CORAL REEF CONSERVATION PROGRAM MAPPING ACHIEVEMENTS AND UNMET NEEDS

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MILLER, J; BATTISTA, T., PRITCHETT, A;
ROHMANN, S; ROONEY, J

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Executive Summary

Since 1999 the United States has recognized the importance of coral reef conservation as part of a comprehensive ocean policy, and mapping has been a consistent element of these plans and policies. Important mandates for mapping include the Coral Reef Protection Executive Order 13089, the Coral Reef Conservation Act, the National Action Plan to Conserve Coral Reefs ("produce comprehensive digital maps of all coral reefs in the U.S. States and Trust Territories within 5 to 7 years"), and most recently NOAA's 2010 Next Generation Strategic Plan. All of these emphasize the importance of providing basic geospatial services that include accurate characterizations, charts and maps, and provide coastal managers with the tools and methods to adaptively manage coastal ecosystems.

Between 2000 and 2010 NOAA's Coral Reef Conservation Program (CRCP) invested $26M to map coral reef ecosystems in the Caribbean, Florida, the Gulf of Mexico, the Mariana and Hawaiian Archipelagos, American Samoa and the Pacific Remote Island Areas (PRIA) which cover over 43,000 km^2 in 0-150 m water depths. Matching funds and in-kind support from numerous other NOAA offices and federal and state agencies are estimated at over $37M in this same time period. With this considerable level of support, CRCP and partners have been able to produce benthic habitat maps from satellite imagery and *in situ* optical data in 51% (12,625 km^2) of the shallow (0-30 m) areas; bathymetric coverage from multibeam and Light Detection and Ranging (LiDAR) sensors of 30% (8,654 km^2) and derivative products, such as hard/soft substrate, coral cover and/or benthic habitat maps, for 39% (~16,000 km^2) of the coral reef ecosystems from 0-150m. These investments in equipment, expertise, data acquisition, and map production and dissemination provide valuable services to management communities and, with a stable level of funding, will continue to do so in the future.

In 2007 CRCP began a review of the program, which resulted in refocusing the program to support 3 critical threats and on more management-relevant projects. In 2008/2009 Dr. John Boreman was contracted to assess CRCP's mapping and monitoring programs and his report stated "The goal should be to have 75-100% of coral ecosystems mapped down to a depth of 1,000 m in all jurisdictions**."** In addition it stated "the goals include: update the 1999 national mapping strategy; agree on a basic set of base mapping layers and derived products; and develop tiered mapping priorities." In March 2010 CRCP's Senior Management Council (SMC) made decisions about the CRCP response to the Boreman report. The following charge was given regarding Mapping Achievements and Unmet Needs: "The CRCP would like to see in one document what US coral reefs have been mapped, to what extent they have been mapped, and what remains to be done. Based on this information, the CRCP will be able to make more informed decisions about mapping priorities and what the relative funding should be for the basins. The CRCP has asked the mapping teams to create this document. The completion date for this document is February 2011. The SMC has also agreed to dedicate a set amount on an annual basis to mapping to ensure program continuity and easier long-term planning. The tentative amount for this mapping "box" (subject to SMC review of the Achievements and Unmet Needs document) is **$1.5 million annually or 5% of CRCP budget.**

Maps are a critical cornerstone of coral reef management, research and planning, with direct links to management needs in a number of forms. Given increased CRCP emphasis on management-relevant projects, important questions are "what types of maps and projects are needed" and "how do these products fulfill management and research needs". The following list illustrates how primary mapping data and derived products continue to be critical for both management and research:

- CRCP depth data (bathymetry) are used to **define management boundaries for Marine Protected Areas (MPAs)** in the Northwestern Hawaiian Islands (NWHI), Pacific Marine National Monuments, Samoa, and fisheries reserves in the main Hawaiian Islands (MHI).
- Depth data, maps of hard/soft substrates and/or habitat maps are used to **create scientifically valid sampling plans (random stratified sampling)** to aid managers in establishing annual catch limits (ACLs) and assess management efforts to reduce land-based sources of pollution (LBSP). Random stratified sampling plans have been used in the Caribbean since 2001 and in the Pacific since 2006.
- Habitat maps are used to **support Essential Fish Habitat (EFH) and critical habitat for *Endangered Species Act* (ESA) delineations**. Examples include *Acropora* corals, Nassau grouper and potentially 82 coral species currently petitioned under ESA.
- Benthic habitat maps and bathymetry derivatives are used to **evaluate the effectiveness of MPAs** in American Samoa, USVI, Puerto Rico, and Florida Keys National Marine Sanctuary.
- Benthic habitat maps and/or coral cover maps are used to help management agencies **identify possible mitigation sites and understand potential impacts of construction projects and military activities** at locations including Apra Harbor, Guam; Saipan Anchorage and the islands of Pagan, Tinian and Maug in CNMI; MHI cable routes; and Florida Reef Tract.
- Habitat maps are used for **research and monitoring of coral reef resiliency, sea-level change, climate change, and ocean acidification** throughout the Pacific, Caribbean, and Florida.
- Depth and benthic habitat maps are needed before and after adverse events to **assess damage to reefs from groundings, oil spills, storms or tsunamis** including sites in MHI, NWHI, Florida Keys, and American Samoa.

Overall Accomplishments:

This report distinguishes between the "primary data" (PD) that needs to be collected in order to provide a range of "derivative products" (DP). Primary data include satellite imagery from sensors such as IKONOS or WorldView; bathymetric (depth) and backscatter (imagery) data from acoustic multibeam sonars and Light Ranging and Detection optical sensors (LiDAR); and ground-truth data from *in situ* optical sensors on tow sleds or other vehicles and diver videos and photographs. Derivative products include bathymetric products such as slope, rugosity or feature maps, and products that integrate multiple types of primary data, including hard/soft, coral cover, and benthic habitat maps. It is important to recognize that, without sufficient primary data (especially *in situ* optical data), it is not possible to produce accurate and complete derivative products.

One of the first products funded by CRCP was acquisition of satellite imagery and *in situ* optical data to produce benthic habitat maps in shallow water (0-30 m) and this was completed for all jurisdictions except the Pacific Remote Island Areas (PRIA). Capabilities and expertise to collect and process multibeam and *in situ* optical data were developed through NCCOS' Biogeography Branch and the Coral Reef Ecosystem Division's (CRED) Pacific Islands Benthic Habitat Mapping Center (PIBHMC). Widespread multibeam data collection has occurred in the Pacific, while in the Caribbean the emphasis has been on multibeam collection in focused areas. This is largely due to availability of a dedicated multibeam-capable launch and available ship time for mapping in Pacific from 2005-2008, versus very limited ship time in the Caribbean and Florida, and the different management priorities in different jurisdictions. Product development in the Pacific beyond the original 0-30 m benthic habitat maps has focused on processing, analysis, and dissemination of the extensive bathymetric data collected, with sufficient ground-truth data to produce advanced derivative products in limited areas. In the Atlantic, efforts beyond the 0-30m benthic habitat maps have focused on working toward a detailed habitat map of the entire Florida reef tract, producing benthic habitat maps from 30-150m in targeted areas of the Caribbean, and the development of seascape benthic habitat maps that integrate multiple technologies and data sources.

CRCP's funding has been critical to all of these efforts. In many cases, partnerships and leveraging costs with other organizations has also been an important element in supporting or prioritizing projects. Co-funding for projects has been received from NOAA's Office of Coast Survey and National Marine Fisheries Service, the Military Sealift Command, the Naval Facilities Engineering Command, the Naval Oceanographic Office, the National Park Service, the State of Hawaii, the University of Hawaii, the Florida Department of Environmental Protection, the Florida Fish and Wildlife Conservation Commission, the Nature Conservancy, and other partners. Moreover, numerous local, territorial, state and federal agencies have provided in-kind support, participated in or benefited from these jointly funded projects.

Future Priorities

Future priorities for mapping will be determined by a combination of factors, the most important of which are level of funding, management relevance, and ship availability. Level of funding will determine which projects can be reasonably undertaken in a given year and may be driven by funding leveraged from non-CRCP sources. The authors of this report consult regularly with all jurisdictions to update their needs and priorities; projects are planned in collaboration with jurisdictional managers and the appendices of this report discuss jurisdictional priorities in detail. Ship availability may in many cases trump both of these factors. In the last decade much of the ship time used for CRCP projects has been funded by NOAA's Office of Marine and Aviation Operations. However, since 2008 ship time for mapping has steadily decreased with little or no mapping ship time expected in the next 2 years. Even if ship time is available, there is an increasing expectation that programs "buy back" ship days. The realities of what can be done without ship support or to buy back ship days will have a significant impact on which projects are feasible in any year.

Although much has been accomplished in the last decade, many types of primary data are still needed in most or all jurisdictions.

- LiDAR data needed between shoreline and inner edge of multibeam swaths (0-20 m) to fill "bathtub ring" gaps – all areas (bathymetry)
- Multibeam data in 15-150 m depths (bathymetry)
- Better resolution satellite data from new sensors or re-interpretation of IKONOS images with new classification schemes (imagery); use of satellite data to produce "estimated depths" from satellite sensors in shallow water until actual bathymetric data available (bathymetry)
- Dense *in situ* optical data in 20-150 m depths (ground-truth)

As new primary data are collected, a standard suite of derivative products will continue to be provided and new products will be developed in response to specific management requests. Development and production of advanced derivative products including integrated "seascape" benthic habitat maps that combine satellite imagery, multibeam and LiDAR bathymetry, and *in situ* optical data from vehicles and divers across the full 0-150 m depth range using an integrated and consistent habitat classification scheme will continue in areas where all types of data are available.

Cost Estimates

Table 7 in the main document provides a prioritization and cost estimate for future projects. It is important to note that contracting costs per square kilometer for commercial LiDAR and/or multibeam surveys vary inversely with the size of the area to be mapped, especially in remote locations, because of relatively fixed deployment costs.

Mapping is expensive. The USGS National Map Budget Request is approximately $42M/year, and NOAA's Office of Coast Survey budget in 2008 was approximately $87M. The CRCP investment of $26M since 2000 with over $37M in matching funds has resulted in significant accomplishments with approximately one-third of coral reef mapping from 0-150 m completed, and the development of core expertise and acquisition of technologies to make these products possible. As CRCP mapping efforts move forward it will be critical to continue leveraging costs through partnerships. For 2011-2012, partner funding is estimated at $2.5M for the Caribbean, $1M for Florida, and still in negotiation for activities in the Pacific. The estimated cost to complete mapping in all Tier 1 CRCP priority (see Section 1.1 Guidelines, pg. 8) geographic areas includes some payment for shiptime and is $52.5M (an additional $17.5M if Tier 2 geographic areas are included) with a similar level of matching funds. Given the $63M ($26 + 37M) investment to map one-third of U.S. coral reef ecosystems, this estimate of $52.5-$70M, which includes costs for ship time buy-back, might be a reasonable rough estimate for completion. However, given that doing small projects is much more expensive, a funding level of $1.5M per year will mean that most projects will be small; thus the estimates may be too low.

Conclusion

Coral reef mapping provides management agencies with numerous critical products that enhance the ability to adaptively manage coastal ecosystems. With $63M in funding, CRCP and partners have accomplished a great deal over the past decade; however, the task of completing mapping U.S. coral reef ecosystems is still immense. By dedicating 5% of the CRCP budget or a reliable $1.5 million annually, gradual progress will continue to be made. These funds will ensure that considerable CRCP investments in developing mapping capabilities will be maintained, along with the demonstrated ability to leverage other resources to more cost-effectively meet mapping and management needs of the CRCP and partner agencies.

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1.0 Background and Introduction

Since 1999 the United States has recognized the importance of coral reef conservation as part of a comprehensive ocean policy, and mapping has been a consistent element of these plans and policies. President Clinton's Executive Order 13089 "Coral Reef Protection" directed the US Coral Reef Task Force (USCRTF) to coordinate a comprehensive program to map and monitor U.S. coral reefs. In response to USCRTF mandates, the National Oceanic and Atmospheric Administration (NOAA) formed the Coral Reef Conservation Program (CRCP) in 1999. The Mapping and Information Synthesis Working Group of the USCRTF developed a *Coral Reef Mapping Implementation Plan (1999)* to provide a framework for mapping all U.S. coral reef habitats. This was the basis for the mapping strategy in the *National Action Plan to Conserve Coral Reefs*, which committed to an ambitious program to produce **comprehensive digital maps of all coral reefs in the U.S. States and Trust Territories within 5 to 7 years**. The National Ocean Policy reinforces the need for mapping data to improve our understanding of ecosystems and ensure management and policies are based upon sound science, and NOAA's 2010 Next Generation Strategic Plan mirrors the need for mapping data. The "Resilient Coastal Communities and Economies" long-term goal states "Geospatial services will support communities, navigation and economic efficiency with **accurate, useful characterizations**, charts and **maps**, assessments, tools, and methods. Coastal decision makers will have the capacity to adaptively manage coastal communities and ecosystems with the best natural and social science available." Evidence of progress towards this goal includes: "An enhanced geospatial framework and **data available** to underpin decision support tools.

Between 2000 and 2010 CRCP invested $26M to map coral reefs in the Caribbean, Florida, the Gulf of Mexico, and the U.S.-affiliated Pacific Islands. With this considerable level of support and over $37M in matching funds or in-kind support from other groups, CRCP has been able to produce benthic habitat maps in 51% of the shallow (0-30 m) areas, bathymetric coverage of 30% and derivative products such as benthic habitat, slope, rugosity, hard/soft, or coral cover maps for 39% of the coral reef ecosystems in 0-150 m water depths. These investments in equipment, expertise, data acquisition, and map production and dissemination continue to provide valuable services to management communities that are beyond the capabilities available in the individual jurisdictions.

In 2007, the CRCP convened an External Review Panel to evaluate the success of the CRCP, and provide guidance to improve the program. Recommendations included: focus the CRCP's goals, emphasize management-relevant science, and emphasize place-based management. As a response to the External Review, in 2007 the CRCP developed a *Roadmap for the Future* to define new CRCP priorities and national-level responsibilities. This led to regional Coral Reef Ecosystem Integrated Observing System (CREIOS) workshops with local management entities to assess mapping and monitoring needs; corresponding documents were produced in 2009. Finally, in FY10, the CRCP engaged a consultant (Dr. John Boreman) to evaluate and report on the CRCP's mapping, monitoring, and assessment activities. A major recommendation of that report, *An Evaluation of the Mapping, Monitoring, and Assessment Activities of NOAA's Coral*

Reef Conservation Program, relevant to mapping is as follows: "**The goal should be to have 75-100% of coral ecosystems mapped down to a depth of 1,000 m in all jurisdictions**". Other goals include: update the 1999 national mapping strategy; agree on a basic set of base mapping layers and derived products; and develop tiered mapping priorities.

In March 2010 CRCP's Senior Management Council (SMC) made decisions about the CRCP response to the Boreman report. The following charge was given regarding **Mapping Achievements and Unmet Needs**: "The CRCP would like to see in one document what US coral reefs have been mapped, to what extent they have been mapped, and what remains to be done. Based on this information, the CRCP will be able to make more informed decisions about mapping priorities and what the relative funding should be for the basins. The CRCP has asked the mapping teams to create this document. The completion date for this document is March 2011. The SMC has also agreed to dedicate a set amount on an annual basis to mapping to ensure program continuity and easier long-term planning. The tentative amount for this mapping "box" (subject to SMC review of the Achievements and Unmet Needs document) is **$1.5 million annually or 5% of the CRCP budget.** The task of mapping all coral reef ecosystems is immense. However, by dedicating a reliable 5% annually, gradual progress will continue to be made. These funds will ensure that CRCP investments in developing mapping capabilities will be maintained, along with the often demonstrated ability to leverage other resources to more cost-effectively meet mapping needs of the CRCP and partner agencies.

1.1 Guidelines

The following is the charge given to the mapping team for production of this document**:**

- The CRCP SMC, Program Manager, and Staff Evaluation and Assessment (SEA) Team are the primary audience for this document, which will be used to inform funding decisions for FY11 and beyond.
- The document should include what has been mapped and what remains to be done. Within what remains to be done, the working group should provide some level of guidance and prioritization as to why these activities need to be done and which are most critical. Discussion of priorities should include connections to specific management actions.
- Reporting on what has been done should include areas outside of the CRCP Geographic Priorities [Tier 1 = FL (the coral reef tract out to ~30 m from Martin County to the Tortugas, including Biscayne Bay and Florida Bay, and that portion of the West Florida Shelf approximately within the northern boundary of the Florida Keys National Marine Sanctuary(FKNMS), Puerto Rico (PR), US Virgin Islands (USVI), Main Hawaiian Islands (MHI), American Samoa (AS), Guam, Commonwealth of the Northern Mariana Islands (CNMI); Tier 2 = Northwestern Hawaiian Islands (NWHI), Pacific Remote Island Areas (PRIA)], but discussion/priorities on what needs to be done should focus on the geographic priority areas listed above.
- The document is meant to focus on shallow (~0-30 m)/mesophotic (~30-150 m) depths. Discussion of what has been done should include deeper mapping supported by CRCP funds, but prioritizing what needs to be done should be confined to mesophotic or shallower depths.
- The Working Group should use its best judgment to define what the document will address as "mapping" as well as what should be considered "fully" mapped. Appropriate area or resolution to be fully mapped may differ between jurisdictions or basins. The SEA Team/Program Manager requests a check-in conversation once these working definitions have been established.

- The Working Group should rely on the *NOAA Coral Reef Ecosystem Integrated Observing System (CREIOS) Workshops Report* as well as their expert opinion to evaluate what mapping activities need to be done. Widespread jurisdictional input is not requested for this effort.
- While the Working Group is not charged with developing a task list or budget within the 5% mapping “box”, these parameters should be considered when developing priorities.

2.0 Why Map?

Mapping has been considered a critical and fundamental need for coral reef management, but the direct links to management needs may not always be obvious to those not directly involved in the work. With the increased CRCP emphasis being on management-relevant projects, important questions are “what types of maps and projects are needed” and “how do these products fulfill management and research needs”. Specific examples are provided to illustrate how primary mapping data and derived products continue to be critical for both research and management; note, however, that this list is not designed to be a totally comprehensive list of all applications of mapping data.

1. Depth data are required to define management boundaries for Marine Protected Areas (MPAs), which relates to CRCP Fishing Impacts Goals to “support effective implementation and management of MPAs and ecological networks of MPAs that protect key coral reef ecosystem components and functions”. Examples:
    - NWHI 2002 cruise to define NWHI Coral Reef Ecosystem Reserve boundaries
    - Establishing boundaries for 4 Marine National Monuments (MNM) in the Pacific, partly based upon depth data, most of which came from CRCP-funded surveys
    - Information being utilized to develop a MPA network along the entire Samoan Archipelago
    - Boundaries of fisheries reserves in MHI defined by both depth and hard/soft criteria in part using data collected by CRCP
2. Depth data to define depth strata, hard/soft maps derived from bathymetry and/or habitat maps are needed for fisheries research and management in order to create scientifically valid sampling plans (random stratified sampling) to assess and monitor the abundance and average size of key coral reef species needed to evaluate fishing impacts (Threat #2), to aid managers in establishing Annual Catch Limits (ACLs), and to assess management efforts to reduce Land-Based Sources of Pollution (LBSP) (Threat #3). Examples:
    - On-going use of depth and hard/soft data to create random stratified sampling strategies for fisheries research in the Pacific since 2006 and Caribbean since 2001, allowing statistically valid analysis of data and creation of regional coral reef fish biomass estimates and maps, showing clear correlations between human population and fish biomass
    - Current projects that use random stratified sampling approach for fisheries monitoring in high priority watersheds to aid managers in Hawaii, Guam, AS, USVI, and Puerto Rico in assessing the effectiveness of actions such as sediment control, algae removal, and protection of herbivorous fish on ecosystem health (Impacts from LBSP Goal)
    - On-going work to increase the number of random stratified sampling coral reef fish surveys in Pacific and Caribbean to aid management agencies in establishing coral fish ACLs (Magnuson-Stevens Reauthorization Act of 2006)

    - Correlation of seafloor characteristics (depth, rugosity, slope) with fish (Magnuson-Stevens Reauthorization Act of 2006) and protected species populations (Endangered Species Act (ESA))
    - Maps provide critical geospatial data needed for random stratified site selection associated with both fisheries-dependent and fisheries-independent monitoring and other habitat and research and monitoring activities along the entire Florida reef tract, Dry Tortugas, USVI, and Puerto Rico by NOAA, the Florida Department of Environmental Protection (DEP), and the Florida Fish and Wildlife Conservation (FWC) Commission.
3. Habitat maps support EFH and critical habitat for ESA delineations
    - Acropora coral species; Nassau grouper; West Indian manatee consultations and recovery planning along the entire Florida reef tract, Dry Tortugas by NOAA and the Florida FWC
    - 82 coral species are currently petitioned under ESA and, if any of these are designated as threatened or endangered, critical habitat maps for U.S. waters will be needed
    - Identification of spawning aggregation sites of federally managed species in the USVI and Puerto Rico for the Caribbean Management Council
4. Habitat maps are used to conduct research on the life history and habitat preferences of overfished or invasive species and to identify management options. Examples:
    - Queen conch and spiny lobster, along the entire Florida reef tract and Dry Tortugas; data are used by NOAA and the Florida FWC
    - Snapper and grouper assemblage analysis conducted within the USVI and Puerto Rico
    - Lionfish, along the entire Florida reef tract and Dry Tortugas. Data are used by NOAA, the National Park Service (NPS), the Florida FWC, and the Florida DEP
    - Invasive algae in the MHI; data are needed by Hawaii Department of Land and Natural Resources (DLNR) and NOAA
5. Bathymetry derivatives such as slope, rugosity, and hard/soft maps and benthic habitat maps from a full suite of satellite imagery, *in situ* optical, and/or bathymetric data help to define current extent of coral reef areas. This aids in the design of MPAs (Fishing Impacts) and has the potential to monitor changes in reef extent over time (Climate Change Impacts). Examples:
    - Comprehensive (0-150 m) benthic habitat maps created as part of a Biogeographic Assessment of American Samoa and Independent Samoa to aid in MPA design
    - Evaluation of MPA management efficacy in USVI Monuments and Fishery Closure Areas of Puerto Rico
    - Habitat maps are used to evaluate the effectiveness of marine reserves and target and non-target fisheries habitat preferences within the FKNMS)
    - Habitat maps are needed to undertake a public process to review current management zones throughout FKNMS and are used for geospatial analyses incorporated into the development, public review, and finalization of management and research activities included in the FKNMS's 5-year management plan
6. Benthic habitat maps and/or coral cover maps are needed to help management agencies understand extent of coral resources, potential impacts of construction projects and possible mitigation sites. Many of these types of needs are relatively short-term and immediate needs; thus they may not be included in longer-term jurisdictional requests. Examples:

  - 2004/2005 Navy/Military Sealift Command (MSC) project to define coral extent in Saipan anchorage, resulting in NOT expanding anchorage into coral-rich areas
  - Information used to support the Monument expansion for Virgin Islands Coral Reef Monument and the Buck Island Reef National Monument
  - Facilitation of access to Apra Harbor, Guam, bathymetric data and production of hard/soft maps to aid management actions with respect to planned expansion of facilities
  - Survey paid for by University of Hawaii (UH) and the State of Hawaii to fill gaps in MHI areas where cable routes are planned, potentially across coral-rich areas, to connect wind farms on less populated islands with Oahu. These areas were also significant gaps for CRCP projects in the MHI and were largely paid for by outside sources.
  - Used to assess impacts and prepare management plans associated with coastal development and related land-based sources of pollution along the entire Florida reef tract and Florida Keys by Florida coastal counties (Martin County, Broward County, Palm Beach County, Dade County, Monroe County), the Florida DEP, the Florida FWC, and NOAA
  - Maps needed for coastal and marine spatial planning activities, such as offshore wind and wave generation projects, planned or underway in the south Florida region

7. Habitat maps are used in research and monitoring of coral reef resiliency, sea-level change, climate change, and ocean acidification (Climate Change: Threat #1)
   - Climate change research and monitoring along the entire Florida reef tract, Dry Tortugas, and Dry Tortugas by The Nature Conservancy (TNC), NOAA, and universities. (e.g., the University of Miami)
   - On-going Pacific Reef Assessment and Monitoring Program (RAMP) time series of oceanographic measurements are critical to understanding of calcification in coral species. Depth and habitat maps are used to define instrument locations
   - Identify monitoring sites or strata for CRCP national monitoring program (NCRMP) climate metrics
8. Depth and benthic habitat maps are needed before and after adverse events to assess damage to reefs from groundings, oil spills, storms or tsunamis.
   - Re-survey of area off Oahu at the request of the Hawaii DLNR where a major grounding event had previously occurred. Surveys in numerous areas in Florida where groundings have occurred (see Figure 1)
   - Used to assess damages caused by hurricane, coral bleaching, and ship groundings in the USVI and Puerto Rico
   - Mapping data provided to assess effects of grounding at Pearl and Hermes Atoll in the NWHI and to provide base layers for Geographic Information Systems (GIS) analysis
   - Habitat maps support response, remediation, and recovery efforts from natural or human-caused hazards, such as a hurricane or oil spill, throughout the entire Florida reef tract, Florida Keys, and Dry Tortugas and are needed by the federal government and the State of Florida.
   - Mapping data used as base layers for assessment of tsunami damage and marine debris in American Samoa.
9. Collaborative collection of bathymetric data in port, harbor and MPA areas. Although charting is not part of core CRCP activities or priorities, charting projects are often jointly funded and critical to reduce risk of groundings and protect coral reef resources:

- Joint CRCP/Office of Coast Survey (OCS) surveys throughout USVI and Puerto Rico
- Surveys conducted of San Juan Anchorage area for US Coast Guard (USCG) San Juan and the Charlotte Amalie navigational channel for the St. Thomas Pilot Association
- Planned joint OCS/CRCP missions in Florida Reef Tract in 2011 and 2012
- Reconnaissance survey in Saipan Harbor in 2003 that was requested by harbormaster because of known shoal spots in coral-rich areas, followed by joint 2007 CRCP/OCS re-charting in Saipan, Tinian and Rota Harbors
- Re-survey of Honolulu Harbor and coincident training operations for subsequent MHI habitat surveys
- Accelerated access to Apra Harbor, Guam, nautical charting surveys conducted by OCS and the Naval Oceanographic Office (NAVOCEANO) through the National Geological Data Center (NGDC). Expanded processing of data to create hard/soft maps needed by Guam management agencies for analysis of potential dredging impacts on valuable coral reef ecosystems in harbor.

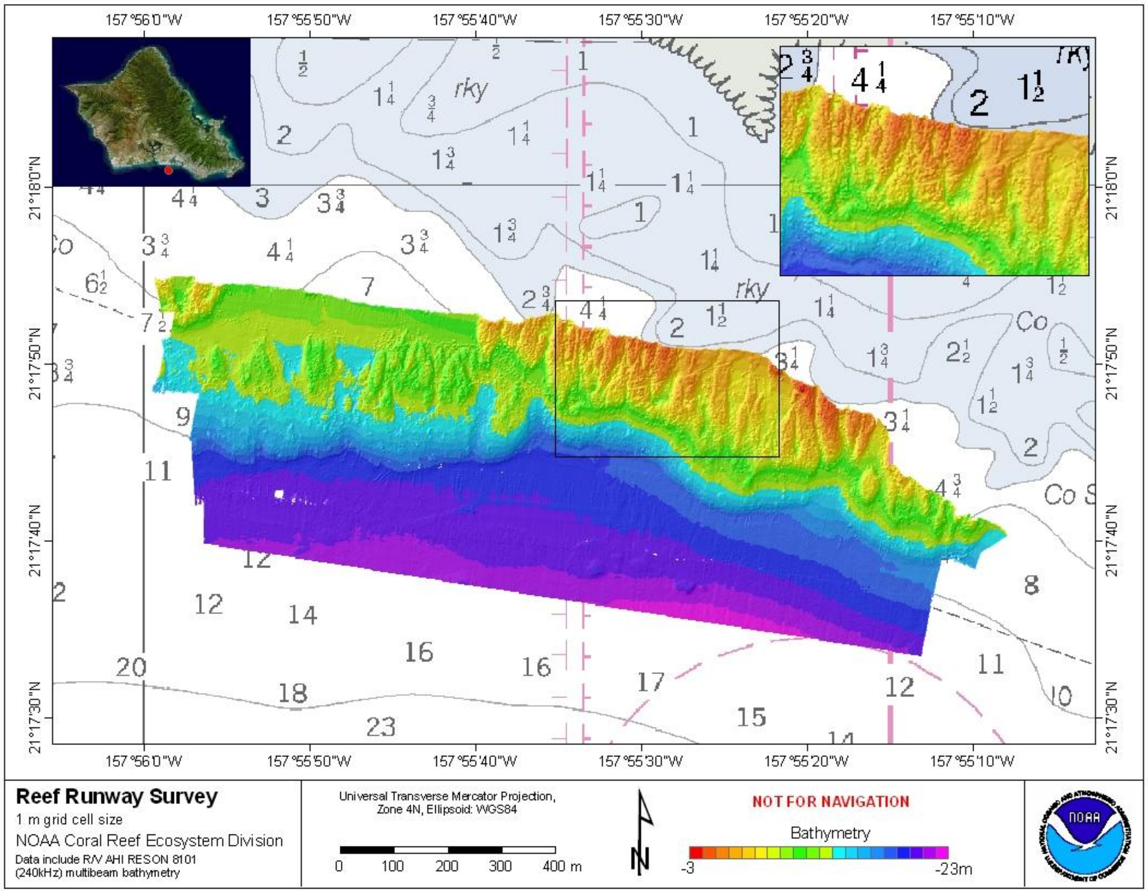


Figure 1: Survey of grounding area near Oahu reef runway

3.0 What Does Mapping Mean?

"Mapping" is a broadly used term that can mean different things to different users. To one user, mapping might mean creating a nautical chart using multibeam sonar or LiDAR technology; however, to others use of IKONOS imagery and optical validation data to create a "benthic habitat map" is what is considered a completed map. Based upon a framework established in the 2004 National Academy of Sciences document, "A Geospatial Framework for the Coastal Zone: National Needs for Coastal Mapping and Charting", this report will provide two metrics of what has been "mapped" in any given area: 1) Primary Data [termed Data Sources in 2004 report] and 2) Derivative Products.

3.1 Primary Mapping Data

To accurately characterize benthic habitats of coral reef ecosystems, several basic types of data must be collected (bathymetry, backscatter, imagery, underwater optical validation) and a variety of techniques are available to provide each data type (Table 1).

The data that have proven most useful for mapping benthic habitats in coral reef ecosystems are: bathymetric LiDAR and backscatter multibeam sonar and backscatter, multispectral imagery, and underwater video and still photographs collected on a suite of platforms. For the purposes of this report, these datasets are considered "**primary data"**, and some level of coverage is required for all U.S. coral reefs. Primary data can be manipulated and integrated to produce a wide range of "secondary or "**derivative products"**, some of which are appropriate for all U.S. coral reefs, while others are more appropriate for addressing site-specific management needs. A brief discussion of these technologies and the associated strengths, limitations, and drawbacks is presented in Appendix A.

Table 1: Mapping Technologies and Capabilities

Data Type	Sensor	Typical Depth Range*	Resolution	Accuracy	Platform
Bathymetry (depth)	Multibeam sonar	5-1000+ m	0.1 m – 10 m	High	Ship/launch
	LiDAR	0-~ 30 m	2-8 m	High	Airborne
	Multi/Hyper-spectral derived depths	0-~12 m	4 m	Low	Satellite
	Single-beam sonar	0-5000 m	Low	Medium	Ship
Backscatter/ Side-Scan	Multibeam	5-2000+ m	0.1 m – 10 m	High	Ship/launch
	LiDAR	0-~ 20 m	2-8 m	High	Airborne
	Side Scan	2-2000+ m	cm	Medium	Tow vehicle
Satellite/Aerial Imagery	Multi-Hyper-Spectral	0-30 m	.5-8 m	High	Satellite or airborne
	Digital Photography	0-30 m	0.1-1 m	High	Airborne
Underwater Validation	*In situ* Optical	0-1000+ m	0.5 mm – 10 cm		Divers, tow vehicles, AUVs
	Laser line scan	0-2000+ m			AUV, Tow vehicle

*Typical depth range is defined as what has been determined to be the effective range that can be expected for useful data from a sensor in average coral reef conditions based upon the authors' experience, not the manufacturers' quoted specifications.

3.2 Derivative Products

A variety of derivative products can be developed from the primary mapping data. It is particularly important to note that without a complete set of primary data, it is not possible to create certain derivative products; for example, without adequate *in situ* optical validation data for groundtruthing, accurate mapping products (e.g., full benthic habitat maps, coral cover maps) cannot be created. A number of different derivative products have been developed by the CRCP mapping team over the last decade, depending upon the types and amount of primary data available in a given area and management requests.

- Shallow habitat maps derived from satellite/airborne imagery and optical validation data in waters from 0-30 m depth
- Bathymetric maps and derivative geomorphic products such as slope, rugosity, and feature maps, generally in 20-150 m depths
- Hard/soft substrate maps created from bathymetric/backscatter data with a minimal amount of optical validation data
- Coral cover and sand maps created from bathymetry/backscatter data with sufficient optical validation data
- Fully integrated, consistent benthic habitat maps using acoustic, satellite imagery or photography and *in situ* optical data from 0-150 m depth. These integrated maps are one critical mapping component of CRCP's efforts since its inception and an important tool needed by resource managers for specific areas of interest, but may not be feasible or the appropriate product for all areas.

Additional map products can be produced to delineate predicted fish distributions, specific types of bottom or cover (e.g., hardbottom, sand, coral, algae), distributions of invasive species, etc. Such products require high densities of primary data and can be tailored to address specific management needs or requests.

3.3 Saipan: An Example of Available Data and Derivative Products

Saipan, CNMI, is an excellent example to illustrate different levels of mapping, based upon a mixture of management needs and corresponding products that have been developed. Figure 2a shows the primary data available around the island of Saipan and Figure 2b shows the derivative products that have been created. Three particular areas around Saipan have been identified as being critical for management concerns and different levels of products exist for each:

- Saipan Lagoon is very shallow (0-10 m) and has been mapped using IKONOS imagery and LiDAR (multibeam collection is not feasible in such shallow water). A benthic habitat map has been created in 2005 using the IKONOS imagery, but in 2008 the management agencies requested re-interpretation for a higher resolution product (2005 minimum mapping unit is 1 acre and considered by management personnel to be too large for detailed analyses needed in Saipan Lagoon) with an updated classification scheme, similar to what has more recently been done in the Caribbean.
- Garapan Anchorage ranges from 10 to 60 m in depth. A partial habitat map of the anchorage from IKONOS imagery is available and bathymetric data were collected in 2003 in 20-200 m water depths. In 2004/2005 the U.S. Navy MSC funded a project to collect 123-linear kilometers of deep (20-100 m) optical validation data, and a coral cover and sand map was produced to inform management agencies on the advisability of expanding the anchorage. With the existing data, it would now be possible to create a continuous, consistently classified, fully integrated benthic habitat map of Saipan Lagoon and the Garapan Anchorage as is discussed in Section 4.
- LauLau Bay and other conservation areas around Saipan are important management areas; they have interpreted benthic habitat maps from IKONOS imagery in the shallowest waters (0-20 m). In 20 m and greater depths, bathymetry data are

available, but there are little or no corresponding optical imagery data; thus it is possible to create geomorphological products, such as hard/soft substrate maps, but not benthic habitat maps. This is a fairly typical scenario around the often steep Pacific islands as well as in Florida and the Caribbean, with interpreted IKONOS imagery products in 0-20 m, little *in situ* optical imagery (20-150 m), geomorphological products from multibeam in greater depths, but no integrated benthic habitat maps from 0-150m.

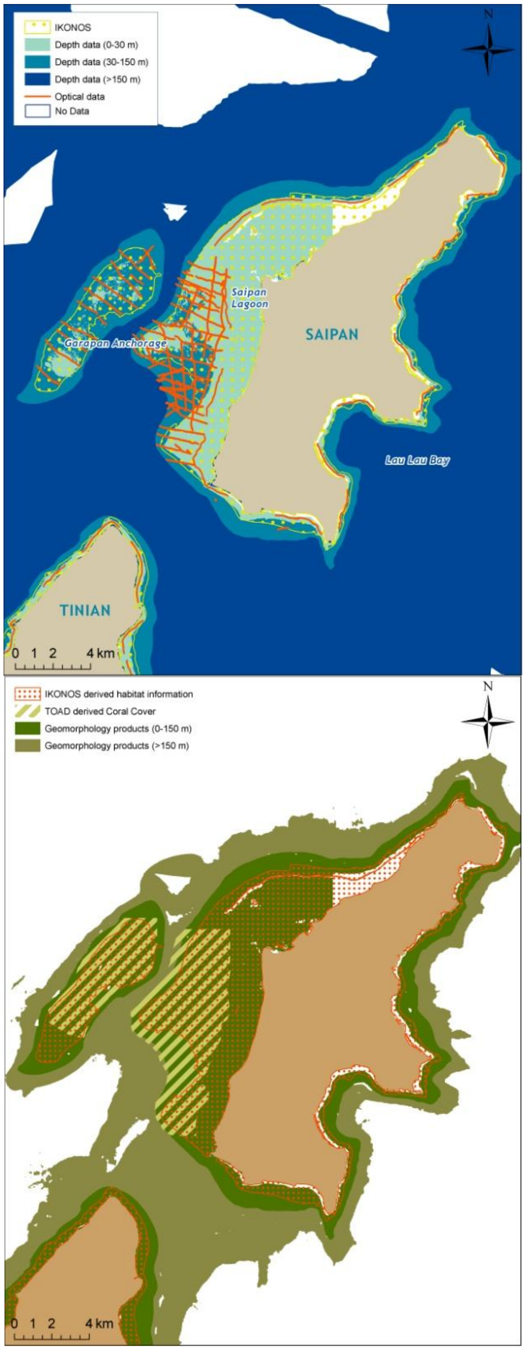


Figure 2: Primary data (top) and derivative products (bottom) around Saipan

3.4 Defining Gaps and Sufficiency

Looking at Saipan as a whole, all areas have some level of “mapping”. However, on the northwestern side and on the eastern side there are almost continuous gaps where no bathymetry (either multibeam or LiDAR) data have been collected in the shallowest areas (0-15 m), but interpreted IKONOS data have been used to create benthic habitat maps. Again, this scenario is fairly typical around many islands in the Pacific and Caribbean, as well as in Florida. In many areas in the Pacific, one of the most frequent requests from both scientists and managers is that accurate bathymetric data in this “bathtub ring” be collected. For example, when CNMI Division of Fish and Wildlife (DFW) was conducting fish monitoring in Tinian, a considerable amount of time and fuel was spent locating potential sampling sites within a pre-designated depth zone. Since accurate depth contours in shallow nearshore reefs did not exist, the process added staff time and resource inefficiencies for agencies that already struggle with capacity for both.

Data for the “bathtub ring” areas can be collected via launch-based multibeam, bathymetric LiDAR, or potentially by satellite “estimated depths” from the new Worldview-2 or GeoEye1 satellite sensors that are potentially more accurate than previous estimated depths from IKONOS. However, all estimated depths should be viewed as surrogates, not substitutes, for primary bathymetric data from multibeam or LiDAR surveys. See Appendix A for a more complete discussion of “estimated depth” accuracies. The “bathtub ring” gap exists for other map datasets besides bathymetry. Hard/soft maps derived from acoustic data need to be integrated with data from shallow water benthic habitat maps to provide complete coverage across the entire depth range of coral reef ecosystems. In most Pacific island areas, shallow *in situ* optical data collected by towboard divers could be integrated with existing *in situ* optical mapping data from deeper sensors to fill the “bathtub ring” gap for these datasets.

In addition to defining what mapping means, another question that arises is, “When is an area considered to be fully mapped?” In the context of this report, better questions to ask would be: “What areas need what products, in which depth ranges, and what has been provided to date?” For example, in critical management areas such as Apra Harbor in Guam, Saipan Anchorage, or federally managed locations such as the Virgin Islands Coral Reef National Monument, St. John, USVI, a suite of products might be currently available including some or all of the products shown in the above bullets. In some areas it may be necessary to re-map, if the resolution and/or quality of the original primary data (e.g., IKONOS, multibeam, or groundtruth data) are insufficient to meet management needs. In other lower priority areas with few management issues, it might suffice to have a single product or even no map at all. Thus in Section 5.1 Table 3, we propose three priority levels be used to determine the level of mapping needed in any given area.

4.0 2001-2010 CRCP Mapping Efforts

The CRCP has made a significant investment ($26 million) since 2001 in developing mapping capabilities that are a) logistically and technologically challenging; b) beyond the capability of local jurisdictions; c) difficult and expensive to re-develop if they are not maintained; and d) uniquely able to address to a wide range of management questions and needs. Two groups in NOAA have been the primary organizations engaged in CRCP mapping: the Biogeography Branch from the National Centers for Coastal Ocean Science (NCCOS), part of the National Ocean Service (NOS) and the Coral Reef Ecosystem Division’s (CRED) Pacific Islands Benthic Habitat Mapping Center (PIBHMC) from the Pacific Islands Fisheries Science Center of the National Marine Fisheries Service (NMFS). Since 2001 CRCP has funded projects to collect numerous different data types for mapping, evaluate the usefulness and cost-effectiveness of each data type and sensor, and develop products to meet the needs of both the scientific and management communities for conservation of coral reef ecosystems. As with any evolving program, some technologies, analysis techniques and products have proved to be more successful than others.

4.1 Data Collection:

One of the first benthic habitat mapping projects conceived under CRCP funding was purchase of satellite and/or airborne imagery data to provide visually interpreted benthic habitat maps in all shallow U.S. coral reef areas (primarily 0-30 m) with the exception of the PRIA, although a benthic habitat map of Palmyra has just been completed with funding from TNC. This approach was chosen because satellite imagery was available commercially and relatively inexpensive compared to collection of other data types; furthermore, benthic habitat maps from satellite imagery could be produced relatively quickly. Images from the IKONOS satellite have been the primary source for these benthic habitat maps, although aerial photos and hyperspectral imagery have also been used. Recently a variety of new satellites and sensors (e.g., WorldView2 and GeoEye1) have become operational, providing higher resolution and possibly superior water penetration; therefore questions have arisen about whether some areas with lower resolution and quality images should be remapped and re-interpreted. In addition, although most imagery techniques do not directly provide hydrographic-quality depth information, research projects have shown that it is possible to derive less accurate “estimated depths” from some subset of the imagery data. In limited areas (NWHI and 12 other Pacific islands for which the satellite image data quality was sufficient to allow analysis), “estimated depths” have been calculated down to ~12 m as a temporary measure until better quality bathymetric data can be collected. New remote sensing technologies have the potential to improve estimated depths, but not replace actual bathymetric data because of inherent inaccuracy associated with these techniques.

In order to create interpreted coral reef benthic habitat maps from any primary data (e.g. satellite imagery, bathymetry), densely spaced underwater *in situ* optical validation data are required. Diver and towed diver observations, videos, and photos have been collected almost continuously since 2001, but are still insufficiently dense and inadequately georeferenced for interpretation in many areas. A number of different systems have been utilized to collect optical imagery to verify the primary data including drop cameras, towed camera systems, and Remotely Operated Vehicles (ROVs). These range from very inexpensive drop camera systems (SeaViewer and MiniBat) that can quickly be deployed from small vessels in shallow water, to more robust drop cameras and towed systems that house multiple sensors (still photos, video, scaling lasers, and positioning) more appropriate for deeper depths. Additionally, ROVs have been used in some geographic areas to optically verify the coral seascape (10-1,000 m water depth). Most recently a bottom-following Autonomous Underwater Vehicle (AUV) has been used. Optical imagery from these instruments has been demonstrated to be critical for seafloor habitat characterization as well as contain valuable data on reef fish communities and invasive species at depths where little or no other data are typically available. Except in a few targeted areas, optical data density in these deeper waters is insufficient to produce accurately interpreted benthic habitat maps.

In 2001 efforts were initiated to acquire multibeam mapping capabilities for the remote and vast Pacific Islands region. An 8-m (25’) launch, R/V *AHI*, with a multibeam sonar that could map in depths between 0-300 m was purchased and outfitted, and this vessel began operations in 2003 from the NOAA Ship *Oscar E. Sette*. In 2002 CRCP funded a cruise aboard the R/V *Kilo Moana* (UH) to conduct multibeam mapping of important management boundaries in the NWHI in collaboration with NOAA OCS, the Office of National Marine Sanctuaries (ONMS), and Ocean

Exploration. In the Caribbean the first CRCP multibeam mapping expedition was conducted aboard the NOAA Ship *Nancy Foster* in 2004 using the same type of sonar as is used aboard the R/V *AHI*; since 2004 multibeam mapping has been done at least once each year from the *Foster* and the ship's multibeam mapping capabilities have steadily improved to include both shallow (0-400m) and mid-depth (10-1000m) multibeam systems. In late 2004 the NOAA Ship *Hi'ialakai* was outfitted with both shallow (0-125 m) and mid-depth (50-3000 m) multibeam sensors and davits to support the R/V *AHI*, and this ship began Pacific mapping missions in 2005 with numerous cruises between 2005 and 2008. Since 2008 availability of ship time for mapping has in general decreased, thus restricting multibeam data collection opportunities on the *Hi'ilakai* and the *Foster*. However, stand-alone operations using the R/V *AHI* were conducted in the MHI in 2009 and 2010, and the *AHI*'s 240-kHz sonar was pole-mounted on the NOAA Ship *Oscar Elton Sette* in 2010 to conduct fisheries-related mapping in the Mariana Archipelago. High-resolution shallow water multibeam and intereferometric sonar mapping has also been conducted in several near-shore coastal and Bay systems in the Caribbean using vessels of opportunity. These include mapping of Jobos Bay and Vieques, Puerto Rico, and Buck Island St Croix, USVI.

On-going collaboration with other mapping organizations, such as NOAA's OCS, Ocean Exploration, and the NAVOCEANO, has increased access to high quality multibeam data funded by other groups or organizations. In some populated areas, such as the MHI and Puerto Rico, bathymetric LiDAR data for shallow waters (0-30 m) not covered by multibeam data have been collected in conjunction with other organizations such as the NPS and US Army Corps of Engineers (USACOE). CRCP has funded additional bathymetric LiDAR collection for the USVI in partnership with US Geological Survey (USGS) and NOAA National Geodetic Survey (NGS) to be conducted in 2012. Additionally, extensive bathymetric LiDAR surveys will be conducted in 2011 for USVI (St. Thomas, St. John, and St. Croix) by contractors (FUGRO LADS) as a result of CRCP collaboration with NOAA's OCS. Starting in FY11, the OCS plans to conduct charting-related acoustic and LiDAR bathymetry and backscatter surveys of much of the Marquesas region of the Florida Keys over the next several years.

4.2 Product Development

Development of derivative products has been somewhat different in the Atlantic and Pacific, primarily due to the extent of the areas, resource availability, and recommendations from local resource managers. For all areas in both oceans, except the PRIA with the exception of Palmyra Atoll, interpreted benthic habitat maps have been created in shallow water from either IKONOS satellite or aerial imagery. These analysis techniques and protocols have also evolved with time and in some areas "remapping" using better quality imagery and more advanced, automated analysis techniques has been suggested or requested.

In the Pacific, availability of a ship and launch with multibeam mapping capabilities for several months of the year for 3 years (2005-2008) resulted in collection of thousands of km^2 of bathymetric data, but limited optical validation data. As multibeam data became available, bathymetry and backscatter processing protocols were established and derivative products such as slope, rugosity, and feature classification were developed. Maps of hard (rock, rubble, etc.) versus soft (sand, silt) substrates have been created for many islands where backscatter imagery data of adequate quality are available (Figure 3a). Preliminary findings from the PIBHMC suggest these derived products are particularly valuable for explaining the distribution of demersal and benthic coral reef fish species and they have been used in conjunction with bathymetric data to provide a basis for statistically-robust random stratification to improve ecosystem monitoring as well.

In the relatively few areas where sufficient optical validation data are available in deeper water, it has been possible to develop more advanced map products including feature maps (termed Benthic Position Index or BPI) to locate certain types of terrain (pinnacles, slopes, etc.), coral cover, sand cover, and interpreted benthic habitat maps. Maps of coral cover have been used to determine an area's suitability as an anchorage location and to evaluate subsea cable routes; they are also valuable products for planning other activities where physical disturbance of the seafloor may occur. Maps of hard versus sediment covered substrates have been requested for all localities in the Pacific, to enhance the design of stratified random sampling schemes for coral reef fishes. They have also been requested to identify sand deposits that may be potential sources of sediment for beach renourishment or to identify candidate sites for the temporary storage of damaged vessels that are interfering with harbor navigation. Once sufficient primary data have been collected, many types of derived products can be created to meet a wide array of management needs. For example, Figure 3b shows areas predicted to be dominated by macroalgae, which are hypothesized to serve as important habitat for smaller reef fish in the NWHI. Other derived products might predict areas of high coral cover, high abundance of certain fish species or functional groups, the distribution of invasive species, etc. For many Pacific areas, a suite of GIS layers has been developed, but insufficient data are available to develop advanced derived map products. Instead, the focus has been on processing and releasing what data are available, as a series of map layers of different habitat characteristics (see Figure 4). All products are available from the PIBHMC website.

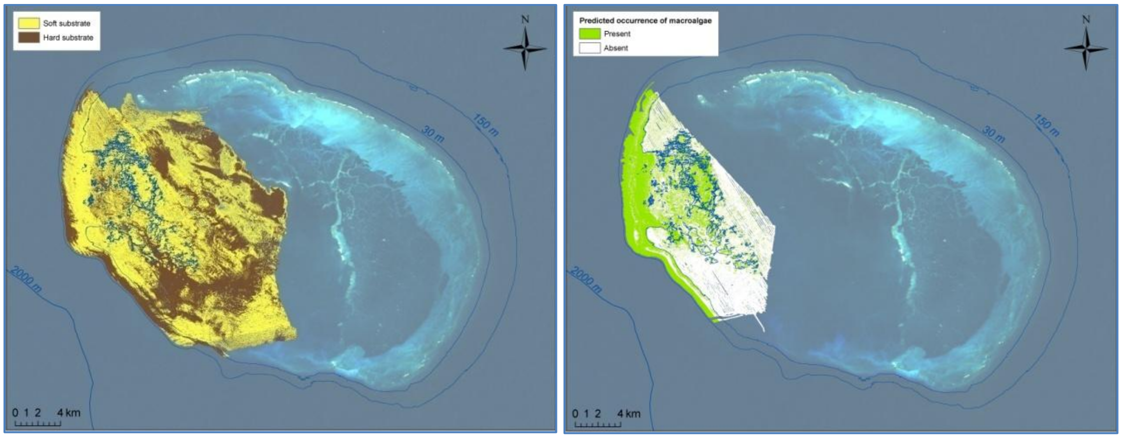


Figure 3a: Hard/soft substrate map derived from bathymetry, backscatter, and optical imagery at French Frigate Shoals (FFS), NWHI. Figure 3b: Predicted algal cover for a portion of the FFS data set.

In the U.S. Caribbean, a full suite of products in limited areas (often Habitat Areas of Particular Concern or MPAs) have been produced for a number of reasons: availability of a survey ship with multibeam and ROV capabilities for only a few weeks each year; study areas that could be accessed locally by divers to gather groundtruth information; and matching funding from other agencies such as the NPS whose focus is on specific protected areas, rather than an entire island or archipelago. The final products for these areas are termed seascape benthic habitat maps and all products are accessible on NCCOS Biogeography Branch website.

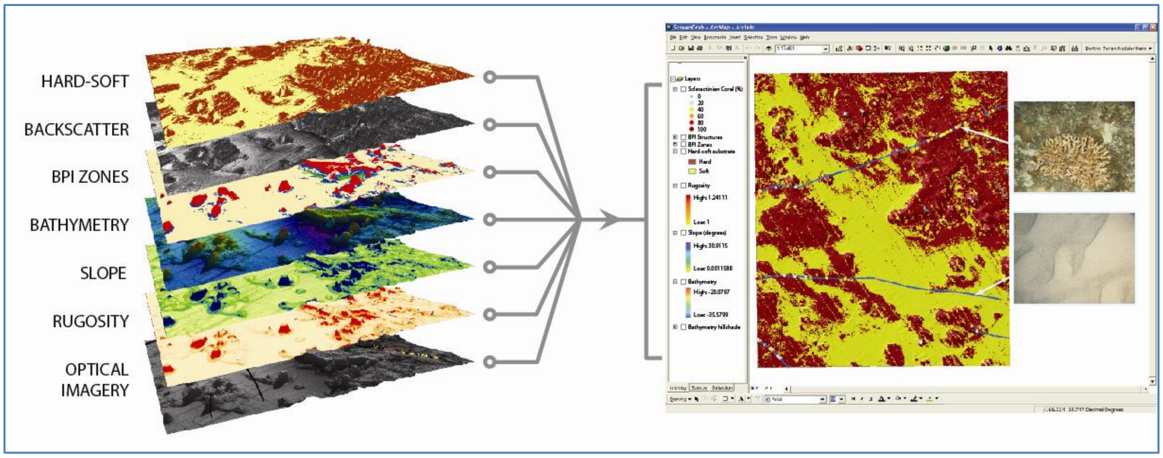


Figure 4: Suite of GIS layers showing different habitat characteristics.

Producing seascape benthic habitat maps has been one critical mapping component of CRCP's efforts since its inception and an important product requested by resource managers for specific areas of interest, particularly in the Caribbean. The seascape-scale benthic habitat maps provide consistently-derived, accurate, and comprehensive information describing the status, extent, and distribution of coral reef ecosystems throughout their range (0-150 m). While various technologies are used to map portions of the seascape, the ability to integrate these components into a spatially and informational consistent product is of importance so resource managers have a seamless source of information on which to base management decisions. These products also provide a critical spatial framework for conducting random stratified monitoring efforts, evaluating MPA area effectiveness, describing fish-habitat utilization linkages and impacts of fishing, identifying spawning aggregation sites, and identifying potential new marine protected area locations.

Since 2001 for all jurisdictions except the PRIA, the Biogeography group has completed shallow-water benthic habitat maps (0-30m) using visual interpretation of airborne or satellite collected imagery to delineate and identify coral ecosystem habitats. These comprehensive, georeferenced maps provide information on biological cover, geomorphological structure, and coral and other habitat distribution. The level of detail the map will portray (minimum mapping unit) is decided in consultation with regional partners, and take into account the primary data used for mapping and the cost and time required to produce the map of the area. Also, visual interpretation has been found to be the most effective technique for analysis of the shallow optical data to produce the 80-95 percent thematically accurate (i.e., the benthic habitat map was statistically tested for accuracy at the major and detailed structure and cover categories found in the classification scheme) maps of shallow water coral ecosystems. Acoustic multibeam data have been collected from ships and small boats for water deeper than 20 meters. However, until recently, there wasn't a proven approach for generating a benthic habitat map product analogous to the shallow-water product. The Biogeography Branch's release of the benthic habitat maps for St John, USVI, provides the first demonstration of a viable technique for 1) generating benthic habitat maps using multibeam data, and 2) a seamless integration of the two products (Figure 5).

A similar set of maps is now being prepared for a biogeographic assessment of American Samoa using techniques developed by the Biogeography Branch to process multibeam and *in situ* optical data collected by the CRED PIBHMC mapping team; sufficient optical data for a complete benthic habitat map are only available around Tutuila. Furthermore, this technique appears to be very promising in its applicability to other data sources such as bathymetric LiDAR and the ability to generate objective map products with limited human modification from satellite or airborne imagery. This technique is more efficient than visual interpretation by orders of magnitude, further advancing the state of mapping towards greater efficiency and repeatability (i.e., mapping as a monitoring tool). Again, creation of seascape benthic habitat maps is only possible if a full suite of satellite imagery, *in situ* optical, and multibeam and/or LiDAR bathymetry is available.

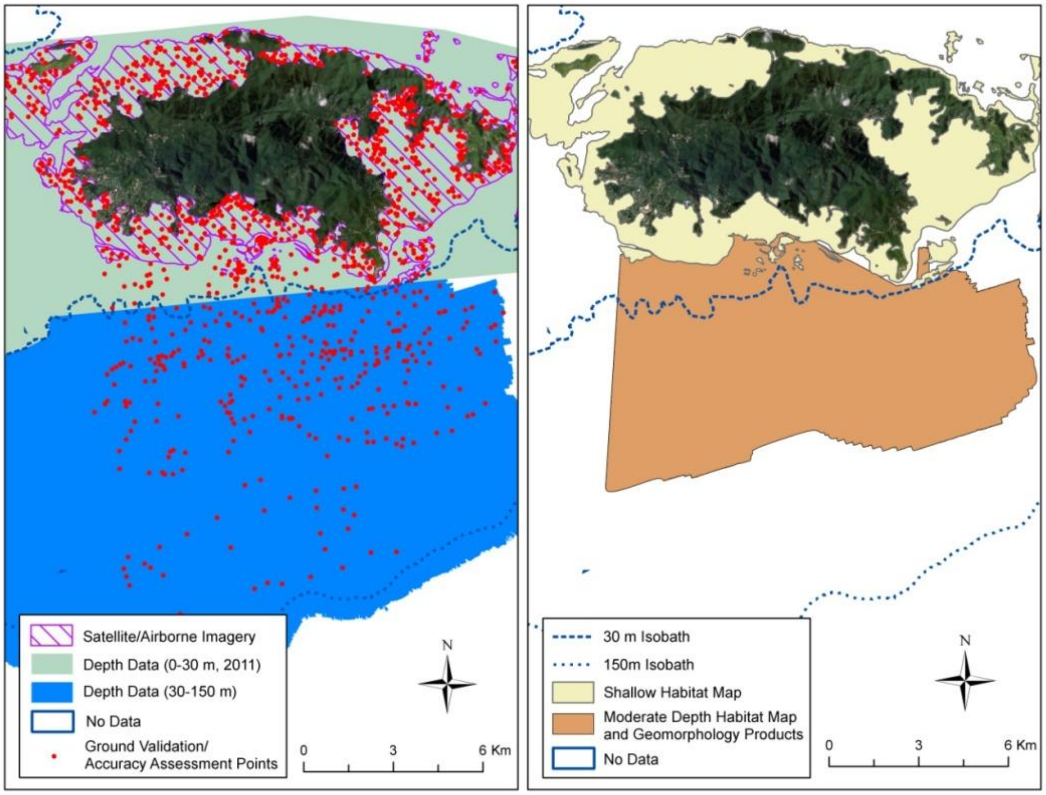


Figure 5: Simplified operational approach for conducting shallow optical and moderate depth acoustic benthic habitat mapping.

Figure 6 portrays a simplified depiction of conducting shallow ‘Optical’ and moderate depth ‘Acoustic’ benthic habitat mapping that is being used by the Biogeography group. By design, the methods and outcomes are virtually identical. Shallow-water maps begin with source imagery that includes either high resolution satellite or airborne imagery (panel A). A visual interpreter creates draft polygon delineations of benthic habitats in a GIS (panel B). Ground truthing data are collected using drop-cameras, divers, or ROV’s to aide in identifying benthic habitat types (Panel C). Accuracy assessment data are also independently collected to thematically assess the accuracy of the map products (Panel C). A final GIS benthic habitat map is created and released with all the supporting source data to the users (Panel D). Using multibeam or bathymetric LiDAR data, the source and derivative layers (e.g. intensity, slope, and rugosity) are processed and created (Panel A). Using semi-automated software, spectral, spatial, and textural features are identified and delineated (Panel B). Ground truthing data are collected using drop-cameras, divers, or ROV’s to aide in identifying benthic habitat types (Panel C). Accuracy Assessment data are also independently collected to thematically assess the accuracy of the map products (Panel C). A final GIS benthic habitat map is created and released with all the supporting source data to the users (Panel D).

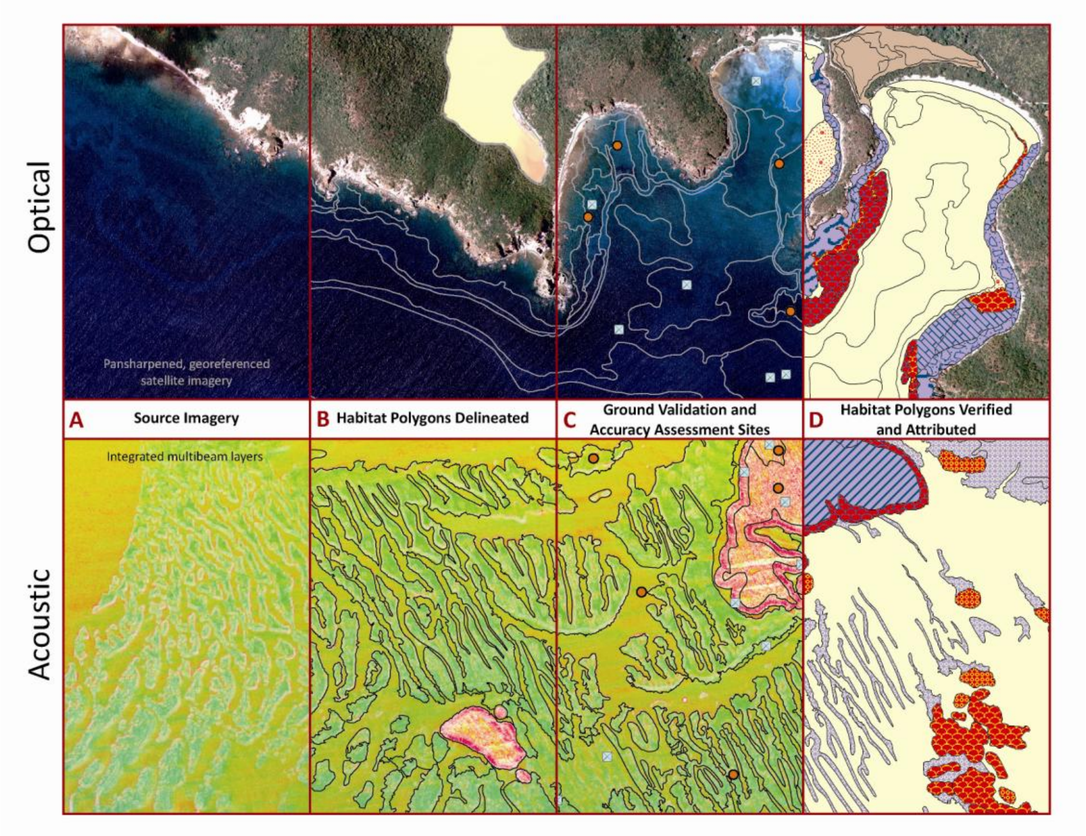


Figure 6: Creation of “seamless” benthic habitat maps using both optical and acoustic data.

In southern Florida, CRCP investments have been used to produce benthic habitat maps of about 3000 sq km of the nearly 6,600 sq km that have been mapped (other Federal and state investments were used to map the remaining 3,600 sq km). A detailed benthic habitat map has been completed using CRCP investments for the reef tract in Martin, Palm Beach, Broward, and Dade Counties. CRCP funds have been used to complete a benthic habitat map of about 2000 sq km of the reef tract and Hawk Channel. CRCP funds also have used to purchase and make available nearly 9,200 sq km of high-resolution satellite imagery and 3,800 underwater video clips and still images to support both mapping and other management-related activities. The satellite imagery and underwater data have been made available using both Google Earth and Google Maps.

4.3 CRCP Mapping Accomplishments

Table 2 provides a high-level overview of CRCP mapping accomplishments from 2000 through 2010. Note: Estimates of the percentage of 0-150 m seafloor incorporated into MPAs is only approximate due to boundaries at different depths than 150 m. Appendices B through H discuss the mapping accomplishments in the Tier 1 (B: American Samoa, C: Florida Reef Tract, D: Main Hawaiian Islands, E: Mariana Archipelago, G: Puerto Rico, H: USVI and) and Tier 2 (D: NWHI, F: PRIA) jurisdictions in detail, as well as the future priorities for mapping in each jurisdiction as determined from jurisdictional inputs and mapping accomplishments to date.

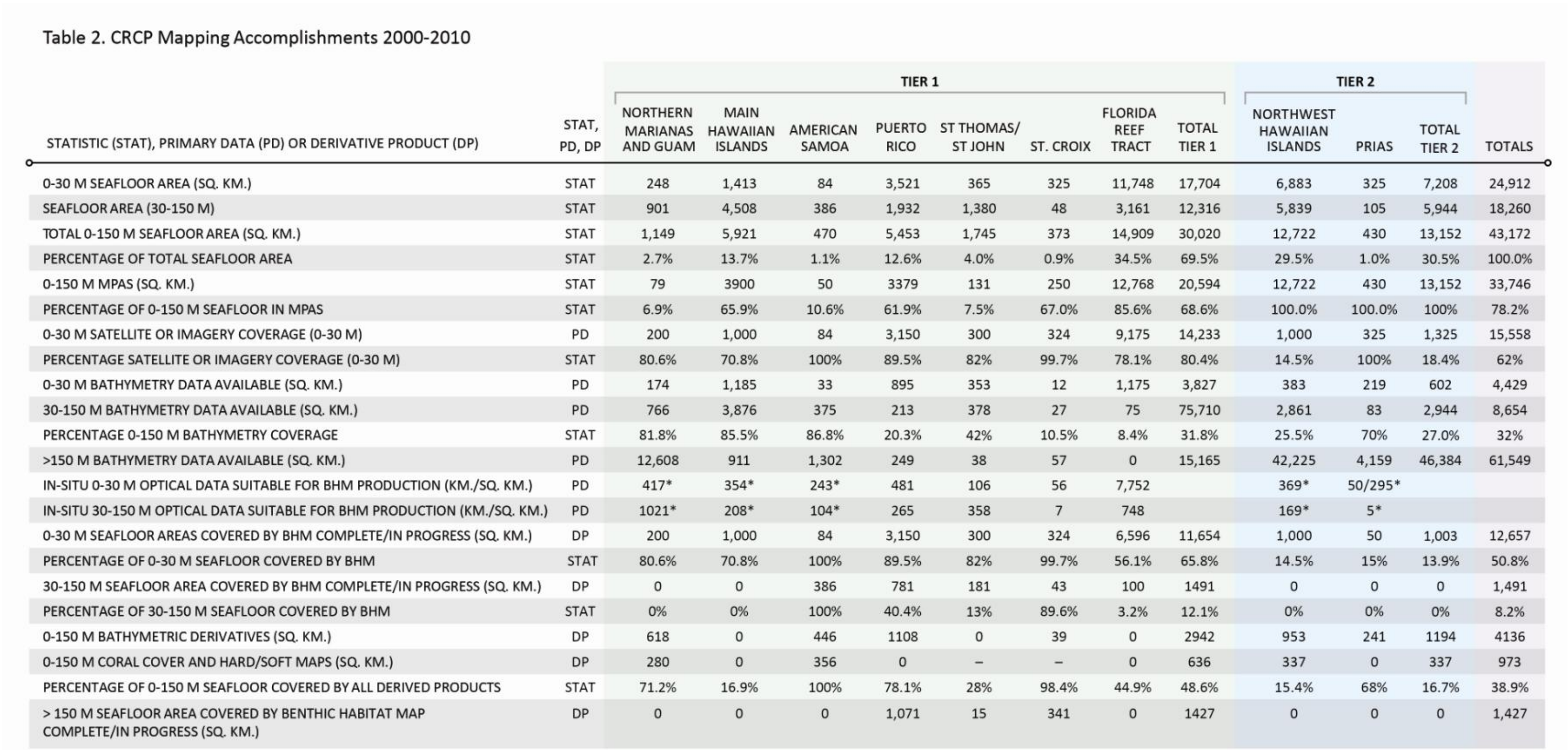


Table 2. CRCP Mapping Accomplishments 2000-2010

		TIER 1								TIER 2			
STATISTIC (STAT), PRIMARY DATA (PD) OR DERIVATIVE PRODUCT (DP)	STAT, PD, DP	NORTHERN MARIANAS AND GUAM	MAIN HAWAIIAN ISLANDS	AMERICAN SAMOA	PUERTO RICO	ST THOMAS/ ST JOHN	ST. CROIX	FLORIDA REEF TRACT	TOTAL TIER 1	NORTHWEST HAWAIIAN ISLANDS	PRIAS	TOTAL TIER 2	TOTALS
0-30 M SEAFLOOR AREA (SQ. KM.)	STAT	248	1,413	84	3,521	365	325	11,748	17,704	6,883	325	7,208	24,912
SEAFLOOR AREA (30-150 M)	STAT	901	4,508	386	1,932	1,380	48	3,161	12,316	5,839	105	5,944	18,260
TOTAL 0-150 M SEAFLOOR AREA (SQ. KM.)	STAT	1,149	5,921	470	5,453	1,745	373	14,909	30,020	12,722	430	13,152	43,172
PERCENTAGE OF TOTAL SEAFLOOR AREA	STAT	2.7%	13.7%	1.1%	12.6%	4.0%	0.9%	34.5%	69.5%	29.5%	1.0%	30.5%	100.0%
0-150 M MPAS (SQ. KM.)	STAT	79	3900	50	3379	131	250	12,768	20,594	12,722	430	13,152	33,746
PERCENTAGE OF 0-150 M SEAFLOOR IN MPAS	STAT	6.9%	65.9%	10.6%	61.9%	7.5%	67.0%	85.6%	68.6%	100.0%	100.0%	100%	78.2%
0-30 M SATELLITE OR IMAGERY COVERAGE (0-30 M)	PD	200	1,000	84	3,150	300	324	9,175	14,233	1,000	325	1,325	15,558
PERCENTAGE SATELLITE OR IMAGERY COVERAGE (0-30 M)	STAT	80.6%	70.8%	100%	89.5%	82%	99.7%	78.1%	80.4%	14.5%	100%	18.4%	62%
0-30 M BATHYMETRY DATA AVAILABLE (SQ. KM.)	PD	174	1,185	33	895	353	12	1,175	3,827	383	219	602	4,429
30-150 M BATHYMETRY DATA AVAILABLE (SQ. KM.)	PD	766	3,876	375	213	378	27	75	75,710	2,861	83	2,944	8,654
PERCENTAGE 0-150 M BATHYMETRY COVERAGE	STAT	81.8%	85.5%	86.8%	20.3%	42%	10.5%	8.4%	31.8%	25.5%	70%	27.0%	32%
>150 M BATHYMETRY DATA AVAILABLE (SQ. KM.)	PD	12,608	911	1,302	249	38	57	0	15,165	42,225	4,159	46,384	61,549
IN-SITU 0-30 M OPTICAL DATA SUITABLE FOR BHM PRODUCTION (KM./SQ. KM.)	PD	417*	354*	243*	481	106	56	7,752		369*	50/295*		
IN-SITU 30-150 M OPTICAL DATA SUITABLE FOR BHM PRODUCTION (KM./SQ. KM.)	PD	1021*	208*	104*	265	358	7	748		169*	5*		
0-30 M SEAFLOOR AREAS COVERED BY BHM COMPLETE/IN PROGRESS (SQ. KM.)	DP	200	1,000	84	3,150	300	324	6,596	11,654	1,000	50	1,003	12,657
PERCENTAGE OF 0-30 M SEAFLOOR COVERED BY BHM	STAT	80.6%	70.8%	100%	89.5%	82%	99.7%	56.1%	65.8%	14.5%	15%	13.9%	50.8%
30-150 M SEAFLOOR AREA COVERED BY BHM COMPLETE/IN PROGRESS (SQ. KM.)	DP	0	0	386	781	181	43	100	1491	0	0	0	1,491
PERCENTAGE OF 30-150 M SEAFLOOR COVERED BY BHM	STAT	0%	0%	100%	40.4%	13%	89.6%	3.2%	12.1%	0%	0%	0%	8.2%
0-150 M BATHYMETRIC DERIVATIVES (SQ. KM.)	DP	618	0	446	1108	0	39	0	2942	953	241	1194	4136
0-150 M CORAL COVER AND HARD/SOFT MAPS (SQ. KM.)	DP	280	0	356	0	–	–	0	636	337	0	337	973
PERCENTAGE OF 0-150 M SEAFLOOR COVERED BY ALL DERIVED PRODUCTS	STAT	71.2%	16.9%	100%	78.1%	28%	98.4%	44.9%	48.6%	15.4%	68%	16.7%	38.9%
> 150 M SEAFLOOR AREA COVERED BY BENTHIC HABITAT MAP COMPLETE/IN PROGRESS (SQ. KM.)	DP	0	0	0	1,071	15	341	0	1427	0	0	0	1,427

* indicates linear kilometers.

The Gulf of Mexico (GOM) is not included in the Table 2 statistics because it is no longer a Tier 1 or 2 priority for CRCP; however, some mapping in the GOM was funded by CRCP in previous years. For example, benthic habitat maps and bathymetry are available for portions of Habitat Areas of Particular Concern and the Flower Garden Banks National Marine Sanctuary in the GOM, which cover 6,165 km^2. However, little or no bathymetric data or benthic habitat maps are available for the 0-150 m portion of the west Florida shelf, which covers almost 100,000 km^2.

5.0 Future Work

5.1 Priorities for Future Work

A stratified approach would seem most logical to determine mapping priorities in any given area or around an island as a whole. Table 3 presents a suggested general prioritization method for determining levels of mapping data and products needed, which is then used to estimate costs in Table 6. Priority 1 indicates areas (sometimes not the entire island) that have been identified as high priority management areas for which a full suite of primary data and integrated products is strongly recommended. Populated islands with numerous management issues and marine protected areas are generally Priority 1 areas. Priority 2 represents areas where all primary data are recommended, but it may not be possible to provide complete optical coverage due to survey logistics, particularly in steep areas; thus this may preclude producing a full suite of map products. Areas designated as CRCP “Tier 2” geographic priorities include the NWHI and the PRIA; mapping needs in these areas are thus generally designated as Priority 2 or lower, here as well. Priority 3 represents areas where satellite imagery and/or bathymetry are recommended, but only moderate levels of coverage by *in situ* optical data are required and production of a full suite of interpreted derived products is of low priority. In general, mapping should be conducted in higher priority areas before lower priority areas; however, if mapping assets are deployed in a remote area, it often makes economic and logistical sense to collect whatever data time allows since it may be the only time that a ship or aircraft is in the area. Likewise, if logistical or financial support is provided from non-CRCP sources that may justify conducting mapping in lower priority areas for CRCP first, and it is important that CRCP consider working in areas where advantage can be gained through partnerships, even if they are not the highest CRCP priority area.

Table 3: Recommended Mapping Priority Levels and Associated Products.

Priority	**Satellite (IKONOS or other**		**Bathy (LiDAR or MB)**		***In situ* Optical**		**BHM (satellite product)**		**Bathy. Deriv. (slope, rugosity, etc.**		**Integrated Products**
Depth (m)	0-30	30-150	0-30	30-150	0-30	30-150	0-30	30-150	0-30	30-150	0-150
1	R	na	R	R	d	d	R	na	R	R	R
2	R	na	R	R	d	m	R	na	R	R	R*
3	R	na	**	R	m	m		na	**	R	R*

R - Data are strongly recommended.
na – Not available
d - Dense coverage of *in situ* optical data is required in order to produce derivative products.
m – Moderate coverage of *in situ* optical data is recommended. However, it may not be logistically feasible to collect adequate optical data in very steep and low priority regions to support the development of fully integrated map products.
* The development of some map products produced from the integration of multiple sources of data may be limited or precluded altogether by lower quality data (e.g., satellite-derived bathymetry) or insufficient data (e.g., *in situ* optical data).

> **Shallow water bathymetry data in Priority 3 areas can be met with products derived from multispectral satellite imagery, from sensors such as GeoEye1 or WorldView-2, and may be used as an **interim** product for higher priority areas. These data are typically not adequate for developing some bathymetric derivatives such as rugosity.

Other than maps of hard versus soft substrates and coral cover, there is presently not a standard suite of integrated map products being developed for all areas in the Pacific. As additional primary data are collected and processed, it may be feasible to routinely produce maps of ecosystem characteristics such as distributions of particular habitats or species of interest. Other maps will be developed to meet specific management needs, generally for smaller, high-priority areas.

In all areas, but especially in the Pacific, there is a significant need to bridge the gap between the shoreline and the nearshore extent of multibeam coverage. As mentioned above, depths derived from satellite imagery can be used on an interim basis to provide bathymetric coverage until LiDAR data are available. Hard/soft maps derived from acoustic data need to be integrated with data from shallow water benthic habitat maps to provide complete coverage across the entire depth range of coral reef ecosystems. Other derived layers face similar challenges and in many cases it may not be technologically or logistically feasible to fill these gaps except in small, high priority areas (see further details on American Samoa, Hawaii and Marianas mapping priorities in Appendices). In areas where sufficient data exist or can be collected, collaborative work between the Biogeography group and PIBHMC will continue to product seascape benthic habitat maps wherever possible.

Given the limiting factor of the number of NOAA ship days available to conduct moderate depth mapping activities (30-150m), the projected approach for the coming years will be to continue with mapping in targeted high priority areas indicated by jurisdictional partners and leveraging costs through partnerships. In the Pacific, if ship time is not available, shore-based operations including R/V *AHI* multibeam mapping and *in situ* optical data collection can be conducted, particularly in Guam (multibeam and *in situ* optical), American Samoa (additional *in situ* optical data around the Manua islands as requested by DMWR), CNMI (multibeam and *in situ* optical) and the MHI (multibeam and *in situ* optical), which still have significant unmapped areas in critical management areas; however, completion of work in more remote areas in the NWHI, PRIA and CNMI will not be possible without shipboard support. Pacific LiDAR mapping is expensive, particularly in areas with little infrastructure, and must necessarily be done by contract; joint funding in partnership with other groups is required and will be pursued. Significant shallow water progress will be made in FY11-12 in St Thomas and St John, USVI, but significant gaps remain for St. Croix and Puerto Rico. Collaborative cost sharing partnerships will continue to be pursued in order to cost-share expensive shallow-water data collection efforts. This model has been successful in several instances within the USVI. NOAA efforts will continue to focus on creating integrated fully classified landscape maps of seafloor habitats using the approaches that have been implemented in St John. USVI (for further details on USVI and Puerto Rico mapping priorities see Appendices)

In southern Florida, the priority activities (based on the CREIOS meeting and partner input in 2010) are: 1) complete the habitat maps of Hawk Channel and Florida Bay (currently underway); 2) complete mapping a portion of the Backcountry area using available satellite imagery (currently underway); 3) complete acoustic data acquisition and mapping of current unknown areas in Hawk Channel (FWC effort to be started in 2011 using NMFS grant funds); 4) coordinate with the OCS and NMFS to collect bathymetric LiDAR and acoustic data of the Marquesas area suitable for habitat mapping; 5) generate a habitat map of the Marquesas area using the bathymetry data described above; and 6) generate a seamless, consistent habitat map of the entire south Florida reef tract using available habitat maps produced by NOAA, FWC, the NPS, and universities.

5.2 Cost Estimates for Future Work

Two models must be considered when discussing cost estimates for future surveys:

1. Collection and processing of data using primarily NOAA assets, including ships, launches, equipment and personnel.
2. Commercial surveys to collect base layer data, particularly multibeam and LiDAR, with analysis being done by NOAA personnel.

In all jurisdictions, CRCP has purchased or contracted for satellite and aerial data commercially. Bathymetric LiDAR data collection must be done commercially since NOAA has no in-house systems and has often been funded by or in collaboration with other agencies or NOAA groups. In the Pacific region almost all multibeam and optical data collected to date have been collected by NOAA personnel aboard NOAA vessels using sonars, vehicles, and cameras purchased by the CRCP. In the Caribbean and Florida, a mixture of the two models has been used to collect multibeam and optical data, but the processing has been done and products created by personnel from the NOAA Biogeography Branch and partners.

An additional cost factor must also be considered and that is "to what standard will data be collected?" CRCP's need is primarily for benthic habitat mapping to aid decision making and ecosystem-based management. However, many of CRCP's surveys to date have been conducted in concert with NOAA's OCS, some of them to Special Order or Order 1 standards. Bathymetric mapping using LiDAR or multibeam to Special Order or Order 1 International Hydrographic Organization (IHO) Standards can greatly increase the time needed and thus the cost of a survey. One example is Saipan Harbor, where a survey for benthic habitat mapping required less than a day, but a survey to Order 1 IHO standards took 10 operational days, and this is a fairly typical difference between benthic habitat surveys and higher order surveys that require 200% multibeam coverage, sidescan data, and repeated verification checks. There is also a strong interagency mandate to "map once but use many times", but no clear guidance on cost sharing to offset higher costs associated with mapping to higher order IHO standards. Since data collected by CRCP have already been extensively used to update nautical charts in remote areas that previously had little or no recent data, the mapping team proposes that CRCP surveys be done to the less stringent Order 1b IHO standards, which should not increase cost significantly:

> Order 1b is intended for areas shallower than 100 meters where a general depiction of the seabed is considered adequate for the type of surface shipping expected to transit the area. A *full sea floor search* is not required which means some *features* may be missed although the maximum permissible line spacing will limit the size of the *features* that are likely to remain undetected.

For Model #1, estimation of the ship and personnel time (i.e. number of days needed to deploy to and conduct surveys) needed to collect multibeam and optical data with existing CRCP assets is the most logical way to provide a metric of costs, particularly since NOAA and CRCP have invested a considerable amount in the last decade on ships and shipboard equipment, small boats, equipment, computers, software, and personnel training needed to map coral reef areas. It should also be noted that if this core expertise and equipment is not used, it will rapidly become obsolete or disappear. After developing estimates of the time and assets needed to complete mapping in a particular area, additional estimates of personnel time needed to do data analysis and produce a variety of products can be made, and this is often a multiplier of the number of survey days needed to collect the data.

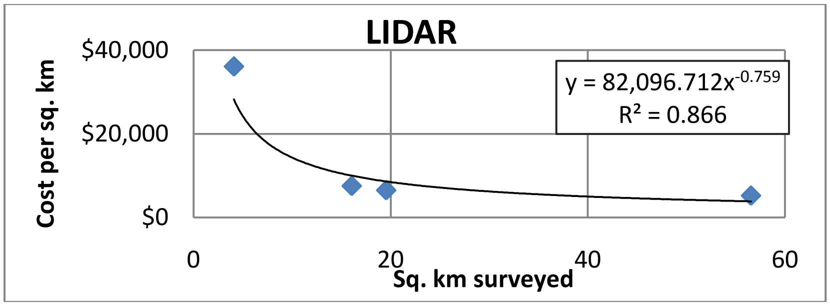
As discussed previously, one problem associated with Model #1 is the decreasing availability of NOAA ship time to conduct mapping and monitoring work, particularly in remote areas where NOAA is the only agency with extensive capability. Ship costs are certainly the most significant costs that must be considered in estimating mapping costs; they have also risen dramatically with higher fuel costs and an evolving NOAA fleet including ships that are more expensive to maintain than previous vessels. To date NOAA's Office of Marine and Aviation Operations (OMAO) has provided most of the ship time for mapping free of charge to CRCP. However, since 2008 sea days for mapping have decreased dramatically and there is little indication in the OMAO ship schedules for out-years that this will change in the foreseeable future. Thus, projected mapping costs should include at least a portion of the ship costs for performing this work, since it is unlikely that free ship time will be provided by NOAA for this work and sea days will have to be "bought back" or charter vessels used. Buy-back costs for the NOAA Ship *Hi'ialakai* were ~$13,000/day in 2010. Equivalent vessels are available through the University-National Oceanographic Laboratory System and 2008 daily costs to use modern multibeam-capable vessels were in the range of $30,000-$35,000/day. Launch costs are estimated at $4000/day and these costs include maintenance of a complex vessel and engine, generator, air conditioning, and survey systems, software licenses and personnel; similar commercial vessels in Hawaii charge $12,500 to $75,000/day for survey.

Table 4. Model 1 – Daily Cost Estimation for NOAA Personnel to Perform Multibeam and Optical Surveys and to Process the Primary Data. Note that costs to fully integrate data into benthic habitat maps are not included in this cost estimate.

Daily Cost Estimate	OMAO provided ship time	NOAA ship buy back	Charter ship costs
Ship costs	$0	$15,000	$35,000
Launch costs	$4,000	$4,000	$4,000
Personnel costs	$1,300	$1,300	$1,300
Processing/product costs for primary data	$3,900	$3,900	$3,900
Total daily costs	$9,200	$24,200	$44,200

For Model #2, commercial surveys rates based upon a cost per km^2 are the best way to estimate costs. The mapping team has reviewed known commercial costs for LiDAR and multibeam mapping from OCS surveys, however, it must be noted that most of OCS surveys are done to the more stringent Special Order or Class 1 IHO standards. OCS costs per km^2 varied by almost an order of magnitude; LiDAR surveys ranged in cost from $36,052/km^2 to $5,227/km^2 with an average cost of $13,833/km^2, and multibeam surveys ranged in cost from $19,836/km^2 to $2,101/km^2 with an average cost of $8,557/km^2.

These cost variations might be partially attributed to mapping to different survey standards, as discussed previously. Another major factor in multibeam mapping is that shallower (0-30 m) surveys require much more time than deep surveys and are thus more expensive. Deployment costs in remote areas versus areas with better infrastructure are also a factor, but almost all areas for coral survey can be considered relatively remote. As is clearly shown in Fig. 7, the greater the area surveyed, the less expensive it is to survey per sq km, because the mobilization and demobilization costs remain almost the same no matter what area is surveyed. CRCP could expect to gain survey efficiency due to large areas being surveyed in only 3 major (the NWHI, Puerto Rico, and Florida Keys) regions, assuming that an entire large area would be surveyed in one or two deployments; however, many remaining areas to be mapped are quite small and costs would be expected to be much higher in those areas. Assuming that all CRCP surveys can be considered remote (more costly) and that they will be done only to Order 1b IHO standards, the major cost drivers for remaining surveys will be the size of the areas to be mapped and for multibeam surveys, the depth of water to be mapped.



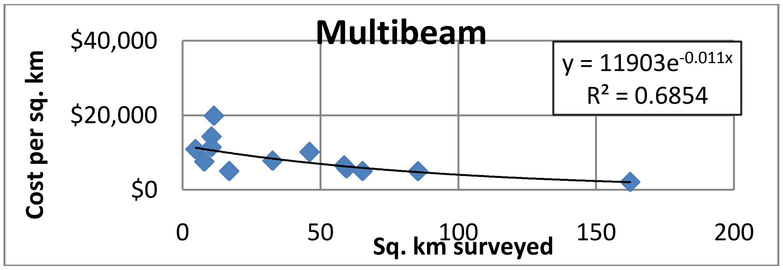


Figure 7. LiDAR and multibeam mapping costs per km^2

Table 5: Model 2 Commercial Cost Estimates per km^2.

Collection Area	Multibeam 0-30 m	LiDAR 0-30 m	Multibeam 30-150 m
< 50 km^2	$19,836	$36,052	$4,000
50-100 km^2	$8,557	$13,833	$2,101
> 100 km^2	$2,101	$5,227	$2,101

Processing costs to integrate satellite, acoustic, and *in situ* optical data are estimated to require $3900/day for each day of survey data and by area for commercial work.

5.3 Priorities and Estimated Costs for Future Work

Given the original goal of completion of coral reef mapping in 5-7 years and $26M +$37M (Table 6) spent on mapping since 1999, the high estimates in Table 7 might seem a bit daunting. However to provide some context, the USGS annual budget request for The National Map program was ~$43M; the West Coast Governor's Seafloor Mapping Plan budgets over $87M for mapping on the coasts of Washington, Oregon, and California through 2020; and NOAA's OCS had an annual budget of $87.8M in 2008. Considering these large figures that demonstrate the high costs for mapping overall, CRCP has managed to accomplish a great deal in terms of progress in mapping the coral reef ecosystems in U.S. waters with a fairly modest investment.

An important component of the future mapping strategy is to work collaboratively to continue mapping of coral reef ecosystems. The proposed $1.5 M budget for CRCP mapping will obviously not cover all mapping needs, but it is important to establish this stable base level of funding to maintain in-house capabilities and then continue to work to leverage additional funds from other organizations. Efforts by Biogeography and CRED mapping personnel to form long-term partnerships with other mapping groups both within and outside of NOAA have resulted in significant matching or in-kind funding since the beginning of the mapping program with numerous examples of successful collaborative projects in the NWHI, MHI, American Samoa, CNMI, Guam, the PRIA, Puerto Rico, the USVI, and Florida. Matching support in the next 2 years is expected to be at least $2.5M in the Caribbean and $1M in Florida, and funding for joint projects in the MHI is in negotiation.

Biogeography and CRED personnel have also been involved in the NOAA and national program to promote integrated mapping since 2002, which has resulted in the Ocean and Coastal Integrated Mapping Act (a part of Public Law 111-01, the Public Land Management Act of 2009). Important NOAA partners include OCS, OMAO, the ONMS, NGDC, the National Geodetic Center, Ocean Exploration, and the Integrated Ocean and Coastal Mapping group. Partnerships outside of NOAA include: NAVOCEANO, USACOE, the US Naval Facilities Engineering Command, MSC, USCG, NPS, USGS, the US Fish and Wildlife Service (USFWS), UH, the University of Puerto Rico (UPR) and the University of the Virgin Islands (UVI), the Joint Hydrographic Center at the University of New Hampshire, TNC, and numerous other state and local agencies. Table 6 provides an estimate of matching funds for mapping work and demonstrates the level of collaboration already in place.

Table 7 provides cost estimates for future mapping work. As discussed in Section 5. 2, numerous assumptions are included in making these estimates, so they should certainly be considered to be a rough order of magnitude (ROM), rather than a strict guideline to actual costs. Approximately one-third of the coral reef ecosystems discussed in this document have been mapped for $26M plus $37M in matching funds. The estimated cost to complete the rest of the mapping, $52-$70M, includes some payment for ship time and assumes a similar level of matching funds. It is a reasonable but possibly low ROM estimate to complete mapping the remaining two-thirds of coral reef ecosystems, especially if the funding level means that only small scale projects are undertaken

Table 6: Matching Funds for Mapping 2001-2011

Area	Sub-Area	Years	Direct Funding	Sur vey	Equipment	Processing/Reports	In-Kind Support	In-Kind Funding	Funding or Participation
Pacific									
	Mariana Archipelago								
	Saipan Anchorage Optical	2004/5	$298K	x	x	x	Boat charter (MSC)	$100K	NAVFAC, MSC
	Saipan, Tinian, Rota Harbors	2007/8		x		x	30 days personnel		OCS, NOAA Geodetic Survey
	All islands Mariana Archipelago	2007					30 days Hi'ialakai	~$900K	OMAO
	Apra Harbor, Guam	2008		x		x	Entire survey	~$300K	OCS, NAVOCEANO
	Deliver Mapping Data	2007/8	$100K			x			NAVFAC
	Rota, FDM	2010		x		x	3 wks Sette, FDM data	~$630K	NMFS,OMAO,UoG, NAVO
	Offshore Banks, Guam	2010		x		x	3 wks Sette	~$630K	NMFS, UoG,OMAO
	MHI								
	Niihau, Penguin Bank, Hawaii	2005/6		x		x	Ship Time, Personnel		ONMS, OE
	Niihau, Penguin Bank, Hawaii	2005/6					62 days Hi'ialakai	~$1.9M	OMAO
	Mesophotic Surveys, Maui	2009/10/11	$95	x	x	xx	1 mo Sette/Hiialakai, 1 mo. UH ship	$316	CSCOR, HURL, UH
	Honolulu Harbor	2009		x		xx	Survey, All processing		OCS
	Oahu, Maui County Cable Survey	2009	$90K	x		xx	All processing		UH, State of Hawaii
	NWHI								
	NWHI Reserve Boundaries	2002/3		x			Kilo Moana cruise	$500K	ONMS, Ocean Exploration
						x	2 months personnel on cruise		OCS
	FFS, Maro,PH,Kure,Brooks, etc.	2005/8					113 days Hi'ialakai	~$3.4M	NMAO
	Nihoa, FFS, Necker	2005		x		x	3 weeks cruise personnel		PIRO
	Penguin Bank, Hawaii	2006		x		x	4 weeks cruise personnel		USFWS, ONMS, OCS
	Kure and Pearl and Hermes	2006		x		x	8 weeks cruise personnel		USFWS, ONMS, USFWS
	PRIA								
	Johnston, Howland, Baker	2006					22 days Hi'ialakai	~$660K	OMAO
	Jarvis, Kingman, Palmyra	2006					24 days Hi'ialakai	~$720K	OMAO

Area	Sub-Area	Years	Direct Funding	Sur vey	Equip-ment	Processing/ Reports	In-Kind Support	In-Kind Funding	Funding or Participation
	Wake	2007					21 days Hi'ialakai	~$630K	OMAO
	Palmyra Atoll	2009	$50k	x		x	Mapping		TNC
	American Samoa								
	Rose, Swains Island	2006					30 days Hi'ialakai	~$900K	OMAO
	Equipment								
	2 Multibeam sonars for Hi'ialakai	2004	$3M+		x		Equipment and installation		OMAO/Earmark
	2 transducers/computer	2010	$370 K		x		Backup equipment for R/V AHI		OMAO
Caribbean									
	USVI								
	St. Croix, St. John, St. Thomas	2004	$450 K	X	X	X	17 Days Nancy Foster, NPS Launch 14 days	$372K	NPS, OMAO
	St. Croix, St. John, St. Thomas	2005	$225 K	X	X	X	21 Days Nancy Foster, NPS Launch 14 days	$450K	NPS, OMAO
	St John	2006	$125 K	X	X	X	NPS Launch 14 days	$40k	NPS
	St John	2008	$150 K	X	X	X	NPS Launch 14 days	$40k	NPS
	St. Croix	2009	$100 K	X	X		NPS Launch 14 days	$40k	NPS
	St. Thomas, St. John	2009	$100 K	X	X	X	NPS Launch 14 days	$40k	NOAA Marine Debris, NPS
	USVI	2010	$310 K	X	X	X	24 Days Nancy Foster, NPS Launch 14 days	$1.2M	NOAA OCS
	Puerto Rico								
	Southwest PR	2006	$220 K	X	X	X	17 Days Nancy Foster	$332 K	OMAO
	Cabo Rojo	2006		X			Airborne LiDAR	$1.5M	NOAA NWS
	Western PR	2007	$225 K	X	X	X	16 Days Nancy Foster	$312 K	OMAO
	Western PR	2008	$225 K	X	X	X	16 Days Nancy Foster	$312 K	OMAO
	Eastern PR	2009	$225 K	X	X	X	12 Days Nancy Foster	$234 K	OMAO
	Jobos Bay	2008-09	$250k	X			NERR Launch 28 Days	$100k	USDA, NERR
	Equipment								
	Reson 8125	2009			x			$125k	OMAO

Florida									
	Florida Reef Tract	2005-2009		x		x	Project manager time	~$350K	NOS/SPO
	Florida Reef Tract	2009-2011		x		x	Project manager time	~$100K	NOS/ONMS
	Florida Reef Tract	2005-2011				x	Staff and facilities support	~$350K	NOS/ONMS
	Florida Reef Tract	2007		x			Fugro LiDAR acquisition	~$25K	NOS/NGS
	Florida Reef Tract	2010	$300K	x			Acoustic data acquisition using TJ & launches		NOS/OCS
	Marquesas	2011-2015	~$2.5 million	x		x	Planned bathy LiDAR and acoustic data acquisition		NOS/OCS
	Florida Reef Tract	2006-2011				x	Bathy LiDAR access	~$50K	NOS/CSC
	Florida Reef Tract	2006-2011				x	COOP used, in part, to support project goals	~$250K	NOS/NCCOS
	Florida Reef Tract	2005-2011				x	Staff support (GIS; data management; etc)	~$150K	NOS/NCCOS
	Florida Bay	2005-2011		x		x	Staff,GIS support, mapping	~$500K	Florida FWC
	Florida Bay and Biscayne Bay	2006		x			Acquisition of aerial photography for mapping	~$250K	Florida FWC
	Marquesas/Quicksands	2009-2011	$375K	x		x	Wildlife Legacy grant		Florida FWC
	Acropora Critical Habitats	2010-2012	$2 million	x	x	x	NMGS/ESD grant to monitor and map		Florida FWC
		2011-2015	$707	x		x	NOS/OCRM CZ 309 grant to develop mapping products		Florida FWC
	Martin, Palm Beach, Broward, and Dade County	2005-2011		x			Staff support and mapping of benthic habitats	~$1.5M	Florida DEP
	Florida Keys National Marine Sanctuary	2005-2011		x			Staff time to support coral and fish monitoring	~$250K	University of Miami
	Florida Keys	2005-2011		x			Staff time. seagrass surveys	~$500K	FIU
	Broward County	2007-2011				x	Staff time, HMT and AA activities	~$100K	NCRI
	Biscayne National Park, DTRO	2005-2011		x			Staff time mapping through FWC and contractors	~$1M	NPS
	Biscayne National Park, DTRO	2006-2011		x			Staff time and EARRL LiDAR acquisition	~$1M	USGS
Totals for All Areas			**~$13.6M**					**~$23.6M**	

Table 7: High Level Summary of Costs to Complete Mapping in Tier 1 and Tier 2 CRCP Areas

Juris-diction	Prio.	Locations	Depths (m)	Model/Method	Area to Map (sq km)	Cost/ sq km	# Days	Cost/day	Primary Data Cost	Integrated Product	Total ROM Costs	Possible Partners
Mariana	1	Guam, Saipan, Rota, Aguijan	0-30	2/LiDAR	86	$14,000			$1,204,000	$32,960	$1.25M	Navy, CNMI, Guam
	1	Guam, Aguijan, Rota, Offshore Banks (include Tinian and Saipan for optical)	30-150	1/Ship/launch 1/Optical	130		14 71	$24,200 $24,200	$338,800 $1,422,200	$111,240	$1.5M	NMFS, Navy
	1	Saipan Lagoon -- higher resolution	0-10	Satellite	10	$4,000			$40,000	$15,000	$65K	CNMI
	1	Pagan, Maug, FDP, Asuncion	0-150	1/Optical			43	$24,200	$746,200	$20,188	$875K	Navy, MNM
			0-30	2/LiDAR	7	$15,000			$105,000			
	2/3	All other islands	0-150	1/Optical	13		55	$24,200	$904,000	$16,892	$920K	CNMI
			0-30	Satellite/WV2		$0						
Hawaii	1	MHI	0-150 0-150	1/Launch 1/Optical			30 161	$9,200 $24,200	$276,000 $2,040,600	$92,288	$2.5M	OCS, UH, NPS DLNR
Am. Samoa	1	All Islands	0-30	2/LiDAR	51	$14,000			$1.2M*		$1.9M	NPS, NMS, MNM
	1	All Islands Optical Data	0-150	1/Optical			27		$652,600	$32,960		
USVI	1	St Thomas/St. John	30-150	1/Ship/launch	1,002		30	$24,200	$726,000	$120,000	$906K	
				1/Optical			30	$2,000	$60,000			

Juris-diction	Prio.	Locations	Depths (m)	Model/Method	Area to Map (sq km)	Cost/ sq km	# Days	Cost/day	Primary Data Cost	Integrated Product	Total ROM Costs	Possible Partners
	1	St Croix	0-30	1/LiDAR	313	$14,000			$4.3 M	$80,000	$4.4 M	NPS, UVI, CFMC, CZM, OCS
				1/Optical			20	$500	$10,000			
	1	St Croix	30-150	1/Ship/launch	21		2	$24,200	$48,400	$10,000	$62.5K	
				1/Optical			2	$2,000	$4,000			
Puerto Rico	1	Puerto Rico	0-30	1/LiDAR	2,626	$5,227			$14 M	$240,000	$14.5 M	
				1/Optical			60	$500	$30,000			
	1	Puerto Rico	30-150	1/Ship/launch	1,719		50	$24,200	$1.2 M	$200,000	$1.5 M	UPR, DPNR, CFMC, CZM, OCS
				1/Optical			50	$2,000	$100,000			
Florida	1	Florida	0-30	1/Ship/launch	10,573		991	$24,200	$24 M	$4 M	$28 M	
				1/Optical			40	$500	$20,000			
Tier 1 Total											$52.5M	
Hawaii	2	NWHI	0-30 20-150	2/LiDAR 1/Multibeam	4,000 8,600		350	24,200	$5-7M* $8,470,000	$1.5M	$17M	PMNM
PRIA	2	Kingman & Palmyra (only)	20-150	1/Ship/launch							$3 M	OCS, FWC, NCRI, DEP, USF, NMFS
				1/Optical			61	$24,200	$1,365,800	$140,492		
			30-150	1/Ship/launch	3,086		107	$24,200	$2.6 M	$428,000		
			10-150	1/Ship/Launch /Optical	106		18	$24,200	$435,600	$11K	$450K	
Tier 2 Total											$20.5M	
Total											$73M	

***** indicates estimate used was submitted as a proposal package.

List of Acronyms

ACL	Annual Catch Limit
AS	American Samoa
AUV	Autonomous Underwater Vehicle
BPI	Bathymetric Position Index
CNMI	Commonwealth of the Northern Mariana Islands
CRCP	Coral Reef Conservation Program
CRED	Coral Reef Ecosystem Division
CREIOS	Coral Reef Ecosystem Integrated Observing System
CFMC	Caribbean Fisheries Management Council
CZM	Coastal Zone Management (USVI)
DEP	Department of Environmental Protection (Florida)
DFW	Department of Fish and Wildlife (CNMI)
DLNR	Department of Land and Natural Resources (Hawaii)
DPN	Department of Planning and Natural Resources (USVI)
EFH	Essential Fish Habitat
ESA	Endangered Species Act
FKNMS	Florida Keys National Marine Sanctuary
FWC	Fish and Wildlife Conservation (Commission, Florida)
GIS	Geographic Information System
HMRG	Hawaii Mapping Research Group
HURL	Hawaii Undersea Research Laboratory
IHO	International Hydrographic Organization
LBSP	Land Based Sources of Pollution
LiDAR	Light Detection and Ranging
MHI	Main Hawaiian Islands
MIP	Mapping Implementation Plan
MNM	Marine National Monument
MPA	Marine Protected Area
MSC	Military Sealift Command
NAVOCEANO	Naval Oceanographic Office
NCRI	National Coral Reef Institute
NGDC	National Geophysical Data Center (NOAA)
NGS	National Geodetic Survey (NOAA)
NMFS	National Marine Fisheries Service (NOAA)
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
NWHI	Northwestern Hawaiian Islands
OCS	Office of Coast Survey (NOAA)
OE	Ocean Exploration (NOAA)
OMAO	Office of Marine and Aviation Operations (NOAA)
ONMS	Office of National Marine Sanctuaries (NOAA)
PMNM	Papahānaumokuākea Marine National Monument
PIBHMC	Pacific Islands Benthic Habitat Mapping Center
PRIA	Pacific Remote Island Areas
RAMP	Reef Assessment and Monitoring Program

ROM	Rough Order of Magnitude
ROV	Remotely Operated Vehicle
SEATeam	Staff Evaluation and Assessment Team (CRCP)
SMC	Senior Management Council (CRCP)
TNC	The Nature Conservancy
UH	University of Hawaii
UPR	University of Puerto Rico
USACOE	U.S. Army Corps of Engineers
USCG	U.S. Coast Guard
USCRTF	U.S. Coral Reef Task Force
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
USVI	U.S. Virgin Islands
UVI	University of the Virgin Islands

Appendix A: Mapping Technologies

Underwater Validation Data

When considering what “benthic habitat mapping” encompasses, it should be kept in mind that it is not possible to accurately interpret remotely sensed data without corresponding underwater validation information. Whether using satellite imagery, multibeam sonars, or LiDAR data, none of these provide direct observations of the seafloor and the benthic and demersal communities found there. Although in other types of coastal zones it may be possible to collect sediment or other bottom samples, optical validation using diver observations, still photos, or video are the only practical options in coral rich areas due to the nature of the bottom. Therefore it is critical that corresponding underwater observations be made that are sufficiently dense to characterize and provide validation of the remotely sensed data**.** The optical information can be in the form of direct visual observations, still photographs, videos, or laser-line scan data and can be collected using a number of different vehicles, including divers, drop cameras, towboards, towed camera sleds, baited camera stations, Remotely Operated Vehicles (ROVs), Autonomous Underwater Vehicles (AUVs), and submersibles.

In general, dense direct visual observations are only feasible in 0-30 m water depths due to the realities of diving logistics and regulations. Diver observations are routinely collected as part of CRCP biological monitoring activities, and generally visual observations are backed up by either still photos or videos; diver observations are done both at specific dive sites and across broader areas using “manta-type” towboards. In deeper waters, a number of different techniques have been used with various degrees of success. Both video and still photography techniques are routinely used, but these are greatly complicated by low light conditions in deeper waters and frequent night operations, thus requiring underwater lights as well as cameras. Laser line scan operations were also tested, but operations were very expensive and the sensors proved to be somewhat unreliable.

A major consideration for collection of deeper observational data is the vehicle used for data collection. Any equipment deployed over the side of the ship, whether attached to the ship or not, is at risk of being lost or damaged; working in rapidly changing coral reef terrains greatly increases the risk of damage or loss. Camera sleds have a great range of complexities and costs, ranging from a simple lowered frame with a recording video camera attached, to tow bodies or Remotely Operated Vehicles (ROVs) with umbilical cords that can telemeter photos and video data and provide remote motion control, to pre-programmed terrain-following AUVs (no umbilical) that can send photos to the surface. Regardless of the vehicle being used, collection of such observational data requires ship time, the proper equipment, and personnel with expertise in photography, electronics, equipment operations, and data analysis. Collection of *sufficient* observational data to interpret remote sensing data is very time-consuming and has significant associated equipment and personnel costs. It should be noted that there is little or no monitoring of in coral reef ecosystems below depths of ~30 m in most localities. However, optical mapping technologies can also be applied to monitoring of the more than 60% of the seafloor in coral reef ecosystems (in the Pacific at least) found at depths between 30-150 m.

Satellite and Airborne Imaging Techniques

Hyperspectral sensors measure energy in narrower and more numerous spectral bands than multispectral sensors. Generally hyperspectral sensors have higher resolution and are used on aircraft, while multispectral sensors have somewhat lower resolution and are used on satellites. Both technologies are limited by atmospheric conditions, cloud cover, and water turbidity. The primary source of data used to date for production of interpreted shallow-water CRCP-funded benthic habitat maps has been IKONOS imagery, although hyperspectral imagery was contracted for with varying success in some areas. The IKONOS satellite was launched in 1999 and has panchromatic, blue, green, red and near infrared bands and multiple 11 km wide swaths can be combined to cover 1000s of km^2. The 3.2-4.0 m resolution multispectral imagery has been used for production of the CRCP shallow-water benthic habitat maps. Since 2001 when the project was first conceived, the types, resolution, and quality of multi- (e.g., Quickbird, Worldview 2) and hyperspectral sensors have increased substantially and CRCP scientists have been investigating future use of these newer technologies.

As noted above, numerous operational factors can and do affect the quality of the multi- and hyperspectral images. For example, the suitability of all aerial or satellite imagery for habitat mapping is affected by clouds, cloud shadows, poor water clarity, sea state (wave size and direction), sun glint, and varying spectral characteristics between adjacent images or swaths. In a number of areas, purchase of better quality images using newer technologies with higher resolution could substantially improve the quality of the existing interpreted shallow-water benthic habitat maps. The NWHI also served as the beta-test area for development of a benthic habitat classification scheme and semi-automated mapping techniques that have evolved significantly since that time. Reinterpretation using the now-standardized classification scheme and semi-automated mapping procedures now under development may be advisable in some areas.

Continuous depth surfaces from the shoreline to deeper waters are needed for a variety of scientific and management purposes. In the shallow areas (0 to 10-20 m) between the shoreline and where multibeam and/or LiDAR data are available to provide accurate depth information, significant gaps exist, thus leading to investigation of how useful satellite imagery could be to provide this information. The IKONOS imagery has been used in some selected areas to derive “estimated depths” using several different algorithms; statistical analysis has been conducted to determine both which algorithm(s) is/are best and the quality of the multispectral data. In general, where IKONOS image quality proved to be sufficiently good, the estimated depths can be used to calculate depth contours down to ~12 m, but are not suitable for other analyses such as rugosity and complexity. Although less than ideal and useful only in the shallowest waters, these estimated depths provide information that is needed to create continuous data sets. It is possible the newer multispectral technologies could provide better quality “estimated depth" data or that eventually LiDAR or multibeam mapping are needed to fill these gaps.

In January of 2010 DigitalGlobe's WorldView-2 satellite sensor became operational. This high-resolution sensor features 8 multispectral bands including one covering wavelengths slightly shorter (400 – 450 nm) than those of traditional blue bands. Digital Globe refers to this as the "coastal band" and it is specifically designed to "support bathymetric studies based upon its chlorophyll and water penetration characteristics." CRED is obtaining WorldView-2 imagery from non-CRCP sources and is developing methods to utilize this imagery to estimate depths in nearshore areas, as a temporary surrogate measure until bathymetric LiDAR data are collected. **Results and analyses are not yet available for comparison of WorldView-2 estimated depths with bathymetry estimated from IKONOs imagery or collected using other sensors.** However, the consensus from the mapping team members is that it is very unlikely that "estimated depths" will be sufficiently accurate to replace bathymetric LiDAR or multibeam data.

Sonars – Multibeam, Single-beam, and Side-Scan

Since the late 1990s high-frequency multibeam sonars have been used in shallow waters to produce nautical charts and thus were considered to be excellent candidates to provide accurate- and dense-enough data to characterize coral reef ecosystems. Although production of the bathymetric data sets was well established by 2001, use of multibeam data to create coral reef ecosystem benthic habitat maps was almost completely new.

Multibeam sonars transmit and receive sound to map the seafloor; accurate depths are calculated using precise time from signal transmit to receive and speed of sound in the water column. The range (greatest depth the sonar can reach) and resolution of sonar are both dependent upon the frequency of the sound – lower frequencies have greater ranges but lower resolution; higher frequencies have lower ranges and higher resolution. Thus, high frequency systems (100-300 kHz) are used to map coral reefs, while lower frequency systems (12-100 kHz) are used to map deeper habitats.

Multibeam sonars are usually mounted on the hull of a launch or ship and require additional expensive equipment to operate, in particular highly accurate time, position, and motion sensors to properly determine depth and location of each reading or beam. As the name indicates, multibeam sonars provide multiple depth readings (typically 100-500) with each sonar cycle or "ping", while single-beam sonars provide only a single reading. (Note: Single-beam sonars and related bottom classification systems have not proved to be optimal for coral reef mapping because they do not provide dense-enough information to characterize these complex ecosystems.) The 100-500 simultaneous readings provide a "swath" of data perpendicular to the direction of a vessel's travel. The swath width is generally 3 to 7 times the depth of the water with swath widths of up to 20 km for deep systems; however in shallow water, the swath becomes quite narrow (10 m depth = ~50 m swath width) and mapping is much slower. Typical coverage rates at a survey speed of 6 kts at 10 m depths is 0.5 km^2/hr and at 50 m depths, 2.75 km^2/hr. The "footprint" and spacing of the beams across the swath are determined by the system design (beam size), and the footprint of the beam on the seafloor increases with depth, just as the swath width increases with depth.

Because multibeam technology is widely available on NOAA ships and the agency has personnel who are capable of collecting and processing the data, it has been possible to incrementally perform multibeam mapping on dedicated cruises or in collaboration with other activities during cruises. The greatest limitations for multibeam mapping have been:

- Availability of ships, launches, and multibeam systems
- Safety of operations in nearshore environments and resultant inability to map in 0-15 m water depths
- Narrow swath width in shallow water results in very slow mapping.

Although multibeam sonar design is optimized for bathymetric mapping, modern multibeams also collect excellent quality backscatter imagery by recording and analyzing the shape of the returned signal. These backscatter data provide useful information about seafloor characteristics such as roughness and hardness, but analysis of backscatter imagery is complicated by numerous factors (seafloor slope, data collection techniques and parameters) and must be done carefully to minimize artifacts that can degrade the data quality. High quality backscatter data are very useful as inputs for and creation of products such as hard/soft maps and as inputs for benthic habitat maps. Backscatter data per se do not provide direct indicators of seafloor type and optical data are needed to accurately interpret the multibeam data.

Multibeam backscatter data are similar to “side-scan” sonar data. Side-scan sonars are primarily designed to collect imagery data, but high-end side-scans can also provide bathymetry that is somewhat less accurate than multibeam bathymetry. Unlike hull-mounted multibeams, side-scan sonars are towed near the seafloor and most often used for object detection. Towing is challenging in rugged coral environment, thus equipment can easily be lost; in addition navigation for towed devices is much less accurate than for multibeam systems with integrated high-precision vertical references. For these operational reasons and because multibeam backscatter data are now generally comparable to side-scan imagery in usefulness, multibeam sonars have been the preferred acoustic method for collection of bathymetry and backscatter in coral ecosystems.

Intereferometric sidescan sonars have been used by NOAA and other mapping agencies with success in a number of locales. The benefit of these systems is that they support simultaneous bathymetry and sidescan backscatter information, analogous to that of the multibeam systems being used. The additional benefit of these intereferometric systems is that they are ideally suited for shallow-water application, providing data collection efficiencies 3-4 times that of a multibeam system. Generally these systems can support data collection at 10 times water depth at survey speeds of 6 to 7 knots. While the sidescan data is of superior quality to that collection by multibeam systems, the bathymetry quality has been determined to be inferior to that of a multibeam system and unable to meet IHO Order 1 Specifications. However the efficiencies become approximately equal at 20 meter water depths or deeper. These systems are particularly advantageous in turbid waters where surveys using optical LiDAR systems would be ineffective, such as in coastal waters and embayments around Puerto Rico and Hawk Channel, FL.

Light Detection and Ranging – LiDAR

LiDAR systems use high-powered lasers to transmit energy from an aircraft or helicopter through the air and water column; a time-difference measurement is used to calculate the depth of the seafloor. Near-infrared and green electromagnetic energy (200-4000 Hz) are used in LiDAR systems. The infrared light is reflected back to the aircraft by the water surface, while the green light travels through the water column, and the time difference between the two is used to calculate the depth of the seafloor. Although theoretically LiDAR can penetrate to 70 m water depth, water clarity is an important factor in determining the actual penetration and the range is sometimes only 15-30 m in actuality. However, in the area between the shoreline and 15-20 m that is critical for characterization of coral habitats and where multibeam surveys are very slow, dangerous, or even impossible, LiDAR is realistically the best option to provide high quality, accurate bathymetric and backscatter-like information needed. As this critical gap has been identified, managers and scientists have increasingly been requesting that LiDAR surveys be conducted in the shallowest areas. LiDAR can also be used for both terrestrial and seafloor mapping and thus tie together topographic and bathymetric surfaces.

LiDAR systems also require expensive, highly accurate vertical reference systems for the same reasons as multibeam sonars, to accurately determine depth and position of each reading. LiDAR produces multiple depths (25-110) across the swath; the swath width (~100-220 m) is constant and up to 5 times wider than a ship or launch with multibeam can collect, especially in very shallow (< 10 m) water depths. Beam spacing and footprints range from 2-8 m with a somewhat larger spacing and footprint than comparable multibeam data in shallow water, thus providing lower resolution. Horizontal and vertical accuracies are similar to multibeam data.

Aircraft and helicopter speeds during mapping range from 90-160 knots (50-82 m/sec), flying at altitudes of 200-400 m; overall coverage rates are 16-25 km^2/hr. When comparing multibeam and LiDAR surveys in shallow areas with nearby support facilities, LiDAR can cost 25-50% of ship or launch-based multibeam operations; however, the cost analysis discussed in the main document showed that LiDAR surveys were, in general, more expensive than those using multibeam. In remote areas with limited or no support facilities, mobilization and operational costs escalate quickly, especially if multiple mobilizations are required. LiDAR surveys are generally done by commercial companies with the specialized aircraft and systems required to perform these surveys; thus the relatively high initial costs to contract for the surveys, especially in remote areas, has to date been a limiting factor in using the technology. One suggested scenario for LiDAR mapping in remote locations is use of a ship-based helicopter, but simultaneous use of a ship and helicopter further increases the costs.

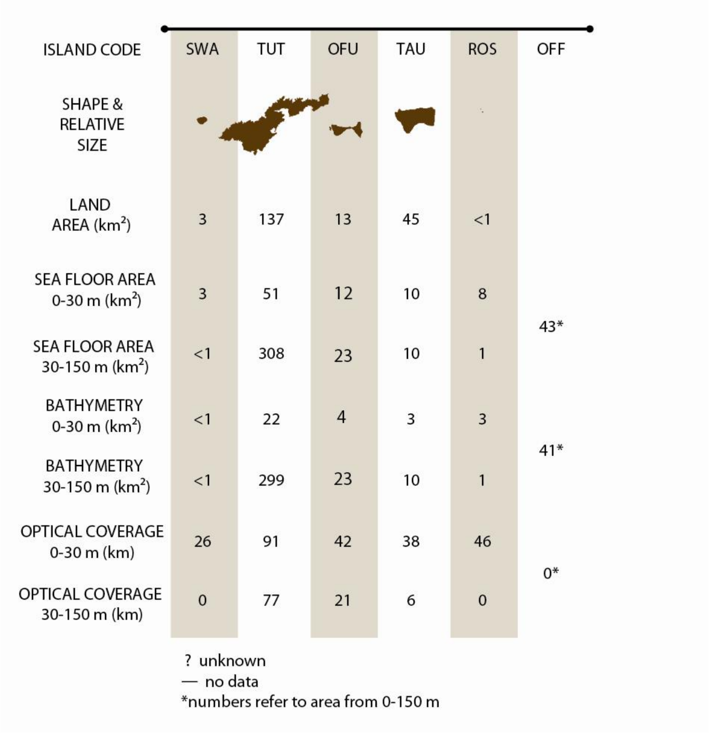
LiDAR imagery data, providing information similar to backscatter or side-scan data, are also being produced by analyzing the shape of the returned signal. This technology is relatively new, and initial studies (Costa, Battista, and Pittman, 2009) have shown that LiDAR imagery is somewhat less accurate in discriminating seafloor types in coral-rich areas than corresponding multibeam backscatter data.

Appendix B: American Samoa

American Samoa consists of 7 islands totaling only 470 km^2 in the 0-150 m depth range, or 1.1% of the total coral reef ecosystems discussed in this document. Marine Protected Areas (MPAs) include the Rose Atoll Marine National Monument (9 km^2 in the 0-150 m range), the National Park of American Samoa (43.4 km^2 in the 0-150 m range), the Fagatele Bay National Marine Sanctuary, and numerous other small areas, totaling approximately 50 km^2 (~10.6% of 0-150 m seafloor in American Samoa.) A biogeographic assessment is currently in preparation and this assessment will help to determine additional MPAs in American Samoa.

Interpreted IKONOS benthic habitat maps have been created for all of the islands of American Samoa and a biogeographic assessment is currently being prepared to help in selection/designation of MPAs. This assessment will include an integrated benthic habitat map for Tutuila. Multibeam mapping around all islands was collected by CRED and is complete to depths of ~ 200 m, but LiDAR data are needed to fill gaps in critical areas between 0 and 20 m. Shallow multibeam data in Fagatele Bay and the National Park and deeper (> 200 m) multibeam data have been collected during academic cruises in the area and those data are available from an Oregon State University website. An unsolicited proposal was recently received to do topographic and bathymetric LiDAR mapping in American Samoa. Extensive products from multibeam data have been created for all islands. Tables B-1, B-2, and B-3 provide data on the extent of mapping around each of the islands in American Samoa.

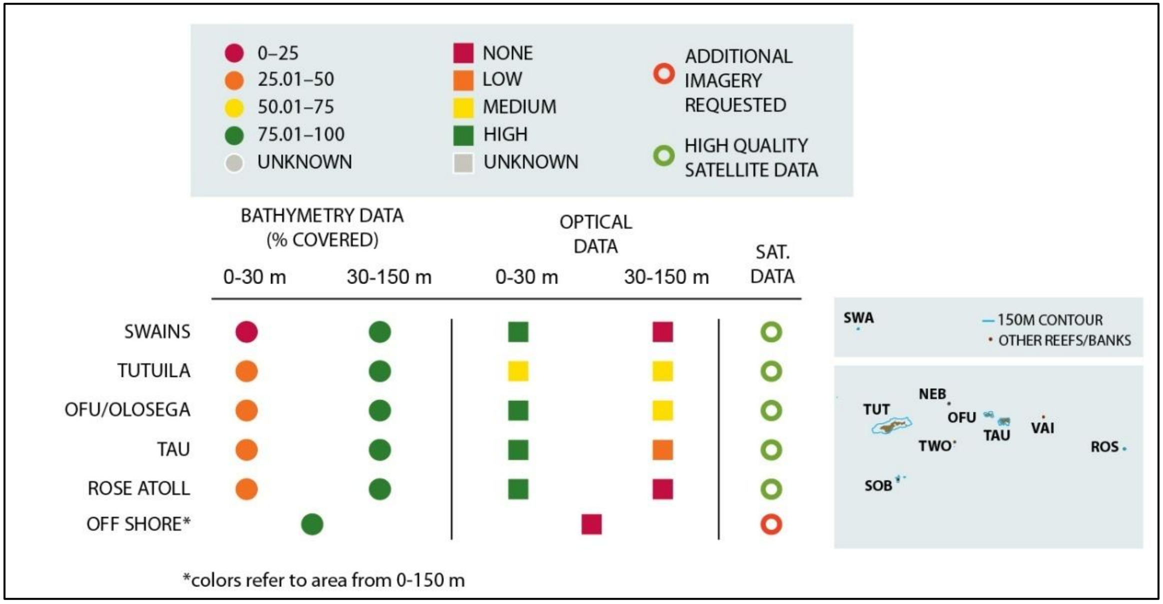
Table B-1: American Samoa Land and Seafloor Area and Primary Data Coverage.



ISLAND CODE	SWA	TUT	OFU	TAU	ROS	OFF
SHAPE & RELATIVE SIZE						
LAND AREA (km^2)	3	137	13	45	<1	
SEA FLOOR AREA 0-30 m (km^2)	3	51	12	10	8	43*
SEA FLOOR AREA 30-150 m (km^2)	<1	308	23	10	1	
BATHYMETRY 0-30 m (km^2)	<1	22	4	3	3	41*
BATHYMETRY 30-150 m (km^2)	<1	299	23	10	1	
OPTICAL COVERAGE 0-30 m (km)	26	91	42	38	46	0*
OPTICAL COVERAGE 30-150 m (km)	0	77	21	6	0	

? unknown
— no data
*numbers refer to area from 0-150 m

Table B-2: American Samoa Level of Primary Data Available

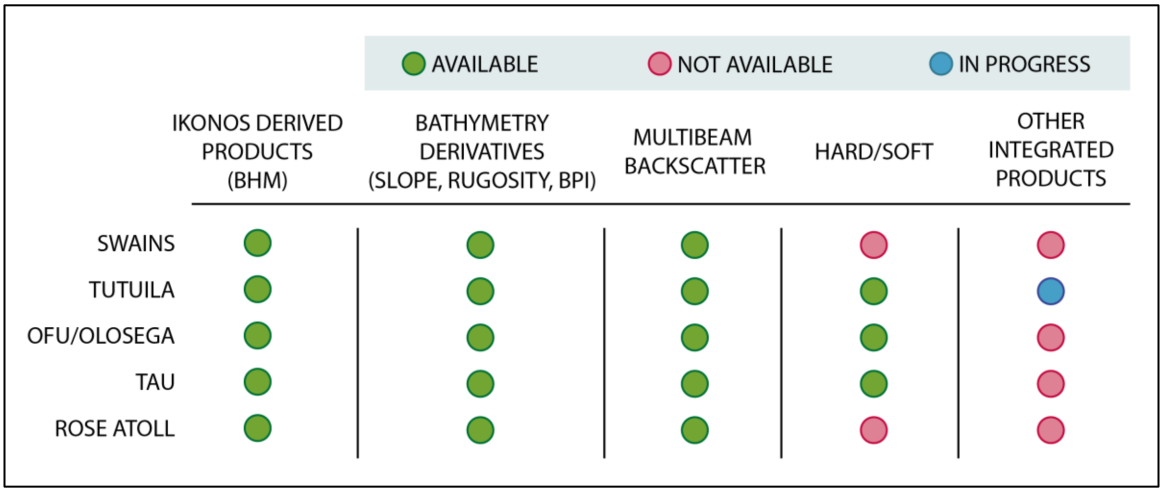


🔴 0–25	🟥 NONE	⭕ ADDITIONAL IMAGERY REQUESTED
🟠 25.01–50	🟧 LOW	◯ HIGH QUALITY SATELLITE DATA
🟡 50.01–75	🟨 MEDIUM	
🟢 75.01–100	🟩 HIGH	
⚪ UNKNOWN	⬜ UNKNOWN	

	BATHYMETRY DATA (% COVERED)		OPTICAL DATA		SAT. DATA
	0-30 m	30-150 m	0-30 m	30-150 m	
SWAINS	🔴	🟢	🟩	🟥	◯
TUTUILA	🟠	🟢	🟨	🟨	◯
OFU/OLOSEGA	🟠	🟢	🟩	🟨	◯
TAU	🟠	🟢	🟩	🟧	◯
ROSE ATOLL	🟠	🟢	🟩	🟥	◯
OFF SHORE*	🟢		🟥		⭕

*colors refer to area from 0-150 m

Table B-3: American Samoa Products Available



🟢 AVAILABLE 🔴 NOT AVAILABLE 🔵 IN PROGRESS

	IKONOS DERIVED PRODUCTS (BHM)	BATHYMETRY DERIVATIVES (SLOPE, RUGOSITY, BPI)	MULTIBEAM BACKSCATTER	HARD/SOFT	OTHER INTEGRATED PRODUCTS
SWAINS	🟢	🟢	🟢	🔴	🔴
TUTUILA	🟢	🟢	🟢	🟢	🔵
OFU/OLOSEGA	🟢	🟢	🟢	🟢	🔴
TAU	🟢	🟢	🟢	🟢	🔴
ROSE ATOLL	🟢	🟢	🟢	🔴	🔴

Priorities for Mapping in American Samoa

The following mapping needs for American Samoa were identified during the 2008 CREIOS meeting and updated via e-mail in 2010.

- Information gaps for MPA process: A major management priority is the governmental mandate for establishing MPAs. The lack of base maps is a significant hindrance to choosing areas for MPAs. AS needs information in some areas, including integrated shallow-to-deep maps, habitat maps for the seamounts and banks around Tutuila, and maps of areas that have not been mapped (about 15% of the National Park) due to cloud cover over the island. In 2010 managers suggested that focus for coral mapping be on the 0-100 m range, although mapping in deeper waters is useful for fisheries information. *A Biogeographic Assessment is currently being prepared with application for MPAs. In addition discussions are underway for LiDAR mapping in American Samoa.*

- Bathymetric data: AS needs good bathymetric data for hydrodynamic modeling. AS also needs a pseudo-bathymetric product; a composite product is available but may not include all the area and data needed. AS needs access to Light Detection and Ranging () data from the Navy. Both Samoa and American Samoa need access to digital topographic data (for terrestrial areas) collected by New Zealand. AS National Park Service (NPS) has imagery but needs assistance to sort or process it. The priority is to gather data from multiple sources and begin integrating Samoa and American Samoa data. *An unsolicited proposal has been received from Photo Science to do topographic and LiDAR mapping in American Samoa. NOAA also suggested that the contractor contact managers in Samoa and propose LiDAR mapping if they were going to be in American Samoa, since deployment costs to isolated regions are a major cost driver.*
- Benthic habitat map products: AS needs greater ground-truthing and evolution away from the coral-centric classification. AS needs help identifying what products (*i.e.*, maps, imagery) are available and applying the maps to support local monitoring and management via GIS expertise. Graduate student projects and partnerships with the NOAA Pacific Services Center (PSC) could help disseminate imagery, conduct analyses and re-interpret data. The priority is to develop seamless simplified substrate maps (*i.e.*, hard vs. soft surfaces) from the shoreline to 1000 m. AS does not necessarily need higher resolution.
- Airport expansion: AS needs an integrated GIS product that could inform this process. *An integrated GIS product for the Ofu airport area was provided to American Samoa in 2007.*
- Additional *in situ* optical data around the Manua Islands was requested as a high priority in 2010 and again in 2011 by DMWR representatives.

Appendix C: Florida Reef Tract

As directed by the SMC and SEATeam, this document is focused on the coral reef ecosystems of the 4 southeastern counties of Florida. The geographic area of interest—where detailed, geo-referenced, thematically accurate shallow-water benthic habitat and bathymetry maps are needed—is defined based on conservation, regulatory, or management requirements. This area encompasses the shallow-water coral ecosystems found in the nearshore waters of Martin, Broward, Palm Beach, and Dade Counties. A total of 14,909 km^2 is located in depths of 0-150 m in these areas, which represents 34.4% of the coral reef ecosystems discussed in this document. MPAs included within the 4 counties include Biscayne National Park, Tortugas Ecological Reserve, the Dry Tortugas National Park, Florida Bay, the National Wildlife Refuges, and the FKNMS, and these MPAs encompass approximately 12,768 km^2 of seafloor in 0-150 m depths (note the 100 fm = 183 m contour was used for this calculation); thus over 85% of the Florida Reef Tract is afforded some form of protection. All unmapped areas discussed here are in the FKNMS.

Starting in 1991, NOAA and the Florida Fish and Wildlife Conservation Commission (FWC) used color aerial photography collected in 1991-1992 to generate a detailed benthic habitat map of the Florida Keys area. That effort completed in 1998, and a similar effort for Biscayne Bay, completed in 2000, resulted in a habitat map covering 5,918 km^2. Because of persistent turbidity and other issues, an extensive area west of Key West within the Marquesas was not mapped at all. This area in the Marquesas remains unmapped and is a top priority area to be mapped according to south Florida reef managers. In 2002, the National Coral Reef Institute (NCRI) at NOVA Southeastern University used bathymetric LiDAR and side scan sonar data to produce a 254-km^2 habitat map of the nearshore reefs of Palm Beach County, Florida. In 2004, the NCRI completed a 112 km^2 benthic habitat map of Broward County, Florida using similar data.

In 2004, NOAA convened several meetings in Florida to receive input from universities, state regulatory and management agencies, federal agencies, and non-governmental organizations involved in the conservation and management of Florida's coral ecosystems and the need for detailed seafloor habitat maps to support those conservation and management activities. Using that input, NOAA developed a Southern Florida Shallow-water Coral Ecosystem Mapping Implementation Plan (MIP; Rohmann and Monaco, 2005). The MIP presented a rationale for the need and how to produce shallow-water (~0-40 m; 0-22 fm) seafloor habitat maps of nearly 13,000 km^2 is in southern Florida. It also discussed the need to produce shallow-water (0-200 m; 0-109 fm) bathymetric maps for all of Florida. Completion of these maps remains the priorities for Southern Florida.

In 2005, the FWC used aerial photography collected in 2004 to complete a 1,525 km^2 benthic habitat map of Florida Bay. Since 2005, NOAA, FWC, NPS, and the NCRI have continued to generate new or updated benthic habitat maps of the south Florida region Figure C-1. To date, FWC and NCRI have completed habitat maps of 4,310 km^2, almost exclusively within the 0-30 m depth regime. NOAA and FWC currently have mapping efforts underway that, when completed, will cover 4,993 km^2, again almost exclusively within the 0-30 m depth regime. Approximately 378 km^2 of the NOAA map has been mapped as “unknown,” due primarily to either turbidity or water depth. The FWC has received funds from the National Marine Fisheries Service to support ship-based acoustic data to perform mapping of a portion of the “unknown” area. NOAA’s Office of the Coast Survey (OCS) plans in FY11 and out years to collect airborne bathymetric LiDAR or ship-based acoustic sonar data to support habitat mapping of the remainder of the “unknown” area and much of the Marquesas area of the Florida Keys. The OCS’s data acquisitions will occur both within the 0-30 m depth regime and in the 30-150 m depth regimes.

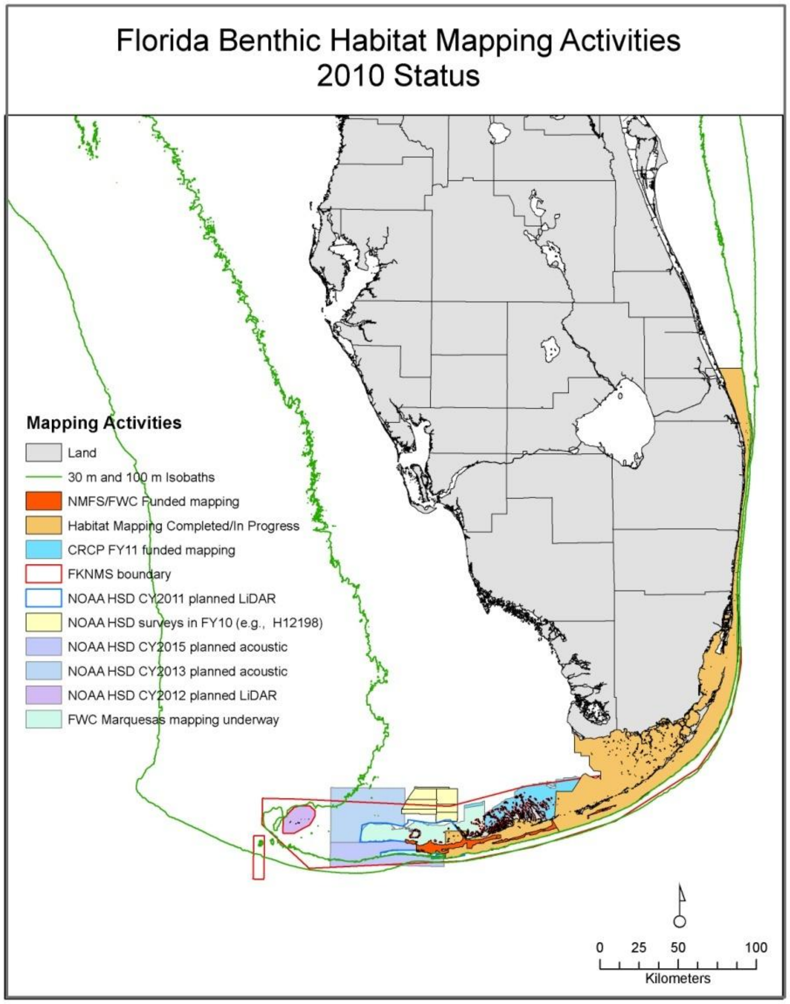


Figure C-1: Florida Benthic Habitat Mapping 2010 Status

Table C: South Florida Habitat Mapping and Data Gaps

	Area Sq.km.	% Area
Land*	18,710	
Seafloor Area (0-30 m)**	11,748	
Seafloor Area (30-150 m)**	3,161	
Seafloor Area with Completed/In-progress Benthic Habitat Map (0-30 m)**,#,$	6,596	56.1
Seafloor Area with Completed/In-progress Benthic Habitat Map (30-150 m)**	100	3.2
FWC Completed Benthic Habitat Maps (0-30 m)**,#	3,345	28.5
NCRI Completed Benthic Habitat Maps (0-30 m)**,^	965	8.2
NOAA In-progress Benthic Habitat Maps (0-30 m)**,$$	2,863	24.4
FWC In-progress Benthic Habitat Maps (0-30 m)**,#	2,130	18.1
Seafloor Area without a Benthic Habitat Map (0-30 m)	5,152	43.9
Seafloor Area without a Benthic Habitat Map (30-150 m)	3,061	96.8
Bathymetry Data Available (0-30 m)**,%	1,175	10.0
Bathymetry Data Available (30-150 m)**,$$	75	2.4
In-situ Optical Coverage Adequate for Map Production (0-30 m)**,&	7,752	66.0
In-situ Optical Coverage Adequate for Map Production (30-150 m)**,&	100	3.2
Satellite or Airborne Imagery Coverage (0-30 m)**,&	9,175	78.1
Satellite or Airborne Imagery Coverage (30-150 m)**,&	748	23.7
Unknown Areas within Benthic Habitat Map Coverage (0-30 m)	378	3.2
NOAA acoustic bathymetry data collections in FY10 (0-30 m)**	250	
NOAA planned Marquesas bathy LiDAR collections in FY11 (0-30 m)	1,532	
NOAA planned DTRO bathy LiDAR collections in FY12 (0-30 m)	264	
NOAA planned Marquesas acoustic bathy data collections in FY13 (0-30 m)	836	
NOAA planned Marquesas acoustic bathy data collections in FY13 (30-150 m)**	50	
NOAA planned Marquesas acoustic bathy data collections in FY15 (0-30 m)	836	
NOAA planned Marquesas acoustic bathy data collections in FY15 (30-150 m)**	561	

* - stops at northern extent of Martin County Florida and includes only portions of southern Florida counties and Everglades NP.

** - stops at northern extent of Martin County Florida and approximate FKNMS boundary in the Gulf of Mexico

- some completed FWC maps overlap; FWC in-progress maps to be completed in 2011

$ - NOAA maps are provisional until accuracy assessments and reef manager expert review is completed

^ - includes Martin, Palm Beach, Broward, and Dade Counties

$$ - includes bathy LiDAR data from NCRI and NOAA CCFHR acoustic data

% - includes bathy LiDAR data from NCRI and NASA/USGS and NOAA CCFHR acoustic data

& - only includes in-situ optical data or imagery collected since 2005

In southern Florida, the priority activities (based on the CREIOS meeting and subsequent discussions in 2010 and 2011) are:

- complete the habitat maps of Hawk Channel and Florida Bay (currently underway);
- complete mapping a portion of the Backcountry area using available satellite imagery (currently underway);
- complete acoustic data acquisition and mapping of current unknown areas in Hawk Channel (FWC effort to be started in 2011 using NMFS grant funds);
- coordinate with the OCS and NMFS to collect bathymetric LiDAR and acoustic data of the Marquesas area, the deep channel between the Marquesas and Dry Tortugas, and along the outer reef tract that are suitable for habitat mapping;
- generate a habitat map of the Marquesas area using the bathymetry data described above; and
- generate a seamless, consistent habitat map of the entire south Florida reef tract using available habitat maps produced by NOAA, FWC, the NPS, and universities.

Appendix D: The Hawaiian Archipelago (MHI and NWHI)

The Hawaiian Archipelago includes both the Main Hawaiian Islands (MHI) and the Northwestern Hawaiian Islands (NWHI), encompassing respectively 6,125 km^2 and 12,722 km^2 of seafloor in the 0-150 m depth ranges. This represents 14.1% and 29.3% (total 43.4%) of the U.S. coral reef ecosystems discussed in this document. The entire area of the NWHI is protected as the Papahānaumokuākea Marine National Monument and also as a World Heritage Site. In the MHI MPAs cover approximately 3900 km^2 in the 0-150 m depth range (63.7% of total), which includes the 3558 km^2 Humpback Whale National Marine Sanctuary and the 115-km^2 Kahoolawe Island Reserve. No bottom fisheries management areas were included in these statistics because their 50-200 fm boundaries are generally deeper than our areas of interest.

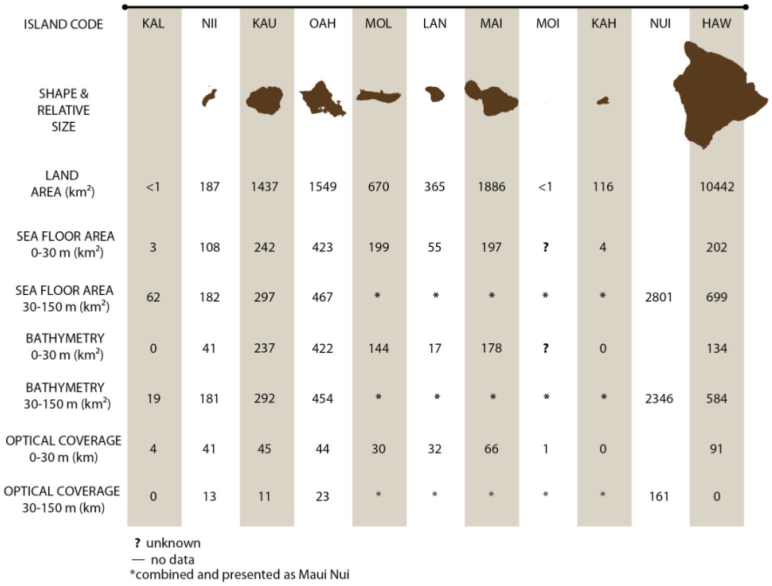
Interpreted benthic habitat maps from IKONOS imagery are available for both the MHI and the NWHI. However, the NWHI maps were done using early IKONOS images that were not of high quality and a habitat mapping scheme that has changed considerably since that time. New Digital Globe imagery is available for all of the NWHI except Maro Reef and is currently being evaluated for quality and coverage.

A synthesis of MHI bathymetric data is served on-line by the Hawaii Mapping Research Group (HMRG). Although almost complete coverage exists (See Tables C-1 and C-2), it should be noted that these data come from ships and sonars dating back to the 1980's; thus the data quality and resolution are quite variable. LiDAR data from ACOE are available for most of the islands. Most gaps that remain are in areas too deep for LiDAR, but too shallow for ship-based multibeam surveys in water depths between 10 and 100 m. Since 2008 most gaps around Oahu and Molokai have been filled by multibeam mapping using the R/V *AHI*; however gaps still exist, particularly around the islands of Maui, Lanai and Kaho'olawe (note: Kaho'olawe mapping is unlikely due to issues with access restrictions around this island.) Few interpreted bathymetric products exist for the MHI and finer resolution grids (the current HMRG grid is 50-m cell size) are needed by a number of agencies. Bathymetric mapping in the NWHI remains only 25-50% complete around most islands and banks. Almost all of the shallower (0-50 m) NWHI data have been collected using CRCP funding; a joint CRCP/NMS/Ocean Exploration/HURL cruise in 2002 collected 25-, 50-, 100-fm boundary data; and a limited amount of deeper mapping has been done by UH and HURL. No ship time has been allocated for mapping cruises since 2008 and none is currently on the schedule for the foreseeable future. See Tables D-1, D-2 and D-3.

The Main Hawaiian Islands

Tables D-1, D-2, and D-3 present the data and products available for the MHI.

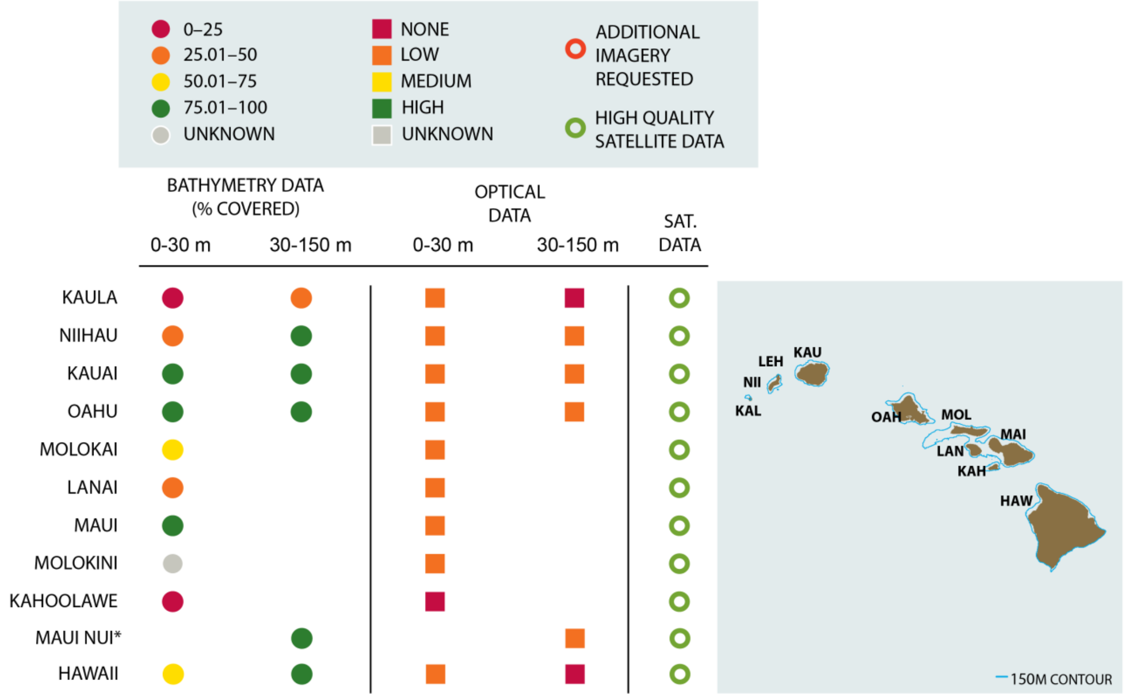
Table D-1: MHI Land and Seafloor Area and Primary Data Coverage



ISLAND CODE	KAL	NII	KAU	OAH	MOL	LAN	MAI	MOI	KAH	NUI	HAW
SHAPE & RELATIVE SIZE											
LAND AREA (km²)	<1	187	1437	1549	670	365	1886	<1	116		10442
SEA FLOOR AREA 0-30 m (km²)	3	108	242	423	199	55	197	?	4		202
SEA FLOOR AREA 30-150 m (km²)	62	182	297	467	*	*	*	*	*	2801	699
BATHYMETRY 0-30 m (km²)	0	41	237	422	144	17	178	?	0		134
BATHYMETRY 30-150 m (km²)	19	181	292	454	*	*	*	*	*	2346	584
OPTICAL COVERAGE 0-30 m (km)	4	41	45	44	30	32	66	1	0		91
OPTICAL COVERAGE 30-150 m (km)	0	13	11	23	*	*	*	*	*	161	0

? unknown
— no data
*combined and presented as Maui Nui

Table D-2: MHI – Level of Primary Data Available. Note: Access restrictions preclude mapping around Kahoolawe.



🔴 0–25	🟥 NONE	⭕ ADDITIONAL IMAGERY REQUESTED
🟠 25.01–50	🟧 LOW	○ HIGH QUALITY SATELLITE DATA
🟡 50.01–75	🟨 MEDIUM	
🟢 75.01–100	🟩 HIGH	
⚪ UNKNOWN	⬜ UNKNOWN	

	BATHYMETRY DATA (% COVERED)		OPTICAL DATA		SAT. DATA
	0-30 m	30-150 m	0-30 m	30-150 m	
KAULA	🔴	🟠	🟧	🟥	○
NIIHAU	🟠	🟢	🟧	🟧	○
KAUAI	🟢	🟢	🟧	🟧	○
OAHU	🟢	🟢	🟧	🟧	○
MOLOKAI	🟡		🟧		○
LANAI	🟠		🟧		○
MAUI	🟢		🟧		○
MOLOKINI	⚪		🟧		○
KAHOOLAWE	🔴		🟥		○
MAUI NUI*		🟢		🟧	○
HAWAII	🟡	🟢	🟧	🟥	○

*MAUI NUI includes the areas of Molokai, Lanai, Maui, Molokini, Kahoolawe between 30-150 meters.

Table D-3: MHI Products Available

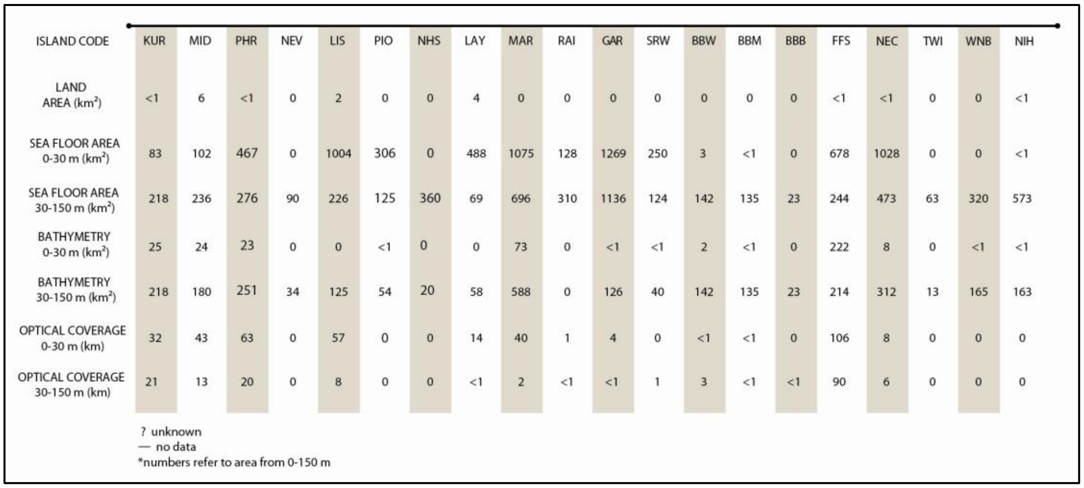
🟢 AVAILABLE 🔴 NOT AVAILABLE ⚪ INSUFFICIENT DATA

	IKONOS DERIVED PRODUCTS (BHM)	BATHYMETRY DERIVATIVES (SLOPE, RUGOSITY, BPI)	MULTIBEAM BACKSCATTER	HARD/SOFT	OTHER INTEGRATED PRODUCTS
KAULA	🟢	🔴	🔴	🔴	🔴
NIIHAU	🟢	🟢	🟢	🔴	🔴
KAUAI	🟢	🔴	🔴	🔴	🔴
OAHU	🟢	🔴	🔴	🔴	🔴
MOLOKAI	🟢	🔴	🔴	🔴	🔴
LANAI	🟢	🔴	🔴	🔴	🔴
MAUI	🟢	🔴	🔴	🔴	🔴
MOLOKINI	🟢	🔴	🔴	🔴	🔴
KAHOOLAWE	🔴	🔴	🔴	🔴	🔴
HAWAII	🟢	🔴	🔴	🔴	🔴

The Northwestern Hawaiian Islands

Tables D-4, D-5, and D-6 present data and products available for the NWHI.

Table D-4: NWHI Land and Seafloor Area and Primary Data Coverage. See Table D-6 for island size and location.



ISLAND CODE	KUR	MID	PHR	NEV	LIS	PIO	NHS	LAY	MAR	RAI	GAR	SRW	BBW	BBM	BBB	FFS	NEC	TWI	WNB	NIH
LAND AREA (km²)	<1	6	<1	0	2	0	0	4	0	0	0	0	0	0	0	<1	<1	0	0	<1
SEA FLOOR AREA 0-30 m (km²)	83	102	467	0	1004	306	0	488	1075	128	1269	250	3	<1	0	678	1028	0	0	<1
SEA FLOOR AREA 30-150 m (km²)	218	236	276	90	226	125	360	69	696	310	1136	124	142	135	23	244	473	63	320	573
BATHYMETRY 0-30 m (km²)	25	24	23	0	0	<1	0	0	73	0	<1	<1	2	<1	0	222	8	0	<1	<1
BATHYMETRY 30-150 m (km²)	218	180	251	34	125	54	20	58	588	0	126	40	142	135	23	214	312	13	165	163
OPTICAL COVERAGE 0-30 m (km)	32	43	63	0	57	0	0	14	40	1	4	0	<1	<1	0	106	8	0	0	0
OPTICAL COVERAGE 30-150 m (km)	21	13	20	0	8	0	0	<1	2	<1	<1	1	3	<1	<1	90	6	0	0	0

? unknown
— no data
*numbers refer to area from 0-150 m

Table D-5: NWHI Level of Primary Data Available

🔴 0–25	🟥 NONE	⭕ ADDITIONAL IMAGERY REQUESTED
🟠 25.01–50	🟧 LOW	○ HIGH QUALITY SATELLITE DATA
🟡 50.01–75	🟨 MEDIUM	
🟢 75.01–100	🟩 HIGH	
⚪ UNKNOWN	⬜ UNKNOWN	

	BATHYMETRY DATA (% COVERED)		OPTICAL DATA		
	0-30 m	30-150 m	0-30 m	30-150 m	SAT. DATA
KURE ATOLL	🟠	🟢	🟧	🟨	○
MIDWAY ATOLL	🔴	🟢	🟧	🟧	○
PEARL AND HERMES ATOLL	🔴	🟢	🟧	🟨	○
NEVA BANK	🔴	🟠	🟥	🟥	⭕
LISIANSKI	🔴	🟡	🟧	🟧	○
PIONEER BANK	🔴	🟠	🟥	🟥	⭕
NORTHAMPTON SEAMOUNTS	🔴	🔴	🟥	🟥	⭕
LAYSAN	🔴	🟢	🟧	🟧	○
MARO REEF	🔴	🟢	🟧	🟧	○
RAITA BANK	🔴	🔴	🟧	🟧	⭕
GARDNER	🔴	🔴	🟧	🟧	⭕
ST. ROGATEIN BANK-WEST	🔴	🟠	🟥	🟧	⭕
BROOKS BANK-WEST	🟢	🟢	🟧	🟧	⭕
BROOKS BANK-MIDDLE	🟢	🟢	🟧	🟧	⭕
BABY BROOKS BANK	🔴	🟢	🟥	🟧	⭕
FRENCH FRIGATE SHOALS	🟠	🟢	🟧	🟨	○
NECKER ISLAND	🔴	🟡	🟧	🟧	○
TWIN BANKS	🔴	🔴	🟥	🟥	⭕
WEST NIHOA BANK	🔴	🟡	🟥	🟥	⭕
NIHOA	🔴	🟠	🟥	🟥	○

Table D-6: NWHI Derivative Products Available

🟢 AVAILABLE 🔴 NOT AVAILABLE ⚪ INSUFFICIENT DATA

	IKONOS DERIVED PRODUCTS (BHM)	BATHYMETRY DERIVATIVES (SLOPE, RUGOSITY, BPI)	MULTIBEAM BACKSCATTER	HARD/SOFT	OTHER INTEGRATED PRODUCTS
KURE ATOLL	🟢	🟢	🟢	🔴	🔴
MIDWAY ATOLL	🟢	🔴	🔴	🔴	🔴
PEARL AND HERMES ATOLL	🟢	🟢	🟢	🔴	🔴
NEVA BANK	🔴	🔴	🔴	🔴	🔴
LISIANSKI	🟢	🔴	🔴	🔴	🔴
PIONER BANK	🔴	🔴	🔴	🔴	🔴
NORTHAMPTON SEAMOUNTS	🔴	🔴	🔴	🔴	🔴
LAYSAN	🟢	🔴	🔴	🔴	🔴
MARO REEF	🟢	🔴	⚪	🔴	🔴
RAITA BANK	🔴	🔴	🔴	🔴	🔴
GARDNER	🔴	🔴	🔴	🔴	🔴
ST. ROGATEIN BANK-WEST	🔴	🔴	🔴	🔴	🔴
BROOKS BANK-WEST	🔴	🔴	🔴	🔴	🔴
BROOKS BANK-MIDDLE	🔴	🔴	🔴	🔴	🔴
BABY BROOKS BANK	🔴	🔴	🔴	🔴	🔴
FRENCH FRIGATE SHOALS	🟢	🟢	🟢	🟢	🔴
NECKER ISLAND	🟢	🔴	🔴	🔴	🔴
TWIN BANKS	🔴	🔴	🔴	🔴	🔴
WEST NIHOA BANK	🔴	🔴	🔴	🔴	🔴
NIHOA	🟢	🔴	🔴	🔴	🔴

Table D-6: Products Available for NWHI

Priorities for Mapping in the Hawaiian Archipelago

The following is a summary of mapping needs from the 2008 CREIOS meeting. Italicized font indicates work that has been done to fulfill these requests since 2008.

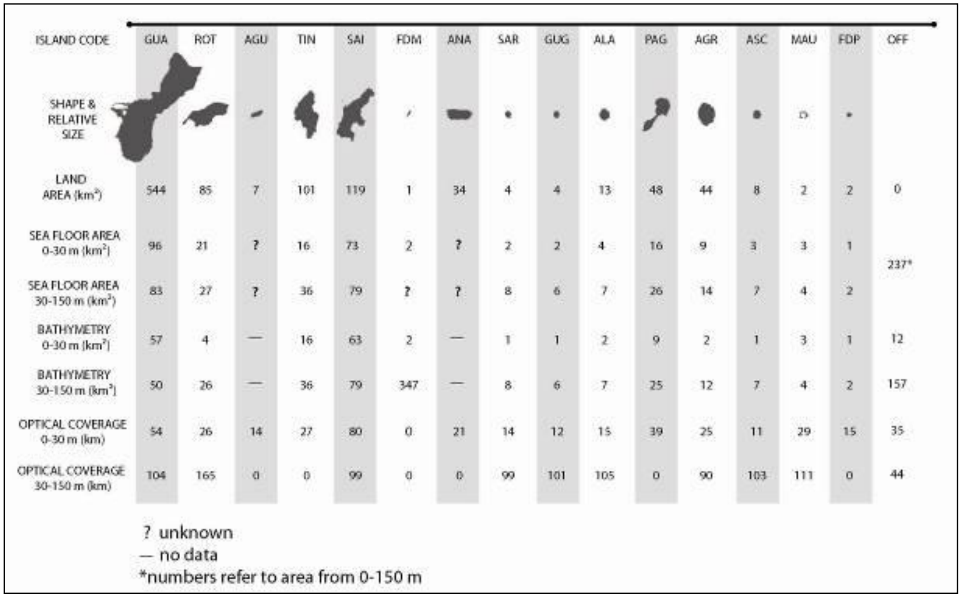
- Bathymetric data: Hawai'i has a critical need to fill bathymetric data gaps in areas not covered by existing LiDAR and ship-based multibeam (20-250 m) data in the MHI. While there is high resolution bathymetric LiDAR data available for most of the MHI, only 25-50% of the necessary data has been collected in the NWHI. *Many gaps around Oahu, Molokai, and Lanai have been filled with multibeam data collected in 2009 and 2010 by the R/V AHI, but more AHI work is needed around Maui and Lanai. No work is planned around Kaho'olawe due to access restrictions. Lack of ship time has limited multibeam data collection in the NWHI since 2008 and no additional bathymetric LiDAR has been collected in the NWHI due to funding constraints.*
- In general. CRED focuses bathymetric data collection in depths of 15-250 m, which leaves a gap in shallow-water near-shore areas (<15 m). In the NWHI, shallow water *depths* have been estimated from IKONOS imagery, but that pseudo-bathymetry product is unreliable in depths greater than ~7m (note: this estimate is from CREIOS report). Both the NWHI and MHI have a critical need for additional satellite imagery to replace some existing scenes with poor image quality (due to cloud cover, turbidity, and other optical issues. *New World View-2 images now available for all NWHI except Maro Reef.*
- Data access: Hawai'i needs access to NOAA bathymetric data for the MHI. Department of Land and Natural Resources (DLNR) and NPS need assistance on existing products, and arrange to better coordinate with the University of Hawai'i Pacific Islands Benthic Habitat Mapping Center. *All bathymetric data collected in the MHI is currently available online at www.soest.hawaii.edu/hmrg. However, the grid resolution of the data is at 50 m and numerous requests for higher resolution grids in shallow areas (< 150 m) have been received. Data collected by NOAA around Ni'ihau and Penguin Bank are available at 5-m resolution.*
- Instrumentation: Hawai'i expressed interest using the *R/V AHI* (Acoustic Habitat Investigator) to identify and assess critical fish habitat. *R/V AHI has collected multibeam data in some areas (see 1st bullet); need to better define what type of projects are envisioned to identify and assess critical fish habitat.*
- The National Park Service has expressed interest in data collection in National Park areas, similar to work that has been done in American Samoa (2010 additional request).
- CRCP has designated the NWHI as a Tier 2 priority for mapping and monitoring.

Appendix E: Mariana Archipelago (CNMI and Guam)

The Marina Archipelago includes both the Commonwealth of the Northern Mariana Islands and the Territory of Guam. The seafloor in the Mariana Archipelago includes 1,149 km^2 of seafloor in the 0-150 m range, which represents only 2.6% of the coral reef ecosystems discussed in this document. The 3 northern islands of the archipelago, Farallon de Pajaros, Maug, and Asuncion, were designated as part of the Marianas Trench Marine National Monument in 2009; these encompass a total of 21 km^2 in the 0-150 m depths range. In addition to this MPA there are 7 additional MPAs on the islands of Saipan, Tinian, and Rota and these total approximately (area of the Tinian MPA is not yet available) 19 km^2. Guam MPA's encompass approximately 40 km^2. Thus the total 0-150 m depth area in MPAs in the Mariana Archipelago is approximately 79 km^2, protecting approximately 6.7% of the seafloor in the 0-150 m depths range.

In the Mariana Archipelago, interpreted IKONOS imagery and shallow multibeam data have been collected by CRCP around most of the islands of the Archipelago, with the major exception that Guam has less than 50% bathymetric coverage in 0-300 m. Somewhat spotty U.S. Navy LiDAR data are available around Guam and Saipan, with almost complete LiDAR coverage on Tinian. NOAA OCS in collaboration with CRCP collected multibeam data in Saipan, Tinian, and Rota harbors and NAVOCEANO and OCS conducted a joint multibeam survey of Apra Harbor, which was provided to management groups through CRCP. NAVOCEANO has also conducted sonar tests on Farallon de Medinilla (FDM) and made the data available to CRCP. Academic and NOAA mutlibeam data from deeper (> 100 m) geologic work are also available. A subset of the offshore banks (Galvez, S. Galvez, 11-mile reef, and 2 banks near FDM) has been mapped using multibeam. Optical groundtruth data have been collected at varying levels, with low coverage in 30-150 m depths around all islands. Tables E1, E2, and E3 summarize primary data and mapping products in the Mariana Archipelago.

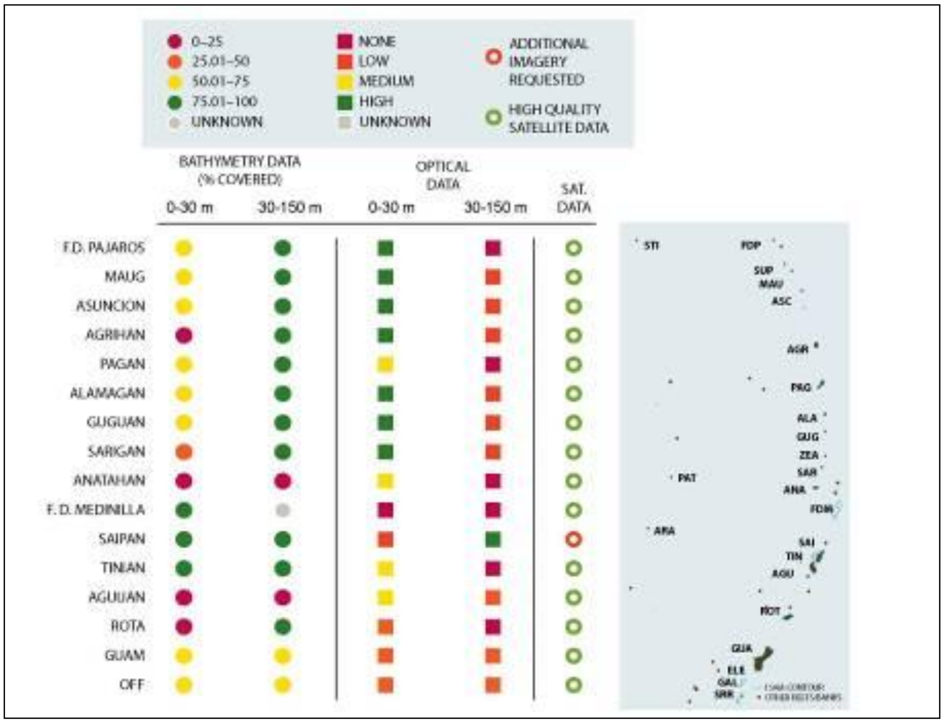
Table E-1: Mariana Archipelago Land and Seafloor Area and Primary Data Coverage



ISLAND CODE	GUA	ROT	AGU	TIN	SAI	FDM	ANA	SAR	GUG	ALA	PAG	AGR	ASC	MAU	FDP	OFF
SHAPE & RELATIVE SIZE																
LAND AREA (km^2)	544	85	7	101	119	1	34	4	4	13	48	44	8	2	2	0
SEA FLOOR AREA 0-30 m (km^2)	96	21	?	16	73	2	?	2	2	4	16	9	3	3	1	237*
SEA FLOOR AREA 30-150 m (km^2)	83	27	?	36	79	?	?	8	6	7	26	14	7	4	2	
BATHYMETRY 0-30 m (km^2)	57	4	—	16	63	2	—	1	1	2	9	2	1	3	1	12
BATHYMETRY 30-150 m (km^2)	50	26	—	36	79	347	—	8	6	7	25	12	7	4	2	157
OPTICAL COVERAGE 0-30 m (km)	54	26	14	27	80	0	21	14	12	15	39	25	11	29	15	35
OPTICAL COVERAGE 30-150 m (km)	104	165	0	0	99	0	0	99	101	105	0	90	103	111	0	44

? unknown
— no data
*numbers refer to area from 0-150 m

Table E-2: Mariana Archipelago – Level of Primary Data Available



🔴 0–25
🟠 25.01–50
🟡 50.01–75
🟢 75.01–100
⚪ UNKNOWN

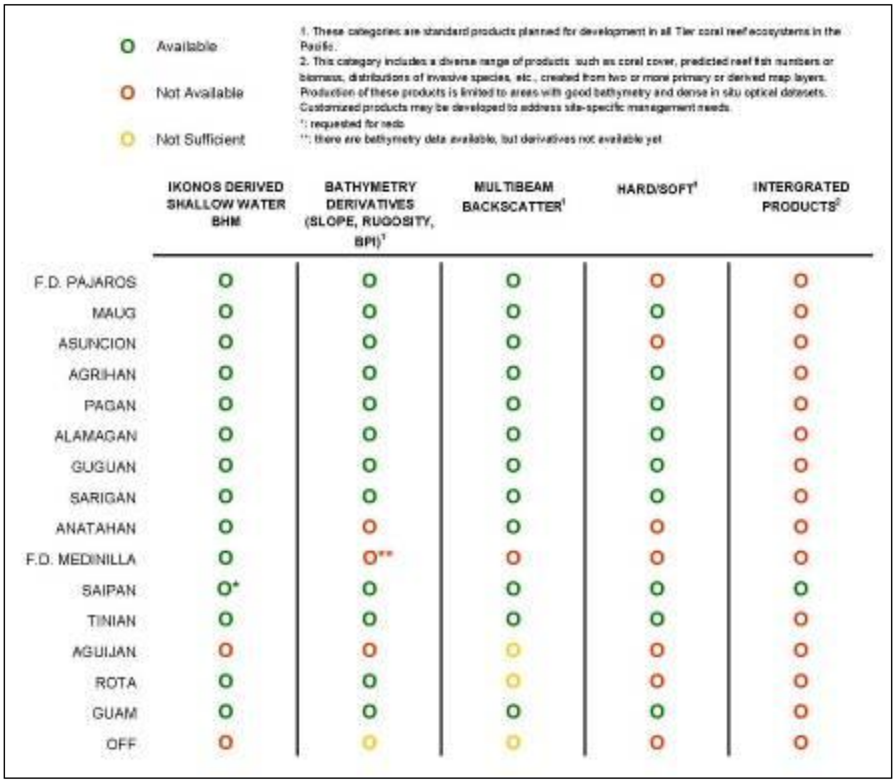
🟥 NONE
🟧 LOW
🟨 MEDIUM
🟩 HIGH
⬜ UNKNOWN

⭕ ADDITIONAL IMAGERY REQUESTED

🟢 HIGH QUALITY SATELLITE DATA

	BATHYMETRY DATA (% COVERED)		OPTICAL DATA		SAT. DATA
	0-30 m	30-150 m	0-30 m	30-150 m	
F.D. PAJAROS	🟡	🟢	🟩	🟥	🟢
MAUG	🟡	🟢	🟩	🟧	🟢
ASUNCION	🟡	🟢	🟩	🟧	🟢
AGRIHAN	🔴	🟢	🟩	🟧	🟢
PAGAN	🟡	🟢	🟨	🟥	🟢
ALAMAGAN	🟡	🟢	🟩	🟧	🟢
GUGUAN	🟡	🟢	🟩	🟧	🟢
SARIGAN	🟠	🟢	🟩	🟧	🟢
ANATAHAN	🔴	🔴	🟨	🟥	🟢
F. D. MEDINILLA	🟢	⚪	🟥	🟥	🟢
SAIPAN	🟢	🟢	🟧	🟩	⭕
TINIAN	🟢	🟢	🟨	🟥	🟢
AGUIJAN	🔴	🔴	🟨	🟧	🟢
ROTA	🔴	🟢	🟧	🟥	🟢
GUAM	🟡	🟡	🟧	🟧	🟢
OFF	🟡	🟡	🟧	🟧	🟢

Table E-3: Mariana Archipelago Products Available



🟢 Available

🟠 Not Available

🟡 Not Sufficient

1. These categories are standard products planned for development in all Tier coral reef ecosystems in the Pacific.
2. This category includes a diverse range of products such as coral cover, predicted reef fish numbers or biomass, distributions of invasive species, etc., created from two or more primary or derived map layers. Production of these products is limited to areas with good bathymetry and dense in situ optical datasets. Customized products may be developed to address site-specific management needs.
*: requested for reds
**: there are bathymetry data available, but derivatives not available yet

	IKONOS DERIVED SHALLOW WATER BHM	BATHYMETRY DERIVATIVES (SLOPE, RUGOSITY, BPI)[1]	MULTIBEAM BACKSCATTER[1]	HARD/SOFT[1]	INTERGRATED PRODUCTS[2]
F.D. PAJAROS	🟢	🟢	🟢	🟠	🟠
MAUG	🟢	🟢	🟢	🟢	🟠
ASUNCION	🟢	🟢	🟢	🟠	🟠
AGRIHAN	🟢	🟢	🟢	🟢	🟠
PAGAN	🟢	🟢	🟢	🟢	🟠
ALAMAGAN	🟢	🟢	🟢	🟢	🟠
GUGUAN	🟢	🟢	🟢	🟢	🟠
SARIGAN	🟢	🟢	🟢	🟢	🟠
ANATAHAN	🟢	🟠	🟢	🟠	🟠
F.D. MEDINILLA	🟢	🟠**	🟠	🟠	🟠
SAIPAN	🟢*	🟢	🟢	🟢	🟢
TINIAN	🟢	🟢	🟢	🟢	🟠
AGUIJAN	🟠	🟠	🟡	🟠	🟠
ROTA	🟢	🟢	🟡	🟠	🟠
GUAM	🟢	🟢	🟢	🟢	🟠
OFF	🟠	🟡	🟡	🟠	🟠

Priorities for Mapping in the Mariana Archipelago

During the previously mentioned 2008/2009 CREIOS workshops, managers, scientists, and local stakeholders from all jurisdictions were asked to develop a list of priority mapping needs, given what had been mapped to date. From the ensuing CREIOS summary documents, the following were the top priorities for Guam and CNMI. Notes are added to indicate if requests have been fulfilled or additional requests received since the CREIOS workshop.

<u>Guam</u>

- Apra Harbor: Guam has an immediate need for maps of Apra Harbor… *Request fulfilled by providing access to data collected for nautical charting by NOAA Office of Coast Survey and the U.S. Naval Oceanographic Office.*
- Bathymetric Data: Guam needs to obtain, better understand, and apply multibeam, backscatter, and LiDAR data products to management data questions. *Backscatter and hard/soft maps of Apra Harbor have been developed and are available for public download on the PIBHMC website.*
- Benthic Habitat Map Products: Guam requests more information about NOAA's benthic habitat mapping capabilities, including higher resolution mapping, assessment accuracy and repeat mapping as a basis for change detection. *A PIFSC-funded cruise to the Mariana Archipelago in February and March 2010 included a 6-week-long leg that was mostly mapping oriented. Priorities for that cruise were developed based on inputs from managers in Guam and included discussions of the capabilities and limitations of different types of mapping equipment and products. Additionally, accuracy assessments are included in the metadata records for all map products. Both map products and metadata are available to the public for download Repeated mapping for change detection is feasible only for small high priority areas, particularly since logistical limitations have thus far precluded complete mapping of even all priority one areas.*
- Map Resolution: NOAA capabilities may be suitable for particular high priority sites, but not for island-wide assessments. Guam needs focused applications such as the creation of higher resolution maps to address management concerns regarding *Acropora* as a signature in early warnings for bleaching, and to tease out the difference among soft and hard coral areas. Guam recognizes their reliance on NOAA for these data sets, but wants to better understand how they can get their local priority needs addressed by NOAA. *CRED has established scientific liaisons for each jurisdiction including Guam. Marine resource managers in Guam know their liaison, and know that that person serves as a conduit for forwarding their needs. Priorities for the PIFSC-funded 2010 cruise were developed based on extensive discussions and consensus-building with local managers.*
- Complete Guam Mapping: (On-going Request) About half of Guam remains unmapped in the 0-300 m range with some LiDAR and some multibeam data available.

- Offshore Banks: Offshore banks are important both for coral and fishing interests, and mapping was requested in 2009. *A 2010 fisheries cruise aboard the Oscar Elton Sette completed multibeam surveys of Galvez Bank and 11-mile Reef. These banks still lack adequate in situ optical data and Santa Rose bank needs both in-situ optical and multibeam surveys.*

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CNMI

- Habitat Maps: Benthic shallow water habitat mapping is being done by NOAA Center for Coastal Monitoring and Assessment (CCMA) at a smaller mapping unit in the Caribbean (funded by NPS) and using a new classification system… CNMI expressed interest in learning about this new classification system once it is finalized in the Caribbean. *Although this request was made at the 2008 CREIOS meeting, there has been no action between CNMI and the Biogeography group to date. Given the availability of complete data in the Saipan Lagoon/Garapan Anchorage area, it is recommended that a joint project for an integrated and/or higher resolution landscape benthic habitat map be considered by CNMI and CRCP mapping groups for the FY12 funding cycle.*
- Change Analysis: CNMI is interested in using maps and remote sensing imagery for change detection and expressed interest in leveraging purchasing power for new imagery through NOAA. NASA had previously offered support with hyperspectral data. *Imagery is now being collected across the U.S.-affiliated Pacific Islands, by a consortium of Federal agencies, with the WorldView-2 sensor. An inquiry has been sent to see if we can provide copies of the imagery to partners in CNMI. The CRED Mapping Group has started what will be at least a several year project to derive bathymetry data for all areas in the Pacific that lack LiDAR coverage.*
- Bathymetric Data: Bathymetric data have been collected by CRED in water depths of 15-1000 m, which leaves a gap in critical near-shore areas (< 15 m) that are too shallow for the ship (or launch) to enter, and to date has been filled by estimated depths from IKONOS imagery and shallow water habitat maps. CNMI would like access to the Navy's LiDAR data to fill additional gaps in bathymetric data for some locations. *To date, LiDAR data are available only for Tinian (almost complete coverage) and some areas of Saipan. All populated islands, islands in the Mariana Trench MNM, and important management islands (Pagan and FDM) should have LiDAR data. Evaluation is currently being done to determine if estimated depths from the WorldView2 satellite imagery are more accurate and extend deeper than the existing IKONOS imagery and could thus be used in Priority 2 areas. .*
- Benthic Habitat Maps: CNMI needs to receive technical support on any new or updated maps products and requests more involvement in the design of future mapping surveys. CRED has addressed classification issues in deeper waters via a GIS database using a variety of layers (…) rather than producing a final benthic habitat map. CNMI also needs a process for rapid and on-demand creation of GIS maps for managers to address specific and immediate questions. *Input from managers in CNMI was actively sought to help guide decisions on tasks to*

accomplish during 3 weeks of a 6-week cruise to the Mariana Archipelago early in 2010. The CRED Information Services group is actively working on a multi-year project to enable the production of web-based custom map products using any dataset from the CRED database

- Map Resolution: CNMI needs increased spatial resolution on their baseline shallow water habitat maps in selected areas, especially Saipan Lagoon. *New satellite imagery from systems such as WorldView2 should provide better resolution. WorldView-2 imagery is gradually becoming available. A project to refine methods for deriving depths from this sensor, and then to apply them to imagery from high-priority areas has been started.*
- Instrumentation: Use of R/V *AHI* and TOAD. *Request cancelled due to insufficient resolution of TOAD optical data. However, a high-resolution still camera has recently been added to the TOAD, as well as to the SeaBED AUV CRED operates in conjunction with the Northwest Fisheries Science Center.*
- Bathymetry Data (On-going and 2009 requests). Complete mapping of Priority 1 areas including Rota and Aguijan and provide maps of Farallon de Medinilla (FDM) and offshore banks. *2010 cruise aboard Oscar Elton Sette mapped at Rota to ~ 40 m depths, completed mapping at FDM (including NAVOCEANO data), and mapped 2 additional offshore banks near FDM.*

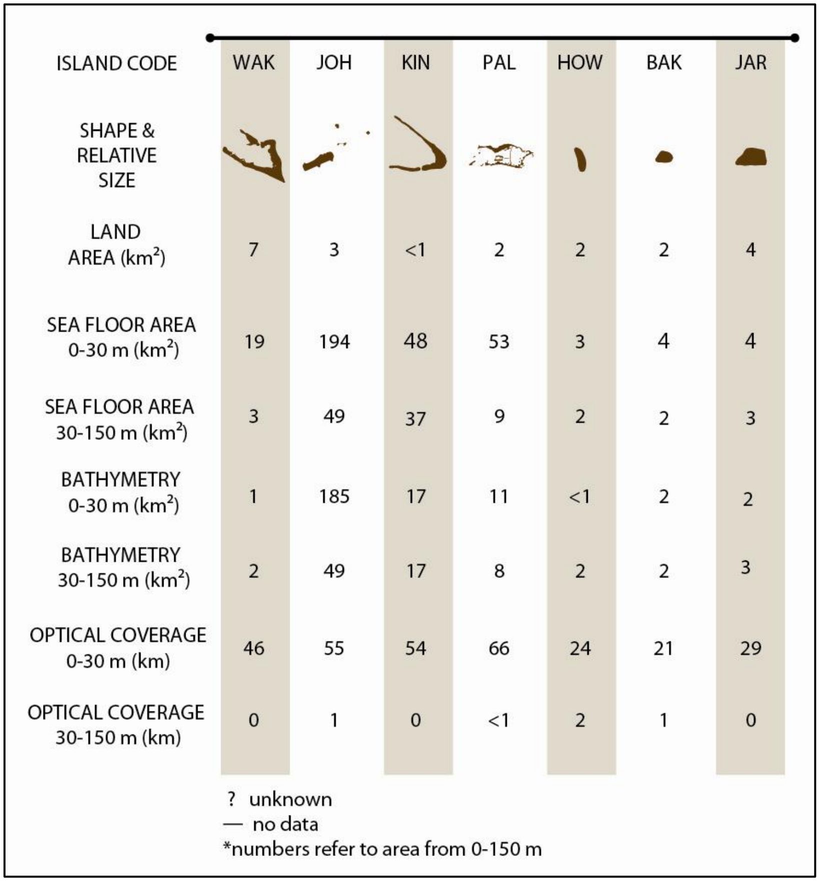
Table 3 provided a general listing of what mapping data and products are required for areas with different priorities. Those priorities for mapping are driven by several factors, including: CRCP Geographic priorities, known or anticipated management needs, areas with near complete coverage of primary data, and areas where other resources (e.g., ship time, non-CRCP funding for data collection or processing, etc.) can be leveraged. Management needs and the availability of other resources change rapidly, so mapping priorities will change as well.

Appendix F – Pacific Remote Island Areas (PRIA)

The Pacific Remote Island Areas (PRIA) include the Wake and Johnston Atolls, Kingman Reef, and Palmyra, Howland, Baker and Jarvis Islands, which total only 430 km^2 in the 0-150 m depth range or 1% of the total coral reef ecosystems discussed in this document. All of these islands except Wake were protected as National Wildlife Refuges until 2009, when they were designated as the Pacific Remote Islands Marine National Monument under which 100% of the 0-150 m seafloor is protected.

Although IKONOS data are available for the PRIA, no interpreted benthic habitat maps have been produced except for Palmyra and production of this product was funded by The Nature Conservancy, which maintains a research station on the island. Multibeam mapping has been completed by CRCP around Howland, Baker, Jarvis and Wake Islands; additional mapping is needed in lagoon and shallow areas at Kingman Reef, Palmyra Atoll, and Johnston Atoll. Deeper multibeam data around Kingman and Palmyra were collected by HURL and NOAA for the Law of the Sea projects. Gaps exist between 0 and 20 m at all islands that could only be filled by LiDAR data. Optical data are relatively sparse at all PRIA sites. Tables E-1, E-2, and E-3 provide an overview of primary data and data products for the PRIA.

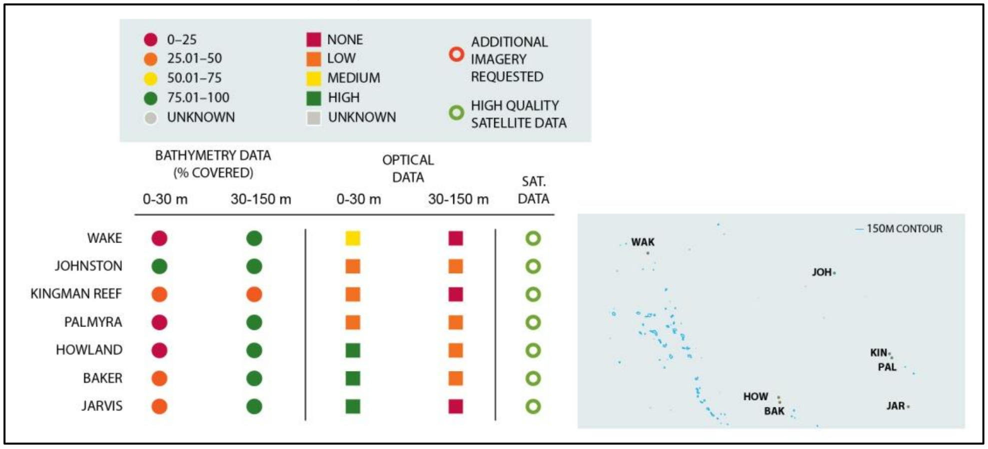
Table F-1: PRIA Land and Seafloor Area and Primary Data Coverage



ISLAND CODE	WAK	JOH	KIN	PAL	HOW	BAK	JAR
SHAPE & RELATIVE SIZE							
LAND AREA (km^2)	7	3	<1	2	2	2	4
SEA FLOOR AREA 0-30 m (km^2)	19	194	48	53	3	4	4
SEA FLOOR AREA 30-150 m (km^2)	3	49	37	9	2	2	3
BATHYMETRY 0-30 m (km^2)	1	185	17	11	<1	2	2
BATHYMETRY 30-150 m (km^2)	2	49	17	8	2	2	3
OPTICAL COVERAGE 0-30 m (km)	46	55	54	66	24	21	29
OPTICAL COVERAGE 30-150 m (km)	0	1	0	<1	2	1	0

? unknown
— no data
*numbers refer to area from 0-150 m

Table F-2. PRIA Level of Primary Data Available



🔴 0–25
🟠 25.01–50
🟡 50.01–75
🟢 75.01–100
⚪ UNKNOWN

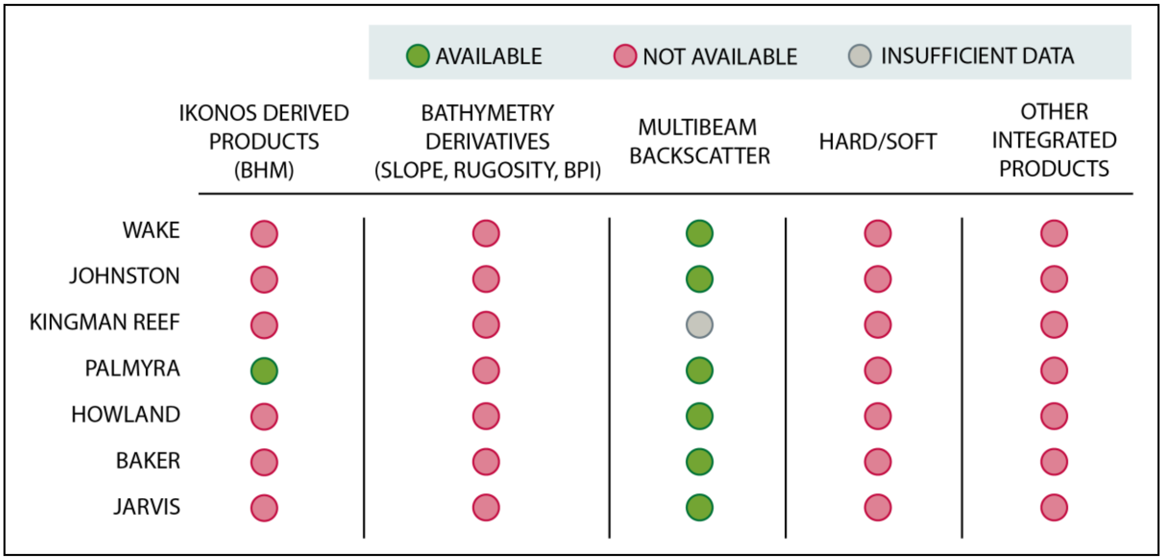
🟥 NONE
🟧 LOW
🟨 MEDIUM
🟩 HIGH
⬜ UNKNOWN

○ ADDITIONAL IMAGERY REQUESTED

○ HIGH QUALITY SATELLITE DATA

	BATHYMETRY DATA (% COVERED)		OPTICAL DATA		SAT. DATA
	0-30 m	30-150 m	0-30 m	30-150 m	
WAKE	🔴	🟢	🟨	🟥	○
JOHNSTON	🟢	🟢	🟧	🟧	○
KINGMAN REEF	🟠	🟠	🟧	🟥	○
PALMYRA	🔴	🟢	🟧	🟧	○
HOWLAND	🔴	🟢	🟩	🟧	○
BAKER	🟠	🟢	🟩	🟧	○
JARVIS	🟠	🟢	🟩	🟥	○

Table F-3: PRIA Products Available



🟢 AVAILABLE 🔴 NOT AVAILABLE ⚪ INSUFFICIENT DATA

	IKONOS DERIVED PRODUCTS (BHM)	BATHYMETRY DERIVATIVES (SLOPE, RUGOSITY, BPI)	MULTIBEAM BACKSCATTER	HARD/SOFT	OTHER INTEGRATED PRODUCTS
WAKE	🔴	🔴	🟢	🔴	🔴
JOHNSTON	🔴	🔴	🟢	🔴	🔴
KINGMAN REEF	🔴	🔴	⚪	🔴	🔴
PALMYRA	🟢	🔴	🟢	🔴	🔴
HOWLAND	🔴	🔴	🟢	🔴	🔴
BAKER	🔴	🔴	🟢	🔴	🔴
JARVIS	🔴	🔴	🟢	🔴	🔴

PRIA Mapping Priorities

No PRIA priorities were identified at the 2008 CREIOS conference. The PRIA have been identified as a CRCP Tier 2 priority. Thus PRIA mapping priorities are defined as follows:

- Create interpreted benthic habitat maps from existing IKONOS imagery.
- Complete multibeam mapping in the lagoon at Kingman Reef.
- Complete multibeam mapping in shallow areas to east and west of Palmyra Atoll.
- Complete multibeam mapping or fly LiDAR in lagoon at Johnston Atoll.

Appendix G: Puerto Rico

Puerto Rico includes the main island as well as several offshore islands (Vieques, Culebra, Mona, Culebrita and Desecheo) and Cays. The seafloor in Puerto Rico includes 5,453 km^2 of seafloor in the 0-150 m range. Puerto Rico contains thirty-two Marine Protected Areas designated by the Commonwealth including areas closed to fishing activities (Bajo De Cico, Tormaline Bank, Abir La Sierra). The total area within 0-150 m water depth encompassing all the MPA's is approximately 3,515 km^2 or 64.4%.

Comprehensive shallow water benthic habitat maps for the Puerto Rico were completed in 1999 using airborne photography. With the advent and availability of acoustic multibeam, extensive efforts have been undertaken to collect source data and produce benthic habitat maps for the shallow to moderate depth coral reef ecosystems within high priority Marine Protected Areas (Bajo De Cico, Tormaline Bank, Abir La Sierra, La Parguera, Mona Island, El Seco, Virgin Passage, and Vieques). Additionally, more contemporary high resolution map products were created for the Jobos Bay NERR in 2010 using intereferometric sonar and airborne imagery. Efforts are underway to create more contemporary high resolution maps of the Guanica project area to be completed in 2011. All other priority areas indicated in the Table G-1 are presently unfunded for completion. Significant bathymetric LiDAR, ship-based multibeam, optical ground-truthing, and benthic habitat mapping will be needed to complete these additional high-priority areas.

Table G-1: Priorities (Pri) for Mapping in Puerto Rico

Location	Subarea/Depth	Pri.	Primary Data Needed	Products Needed
La Cordillera [1]	0-30 m	2	A, B, C	D, E
Baja Holiday [2]	0-30 m	1	A, B, C	D, E
Cabo Engano[3]	30-150 m	2	A, B	D, E
Cabo San Juan Shelf [4]	30-150 m	1	A, B	D, E
Caja de Muertos[5]	30-150 m	2	A, B	D, E
Comezon[6]	0-30 m	1	A, B, C	D, E
Culebra[7]	0-30 m	1	A, B, C	D, E
Desecheo[8]	0-30 m	1	A, B, C	D, E
	30-150 m	2	A, B	D, E
East Culebrita[9]	0-30 m	2	A, B, C	D, E
	30-150 m	2	A, B	D, E
Grappler Bank[10]	30-150 m	2	A, B	D, E
Los Placeres[11]	30-150 m	2	A, B	D, E
Los Rabos[12]	30-150 m	1	A, B	D, E
Mona[13]	0-30 m	2	A, B, C	D, E
North of Culebra[14]	30-150 m	2	A, B	D, E
Pichincho[15]	30-150 m	2	A, B	D, E
Ponce[16]	30-150 m	2	A, B	D, E

Southeast Bank[17]	30-150 m	1	A, B	D, E
Vieques[18]	30-150 m	2	A, B	D, E
Monito[19]	0-30 m	2	A, B, C	D, E
	30-150 m	2	A, B	D, E
Nearshore Areas[20]	0-30 m	1	A, B, C	D, E
Guanica[21]	0-30 m	1	A	D

A – bathymetry, B – in situ optical, C – Satellite/airborne imagery, D – geomorphologic , E – benthic habitat map

1-20 - No funded activities for FY11-12.
21 – Shallow-water Benthic Habitat maps will be created in FY11. Bathymetric data collection and geomorphological products are yet unfunded.

The following mapping needs for Puerto Rico were identified during the 2008 CREIOS meeting and Prioritization Meeting held with Jurisdictional Partners in 2008.

- High resolution nearshore bathymetry, in situ optical ground-truthing data, satellite/airborne imagery, more contemporary benthic habitat products, and geomorphologic products for explicitly identified nearshore areas (Monito, Mona, East Culebrita, Comezon, Culebra, Desecheo, Baja Holiday, and La Cordillera) and more generalized nearshore areas (north shore and area surrounding Roosevelt Roads encompassing out to Culebra and Vieques). In particular these requests target the collection of data to support shallow reefs and *Acropora* identification.
- High resolution nearshore bathymetry, *in situ* optical ground-truthing data, more contemporary benthic habitat products, and geomorphologic products for explicitly identified for explicitly identified midwater locales (Cabo Engano, Cabo San Juan Shelf, Caja de Muertos, Desecheo, East Culebrita, Grappler Bank, Los Placeres, Los Rabos, North of Culebra, Pichincho, Ponce, Southwest Bank, Vieques, Monito). In particular the request target the collection of data to support the identification of mesophotic coral reefs, intensive fishing efforts, Spawning Aggregation sites, protected species, and fishery closure areas.

Appendix H: US Virgin Islands

The US Virgin Islands includes St. Thomas, St. John, and St. Croix as well as their respective offshore cays. The seafloor in the USVI includes 1,745 km^2 (St. Thomas/St. John) and 373 km^2 (St. Croix) of seafloor in the 0-150 m range. The USVI contains twelve MPAs which includes a combination of federally designated Monuments (Buck Island Reef National Monument and the Virgin Islands Coral Reef National Monument), National Parks (Virgin Islands National Park), Ecological Preserves (Salt River Bay National Historical Park and Ecological Preserve), and Territorial Protected Areas, and Conservation Districts. The total area within 0-150 m water depth encompassing all the aforementioned MPA is approximately 420 km^2 or 19.8%.

St John

Comprehensive shallow water benthic habitat maps for the St John were completed in 1999 using airborne photography. With the advent and availability of acoustic multibeam, extensive efforts have been undertaken to collect source data and produce benthic habitat maps for the moderate depth coral reef ecosystems. Large tracts of the shelf slope south of St Thomas and St John have been completed, with most of the remaining gaps to be completed in 2011 and 2012. Bathymetric LiDAR and geomorphogical products will be collected and completed for shallow water of St John in 2011. In 2010, revised finer-scale benthic habitat maps were completed for St John with NPS funding. Virtually all of the optical source data for this region has or will be collected in 2011. This project also integrated the use of CRCP-funded multibeam data (2004-2011) for the south shore of St John. As a result, a product was produced which demonstrates a seamless shallow to moderate depth benthic habitat map and a critical methodology for producing habitat maps from multibeam data. The methodology, developed by the Biogeographic Branch, provides the critical framework for creating benthic habitat maps for other locales where multibeam data has been or will be collected (Table H-1).

Table H-1 Priorities for Mapping in St. John, USVI

Location	Subarea/Depth	PRI.	Primary Data Needed	Products Needed
Fish Bay [1]	0-30 m	1	A, B	D
Coral Bay [2]	0-30 m	1	A, B	D
Hawksnest Bay [3]	0-30 m	1	A, B	D
Mid-Shelf Reef [4]	30-150 m	2	A, B	D, E
Haulover Bay [5]	0-30 m	2	A, B	D
Nat'l Monument[6]	0-30 m	2	A, B	D
	30-150 m	2		
DPNR APC[7]	0-30 m	2	A, B	D
	30-150 m	2	A, B	D
Nat'l Park[8]	0-30 m	2	A, B	D
	30-150 m	2	A, B	D

A – bathymetry, B – *in situ* optical, C – Satellite/airborne imagery, D – geomorphologic , E – benthic habitat map

1- A, B, and D to be completed in 2011.
2- A, B, and D to be completed in 2011.
3- A, B, and D to be completed in FY11.
4- 75% of A, B, C, D, and E will be completed in 2012.
5- A, B, and D to be completed in 2011.
6- A, B, and D to be completed in 2011.
7- A, B, and D to be completed in 2012.
8- A, B, and D to be completed in 2011.

The following mapping needs for St John, USVI were identified during the 2008 CREIOS meeting and USVI Coral Reef Management Priorities document.

- High resolution nearshore bathymetry, in situ optical ground-truthing data and geomorphologic products for priority MPA sites Fish Bay, Coral, Bay, Hawksnest Bay, and Haulover Bay.
- High resolution nearshore bathymetry, *in situ* optical ground-truthing data and geomorphologic products for DPNR APC's (Enighed Pond-Cruz Bay, Chocolate Hole-Great Cruz Bay, and Coral Bay).
- High resolution nearshore bathymetry, *in situ* optical ground-truthing data, geomorphologic products, and more contemporary benthic habitat products for the Mid-shelf Reef complex along the shelf edge and the Federally managed Virgin Islands National Park and Coral Reef National Monument.

St Thomas

Comprehensive shallow water benthic habitat maps for the St Thomas were completed in 1999 using airborne photography. With the advent and availability of acoustic multibeam, extensive efforts have been undertaken to collect source data and produce benthic habitat maps for the moderate depth coral reef ecosystems. Large tracts of the shelf slope south of St Thomas and St John have been completed, with most of the remaining gaps to be completed in 2011 and 2012. Bathymetric LiDAR and geomorphogical products will be collected and completed for shallow water of St Thomas in 2011-2012. Revised finer-scale benthic habitat maps will be completed for the Jurisdictions high priority sites: St Thomas East End Reserve, Cas Cay-Mangrove Lagoon Marine Reserve, and St James Marine Reserve. Virtually all of the optical source data for this region has been or will be collected in 2011-2012 (Table H-2). This project also integrated the use of CRCP-funded multibeam data (2004-08) for the south shore of St Thomas. A seamless shallow to moderate depth benthic habitat map will be created using the Biogeographic Branch methodology upon completion of data collection in 2012.

Table H-2 Priorities for Mapping in St. Thomas, USVI

Location	Subarea/Depth	PRI.	Primary Data Needed	Products Needed
STEER [1]	0-30 m	1	A, B	D, E
Magens Bay APC [2]	0-30 m	2	A, B	D, E
	30-150 m	2	A, B	D, E
Offshore Cays[3]	0-30 m	2	A, B	D, E
	30-150 m		A, B	D, E
Mesophotic Reef [4]	30-150 m	2	A, B	D, E
Vessup Bay/East End APC[5]	0-30 m	2	A, B	D, E
	30-150 m	2	A, B	D, E
Benner Bay APC[6]	0-30 m	2	A, B	D, E
	30-150 m	2	A, B	D, E
Botany Bay APC[7]	0-30 m	2	A, B	D, E
	30-150 m	2	A, B	D, E
STT Harbor APC[8]		2	A, B	D, E
		2	A, B	D, E
Mandahl Bay APC[9]		2	A, B	D, E
		2	A, B	D, E

A – bathymetry, B – *in situ* optical, C – Satellite/airborne imagery, D – geomorphologic , E – benthic habitat map

1- A, B, D and E to be completed in 2011.
2- 0-30m A to be completed in 2012.
3- 75% 0-30m A to be completed in 2011 and 2012.
4- A, B, D and E to be completed in 2011.
5- 0-30m A to be completed in 2011 and 2012.
6- 0-30m A to be completed in 2011 and 2012.
7- 50% of 0-30m A to be completed in 2011 and 2012.
8- 50% of 0-30m A to be completed in 2012.
9- 0-30m A to be completed in 2011.

The following mapping needs for St. Thomas, USVI were identified during the 2008 CREIOS meeting and USVI Coral Reef Management Priorities document.

- High resolution nearshore bathymetry, *in situ* optical ground-truthing data, more contemporary benthic habitat products, and geomorphologic products for the priority MPA site - St. Thomas East End Reserve.
- High resolution nearshore bathymetry, in situ optical ground-truthing data, more contemporary benthic habitat products, and geomorphologic for DPNR APC's (Magens Bay and Watershed, Botany Bay, St. Thomas Harbor and Waterfront, Mandahl Bay, Vessup Bay-East End, Mangrove Lagoon-Benner Bay).

- High resolution nearshore bathymetry, in situ optical ground-truthing data, more contemporary benthic habitat products, and geomorphologic for DPNR Offshore Cays (Great St. James, Little St. James, Thatch Cay, Mingo Cay, Lovango Cay, Inner Brass Cay, and Hans Lollick).
- High resolution nearshore bathymetry, *in situ* optical ground-truthing data, geomorphologic products, and more contemporary benthic habitat products for the Mesophotic Reef complex along the shelf edge.

St Croix

Comprehensive shallow water benthic habitat maps for the St Croix were completed in 1999 using airborne photography. With the advent and availability of acoustic multibeam, extensive efforts have been undertaken to collect source data and produce benthic habitat maps for the shallow to moderate depth coral reef ecosystems within the Buck Island Reef National Monument (BUIS), Salt River Bay National Historical Park and Ecological Reserve (SARI), and northern St Croix shelf complex using ship and launch based multibeam systems and satellite imagery. Bathymetric LiDAR and geomorphogical products will be collected and completed for shallow water (0-30m) of BUIS and SARI in 2011 (Table H-3). This effort is being conducted by FUGRO LADS with no investment by CRCP. Optical groundtruthing source data and benthic habitat mapping product development will need to be funded in order to complete these areas. All other priority areas indicated including the APC's are presently unfunded for completion. Significant bathymetric LiDAR, ship-based multibeam, optical ground-truthing, and benthic habitat mapping will be needed to complete these additional high priority areas.

Table H-3 Priorities for Mapping in St. Croix, USVI

Location	Subarea/Depth	PRI.	Primary Data Needed	Products Needed
EEMP [1]	0-30 m	1	A, B, C	D, E
Salt River Res. [2]	0-30 m	2	A, B	D, E
	30-150 m	2	A, B	D, E
Linear Reef[3]	0-30 m	2	A, B, C	D, E
	30-150 m		A, B	D, E
NW Shore [4]	30-150 m	2	A, B	D, E
South Ind. APC[5]	0-30 m	2	A, B, C	D, E
	30-150 m	2	A, B	D, E
Buck Is. Mon.[6]	0-30 m	2		
	30-150 m	2		
Coral Reef System APC[7]	0-30 m	2	A, B, C	D, E
	30-150 m	2	A, B	D, E
Southgate Pond APC[8]	0-30 m	2	A, B, C	D, E
	30-150 m	2	A, B	D, E

Sandy Point APC[9]	0-30 m	2	A, B, C	D, E
	30-150 m	2	A, B	D, E
Great Pond APC[10]	0-30 m	2	A, B, C	D, E
	30-150 m	2	A, B	D, E
Frederiksted APC[11]	0-30 m	2	A, B, C	D, E
	30-150 m	2	A, B	D, E
Christiansted APC[12]	0-30 m	2	A, B, C	D, E
	30-150 m	2	A, B	D, E

A – bathymetry, B – *in situ* optical, C – Satellite/airborne imagery, D – geomorphologic , E – benthic habitat map

1- 25% 0-30m A, B, D and E to be completed in FY2012.
2- 50% 0-30m A, B, D and E to be completed in FY2011.
3-12 - No funded activities.

The following mapping needs for St. Croix, USVI were identified during the 2008 CREIOS meeting and USVI Coral Reef Management Priorities document.

- High resolution nearshore bathymetry, *in situ* optical ground-truthing data, more contemporary benthic habitat products, and geomorphologic products for priority MPA site – East End Marine Park.
- High resolution nearshore bathymetry, *in situ* optical ground-truthing data, more contemporary benthic habitat products, and geomorphologic products for DPNR APC Sites (Christiansted Waterfront, Southgate Pond-Chenay Bay, St Croix Coral Reef System, East End, Great Pond and Great Pond Bay, Southshore Industrial Area, Sandy Point, Frederiksted Waterfront, Salt River Bay and Watershed).
- High resolution nearshore bathymetry, in situ optical ground-truthing data, more contemporary benthic habitat products, and geomorphologic products for spatial undefined areas (Linear Reef and Northwest Shore).
- High resolution nearshore bathymetry, in situ optical ground-truthing data, geomorphologic products, and more contemporary benthic habitat products for the Federally managed Buck Island Reef National Monument and Salt River Bay National Historical Park and Ecological Reserve.