

## A Strategy to Map State, Commonwealth, Territory, and Freely Associated State Coral Reef Ecosystems in the U.S.

Coral Reef Task Force  
Mapping and Information Synthesis Working Group  
March 5-6, 1999

### Goal

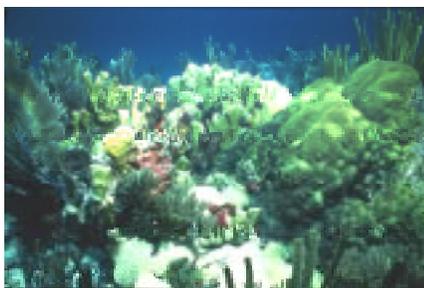
*Produce comprehensive digital coral reef ecosystem maps for all States, Commonwealths, Territories and Freely Associated States of the U.S. in seven years.*

### Why are coral reef ecosystem maps needed now?

Coral reef ecosystems in both the Atlantic and Pacific are being negatively affected by natural and human stresses. Severe weather patterns, abnormal fluctuations in sea surface temperature, and instances of coral disease are disrupting reef growth or killing reefs outright.

Overfishing and destructive fishing practices also threaten these resources. Coral reefs provide important fishery resources, and thousands of people depend on them for food. In addition, the collection of marine aquarium organisms using unsustainable practices has dramatically affected some coral reef areas.

The single largest threat—rapidly increasing population—is responsible for the greatest stress on the reefs.



**Photo 1. Coral reefs are important habitat for thousands of marine species.**

Sediment and other pollutants running off of land from farming activities, urbanization, and sewage disposal can devastate coral reef ecosystems. Ship groundings and derelict fishing gear also damage reefs.

These factors affect not only U.S. coral reefs in the Atlantic and Pacific, but reefs worldwide, and demonstrate a need to focus attention on coral reef health. Efforts to assess the impacts of natural and human stresses on the reefs require detailed, comprehensive maps. Detailed maps can be used to:

- Recognize the importance and location of historic cultural fishing areas;
- Develop better marine environmental education programs that stress the importance of coral reef ecosystems and their conservation;
- Locate marine hazards to avoid navigation-related impacts;
- Evaluate and identify areas where coral reef management efforts are needed immediately;
- Characterize and evaluate the status of the essential habitat of commercial and non-commercial marine species;
- Develop long-range policies for the sustainable management of commercial fish stocks;
- Designate and develop management strategies for marine protected areas;
- Evaluate and identify areas where intensive monitoring is needed;
- Predict and model the potential damage to populated areas caused by severe weather;
- Support activities that evaluate the success of watershed-based water quality management strategies;
- Support activities that evaluate the success of urban and agricultural

### Need for Partnerships

Producing digital coral reef map products depends on substantial levels of investment and the development of local and higher-level partnerships. Partnerships are essential to the reaching this goal, since no single organization has the resources to complete such an extensive mapping activity. Partnerships must be developed that include the native islanders who live on and use the land and water. Partnerships among the native islanders and the federal and state agencies, who are the trustees and stewards of many of the coral reefs, also need to be developed. Partnerships also are needed among the federal and state agencies that manage the wildlife refuges, parks, and marine sanctuaries.

- land use management policies;
- Provide a baseline for damage assessment and restoration efforts;
- Recognize the role Federal stewardship has in defining resource management responsibilities for Pacific Island coral reefs; and
- Develop capabilities to conduct long-term change analyses.

### What Needs to be Done Now?

The following three activities—and the private and public partnerships that help make them happen—are critical to reaching the overall goal of mapping coral reef ecosystems.

1. Complete a comprehensive inventory of available digital and other coral reef maps for the States, Commonwealths, Territories, and Freely

*Associated States of the U.S. in the Pacific (Appendix 1).* The inventory, which gathers information from both site visits and questionnaire responses, will provide a clear picture of where coral reef information is available and where gaps exist. To date, limited information has been provided for some of the Pacific Islands. The available information indicates that critical gaps exist in the Pacific. Characterizing these gaps will provide the basis for developing a strategy to map the Pacific—an area that, by most estimates, has 80-85 percent of the U.S. coral reefs.

2. *Assure completion of the Puerto Rico and U.S. Virgin Island coral reef ecosystem mapping activity (Appendix 2).* This activity will produce a comprehensive digital coral reef-map product. It also will provide valuable insights about the use of remote sensing technologies to map coral reef ecosystems; technologies that can be used in the Pacific to conduct more efficient and cost-effective coral reef mapping. These efforts—and the partnerships needed to ensure their success—are critical to the overall goal of mapping U.S. coral reef ecosystems in the Caribbean.

### A Mapping Model

Maps are visual representations of spatial data and are designed to convey information. Maps also are a critical component of any activity to study, manage, conserve, or protect coral reef ecosystems. A widely-accepted model of the type of maps needed is the *Benthic Habitats of the Florida Keys* CD-ROM (Appendix 3). Over 900 of these CDs have been distributed. It provides an example of a mapping capability and the starting place for the development of better, more complete tools to meet the coral reef mapping needs of researchers, managers, and concerned citizens.

3. *Develop a detailed plan to map the remaining States, Commonwealths, Territories, and Freely Associated States coral reef ecosystems in the U.S.* The plan will incorporate and build on the knowledge gained and technologies used to map Florida Keys and Caribbean coral reefs. It also will address the data gaps identified by the inventory. One key component—a standardized classification scheme for Pacific reef ecosystems—already exists. The plan will include detailed activity descriptions.

### How Can This be Accomplished?

Mapping all of the Pacific and remaining Caribbean coral reef ecosystems is a daunting task. Two elements hold the key to being successful: Partnerships and Technologies. Partnerships with local, state, and federal agencies that have a stake in managing and protecting these areas are one key to the success of this mapping activity. A partnership between the State of Florida and NOAA was essential to completing the Florida Keys mapping project. Partnerships are the foundation of the ongoing Caribbean coral reef mapping effort. Partnerships will be forged for coral reef mapping in the Pacific. Partners are needed who can provide:

- Funding;
- Technical expertise;
- Cultural and historical knowledge; and
- In-kind services, such as boat support or data processing.

### Partnerships

The following potential partners have been identified in the Pacific region. Other partners are welcome.

#### Non-government partners:

- Ahupua'a Action Alliance, Hawaii
- Save Our Seas, Hawaii
- Belt Collins Hawaii
- University of Hawaii at Manoa
- Waikiki Aquarium
- Bishop Museum of Natural Sciences

### Some Pacific coral reef mapping activities that must be initiated:

- Identify and enlist the help of local coral reef mapping experts;
- Identify partners to participate in the mapping process;
- Resolve datum inconsistencies in the Pacific region;
- Plan and conduct any required aerial photography missions;
- Identify and test remote sensing technologies to map Pacific reefs;
- Design and develop the Pacific remote sensing mission;
- Produce a set of digital Pacific coral reef maps;
- Produce a set of digital Pacific Island shoreline maps;
- Produce a set of digital shallow-water (less than 100 meters) bathymetry maps;
- Design and implement a capability to deliver the data products to the user community; and
- Build and implement a local capacity to map, analyze, and manage coral reef ecosystems.

- The Nature Conservancy of Hawaii
- Sierra Club
- Northern Marianas College
- University of Guam
- Pacific Basin Development Council

#### State, Commonwealth, Territory, and Freely Associated State partners:

- Hawaii Department of Lands and Natural Resources
- Hawaii Department of Business, Economic Development and Tourism
- Government of American Samoa
- National Park of American Samoa
- American Samoa Department of Marine & Wildlife Resources
- Commonwealth of the Northern Mariana Islands, Coastal Resources Management Office
- Commonwealth of the Northern Mariana Islands, Division of Environmental Quality
- Commonwealth of the Northern Mariana Islands, Governor's Office

- Commonwealth of the Northern Mariana Islands, Department of Lands and Natural Resources
- Guam Department of Agriculture
- Government of Guam, Bureau of Planning
- Hawaii Office of Hawaiian Affairs

#### Federal partners:

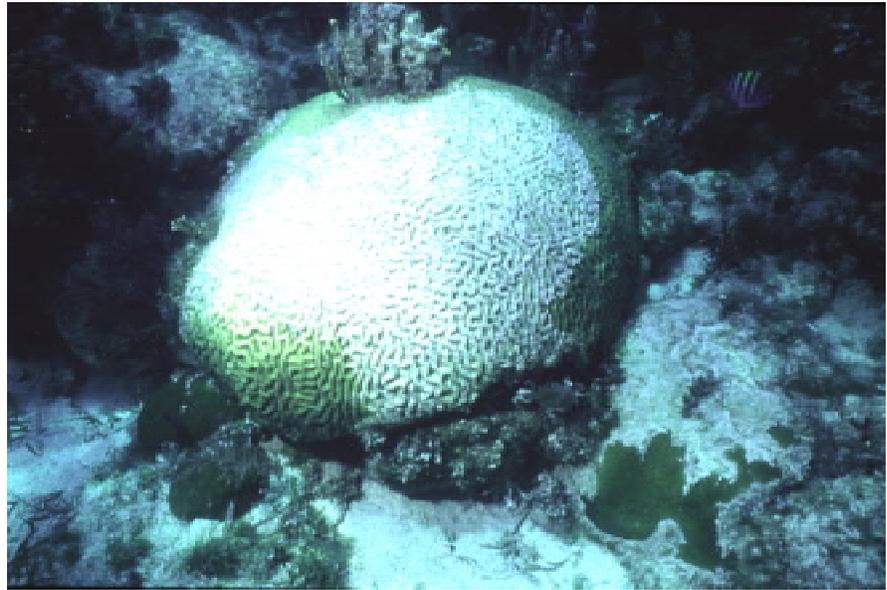
- U.S. Geological Survey
- U.S. Fish and Wildlife Service
- National Park Service
- Federal Emergency Management Agency
- Western Pacific Fishery Management Council
- National Ocean Service, NOAA
- National Marine Fisheries Service, NOAA
- National Environmental Satellite, Data, and Information Service, NOAA
- Pacific Disaster Center
- Department of Defense
- National Aeronautics and Space Administration
- Environmental Protection Agency

#### **Technologies**

Technology is the second key to successfully mapping Pacific coral reefs. Both existing and new technologies need to be investigated. Instruments for mapping shallow (0–20 meters) and deep water (20–50 meter) coral reefs will be needed. Extensive ground-truthing will be needed to properly calibrate these instruments. Numerous federal, state and private organizations have used or, currently, are using these technologies to collect bathymetry, and to characterize, map, and assess the health of coral reefs in



**Photo 2. Overfishing poses a significant threat to Pacific coral reef ecosystems.**



**Photo 3. Bleaching affects coral reefs in both the Atlantic and Pacific.**

selected areas. This valuable work should form the basis for expanded mapping activities. Some existing technologies in use include:

- Airborne Light Detection and Ranging (LIDAR) systems to map shallow water bathymetry;
- In-situ side-scan and multi-beam SONAR systems to map coral reef ecosystems;
- In-situ multispectral systems to map corals and evaluate coral health;
- Airborne hyperspectral systems to map coral reef ecosystems; and
- Satellite hyperspectral systems to map reef ecosystems.

New remote sensing technologies hold promise for providing comprehensive, moderate- to high-resolution coral reef maps. They also hold promise as tools for conducting both short-term (2–5 years) and long-term (5–20 years) coral reef assessments. All of these technologies will require calibration and ground-truthing before reliable coral reef maps can be produced. Some of the new technologies include:

- The 15 meter resolution, panchromatic Landsat-7 satellite;
- The 1 meter panchromatic and 4 meter multispectral ORBIMAGE satellite;

- The Naval EarthMap Observer (NEMO) hyperspectral satellite to be launched in 2000; and
- The National Technical Means satellites.

#### **Long-term Coral Reef Monitoring**

Remote sensing technology can be used to produce coral reef maps at a given point in time and to conduct long-term coral reef monitoring. Long-term monitoring requires that stable, well-calibrated instruments and analytical methods (i.e., expert systems) exist. The technologies need to be able to detect changes in the coral reefs that are not caused by variability in the overlying water column. Activities will need to continue that assess the ability of both existing and new technologies to conduct long-term coral reef ecosystem monitoring.

#### **Preliminary Mapping Product Development Schedule**

Figure 1 provides a series of coral reef-related mapping activities and estimates of the time needed to conduct them. Two of the activities have already been initiated. Depending on priorities, several other activities—such as developing digital shoreline for

several Pacific islands—could be started in the first year. Other activities can be started or delayed based on future priorities. For example, the northwest Hawaiian islands might be a higher priority for mapping than the main islands.

**Summary**

This strategy is a critical first step to identify priorities for producing comprehensive digital coral reef ecosystem maps for all States, Commonwealths, Territories, and Freely Associated States of the U.S. in seven years. The knowledge and expertise gained from the recently completed

Florida Keys mapping effort and the ongoing Caribbean mapping effort are vital to ensuring that the best technologies are used to produce the most cost-effective Pacific region coral reef maps in the least amount of time. The strategy shows that decisionmakers will need to consider available fiscal and other resources when prioritizing where to map coral reefs. No single agency is capable of mapping Pacific coral reefs. This strategy identifies the potential partners who, by pooling resources, have the capacity to generate such maps.

**Mapping and Information Synthesis working group participants:**

Non-government:

- Ahupua'a Action Alliance, Hawaii
- Save Our Seas, Hawaii
- Belt Collins Hawaii
- University of Hawaii at Manoa
- University of the Virgin Islands
- Waikiki Aquarium
- Bishop Museum of Natural Sciences
- The Nature Conservancy of Hawaii
- Sierra Club
- World Resources Institute
- Center for Marine Conservation
- College of the Northern Marianas
- University of Guam
- University of North Carolina, Wilmington
- Pacific Basin Development Council

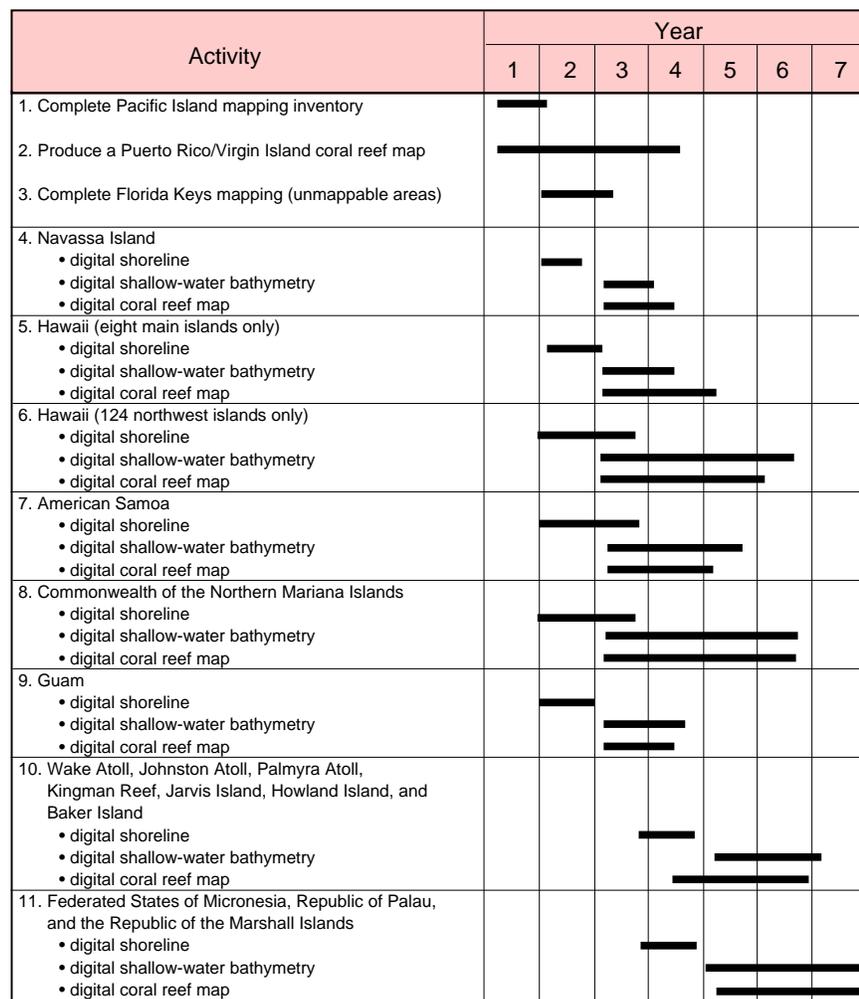
State, Commonwealth, Territory, and Freely Associated State:

- American Samoa, Governor's Office
- American Samoa Department of Marine and Wildlife Resources
- Hawaii Department of Land and Natural Resources
- Hawaii Department of Business, Economic Development and Tourism
- National Park of America Samoa
- American Samoa Department of Marine & Wildlife Resources
- Commonwealth of the Northern Mariana Islands, Coastal Resources Management Office
- Commonwealth of the Northern Mariana Islands, Division of Environmental Quality
- Commonwealth of the Northern Mariana Islands, Governor's Office
- Commonwealth of the Northern Mariana Islands, Department of Lands and Natural Resources
- Guam Department of Agriculture
- Government of Guam, Bureau of Planning
- Guam Coastal Management Program
- Hawaii Office of Hawaiian Affairs
- Puerto Rico Department of Natural and Environmental Resources

Federal:

- U.S. Geological Survey
- U.S. Fish and Wildlife Service
- National Park Service
- Federal Emergency Management Agency
- Western Pacific Fishery Management Council
- National Oceanic and Atmospheric Administration
- Department of Justice
- Agency for International Development
- Department of Agriculture
- Pacific Disaster Center
- Department of Defense
- National Science Foundation
- National Aeronautics and Space Administration
- Environmental Protection Agency

**Figure 1. Estimated time needed to complete coral reef and other mapping activities.**



Except for 1 and 2, numbers do not imply any activity priority. Time lines also do not indicate activity priority.

## Appendix 1. A Preliminary Assessment of Pacific Islands Digital Coral Reef Mapping Information.

*A preliminary assessment of availability of digital coral reef map information was conducted in the Pacific region. The state, commonwealths, territories, and freely associated states in the Pacific include an estimated 80—85 percent of U.S. coral reef ecosystems. Having digital maps of these areas is a critical component in their study, management, and protection.*

### Approach

In any effort to provide digital mapping products, the first step is to determine what already has been done. Two activities were undertaken to assess the availability of digital and other mapping products for the Pacific region. An inventory mail-out and a regional visit were used. The inventory was mailed to over 50 individuals representing federal, state, and local agencies and organizations in the Pacific region. Following the inventory mail-out, a site visit was conducted to follow-up on the inventory. Hawaii was chosen for the site visit. Hawaii is where Pacific region offices of many federal agencies are located. Its state offices and university routinely cooperate with the other U.S. islands in the Pacific on coral reef-related issues. Finally, Hawaii has the largest population and combined land area of all U.S.-Pacific responsibility.

### Preliminary Results

The results of the preliminary inventory and the visit to Hawai'i demonstrate that the vast majority of the coral reefs in the Pacific region (over 13,000 sq. km. of the estimated total of 16,879 sq. km.) are unmapped, and large gaps exist in the information available to generate such maps. Visits to the remaining areas should clarify the picture regarding the availability of digital coral reef maps. Additionally most of these areas do not have other

essential thematic data, such as shoreline or near-shore bathymetry, available.

### Future Activities

Site visits to the remaining major Pacific islands are needed to complete the assessment. The mail-out inventory was not successful in providing a clear picture of the types of digital coral reef data for these islands. Face-to-face discussions always produce a better synopsis of available information. These meetings also provide the opportunity to discuss the Pacific coral reef mapping project and to begin developing the partnerships for completing the mapping project.

Pacific regional agencies contacted for this preliminary assessment are listed below. Results of the inventory and site visit are presented in Figure 2.

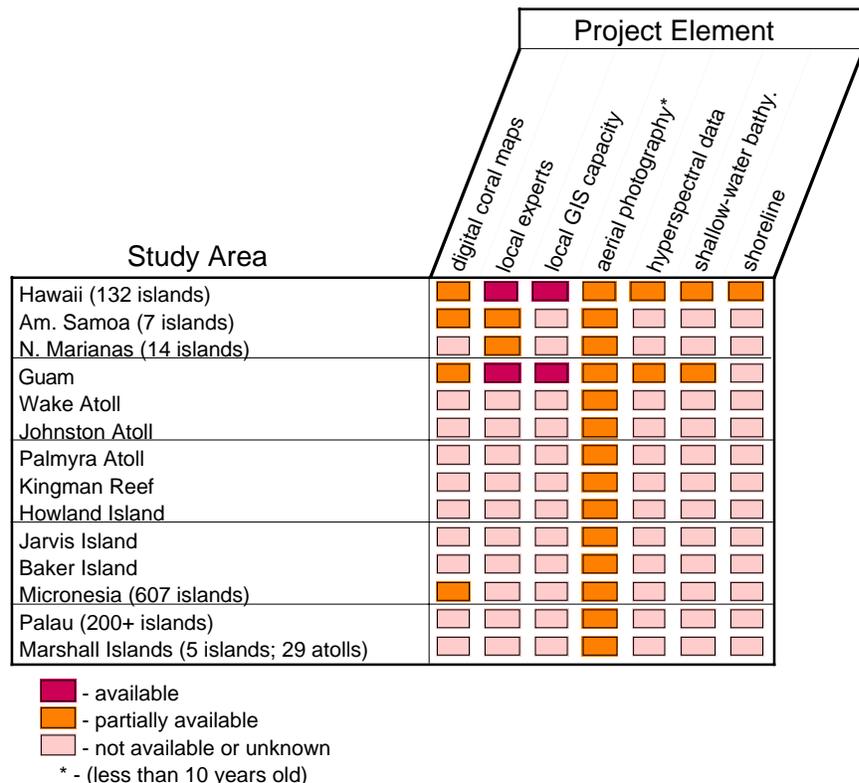
#### American Samoa:

- Governor of American Samoa
- Department of Commerce
- Environmental Protection Agency
- Department of Marine & Wildlife Resources
- Fagatele Bay National Marine Sanctuary
- National Park of America Samoa

#### Commonwealth of the Northern Mariana Islands:

- Special Assistant to the Governor for Environment
- Department of Lands and Natural Resources, Division of Fish and Wildlife
- Division of Environmental Quality, Marine Monitoring Program
- Coastal Resources Management Office
- Northern Marianas College, Aquatic Resource Extension Agent

**Figure 2. Results of the preliminary inventory and site visit.**



Guam:

- Department of Agriculture, Division of Aquatic and Wildlife Resources
- Coastal Management Program
- Bureau of Planning
- University of Guam

Hawaii:

- U.S. Army Corps of Engineers
- Federal Emergency Management Agency
- U. S. Geological Survey
- U.S. Fish and Wildlife Service, Pacific Islands Ecoregion
- Western Pacific Fisheries Management Council
- National Marine Fisheries Service, Pacific Area Office
- National Environmental Satellite, Data, and Information Service
- National Ocean Service
- Department of Business, Economic Development and Tourism
- Department of Land and Natural Resources
- Hawaii Coastal Zone Management Program
- Hawaii Cooperative Fishery Research Unit
- University of Hawaii at Manoa
- Oceanic Institute, Center for Applied Aquaculture
- Pacific Basin Development Council
- Bishop Museum, Pacific Science Association
- Waikiki Aquarium
- The Nature Conservancy of Hawaii
- Sierra Club

## Appendix 2. The role of the Puerto Rico and U.S. Virgin Islands coral reef mapping activity in developing the Coral Reef Task Force mapping strategy.

### Project Description

Coral reef ecosystems in Puerto Rico and the U.S. Virgin Islands are being mapped using methods similar to those used in the Florida Keys (i.e., classification and GIS compilation of benthic habitat areas from aerial photography). A classification manual—which contains a text description and image of each habitat type—will be developed as part of the mapping process. In addition, experiments are being conducted to identify and test new remote sensing technologies that may improve and accelerate development of the coral reef mapping product. Figure 3 presents a time line for completing the Caribbean coral reef mapping activity.

### New Technologies

Two remote sensing technologies, unsupervised coral reef classification of scanned aerial photography images and hyperspectral identification and classification of coral reef features, are being tested as tools to improve the accuracy of the maps derived from aerial photography. Even with a classification manual, expert knowledge of the local ecosystem is needed to verify the photographic classifications. The unsupervised classification of scanned images uses computer software to automatically separate out the “red-green-blue spectral signatures” of each habitat type. Computer algorithms are then developed to distinguish many habitat classes. Raster and vector maps of the habitats can then be generated from these data.

Hyperspectral identification and classification of coral reef features uses up to 244 individual color bands to define a “spectral signature” for each benthic habitat (typically, 7—10 bands are used to classify benthic habitats).

The hyperspectral signature of each habitat is then used to generate a raster or vector benthic habitat map.

### Technologies for Pacific Mapping

The development and testing of these new technologies is critical to coral reef mapping in the Pacific for several reasons. First, processing and classifying benthic habitats from aerial photography is costly and time-consuming; unsupervised and/or hyperspectral classification of benthic communities should be more cost effective. Second, classification of benthic habitats from aerial photography is dependent on local expert knowledge; unsupervised and/or hyperspectral classification of benthic communities uses computers. Third, maps showing changes in benthic habitats over time are too expensive and time-consuming to produce using “traditional” methods; unsupervised and/or hyperspectral classification of benthic communities should be able to produce time-series maps much more efficiently. Finally, benthic habitat maps generated using local experts cannot be updated quickly or easily; unsupervised and/or hyperspectral

benthic maps can be generated by computers as soon as the “raw” data are acquired.

### Next Steps in the Caribbean

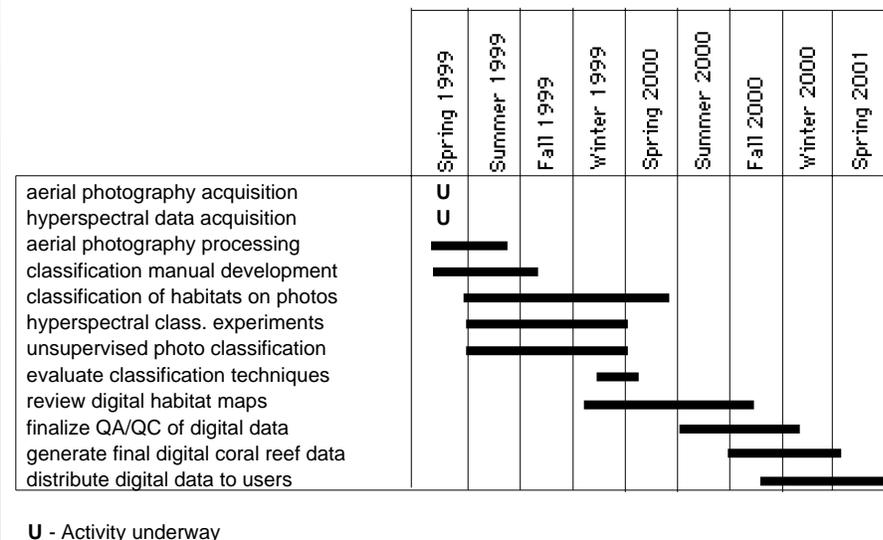
The results of the remote sensing experiments need to be evaluated for their applicability to the Pacific. Researchers currently are using airborne hyperspectral instruments in selected Pacific island areas. Experiments also need to be undertaken that investigate using satellite remote sensing platforms to classify and map Pacific coral reefs.

### Caribbean Mapping Partnerships

Partners in the Puerto Rico/U.S. Virgin Islands coral reef ecosystem mapping activity.

- University of Puerto Rico, Department of Marine Sciences
- Puerto Rico Coastal Zone Management Program
- Government of Puerto Rico, Department of Natural and Environmental Resources
- The University of the Virgin Islands, Conservation Data Center

**Figure 3. Coral reef mapping activities in Puerto Rico and the U.S. Virgin Islands.**



- The University of the Virgin Islands,  
MacLean Marine Science Center
- Government of the Virgin Islands,  
Department of Planning and Natural  
Resources
- U.S. Virgin Island Coastal Zone  
Management Program
- Department of Defense
- U.S. Fish and Wildlife Service
- U.S. Geological Survey
- National Park Service, U.S. Virgin  
Islands
- National Marine Fisheries Service
  - Office of Habitat Conservation
  - Office of Protected Resources
- Caribbean Fisheries Management  
Council
- National Ocean Service
  - National Centers for Coastal  
Ocean Science
  - Office of Coastal Resource  
Management; Hobos Bay National  
Estuarine Research Reserve
  - Special Projects Office
  - National Geodetic Survey
  - Coastal Services Center
  - Office of Response and Restora-  
tion

## Appendix 3. A new model for coral reef ecosystem mapping.

The *Benthic Habitats of the Florida Keys* CD-ROM represents a new model for the type of tool needed to study, manage, and protect coral reef ecosystems, not only in the Florida Keys, but wherever they exist.

### A Decision-making Tool

With the information and mapping capabilities provided on the CD-ROM, researchers, resource managers, and concerned citizens can map Florida Keys coral reefs and seagrass beds, overlay other digital data, and perform spatial analyses. Other thematic data, such as bathymetry, aids to navigation, land, and protected area boundaries, are included on the CD-ROM. With these data, GIS analyses can be conducted and maps can be made to:

- Locate and characterize marine hazards;
- Characterize and evaluate the status of the essential habitat of commercial and non-commercial marine animals;
- Designate and develop management strategies for marine protected areas;
- Evaluate and identify areas where intensive monitoring is needed;
- Evaluate and measure the success of watershed-based water quality management strategies;
- Evaluate the success of urban and agricultural land use management policies;
- Provide a baseline for damage assessment and restoration efforts; and
- Develop capabilities to conduct long-term change analyses.

### A Mapping Tool

The *Benthic Habitats* CD is a model for a new type of coral reef mapping product. It represents new ideas for how these tools can be made and provided to users.

- It demonstrates how partners—federal and state agencies in this case—can join together and pool their resources to generate comprehensive coral reef ecosystem maps.
- It demonstrates how aerial photography can be used to generate high-quality and accurate digital coral reef ecosystem maps.
- It demonstrates how digital coral reef ecosystem maps can be distributed using widely-available media.
- It demonstrates how new capabilities can be provided to researchers and managers to map and analyze information associated with coral reef protection and use.
- It demonstrates how coral reef mapping information can be packaged to meet the needs of many user communities.

### Product Description

The CD-ROM consists of three parts: 1) a narrated multimedia introduction describing what benthic habitats are, why they are important and need to be mapped, and how they were mapped to produce the CD; 2) a mapping capability; and 3) a narrated tutorial explaining how to use the mapping capability. Also provided on the CD-ROM are all the software applications needed to view the multimedia introduction, read and print the documentation, and launch the mapping capability.

The benthic habitats of the Florida Keys were mapped from a series of 450 aerial photographs. Ecologists outlined the boundaries of specific habitat types by interpreting color patterns on the photographs. Groundtruthing was conducted to verify a portion of the boundaries. Benthic habitats were classified into four major categories—corals, seagrasses, hardbottom, and

bare substrate—and 24 subcategories, such as sparse seagrass and patch reef. Habitat boundaries were georeferenced and digitized to create computer maps. These digital data were then incorporated into a geographic information system for electronic mapping.

Maps and associated data may be viewed directly through the GIS application provided on the CD-ROM. Special buttons and menus in the application enable a user to select and view the maps and portray different information on them. An area of interest may be selected either from a list, or by drawing a box on the screen using the cursor. Users may then overlay their own geographic data on the maps. The GIS application allows unlimited map and data display, browsing, querying and printing capabilities.