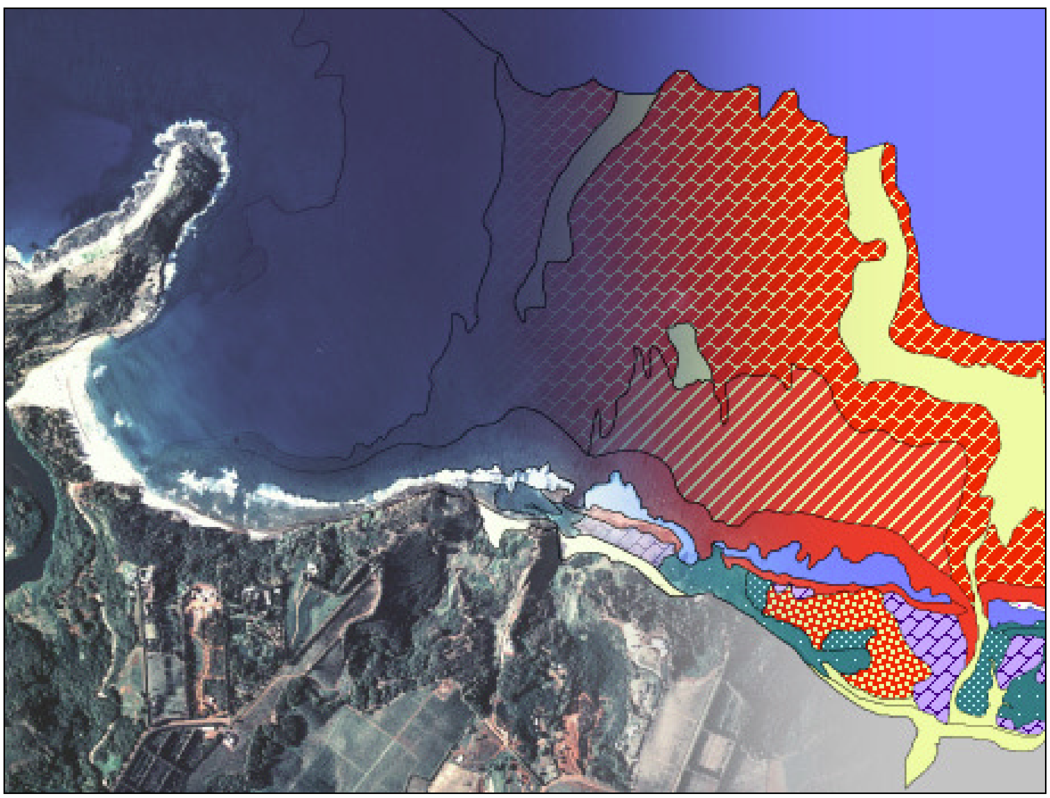
Benthic Habitats of the Main Hawaiian Islands

Interim Product



NOAA National Ocean Service
National Centers for Coastal Ocean Science
Center for Coastal Monitoring and Assessment
Biogeography Team

Contents:

Citation: Coyne, M. S.[1], T. A. Battista[1], M. Anderson[2], J. Waddell[1], W. Smith[3], P. Jokiel[3], M. S. Kendall[1], and M. E. Monaco[1]. 2003. NOAA Technical Memorandum NOS NCCOS CCMA 152 (On-line). Benthic Habitats of the Main Hawaiian Islands URL: http://biogeo.nos.noaa.gov/projects/mapping/pacific/. Also available on U.S. National Oceanic and Atmospheric Administration. National Ocean Service, National Centers for Coastal Ocean Science, Biogeography Program. 2003. (CD-ROM). Benthic Habitats of the Main Hawaiian Islands. Silver Spring, MD: National Oceanic and Atmospheric Administration.

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Introduction

The National Oceanic and Atmospheric Administration (NOAA) National Ocean Service (NOS) initiated a coral reef research program in 1999 to map, assess, inventory, and monitor U.S. coral reef ecosystems (Monaco et al. 2001). These activities were implemented in response to requirements outlined in the *Mapping Implementation Plan* developed by the Mapping and Information Synthesis Working Group (MISWG) of the Coral Reef Task Force (CRTF) (MISWG 1999). As part of the MISWG of the CRTF, NOS' Biogeography Team has been charged with the development and implementation of a plan to produce comprehensive digital coral-reef ecosystem maps for all U.S. States, Territories, and Commonwealths within five to seven years. Joint activities between Federal agencies are particularly important to map, research, monitor, manage, and restore coral reef ecosystems. In response to the Executive Order 13089, NOS is conducting research to digitally map biotic resources and coordinate a long-term monitoring program that can detect and predict change in U.S. coral reefs, and their associated habitats and biological communities.

Most U.S. coral reef resources have not been digitally mapped at a scale or resolution sufficient for assessment, monitoring, and/or research to support resource management. Thus, a large portion of NOS' coral reef research activities have focused on mapping of U.S. coral reef ecosystems. The map products will provide the fundamental spatial organizing framework to implement and integrate research programs and provide the capability to effectively communicate information and results to coral reef ecosystem managers. Although the NOS coral program is relatively young, it has had tremendous success in advancing towards the goal to protect, conserve, and enhance the health of U.S. coral reef ecosystems. One objective of the program was to create benthic habitat maps to support coral reef research to enable development of products that support management needs and questions. An initial step in producing benthic habitat maps is the development of a habitat classification scheme. The purpose of this document is to outline the benthic habitat classification scheme and protocols used to map the main Hawaiian Islands: Hawaii, Maui, Molokai, Lanai, Oahu, Kauai, and Niihau.

Twenty-seven distinct benthic habitat types within eleven zones were mapped directly into a geographic information system (GIS) using visual interpretation of orthorectified aerial photographs and hyperspectral imagery. Benthic features were mapped that covered an area of 790 km^2. In all, 204 km^2 of unconsolidated sediment, 171 km^2 of submerged vegetation, and 415 km^2 of coral reef and colonized hardbottom were mapped.

To supplement the maps, digital scans of the original aerial photographs, georeferenced mosaics, a GIS mapping tool for use with ArcView, and supporting data sets were also created. To see or download this information, visit http://biogeo.nos.noaa.gov/projects/mapping/pacific/.

This document will show data users how the data was collected and help them replicate the data for comparison purposes at a later date. Document contents include:

- A description of each of the habitat classifications with example aerial and underwater photographs
- Directions for using the "habitat digitizer" extension to ArcView 3.2
- A description of the specific methods used to create the habitat maps
- An assessment of the thematic accuracy of the maps along with a comparison of map accuracy utilizing different source imagery

Developing the Habitat Classification Scheme

A hierarchical classification scheme was created to define and delineate 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. unpublished), other coral reef systems (Kruer 1995; Reid and Kruer 1998; Lindeman et al. 1998; Sheppard et al. 1998; Vierros 1997; Chauvaud et al. 1998; Florida Fish and Wildlife Conservation Commission, Florida Marine Research Institute and NOAA, 1998; Mumby et al. 1998; NOAA et al. 1998; Kendall et al. 2001), quantitative habitat data for the Hawaiian Islands, the minimum mapping unit (MMU - 1 acre for visual photointerpretation), and analysis of the spatial and spectral limitations of aerial photography and hyperspectral 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 the Hawaiian Islands, 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 initial classification scheme was developed through a series of workshops with managers, academics and other local experts in the Hawaiian Islands. 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.

General Description of the Classification Scheme

The classification scheme defines benthic communities on the basis of two attributes: large geographic "zones" which are composed of smaller "habitats". Zone refers only to benthic community location and habitat refers only to substrate and/or cover type. Every polygon on the benthic community map will be assigned a habitat within a zone (e.g. sand in the lagoon, or sand on the bank). Zone indicates polygon location and habitat indicates composition of each benthic community delineated. Combinations of habitat and zone that are analogous to traditionally used terminology are noted where appropriate. The description of each zone and habitat includes example images. Where available, both underwater and aerial photographs are included for habitats. Aerial images are included for zones. The zone/habitat approach to the classification scheme was developed by the Caribbean Fishery Management Council; Dr. Ken Lindeman, Environmental Defense; and the NOS Biogeography Team to couple habitats to species distribution (Christensen et al. 2003).

Eleven mutually exclusive zones were identified from land to open water corresponding to typical insular shelf and coral reef geomorphology (Fig. 1-2). These zones include: land, vertical wall, shoreline intertidal, lagoon, reef flat, back reef, reef crest, fore reef, bank/shelf, bank/shelf escarpment, channel, and dredged (since this condition eliminates natural geomorphology). Zone refers only to each benthic community's location and does not address substrate or cover types within. For example, the lagoon zone may include patch reefs, sand, and seagrass beds; however, these are considered structural elements that may or may not occur within the lagoon zone and therefore, are not used to define it. Twenty-seven distinct and non-overlapping habitat types were identified that could be mapped by visual interpretation of remotely collected imagery. Habitats or features that cover areas smaller than the MMU were not considered. For example, sand halos surrounding patch reefs are too small to be mapped independently. Habitat refers only to each benthic community's substrate and/or cover type and does not address location on the shelf. Habitats are defined in a collapsible hierarchy ranging from four broad classes (unconsolidated sediment, submerged vegetation, coral reef and hardbottom, and other), to more detailed categories (e.g., emergent vegetation, seagrass, algae, individual patch reefs, uncolonized volcanic rock), to patchiness of some specific features (e.g., 50-90 percent cover of macroalgae).

Zones:

Land
Shoreline Intertidal
Vertical Wall*
Lagoon
Back Reef (w/ Lagoon, see barrier reef - Figure 1)
Reef Flat (w/o Lagoon, see fringing reef - Figure 2)
Reef Crest
Fore Reef
Bank/Shelf
Bank/Shelf Escarpment
Channel*
Dredged*
Unknown

*not depicted in figures

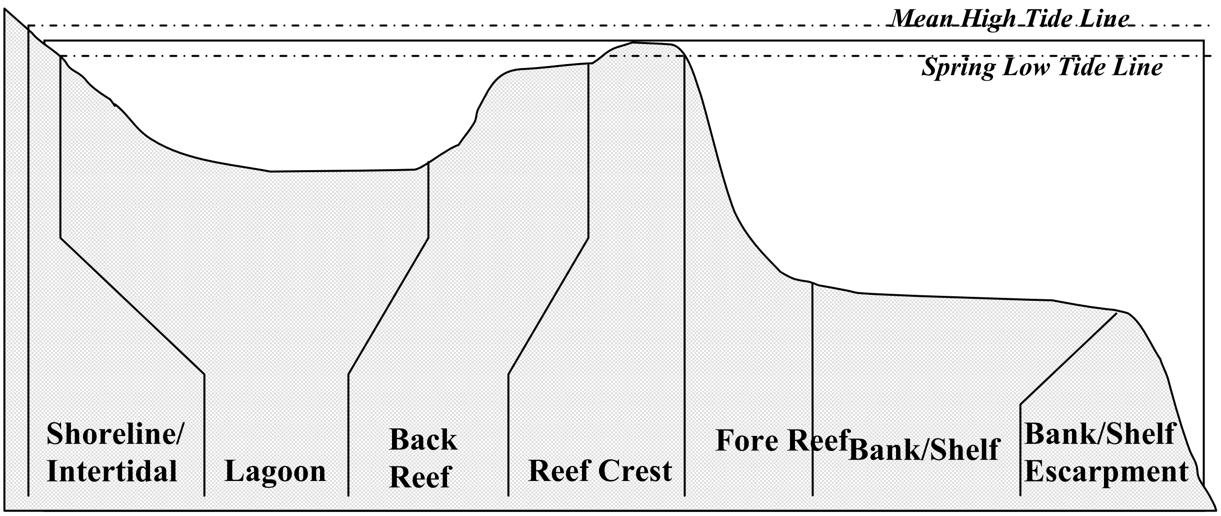


Figure 1. Barrier reef cross-section. Reef separated from the shore by a relatively wide, deep lagoon.

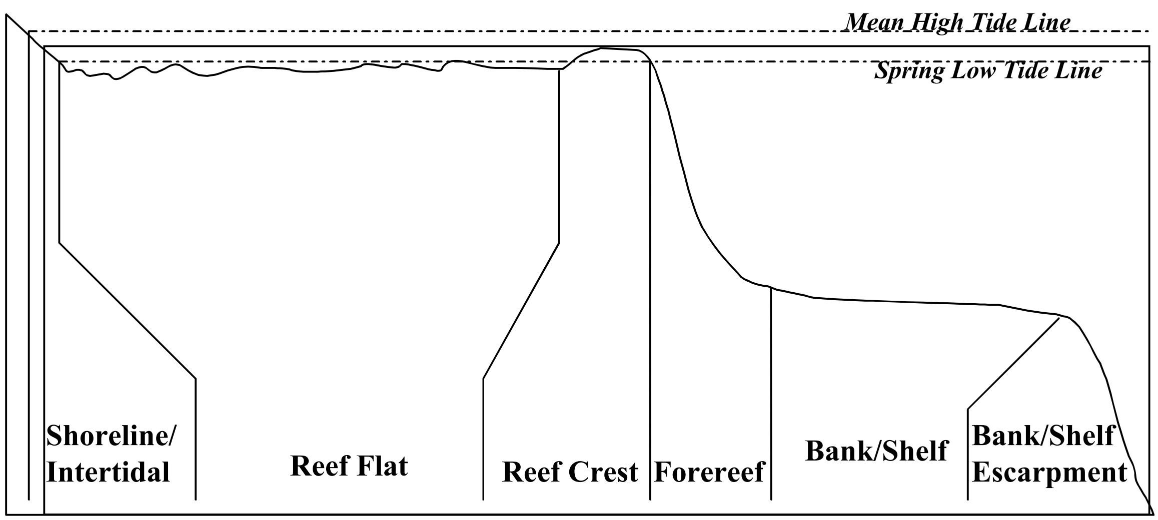


Figure 2. Fringing reef cross-section. Reef platform is continuous with the shore.

Habitats:

- **Unconsolidated Sediment (0%-<10% submerged vegetation)**
    - **Mud**
    - **Sand**

- **Submerged Vegetation**
    - **Seagrass**
        - **Continuous Seagrass (90%-100% Cover)**
        - **Patchy (Discontinuous) Seagrass (50%-<90% Cover)**
        - **Patchy (Discontinuous) Seagrass (10%-50% Cover)**
    - **Macroalgae (fleshy and turf)**
        - **Continuous Macroalgae (90%-100% Cover)**
        - **Patchy (Discontinuous) Macroalgae (50%-<90% Cover)**
        - **Patchy (Discontinuous) Macroalgae (10%-<50% Cover)**

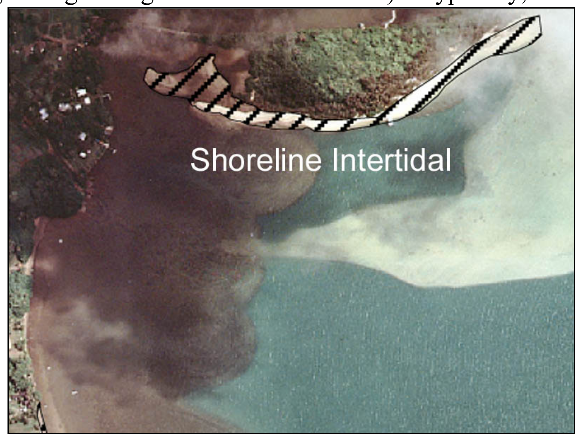
- **Coral Reef and Hardbottom**
    - **Coral Reef and Colonized Hardbottom**
        - **Linear Reef**
        - **Aggregated Coral**
        - **Spur and Groove**
        - **Individual Patch Reef**
        - **Aggregated Patch Reef**
        - **Scattered Coral/Rock in Unconsolidated Sediment**
        - **Colonized Pavement**
        - **Colonized Volcanic Rock/Boulder**
        - **Colonized Pavement with Sand Channels**
    - **Uncolonized Hardbottom**
        - **Reef Rubble**
        - **Uncolonized Pavement**
        - **Uncolonized Volcanic Rock/Boulder**
        - **Uncolonized Pavement with Sand Channels**
    - **Encrusting/Coralline Algae**
        - **Continuous Encrusting/Coralline Algae (90%-100% Cover)**
        - **Patchy (Discontinuous) Encrusting/Coralline Algae (50%-<90% Cover)**
        - **Patchy (Discontinuous) Encrusting/Coralline Algae (10%-<50% Cover)**

- **Other Delineations**
    - **Land**
    - **Emergent Vegetation**
    - **Artificial**
    - **Unknown**

Description of Zones

Shoreline Intertidal: Area between the mean high water line (or landward edge of emergent vegetation when present) and lowest spring tide level (excluding emergent segments of barrier reefs). Typically, this zone is narrow due to the small tidal range in the main Hawaiian Islands.

Typical Habitats: Mangrove, hao, sand, seagrass, and uncolonized volcanic/carbonate rock.

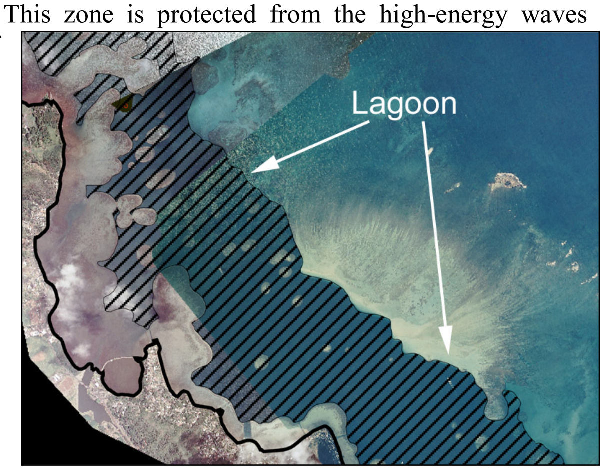


Vertical Wall: Area with near-vertical slope from shore to shelf or shelf escarpment. This zone is typically narrow and may not be distinguishable in remotely gathered imagery, but is included because it is recognized as a biologically important feature.

Typical Habitats: volcanic rock, algae, coral.

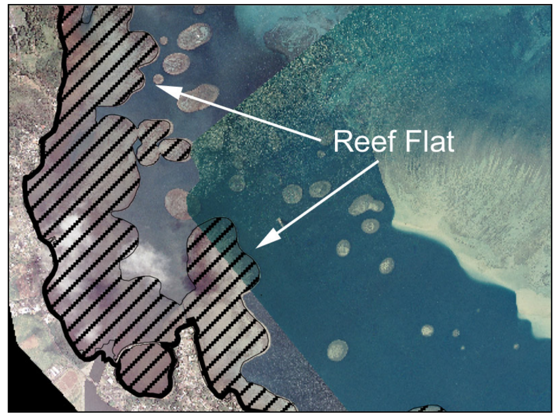
Lagoon: Shallow area (relative to the deeper water of the bank/shelf) between the shoreline intertidal zone and the back reef of a reef or a barrier island. This zone is protected from the high-energy waves commonly experienced on the bank/shelf and reef crest. If no reef crest is present there is no lagoon zone.

Typical Habitats: Sand, seagrass, algae, pavement, volcanic/carbonate rock, and patch reefs.



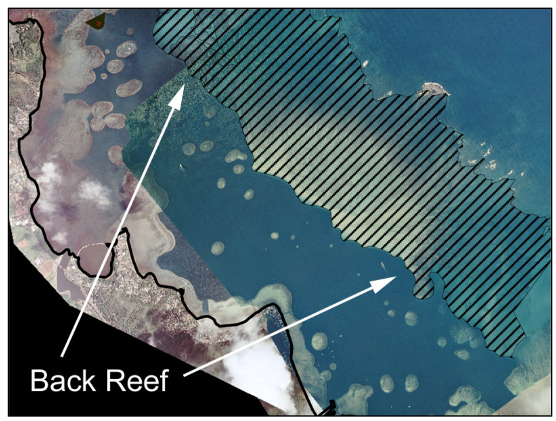
Reef Flat: Shallow (semi-exposed) area between the shoreline intertidal zone and the reef crest of a fringing reef. This zone is protected from the high-energy waves commonly experienced on the shelf and reef crest. Reef flat is typically not present if there is a lagoon zone.

Typical Habitats: Sand, reef rubble, seagrass, algae, and patch reef.



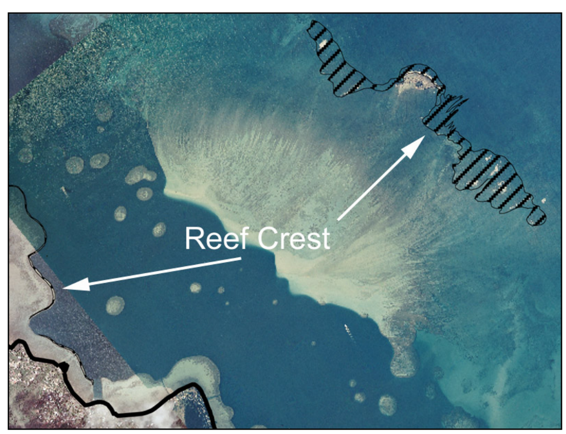
Back Reef: Area between the seaward edge of a lagoon floor and the landward edge of a reef crest. This zone is present when a reef crest and lagoon exist.

Typical Habitats: Sand, reef rubble, seagrass, algae, linear reef, and patch reef.



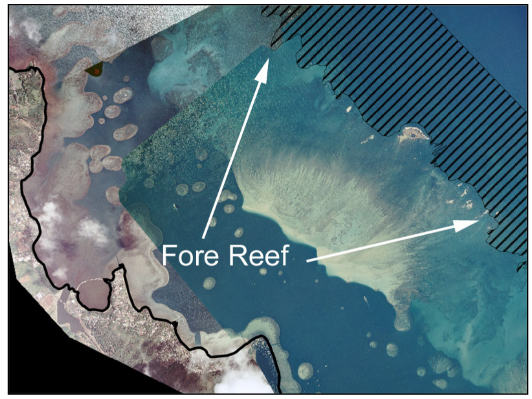
Reef Crest: The flattened, emergent (especially during low tides) or nearly emergent segment of a reef. This zone lies between the back reef and fore reef zones. Breaking waves will often be visible in aerial images at the seaward edge of this zone.

Typical Habitats: Reef rubble, linear reef, and aggregated coral.



Fore Reef: Area from the seaward edge of the reef crest that slopes into deeper water to the landward edge of the bank/shelf platform. Features not forming an emergent reef crest but still having a seaward-facing slope that is significantly greater than the slope of the bank/shelf are also designated as fore reef (Fig. 2).

Typical Habitats: Linear reef and spur and groove.



Bank/Shelf: Deep water area (relative to the shallow water in a lagoon) extending offshore from the seaward edge of the fore reef to the beginning of the escarpment where the insular shelf drops off into deep, oceanic water. The bank/shelf is the flattened platform between the fore reef and deep open ocean waters or between the shoreline/intertidal zone and open ocean if no reef crest is present.

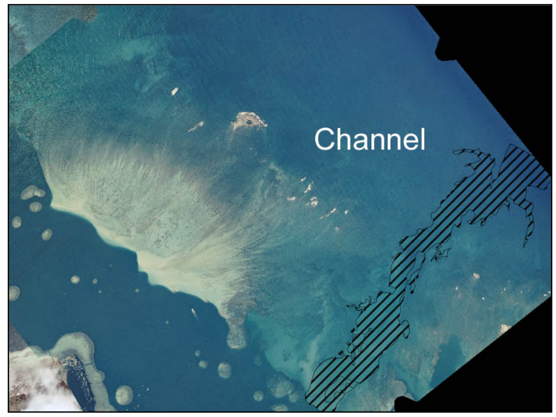
Typical Habitats: Sand, patch reefs, algae, seagrass, linear reef, colonized and uncolonized pavement, colonized and uncolonized pavement with sand channels, and other coral reef habitats.

Shelf Escarpment: The edge of the bank/shelf where depth increases rapidly into deep, oceanic water. This zone begins at approximately 20 to 30 meters depth, near the depth limit of features visible in aerial images. This zone extends well into depths exceeding those that can be seen on aerial photographs and is intended to capture the transition from the shelf to deep waters of the open ocean.

Typical Habitats: Sand, linear reef, and spur and groove.

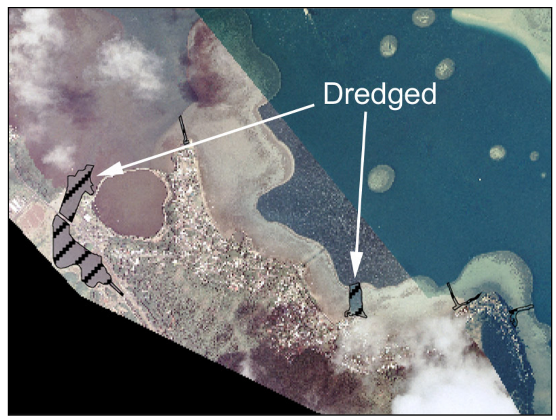
Channel: Naturally occurring channels that often cut across several other zones.

Typical Habitats: Sand, mud, uncolonized pavement.

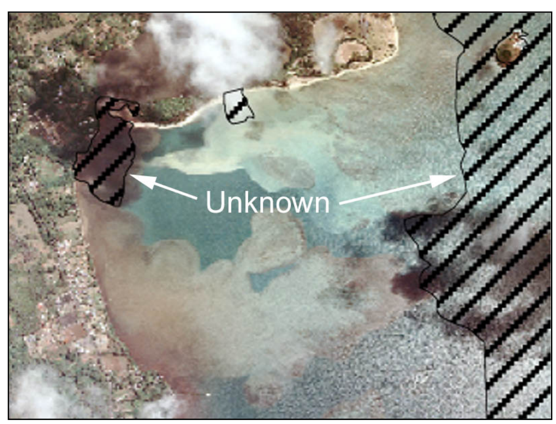


Dredged: Area in which natural geomorphology is disrupted or altered by excavation or dredging.

Typical Habitats: Sand, mud.



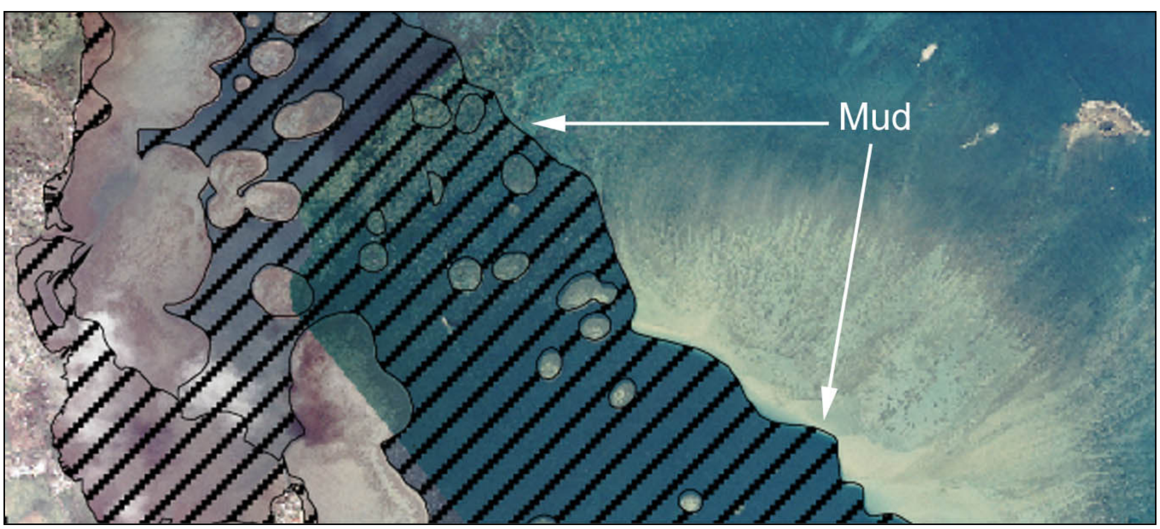
Unknown: Zone uninterpretable due to turbidity, cloud cover, water depth, or other interference.



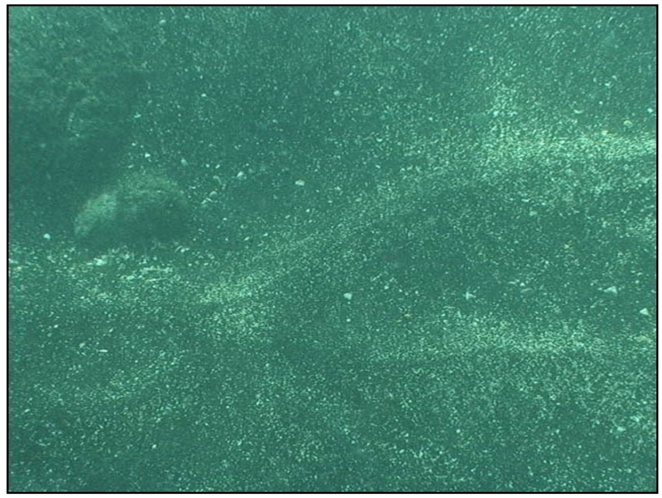
Description of Habitats

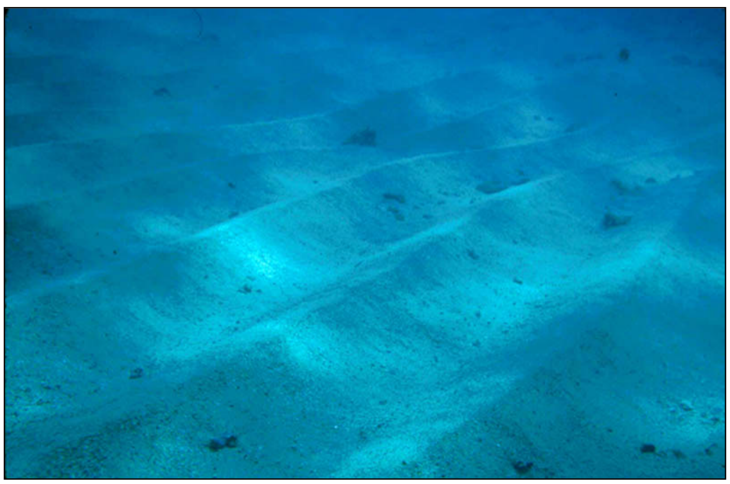
Unconsolidated Sediment: Unconsolidated sediment with less than 10 percent cover of submerged vegetation.

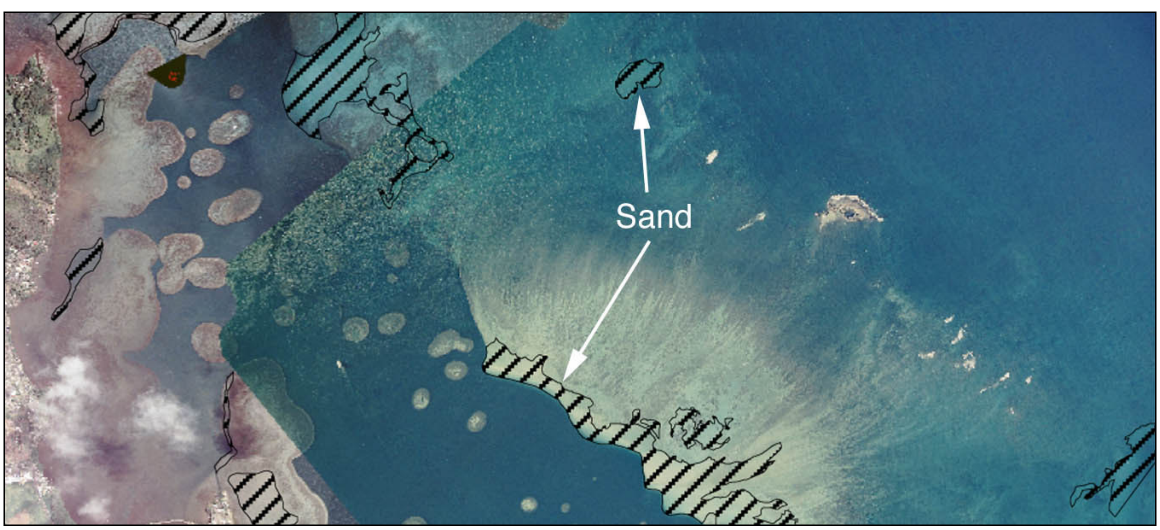
Mud: Fine sediment often associated with river discharge and buildup of organic material in areas sheltered from high-energy waves and currents.



Sand: Coarse sediment typically found in areas exposed to currents or wave energy.







Submerged Vegetation: Greater than 10 percent cover of submerged vegetation in unspecified substrate type (usually sand, mud, or hardbottom).

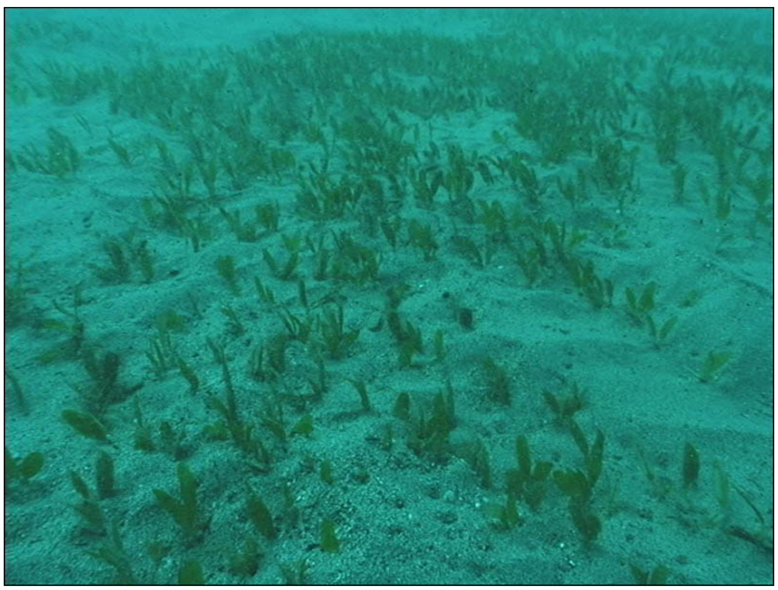
Seagrass: Habitat with 10 percent or more cover of seagrass (e.g., *Halophila sp.*).

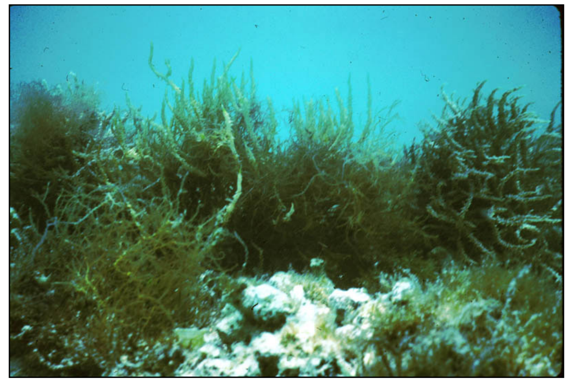
Continuous Seagrass: Seagrass covering 90 percent or more of the substrate. May include blowouts of less than 10% of the total area that are too small to be mapped independently (less than the MMU). This includes continuous beds of any shoot density (may be a continuous sparse or dense bed).

Patchy Seagrass: Discontinuous seagrass with breaks in coverage that are too diffuse or irregular, or result in isolated patches of seagrass that are too small (less than the MMU) to be mapped as continuous seagrass.

Patchy Seagrass (50%-90% cover)
Patchy Seagrass (10%-50% cover)

Representative Species:
Halophila sp.





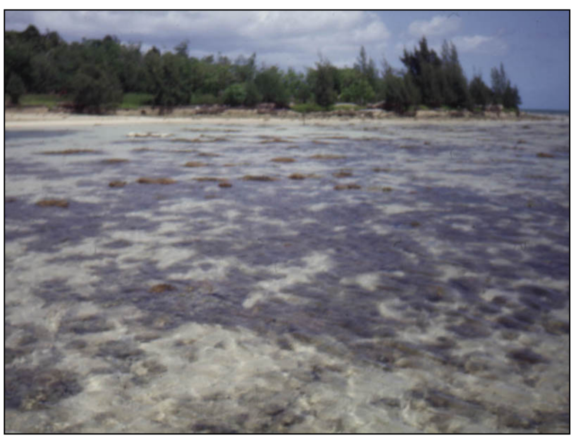
Macroalgae: An area with 10 percent or greater coverage of any combination of numerous species of red, green, or brown macroalgae. Usually occurs in shallow backreef and deeper waters on the bank/shelf zone. High relief (hardbottom) habitats take precedence over macroalgae cover.

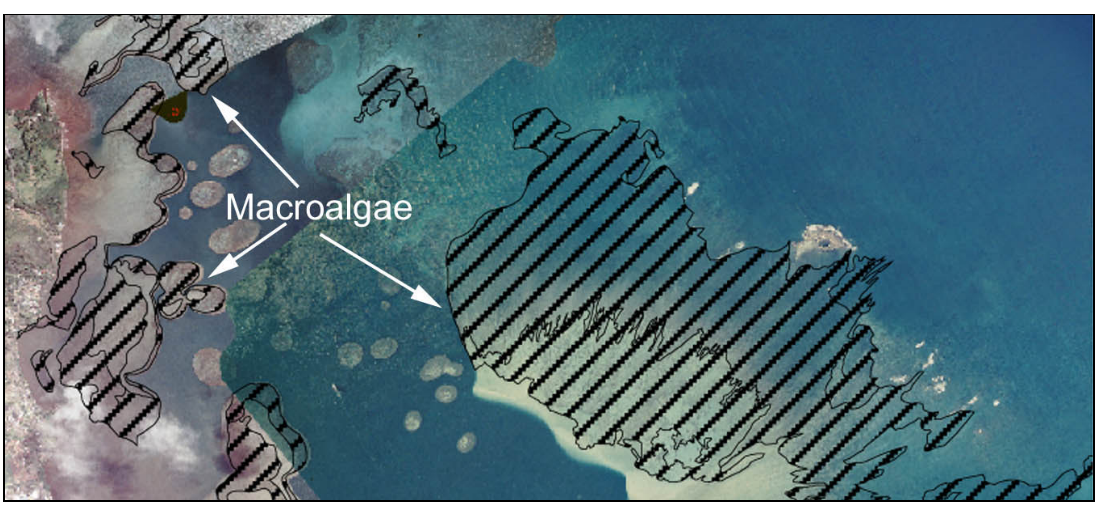
Continuous Macroalgae: Macroalgae covering 90 percent or greater of the substrate. May include blowouts of less than 10 percent of the total area that are too small to be mapped independently (less than the MMU). This includes continuous beds of any density (may be a continuous, sparse or dense bed).

Patchy Macroalgae: Discontinuous macroalgae with breaks in coverage that are too diffuse or irregular, or result in isolated patches of macroalgae that are too small (smaller than the MMU) to be mapped as continuous macroalgae.

Patchy Macroalgae (50%-<90% cover)
Patchy Macroalgae (10%-<50% cover)

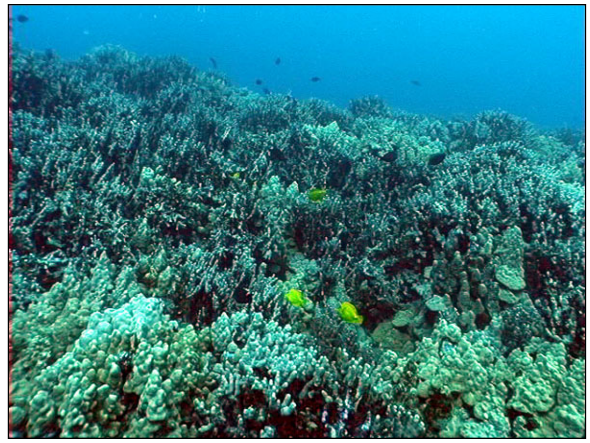
Representative Species:
Dictyosphaeria spp.
Halimeda spp.





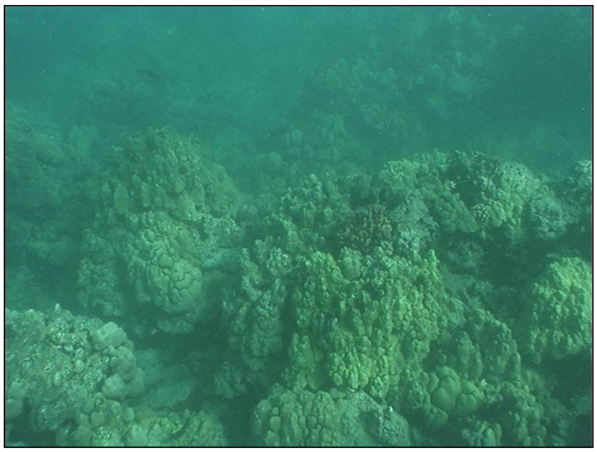
Coral Reef and Hardbottom: Hardened substrate of unspecified relief formed by the deposition of calcium carbonate by reef building corals and other organisms (relict or ongoing) or existing as exposed bedrock or volcanic rock.

Coral Reef and Colonized Hardbottom: Substrates formed by the deposition of calcium carbonate by reef building corals and other organisms. Habitats within this category have some colonization by live coral, unlike the uncolonized hardbottom category.



Linear Reef: Linear coral formations that are oriented parallel to shore or the shelf edge. These features follow the contours of the shore/shelf edge. This category is used for such commonly used terms as fore reef, fringing reef, and shelf edge reef.

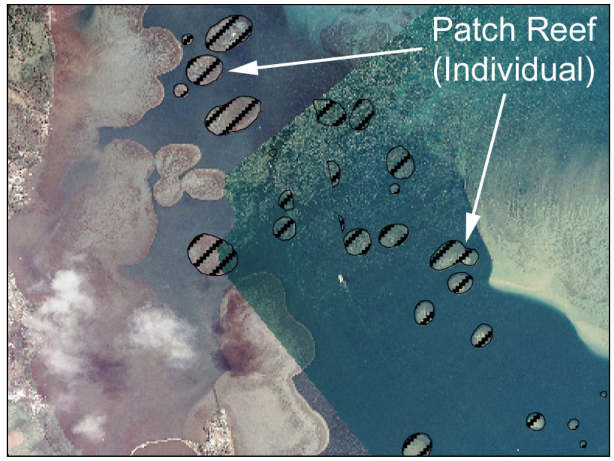
Aggregated Coral: Coral-dominated formations with high relief and structural complexity. Often serve the same role as linear reef in fringing reef systems where the reef crest is relatively unorganized.



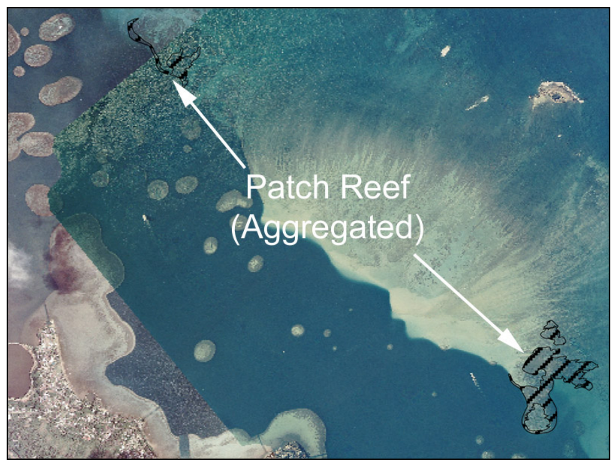
Spur and Groove: Habitat having alternating sand and coral formations that are oriented perpendicular to the shore or bank/shelf escarpment. The coral formations (spurs) of this feature typically have a high vertical relief relative to pavement with sand channels (see below) and are separated from each other by 1-5 meters of sand or bare hardbottom (grooves), although the height and width of these elements may vary considerably. This habitat type typically occurs in the fore reef or bank/shelf escarpment zone.

Patch Reef(s): Coral formations that are isolated from other coral reef formations by sand, seagrass, or other habitats and that have no organized structural axis relative to the contours of the shore or shelf edge.

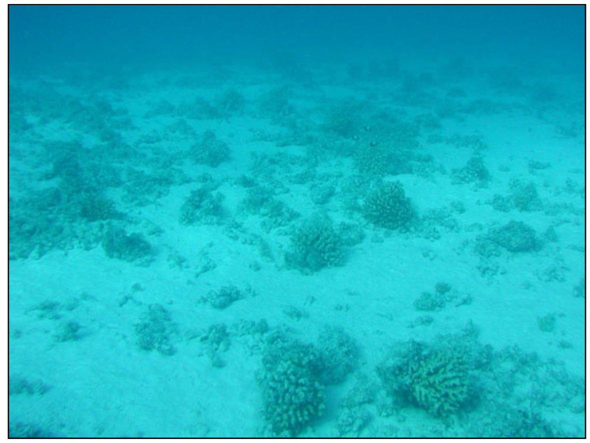
Individual patch reef:
Distinctive single patch reefs that are larger than or equal to the MMU.

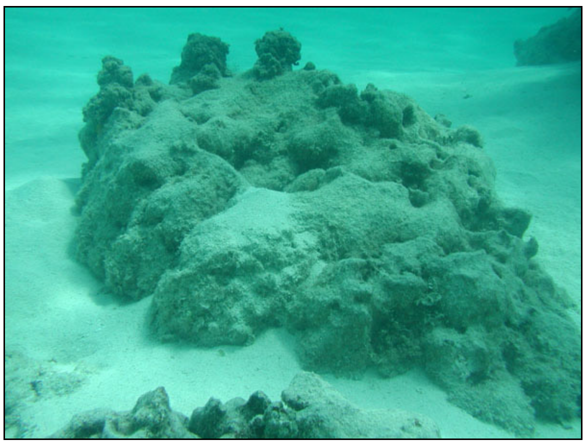


Aggregate patch reefs:
Clustered patch reefs that individually are too small (less than the MMU) or are too close together to map separately.

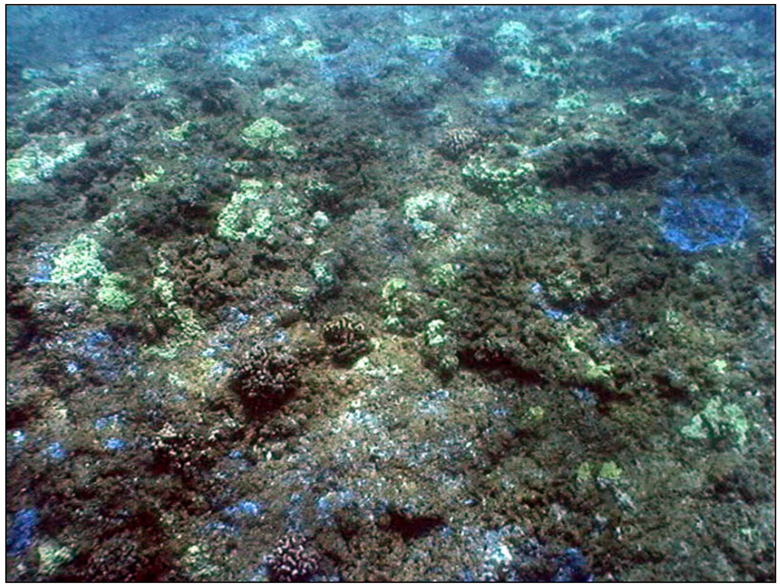


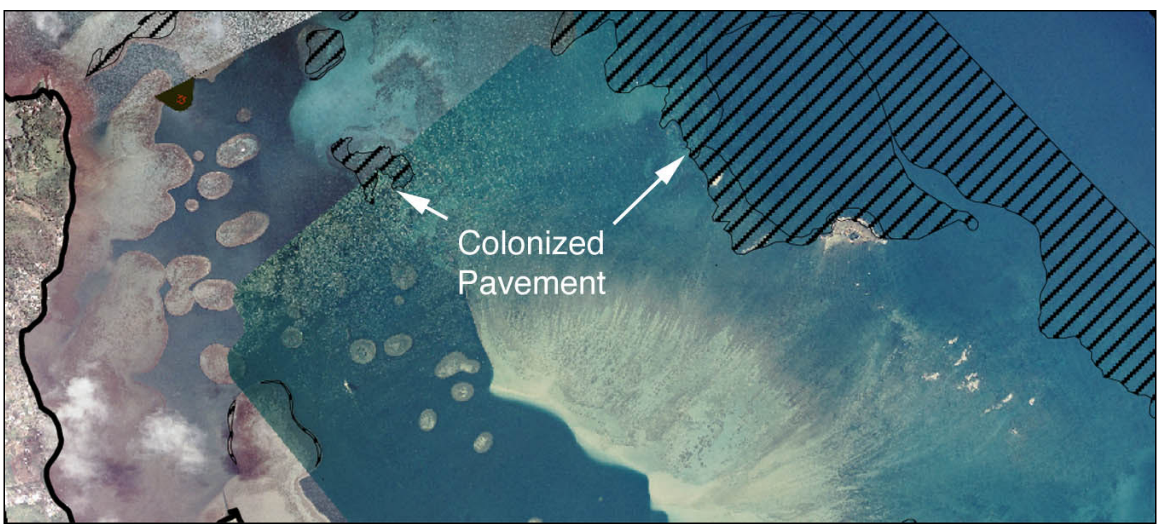
Scattered Coral/Rock in Unconsolidated Sediment: Primarily sand or seagrass bottom with scattered rocks or small, isolated coral heads that are too small to be delineated individually (i.e. smaller than individual patch reef).



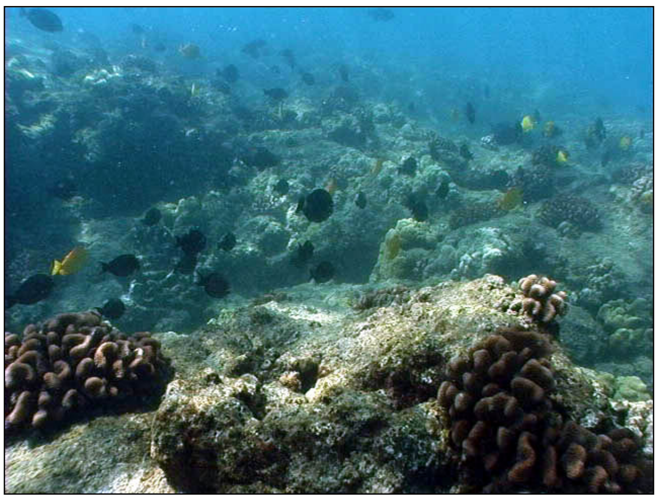


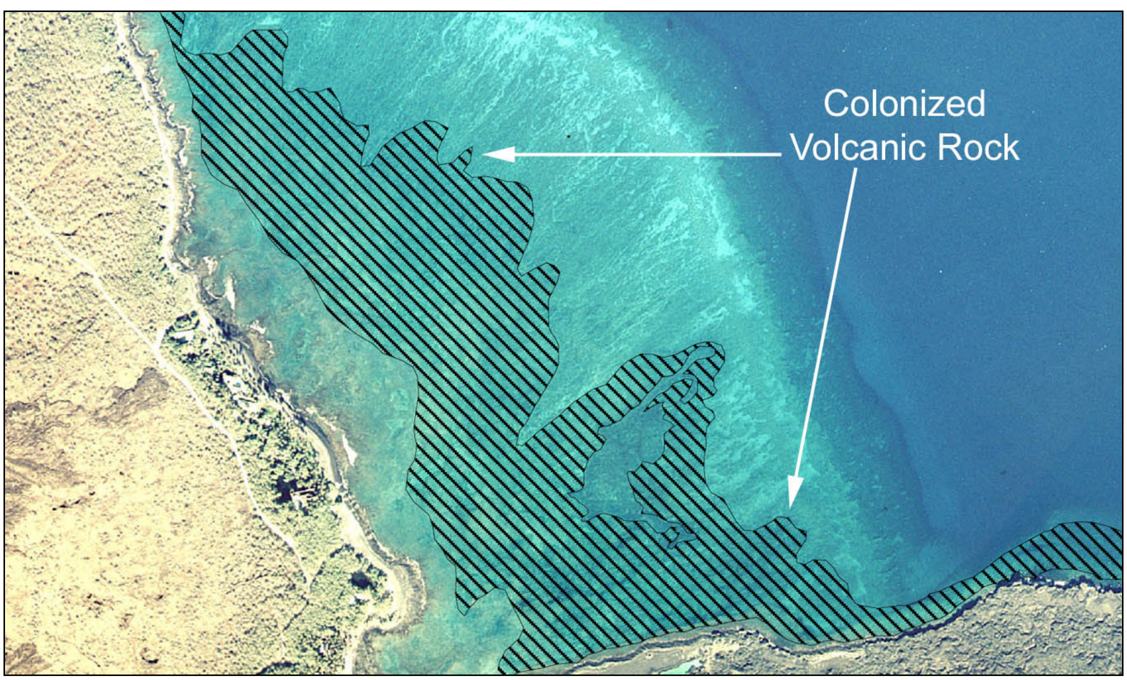
Colonized Pavement: Flat, low-relief, solid carbonate rock with coverage of macroalgae, hard coral, zoanthids, and other sessile invertebrates that are dense enough to begin to obscure the underlying surface.





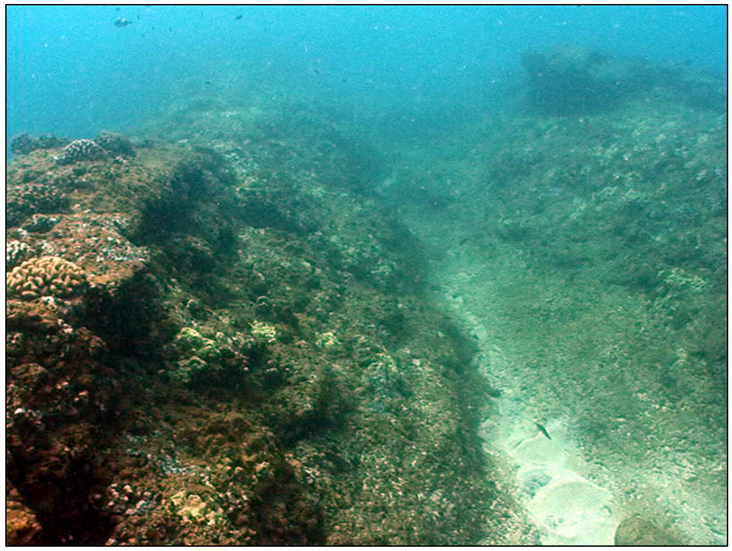
Colonized Volcanic Rock/Boulder: Solid volcanic rock that has coverage of macroalgae, hard coral, zoanthids, and other sessile invertebrates that begins to obscure the underlying surface.

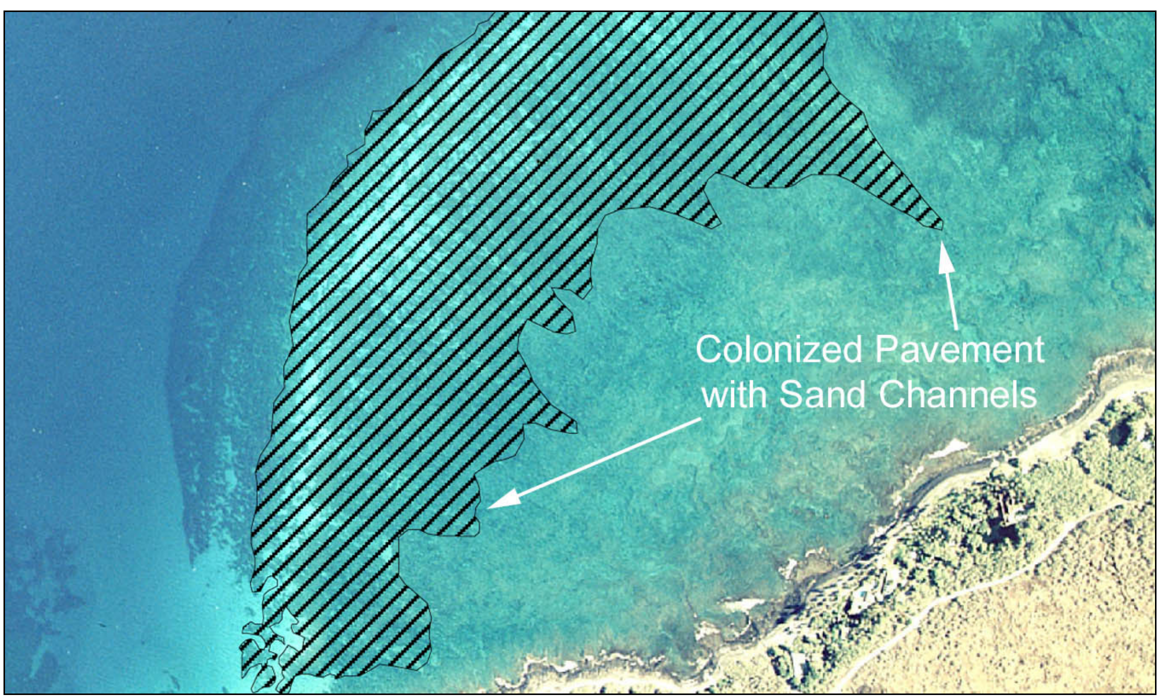




Colonized Pavement with Sand Channels: Habitat having alternating sand and colonized pavement formations that are oriented perpendicular to the shore or bank/shelf escarpment. The sand channels of this feature have low vertical relief relative to spur and groove formations. This habitat type occurs in areas exposed to moderate wave surge, such as the bank/shelf zone.

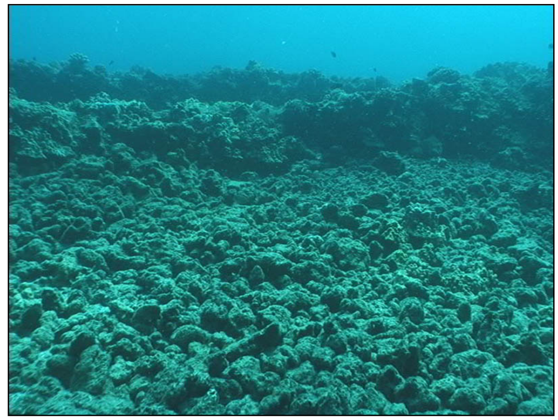
Representative Species/Live Coral Community:
Porites compressa
Porites lobata
Montipora spp.
Pocillopora meandrina

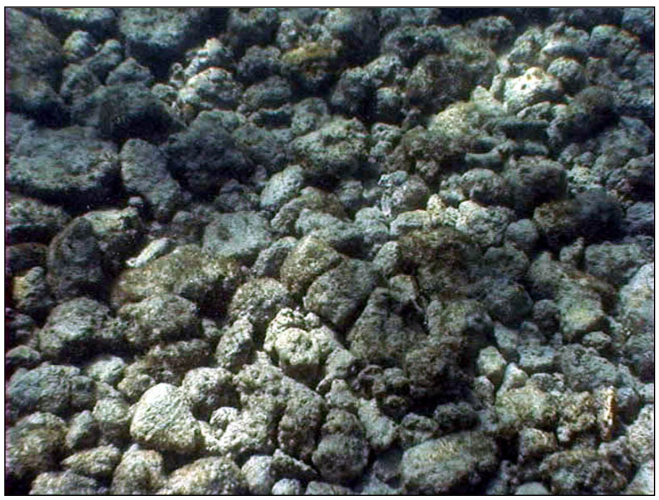


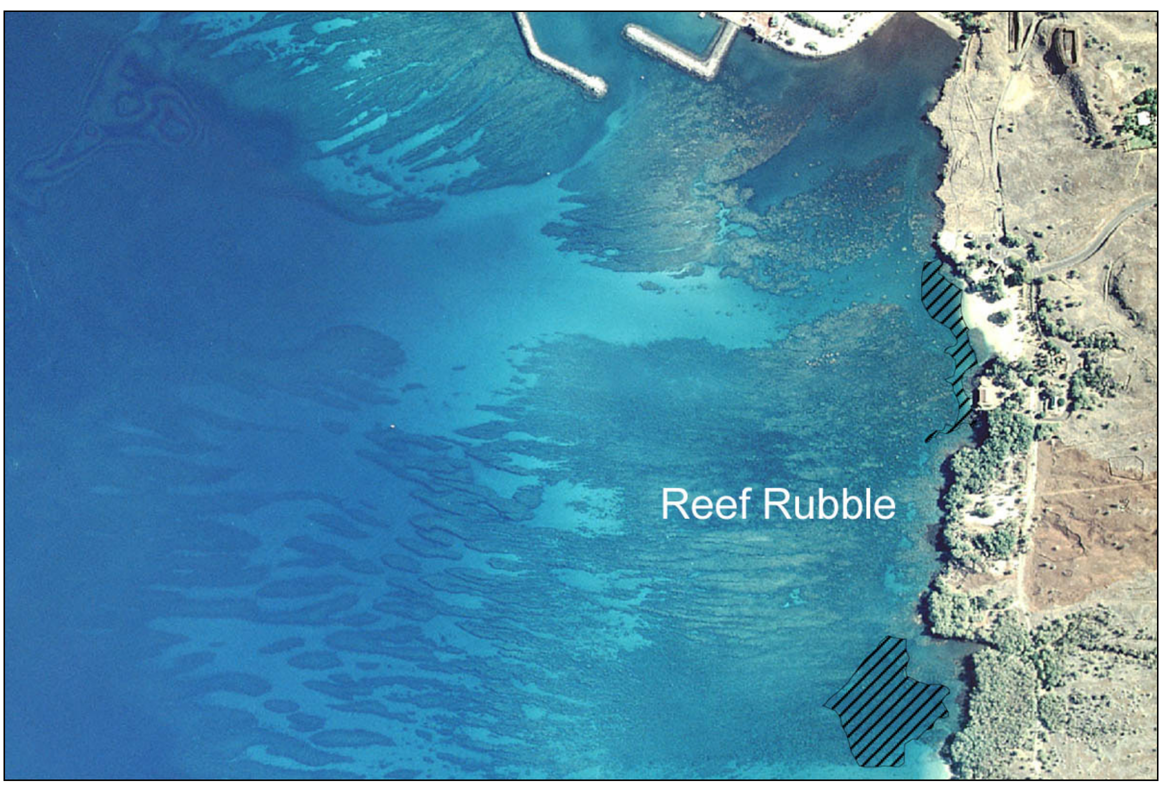


Uncolonized Hardbottom: Hard substrate composed of relict deposits of calcium carbonate or exposed volcanic rock.

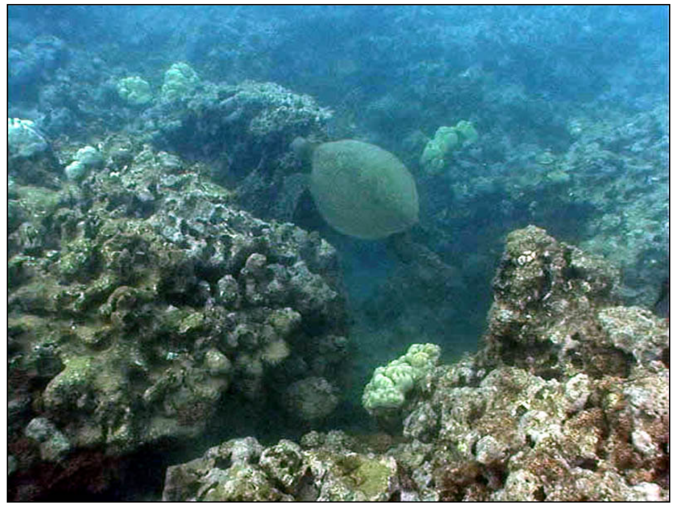
Reef Rubble: Dead, unstable coral rubble often colonized with filamentous or other macroalgae. This habitat often occurs landward of well developed reef formations in the reef crest or back reef zone.

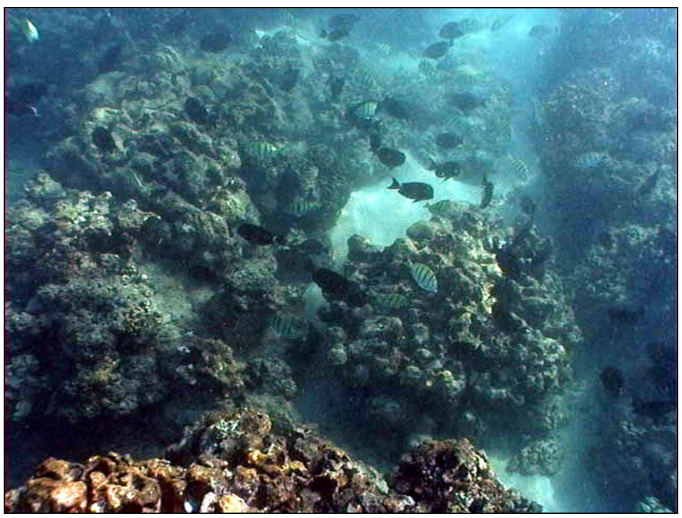


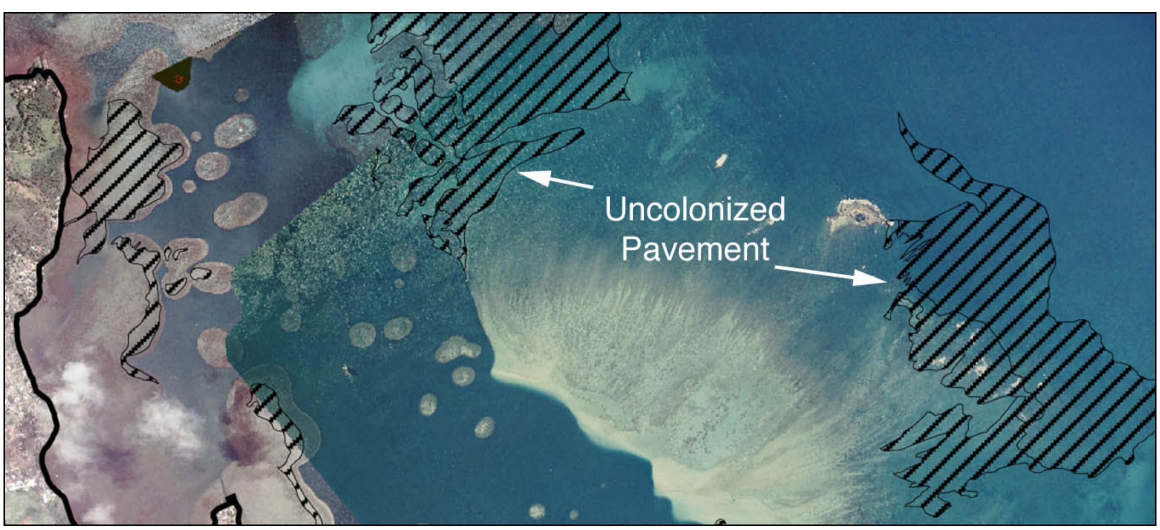




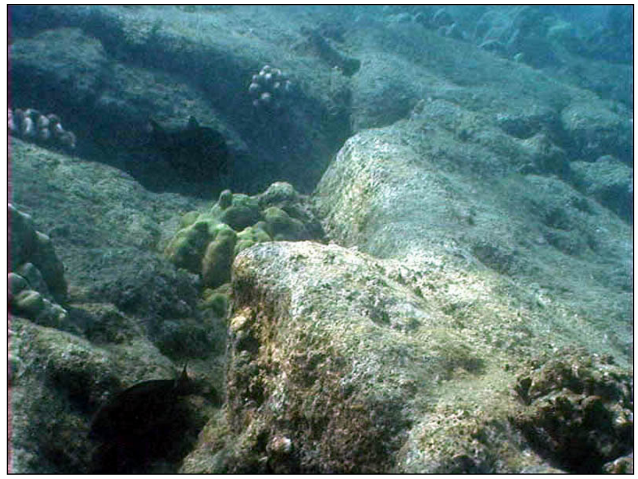
Uncolonized Pavement: Flat, low relief, solid carbonate rock that is often covered by a thin sand veneer. The pavement's surface often has sparse coverage of macroalgae, hard coral, zoanthids, and other sessile invertebrates that does not obscure the underlying surface.

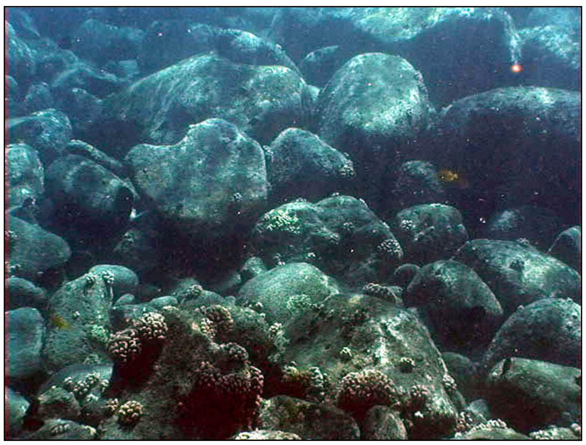


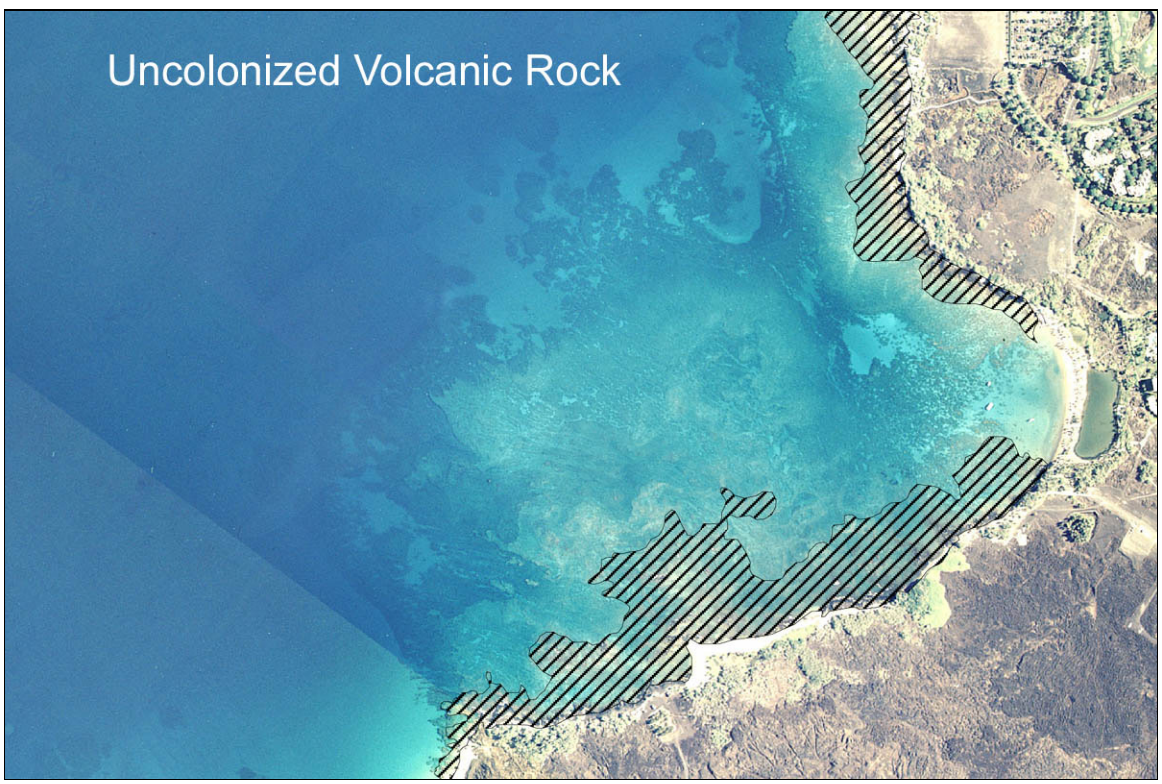




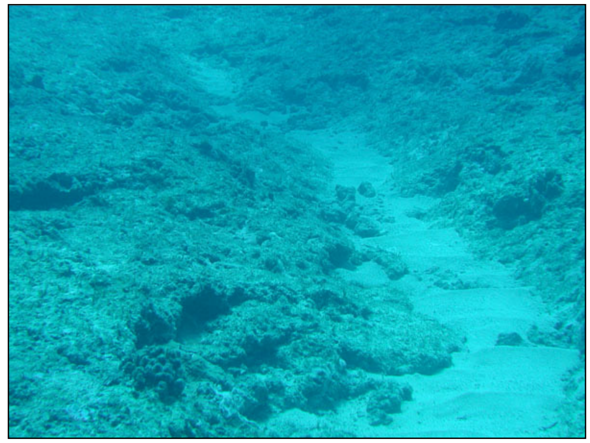
Uncolonized Volcanic Rock/Boulder:
Exposed volcanic rock that has sparse coverage of macroalgae, hard coral, zoanthids and other sessile invertebrates that does not obscure the underlying surface.







Uncolonized Pavement with Sand Channels: Habitat having alternating sand and uncolonized pavement formations that are oriented perpendicular to the shore or bank/shelf escarpment. The sand channels of this feature have low vertical relief relative to spur and groove formations. This habitat type occurs in areas exposed to moderate wave surge such as the bank/shelf zone.



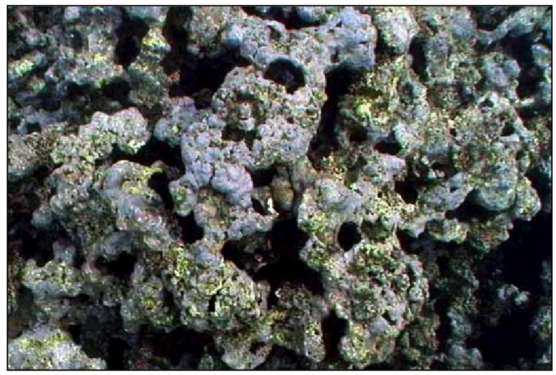
Encrusting/Coralline Algae: An area with 10 percent or greater coverage of any combination of numerous species of encrusting or coralline algae. May occur in shallow backreef, relatively shallow waters on the bank/shelf zone, and at depth.

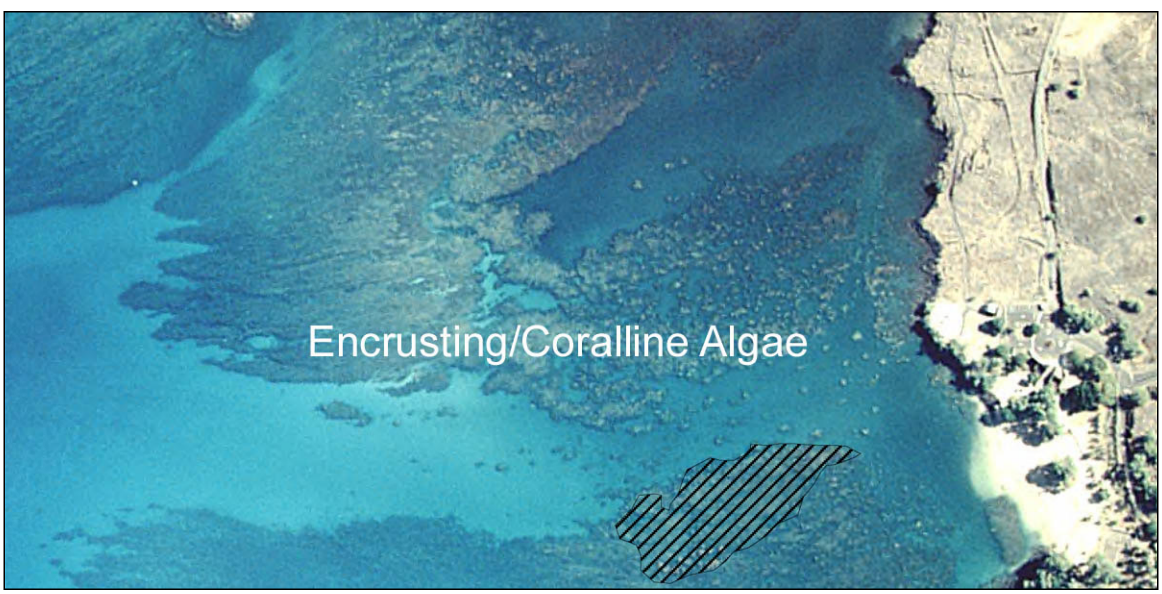
Continuous Encrusting/Coralline Algae: Encrusting/coralline algae covering 90 percent or more of the substrate.

Patchy Encrusting/Coralline Algae: Discontinuous encrusting/coralline algae with breaks in coverage that are too diffuse or irregular, or result in isolated patches of coralline algae that are too small (less than the MMU) to be mapped as continuous coralline algae.

Patchy Encrusting/Coralline Algae (50%-<90% cover)
Patchy Encrusting/Coralline Algae (10%-<50% cover)

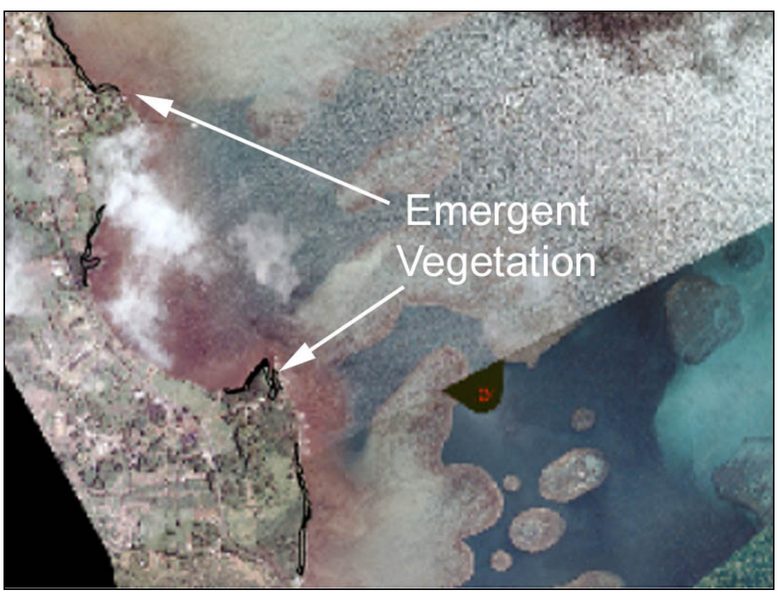
Representative Sp*ecies:*
Porolithon gardineri



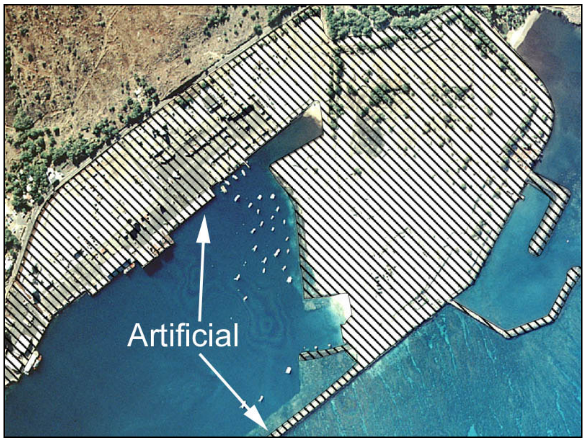


Other Delineations:

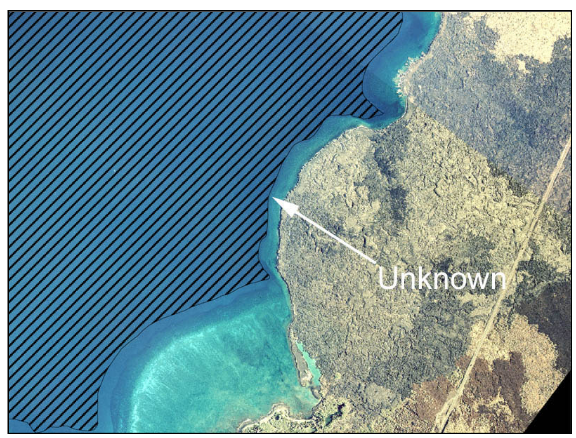
Emergent Vegetation: Emergent habitat composed primarily of *Rhizophora* mangle (red mangrove) and hao trees. Generally found in areas sheltered from high-energy waves. This habitat type is usually found in the shoreline/intertidal, back reef, or barrier reef crest zone.

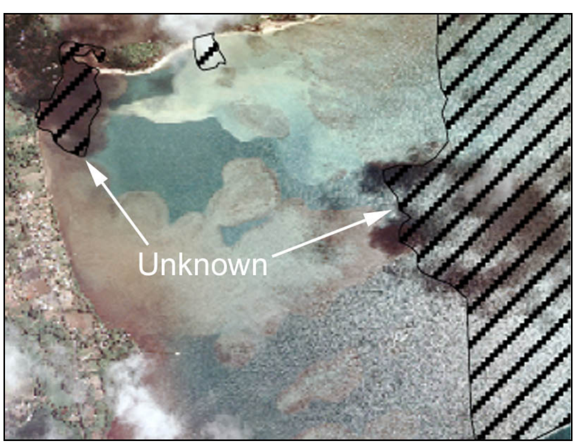


Artificial: Man-made habitats such as submerged wrecks, large piers, submerged portions of rip-rap jetties, and the shoreline of islands created from dredge spoil. Includes active and remnant fish ponds walled off from the open ocean along the shoreline, often along a reef crest.



Unknown: Bottom type uninterpretable due to turbidity, cloud cover, water depth, or other interference.





Chapter 2: On-Screen Mapping with ArcView's Habitat Digitizer

The habitat digitizer extension to ArcView 3.x was developed to facilitate mapping benthic habitats of Puerto Rico and the U.S. Virgin Islands (Kendall et al. 2001) and was also used for mapping the main Hawaiian Islands. The extension was originally created to map habitats using this scheme by visually interpreting orthorectified aerial photos. The extension's capabilities have been expanded to allow users to map from other georeferenced image data such as satellite images and side scan sonar. The extension allows users to rapidly delineate and attribute polygons using simple menus. It also allows new hierarchical classification schemes to be easily created, modified, and saved for use on future mapping projects.

The extension is available on the "Benthic Habitats of the Main Hawaiian Islands CD-ROM" (Kendall et al. 2001). The latest version can be found on the internet at *http://biogeo.nos.noaa.gov/products/.* The extension and accessory files are found in the "Habitat_Digitizer.zip" folder. This folder contains three files including:

habitat.avx	the extension
coral.hcs	a habitat classification scheme for tropical marine habitats
coral.avl	an example legend for the coral.hcs classification scheme

Hardware and Software Requirements

The habitat digitizer extension is compatible with ArcView 3.x and requires hardware similar to that recommended for proper operation of ArcView. Additional memory may enhance performance for handling large image files. The appropriate Image Support extension (TIFF, MrSID, etc.) is required depending on the format of the image files used. The Image Analyst extension is not necessary, but is recommended to facilitate manipulation of image brightness, contrast, and color balance.

Getting started

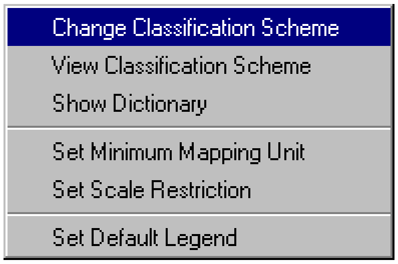
To begin using Habitat Digitizer, save the habitat.avx file in either ArcView's Ext32 directory or the USEREXT directory. The coral.hcs and coral.avl files can be saved anywhere, but they should preferably be placed in the ArcView project's working directory.

After starting ArcView, load the Habitat Digitizer Extension (and any other desired extensions) by selecting "File/Extensions…" and click on the box next to the Habitat Digitizer Extension in the "Available Extensions" list. Click "OK" to install the extension. If a project already exists that used the Habitat Digitizer Extension, opening the project will automatically load the extension.

Setting the Projection Parameters for the Image Data:

The Habitat Digitizer enables users to specify a minimum mapping unit (MMU), digitizing scale, and offers several other spatial functions that require the View's projection and map units to be set properly. The projection properties of the View must be set to those of the image data from which habitats are being interpreted. Once the View's projection is set properly, shapefiles created using Habitat Digitizer will be unprojected (in decimal degrees). To set the projection properties, select View/Properties and set the map and distance units as well as the Projection information of the image. If this information is not set, the shapefile will be created in the projection coordinates of the image files.

The Habitat Digitizer Menu



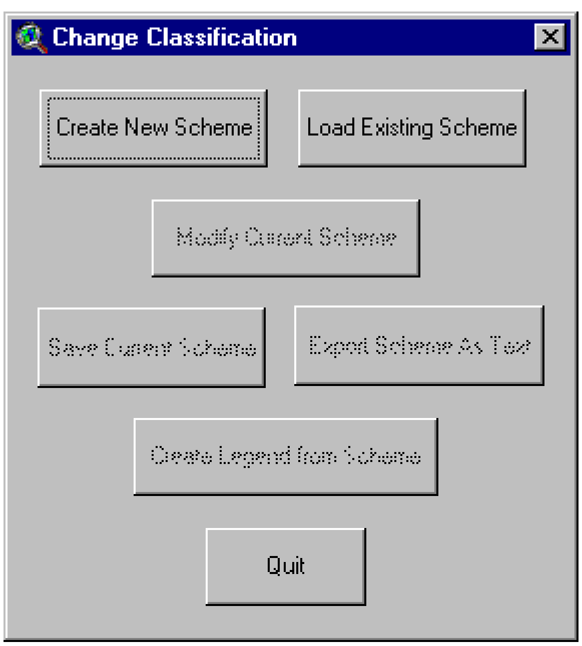
Once the Habitat Digitizer Extension has been activated the "Habitat Digitizer" pull-down menu and digitizing tools which control the functions of the extension will appear on the ArcView toolbar. Beginning with the process of creating and loading classification schemes, a detailed description and instructions for each function in the extension are provided below.

Creating a new classification scheme

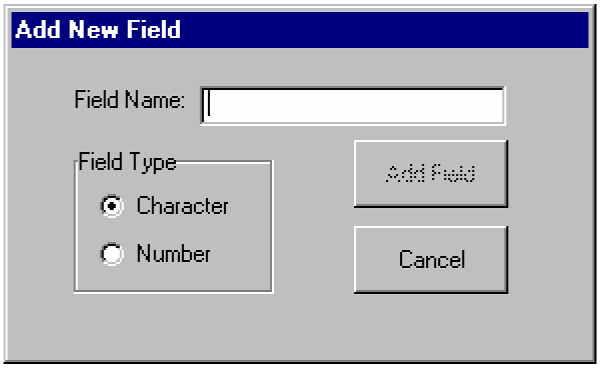
Unless an existing classification scheme such as coral.hcs is used, a new scheme must first be created to use the extension. Before creating a new scheme using the dialogs of the extension, it may be useful to sketch the scheme out on paper to ensure that all fields and categories in the hierarchy are entered properly. There are several advantages to using a scheme with a hierarchical structure including: the detail of habitat categories can be expanded or collapsed to suit user needs, the thematic accuracy of each category/hierarchical level can be determined, and additional categories can be easily added or deleted at any level of the scheme to suit user needs. An example of a scheme framework is provided in Table 2.1 below.

Table 2.1: Example Classification Scheme Framework

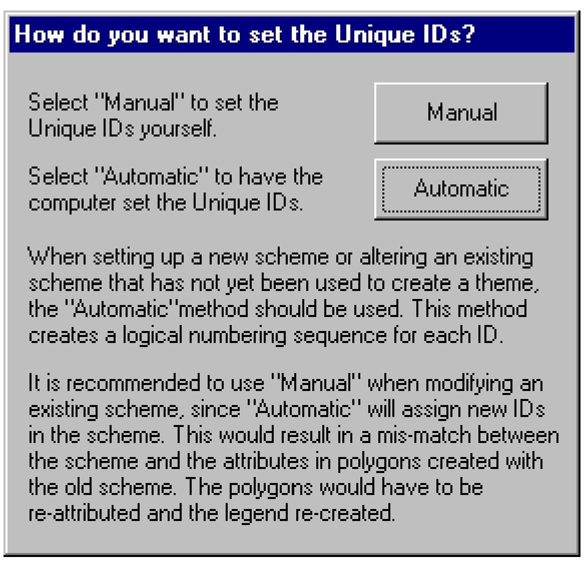
Field 1	*Field 2*	*Field 3*	*Field 4*	*UniqueID*
Category 1	**Subcategory 1**	**Subcategory 1**	**(empty)**	**111**
		Subcategory 2		**112**
	Subcategory 2	**Subcategory 1**		**121**
		Subcategory 2		**122**
Category 2	**Subcategory 1**	**Subcategory 1**		**221**
		Subcategory 2		**222**
	Subcategory 2			**22**
Category 3	**Subcategory 1**			**31**
	Subcategory 2			**32**



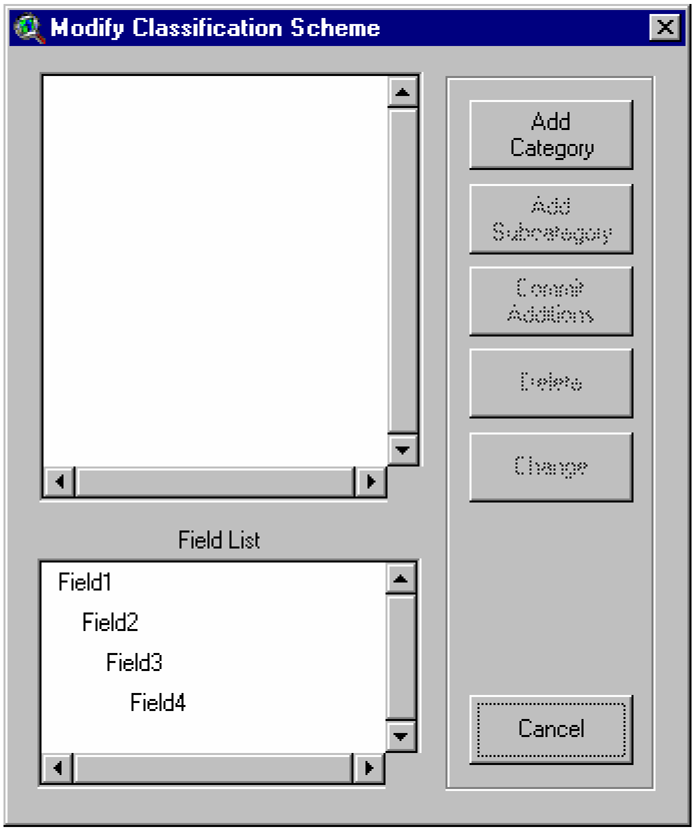
To create the new scheme using the extension, select **Habitat Digitizer/Change Classification Scheme** and in the next dialog box, select **Create New Scheme**. Type the name of the new classification scheme in the message box and click **Okay**. The other options in this dialog will be unavailable until a scheme has been either created or loaded.



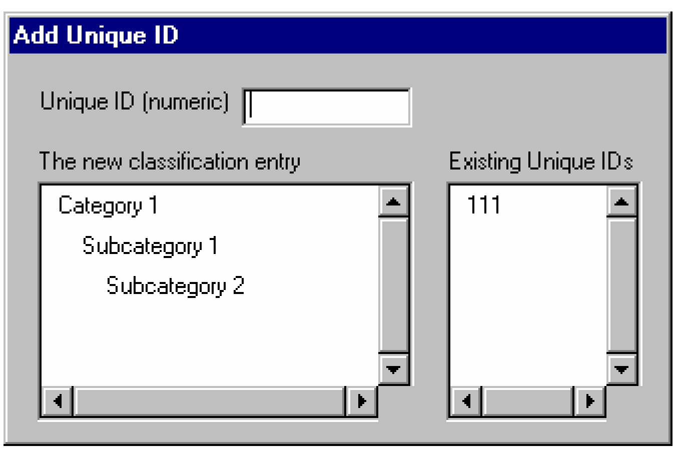
In the "Add New Field" dialog, selecting **Cancel** will end the creation process without creating a scheme. Once the first field name has been added, this button is replaced with the **Finished** button, which will complete the field naming process and go to the next step in creating the scheme. First, type in the field name for the most general hierarchical level in the new classification scheme (Field 1 in Table 2.1). Field names are limited to 10 characters in length. Select whether the field will be character or numeric and click **Add Field**. Add additional field names in the order of the classification hierarchy. A fieldname must be entered for every level in the hierarchy. Because new fields cannot be added after the scheme creation process is closed, add a few extra fields as placeholders in case any additional unforeseen levels in the hierarchy are required at a later time. After all the field names have been entered select **Finished** to proceed to the next step. Once **Finished** is selected, no additional fields may be added to the classification scheme. Note that a field named "UniqueID" is added automatically after **Finished** is selected.



The extension uses the uniqueID field to identify each possible combination of hierarchical categories with one unique number (see Table 2.1). ArcView uses uniqueIDs to link polygon attributes to the legend. The dialog at left sets the method of assigning uniqueIDs. When setting up a new scheme or altering an existing scheme that has not yet been used to create a theme, the **Automatic** method should be used. The **Automatic** method creates a logical numbering sequence for each uniqueID (see Table 2.1). When modifying a scheme that has already been used to create a theme, use the **Manual** method. If **Automatic** was used, new uniqueID's would be assigned to the scheme, creating a mis-match between the ID's of the new scheme and those of the polygons attributed using the old scheme.

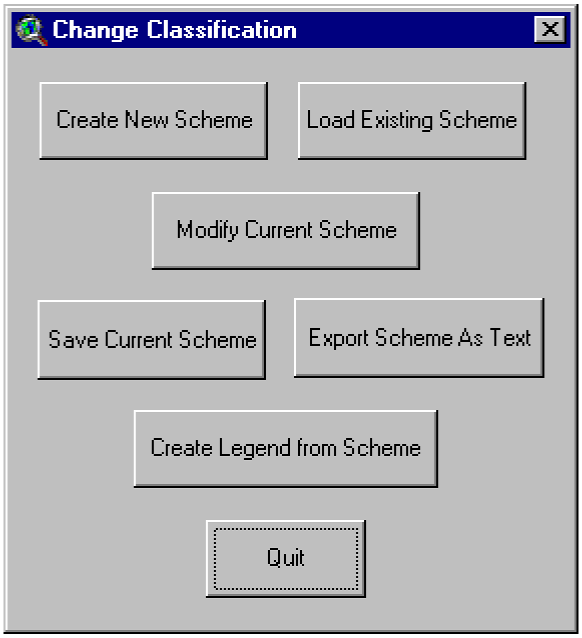


In the "Modify Classification Scheme" dialog, categories and subcategories can be added to a new or existing classification scheme. Begin by adding a category to the most general level in the classification hierarchy (Category 1 in Table 2.1). Click **Add Category**, then type the category name and click **Okay**. Additional categories at this level in the hierarchy can be added in this way. Adding a category at this level will activate the **Add Subcategory** button. Subcategories are added within individual categories by selecting the category of interest then clicking **Add Subcategory** and completing the dialog boxes. If the uniqueIDs are to be assigned using the **Automatic** option (previous dialog), the **Delete** and **Change** buttons are activated and can now be used to modify category names. In the **Automatic** method, clicking the **Finished** button will assign a uniqueID to each classification combination. If **Manual** was selected, the **Delete** and **Change** buttons will not be activated until the uniqueIDs for each of the categories and subcategories have been added (next dialog). To add uniqueIDs manually, click the **Commit Additions** button after all categories and subcategories have been added, then complete the **Add Unique ID** dialogue box as described below. Once the uniqueIDs have been assigned the **Delete** and **Change** buttons will be activated. If the **Cancel** button is selected, the scheme creation process will end without creating a scheme.



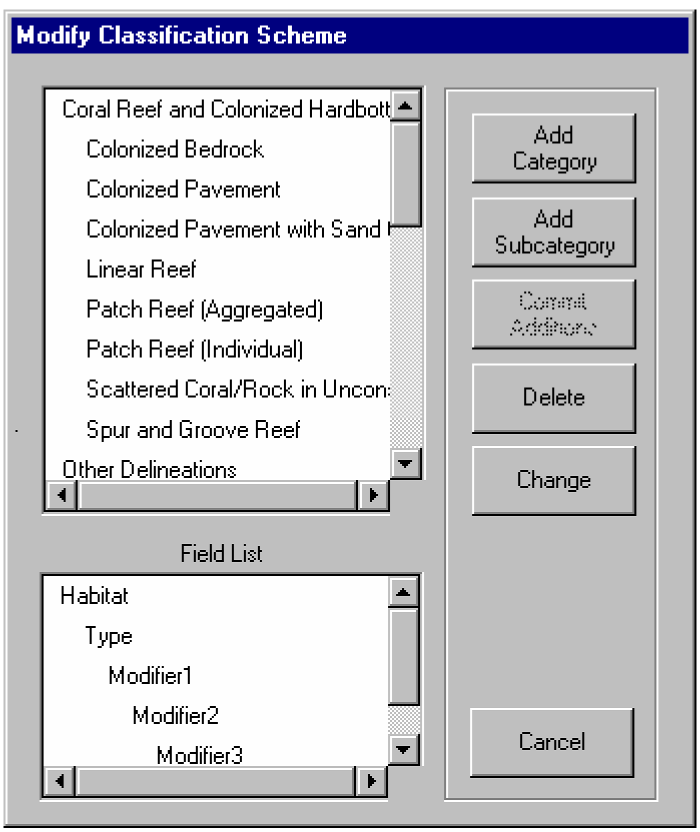
If **Manual** was selected for assigning uniqueIDs, the "Add Unique ID" dialog will appear after selecting **Commit Additions**. A unique numeric identifier must be entered for each possible combination of classifications in the hierarchy. The **Existing Unique IDs** list shows which numbers are already used in the scheme. Duplicate numbers cannot be added. See Table 2.1 or the coral.hcs scheme that is included with the extension to get suggestions on how to assign **uniqueIDs**. Once uniqueIDs are set through either the **Manual** or **Automatic** method and **Finished** is selected in the "Modify Classification Scheme" dialog, the new scheme can be saved and used to digitize habitats.

Saving, Re-Loading, and Creating Scheme Legends



Once you have finished creating or modifying a scheme, save the scheme to a file by selecting **Save Current Scheme** in the "Change Classification" dialog box. The file will be saved as a *.hcs (habitat classification scheme) file. To access this scheme, select **Load Existing Scheme** in the "Change Classification" dialog box. A file selection dialog will open showing only the *.hcs files. Additional options that can be used at this time include the **Export Scheme As Text** button which will create a text file showing the hierarchical structure of the scheme, and the **Create Legend from Scheme** button which will create a legend that contains each uniqueID and its attributes. Legend labels will have all of the categories in the classification hierarchy concatenated into one string. Colors will be randomly selected and an additional **Unclassified** category will be added with a uniqueID of zero.

Editing an existing classification scheme

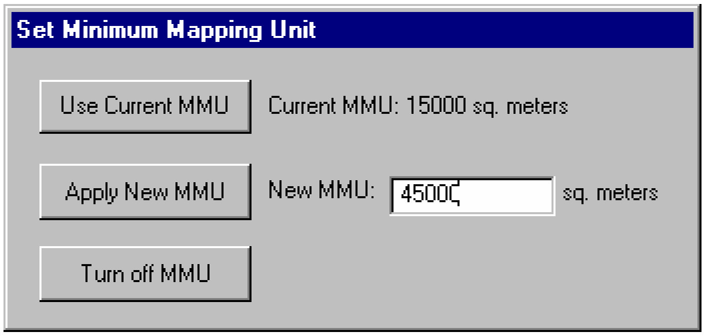


To edit an existing scheme, select **Modify Current Scheme** in the "Change Classification" dialog box. After selecting the method of assigning the uniqueID (in this case, using **Manual** is recommended), the "Modify Classification Scheme" dialog appears. Follow the same instructions in **Creating a New Scheme** to edit this scheme using the dialog at left.

Digitizing Restrictions

Minimum Mapping Unit

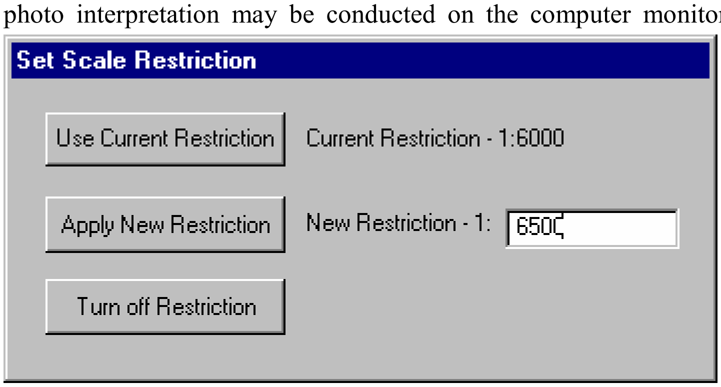
Depending on the quality of aerial images used and the specific goals of the project, it is often desirable to limit the minimum size of the features that are delineated. For example, poor image resolution may preclude the interpretation of features smaller than some minimum size threshold. Other features, while interpretable in the imagery, may simply be too small and therefore beyond the scope or goals of the desired map product. To limit the size of the features that can be digitized in the habitat map, a minimum mapping unit (MMU) can be set in Habitat Digitizer. Features must be larger than the MMU to be included in the habitat map.



Set the MMU restriction by selecting **Habitat Digitizer/Set Minimum Mapping Unit**. If the view's map and distance units are set, a dialog will appear showing the current MMU. Enter the desired numerical MMU into the text box and select **Apply New MMU**. If a satisfactory MMU has already been set, **Use Current MMU** will close the dialog without changing the MMU. Once an MMU is set, if the area of a newly digitized polygon is below the value specified, a message box will ask whether the polygon should be added to the theme. If no MMU restriction is desired, **Habitat Digitizer/Set Minimum Mapping Unit/Turn off MMU** will allow digitizing polygons with no size restriction.

Scale Restriction

It is possible to adjust the scale of the image files as they appear on the computer monitor. For example, the scale of hard copy photographs used for mapping may be 1:48000, however the actual photo interpretation may be conducted on the computer monitor while zoomed in on the scanned photographs at a much larger scale (e.g.1:6000). It is often desirable to conduct all polygon delineation at the same scale, so that all polygons have the same level of detail. Set the scale restriction by selecting **Habitat Digitizer/Set Scale Restriction**. Enter a number in the text box and select **Apply New Restriction**. If digitizing is attemped while a scale restriction is in place and the view is not at the specified scale, a message box will appear and offer to zoom the view to the proper scale. If **No** is selected, a polygon cannot be digitized. If a scale restriction is not desired, use **Habitat Digitizer/Set Scale Restriction/Turn off Restriction** to allow digitizing at any scale. The view's map and distance units must be set to use this tool.



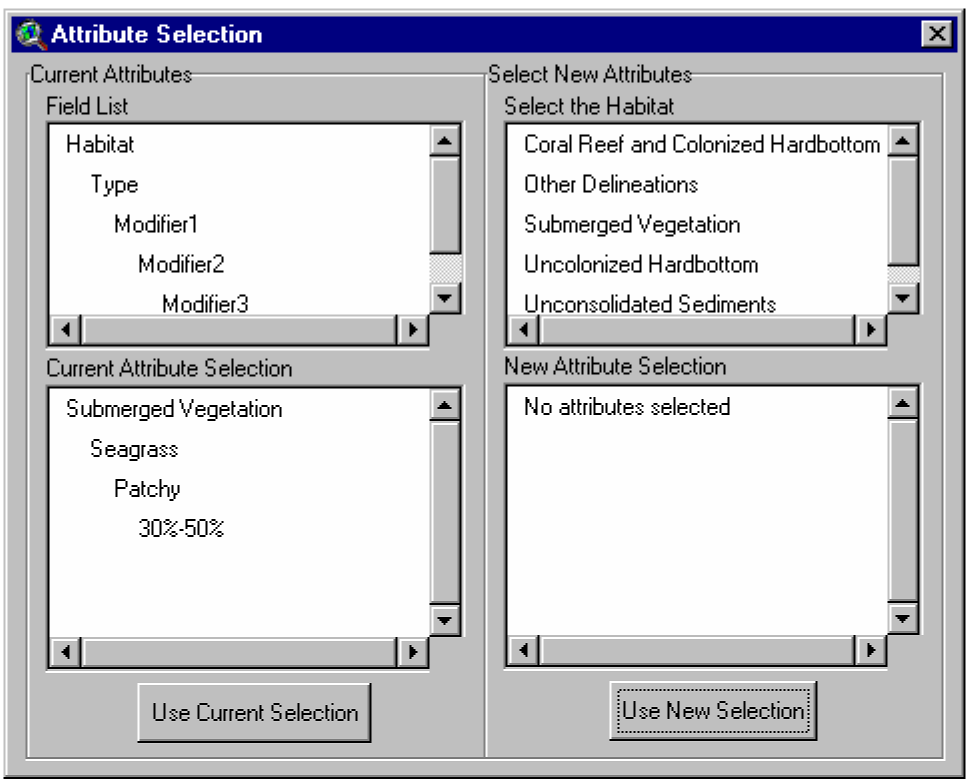
Creating a theme and using the digitizing tools

Once a classification scheme has been loaded, this button creates an empty theme with the appropriate fields. If a default legend has not been created using **Habitat Digitizer/Set Default Legend** or the **Change Classification** dialog, a dialog will appear to select a legend file. A second message box will appear asking if this legend should be made the default legend for all new themes created using this classification scheme. After creating a new theme, set the snapping tolerance by using the menu selection **Theme/Properties** and in the **Editing** selection, click the **General** box and set the tolerance to a number smaller than the pixel size of the images used for interpretation (since no interpretation will presumably be conducted within pixels). If this is not done, adjacent polygons will not always share a common border.

To start digitizing a new polygon, select this tool and trace the feature of interest by clicking around its perimeter with the mouse. A double click closes each new polygon. If a polygon is digitized inside or completely around an existing polygon, "donut" and "donut hole" polygons will be formed. Once the polygon is complete, a message box will allow the classification to be set as outlined below.

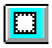
Use this tool to add a polygon adjacent to an existing polygon. To create a polygon using this tool, start tracing a line inside of an existing polygon and end the line by clicking twice inside of the same or another existing polygon. This tool will not work when attempting to digitize a polygon inside of another polygon (use the Split tool below to do that). The scale restriction and MMU also apply to this tool. If several polygons are created with a single line and some are below the MMU, a warning message will appear. If **No** is selected on the warning message only the polygons that fall below the MMU will be removed.

Once polygons are completed using the **Add** and **Append** tools, a dialog will appear to guide assignment of classification attributes.

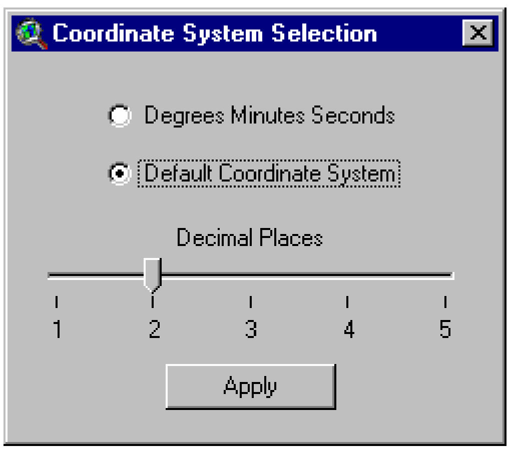


The **Field List** displays the hierarchical structure of the fields in the scheme. **Current Attribute Selection** shows the classification type, if any, currently selected. Either select **Use Current Selection** or select a new classification type by clicking through the desired classification attributes in the **Select New Attributes** window. As new attributes are selected they will be displayed in the **New Attribute Selection** window. The **Use New Selection** button will be activated when the attribute in the lowest hierarchical level for the new classification is selected.


This tool splits one or more polygons into several polygons. All of the attribute information for the resulting polygons will be the same as the original(s), but can be changed as explained below under "Tools from the Right Mouse Button". Please note that due to a bug in ArcView, this tool sporatically works when attempting to split along the inside border of a donut polygon. The scale restriction and MMU also apply to this tool. If several polygons are split and some of the resulting polygons fall below the MMU, choosing **No** will remove the entire line and merge the split polygons back together.


This tool places a MMU sized red box on the view by clicking the button and then clicking directly in the View at the desired location. This box enables users to estimate the size of features in the imagery relative to the MMU. This box disappears when panning, zooming in or out, or after completing a polygon. To use this feature while adding a new polygon see "Tools from the Right Mouse Button" below.


This tool brings up a dialog to display the cursor's x/y position in the upper right hand corner of the ArcView window in either the coordinate system of the view (default) showing from 1-5 significant digits, or in degrees, minutes, and seconds. This requires that the view's projection be set and the map units specified.



Tools from the Right Mouse Button

Click and hold down the right mouse button to view a list of additional tools and options:

Panning will recenter the display over the spot where the right mouse button was clicked. This is useful while digitizing large polygons that do not fit entirely within the view frame.

Pan to Location will center the display at the coordinates entered in a message box.

Show attributes will display a message box showing the habitat attributes for the currently selected polygon.

Change habitat attribute will allow the user to change the habitat attributes for polygons that are selected.

MMU Box places an MMU box on the View where the right mouse button was clicked (can be added while digitizing a polygon).

Polygon Area shows the area of a selected polygon.

When a project is saved, the settings (classification scheme, MMU, scale restriction, default legend, cursor display precision, and current attribute selection) will be stored along with the project. Upon opening the saved project, these settings will be restored and do not need to be re-entered.

Chapter 3: Creating and Interpreting Digital Orthophotographs

Habitat maps of the main Hawaiians Islands were created by visual interpretation of aerial photos and hyperspectral imagery using the Habitat Digitizer extension (Chapter 2). Aerial photographs are valuable tools for natural resource managers and researchers since they provide an excellent record of the location and extent of habitats. However, spatial distortions in aerial photos due to such factors as camera angle, lens characteristics, and relief displacement must be accounted for during analysis to prevent incorrect measurements of area, distance, and other spatial parameters. These distortions of scale within an image can be removed through orthorectification. During orthorectification, digital scans of aerial photos are subjected to algorithms that eliminate each source of spatial distortion. The result is a georeferenced digital mosaic of several photographs with uniform scale throughout the mosaic. After an orthorectified mosaic is created, photointerpreters 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 Habitat Digitizer. Through this process, natural resource managers and researchers are provided with spatially accurate maps of habitats and other features visible in the imagery.

Creating the Digital Mosaic

Aerial photographs were acquired for the main Hawaiians Islands Benthic Mapping Project in 2000 by NOAA Aircraft Operation Centers aircraft and National Geodetic Survey cameras and personnel. Approximately 1,449, color, nine by nine inch photos were taken of the coastal waters of the main Hawaiian Islands at 1:24,000 scale. Specific sun angle and maximum percent cloud cover restrictions were adhered to when possible during photography missions to ensure collection of high quality imagery for the purpose of benthic mapping. In addition, consecutive photos were taken at 60 percent overlap on individual flightlines and 30 percent overlap on adjacent flightlines to allow for orthorectification and elimination of sun glint.

Prints and diapositives (color transparencies) were created from the original negatives. Diapositives were then scanned at a resolution of 500 dots per inch (DPI) using a photogrammetric quality scanner, yielding one by one meter pixels for the 1:24,000 scale photography. All scans were saved in tagged image file format (TIFF) for the purposes of orthorectification and photointerpretation. Original TIFFs were also converted to *.jpg format to reduce file size and facilitate web-based image distribution, and are currently available on the NOAA Biogeography Program's web site at 72, 150, and 500 DPI resolution (http://biogeo.nos.noaa.gov/products/data/photos/).

Georeferencing/mosaicing of the TIFFs was performed using a variety of softcopy photogrammetric software including Socet Set Version 4.2.1, Autometric Softplotter, PCI OrthoEngine, and Erdas OrthoBase. First, lens correction parameters were applied to each frame to eliminate image distortion. Airborne kinematic GPS (location of the aircraft at the time of each exposure) was then used, when available, to provide a first order geolocation. When this information was not available, measurements were made between flightline strips for input into aerial triangulation software to provide preliminary co-registration.

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) were then used to further co-register the imagery, especially for photos taken over open water where ground control points were not available (see below). Softcopy photogrammetry software has limited ability to automatically find such features common to overlapping photographs but this automated function performs poorly for submerged features.

Fixed ground features visible in the scanned photos were selected for ground control points (GCPs) which were then used to georeference the imagery (i.e. link the image pixels to a real world coordinate system such as latitude/longitude). GCPs were measured using DGPS (Differentially-corrected Global Positioning System). We obtained points with a wide distribution throughout the imagery, especially on peninsulas and outer islands whenever possible since this results in the most accurate registration throughout each image (http://biogeo.nos.noaa.gov/projects/mapping/pacific/main8/data/). Only ground control points for terrestrial features were collected due to the difficulty of obtaining precise positions for submerged features.

Pre-existing U.S. Geological Survey (USGS) 10-meter digital elevation models were used to correct for relief displacement (http://biogeo.nos.noaa.gov/products/mapping/dems/). Once a draft orthorectified mosaic was produced, a set of independent ground control points (i.e. check points) were used to measure the quality of each mosaic's rectification and ensure that it adhered to horizontal and vertical spatial accuracy limits. If the spatial accuracy was not acceptable based on this comparison, additional modifications were made to the GCPs, tie-points, etc., until a satisfactory mosaic was created for each island. In general, mosaics were georeferenced such that pixels are positioned within one pixel width of their correct location.

Average spatial accuracy of the individual mosaics is reported in Table 3.1. Values reported (pixel units) are the calculated root mean square error (RMSE) between the geometrically transformed mosaic solution and actual check point coordinates. RMSE is an industry standard for reporting the accuracy of orthorectified products. RMSE is variable within different areas of each mosaic. Features near land (near GCPs) are generally georeferenced with accuracy similar to the values reported in the table while the accuracy of features away from land is generally not as good. Where no land is in the original photographic frame only kinematic GPS and tie points were used to georeference the images.

Once all the photos were orthorectified, the best segments of each photo were selected for creation of the final mosaic. Segments of each photo were selected to minimize sun glint, cloud interference, turbidity, etc. in the final mosaic. Where possible, parts of images obscured by sun glint or clouds were 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 areas could not be replaced with overlapping imagery. In these areas, such obstructions were minimized but could not be eliminated completely.

Final mosaics were created in "geoTIF" file format (georeferenced image file) with the following projection parameters: North American Datum 83, Universal Transverse Mercator (UTM) Zone 4 for Niihau, Kauai, Oahu, Molokai, Lanai, and Maui, and UTM Zone 5 for Hawaii. These files are available on the "Benthic Habitats of main Hawaiian Islands" CD-ROM and at the NOAA Biogeography Program web site in Mr.SID format. No color balancing was attempted since this alters color and textural signatures in the original imagery and interferes with the photointerpreter's ability to delineate habitats. As a result, mosaics have visible seams between adjacent photos. This provides the photointerpreter with "true color" imagery for maximum ability to identify and delineate benthic features.

Table 3.1: Mosaic Specifications for each Island. RMSE are in pixels.

Location	*UTM Zone*	*Photo Scale*	*Pixel Width (m)*	*# of Photos*	*RMSE X*	*RMSE Y*	*RMSE Z*
Niihau	4	1:24000	1.0	15	0.054	1.120	0.300
Kauai	4	1:24000	1.0	66	2.582	2.884	1.453
Oahu	4	1:24000	1.0	25	1.437	1.382	1.139
Lanai	4	1:24000	1.0	11	1.687	1.873	1.116
Molokai	4	1:24000	1.0	31	.887	1.024	0.027
Maui	4	1:24000	1.0	37	1.417	1.223	1.502
Hawaii	5	1:24000	1.0	21	1.169	1.093	.566

Digitizing Benthic Habitats

Coral reef benthic habitat maps were digitized by delineating habitat boundaries from georeferenced imagery loaded into ArcView GIS software with Image Analysis and the NOAA digitizing extension activated. Mosaiced color aerial photography scanned at one meter resolution, AURORA hyperspectral imagery collected at three meter and IKONOS satellite imagery collected at four meter resolution were provided for this work. Digitizing was conducted using heads-up computer screen methods with the minimum mapping unit (MMU) set to 1 acre and image scale at 1:6,000. This ensures that the level of detail produced by the photointerpreter is uniform throughout all products that have been provided on this CD-ROM.

All three types of remotely sensed imagery were processed by NOS prior to map production. Individual color aerial photographs were georeferenced and mosaiced. The hyperspectral data composed of 72 ten nm wide bands were subsetted to three band composites that enhanced deep and shallow water features. IKONOS satellite imagery was corrected for atmospheric and water column effects. During the digitizing process, image stretches and manipulating image contrast, brightness and color balance were performed in the ArcView Image Analysis Extension to enhance features in the processed imagery.

Within the extents of the color aerial photography, high quality 1:24,000 scale diapositives were available to aid the photointerpreter in the determination of habitat boundaries and type. These were viewed using a magnifying loop on a light table.

The habitat boundaries were visually interpreted based on the signature (color and texture) of visible features. Habitat boundaries were delineated on computer screen and attributed in the GIS using the NOAA digitizing extension. Initially, a boundary around the entire image was generated and subdivided to discrete polygons representing the detailed habitats and zones defined in the Coral Reef Habitat Classification Scheme for the main Hawaiian Islands.

Ground Validation

A first draft map was completed using the above methods and features in the imagery where uncertainties existed, due to confusing or difficult to interpret signatures, were identified for future ground validation effort. An ArcView GIS point theme was generated with points positioned on the features of uncertain habitat type or along transects through gradients between habitat types. The GIS points were converted to GPS waypoints using Trimble Pathfinder Software and were navigated to in the field using a Trimble GeoExplorer 3 GPS data logger.

Color prints of the imagery overlaid by the draft habitat map and waypoints were laminated and taken into the field to assist in the identification of signatures in the imagery and actual habitat type at each waypoint. A benthic habitat characterization was conducted at each site by snorkeling, free diving or via observations from the surface where water depth and clarity permitted. GPS data were collected at each location and site ID, depth, habitat type, zone and the method used to make the assessment were recorded on the GPS data logger. Longhand notes and descriptive information were hand written in waterproof notebooks.

All field data were processed at the end of each field day. The data from the GPS data logger were downloaded and differentially corrected to the closest Continuously Operating Reference System (CORS). These data were converted to a text file that included geographic position and descriptive spatial statistics, which were automatically generated from the GPS data logger. A comments field was added to the text file and longhand field notes were manually entered. The file was converted to an ArcView shape file and overlaid on the original imagery and, where necessary, polygon boundaries were created or revised based on field observations using the NOAA digitizing extension. This second draft map was submitted for accuracy assessment.

Chapter 4: Assessment of Classification Accuracy

It is invalid to assume that habitat maps generated from photointerpretation of remotely sensed imagery are 100% correct. 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 what percentage of the polygons of a particular class are correctly attributed. This parameter is called "users accuracy". Furthermore, remotely sensed imagery that may be suitable for mapping coral reef habitats can be acquired from a wide variety of platforms and imaging systems, each having it's own strengths and limitations. It is important to identify the technical merits of each including the thematic accuracy of the map products.

Benthic habitat maps in ArcView GIS format were prepared by visually interpreting the three types of remotely sensed imagery. Conventional methods for assessing the accuracy of living resource maps prepared from visual interpretation of remotely sensed imagery were applied to meet two objectives. The first was to identify and compare thematic accuracy of maps prepared from the three sources of remotely sensed imagery and the second was to generate a scientifically sound statistical estimate of the thematic accuracy of the final map products. To meet the first objective, the accuracy of the benthic habitat maps in the four test areas was completed for each of the imagery types. These were contrasted to compare the accuracy of each. To meet the second objective, the data were then combined and analyzed to establish an accuracy of the final mapped products.

The thematic accuracy of all mapped products was determined at the four most general levels of the classification scheme including unconsolidated sediment, submerged vegetation, coral reef/hard bottom and other. Four coral reef test areas were selected based on the diversity of the habitat types and to assure that all benthic habitats throughout the Hawaiian Islands were represented. The accuracy of all maps is, therefore, considered a conservative representation of the thematic accuracy of the habitat maps prepared using the same methods for imagery collected throughout the remainder of the main Hawaiian Islands.

Goals of Accuracy Assessment

1) Compare the thematic accuracy of benthic habitat maps prepared from three sources of remotely sensed imagery
2) Establish a statistically sound thematic accuracy for routine production of habitat maps for the main Hawaiian Islands

Evaluating Thematic Accuracy: Thematic Accuracy in the Main Hawaiian Islands

Four field test areas comprising over 100 square kilometers of coral reef area were established to determine the thematic accuracy of the benthic habitat maps prepared from the color aerial photography, hyperspectral airborne and IKONOS satellite imagery. Each area extends from shore to a depth of approximately 30 meters. The first was located on the Kona Coast in the District of South Kohala on the west side of the

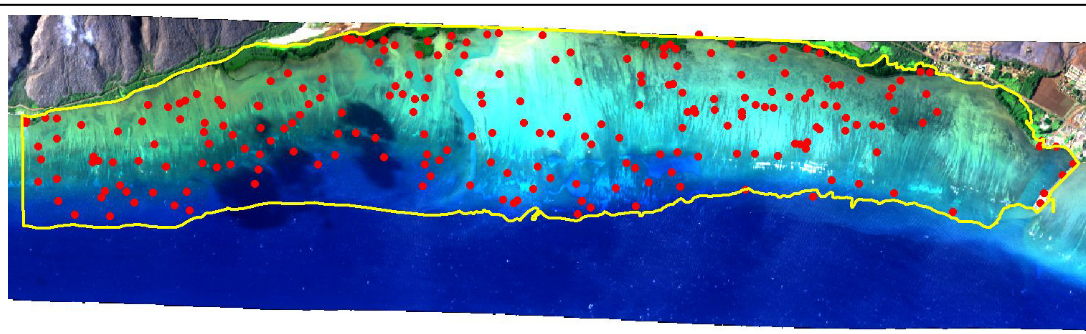


Figure 1. Distribution of accuracy assessment points (N=231) in red within the Molokai test site boundary displayed in yellow.

island of Hawaii. It extends from Kawaihae Harbor to Kiholo Bay. The second study area is located in Kaneohe Bay on the island of Oahu. It extends from the Sam Pan Channel on the south end of the bay to Chinaman's Hat on the north end of the bay. The third area is on the Island of Maui from Maalaea Harbor to Makena Beach and the fourth is illustrated here and is located on the south shore of the Island of Molokai from Palaau to the Kaunakakai Pier (Figure 1).

A single NOAA contractor conducted all image interpretation and digitizing. The field habitat characterization data collection methods for thematic accuracy assessment differed little from the methods used to collect data for ground validation. The primary distinction between the two data sets was the method of selection of the field points. The assessment sites for ground validation were selected to specifically investigate habitat types and gradients of spectral signatures in the imagery and a random stratified sampling method was implemented to select field sites to test map accuracy. Subsequent to completion of the second draft coral reef habitat maps, polygons representing detailed habitats were aggregated into the three major classes and at least 50 random geographically referenced points were created in each (Congalton 1991). Waypoint files were generated from these points and all waypoints that could be safely accessed were navigated to using a Trimble Geo Explorer 3 GPS data logger. Upon arriving at the waypoint, a weighted meter line was dropped, a buoy fastened and site and habitat specific data collection was undertaken.

Three benthic habitat assessments were conducted. A point assessment was conducted by surveying the one square meter area around the point where the weight dropped. Two area assessments were conducted in an area of a seven meter radius around the weight. The first assessment identified the most common habitat type within the area and the second identified the second most common habitat type with in the area. The depth of the site was recorded using a hand held depth sounder. Benthic habitat assessments were made using a glass bottom look box, diving or observing from the surface. All diving was conducted by breath holding or snorkeling on the surface. In areas where waves and sea conditions were prohibitive to safely accessing the waypoint by boat, the GPS was 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 were recorded 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 were downloaded, differentially corrected and seamlessly converted to ArcView GIS format. All hand written descriptions were entered in waterproof notebooks and transferred to the GIS by hand. A total of 1,225 benthic habitat characterizations were completed in all four test areas combined (Table 1).

To maintain objectivity in the analysis of accuracy, an independent team conducted this work. The Coral Reef Assessment and Monitoring Program (CRAMP) biologists of the Hawaii Institute of Marine Biology from the University of Hawaii at Manoa made the official judgments. The accuracy assessment point theme and the benthic habitat polygon theme were overlaid on the imagery in the GIS. The GIS was queried to select all points within the polygons that matched the polygon habitat type. These were set aside as correct calls. The mismatched pairs were closely examined.

Test Area	Number of Field Assessments
Kaneohe Bay	393
Kona Coast	304
Maui	297
Molokai	231
Total	1,225

Table 1. Number of field assessments acquired at each of the four test sites

The classification errors that occurred between the MMU and size of accuracy assessment areas were accounted for in this analysis. A map classification was not considered incorrect in a case where a seven meter radius field assessment fell on a habitat feature in the field that was smaller than the one acre MMU. For example, if a field assessment fell on a small patch reef surrounded by sand that was less than the MMU and thus was not mapped, the point was excluded from the accuracy assessment report. Points that fell close to polygon boundaries were all included as it was assumed that the probability of error contributing to false negatives would be equal to that for false positives. Furthermore, the three types of imagery were acquired during different days with different weather conditions. The habitat type for the portions of the test area that were not interpretable due to cloud cover, glint or water quality were classified as "unknown". The accuracy assessment points that fell within polygons with the habitat type of "unknown" were not included in the accuracy analysis.

Results of overall accuracy assessment of benthic habitat map products

Thematic accuracy of the benthic habitat maps was determined using the above methods. The mapped habitat type was compared with that of the actual habitat type from field observation. The data was organized into a matrix with columns representing the field habitat assessment and rows organized into mapped habitat type. The correct class for each of the incorrect attributes was recorded and included in a comprehensive matrix at the most detailed level of the classification scheme. Twelve of these detailed matrices were generated, one for each of the types of imagery at each of the four test areas (Table 2 on following page). Error matrices were prepared at the detailed level to identify patterns of confusion in the interpretation of the signatures in the imagery. This information has been incorporated into ongoing work to improve the accuracy of future mapped products.

The overall accuracy was calculated by dividing the total correct determinations by the total number of assessments. This result only incorporates the major diagonal of the table and excludes the omission and commission errors whereas the Kappa analysis (Cohen, 1960) indirectly incorporates the off-diagonal elements as a product of the row and column marginals. The Tau analysis generates a similar statistic as Kappa but compensates for unequal probabilities of groups or for differences in numbers of groups (Ma and Redmond, 1995). This assessment lends itself to statistical analysis wherein the photointerpreter's determination is assigned a probability that it occurred at random. The data was then aggregated to the four most general levels of the classification scheme and twelve error matrices were generated, one for each of the image types at each of the four test areas (Table 3).

Actual Habitat Type

Mapped Habitat Type	*Coral Reef/ Hardbottom*	*Submerged Vegetation*	*Unconsolidated Sediment*	*Other*
Coral Reef/ Hardbottom	136 96%(U) (89%(P)	5	1	1
Submerged Vegetation	13	66 83%(U) 87%(P)	1	0
Unconsolidated Sediment	4	5	88 90%(U) 98%(P)	0
Other	0	0	0	9 100%(U) 90%(P)

Overall Accuracy: 91%

Table 3. Sample error matrix of major classes of classification scheme prepared from visual interpretation of hyperspectral imagery at the Kaneohe Bay test site. Numbers in matrix indicate class coincidence, (U) indicates users accuracy and (P) indicates producers accuracy based on the analysis of 329 field assessments.

		FIELD ASSESSMENT													Row	User's
POLYGON ATTRIBUTE		*AgCr*	*SnG*	*ColPv*	*Artf*	*LCorAl*	*LMacAl*	*SCRUS*	*MMacAl*	*EmgVg*	*Mud*	*RR*	*SAND*	*LinReef*	*UnColPv*	**Totals**	**Accuracy**
	AgCr	**27**	1										2			**30**	**90%**
	SnG		**0**													**0**	
	ColPv	2		**1**												**3**	**33%**
	Artf				**7**											**7**	**100%**
	LCorAl			1		**0**	1									**2NA**	**0%**
	LMacAl						**38**						2			**45**	**84%**
	SCRUS							**10**							1	**11**	**91%**
	MMacAl			1			4		**5**				1			**11**	**45%**
	EmgVg							4		**21**				1		**21**	**100%**
	Mud										**1**					**1**	**100%**
	RR															**1**	**100%**
	SAND						2				1		**38**			**41**	**93%**
	LinReef										**1**					**37**	**100%**
	UnColPv							1							**6**	**7**	**86%**
Column Totals		**29**	**1**	**3**	**7**	**0**	**45**	**11**	**9**	**21**	**2**	**1**	**37** **43**	**37**	**8**	**217**	
Producer's Accuracy		**93%**	**0%**	**33%**	**100%**	**NA**	**84%**	**91%**	**56%**	**100%**	**50%**	**100%**	**88%**	**100%**	**75%**		

Detailed Overall Accuracy **88.5%**

Table 2. Sample error matrix of detailed classes of the classification scheme prepared from visual interpretation of color aerial photography at the Molokai test site. Numbers in matrix indicate class coincidence, (U) indicates users accuracy and (P) indicates producers accuracy based on the analysis of 217 field assessments. Column and row headings have been abbreviated. AgCr: aggregated coral, SnG: spur and groove, ColPv: colonized pavement, Artf: artificial, LCorAl: Coralline algae (10%-<50% cover), LMacAl: macroalgae (10%-<50% cover), MMacAl: Macroalgae (50%-<90% cover), EmgVg: emergent vegetation, RR: reef rubble, LinReef: linear reef and UnColPv: uncolonized pavement.

The most common and generally accepted statistic used to represent the accuracy of map products is the over all accuracy. The average accuracy for the map products prepared from each of the imagery types was estimated by combining the results from the four test areas. This summary was completed for both detailed and major habitat accuracy assessment (Table 4). Though the accuracy of maps prepared from IKONOS

Accuracy Statistics

Imagery Type (All test areas Combined)	*Overall Accuracy at Detailed Habitat Level*	*Over all Accuracy at Major Habitat Level*	*Kappa for Major habitat Level*	*Tau for Major Habitat Level*
Color Aerial Photography	80.8%	90.7%	0.87	0.87
Hyperspectral Imagery	78.1%	89.0%	0.85	0.86
IKONOS Satellite Imagery	74.1%	86.5%	0.82	0.83

Table 4. Accuracy of final map products summarized for each of the three types of imagery. An overall accuracy was estimated to be 90% at major level and 80% at detailed level (Kappa and Tau 0.86) as color aerial photography was predominantly used for map preparation.

satellite imagery were tested, IKONOS imagery was not used to prepare the final benthic habitat maps for the main Hawaiian Islands. Thus, the overall accuracy of the final mapped product prepared from the visual interpretation of imagery for the main Hawaiian Islands is estimated to be 90% (Kappa and Tau 0.86) for the major class level and 80% at the most detailed level of the classification scheme. Kappa and Tau were calculated and reported for the major habitat levels but not calculated for the detailed level.

Comparison of Thematic Accuracy of Map Products Generated from Color Aerial Photography, Hyperspectral Imagery and IKONOS Satellite Imagery

The cost effectiveness of acquisition and processing of remotely sensed imagery varies significantly between types of platforms deployed and imaging systems used to acquire the data. Logistics constrain the area accessible by fixed wing platforms while satellite imagery is relatively inexpensive for large scale acquisitions. The enhanced spectral resolution of hyperspectral and control of bandwidth of multispectral data yield an advantage over color aerial photography particularly when coral health and time series analysis of coral reef community structure are of interest. NOAA is transitioning away from aerial photography in very large and remote areas that are difficult to access by airplane. As a result, it is important to identify the strengths and weaknesses of the map products prepared from each of the types of digital imagery. Of particular interest is the thematic accuracy of the mapped products.

The Z test or Z score, which reveals the probability that there is no difference between the accuracy of the maps in a contrast, was applied to these data. A contrast result of an absolute value of 1.96 or less indicates a 95% confidence that there is no significant difference between the accuracy of the maps being compared. Three of the four contrasts between the accuracy of maps prepared from one meter color aerial photography and three meter hyperspectral imagery resulted in a insignificant difference (Table 5). The contrasts conducted between maps prepared from three meter hyperspectral and four meter IKONOS satellite imagery all showed insignificant differences. Two of the four contrasts conducted between maps prepared from one meter color aerial photography and 4 meter IKONOS satellite imagery resulted in significant difference at 95% confidence interval. When all four sites were combined, there was no significant difference between the map accuracy when contrasting color aerial photography and hyperspectral imagery or when contrasting hyperspectral imagery with IKONOS satellite imagery. The contrast between color aerial photography and IKONOS satellite imagery yielded an absolute Z value of 3.07 indicating that there is a significant difference between the accuracy of habitat maps produced from these image sources.

The work conducted here was not designed to analyze the difference in map accuracy based on pixel size independent of color of an image or vise versa. While the two are statistically inseparable in this work, extensive exposure to these data led the photointerpreter to observations that may be noteworthy. Both image color and pixel size has been carefully observed during this work.

Test Area	Image Type	*IKONOS*	*HSI*
MAUI	*Color*	0.9990	-0.6166
	IKONOS		-0.0824
MOLOKAI	*Color*	2.6216	-2.3735
	IKONOS		-0.2922
OAHU	*Color*	1.5673	-0.3975
	IKONOS		-1.8923
HAWAII	*Color*	2.0126	0.8084
	IKONOS		-1.1730
ALL COMBINED	*Color*	-3.0709	1.4236
	IKONOS		-1.5961

Difference Significant
$P<0.05$

Table 5. Summary of the probability that photointerpretation of coral reef habitat from color aerial photography, hyperspectral and IKONOS Satellite imagery are equivalent: P = 0.05 or less with significant difference highlighted.

In general, it may be stated that pixel size impacts the ability to interpret features in an image more than color when an image is displayed in true color. However, without recognizing that manipulation of the large number of bands in a hyperspectral image and optimizing bandwidth in a multispectral image introduces some compensation for the lower resolution, very important observations would be overlooked. The imagery types used in this work have been optimized to maximize true color and during the map preparation the color has been strategically manipulated to extract the most habitat information. Specific band combinations were selected that enhanced feature detection in shallow and deep water using hyperspectral imagery. The IKONOS satellite imagery was provided to the contractor preprocessed to remove atmospheric effects and compensate for water column effects. Furthermore, diapositives of the color aerial photography were viewed on a light table allowing for additional color contrast to enhance the textural information needed for visual interpretation. Though not scientifically tested here, it is believed that if this work had addressed variable pixel size within the same imagery source, the statistical differences between the accuracy of these maps would have been much more significant. These enhancements have resulted in considerable compensation for the reduced resolution due to pixel size.

While it may be intuitive that smaller pixel size improves resolution and accuracy of the mapped product results, it may be less obvious that the relationship is not a function of the linear dimension of the pixel but of the area of the pixel. The one meter color aerial photography may be 16 times more resolved than the four meter IKONOS imagery. Although the linear pixel size of the hyperspectral imagery is only slightly different than the IKONOS satellite imagery, the area of the pixel differs by nearly 50%. Taken in this context the conclusion that accuracy of the maps produced from one meter pixel data were significantly more accurate than the maps generated from four meter pixel data when applying a 95% confidence interval comes as no surprise. However, the results show that when applying a 90% confidence interval there are no significant differences between the accuracy of any of the maps. Thus, it appears that the ability to generate coral reef habitat maps with an overall accuracy of 90% at a 95% confidence interval is reaching a threshold using imagery with three meter pixel size allowing for spectral enhancement of the imagery with reduced resolution.

Increasing the intensity of field observation can partially compensate for this decrease in accuracy of the maps generated from the larger pixels. Habitat maps prepared from IKONOS satellite imagery should be accompanied by field observations wherever possible and if field observations are not feasible, accuracy standards should be assigned accordingly.

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