypoints (survey start and stop points), trackline files, and SBE 39 depth and temperature data (recorded every 5 sec) were downloaded for each towed-diver survey of the day. All geo-referenced tracklines had associated, inherent positioning errors created by the difference between the location of the GPS unit aboard the towboat and the underwater position of the towed divers. To reduce this source of error, a custom-designed ArcView script was written based on a “layback” model created during the development of towed-diver survey methods (Kenyon et al., 2006a). The layback model was applied to all downloaded tow tracks within ArcView, which used SBE 39 depth and temperature data merged with GPS track information to calculate more accurate diver positions. Data were then uploaded into ArcGIS for further analysis with towed-diver data.

Data Collection

Data from towed-diver surveys were collected through direct diver observations and electronic instrumentation attached to the towboards. Observations were recorded by both the benthic and fish diver/observer every 5 min (~ 200 m survey length), summarizing the benthic habitat and biological organisms encountered throughout the segment. A total of 10 observations were made over a typical 50 min survey, although the actual time and length of surveys varied depending on environmental conditions, diver air supply, bottom time, etc.

Temperature and depth data for each towed diver were recorded every 5 sec using an attached SBE 39 temperature and pressure recorder, while image data were collected using a forward-facing video and a downward-facing video or digital still camera. Details on diver observations and accessory instrument data collection techniques are discussed below.

Diver Observations

Benthic

Benthic towed-diver methods changed among the field surveys completed in 2002, 2004, and 2006 with the hope of fine-tuning data resolution and reducing the underwater task loading of the diver/observer. Methodological changes were generally limited to two aspects of the protocols: classification of benthic substrate categories and estimation of benthic substrate percent cover. Details on the interannual variations of towed-diver survey methods are outlined in Table 2.4.2a.

At 5-min intervals, the benthic diver/observer recorded a suite of information including: the predominant reef zone (forereef, backreef, lagoon, bank, bank escarpment, and channel), estimates of average habitat complexity, estimates of average percent cover for benthic substrate types (live and stressed hard coral, fleshy/macroalgae, coralline algae, sand, and

rubble), and counts of macroinvertebrates (COTS, sea urchin, sea cucumber, and giant clam) encountered within a 10-m tow swath (5 m on either side of the tow line).

Table 2.4.2a. Benthic cover composition categories (Kenyon et al., 2006a).

Benthic Category	Description	Year
Live Hard Coral	All live hard coral species observed in the tow path. This included both stressed (see below), and unstressed corals. It did not include soft corals or dead coral. Live hard corals were characterized by colonies or portions of colonies covered with living tissue. Living tissue usually appeared colored (e.g., olive green, brown or bluish lavender) because of the presence of pigments in coral tissue and/or their symbiotic zooxanthellae; however, stressed coral tissue can also appear pale or completely white.	2002 2004 2006
Stressed Coral	Live hard coral that appeared to be stressed or bleached as a result of loss of zooxanthellae and/or their pigments. Signs of stress included pale to white coloration caused by bleaching, COTS predation, disease or recent coral death. Recently dead corals were characterized by a heavily bleached white coloration representing exposed coral skeleton. In some cases it might be hard to differentiate between recently dead and severely bleached corals; for this reason, they were both classified as stressed.	2004 2006
Dead Coral	Bare white colonies (or portions of) that had lost living tissue and had not been visibly encrusted by macroalgae or epiphytes were classified as dead coral. Lack of encrustation suggested tissue death was recent relative to encrusted portions of dead colonies. Dead coral with macroalgae growth, epiphytes or other forms of substrate cover were considered part of the fleshy/macroalgae or other category.	2002
Soft Coral	All soft corals observed in the tow swath.	2006
Fleshy Algae	Fleshy or frondose algae (e.g., <i>Sargassum</i> or <i>Padina</i>), heavily calcified (e.g., <i>Halimeda</i>) species and turf algae.	2002 2004
Macro-algae	Macroalgae were characterized by the fleshy or frondose algae (e.g., <i>Sargassum</i> or <i>Padina</i>) and heavily calcified (e.g., <i>Halimeda</i>) species. This did not include turf algae.	2006
Coralline Algae	Encrusting calcareous algal species observed within the tow swath. These encrusting algae deposit calcium carbonate as part of their structure, often giving a pinkish or lavender appearance to the encrusted substrate. In some areas these algae can also form three-dimensional spires.	2002 2004 2006
Sand	Sand was characterized by unconsolidated sediment, ranging in texture and size from fine to coarse and including both inorganic (eroded rock) and organic (eroded fragments of calcareous organisms) sediments.	2002 2004 2006
Rubble	Unconsolidated fragments of coral skeleton or reef rock whose sizes are larger than sand. May be visibly encrusted by macroalgae, calcareous algae or corals.	2002 2004
Rubble	Unconsolidated fragments of coral skeleton or reef rock whose sizes are larger than sand. Only rubble that was not visibly encrusted by macroalgae, calcareous algae or corals was included.	2006
Carbonate Pavement	Consolidated substrate, typically composed of calcareous and/or basaltic elements, which have become cemented together by biogenic and physical processes.	2002 2004

Estimates of habitat complexity were subjective assessments of topographical diversity and complexity of the benthic habitat and were classified according to one of six categories: low, medium-low, medium, medium-high, high, and very high (Fig. 2.4.2b). As examples, low habitat complexity is often associated with flat sand plains or rubble habitats; medium habitat complexity is often associated with small to moderate spur and groove, coral or boulder habitats; and high or very high habitat complexity are often observed as high or extreme vertical relief associated with steep spur-and-groove canyons, pinnacles, and walls.

Estimates of average benthic substrate cover were recorded as direct percents during ASRAMP 2002 and 2004 and then as percentage bins ranging from 1 to 10 during ASRAMP 2006. Descriptions of benthic substrate categories and the percentage bins used in 2006 are described in Tables 2.2.3c and 2.2.3d, respectively. Noncoral macroinvertebrates,

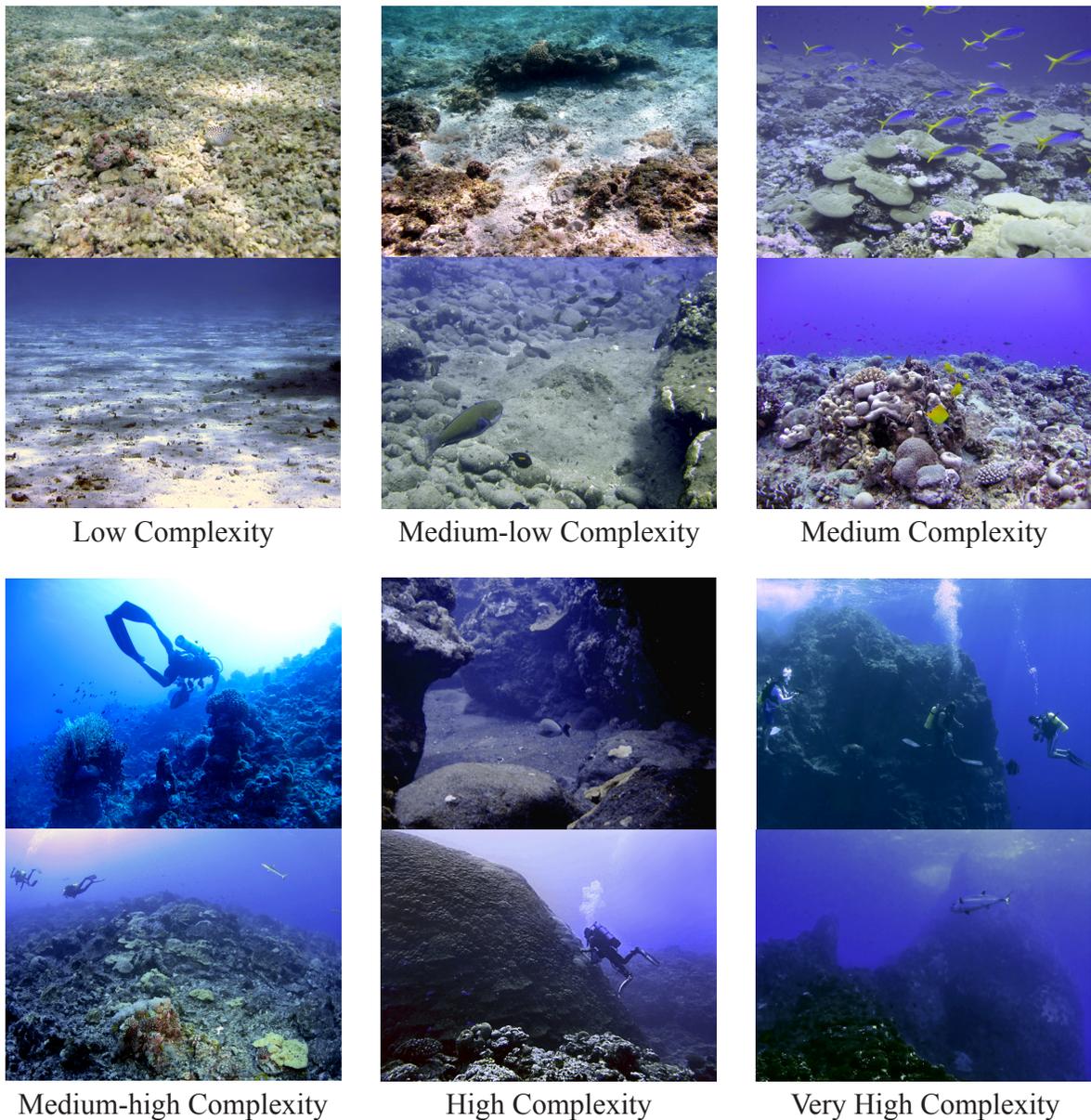


Figure 2.4.2b. Examples of low, medium-low, medium, medium-high, high, and very high complexity habitats. Note that towed divers calculate average complexity during each 5-min sampling period as they regularly encounter multiple habitat types. (Photographs provided by NOAA PIFSC CREED)

except COTS, were counted singly up to 25 and then binned as follows: 26–50, 51–100, 101–250, 251–500, 501–1000, and > 1000 organisms. COTS were counted singly up to 100 organisms.

Results from benthic towed-diver observations were used to create: (1) habitat characterization maps for habitat complexity, sand, rubble, hard substrate/carbonate pavement, and live coral (discussed in Section 2.2.3: Optical Validation Surveys); (2) percent cover for live coral, stressed/dead coral, fleshy/macroalgae, and coralline algae, and (3) macroinvertebrate densities and distribution maps.

Diver observations for each 5-min tow segment were graphically projected onto ArcGIS maps using the midpoint for each tow segment (tow segment length = ~ 200 m, midpoint = ~ 100 m). For benthic cover estimates, midpoint values in 2002 and 2004 were projected as the direct percents recorded by towed divers, while in 2006 the midpoint values were projected as the midpoint of the binned observations (midpoints of percent cover bins are listed in Table 2.4.2b). Macroinvertebrate values were projected as the total number of organisms observed per tow segment or as the midpoint of their binned range. Densities were calculated as the total number of macroinvertebrates observed during a tow divided by the area covered during the tow (10-m tow swath multiplied by tow length and presented in hectares).

Table 2.4.2b. Benthic cover binning categories used during ASRAMP 2006 towed-diver surveys.

Bin	Benthic Cover (%)	Midpoint
1	0.1–1	0.5
2	1.1–5	2.5
3	5.1–10	7.5
4	10.1–20	15.0
5	20.1–30	25.0
6	30.1–40	35.0
7	40.1–50	45.0
8	50.1–62.5	56.25
9	62.6–75	68.75
10	75.1–100	87.5

Fish

During each 5-min tow segment, the fish towed diver conducted a 360-degree scan during the first minute of the survey, recording all fish ≥ 50 cm total length within the range of visibility. During the remaining 4 min of each 5-min segment, all large fish ≥ 50 cm in total length that appeared within a 10-m survey swath (5 m to either side of the towline and 10 m in front were recorded). Species of particular concern observed outside the survey swath were classified as presence/absence data and recorded separately from the quantitative towed-diver survey data.

Results from towed-diver fish observations were used to calculate large-fish biomass figures for each tow and ultimately for each island. The length of each individual was determined visually with each individual being assigned to predetermined size classes. Large-fish biomass was calculated for each towed-diver survey by applying the midpoint length for each size class to published length-weight relationships ($w = a \times L^b$) for individual species (Kulbicki

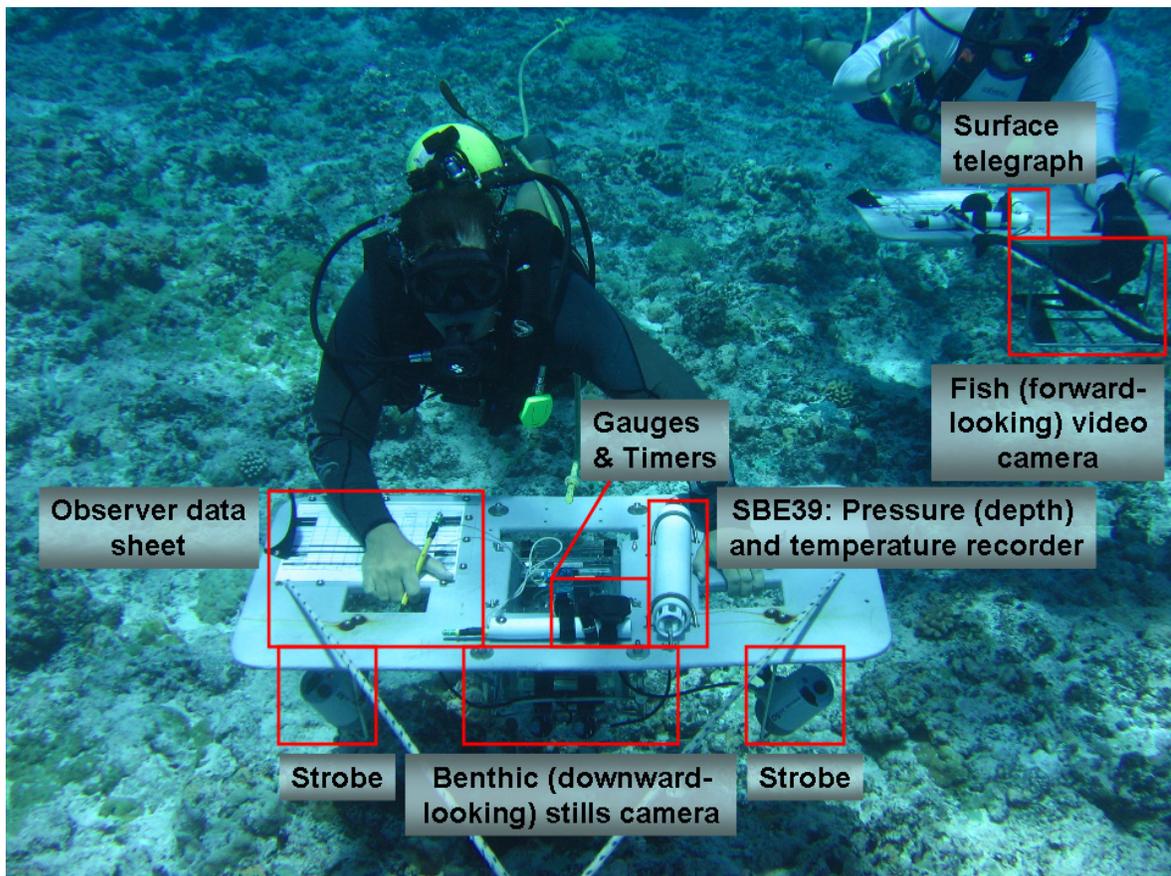


Figure 2.4.2c. SBE 39 temperature and pressure units and other towed-diver instrumentation. (Photograph provided by NOAA PIFSC CRED)

et al., 2005). When species-specific length-weight formulas were not available, formulas for the next higher class (genera, body type, etc.) were used. Large-fish sightings were summed for each tow segment and used to calculate total biomass estimates per tow as well as the biomass by fish family.

Accessory Instrumentation

Forward-facing Video Camera

A forward-facing digital video camera was attached to the fish towboard and used to collect streaming video images on Mini DV. Video footage from the forward-facing camera was archived as a durable record of the fish towed-diver survey track and can be used to quantify habitat composition and complexity, as well as abundance and distribution of ecologically and economically important fish taxa. No results derived from fish video imagery are presented in this report.

Downward-facing Video Camera and High-resolution Still Camera

A downward-facing digital video camera in a Gates underwater housing was mounted on the benthic towboard and used to record the benthos along each tow track during ASRAMP 2002. During ASRAMP 2004 and 2006, the benthos was documented using a downward-facing, high-resolution, digital still camera (Canon EOS-10D) in a customized underwater housing with dual Ikelite strobes. The camera was programmed to automatically photograph the benthos every 15 sec. In all survey years, the diver/observer attempted to maintain the downward-looking video/high-resolution still camera 1 to 2 m above the bottom.

Results from towed-diver benthic videos/photographs are archived as durable records of the benthos at the various islands and atolls. Some of these data have been analyzed by researchers who subsampled frame grabs/photos for more detailed benthic composition analyses (Kenyon et al., 2006a). These results are not presented in this report.

Temperature and Pressure Recorders

SBE 39 temperature and pressure recorders were mounted on both benthic and fish towboards to accurately determine the temperature and depth of each diver and camera during towed-diver benthic and fish surveys. Data from both SBE 39 recorders were downloaded at the end of the day and merged with GPS tracklines to obtain accurate diver positions using the layback model described above. An image of a towboard with a subsurface temperature and pressure recorder and additional instrumentation (e.g., dive bottom timers/backup depth gauge, survey timers, and telegraph) is shown in Figure 2.4.2c.

Only depth data from SBE 39 temperature and pressure recorders are presented in this report. Mean depths for each tow segment were calculated and used to create depth distribution maps for each survey year.

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