CORAL REEF CONSERVATION PROGRAM

Mapping the Shallow-water Coral Ecosystems of the Freely Associated States: An Implementation Plan

About This Document

This Freely Associated States Shallow-water Coral Ecosystem Mapping Implementation Plan (FAS MIP) presents a framework for the development of shallow-water (~0–40 m; 0–22 fm) benthic habitat and possibly bathymetric maps of critical areas of the Freely Associated States (FAS). The FAS is made up of three self-governing groups of islands and atolls—the Republic of Palau (Palau), the Federated States of Micronesia (FSM), and the Republic of the Marshall Islands (RMI)—that are affiliated with the United States through Compacts of Free Association.

This MIP was developed with extensive input from colleges, national and state regulatory and management agencies, federal agencies, non-governmental organizations, and individuals involved in or supporting the conservation and management of the FAS's coral ecosystems. A list of organizations and individuals that provided input to the development of this MIP is provided in Appendix 1.

This MIP has been developed to complement the Coral Reef Mapping Implementation Plan (2nd Draft) released in 1999 by the U.S. Coral Reef Task Force's Mapping and Information Synthesis Working Group. That plan focused on mapping United States and FAS shallow-water (then defined as <30 m) coral reefs by 2009, based on available funding and geographic priorities, using primarily visual interpretation of aerial photography and satellite imagery. This MIP focuses on mapping the shallow-water (now defined as 0–40 m, rather than 0–30 m) coral ecosystems of the FAS using a suite of technologies and map development procedures. Both this FAS MIP and the 1999 Coral Reef Mapping Implementation Plan (2nd Draft) support to goals of the National Action Plan to Conserve Coral Reefs (U.S. Coral Reef Task Force, 2000).

This FAS MIP presents a framework for mapping the coral ecosystems of the FAS and should be considered an evolving document. As priorities change, funding opportunities arise, new data are collected, and new technologies become available, the information presented herein will change.

Introduction

The coral ecosystems of the FAS are extensive. Using unpublished estimates derived from analysis of visible shallow-water features in Landsat satellite imagery, Palau potentially has approximately 2,529 sq km, FSM potentially has approximately 14,517 sq km, and RMI potentially has approximately 13,456 sq km of coral ecosystems. In combination, the 30,502 sq km of FAS potential shallow-water coral ecosystems is equivalent to about 83 percent of the 36,812 sq km of potential shallow-water tropical and subtropical coral ecosystems found in the U.S. (Rohmann et al., in press). Priority areas to be mapped have been identified either in publications (for FSM) or during the April 2005 meetings. These priority areas are listed in the meeting summaries near the end of this MIP.

Considerable research has described the interconnectedness of the various habitat components of a coral ecosystem and the critical need for their conservation and management (Parrish, 1989; Mumby et al., 2004; Christensen et al., 2003). Research also has described the impact of over-fishing and the loss of critical habitat on coral ecosystem communities (Dulvy et al., 2004; Friedlander and DeMartini, 2002, Gardner et al., 2003). Finally, research has described the dynamics of coral ecosystem biologic communities and long-term declines of Caribbean coral ecosystems (Pandolfi, 2002; Pandolfi et al., 2003, Gardner et al., 2003). The products developed as a result of this mapping effort will support the ongoing need to evaluate the long-term condition and status of the coral ecosystems of the FAS. These products also will support Geographic Information System (GIS) based integration of mapping and monitoring activities (Monaco et al., 2001).

Some Definitions

A coral ecosystem is composed of both habitats and structural zones. Benthic habitats found in a coral ecosystem include unconsolidated sediments (e.g., sand and mud); mangrove; submerged vegetation (e.g., seagrass and algae); hermatypic coral reefs and associated colonized hard bottom habitats (e.g., spur and groove, individual and aggregated patch reefs, and gorgonian-colonized pavement and bedrock); and uncolonized hard bottom (e.g., reef rubble and uncolonized bedrock). Typical structural zones include the reef crest, fore reef, reef flat, and lagoon (Rohmann et al., in press).

For this MIP, shallow-water will refer to the 0-40 m depth regime. This depth regime generally represents where most hermatypic coral species are found and where most direct impacts from pollution and coastal development occur.

Several general categories of mapping data or products are referred to in this MIP and brief descriptions of these are provided. Also, various technical phrases are used when discussing the acquisition and processing of data to produce bathymetry and associated habitat maps. Descriptions of these also are presented below.

—Benthic Habitat Maps: Maps that provide information about the area or environment where an organism or ecological community normally lives or occurs. The maps classify benthic habitats found on the seafloor based on geomorphology (e.g., pavement), zonation (e.g., reef crest), and biological cover (e.g., seagrass). The production of benthic habitat maps includes an independent assessment of their thematic accuracy.

—Bathymetric Maps: Maps that provide information about the depth of water from the surface to the seaflor in a water body.

—Imagery Data: Digital data that provide an indirect indication of the character of the seafloor. Sources of imagery data include backscatter data from multibeam sonar systems, side-scan sonar data, and other remotely sensed data, such as satellite or airborne imagery.

—Optical Observation Imagery: Information that represents direct observation of the seafloor and can be used to directly characterize the features found on the seafloor. When com-

bined with bathymetric data and imagery data, optical observation imagery can be used to develop benthic habitat maps. Sources of optical observation imagery include Remotely Operated Vehicles (ROVs), Autonomous Underwater Vehicles (AUVs), manned submersibles, Laser Line Scanning (LLS) technologies, drop cameras, towed cameras, and SCUBA divers. These optical validation data are necessary to produce accurate benthic habitat maps.

Why Map?

Maps of the shallow-water coral ecosystems of Palau, the FSM, and the RMI are needed to support many national, state, federal, and international conservation and management objectives and research activities. The Global Environmental Facility/United National Environment Programme has completed a Biodiversity Strategy and Action Plan for the RMI (GEF/UNEP, 2000), and a National Biodiversity Strategy and Action Plan for the FSM (GEF/UNEP 2002). A similar project is currently underway for Palau. The Nature Conservancy recently published a multi-organization supported study entitled "A Blueprint for Conserving the Biodiversity of the Federated States of Micronesia" (TNC, 2003). These studies help define priorities for protecting and managing coral ecosystems and monitoring their condition. Maps are a critical component of characterization and monitoring activities and ecosystem-based management activities. Other uses of the maps include depicting management and conservation boundaries, characterizing essential marine organism habitat, monitoring the baseline condition of the reef ecosystems and factors affecting their condition, enforcing regulations on fishing and similar activities and, where applicable, assessing the extent and impact of marine debris on the reefs. In addition, maps will be critical for assessing changes taking place in the reef ecosystems of these areas over time.

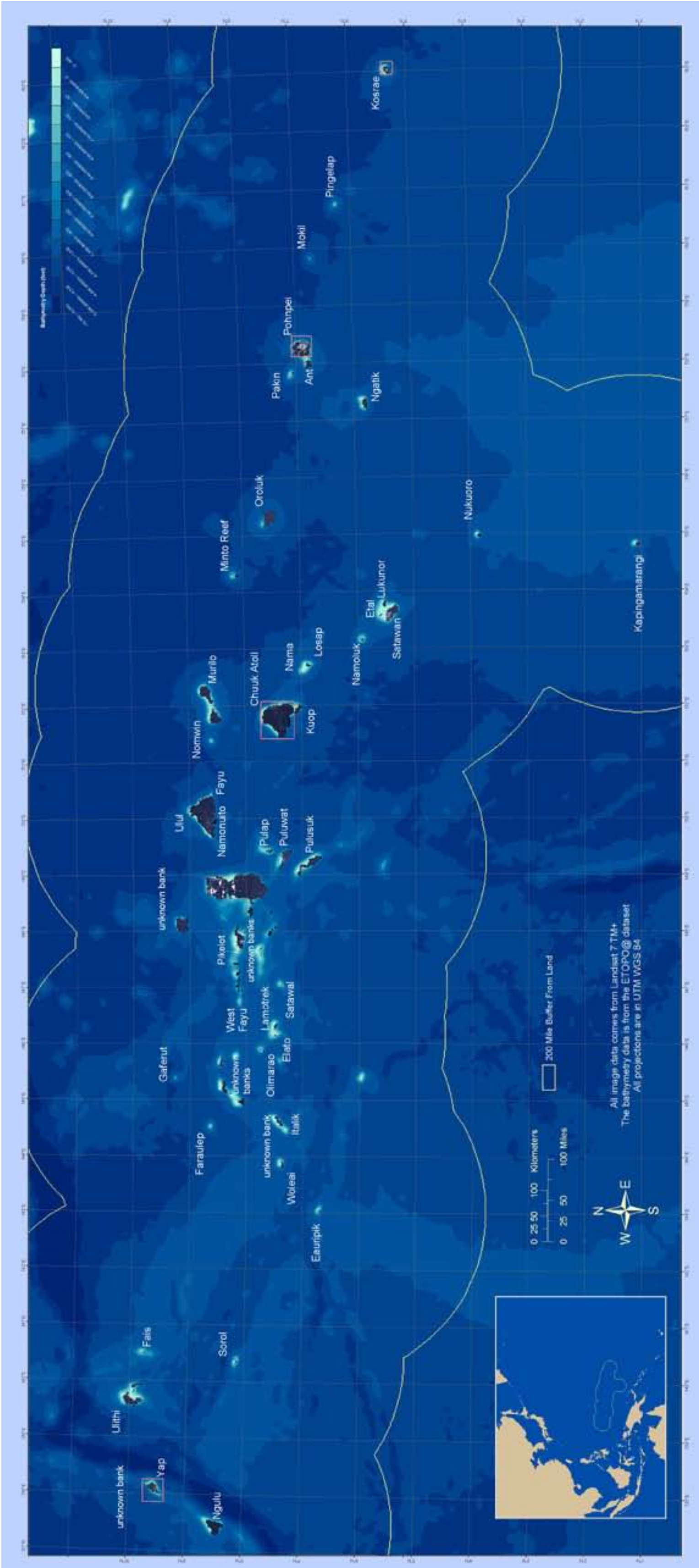
Many organizations in the FAS have indicated the need for comprehensive, high-resolution imagery of the coral ecosystem areas in their regions. These images—e.g., moderate or high-resolution satellite imagery—can be used for many purposes, including coral ecosystem characterization and monitoring. NOAA's Coral Ecosystem Mapping Team has used high-resolution satellite imagery to generate detailed benthic habitat maps of American Samoa, Guam, the Northern Marianas, the Northwestern Hawaiian Islands, and nearly 60 percent of the main eight Hawaiian Islands (see http://biogeo.nos.noaa.gov). Providing moderate resolution satellite imagery of as much of the FAS as possible and high-resolution satellite imagery of targeted, priority areas of the FAS would be a critical source of information to support FAS coral ecosystem conservation and management.

Mapping Activities

In 2000, the National Aeronautics and Space Administration and the University of South Florida began developing the Millennium 2000 global, shallow-water, geomorphological map of coral ecosystems. The project primarily used Landsat 7 moderate resolution (~30 m pixels) as the basis for defining over 250 different categories of geomorphological features associated with coral ecosystems. The Millennium 200 geomorphological maps of the FAS are complete and may be obtained by contacting Serge Andrefouet, UR Coreus - Institut de Recherche pour le Développement (IRD), BP A5 - 98848 Nouméa cedex - Nouvelle Calédonie, Tél (+687) 26 08 00; Fax (+687) 26 43 26; andrefou@noumea.ird.nc.

In 2005, NOAA initiated a project to begin mapping the shallow-water coral ecosystems associated with Babeldaob, Koror, and neighboring islands in Palau. NOAA is using high-resolution (1 m pan-sharpened 4 m pixel) satellite imagery as the basis for that mapping effort. Maps for about 45-50 percent of the Palau coral ecosystems are anticipated to be completed by the end of May 2006.

An overarching goal of the U.S. Coral Reef Task Force is to preserve and enhance the living resources of coral ecosystems, including those in the FAS. A major challenge with reaching that goal and with coral ecosystem resource management is the difficulty in discriminating natural variation in ecosystems from changes or declines caused by human impacts that may be managed, such as wastewater and stormwater treatment and disposal. Long-term data sets and research to determine thresholds that result in shifts in community structure, in conjunction with a detailed ecosystem map, are required to understand and effectively manage this large marine ecosystem. In addition, many mobile species utilize different habitat types over the course of their life histories. FAS coral ecosystem maps that could be used to support analysis of the distribution of and spatial relationships among



A Landsat satellite-based mosaic of the islands and atolls in the Federated States of Micronesia.

different habitat types is essential as researchers and managers move toward improving our understanding of ontogenetic habitat changes and possible management actions related to protecting entire life cycles, from larval settlement through juvenile growth and adult reproduction.

Need for Partnerships

Partnerships with local, state, national, NGO, and federal agencies are an essential component of any effort to generate coral reef maps. No single agency has the resources needed to complete an extensive mapping activity. Successfully mapping the FAS also will require partnerships among the organizations—local, state, national, and federal—that manage the refuges, parks, marine sanctuaries, and other conservation areas associated with FAS coral reefs.

Mapping Priorities

Geographic Area of Interest

The geographic area of interest—where characterization of shallow-water benthic habitats is needed—can be defined based on both geographic location and management or conservation priorities. In general, FAS national and state management and regulatory agencies, as well as federal management and regulatory agencies, researchers, and other organizations indicated that the most critical areas that are facing conservation and management challenges in the FAS should be the ones that are mapped first. Within priority areas are the coral ecosystems most directly affected by coastal development, commercial and recreational fisheries, and other coastal zone management-related issues.

Many FAS coral ecosystem researchers and conservation and management personnel indicated a less critical, but nevertheless important need to characterize all FAS shallow-water coral ecosystems. After being shown the Millennium 2000 maps, many felt this product would provide a good overall map product for non-priority areas. A discussion of what each Freely Associated State considers to be priority areas is presented in subsequent sections.

Minimum Mapping Unit

A minimum mapping unit—usually described in sq m—is the smallest feature (e.g., an individual patch reef) or aggregate of features (e.g., scattered coral heads on hard bottom) that is delineated using a given source of imagery (e.g., moderate-resolution or high-resolution satellite imagery) and mapping protocol (e.g., computerized image analysis or visual interpretation). Deciding on an MMU is a balance between providing maps with sufficient detail that meets the requirements of people using them and the time and cost to make the maps.

The NOAA Coral Ecosystem Mapping Team has used a MMU of ~4,047 sq m (~1.0 acre; 0.004 sq km) and visual interpretation to map the benthic habitats in Puerto Rico, US Virgin Islands, Hawaii, American Samoa, Guam, and the Northern Marianas. An MMU of ~100 sq m (0.0247 acre; 0.0001 sq km) and semi-automated image analysis was used when mapping the benthic habitats of the Northwestern Hawaiian Islands. In some areas, such as Buck Island Reef National Monument in St Croix, U.S. Virgin Islands, maps with an MMU of 100 sq m also have been produced.

Generally, the size of the MMU represents a tradeoff between the desire to map small features (e.g., individual coral heads or patch reefs) and the time required to identify and classify all the features visible in the data. The smaller the MMU, the more individual features will be mapped and, depending on the technique used to characterize the features, can increase the time required to produce the map. The ability to assess the thematic accuracy (i.e., how many of the benthic habitat features are correctly classified) also is a factor in setting the MMU size. Depending on the overall size of the study area, the biologic and structural complexity, and the MMU size of the area being mapped, hundreds to thousands of field habitat observations may need to be collected to adequately assess map thematic accuracy. Collecting these field habitat observations can be an expensive and time-consuming effort. There is broad consensus that the research, conservation, and management community using the maps very much prefers thematic accuracy to spatial detail.

Some research, conservation, and management activities may require setting a smaller MMU than typically set for synoptic mapping efforts. This can be accomplished using digital imagery and state-of-the-art GIS and image analysis software. Mapping smaller areas using a smaller MMU is frequently done as part of spatially explicit analyses of habitat utilization by fishes or other marine organisms. The more generalized "base map" with the larger MMU can be used as the starting point for developing more detailed maps, where the more detailed habitat maps "nest" inside the more generalized base map.

The Mapping Procedure

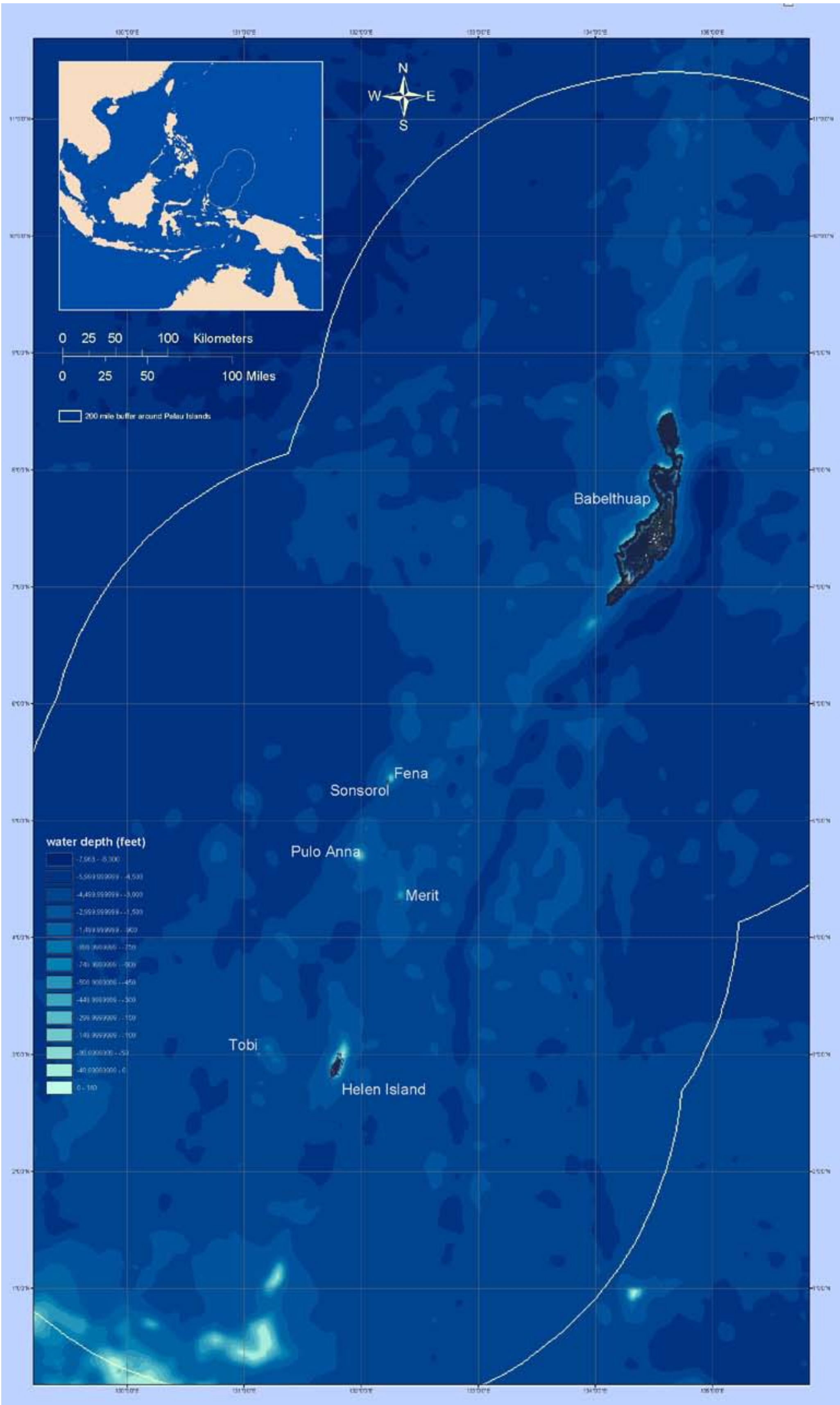
Maps of the FAS shallow-water coral reef ecosystems will come from two sources: 1) map products generated by the Millennium 2000 mapping project described above; and 2) for priority areas, visual interpretation of high-resolution satellite imagery. There is research underway to develop procedures for semi-automated spectral analysis of satellite imagery to generate benthic habitat maps. Once validated, spectral analysis should both reduce the time required to produce maps and reduce costs.

Visual Interpretation

Visual interpretation of high-resolution (4 m pixel), color satellite imagery can accurately discriminate 25 or more habitat categories. NOAA has used visual interpretation to map the shallow water coral reef ecosystems of portions of the eight main Hawaiian Islands, American Samoa, Guam, and the Northern Marianas, and anticipates using this technique to generate shallow-water benthic habitat maps of the FAS. Maps produced by NOAA using visual interpretation of the high-resolution satellite imagery result in map products with 85-95 percent thematic accuracy.

A Classification Scheme

A hierarchical classification scheme originally developed to describe the benthic habitats of American Samoa, Guam, and the Northern Marianas will be modified to incorporate unique habitats and structural zones present in the FAS. The revised classification scheme will be used by the interpreter as the basis for delineating habitat boundaries visible in the high-resolution satellite imagery. The scheme represents a balance between the need for detailed habitat delineations for research and management activities and the interpreter's ability to discriminate habitats in the imagery. For more information about NOAA's coral ecosystem classification schemes, their importance to the mapping process, and to obtain a copy of the draft scheme, please visit: http://biogeo.nos.noaa.gov//products/us_pac_terr/htm/methods.htm.



A Landsat satellite-based mosaic of the islands and atolls in the Republic of Palau.

Satellite Imagery

Satellite imagery is a valuable tool for natural resource managers and researchers. It provides a snapshot record of the location and extent of habitats at a point in time. NOAA has produced benthic habitat maps of the Northwestern Hawaiian Islands, American Samoa, Guam, and the Northern Mariana Islands, and is currently producing benthic habitat maps of the main Hawaiian Islands and priority areas of Palau using visual interpretation of multispectral, high-resolution, IKONOS satellite imagery and the NOAA Habitat Digitizer extension. Habitat boundaries are delineated around signatures (e.g., areas with specific color and texture patterns) in the orthorectified imagery mosaic corresponding to habitat types associated with a locally specific Classification Scheme. The custom Habitat Digitizer extension is used, which allows the user to digitize at a scale of 1:6,000 with a 1-acre MMU. The Habitat Digitizer allows the user to change the scale of mapping and the size of the MMU. Generally, feature detection of seafloor habitats was possible from the shoreline to water depths of approximately 30 meters, depending on water clarity.

In order to optimize the satellite imagery for visual interpretation, a number of processing steps were implemented to enhance the geopositioning and clarity of the imagery. These steps include: orthorectification to remove spatial distortions in the imagery due to relief displacement; pansharpening using 1 m panchromatic imagery; deglinting; generating normalized reflectance values and, if possible, correcting for water column attenuation (see Appendix 2).

NOAA uses the IKONOS satellite to provide imagery for benthic habitat mapping. The IKONOS satellite provides commercially available panchromatic (black and white) and multispectral (blue/green/red/near-infrared) imagery. IKONOS panchromatic

imagery has a 1 sq m pixel dimension (meaning features larger then 1 m can be detected in the imagery) and a 4 m multispectral pixel dimension (meaning features larger then 16 sq m can be seen in the imagery). The Millennium 2000 mapping project used Landsat satellite imagery, with a 28.8 m (~812 sq m) multispectral pixel and 14.25 m (~203 sq m panchromatic) pixel size.

The IKONOS imagery is purchased in 11 km wide swaths and can be mosaicked together to produce complete images of locales. High-resolution satellite imagery provides precise and robust data with spectral and spatial resolution suitable for shallow water benthic mapping. Both moderate-resolution Landsat and high-resolution satellite imagery provides efficient and effective global coverage for repeated imaging of remote islands that are often obscured by cloud cover. Furthermore, Landsat imagery is available for some areas as far back as 1985, making it an important resource for analyzing change over time.

Based on input received from FAS meeting participants, priority areas where mapping should occur have been identified in Palau, FSM, and RMI (detailed lists are presented in the summaries of meetings included below). The estimated costs for generating benthic habitat maps of priority areas in Palau, FSM, and RMI from IKONOS imagery for are presented in Table 2. Appendix 1 provides a detailed discussion of the process of generating benthic habitat maps using satellite imagery.

Data Processing and Habitat Mapping

Collection of imagery and optical validation data represents a significant commitment of resources and funds. However, data collection alone does not ensure that benthic habitat maps are produced. A significant commitment of resources and funds also is required to process imagery and optical validation data and to synthesize these data with the critical biological information.

Table 2. Estimates for gathering and processing IKONOS satellite imagery and developing benthic habitat maps for the Freely Associated States. Included in the overall cost are estimated costs associated with purchasing and processing the imagery and assessing the accuracy of the resulting benthic habitat maps. The production of benthic habitat maps generally costs between $400–$500/sq km. The cost values presented could overestimate or underestimate actual costs by 25 percent or more.

Location	estimated area to be mapped	estimated imagery purchase cost	estimated cost to produce map	total estimated cost
Palau (Babeldaob/Koror)	2,350	$50/sq km	$350/sq km	$940,000
Palau (southern islands)	700	$50/sq km	$350/sq km	$280,000
FSM (PAAs/PAs)	5,640	$50/sq km	$350/sq km	$2,256,000
FSM (State islands)	3,460	$50/sq km	$350/sq km	$1,384,000
RMI (priority areas)	10,050	$50/sq km	$350/sq km	$4,020,000
RMI (monitoring islands)	4,670	$50/sq km	$350/sq km	$1,868,000

These estimates include some, but not all, imagery purchasing and processing costs. PAAs (Priority Action Areas) and PAs (Priority Areas) were compiled from TNC (2003). FSM State Islands include Chuuk, Kosrae, Pohnpei, and Yap. RMI priority areas and RMI EPA monitoring islands were identified by participants attending April 2005 meeting in Majuro. RMI priority areas includes all RMI EPA monitoring islands. Map production and accuracy assessment costs are based on a cost estimate provided by Analytical Laboratories of Hawaii using IKONOS satellite imagery to produce a benthic habitat map for a portion of the Republic of Palau.

Key Trade-offs

Mapping the shallow-water (~0–40 m) benthic habitats of the FAS will require some technologic, geographic, and other com-

A Landsat satellite-based mosaic of the islands and atolls in the Republic of the Marshall Islands.

promises to be made. It is unlikely that sufficient funding will be available for the sustained period of time needed to comprehensively map all of the FAS's shallow-water coral ecosystems. As a result, priorities will need to be established and tradeoffs made. Below are descriptions of some of the tradeoffs that will be considered and how choices about various aspects of benthic habitat mapping, such as sources of data, the size of the geographic to be mapped, the size of the MMU, and the thematic accuracy of the map products affect these tradeoffs.

Source of Data

The cost of acquiring, processing, georeferencing, and mosaicking the imagery used to generate the benthic habitat map varies considerably depending on the source of the imagery. Aerial photography is relatively inexpensive to collect per unit area, but is relatively expensive to georeference (ortho-rectify) and mosaic together in order to generate a map. High-resolution satellite imagery is more expensive to collect per unit area but is less expensive to georeference and mosaic. Digital camera imagery from aircraft also is relatively inexpensive to collect. The cost to georeference and mosaic the imagery tends to fall between those of aerial photography and high-resolution satellite imagery.

Minimum Mapping Unit size

The size of the Minimum Mapping Unit (MMU) can dramatically affect the time required to produce a benthic habitat map of a given area and, as a result, can dramatically affect the cost of producing a benthic habitat map of a given area. Also, the type of technology that provides the imagery from which the map is generated may have limits on the size of MMU that it can support. Finally, the amount of optical observation information needed to validate the accuracy of the map is directly dependent on the size of the MMU.

Area to be Mapped

As discussed above, the size of the area to be mapped directly affects the level of effort required to acquire imagery, the size of the MMU, and the amount of optical observation information needed, and each of these factors affects the overall cost of producing benthic habitat maps.

Number of Habitat Types

The number of benthic habitat categories—i.e., coral ecosystem complexity—that are classified during the process of generating a map directly affects map production cost. The greater the number of habitat categories defined, the greater the cost of identifying, mapping, and validating the resulting map. Also, the greater the number of benthic habitat categories, the higher the resolution of the imagery required to identify and map the different habitats. Finally, the higher the number of habitat categories mapped, the greater the number of optical observations required to validate the accuracy of the map product.

Thematic Accuracy

Independently evaluating the thematic accuracy of a map of shallow-water benthic habitats is one of the most important aspects of the mapping process. The consensus position among potential users of FAS benthic habitat maps is that higher thematic accuracy—at the expense of a smaller MMU—is preferred. The preferred accuracy is 85-95 percent thematic accuracy for major categories of habitat using high-resolution satellite imagery and 60-75 percent accuracy for Millennium 2000 maps where geomorphological features are mapped. The collection of optical observations to statistically test the accuracy of a map is directly related to required map accuracy: the higher the required accuracy required, the greater the number of optical observations required to analyze accuracy.

Next Steps

Reports were developed that summarized the outcomes of the meetings held in Palau, Pohnpei, and Majuro. These reports are provided below, starting with the Federated States of Micronesia and followed by the Republic of Marshall Islands and the Republic of Palau. The final MIP is available as a PDF on http://biogeo.nos.noaa.gov

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A Summary of the Federated States of Micronesia Shallow-water Coral Ecosystem Mapping Meeting
April 8, 2005
Secretary's Office, Department of Foreign Affairs
Palikir, Pohnpei
Federated States of Micronesia

Attending:
Tony Abraham, Kosrae Marine Resources
Herson Anson, Pohnpei Forestry and Marine Conservation
Arnold Campbell, US Embassy, Kolonia
Cindy Ehmes, Department of Environmental Affairs
Jesse Gajdusek, Yap Resources and Development
Marion Henry, FSM Department of Economic Affairs, Fisheries/Marine Resources
Kichy Joseph, Chuuk
Joe Konno, Chuuk Environmental Protection Agency
Willy Kostka, Conservation Society of Pohnpei
Richard MacKenzie, USDA Forest Service, Inst. Of Pacific Islands Forestry
Franck Magnon, Secretariat of the Pacific Community (SPC)
Dave Mathias, Pohnpei Marine Resources
Mark Monaco, NOS
John Mooteb, Department of Environmental Affairs
Roger Mori, Assistant Secretary, FSM Department of Economic Affairs
Pelson Moses, Pohnpei Marine Resources
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Sinakio Pele, PUC
Steve Rohmann, NOS
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Jenny Waddell, NOS

Opening remarks provided by Roger Mori, Assistant Secretary of the FSM Department of Economic Affairs. Roger urges participants to participate in the development of the FSM Mapping Implementation Plan (MIP).

Marion Henry and Joe Konno indicate that SOPAC has purchased high-resolution satellite imagery of FSM Islands. SOPAC is the South Pacific Applied Geoscience Commission. SOPAC is an inter-governmental, regional organization dedicated to providing services to promote sustainable development. NOS will follow-up on availability of imagery. SOPAC also has purchased some multibeam data for Yap and Chuuk. Again, NOS will investigate those data.

FEMA may have purchased some IKONOS imagery of the main islands. This would almost certainly be the Pacific Disaster Center's imagery purchased in 2001. NOAA does not have any of these images. NOAA has IKONOS imagery of Yap collected in March-April, 2003.

There was considerable interest in the NOAA Monitoring Program and funding availability. This topic was deferred until the afternoon session.

The Forest Service has completed land use characterizations of the FSM. NOAA will work with Forest Service to see if those data can be combined with benthic habitat maps, once these are completed.

The FSM has been extensively involved in the development of two assessments of critical conservation areas in the FSM. The first, The National Biodiversity Strategy and Action Plan (NBSAP), was developed in collaboration with United Nations Development Program (UNDP), Global Environmental Facility (GEF) and World Conservation Union (ICUN). The

second, A Blueprint for Conserving the Biodiversity of the Federated States of Micronesia, was developed in collaboration with The Nature Conservancy. These documents provide a detailed list of the critical marine, coastal, and terrestrial conservation areas in FSM. These documents will be used, in conjunction with direct input from FSM partners, in identifying pilot areas for coral ecosystem mapping efforts. As indicated above, US Forest Service terrestrial maps can be merged with benthic habitat maps to produce Summit-to-Sea maps.

All Priority Action Areas and many Priority Areas, based on the TNC Blueprint report, are included in the following list of important areas to characterize. These include Kosrae (141 sq km), Oroluk (467 sq km), Pohnpei (704 sq km), Ahnd (99 sq km), and Satowan Island (426 sq km), Chuuk (2375 sq km), West Puluwat (266 sq km), Fananu (Nomwin; 339 sq km), and Esan Reef (Lukunor; 72 sq km), Yap (239 sq km), Ulithi (456 sq km), Woleai Atoll (52 sq km), and Ifelug Atoll (5 sq km). The combined area for all locations listed above is approximately 5640 sq km. The area of the four state capitols (i.e., Yap, Chuuk, Pohnpei, and Kosrae) is approximately 3460 sq km.

There could be considerable opportunity for leveraging investments and in-kind services associated with mapping efforts. The MIP will try to describe these opportunities and how these will support mapping goals.

Local Points of Contact (POC) are critical for the success of the Mapping Implementation Plan development process and for the actual mapping effort, once it get underway. NOAA will contact Marion Henry to identify FSM State POCs. Tentative POC list:

Yap: Jesse Gajdusek
Chuuk: Joe Konno
Pohnpei: User Anson
Kosrae: Tony Abraham

The Pohnpei Marine Resources Division (Dave Mathias) is working with the Department of Interior and Jerry Allen from Australia to conduct a fish monitoring activity at a number of locations in Pohnpei lagoons. The data from these surveys could be valuable for mapping efforts as well.

Tony Abraham indicated that fish monitoring, using Reef Check protocols, has been underway for five years around Kosrae. Surveys have mostly been on reef slope areas.

FSM Next Steps:

NOAA will draft the Freely Associated States Shallow-water Coral Ecosystem Mapping Implementation Plan, including a section specifically describing requirements for the Federated States of Micronesia. That draft Plan will be distributed by June 1, 2005 to the participants of the meeting as well as other interested individuals. Comments will be requested by June 20, 2005. Comments received will be incorporated and the final Plan will be distributed. The final Plan will be used as the basis for developing and submitting a proposal the NOAA Coral Reef Conservation Program for funding in FY06.

The Federal Register Notice (FRN) to submit proposals for coral ecosystem monitoring funding through the NOAA Coral Reef Conservation Program will be published on 1 June 2005. Organizations interested in conducing coral ecosystem monitoring should review the FRN and consider submitting a proposal to the NOAA Coral Ecosystem Monitoring Program.

Republic of the Marshall Islands Shallow-water Coral Ecosystem Mapping Meeting
April 14, 2005
College of the Marshall Islands conference room
Majuro, Republic of the Marshall Islands

Attending:
Rito Akilan, RMI Environmental Protection Authority
John Bungitak, RMI Environmental Protection Authority
Don Hess, Chair, Liberal Arts and Sciences, College of the Marshall Islands
Dean Jacobson, Marine Science Program, College of the Marshall Islands
Souvenior Kabua, RMI Environmental Protection Authority
Terry Keju, Marshall Islands Marine Resources Authority (MIMRA)
Caleb McClellen, RMI Environmental Protection Authority
Mark Monaco, NOS
Lihla Noori, RMI Environmental Protection Authority
Silvia Pinca, Marine Science Program, College of the Marshall Islands
Steve Rohmann, NOS
Kenneth Sims, Environmental Management Office, US Army Kwajalein Atoll
Jenny Waddell, NOS
Steve Why, Exec. Dir., Marshall Islands Conservation Society

Meeting with Tom Praster, US Embassy in Majuro
April 15, 2005

There is considerable interest in learning more about the NOAA coral ecosystem monitoring program and potential funding for RMI coral monitoring activities. NOAA will provide follow-up information through the Federal Register Notice. Those funds can be used, in part, to support local capacity building. Other potential sources of support for capacity building include the Pacific Services Center in Honolulu and the Environmental Systems Research Institute (ESRI).

There was interest in how NOAA could support increasing opportunities for getting local communities involved in coral ecosystem conservation and management. Again, coral ecosystem monitoring grants can, in part, be used to support these efforts. RMI also should begin working more closely with non-profit organizations, such as The Nature Conservancy. There is a TNC office covering the FAS located in Pohnpei.

There is some imagery available of some locales in the Marshall Islands. RMI EPA has some IKONOS imagery of Majuro, and portions of Jaluit, Kwajalein, and one other island. The Marshall Islands Electric Power has been involved in purchasing this imagery. RMI EPA is considering submitting a proposal to SOPAC (South Pacific Applied Geoscience Commission) to obtain imagery of other locales. If the imagery is purchased from archive (not a new collection), there is some concern about the timeliness of the imagery. The Marshall Islands Conservation Society is interested in monitoring sea level rise in the Marshall Islands. The imagery may be usable for this analysis. It is unlikely NOAA will be able to purchase new high-resolution satellite imagery in the near future if at all to support sea level rise analyses. NOAA will assess whether or not recently developed deglinting protocols should be used to improve available RMI satellite imagery. Local expertise indicates July is the best time to attempt to acquire imagery of RMI. In addition, a portion of Majuro's reef ecosystem has been surveyed using side scan sonar.

Based on input for CMI, MIMRA, and RMI EPA, the following islands/atolls are priority areas:
Majuro* (368 sq km)
Ebeye (need to confirm listing)
Kwajalein (2460 sq km)
Jaluit* (902 sq km)
Wotje (789 sq km)
Bikini*# (726 sq km)
Enewetak# (1054 sq km)
Mili*# (includes Nadikdik; 906 sq km)
Alinginae*#(157 sq km)
Rongelap*# (1116 sq km)
Ebon# (137 sq km)

Likiep* (490 sq km)
Arno (459 sq km)
Namu (485 sq km)
RMI northern atolls (need specific names)
*- coral ecosystem monitoring activity by RMI EPA occurs here.
- proposed World Heritage site.

The area of all locations listed above is approximately 10,050 sq km. The area of islands and atolls where RMI EPA has conducted monitoring is 4,670 sq km. Excluding the deep lagoons associated with many RMI atolls, EPA estimates the coral ecosystem area at 2,147 sq km.

There is considerable coral ecosystem monitoring underway at numerous locations in the RMI. The College of the Marshall Islands (CMI) has an extensive program, co-funded by US DOI. Some water quality data are collected as part of the coral ecosystem monitoring efforts. In addition, CMI is looking at the spread of coral diseases and Crown of Thorns starfish outbreaks at some RMI locations. The CMI should coordinate with NOAA's coral disease lab in Charleston, SC.

With this number of sites and the size and logistical challenges associated with working in some of these sites, it may be necessary to further prioritize this list to identify critical sites for coral ecosystem mapping efforts. Costs to produce maps are dependent on size of areas to be mapped and logistical and other expenses. Generally, mapping costs average between $400-$500/sq km.

RMI EPA would like to begin developing benthic habitat maps for locations where satellite imagery already exists. The CD-ROM data product for Guam, Am. Samoa, and the Northern Marianas includes a detailed description of how to develop maps, has a detailed description of the classification scheme used, and includes the Habitat Digitized extension. These capabilities should support EPA's effort to initiate mapping some areas. NOAA will investigate whether or not Miles Anderson from Analytical Laboratories of Hawaii conduct a short training session on Majuro later this year.

RMI has 1 meter pan sharpened imagery of Majuro, and panchromatic 1m portions of Jaluit and Wotje. RMI soon will have 1 m pan sharpened of Ebeye (Kwajalein) , Utrik, Ujae and Wotho. Imagery of Utrik, Ujae and Wotho will be purchased for an ADB Outer Islands Project. EPA has completed land use maps of Majuro using the 1 m pan-sharpened image.

RMI has a Coastal Conservation Act that provides some mandates regarding managing land use planning and zoning. In addition, MIMRA and MEIC have used some conservation legislation to set up some MPAs. There is no enforcement of management rules in these areas. Some mangrove locations are conservation areas as well. There is a need to link these management and conservation areas with area mapping priorities. Some conservation efforts are locally (family) efforts. There is a need to link these conservation efforts to locality mapping priorities as well.

The RMI EPA has been identified as the local Point of Contact (POC) for the mapping effort in RMI. The College of the Marshall Islands is secondary POC for the effort. There also is a GIS Users Group chaired by RMI EPA. The mapping effort will coordinate with the POCs and the GIS working group to develop the MIP and set locale mapping priorities.

RMI Next Steps:

NOAA will draft the Freely Associated States Shallow-water Coral Ecosystem Mapping Implementation Plan, including a section specifically describing requirements for the Republic of the Marshall Islands That draft Plan will be distributed by June 1, 2005 to the participants of the meeting as well as other interested individuals. Comments will be requested by June 20, 2005. Comments received will be incorporated and the final Plan will be distributed. The final Plan will be used as the basis for developing and submitting a proposal the NOAA Coral Reef Conservation Program for funding in FY06.

The Federal Register Notice (FRN) to submit proposals for coral ecosystem monitoring funding through the NOAA Coral Reef Conservation Program will be published on June 1, 2005. Organizations interested in conducing coral ecosystem monitoring should review the FRN and consider submitting a proposal to the NOAA Coral Ecosystem Monitoring Program.

Republic of Palau Shallow-water Coral Ecosystem Mapping Meeting
April 5, 2005
Palau International Coral Reef Center (PICRC)
Koror, Palau

Attending:
Miles Anderson, Analytical Laboratories of Hawaii (ALH)
Mike Aulerio, PALARIS
Tim Battista, NOS
Andy Bauman, OERC, Office of the President
Ed Carlson, NOS
Galbraith Gabriel, Palau Automated Land and Resource Information System (PALARIS)
Yimnang Golbuu, Palau International Coral Reef Center (PICRC)
Theo Isamu, Bureau of Marine Resources, Palau Government
Sebastian Marino, Protected Area Network
Irene Mercador-Guzman, PALARIS
Mark Monaco, NOS
Steve Rohmann, NOS
Phoebe Sengebau, Marine Conservation Society
Darlynne Takawo, PALARIS
Jenny Waddell, NOS

Through a combined effort by JICA (Japan International Cooperation Agency), PALARIS, PICRC, and NOAA, high-resolution IKONOS satellite imagery has been obtained for the entire land and barrier reef area of the main islands of Palau. This includes Babeldaob, Koror, the southern islands of Peleliu and Anguar, and the northern islands of of Kayangel. High-resolution imagery has not been purchased for Velasco Reef. Moderate resolution Landsat imagery is available for this area, however. Similarly, Landsat imagery is available for Palau's southwestern islands and atolls (i.e., Helen Reef, Tobi, Fana, Sonsorol, Merit, and Puloanna). Preliminary costs for mapping these southwestern areas using high-resolution satellite imagery and visual interpretation are approximately $220,000.

The license for all the IKONOS imagery has been expanded and the imagery can now be distributed to all interested parties, with the exception of U.S. military agencies. Space Imaging, the company that owns and operates the IKONOS satellite, has produced metadata associated with the collection of the Palau imagery and these metadata will be provided to interested parties.

There sometimes is additional imagery, such as aerial photography, available of an area, such as Palau. For example, in 1994, NOAA conducted an aerial photo mission over much of Palau. These images are valuable, not because they can be used to generate maps, but because they can be used to identify critical areas of interest and may be useful for evaluating change over time in the coral ecosystems. Their vale for mapping is reduced because they are not digital, multispectral data, and because they are not mosaicked, georeferenced data. Many times, the cost of generating digital, georeferenced, mosaics of these images exceeds the cost collecting new imagery.

In cooperation with PICRC and PALARIS, NOAA has collected supplemental GPS ground control data to support the geo-positioning the IKONOS satellite imagery. Using survey grade GPS equipment, several dozen locations throughout the area were geo-positioned to within 2 cm on the earth. These ground control data will be used to georeference the 1-m IKONOS panchromatic (black and white) satellite imagery. The 1-m panchromatic imagery will then be used to georeference the 4-m multispectral (color) imagery. Overall, the geopositioning of the panchromatic imagery will be within 2 m of actual location on the earth and the 4 m multispectral imagery will be geopositioned to within 5 m of actual location on the earth. NOTE: because a high quality, recent Digital Elevation Model (DEM) is currently not available for

Palau, orthorectification of the imagery will not be performed. The imagery will be georeferenced to the NAD83 ellipsoid at the shoreline.

As part of the mapping effort, a shoreline is derived from the IKONOS imagery. This shoreline is not an official NOAA representation of shoreline (there is no tide control and no reference to a tidal datum). Vegetation associated with the shoreline, such as mangrove, is included as emergent vegetation.

The mapping effort will require support from local management and conservation organizations. As was the case with the collection of GPS ground control, there will be a need for various types of logistical and other support (e.g., boats and boat drivers) to ensure success in mapping Palau. There also may be a need to identify local coral ecosystem experts to participate in field surveys. NOAA fully recognizes that considerable expertise exists locally and needs to be used as part of the mapping effort. PALARIS will lead a Palau mapping Steering Committee and will involve other agencies in MIP review. NOAA will revise the MIP based on Steering Committee input.

The development of the Freely Associated States Shallow-water Coral Ecosystem Mapping Implementation Plan, especially that component of the Plan related to Palau, will require that time top review and provide comments to the draft Plan. NOAA will complete the initial drafting and editing of the Plan.

There is a need to identify areas in Palau that can be considered typical of the types of habitats found around the islands. The Palau Mapping Steering Committee needs to identify these test areas. These typical areas will be used to develop the test area benthic habitat maps and will form the basis for mapping other areas throughout Palau. As indicated above, local expertise will provide critical input on the identification of these typical areas. In total, approximately 150 sq km of these typical areas need to be identified. The estimated total area of Palau (i.e., Babeldaob, Koror, and nearby islands and atolls) is 2,350 sq km. Also, Helen Reef (approximately 170 sq km) was mentioned as a priority area where habitat characterization is needed.

There is a need to review the existing classification scheme and modify as needed to incorporate unique habitats found in Palau. The scheme was developed especially for use with high-resolution satellite imagery and a one (1) acre (4,046 sq m) Minimum Mapping Unit (MMU). Decreasing the MMU to, e.g., 0.5 acre (2,023 sq m), increases the time to both generate maps and assess their accuracy. NOAA's experience to date has been that most management and regulatory agencies can work with 1-acre MMU sizes. If more detailed mapping is required this can be accomplished on an as needed basis. NOAA will coordinate the accuracy assessment effort either through the Hawaii Institute of Marine Biology or a group in Palau.

There was some interest in obtaining bathymetry for Palau. While some bathymetry data (e.g., LIDAR) have been collected for selected areas in Palau, a complete bathymetry data set does not exist. The cost of acquiring multibeam data and making a bathymetry map is beyond the scope of this MIP. In places where the seafloor is visible, estimated depth (a surrogate for bathymetry) can be derived from Landsat or similar satellite imagery. These estimated depth data are gross approximations however, and are unsuitable for navigation.

Palau Next Steps:

NOAA will draft the Freely Associated States Shallow-water Coral Ecosystem Mapping Implementation Plan, including a section specifically describing requirements for the Republic of Palau. That draft Plan will be distributed by June 1, 2005 to the participants of the meeting as well as other interested individuals. Comments will be requested by June 20, 2005. Comments received will be incorporated and the final Plan will be distributed. The final Plan will be used as the basis for developing and submitting a proposal the NOAA Coral Reef Conservation Program for funding in FY06. Please be sure to forward the draft MIP to key representatives who were unable to attending the meeting.

The Federal Register Notice (FRN) to submit proposals for coral ecosystem monitoring funding through the NOAA Coral Reef Conservation Program will be published on June 1, 2005. Organizations interested in conducing coral ecosystem monitoring should review the FRN and consider submitting a proposal to the NOAA Coral Ecosystem Monitoring Program.

Appendix 1. A list of organizations and individuals who provided input to the development of the Freely Associated States Shallow-water Coral Ecosystem Mapping Implementation Plan.

NOAA convened meetings in Palau, Pohnpei, and Majuro in April 2005 to gather information from organizations and individuals responsible for management and conservation of the FAS's coral ecosystems. Participants in those meetings, as well as other interested individuals, are provided in this list.

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Appendix 2. Generalized procedures for generating a benthic habitat map from high-resolution satellite imagery.

Mapping the shallow-water (generally, < 30-40 m) benthic habitats of the islands and atolls of the Freely Associated States requires high quality, georeferenced imagery. The NOAA Coral Ecosystem Mapping Team has used commercially available, high-resolution IKONOS satellite imagery to successfully map benthic habitats of Hawaii, American Samoa, Guam, and the Northern Marianas.

Commercially available, high-resolution satellite imagery is particularly useful when mapping remote areas. Using a combination of high-resolution imagery for priority areas and moderate resolution imagery for remaining locations, the NOAA Coral Ecosystem Mapping Team believes maps of the FAS's coral ecosystems can be produced.

Once the imagery is obtained, the procedures described below are followed to generate benthic habitat maps.

<u>Orthorectification</u>

During orthorectification, digital imagery is processed using algorithms that eliminate each source of spatial distortion. The result is a georeferenced digital mosaic of several imagery scenes with uniform scale throughout the mosaic. After an orthorectified mosaic is created, visual interpreters can accurately and reliably delineate the boundaries of features in the imagery as they appear on the computer monitor using a software interface such as the NOAA Habitat Digitizer. Through this process, natural resources managers and researchers are provided with spatially accurate maps of habitats and other features visible in the imagery.

Mosaicking the Imagery

Georeferencing/mosaicking of the imagery is performed using several image analysis software programs, such as PCI OrthoEngine or Erdas OrthoBase. Dependng on which satellite is used, the imagery is initially orthorectified using the RPCs, then further orthorectified with supplemental GPS ground control and corrected for terrain displacement using the Digital Elevation Model data where available. When multiple scenes are available for a given locale, these scenes are collectively incorporated into the orthomosaic using mathematical bundle adjustments. Each scene is exported as a separate orthorectified file for further image processing. In addition, the best portions of each scene are selected for creation of the final "cloud-free" mosaic. Portions of each scene are selected to minimize sun glint, cloud interference, turbidity, etc. in the final mosaic. Where possible, parts of images obscured by sun glint or clouds are replaced with cloud/glint free parts of overlapping images. As a result, most mosaics have few or no clouds or sun glint obscuring bottom features. However, in some cases, clouds, sun glint, or turbid water areas cannot be replaced with overlapping imagery. In these areas, such obstructions are minimized, but cannot be eliminated completely, resulting in unmapped areas.

Ground Control Points (GCPs) for Georeferencing

Fixed ground features, such as the corners of buildings or docks, visible in the imagery are selected for ground control points (GCPs), which are then used to georeference the imagery (i.e., link the image pixels to a real world coordinate system such as Universal Transverse Mercator). NOAA's National Geodetic Survey (NGS), the U.S. Geological Survey, and other organizations use survey quality GPS equipment to gather ground control data. Typically, GCPs are collected to ensure horizontal accuracy to within 5 cm of their location on the earth. Once GCPs are measured, they can be differentially corrected to the closest Continuously Operating Reference System (CORS) location, which further assures their positional accuracy.

GCPs need to be obtained for a wide distribution of locations points throughout the imagery whenever possible, since this results in the most accurate registration throughout each image. Only ground control points for terrestrial features can be collected and used. Because of positional distortion caused by the water column and the difficulty in obtaining precise positions for submerged features, GCPs in the water cannot be used to position imagery.

Image-to-Image Tie-Points

Image to image tie-points (distinct features visible in overlap areas of each frame such as street intersections, piers, coral heads, reef edges, and bridges) are then used to further co-register the imagery, especially for photos taken over open water where ground control points are not available. Softcopy photogrammetry software has the ability to automatically find such features common to overlapping imagery, but this automated function has mixed results for submerged features.

Image Analysis

Several intermediate, derived products are produced as the satellite imagery is processed for use in producing the benthic habitat maps. First, the raw satellite images are converted from Digital Numbers (DNs) to normalized reflectance. Normalized reflectance (or at-satellite reflectance) converts DNs into standardized, satellite-independent, comparable values. First developed for Landsat satellite imagery, the algorithm used to perform this conversion was modified for IKONOS image processing. As part of the conversion from DNs to at-satellite reflectance, the following equation is used (Green et al. 2000).

R = pi * L/ (Eo cos(theta0) 1/r 2)

L = radiance (from calibration provided by Space Imaging)
r = earth-sun distance in Astronomical Units
theta0 = the solar zenith angle
Eo = the mean solar exo-atmospheric irradiance in each band. (A convolution of the spectral response and solar radiation from Neckel and Labs (1984) was used to get Eo.)

The acquisition angles (ephemeris data) of the satellite relative to the ground at the time of image acquisition are also used to position the imagery. Calibration coefficients for the satellite are used to calculate at-satellite radiance, which is then transformed to reflectance. The normalized reflectance imagery is then transformed into water reflectance (or the signal < 10 cm above the water surface). Water reflectance uses the near-infrared band to remove radiance attributed to atmospheric and surface effects (Stumpf et al. 2003). Water reflectance estimates how the signal (photons) received by the satellite is diminished as it passes through the atmosphere on the way down to the water-atmosphere boundary and on the way back up to the satellite after the signal leaves the water-atmosphere boundary. Water reflectance also estimates how the signal at the satellite is diminished by water vapor, clouds, specular effects at the water surface (wave surface glint), and other signal-absorbing and diffusing conditions.

Finalizing the Process

Final mosaics are created in “img” file format (georeferenced image file) with a Universal Transverse Mercator (UTM), projection, North American Horizontal Datum of 1983 (NAD83). These mosaics are color-balanced in order to provide the most seamless, cloud-free product available for creating benthic habitat maps.

Minimum Mapping Unit

A minimum mapping unit—usually described in sq m—is the smallest feature (e.g., an individual patch reef) or aggregate of features (e.g., scattered coral heads on hard bottom) that is delineated using a given source of imagery (e.g., moderate-resolution or high-resolution satellite imagery) and mapping protocol (e.g., computerized image analysis or visual interpretation). Deciding on an MMU is a balance between providing maps with sufficient detail that meets the requirements of people using them and the time and cost to make the maps.

The NOAA Coral Ecosystem Mapping Team has used a MMU of ~4,047 sq m (~1.0 acre; 0.004 sq km) and visual interpretation to map the benthic habitats in Puerto Rico, US Virgin Islands, Hawaii, American Samoa, Guam, and the Northern Marianas. An MMU of ~100 sq m (0.0247 acre; 0.0001 sq km) and semi-automated image analysis was used when mapping the benthic habitats of the Northwestern Hawaiian Islands. In some areas, such as Buck Island Reef National Monument in St Croix, U.S. Virgin Islands, maps with an MMU of 100 sq m also have been produced.

Digitizing Benthic Habitats

The following procedures are relevant to benthic habitat mapping regardless of the where the imagery or other source data (e.g., Landsat or IKONOS imagery) comes from. Some steps described in these procedures may require modification, depending on the type of digital data being used.

Individual georeferenced mosaics are loaded into ArcView with the NOAA Habitat Digitizer and Image Analysis extensions activated. The NOAA habitat digitizer ArcView extension can be downloaded from the following URL: http://biogeo.nos.noaa.gov/products/apps/digitizer/. ArcView’s Image Analysis extension allows each image to be easily manipulated to optimally adjust contrast, brightness, and color. The user sets the MMU in the Habitat Digitizer extension. As discussed previously, the MMU is set based on the source of the imagery, the scale of the maps desired, the costs of completing the maps, and the objectives of the mapping project. Depending on what the MMU is set to, some features visible in the imagery, such as small isolated patch reefs and sea walls that, while important features, are quite small and beyond the scope of this mapping project.

Digitizing scale is typically set to 1:6,000 in the Habitat Digitizer. Experimentation indicated that digitizing at this scale optimizes the trade-off between positional accuracy of lines and time spent digitizing. In general, line placement conducted while zoomed in at large scales results in excellent line accuracy and detail but can be quite time consuming. Conversely, while zoomed out, lines can be drawn quickly but lack both detail and positional accuracy.

Determining the Optimum Digitizing Scale

Results of an experiment conducted during benthic habitat mapping of the Caribbean were used to determine the optimum digitizing scale to maximize accuracy and minimize map production time. In the Caribbean digitizing experiment, a 25 acre area composed of a variety of habitat types was mapped at 1:1,500, 1:3,000, 1:6,000, and 1:12,000 on-screen scale (scale that the image appears on the computer monitor). Five replicates were conducted at each scale. Each trial was timed so we could evaluate the influence of mapping scale on production time. Resulting maps were evaluated for deviations in polygon detail relative to the map digitized at a 1:1,500 scale. At 1:1,500, individual pixels are clearly discernible allowing highly detailed and accurate maps to be created by closely following the contours of even the most convoluted habitat boundary. Additional increases in zoom do not result in an increase in map detail and accuracy since individual pixels are already visible at 1:1,500. Therefore, the map created at a 1:1,500 scale was used as a reference against which to compare maps digitized at scales of 1:3,000, 1:6,000, and 1:12,000.

The results of this experiment indicated that there is no appreciable loss in polygon detail and accuracy by digitizing at 1:6,000 while mapping time was dramatically reduced. Therefore all polygons were digitized at this scale except when subtle habitat boundaries were not easily discernible at 1:6,000 and zooming out to a more broad scale was required to place boundaries correctly. In this case, digitizing generally took place at a scale of approximately 1:10,000.

Visual Interpretation

Using the Habitat Digitizer, habitat boundaries are delineated around seafloor benthic habitat feature signatures (e.g., areas with specific color and texture patterns) in the orthorectified mosaic corresponding to habitat types in the Classification Scheme. This is often accomplished by, first, digitizing a large boundary polygon such as the habitats that compose the shoreline and then appending new polygons to the initial polygon or splitting out smaller polygons within. Each new polygon is attributed with the appropriate habitat designation according to the classification scheme. It is believed that the positional accuracy of polygon boundaries is similar to that of the mosaics since delineation is performed directly on the digital imagery. Brightness, contrast, and occasionally color balance of the mosaic are manipulated with Image Analysis to enhance the interpretability of some subtle features and boundaries. This is particularly helpful in deeper water, where differences in color and texture between adjacent features tend to be subtle and boundaries can be more difficult to detect. Particular caution is used when interpretation is performed from altered images, since results from color and brightness manipulations can sometimes be misleading.

The visual interpreter is typically provided with a series of imagery files to aid in delineating and attributing polygons. In the case of IKONOS imagery, these include the unmodified multispectral scenes (4 m pixel imagery), normalized reflectance scenes (4 m pixel imagery), and pansharpened, multispectral scenes (1 m pixel imagery). Additional collateral information, including previously completed habitat maps, NOS nautical charts, LIDAR data, and other descriptive references dealing with benthic and coastal habitats of the area, are used to assist with image interpretation.

Optical Observation Imagery

Once collected, the bathymetric and imagery data can be used, in combination with optical validation data—actual imagery—of the seafloor, to derive benthic habitat maps. Direct observations and optical technologies are generally used to observe and collect validation data—imagery—of the seafloor. Remotely operated vehicles (ROVs), Autonomous Underwater Vehicles (AUVs), manned submersibles, Laser Line Scanning (LLS) technologies, drop cameras, as well as SCUBA divers can collect imagery of the seafloor. SCUBA divers are generally limited to collecting imagery in shallow water (less than 15 fm). ROVs, AUVs, drop cameras, LLSs, and manned submersibles are able to collect imagery in both shallow and deep water. The challenge is to determine how many observations are needed in order to adequately characterize a region of the seafloor. When the seafloor is relatively homogeneous, fewer images may be needed. A complex seafloor, with outcrops or high rugosity, may require many observations for adequate characterization.

A thorough evaluation of available bathymetry data should be conducted as part of a mission to acquire seafloor optical observation imagery. The evaluation can help establish priority areas and improve efficiency. In addition, every effort should be made to piggyback—use ships of opportunity—on other survey missions.

The costs of acquiring optical observation data vary widely. A ship equipped with an ROV or manned submersible may cost as much as $30,000/day. Safe and efficient operation of these vehicles is contingent on having accurate, detailed bathymetric data. Prioritization of areas to be surveyed also is important. Simple drop cameras or ROVs are much less expensive (~$50,000/system), can readily be used down to ~1000+ m, and are easily deployed from a variety of vessels. Diver observations and photographs are inexpensive and the most common source of validation data in depths down to ~15 fm, but are depth and in-the-water time limited and can be dangerous, particularly in remote areas where no diver facilities, such as hyperbaric chambers, are available.

Ground Validation

Following careful evaluation of the source data (e.g., satellite imagery), and in some cases creation of a "first draft" habitat map through the process outlined in the previous section, selected field sites are visited in the field for typological validation. Selection of field sites where this validation occurs includes: areas in the data with confusing or difficult to interpret signatures; transects across many representative habitat types occurring in different depths and water conditions; a survey of the zones; and confirmation of preliminary habitat delineations if a first draft was produced.

Navigating to field sites is accomplished in a variety of ways including uploading position coordinates from the mosaic into an onboard GPS and navigating to those waypoints using an onboard PC connected to GPS allowing navigation using digital nautical charts or the mosaic and actual visual navigation using landmarks visible in the imagery.

Whenever possible, field activities are conducted in partnership with local experts. Available data (e.g., satellite imagery) and, when available, draft benthic delineations are used in the field to facilitate comparison of feature signatures in the data to actual habitats at each site. Individual sites are visually evaluated by snorkeling and free diving or directly from the boat in shallow, clear water. Habitat transitions are evaluated by swimming transects across habitat types to further guide placement of polygon boundaries.

Habitat type(s), zone, approximate depth, position (GPS), image number, and other descriptive information are recorded at each site. Field data for each site are then compiled into a text table with a latitude/longitude field to allow overlay of the field information on the mosaic and habitat polygons. These data are used as Ground Validation Points. Where depth and water clarity permit, satellite imagery is used to navigate across multiple bottom features allowing continuous confirmation of habitat types and transitions between each site.

Once the field data are collected and processed, polygon boundaries and habitat classifications are created or revised where necessary on the draft map, and zone attributes are assigned to each polygon using the Habitat Digitizer. This draft of the habitat maps is then reviewed and revised with the guidance of a panel of local experts at peer review sessions held at several locations throughout the region and over the Internet. Review session participants typically include members of the local research and management community.

During these peer review sessions, particular attention is given to polygons labeled as "unknown" and areas not visited during ground truth activities. Revisions based on comments from local experts are then completed and final habitat maps are produced. Thematic accuracy is then assessed for these final maps.

Accuracy Assessment

The thematic accuracy of the habitat information depicted on the map—and derived from source data, such as directly observed or remotely sensed data—is determined by the quantitative process of accuracy assessment. The purpose of accuracy assessment is to identify and quantify errors in the maps by comparing the attributes of the map to reference data at various sites. It is important that the mapmaker know how reliably a given habitat can be classified. This parameter is called "producers accuracy." The users of a map product want to know the percentage of the polygons of a particular class or habitat type that are correctly attributed. This parameter is called "users accuracy." Furthermore, the source data that may be suitable for mapping coral reef habitats can be acquired from a wide variety of platforms and imaging systems, each having its own strengths and weaknesses. It is important to identify the technical merits of each imaging platform, one measure of which is the thematic accuracy of the map products.

To determine the overall accuracy of the mapped product, GIS data prepared by visually interpreting satellite imagery or other digital data is assessed for accuracy using conventional methodologies. Specific areas being mapped are used as test areas for the mapping effort. A statistically robust data set composed of random field habitat observations is collected within the test areas to assess the accuracy of the mapped product. These areas are chosen based on input from the local marine biologists and coral reef managers. These groups provide advice on the location of the most diverse benthic communities and also areas of particular importance, based on management strategies and marine protected areas. The goal of this team is to collect accuracy assessment field data representing as many of the habitats that occur in the region as possible.

The thematic accuracy of all mapped products is determined at both the most general and the detailed levels of the classification scheme, including both the biological cover type and geomorphological structure. A representative number of coral ecosystem test areas are selected based on the diversity of the habitat types and to assure that all benthic habitats throughout the study area are represented. The accuracy of the map of the test area(s) is, therefore, considered a conservative representation of the thematic accuracy of the habitat maps prepared for the entire area.

An accuracy assessment process is designed and executed to quantify the thematic accuracy of the maps generated at all levels of the classification scheme. Statistical analysis methods are applied that have been developed by other researchers (Hudson and Ramm 1987, Congalton 1991, Rosenfield et al. 1982). Typically, for mapping coral ecosystem test areas in southern Florida, 20 to 30 field habitat observations are completed per detailed structure as well as detailed biological cover type. The accuracy assessment results are reported using an error matrix that compares the attribute assigned to a polygon that is generated from the interpretation of the source data with that of the determination from field observation. For an area as large and as diverse as southern Florida, input from local experts will be critical to identify the test areas where accuracy assessment will occur.

Benthic habitat maps of these test areas are generated from the source data (satellite imagery or other digital data). All image interpretation and digitization is conducted by personnel with particular expertise in the location and characteristics of southern Florida's benthic habitats. The field habitat characterization data collection methods for thematic accuracy assessment differed little from the data collected for ground validation. The primary distinction between the two data sets is the method of selection of the field points. Where as the assessment sites for ground validation are selected to specifically investigate habitat types and gradients of spectral signatures in the imagery, a random stratified sampling method is implemented to select field sites to test map accuracy (Congalton 1991).

Subsequent to completion of the second draft coral reef habitat maps, waypoints are generated using a stratified random sampling scheme. Twenty to thirty accuracy assessment waypoints are collected per test area for each detailed structure and detailed cover class encountered. Waypoint files are generated from these points and all waypoints that can be safely accessed are navigated to using a portable GPS unit. Upon arriving at the waypoint, a weighted meter line is dropped, a buoy fastened and site and habitat specific data collection is undertaken. After deployment of the buoy, 100 GPS positions are collected at one-second intervals and are averaged to generate a single position for the sampling site, or waypoint.

Three benthic habitat assessments are conducted at each waypoint. A point assessment is conducted by surveying the one square meter area around the point where the weight dropped. Two area assessments are conducted in an area within a seven-meter radius around the weight. The first assessment identifies the most common habitat type within the area and the second identifies the second most common habitat type within the area. The depth of the site is recorded using a hand held depth sounder. Benthic habitat assessments are made using a glass bottom look box, free diving, or observing from the surface. All diving is conducted by breath holding or snorkeling on the surface. In areas where waves and sea conditions are prohibitive to safely accessing the waypoint by boat, the GPS is placed in a watertight box and swam to the survey point.

Data, including, but not limited to, site ID, depth, most common habitat, zone and assessment method are recorded for each waypoint using the GPS data logger equipped with a custom data dictionary designed to meet the specifications of the Coral Reef Habitat Classification Scheme. At the end of each field day, the data in the GPS data logger are downloaded, differentially corrected to the closest CORS station and seamlessly converted to ArcView GIS format. All hand written descriptions for each waypoint are entered in waterproof notebooks and transferred to the GIS by hand. The total number of benthic habitat characterization waypoints collected is dependent on the size of the MMU, the source of the digital data used as the basis for mapping, and the complexity of the ecosystem as defined by the Classification Scheme.

To maintain objectivity in the analysis of accuracy, an independent team should conduct this work. For example, the Coral Reef Assessment and Monitoring Program (CRAMP) biologists from the Hawaii Institute of Marine Biology from the University of Hawaii at Manoa conducted the accuracy assessment of NOAA's recently completed benthic habitat maps of American Samoa, Guam, and the Northern Marianas. The accuracy assessment point theme and the benthic habitat polygon themes are overlaid on the source data (e.g., satellite imagery) in the GIS. The GIS is used to identify and select all points within the polygons that matched the polygon habitat type. These are set aside as correct calls. The mismatched pairs are closely examined to determine how and why the accuracy assessment points do not match the habitat polygons.

The classification errors that occur between the MMU and size of accuracy assessment areas are accounted for in this analysis. A map classification is not considered incorrect in a case where a seven-meter radius field assessment falls on a habitat feature in the field that is smaller than the MMU. For example, if a field assessment falls on a small patch reef surrounded by sand that is less than the MMU and thus is not mapped, the point is excluded from the accuracy assessment report. Points that fall close to polygon boundaries are all included as it is assumed that the probability of error contributing to false negatives is equal to that for false positives. The habitat type for the portions of the test area that is not interpretable due to cloud cover, glint or water quality is classified as "unknown." The accuracy assessment points that fall within polygons with the habitat type of "unknown" are not included in the accuracy analysis.

Data Processing and Habitat Mapping

Collection of bathymetric, imagery, and optical validation data represents a significant commitment of resources and funds. However, data collection alone does not ensure that benthic habitat maps are produced. A significant commitment of resources and funds also is required to process bathymetry, imagery, and optical validation data and to synthesize these data with the critical biological information (Table 7). The resulting maps are needed to create the complete picture of an ecosystem in order to describe and determine Essential Fish Habitat (EFH) and Habitat Areas of Particular Concern (HAPC). A complete assessment of the cost to process the bathymetric and imagery data, incorporate the validation data, and develop maps suitable for EFH and HAPC characterization and implementation needs to be completed.

Key Trade-offs

Mapping the shallow-water (~0–40 m) benthic habitats of the FAS will require some technologic, geographic, and other compromises to be made. It is unlikely that sufficient funding will be available for the sustained period of time needed to comprehensively map all of southern Florida's shallow-water coral ecosystems. As a result, priorities will need to be established and tradeoffs made. Below are descriptions of some of the tradeoffs that will be considered and how choices about various aspects of benthic habitat mapping, such as sources of data, the size of the geographic to be mapped, the size of the MMU, and the thematic accuracy of the map products affect these tradeoffs.

<u>Source of Data</u>

The cost of acquiring, processing, georeferencing, and mosaicking the imagery used to generate the benthic habitat map varies considerably depending on the source of the imagery. Aerial photography is relatively inexpensive to collect per unit area, but is relatively expensive to georeference (ortho-rectify) and mosaic together in order to generate a map. High-resolution satellite imagery is more expensive to collect per unit area but is less expensive to georeference and mosaic. Digital camera imagery from aircraft also is relatively inexpensive to collect. The cost to georeference and mosaic the imagery tends to fall between those of aerial photography and high-resolution satellite imagery. In areas where traditional remote sensing cannot adequately map the area (for example, in areas with consistent turbidity or deep depth), active sensors such as sonars and LIDAR could be used, but have high associated costs.

<u>Minimum Mapping Unit size</u>

The size of the Minimum Mapping Unit (MMU) can dramatically affect the time required to produce a benthic habitat map of a given area and, as a result, can dramatically affect the cost of producing a benthic habitat map of a given area. Also, the type of technology (e.g., Landsat) that provides the imagery from which the map is generated may have limits on the size of MMU that it can support. Finally, the amount of optical observation information needed to validate the accuracy of the map is directly dependent on the size of the MMU.

Area to be Mapped

As discussed above, the size of the area to be mapped directly affects the level of effort required to acquire imagery, the size of the MMU, and the amount of optical observation information needed, and each of these factors affects the overall cost of producing benthic habitat maps.

Number of Habitat Types

The number of benthic habitat categories—i.e., coral ecosystem complexity—that are classified during the process of generating a map directly affects map production cost. The greater the number of habitat categories defined, the greater the cost of identifying, mapping, and validating the resulting map. Also, the greater the number of benthic habitat categories, the higher the resolution of the imagery required to identify and map the different habitats. Finally, the higher the number of habitat categories mapped, the greater the number of optical observations required to validate the accuracy of the map product.

Thematic Accuracy

Independently evaluating the thematic accuracy of a map of shallow-water benthic habitats is one of the most important aspects of the mapping process. The consensus position among potential users of southern Florida benthic habitat maps is that higher thematic accuracy—at the expense of a smaller MMU—is preferred. The preferred accuracy is 90-95 percent thematic accuracy for major categories of habitat. The collection of optical observations to statistically test the accuracy of a map is directly related to required map accuracy: the higher the required accuracy required, the greater the number of optical observations required to analyze accuracy.

Classification Schemes

A classification scheme for categorizing the various habitat types that will be encountered in South Florida will be developed through inter-agency participation. State, local and other federal agencies, as well as local groups representing fishers, divers, etc. will be invited to participate in classification scheme development workshops. NOAA has successfully directed the development of classification schemes for Puerto Rico and the Virgin Islands (Kendall et al, 2003) and the main Hawaiian Islands (Coyne et al., 2001), through consensus-building workshops. The classification scheme for mapping southern Florida's shallow-water benthic habitats also will be developed through a consensus building process.

NOAA Classification Scheme

A hierarchical classification scheme was created to define and delineate shallow-water benthic habitats. The classification scheme was influenced by many factors including: requests from the management community, NOS's coral reef mapping experience in the Florida Keys and Caribbean, existing classification schemes for the Pacific and Hawaiian Islands (Holthus and Maragos 1995; Gulko 1998; Allee et al. 2000), other coral reef systems (Kruer 1995; Reid and Kruer 1998; Lindeman et al. 1998; Sheppard et al. 1998; Vierros 1997; Chauvaud et al. 1998; Mumby et al. 1998; Kendall et al. 2001), quantitative habitat data for the U.S. Pacific Territories, the minimum mapping unit (MMU - 1 acre for visual imagery interpretation), and analysis of the spatial and spectral limitations of IKONOS or Landsat satellite imagery.

The hierarchical scheme allows users to expand or collapse the thematic detail of the resulting map to suit their needs. This is an important aspect of the scheme as it will provide a "common language" to compare and contrast digital maps developed from complementary remote sensing platforms. Furthermore, it is encouraged that additional hierarchical categories be added in the resulting geographic information system by users with more detailed knowledge or data for specific areas. For example, habitat polygons smaller than the MMU can be delineated, such as reef holes found in parts of a marine region, or habitat polygons delineated as colonized pavement using this scheme could be further attributed with health information (i.e., bleached, percent live cover) or species composition (i.e., Porites, Montipora).

The hierarchical scheme was prepared through consultation, meetings, and workshops that included key coral reef biologists, mapping experts, and professionals throughout the Pacific territories. Modifications were made throughout the development process based upon feedback provided by workshop participants and other contributors. Additional modifications were made during the mapping process to ensure that each category definition reflected the intended habitats and zones encountered in the field as accurately as possible. For instance, the separation of biological cover and geomorphological structure in the present scheme represents a significant evolution of previous versions of the classification schemes developed for mapping of the Florida and the U.S. Caribbean.

Classification Scheme Description

The classification scheme defines benthic habitats on the basis of three attributes: large geographic "zones" which are comprised of smaller geomorphological structure and biological cover of the reef system. Every polygon on the benthic community map will be assigned a structure and cover within a zone (i.e., uncolonized sand in the lagoon, or coral on aggregate reef on the bank). Biological cover and geomorphological structure are further defined by three density classes. "Zone" indicates polygon location, "biological cover" indicates the predominant biological component colonizing the surface of the feature, and "geomorphological structure" indicates the physical structural composition of the feature. The description of each cover and structure includes an example image. The zone descriptions include schematic descriptions. The hierarchical scheme was prepared through consultation, meetings, and workshops that included key coral reef biologists, mapping experts, and professionals throughout the island territories. The separation of biological cover and geomorphological structure in the present scheme represents a significant evolution of previous versions of the classification schemes developed for mapping of the Caribbean and Hawaiian Islands. For more detailed descriptions of this classification scheme, please visit: http://biogeo.nos.noaa.gov/products/us_pac_terr/htm/methods.htm