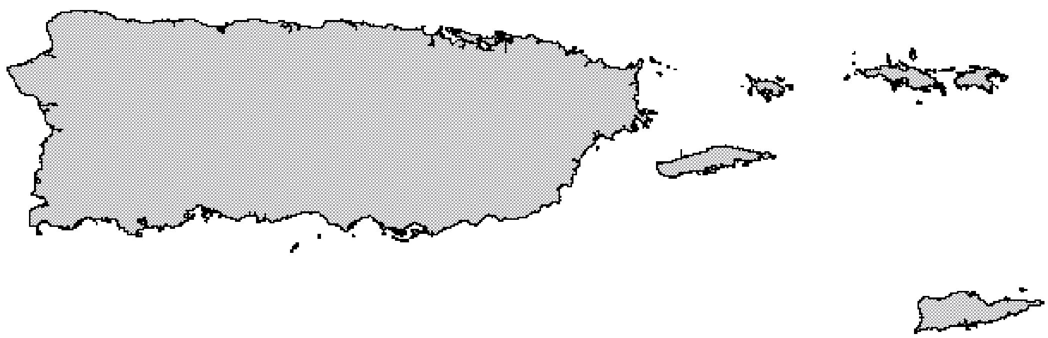
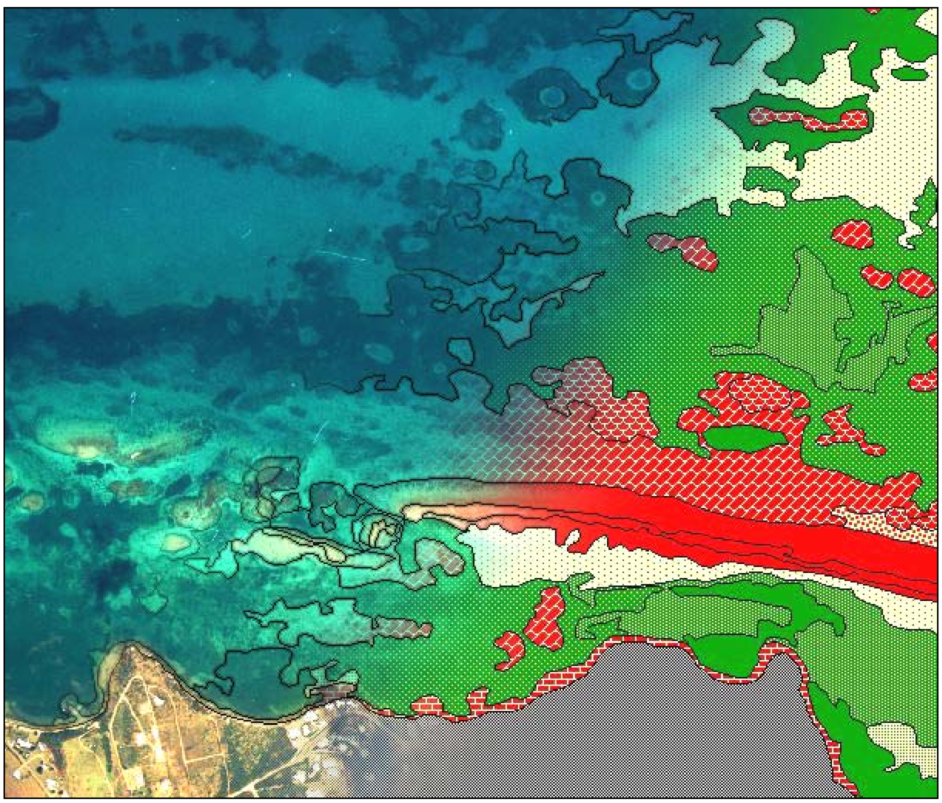


Methods Used to Map the Benthic Habitats of Puerto Rico and the U.S. Virgin Islands



Benthic features were delineated from aerial photos into 26 categories including coral reefs, seagrass beds, and mangroves.

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

Contents:

Introduction

The National Oceanic and Atmospheric Administration (NOAA) National Ocean Service acquired aerial photographs for the nearshore waters of Puerto Rico and the U.S. Virgin Islands in 1999. These images were used to create maps of the region's coral reefs, seagrass beds, mangrove forests, and other important habitats. A primary product of this project is a benthic habitat map. This document describes the specific methods used to create this map.

Twenty-six distinct benthic habitat types within nine zones were mapped directly into a geographic information system (GIS) using visual interpretation of orthorectified aerial photographs. 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/caribbean/.

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
- 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 relative to other mapping techniques

Citation: Kendall, M.S.[1], M.E. Monaco[1], K.R. Buja[1], J.D. Christensen[1], C.R. Kruer[2], and M. Finkbeiner[3,] R.A. Warner[1]. 2001. (On-line). ***Methods Used to Map the Benthic Habitats of Puerto Rico and the U.S. Virgin Islands*** URL: http://biogeo.nos.noaa.gov/projects/mapping/caribbean/startup.htm. Also available on U.S. National Oceanic and Atmospheric Administration. National Ocean Service, National Centers for Coastal Ocean Science Biogeography Program. 2001. (CD-ROM). ***Benthic Habitats of Puerto Rico and the U.S. Virgin Islands***. Silver Spring, MD: National Oceanic and Atmospheric Administration.

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Developing the Habitat Classification Scheme

A hierarchical classification scheme was used to define and delineate habitats. The classification scheme was influenced by many factors including: requests of the management community, existing classification schemes for coastal ecosystems in Puerto Rico (Kruer, 1995; Reid and Kruer, 1998; Lindeman et al.,1998), the Virgin Islands (Conservation Data Center; Beets et al., 1986; Boulon, 1986), other coral reef systems (Holthus and Maragos, 1995; Shepard et al., 1995; 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), quantitative habitat data for Puerto Rico and the Virgin Islands, the minimum mapping unit (MMU- 1 acre for visual photointerpretation), and analysis of the spatial and spectral limitations of the scanned aerial photographs. The scheme is hierarchical to allow users to expand or collapse the detail of the resulting map to suit their needs. Furthermore, it is encouraged that additional hierarchical categories be added in the GIS by users with more detailed knowledge or data for specific areas. For example, habitat polygons delineated as continuous seagrass using this scheme could be further categorized by standing crop information (low, medium, or high shoot density) or species composition (*Thalassia*, *Syringodium*).

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. Both underwater and aerial photographs are included for habitats, whereas only 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.

Nine 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, shoreline/intertidal, lagoon, back reef, reef crest, fore reef, bank/shelf, bank/shelf escarpment, 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-six distinct and non-overlapping habitat types were identified that could be mapped by visual photointerpretation. 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 (e.g. on the shelf or in the lagoon). Habitats are defined in a collapsible hierarchy ranging from four broad classes (submerged vegetation, unconsolidated sediment, coral reef/hard bottom, and other), to more detailed categories (e.g., mangrove, seagrass, algae, individual patch reefs, bedrock, etc.), to patchiness of some specific features (e.g., 50-70 percent cover of seagrass).

Zones:

Land
Shoreline Intertidal
Lagoon
Back Reef
Reef Crest
Fore Reef
Bank/Shelf
Bank/Shelf Escarpment
Dredged*
Unknown

***not depicted in figures**

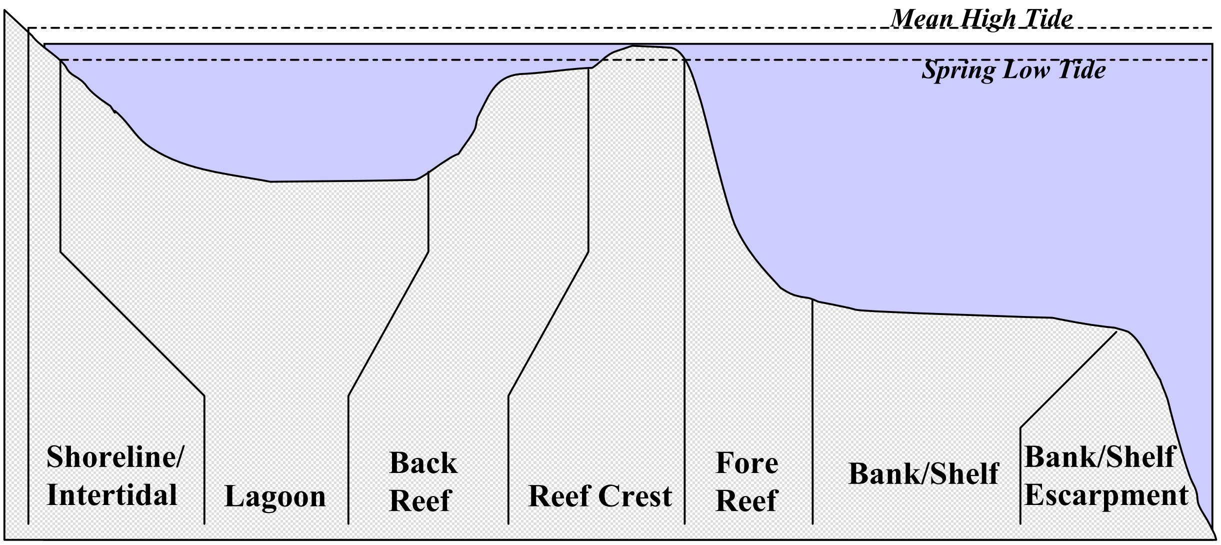


Figure 1. Cross-section of *Zones* where an emergent reef crest is present:

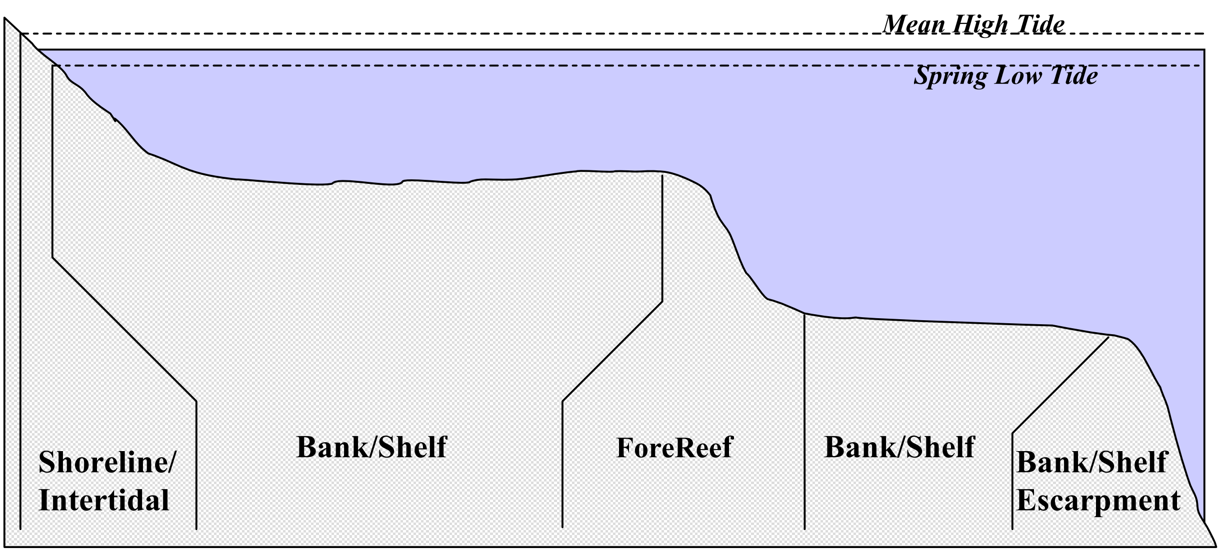


Figure 2. Cross-section of *Zones* where **no** emergent reef crest is present:

Habitats:

Unconsolidated Sediments (0 percent to less than 10 percent submerged vegetation)
- **Sand**
- **Mud**

Submerged Vegetation
- **Seagrass**
  - **Continuous Seagrass (90 percent to less than 100 percent cover)**
  - **Patchy (Discontinuous) Seagrass (70 percent to less than 90 percent cover)**
  - **Patchy (Discontinuous) Seagrass (50 percent to less than 70 percent cover)**
  - **Patchy (Discontinuous) Seagrass (30 percent to less than 50 percent cover)**
  - **Patchy (Discontinuous) Seagrass (10 percent to less than 30 percent cover)**
- **Macroalgae**
  - **Continuous Macroalgae (90 percent to less than 100 percent cover)**
  - **Patchy (Discontinuous) Macroalgae (50 percent to less than 90 percent cover)**
  - **Patchy (Discontinuous) Macroalgae (10 percent to less than 50 percent cover)**

Coral Reef and Hardbottom
- **Coral Reef and Colonized Hardbottom**
  - **Linear Reef**
  - **Spur and Groove**
  - **Individual Patch Reef**
  - **Aggregated Patch Reefs**
  - **Scattered Coral/Rock in Unconsolidated Sediment**
  - **Colonized Pavement**
  - **Colonized Bedrock**
  - **Colonized Pavement with Sand Channels**
- **Uncolonized Hardbottom**
  - **Reef Rubble**
  - **Uncolonized Pavement**
  - **Uncolonized Bedrock**
  - **Uncolonized Pavement with Sand Channels**

Other Delineations
- **Land**
- **Mangrove**
- **Artificial**
- **Unknown**

Zones

Shoreline Intertidal: Area between the mean high water line (or landward edge of mangroves 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 this part of the Caribbean.

Typical Habitats:
Mangrove, sand, seagrass, colonized bedrock, and uncolonized bedrock.

Lagoon: Shallow area (relative to the deeper water of the bank/shelf) between the shoreline intertidal zone and a back reef or 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, bedrock, and patch reefs.

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

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. In aerial images, breaking waves will often be visible at the seaward edge of this zone.

Typical Habitats: Reef rubble and linear reef.

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.

Bank/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 deep, near the depth limit of features visible in aerial images. This zone extends well into depths exceeding those that can be seen on aerial photos and is intended to capture the transition from the bank/shelf to deep waters of the open ocean.

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

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

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

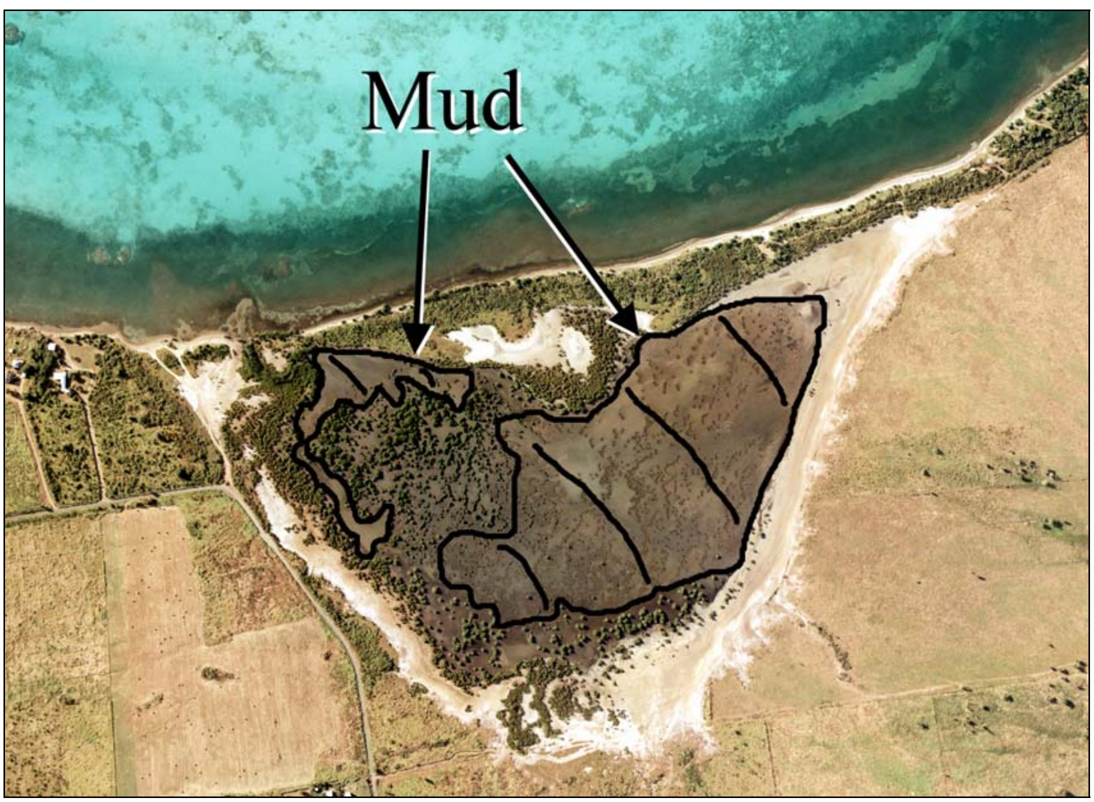
Typical Habitats: Sand, mud, seagrass, or algal bottom.

Unconsolidated Sediment

Habitats:

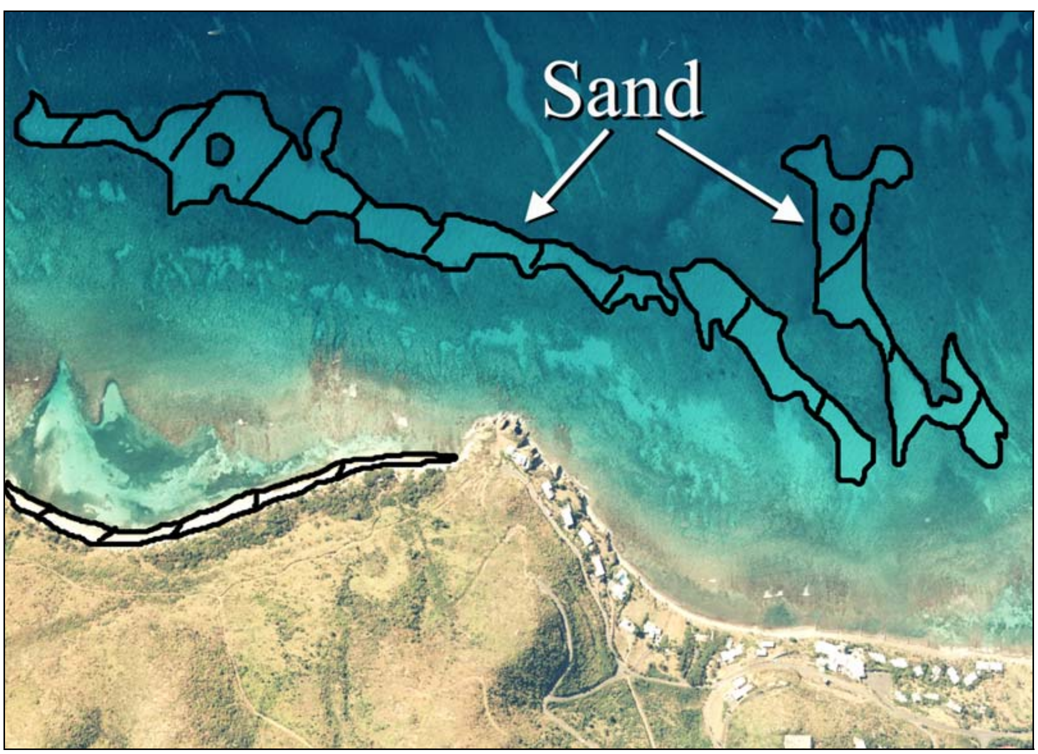
Unconsolidated Sediment: Unconsolidated sediment with less than 10 percent cover of submerged vegetation.

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



Unconsolidated Sediment

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



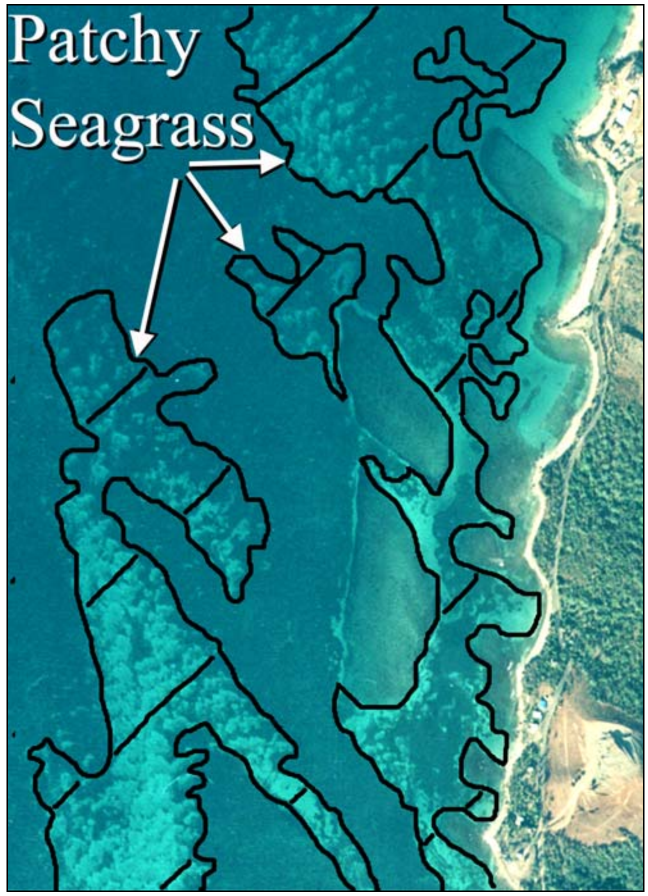
Submerged Vegetation: Greater than 10 percent cover of submerged vegetation in unspecified substrate type (usually sand, mud, or hardbottom).

Seagrass: Habitat with 10 percent or more cover of *Thalassia testudinum*, *Syringodium filiforme*, *Halodule wrightii, Halophila baillonis,* or some combination thereof.

Continuous Seagrass: Seagrass covering 90 percent or more 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 MMU). This includes continuous beds of any shoot density (may be a continuous sparse or dense bed).

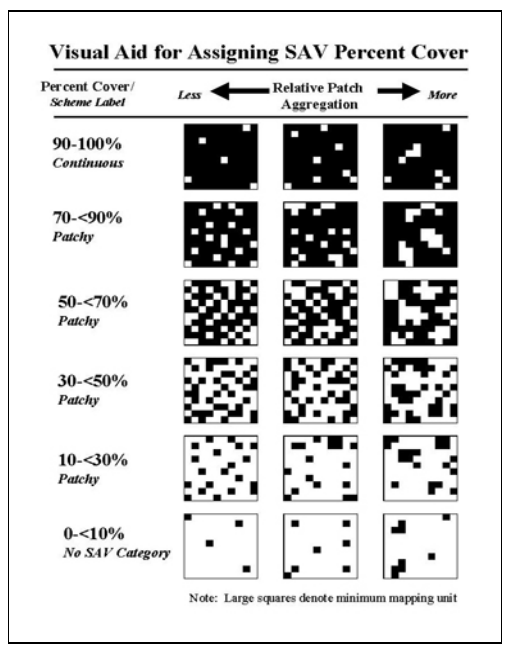
Patchy Seagrass: Discontinuous seagrass with breaks in coverage that are too diffuse or irregular, or result in isolated patches of seagrass that are too small (smaller than the MMU) to be mapped as continuous seagrass.

Representative Species:
Thalassia testudinum
Syringodium filiforme
Halodule wrightii
Halophila baillonis



Visual Aid used for Assigning Degree of Patchiness:

Patchy Seagrass (70 to less than 90 percent cover)
Patchy Seagrass (50 to less than 70 percent cover)
Patchy Seagrass (30 to less than 50 percent cover)
Patchy Seagrass (10 to less than 30 percent cover)



Macroalgae: An area with 10 percent or greater coverage of any combination of numerous species of red, green, or brown macroalgae. Usually occurs in deeper waters on the bank/shelf zone.

Continuous Macroalgae: Macroalgae covering 90 percent or more 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 shoot 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.

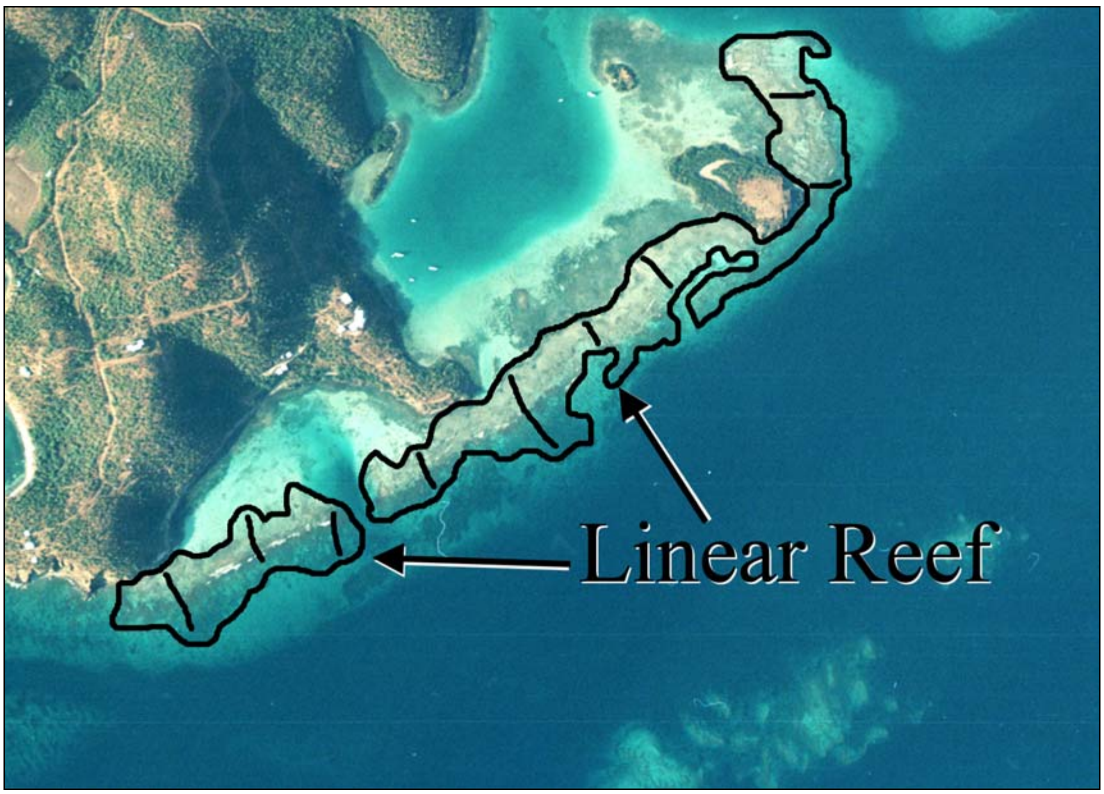
Patchy Macroalgae (50 to less than 90 percent cover)
Patchy Macroalgae (10 to less than 50 percent cover)

Representative Species:
Caulerpa spp.
Dictyota spp.
Halimeda spp.
Lobophora variegata
Laurencia spp.

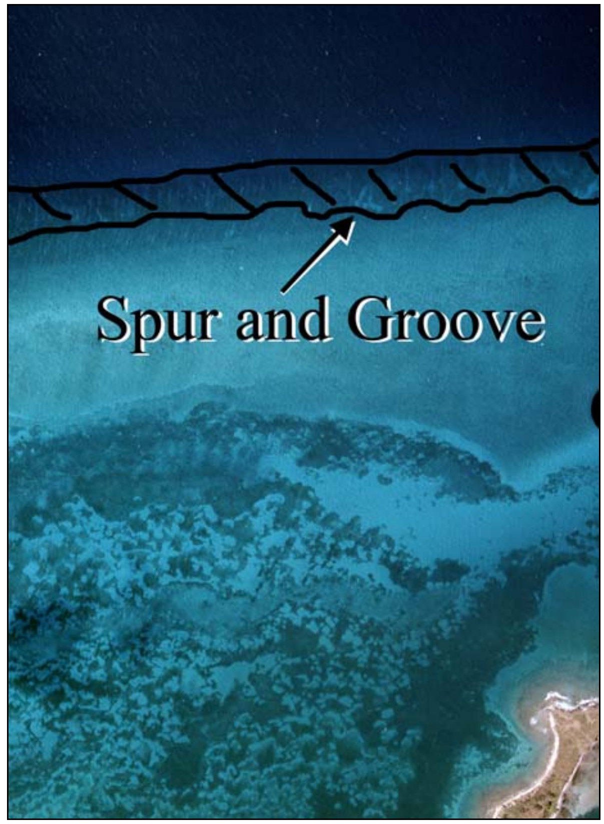
Coral Reef and Hardbottom: Hardened substrate of unspecified relief formed by the deposition of calcium carbonate by reef building corals and other organisms (relict or ongoing) or existing as exposed bedrock.

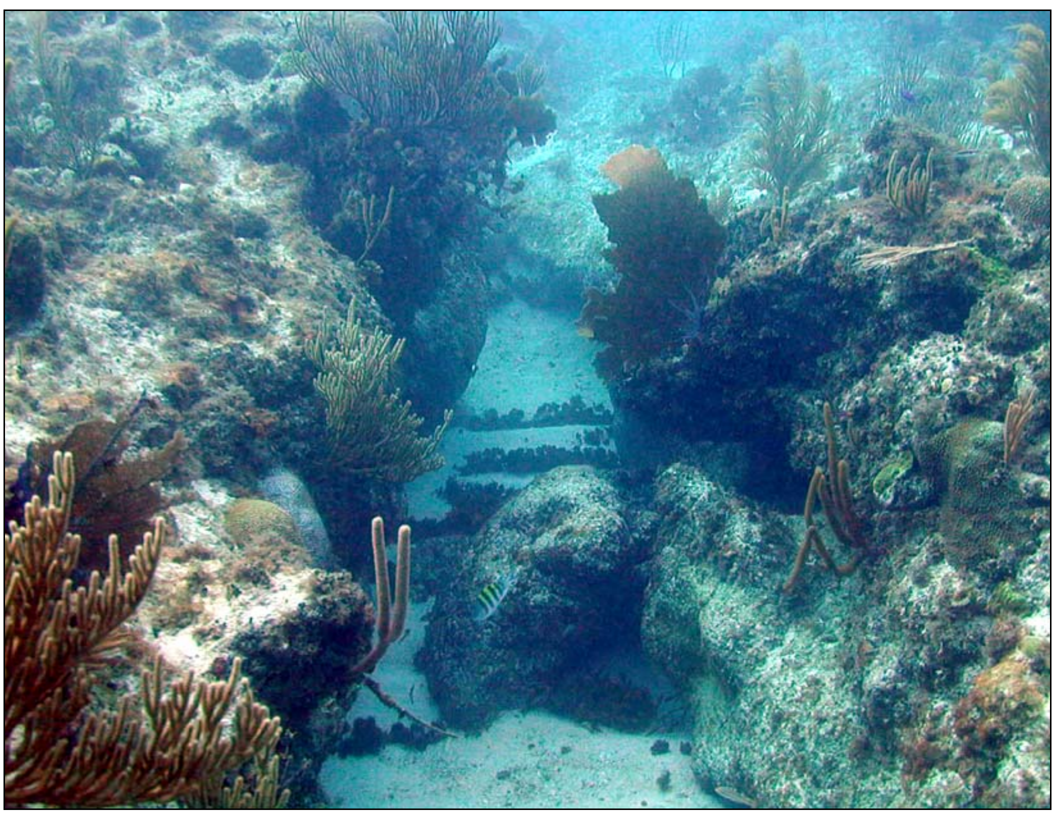
Coral Reef and Colonized Hardbottom: Substrates formed by the deposition of calcium carbonate by reef building corals and other organisms. Habitats within this category have some colonization by live coral, unlike the **Uncolonized Hardbottom** category.

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.



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 compared to pavement with sand channels 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.

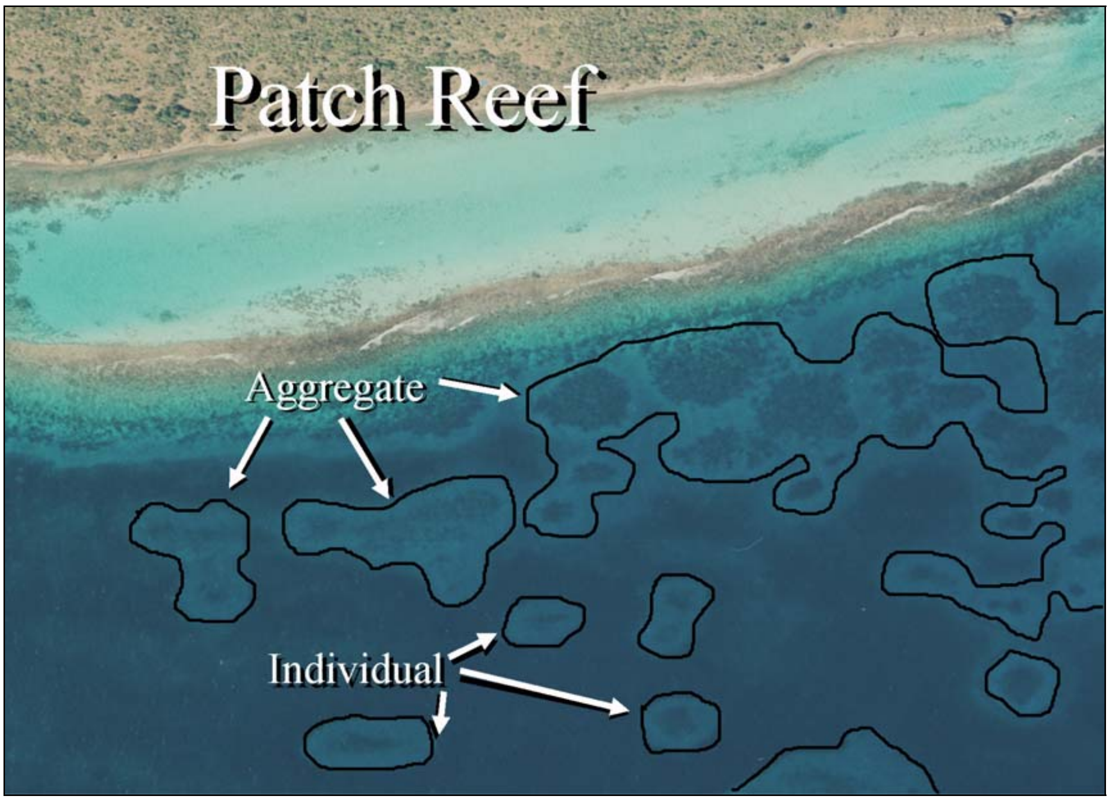




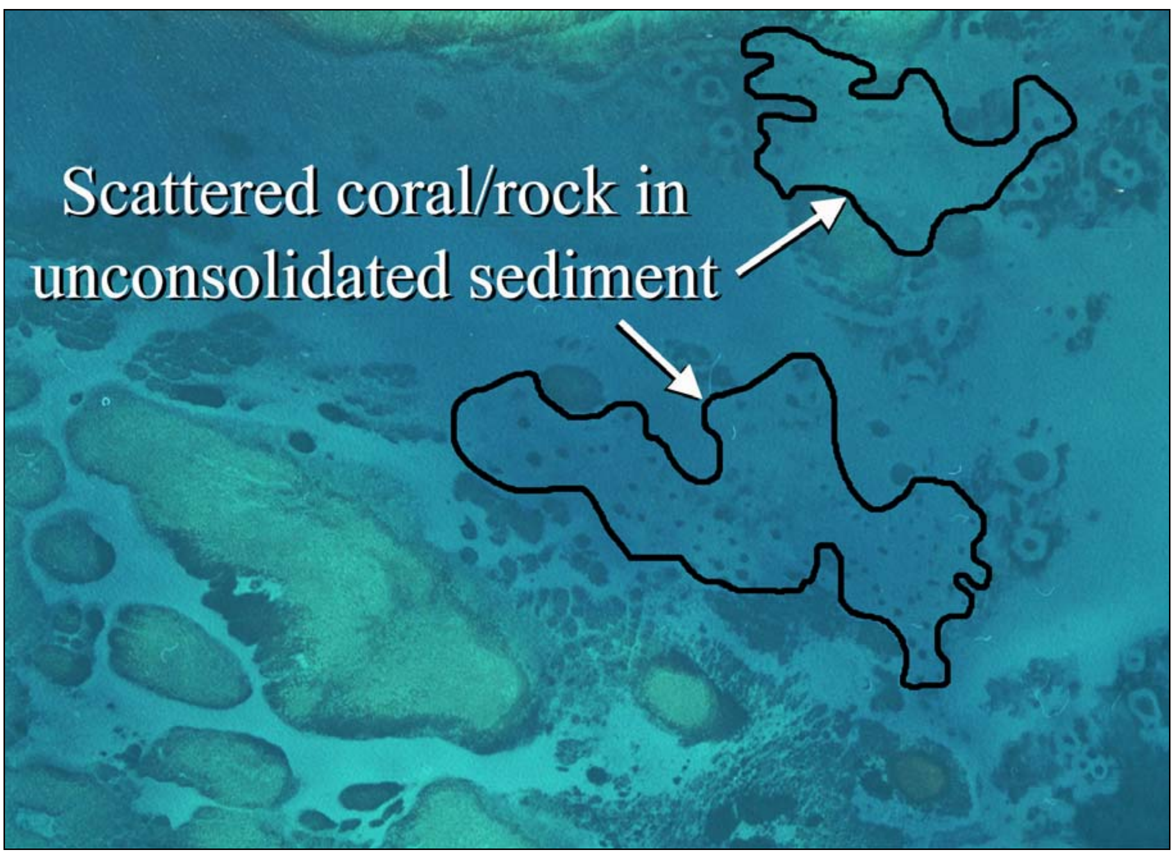
Patch Reef(s): Coral formations that are isolated from other coral reef formations by sand, seagrass, or other habitats and that have no organized structural axis relative to the contours of the shore or shelf edge. A surrounding halo of sand is often a distinguishing feature of this habitat type when it occurs adjacent to submerged vegetation.

Individual patch reef: Distinctive single patch reefs that are equal to or larger than the MMU. When patch reefs occur in submerged vegetation and a halo is present, the halo is included with the patch reef polygon.

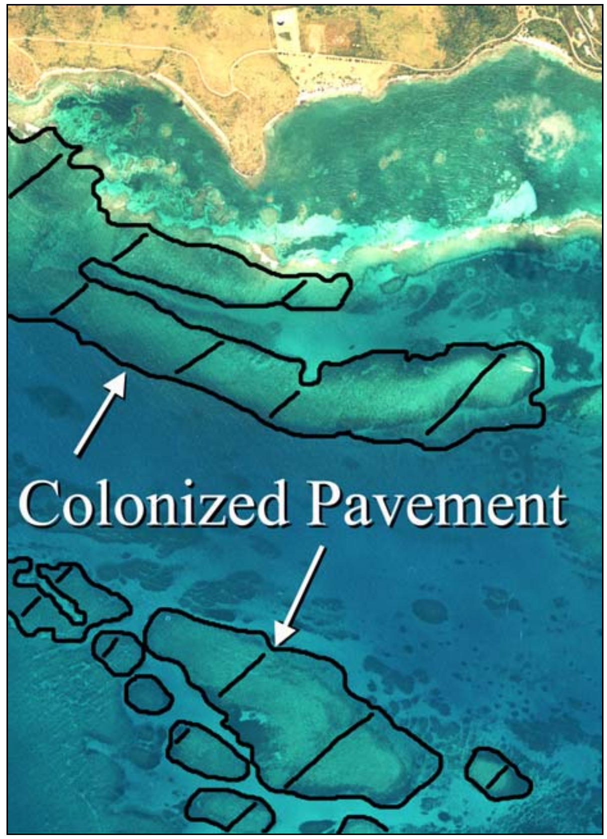
Aggregate patch reefs: Clustered patch reefs that individually are too small (smaller than the MMU) or are too close together to map separately. Where aggregate patch reefs share halos, the halo is included in the polygon.

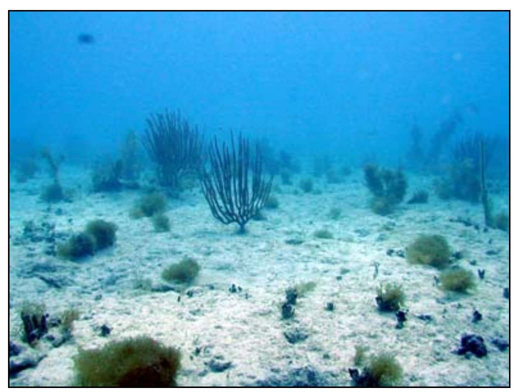


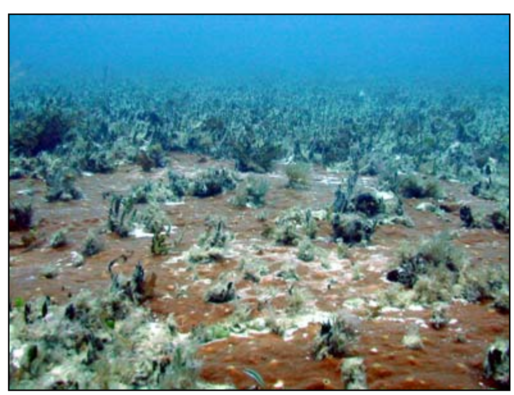
Scattered Coral/Rock in Unconsolidated Sediment: Primarily sand or seagrass bottom with scattered rocks or small, isolated coral heads that are too small to be delineated individually (i.e., smaller than individual patch reef).



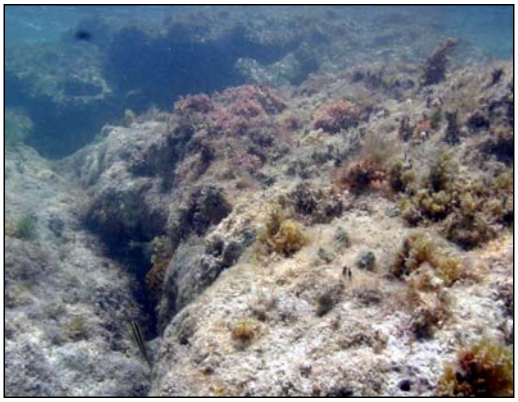
Colonized Pavement: Flat, low-relief, solid carbonate rock with coverage of macroalgae, hard coral, gorgonians, and other sessile invertebrates that are dense enough to partially obscure the underlying carbonate rock.

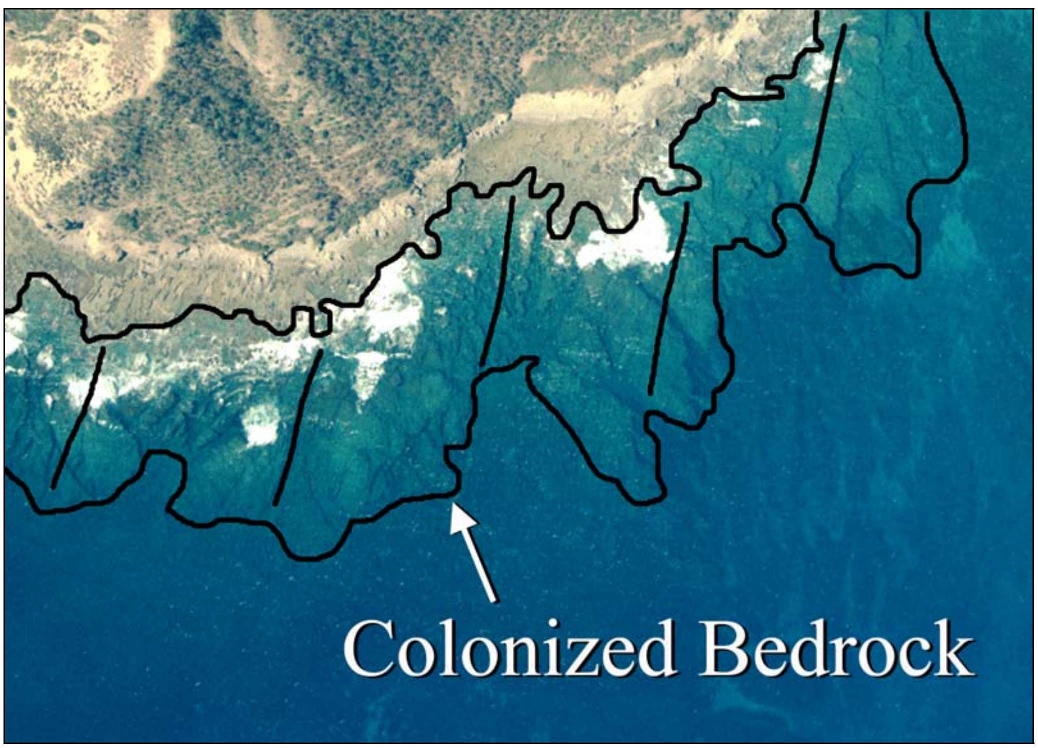




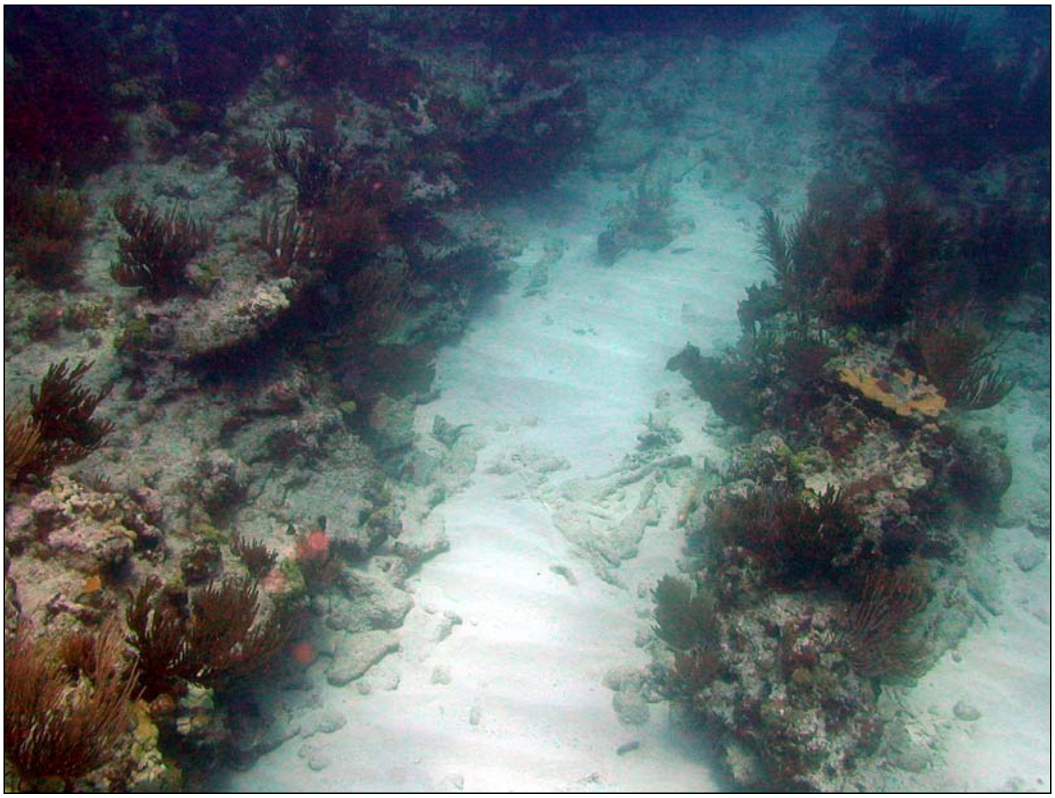


Colonized Bedrock: Exposed bedrock contiguous with the shoreline that has coverage of macroalgae, hard coral, gorgonians, and other sessile invertebrates that partially obscures the underlying rock.





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 compared to spur and groove formations. This habitat type occurs in areas exposed to moderate wave surge such as that found in the bank/shelf zone.

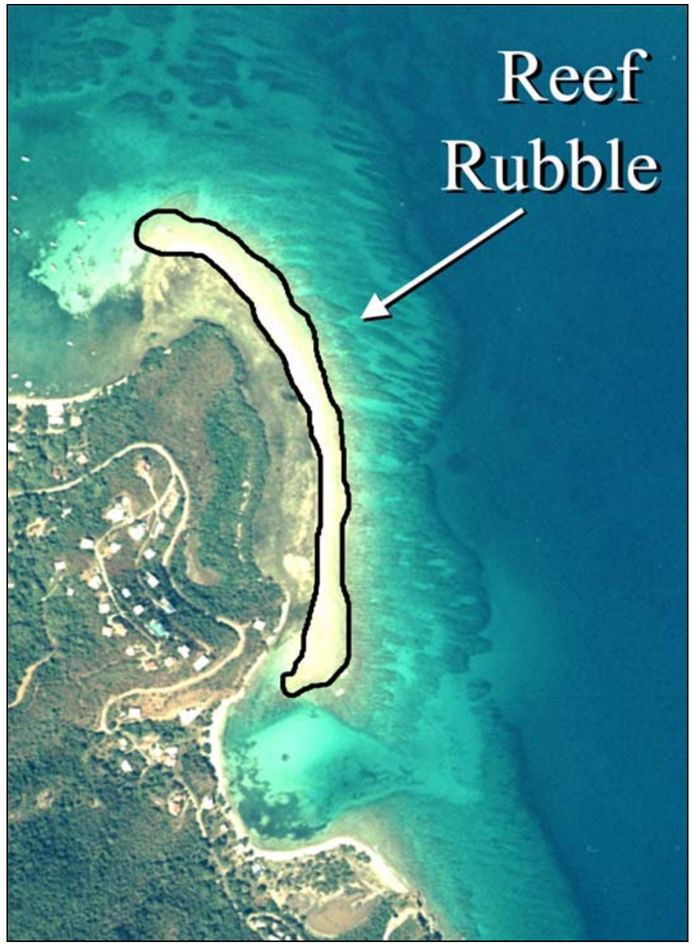


Representative Species:
Acropora palmata
Acropora cervicornis
Diploria spp.
Millepora complanata
Montastrea spp.
Porites spp.
Siderastrea spp.

Un-Colonized Hardbottom

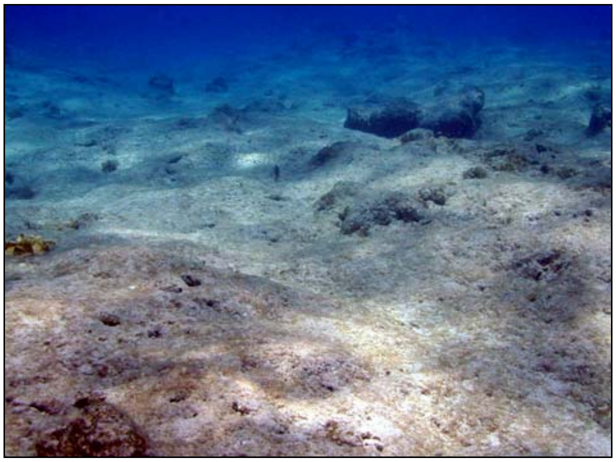
Uncolonized Hardbottom: Hard substrate composed of relict deposits of calcium carbonate or exposed bedrock.

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.



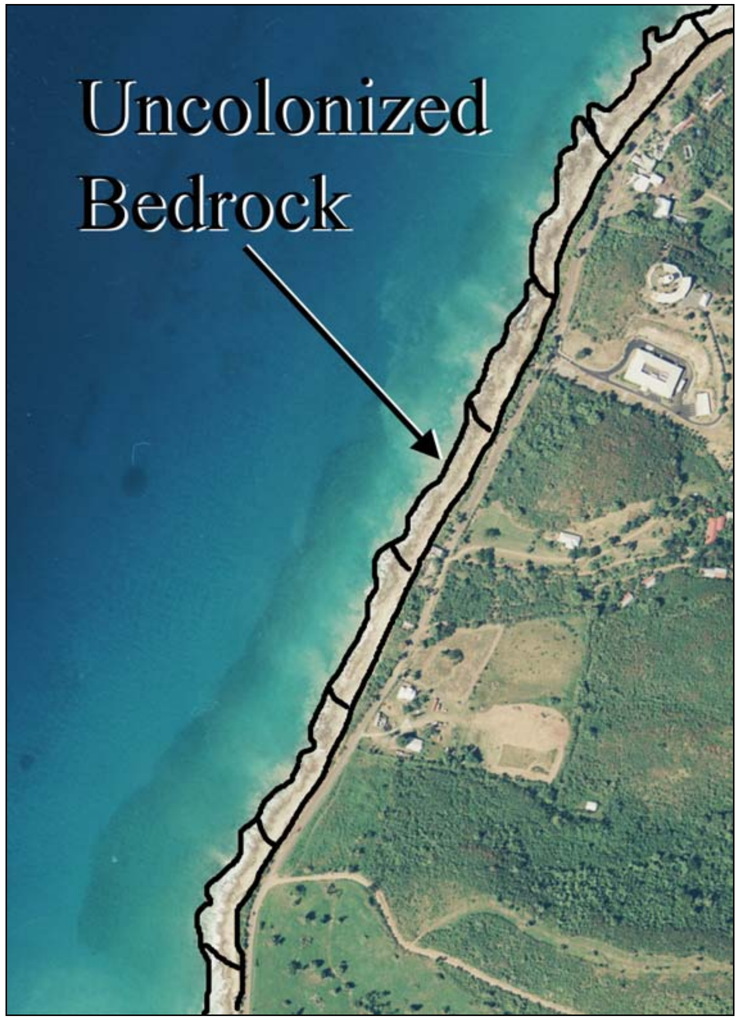
Un-Colonized Hardbottom

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, gorgonians, and other sessile invertebrates that does not obscure the underlying carbonate rock.



Un-Colonized Hardbottom

Uncolonized Bedrock: Exposed bedrock contiguous with the shoreline that has s*parse* coverage of macroalgae, hard coral, gorgonians and other sessile invertebrates that does not obscure the underlying rock.



Un-Colonized Hardbottom

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 compared to spur and groove formations. This habitat type occurs in areas exposed to moderate wave surge such as that found in the bank/shelf zone.

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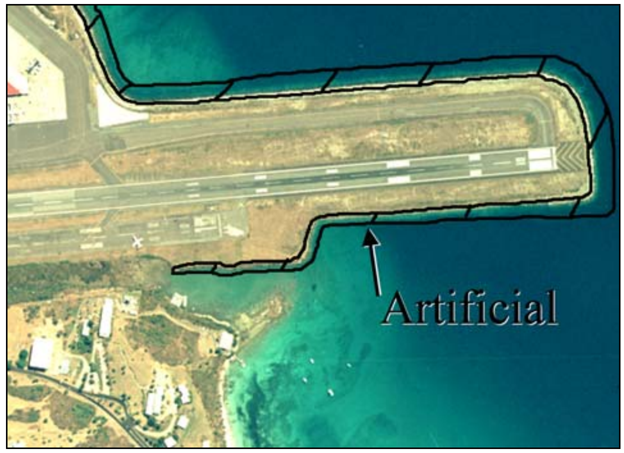
Other Delineations:

Mangrove: Emergent habitat composed of red, black, or white mangroves, or some combination thereof. Mangroves are generally found in areas sheltered from high-energy waves. Mangroves must be part of an open tidal system to be mapped. This habitat type is found only in the shoreline/intertidal, back reef, or barrier reef crest zone.

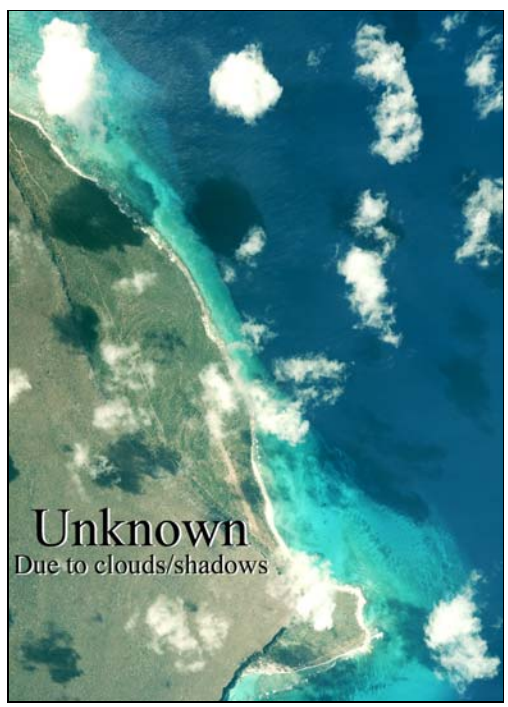
Representative Species:
Rhizophora mangle
Avicennia germinans
Laguncularia racemosa

Other Delineations

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.



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 3.1 was developed to facilitate mapping benthic habitats of Puerto Rico and the U.S. Virgin Islands using the classification scheme described in Chapter 1. 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 Puerto Rico and the U.S.Virgin Islands CD-ROM" or over the Internet at *http://biogeo.nos.noaa.gov/products.* The extension and accessory files are found in "data/ext/hab_dig.zip". This folder contains three files including:

habitat.avx	the extension
coral.hcs	a 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 3.1 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

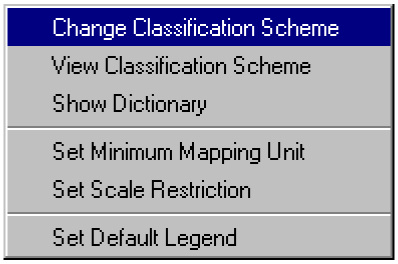
To begin using Habitat Digitizer, save the habitat.avx file in either ArcView's Ext32 directory or the USEREXT directory. The coral.hcs and coral.avl files can be saved anywhere, but they should preferably be placed in the ArcView project's working directory.

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



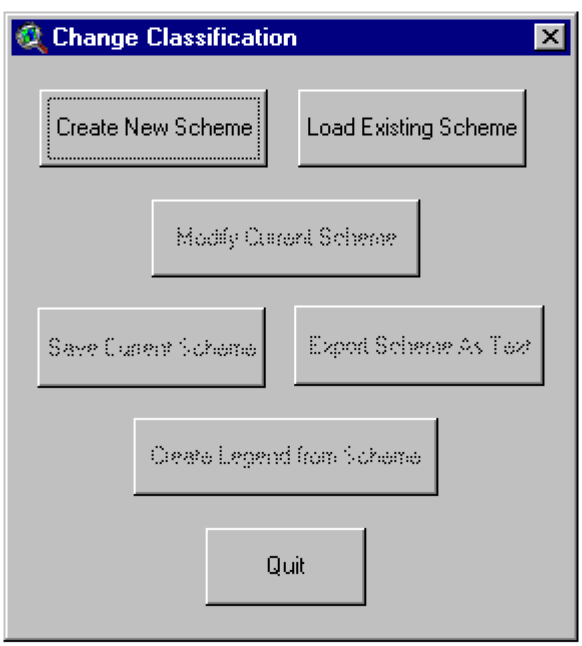
Once the Habitat Digitizer Extension has been activated the "Habitat Digitizer" pull-down menu and digitizing tools which control the functions of the extension will appear on the ArcView toolbar. Beginning with the process of creating and loading classification schemes, a detailed description and instructions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

Creating a new classification scheme

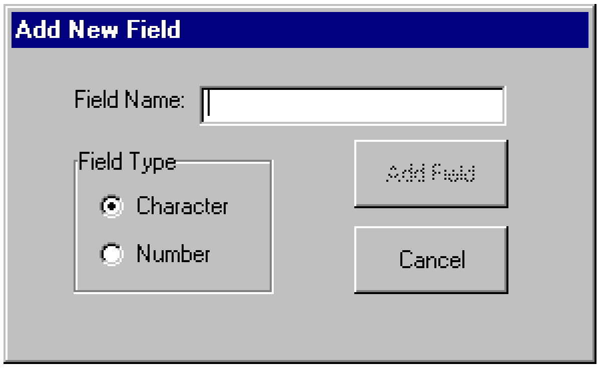
Unless an existing classification scheme such as coral.hcs is used, a new scheme must first be created to use the extension. Before creating a new scheme using the dialogs of the extension, it may be useful to sketch the scheme out on paper to ensure that all fields and categories in the hierarchy are 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

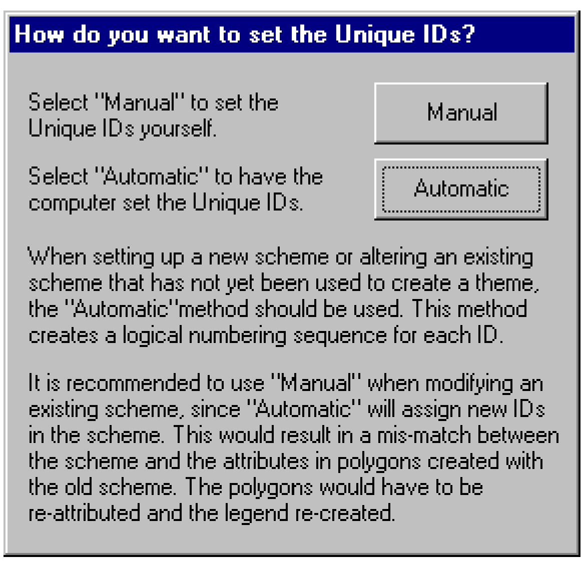
Field 1	*Field 2*	*Field 3*	*Field 4*	*UniqueID*
Category 1	**Subcategory 1**	**Subcategory 1**	**(empty)**	**111**
		Subcategory 2		**112**
	Subcategory 2	**Subcategory 1**		**121**
		Subcategory 2		**122**
Category 2	**Subcategory 1**	**Subcategory 1**		**221**
		Subcategory 2		**222**
	Subcategory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



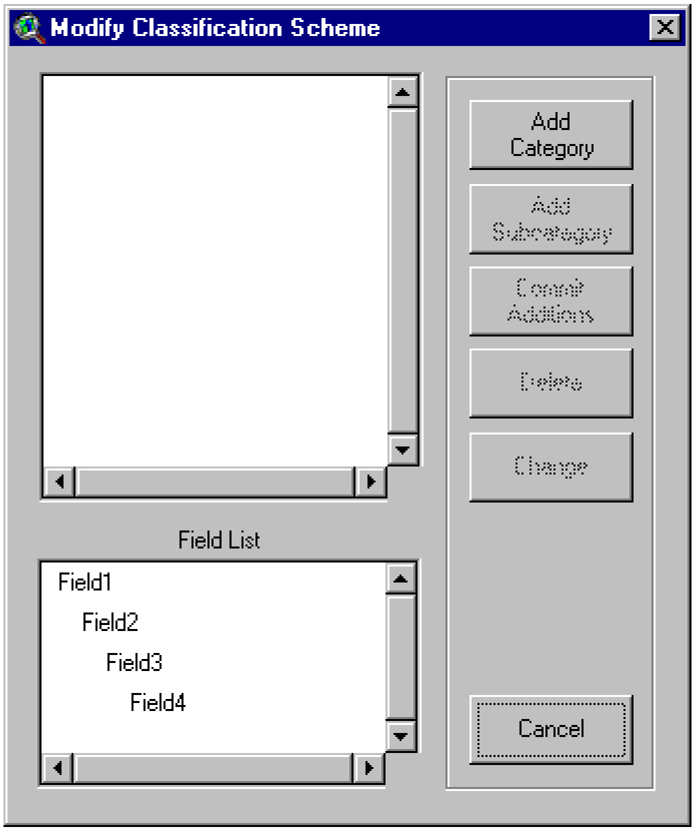
To create the new scheme using the extension, select **Habitat Digitizer/Change Classification Scheme** and in the next dialog box, select **Create New Scheme**. Type the name of the new classification scheme in the message box and click **Okay**. The other options in this dialog will be unavailable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



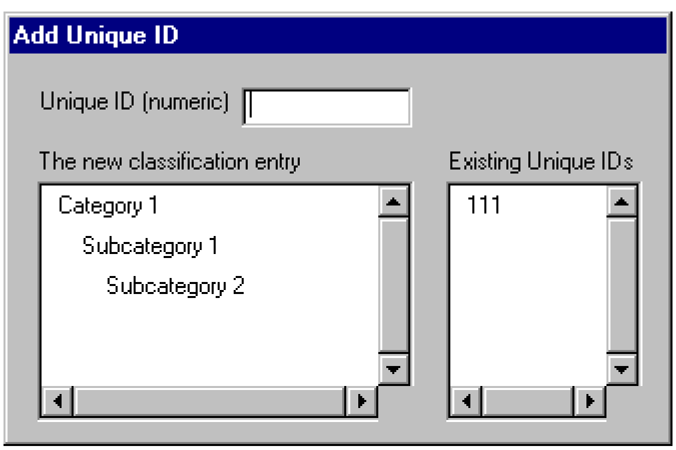
In the "Add New Field" dialog, selecting **Cancel** will end the creation process without creating a scheme. Once the first field name has been added, this button is replaced with the **Finished** button, which will complete the field naming process and go to the next step in creating the scheme. First, 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.

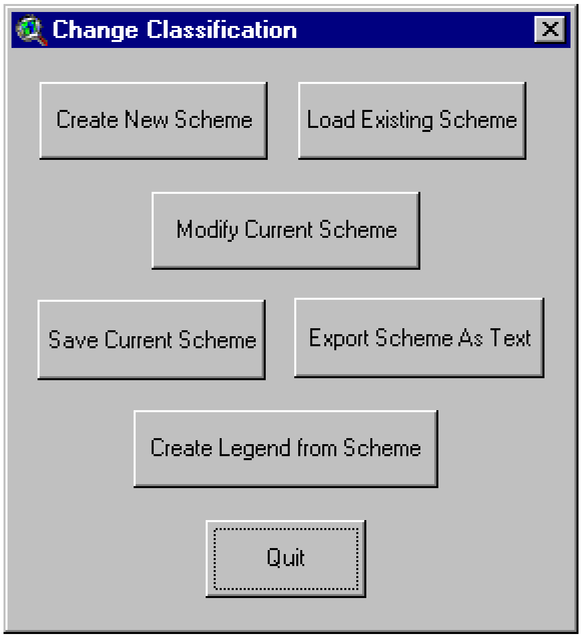


In the "Modify Classification Scheme" dialog, categories and subcategories can be added to a new or existing classification scheme. Begin by adding a category to the most general level in the classification hierarchy (Category 1 in Table 2.1). Click **Add Category**, then type the category name and click **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.



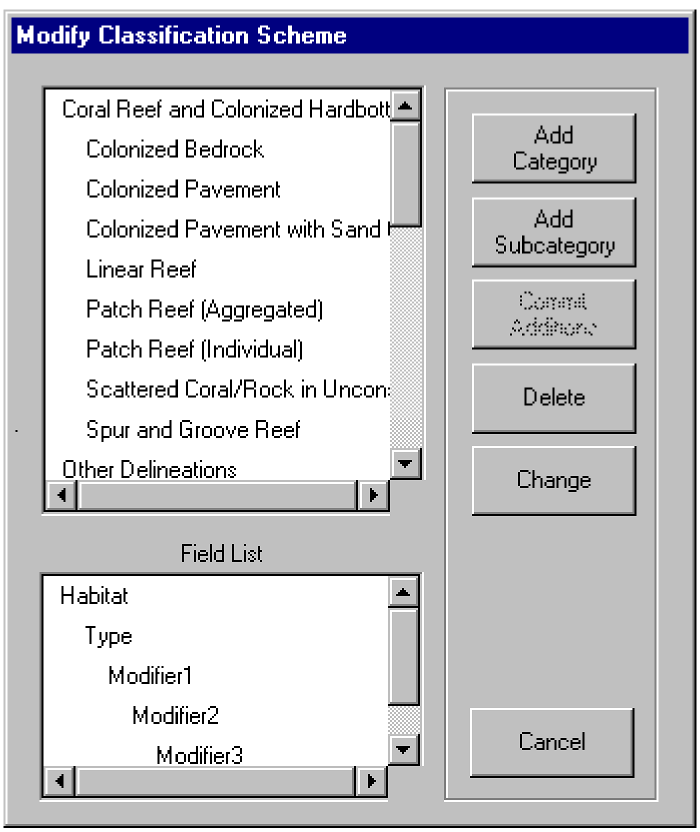
If **Manual** was selected for assigning uniqueIDs, the "Add Unique ID" dialog will appear after selecting **Commit Additions**. A unique numeric identifier must be entered for each possible combination of classifications in the hierarchy. The **Existing Unique IDs** list shows which numbers are already 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 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

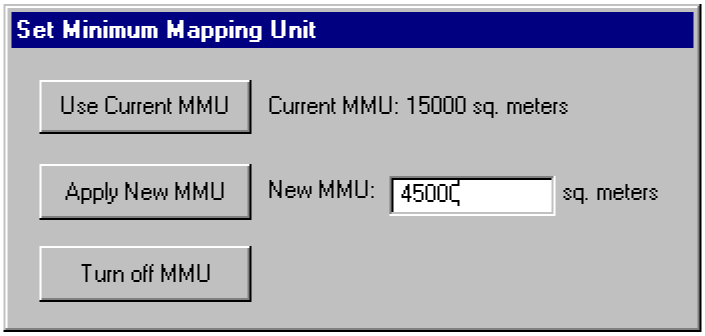


To edit an existing scheme, select **Modify Current Scheme** in the "Change Classification" dialog box. After selecting the method of assigning the uniqueID (in this case, using **Manual** is recommended), the "Modify Classification Scheme" dialog appears. Follow the same instructions in **Creating a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

Digitizing Restrictions

Minimum Mapping Unit

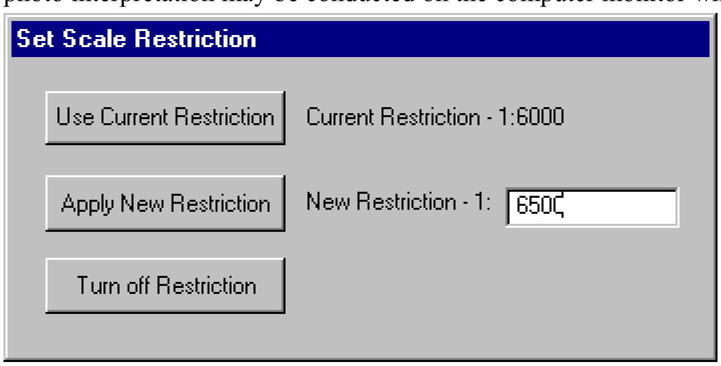
Depending on the quality of aerial images used and the specific goals of the project, it is often desirable to limit the minimum size of the features that are delineated. For example, poor image resolution may preclude the interpretation of features smaller than some minimum size threshold. Other features, 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.

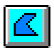
Scale Restriction

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

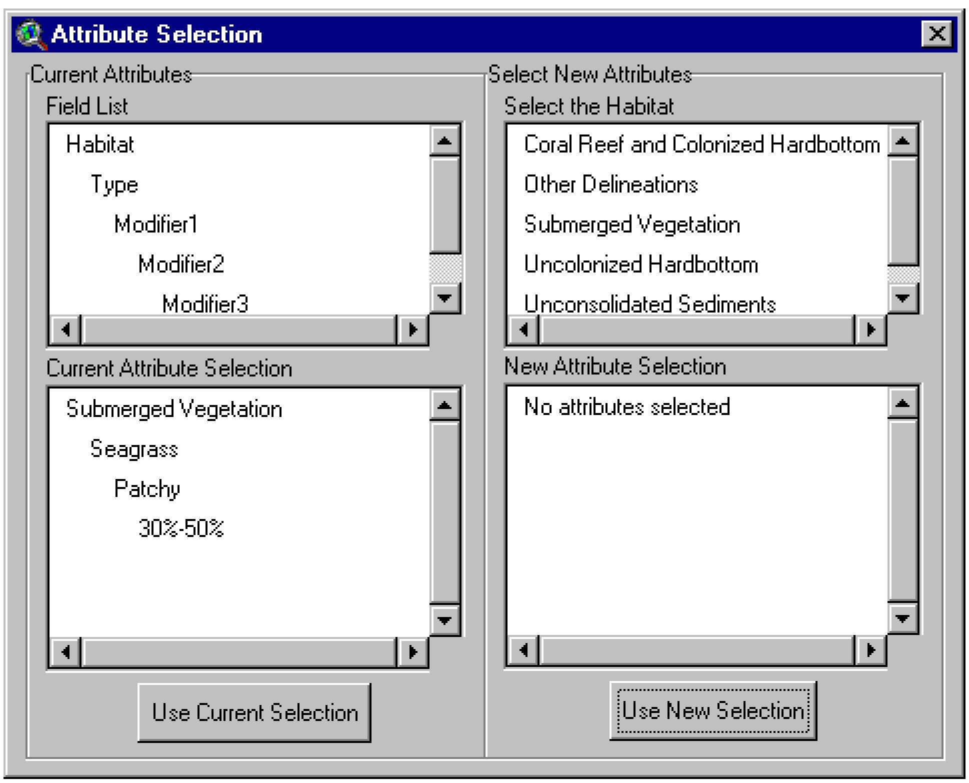
Once a classification scheme has been loaded, this button creates an empty theme with the appropriate fields. If a default legend has not been created using **Habitat Digitizer/Set Default Legend** or the **Change Classification** dialog, a dialog will appear to select a legend file. A second message 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.

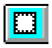
Use this tool to add a polygon adjacent to an existing polygon. To create a polygon using this tool, start tracing a line inside of an existing polygon and end the line by clicking twice inside of the same or another existing polygon. This tool will not work when attempting to digitize a polygon inside 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.

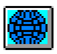
Once polygons are completed using the **Add** and **Append** tools, a dialog will appear to guide assignment of classification attributes.

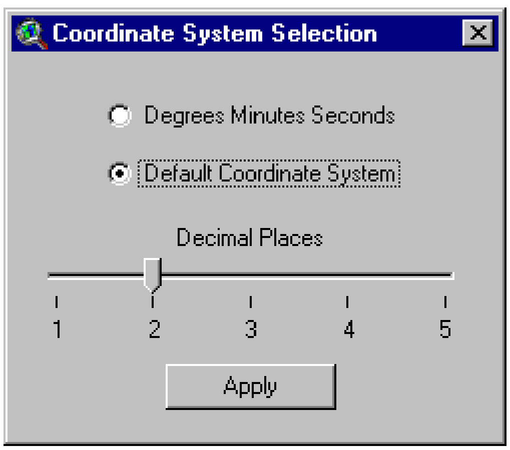


The **Field List** displays the hierarchical structure of the fields in the scheme. **Current Attribute Selection** shows the classification type, if any, currently selected. Either select **Use Current Selection** or select a new classification type by clicking through the desired classification attributes 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 Puerto Rico and the U.S. Virgin Islands were created by visual interpretation of aerial photos using the Habitat Digitizer (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 resources 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 Puerto Rico and U.S. Virgin Islands Benthic Mapping Project in 1999 by NOAA Aircraft Operation Centers aircraft and National Geodetic Survey cameras and personnel. Approximately 600, color, 9 by 9 inch photos were taken of the coastal waters of Puerto Rico and the U.S. Virgin Islands at 1:48000 scale (photography scale varied for some specific islands, see Table 3.1). 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 metric scanner, yielding 2.4 by 2.4 meter pixels for the 1:48000 scale photography (pixel size varied for some specific islands due to the scale of the original photography, see Table 3.1). All scans were saved in tagged image file (TIF) format for the purposes of orthorectification and photointerpretation. Original TIF's 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.

Georeferencing/mosaicing of the TIF's was performed using Socet Set Version 4.2.1. 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 Socet Set 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). Socet Set 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 (GCP's) which were then used to georeference the imagery (i.e. link the image pixels to a real world coordinate system such as latitude/longitude). GCP's were measured using real-time DGPS (differential 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. Only ground control points for terrestrial features were collected due to the difficulty of obtaining precise positions for submerged features (see Appendix 1: Ground Control Points).

A custom digital terrain model (DTM) was then created using the Socet Set software to correct for feature displacement due to terrain effects. To accomplish this, water features and the shoreline were set to an elevation of zero. Preliminary experimentation revealed that the effects of refraction on the position of submerged features in the imagery were not significant (less than one pixel) enough to make a correction for underwater displacement according to Snell's law. Selected land elevation points were then inserted from USGS 1:24000 Digital Elevation Models or other elevation data sets where clouds or other sources of interference prevented the Socet Set software from automatically making an accurate DTM.

Once the terrain models were complete and a draft orthorectified mosaic was produced, a set of independent ground control points was used to measure the quality of each mosaic's rectification and ensure that it met acceptable limits of horizontal spatial accuracy. If the spatial accuracy was not acceptable based on this comparison, additional modifications were made to the DTM, 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 are an average error for all control points used to measure accuracy of the mosaics. Accuracy is variable within different areas of each mosaic. Features near land (near GCP's) 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. Also, spatial accuracy may be especially poor near clouds over land since this interferes with creation of an accurate DTM.

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.

Segments from 309 out of the ~600 original aerial photos were selected to create the final mosaic (Table 3.1). 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 19 for Puerto Rico, and UTM Zone 20 for the U.S.Virgin Islands. These files are available on the "Benthic Habitats of Puerto Rico and the U.S. Virgin 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. Accuracy's are in meters +/- standard deviation.

Location	*UTM Zone*	*Photo Scale*	*Pixel Width (m)*	*# of Photos*	*Avg. Spatial Accuracy X*	*Avg. Spatial Accuracy Y*
St. John	20	1:48000	2.4	14	4.31 +/- 5.2	2.14 +/- 8.4
St.Thomas	20	1:48000	2.4	20	1.48 +/- 1.3	1.05 +/- 3.4
St.Croix	20	1:48000	2.4	27	1.21 +/- 3.0	0.69 +/- 3.4
Culebra	19	1:48000	2.4	14	5.51 +/- 20.1	7.04 +/- 18.2
Mona	19	1:28000	1.5	14	2.76 +/- 9.1	4.06 +/- 4.5
Desecheo	19	1:20000	1.0	3	4.26 +/- 30.0	9.47 +/- 36.4
Puerto Rico: South	19	1:48000	2.4	72	0.06 +/- 3.0	0.89 +/- 4.4
Puerto Rico: East	19	1:48000	2.4	55	0.85 +/- 9.5	2.59 +/- 7.8
Puerto Rico: West	19	1:48000	2.4	34	1.65 +/- 5.1	1.04 +/- 6.7
Puerto Rico: North	19	1:48000	2.4	51	4.88 +/- 9.6	4.06 +/- 5.3

Digitizing Benthic Habitats

Individual georeferenced mosaics were loaded into ArcView with the Habitat Digitizer and Image Analysis extensions activated. Each mosaic was then converted into an image analysis file (IMG) that could be easily manipulated using ArcView's Image Analysis extension (e.g., adjust contrast, brightness, and color). The Minimum Mapping Unit (MMU) restriction was set to 1 acre in the Habitat Digitizer extension. One acre was selected based on the scale of the photography and the objectives of the mapping project. As a result, some features visible in the imagery such as small isolated patch reefs and sea walls that, while important features, are quite small and beyond the scope of this mapping project.

Digitizing scale was set to 1:6000 in the Habitat Digitizer. Experimentation indicated that digitizing at this scale optimizes the tradeoff between positional accuracy of lines and time spent digitizing. In general, line placement conducted while zoomed in at large scales results in excellent line accuracy and detail but can be quite time consuming. Conversely, while zoomed out, lines can be drawn quickly but lack both detail and positional accuracy.

To determine the optimum digitizing scale to maximize accuracy and minimize map production time, a 25 acre area composed of a variety of habitat types was mapped at 1:1500, 1:3000, 1:6000, and 1:12000 on-screen scale (scale that the image appears on the computer monitor as indicated by ArcView). Five replicates were conducted at each scale. Each trial was timed so we could evaluate the influence of mapping scale on production time. Resulting maps were evaluated for deviations in polygon detail relative to the map digitized at 1:1500 scale. At 1:1500, individual pixels are clearly discernable allowing highly detailed and accurate maps to be created by closely following the contours of even the most convoluted habitat boundary. Additional increases in zoom do not result in an increase in map detail and accuracy since individual pixels are already visible at 1:1500. Therefore, the map created at 1:1500 scale was used as a reference against which to compare maps digitized at 1:3000, 1:6000, and 1:12000 scale.

The results of this experiment indicated that there is no appreciable loss in polygon detail and accuracy by digitizing at 1:6000 while mapping time was dramatically reduced. Therefore all polygons were digitized at this scale except when subtle habitat boundaries were not easily discernable at 1:6000 and zooming out to a more broad scale was required to place boundaries correctly. In this case, digitizing generally took place at a scale of approximately 1:10000.

Using the Habitat Digitizer, habitat boundaries were delineated around signatures (e.g., areas with specific color and texture patterns) in the orthorectified mosaic corresponding to habitat types in the classification scheme (Chapter 1). This was often accomplished by first digitizing a large boundary polygon such as the habitats that compose the shoreline and then appending new polygons to the initial polygon or splitting out smaller polygons within. Each new polygon was attributed with the appropriate habitat designation according to the classification scheme. It is believed that the positional accuracy of polygon boundaries is similar to that of the mosaics since delineation is performed directly on the digital imagery. Brightness, contrast, and occasionally color balance of the mosaic were manipulated with Image Analysis to enhance the interpretability of some subtle features and boundaries. This was particularly helpful in deeper water where differences in color and texture between adjacent features tend to be more subtle and boundaries more difficult to detect. Particular caution was used when interpretation was performed from altered images, since results from color and brightness manipulations can sometimes be misleading.

The original 1:48000 scale color prints and diapositives were available to the photointerpreter to aid in delineating and attributing polygons. The high quality diapostives were frequently viewed under magnification on a light table to aid in this process. Additional collateral information including previously completed habitat maps, NOS nautical charts, and other descriptive references dealing with benthic and coastal habitats of Puerto Rico and the U.S. Virgin Islands was used to assist with image interpretation (Kumpf and Randall, 1961; Rodriguez et al, 1977; Morelock, 1978; Adey, 1979; Goenaga and Cintron, 1979; Beach and Trumbull, 1981; Grove, 1983; Beets et al, 1986; Pilkey et al, 1987; Trias, 1991; Rodriguez et al, 1992; Morelock et al, 1994; Bacle, 1995; Reid and Kruer, 1998; Kruer 1995; Garcia et al, 2000; NOAA et al, 2000).

Ground Validation

Following careful evaluation of the aerial photography, and in some cases creation of a "first draft" habitat map through the process outlined above, selected sites were visited in the field for typological validation. This validation included: (1) areas in the aerial photography and mosaic with confusing or difficult to interpret signatures, (2) transects across many representative habitat types occurring in different depths and water conditions, (3) a survey of the Zones, and (4) confirmation of preliminary habitat delineations if a first draft was produced. Navigating to field sites was accomplished in a variety of ways including uploading position coordinates from the mosaic into an onboard GPS and navigating to those waypoints, using an onboard PC connected to GPS allowing navigation using digital nautical charts or the mosaic, and visual navigation using landmarks visible in the diapositives. On most occasions, field activities were conducted with the guidance of local experts.

Diapositives, and when available, draft delineations were used in the field to facilitate comparison of signatures in the imagery to actual habitats at each site. Individual sites were visually evaluated by snorkeling and free diving or directly from the boat in shallow, clear water. Habitat transitions were evaluated by swimming transects across habitat types to further guide placement of polygon boundaries. Habitat type(s), zone, approximate depth, position (GPS), image number, and other descriptive information were recorded at each site. Field data for each site was then compiled into a text table with a latitude/longitude field to allow overlay of the field information on the mosaic and habitat polygons (Appendix 2: Ground Truth Points). Where depth and water clarity permitted, the diapositives were used to navigate across multiple bottom features allowing continuous confirmation of habitat types and transitions between each site.

Following processing of the field data, polygon boundaries and habitat classifications were created or revised where necessary, and zone attributes were assigned to each polygon using the Habitat Digitizer. This draft of the habitat maps was then reviewed and revised with the guidance of a panel of local experts at peer review sessions in Puerto Rico, the U.S. Virgin Islands, and over the internet. Review session participants included members of the local research and management community. During these peer review sessions, particular attention was given to polygons labeled as "unknown" and areas not visited during ground truth activities. Revisions based on comments from local experts were then completed and final habitat maps were produced. Thematic accuracy was assessed for these final maps (see Chapter 4).

Chapter 4: Assessment of Classification Accuracy

Periodic assessment of thematic accuracy during map production is a critical part of any mapping project. Mapmakers want to know how reliably a given habitat type can be classified, this is called “producers accuracy”. Map users want to know what percentage of the polygons labeled with a specific habitat type is classified correctly, this is called “users accuracy” (Congalton, 1991; Verbyla, 1991). Such periodic assessment is necessary to monitor and maintain acceptable standards of quality following creation of each draft. Most importantly, once final products are produced, the reliability of results must be estimated and reported.

Thematic accuracy of the Puerto Rico and U.S. Virgin Islands habitat maps was evaluated for the three most general habitat categories: unconsolidated sediment, submerged vegetation, and coral reef/hard bottom. Accuracy was estimated at each of two locations within the project area that included the full complement of habitat types, depth ranges, and water conditions representative of Puerto Rico and the U.S. Virgin Islands. For this reason, the accuracy of maps measured at these two locations is assumed to be representative of map accuracy elsewhere in the project area. This approach, which focused in two small areas, enabled a statistically robust evaluation of thematic accuracy to be conducted without the logistic difficulty of collecting data for accuracy assessment over the entire project area.

In addition, since a novel mapping approach was used to enhance production time and provide additional project deliverables, it was necessary to ensure that maps produced using the ArcView Extension had comparable accuracy to maps produced using more routinely used techniques. To accomplish this goal, the thematic accuracy of ArcView maps was compared to the accuracy of maps produced using published and well known photogrammetric techniques.

Goals of the accuracy assessment:

1. Compare the thematic accuracy of maps produced from on-screen digitizing using the ArcView Extension to those produced by digitizing directly from hard copy photos using a stereoplotter.
2. Evaluate the ArcView derived products more thoroughly, including areas with different reef environments/ water conditions representative of sites throughout the project extent.

Comparing Thematic Accuracy: On-screen vs. Stereoplotter Digitizing

Buck Island National Monument, St.Croix and the surrounding ecosystem (approximately 5000 acres) was selected as the site for comparing thematic accuracy resulting from on-screen vs. analytical stereoplotter digitizing due to several factors. First, almost all habitat types in the Puerto Rico/ Virgin Islands project area are present at this site (except mud and mangroves). In addition, there is a long history of research focused on the habitat in and around Buck Island resulting in a variety of historical data with which to compare NOAA map products. Finally, there is excellent logistic support for field activities through the National Park Service and USGS.

Maps of this area were created using two techniques; the ArcView Extension and on-screen digitizing process described in Chapter 3, and standard photogrammetric techniques using an analytical stereoplotter to visually interpret benthic features from hard copy photos. Maps derived using the stereoplotter were created by the NOAA Coastal Services Center using Coastal Change Analysis Program (C-CAP) protocols. These protocols include widely accepted and commonly used photogrammetric techniques and instruments (see Dobson et al, 1995 for a complete description of this technique). Under these protocols, habitats were delineated directly from stereo pairs of the hard copy aerial photos that were scanned and used to create the orthorectified mosaics described in Chapter 3. Using the analytical stereoplotter, extremely detailed classification of the hard copy imagery is possible. Since the ArcView digitizing technique used to create maps relied on classification from scans of these photos (less resolution relative to the original hard copy), it was important to determine if there is a difference in thematic accuracy between maps produced using the two techniques given the classification categories and MMU described in Chapter 1.

While map production was underway, habitat type at approximately 120 sites was evaluated in the Buck Island test area to compare with habitat delineations derived from each mapping technique. A stratified sampling protocol was used during which sample sites were pre-selected so that overall thematic accuracy of the three major habitat types across the range of depths and water conditions found in the field could be evaluated. First, a grid with an approximatly1 acre cell size (MMU) was overlaid on the georeferenced mosaic of the test area. Next, one third of the grid cells were randomly selected as potential sample sites. The number of potential sample sites was further reduced by eliminating grid cells that contained multiple habitat types. This reduced the possibility of using sites that straddle polygon boundaries. Sites near habitat boundaries were avoided since comparing these locations with mapped polygons could be confounded by spatial accuracy of linework and/or coordinates of ground truth points. National Ocean Service bathymetry data was then overlaid and used to split the remaining cells into “shallow” or “deep” categories based approximately on the 40-foot isobath to assist with final site selection. This was done to ensure adequate representation of accuracy assessment within two depth strata, since depth is a major factor determining the interpretability of benthic features. Site selection was completed by using visual photointerpretation to select 20 sites for each of the three major habitat types within the two depth strata respectively. This process resulted in a total of 120 preselected sites across the range of depths and habitat types found at the test area.

The accuracy assessment dataset was collected in November 1999 for the Buck Island test area- eight months after the aerial photos were obtained. This short time interval minimized the possibility that habitats could have been altered significantly between the time of the aerial photography and collecting the accuracy assessment data.

A datasheet was created based on the categories in the habitat classification scheme to facilitate assessment of habitat type at each site in the field. Each preselected site was navigated to using real time DGPS. Data recorded at each site included habitat type, depth, and other descriptive information. Depth was determined using a hand-held depth sounder. Habitat type(s) were recorded within an approximately 5-7 meter radius around each pre-selected site. Habitat type directly at the DGPS coordinates was recorded first followed by any secondary habitat types observed within the 5-7m radius of the DGPS point. In most cases, habitat type was the same for the DGPS point and area around each site since we preselected grid cells encompassing areas of uniform tone and texture in the imagery. Logistics prevented evaluation of each site on the scale of the MMU (1 acre). Therefore, potential classification errors resulting from the difference between the MMU and size of accuracy assessment sites were accounted for in the analysis. For example, map classification was not considered incorrect in cases where an accuracy assessment point was scored as “sand” in the 5-7 meter area and the photointerpreter delineated a large, multiple acre polygon as “patchy seagrass”, “aggregated patch reefs”, and “colonized pavement with sand channels” since each of these classification categories have large areas composed of sand.

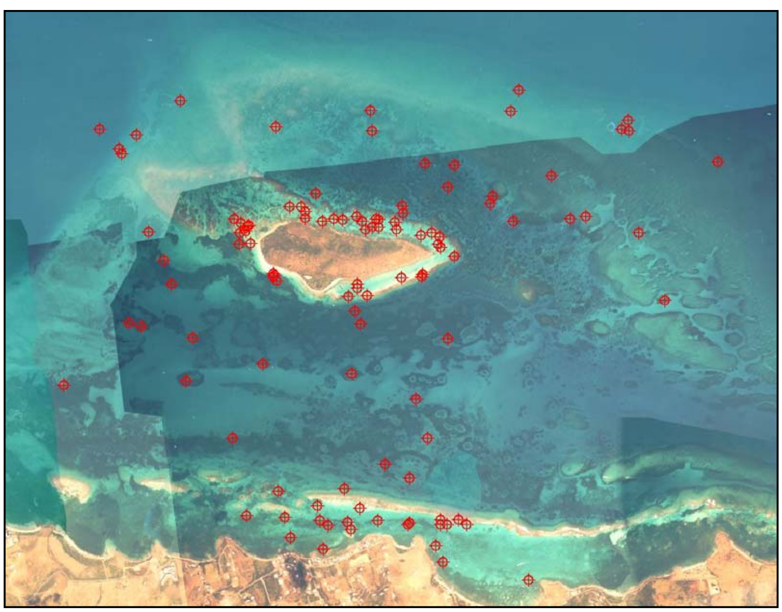


Figure 4.1: Distribution of accuracy assessment points around the Buck Island Reef National Monument test area (n=109).

Logistics prevented reliable data acquisition at 11 of the 120 pre-selected sites. Therefore 109 sites were used for the accuracy assessment (figure 4.1). Data recorded at each site was overlaid onto the habitat maps and compared against the classification assigned by the photointerpreters. After comparing the map classification to each ground truth site, an error matrix was produced displaying both errors of inclusion and exclusion (tables 4.1-4.2). In addition, overall accuracy, users and producer's accuracy, and Kappa Statistic (measure of map accuracy relative to a map with classifications randomly assigned expressed as a percent) were reported.

Results: Thematic Accuracy of On-screen vs. Stereoplotter Digitizing

Comparison with the ground truth data revealed very similar levels of thematic accuracy between the two maps. Overall accuracy was 93.6 percent (Kappa 0.90) for on-screen digitizing and 87.8 percent (Kappa 0.82) for maps digitized directly from stereo pairs. Maps produced from on-screen digitizing were almost 100 percent accurate for the submerged vegetation and unconsolidated sediment categories but misclassified a small percentage of hardbottom sites as unconsolidated sediment. Similarly, the maps produced using the stereoplotter were 100 percent accurate at classifying submerged vegetation but misclassified a small percentage of hardbottom and unconsolidated sediment sites. These findings suggest that both of these mapping techniques result in acceptable levels of thematic accuracy for maps produced at this scale with this type of classification scheme.

Table 4.1: Error matrix for habitat classification using on-screen digitizing at the Buck Island test area. Numbers in the matrix indicate class coincidence, (U) indicates users accuracy, and (P) indicates producers accuracy based on analysis of 109 ground truth points.

Mapped Habitat Type	Actual Habitat Type		
	Coral Reef/ Hardbottom	*Submerged Vegetation*	*Unconsolidated Sediment*
Coral Reef/ Hardbottom	35 97.2% (U) 85.4% (P)	0	1
Submerged Vegetation	0	30 100% (U) 100% (P)	0
Unconsolidated Sediment	6	0	37 86.1% (U) 97.4% (P)

Table 4.2: Error matrix for habitat classification using a stereoplotter at the Buck Island test area. Numbers in the matrix indicate class coincidence, (U) indicates users accuracy, and (P) indicates producers accuracy based on analysis of 98 ground truth points. Slightly fewer points were used in this analysis since the extent of this map was smaller than the distribution of ground truth points.

Mapped Habitat Type	Actual Habitat Type		
	Coral Reef/ Hardbottom	*Submerged Vegetation*	*Unconsolidated Sediment*
Coral Reef/ Hardbottom	35 92.1% (U) 89.7% (P)	0	3
Submerged Vegetation	3	25 75.8% (U) 100% (P)	5
Unconsolidated Sediment	1	0	26 96.3% (U) 76.5% (P)

Methods for Evaluation of Thematic Accuracy for other Reef Morphologies and Water Conditions

The results from the Buck Island test area indicated that thematic accuracy of maps produced from on-screen digitizing was good given the clear water and reef morphologies that are representative of that area. However, both geomorphology and local water conditions can dramatically influence the ability to accurately and consistently photointerpret habitats. Therefore, the thematic accuracy of the ArcView derived products were further evaluated in another area with different water conditions and reef morphologies than those present at the Buck Island site and more representative of the environment found elsewhere in the project area. The La Parguera, Puerto Rico area was chosen for additional evaluation of thematic accuracy. The variety of water conditions and habitat types at this site are representative of those occurring elsewhere in the Puerto Rico project area. In addition, the long history of research focused on the habitat in and around La Parguera by the University of Puerto Rico, Isla Magueyes Campus resulted in a variety of data with which to compare NOAA map products. Furthermore, the University of Puerto Rico provides excellent logistic support for field activities. Sites of accuracy assessment points were selected and analyzed with the same protocol as described above for the Buck Island test area (table 4.3).

Results: Thematic Accuracy for other Reef Morphologies and Water Conditions

Accuracy in the Parguera area was estimated using 200 ground truth points (Fig. 4.2) and was determined to be 93.6 percent overall (Kappa 0.93). Maps were 100 percent accurate for the unconsolidated sediment category and nearly so for coral reef/hardbottom categories. A small percentage of submerged vegetation sites were misclassified as coral reef/hardbottom. These values are well within acceptable levels of thematic accuracy and suggest that other areas in the project area with similar water conditions and reef morphologies will be mapped with similar accuracy.

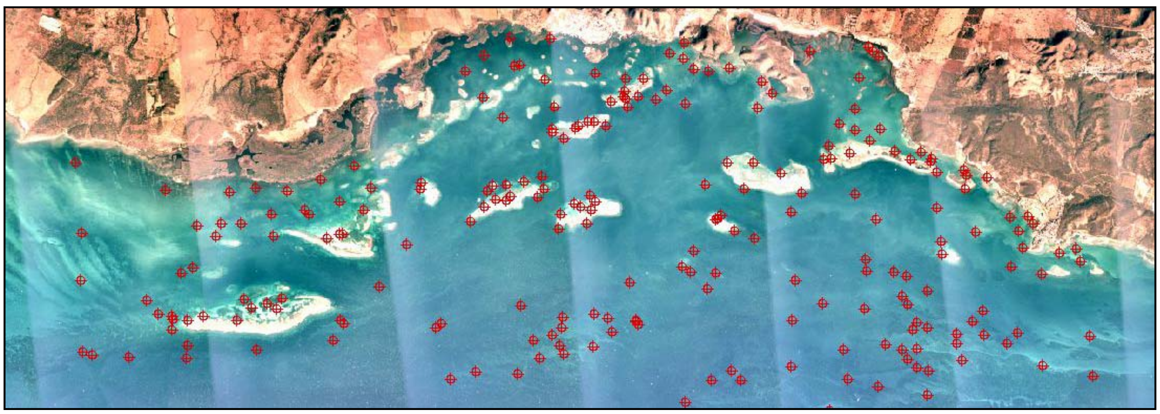


Figure 4.2: Distribution of accuracy assessment points around the La Parguera, Puerto Rico test area (n=200).

Table 4.3: Error matrix for habitat classification at La Parguera. Numbers in the matrix indicate class coincidence, (U) indicates users accuracy, and (P) indicates producers accuracy based on analysis of 200 ground truth points.

Mapped Habitat Type \ Actual Habitat Type	*Coral Reef/ Hardbottom*	*Submerged Vegetation*	*Unconsolidated Sediment*
Coral Reef/ Hardbottom	76 91.6% (U) 98.7% (P)	7	0
Submerged Vegetation	1	92 98.9% (U) 92.9% (P)	0
Unconsolidated Sediment	0	0	24 100% (U) 100% (P)

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