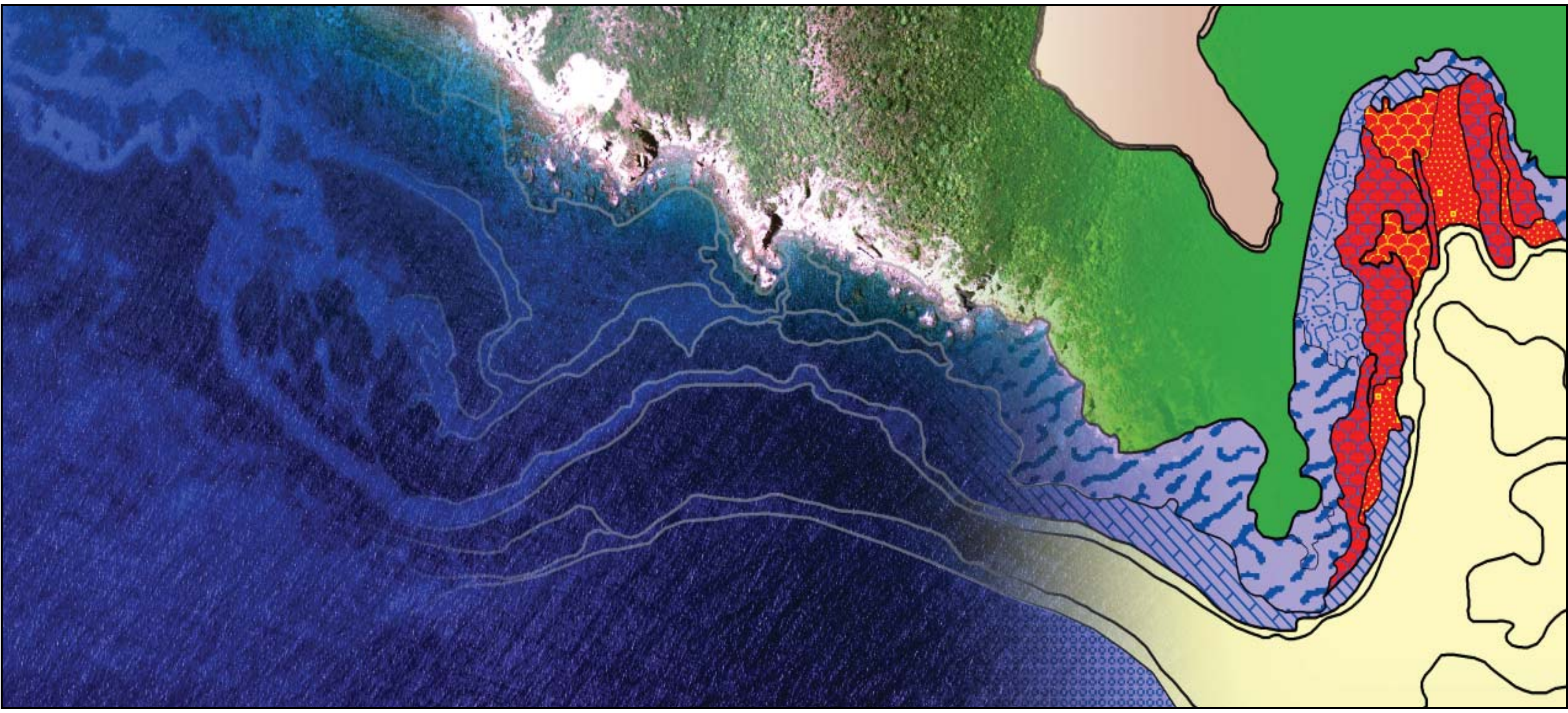
Shallow-Water Benthic Habitats of St. John, U.S. Virgin Islands



Adam G. Zitello
Laurie J. Bauer
Timothy A. Battista
Peter W. Mueller
Matthew S. Kendall
Mark E. Monaco
NOAA CCMA Biogeography Branch

Project Report Produced by NOAA's Biogeography Branch in Cooperation with U.S. National Park Service

NOAA TECHNICAL MEMORANDUM NOS NCCOS 96

Citation:

Zitello, A.G., L.J. Bauer, T.A. Battista, P.W. Mueller, M.S. Kendall and M.E. Monaco. 2009. Shallow-Water Benthic Habitats of St. John, U.S. Virgin Islands. NOAA Technical Memorandum NOS NCCOS 96. Silver Spring, MD. 53 pp.

Shallow-Water Benthic Habitats of St. John, U.S. Virgin Islands

Biogeography Branch
Center for Coastal Monitoring and Assessment (CCMA)
NOAA/NOS/NCCOS
1305 East-West Highway, SSMC4, N/SCI-1
Silver Spring, MD 20910

NOAA Technical Memorandum NOS NCCOS 96

August 2009

Authors:
Adam G. Zitello
Laurie J. Bauer
Timothy A. Battista
Peter W. Mueller
Matthew S. Kendall
Mark E. Monaco

United States Department of Commerce	National Oceanic and Atmospheric Administration	National Ocean Service
Gary Locke Secretary	Jane Lubchenco Administrator	John H. Dunnigan Assistant Administrator

ABOUT THIS DOCUMENT

This report describes the creation and assessment of benthic habitat maps for the nearshore waters of St. John, U.S. Virgin Islands. The objective of this effort, conducted by NOAA's Center for Coastal Monitoring and Assessment - Biogeography Branch in partnership with the U.S. National Park Service (NPS), was to provide spatially-explicit information on the habitat types, biological cover and live coral cover of St. John's coral reef ecosystem. These fine-scale habitat maps, generated by visual interpretion of satellite and airborne imagery, represent a significant improvement from NOAA's 2001 digital maps (Kendall et al.) of the U.S. Caribbean due to an expanded habitat classification scheme, smaller minimum mapping unit, and more recent imagery.

This report consists of four primary components: 1) a description of the benthic habitat classification scheme, 2) description of the techniques used for map creation, 3) an assessment of the map accuracy, and 4) summary of the findings. The maps will be used by NPS and other local partners for planning research and monitoring activities, and will support the management and conservation of the National Parks, Monuments, and other coastal areas around St. John.

This work is part of NOAA Coral Reef Conservation Program's national coral reef ecosystem integrated mapping and monitoring studies throughout the U.S. Caribbean (Monaco et al. 2001).

For more information on this effort please visit:
http://ccma.nos.noaa.gov/ecosystems/coralreef/benthic_usvi.html

Direct questions or comments to:

Mark E. Monaco
Branch Chief
NOAA/NOS/NCCOS/CCMA/Biogeography Branch
1305 East West Highway
SSMC4, N/SCI-1
Silver Spring, MD 20910
Phone: (301) 713-3028 x160
Email: Mark.Monaco@noaa.gov

Or

Timothy A. Battista
Project Manager
NOAA/NOS/NCCOS/CCMA/Biogeography Branch
1305 East West Highway
SSMC4, N/SCI-1
Silver Spring, MD 20910
Phone: (301) 713-3028 x171
Email: Tim.Battista@noaa.gov

All photographs provided in this document were taken by NOAA/NOS/NCCOS/Center for Coastal Monitoring and Assessment Biogeography Branch in St. John, USVI.

This page intentionally left blank.

EXECUTIVE SUMMARY

Coral reef ecosystems of the Virgin Islands Coral Reef National Monument, Virgin Islands National Park and the surrounding waters of St. John, U.S. Virgin Islands are a precious natural resource worthy of special protection and conservation. The mosaic of habitats including coral reefs, seagrasses and mangroves, are home to a diversity of marine organisms. These benthic habitats and their associated inhabitants provide many important ecosystem services to the community of St. John, such as fishing, tourism and shoreline protection. However, coral reef ecosystems throughout the U.S. Caribbean are under increasing pressure from environmental and anthropogenic stressors that threaten to destroy the natural heritage of these marine habitats.

Coral reef ecosystems provide a variety of ecological and economic services to St. John, U.S. Virgin Islands.

Mapping of benthic habitats is an integral component of any effective ecosystem-based management approach. Through the implementation of a multi-year interagency agreement, NOAA's Center for Coastal Monitoring and Assessment - Biogeography Branch and the U.S. National Park Service (NPS) have completed benthic habitat mapping, field validation and accuracy assessment of maps for the nearshore marine environment of St. John. This work is an expansion of ongoing mapping and monitoring efforts conducted by NOAA and NPS in the U.S. Caribbean and replaces previous NOAA maps generated by Kendall et al. (2001) for the waters around St. John. The use of standardized protocols enables the condition of the coral reef ecosystems around St. John to be evaluated in context to the rest of the Virgin Island Territories and other U.S. coral ecosystems. The products from this effort provide an accurate assessment of the abundance and distribution of marine habitats surrounding St. John to support more effective management and conservation of ocean resources within the National Park system.

This report documents the entire process of benthic habitat mapping in St. John. Chapter 1 provides a description of the benthic habitat classification scheme used to categorize the different habitats existing in the nearshore environment. Chapter 2 describes the steps required to create a benthic habitat map from visual interpretation of remotely sensed imagery. Chapter 3 details the process of accuracy assessment and reports on the thematic accuracy of the final maps. Finally, Chapter 4 is a summary of the basic map content and compares the new maps to a previous NOAA effort.

Benthic habitat maps of the nearshore marine environment of St. John, U.S. Virgin Islands were created by visual interpretation of remotely sensed imagery. Overhead imagery, including color orthophotography and IKONOS satellite imagery, proved to be an excellent source from which to visually interpret the location, extent and attributes of marine habitats. NOAA scientists were able to accurately and reliably delineate the boundaries of features on digital imagery using a Geographic Information System (GIS) and field investigations.

The St. John habitat classification scheme defined benthic communities on the basis of four primary coral reef ecosystem attributes: 1) broad geographic zone, 2) geomorphological structure type, 3) dominant biological cover, and 4) degree of live coral cover. Every feature in the benthic habitat map was assigned a designation at each level of the scheme. The ability to apply any component of this scheme was dependent on being able to identify and delineate a given feature in remotely sensed imagery.

An area of 53 km² was described by polygons corresponding to the categories described by the habitat classification scheme. *Unconsolidated Sediment* and *Coral Reef and Hardbottom* each accounted for 27 km^2 of major structure type. *Sand* was the most common detailed structure type, accounting for 43% of the total mapped

area. *Pavement* was the second most dominant structure type overall and was the most common reef type, covering 16% of the mapped area. Another common structure type was *Aggregate Reef*, which contributed to 7% of the total area. Although ecologically significant, patch reefs, in the form of *Individual* and *Aggregated Patch Reefs*, only comprised 3% of all the nearshore habitat mapped around St. John.

The overwhelmingly dominant major biological cover was *Algae*, which accounted for 74% of the 53 km^2 mapped area. Although live coral colonies exist throughout the St. John seascape and are a key component of reef ecosystems, the total area of features dominated by live coral cover was only 0.81 km^2 or 1.5% of the mapped area.

A multitude of fish species school near the structure of a coral reef.

An additional assessment of live coral cover, regardless of biological dominance, suggested that almost all of the total mapped area was comprised of less than 50% coral cover. There were 9 km^2 exhibiting a percent coral cover of 10% to <50%. These areas accounted for 17% of the study area, while 83% had less than 10% coral cover. Furthermore, percent coral cover did not exceed 50% within any polygon delineated in the study. It was observed that some areas of St. John were comprised of greater than 50% coral cover, but these areas were smaller than the minimum mapping unit of 1,000 m^2.

Thematic accuracy was characterized for major and detailed geomorphological structure, major and detailed biological cover, and percent coral cover. The accuracy assessment revealed successful overall map accuracies of over 90% for major structure and cover classes, and over 80% for detailed structure and cover classes.

The 86% accuracy achieved for detailed structure in NOAA's new St. John benthic habitat maps were similar to that of other recent NOAA benthic habitat maps in the Florida Keys (86%), Palau (90%), and the Main Hawaiian Islands (90%). This comparison demonstrates that the needs of coral reef managers and scientists for a dominance based classification scheme were met, with no loss in thematic map accuracy. As a result, these digital map products can be used with confidence by scientists and resource managers for a multitude of different applications.

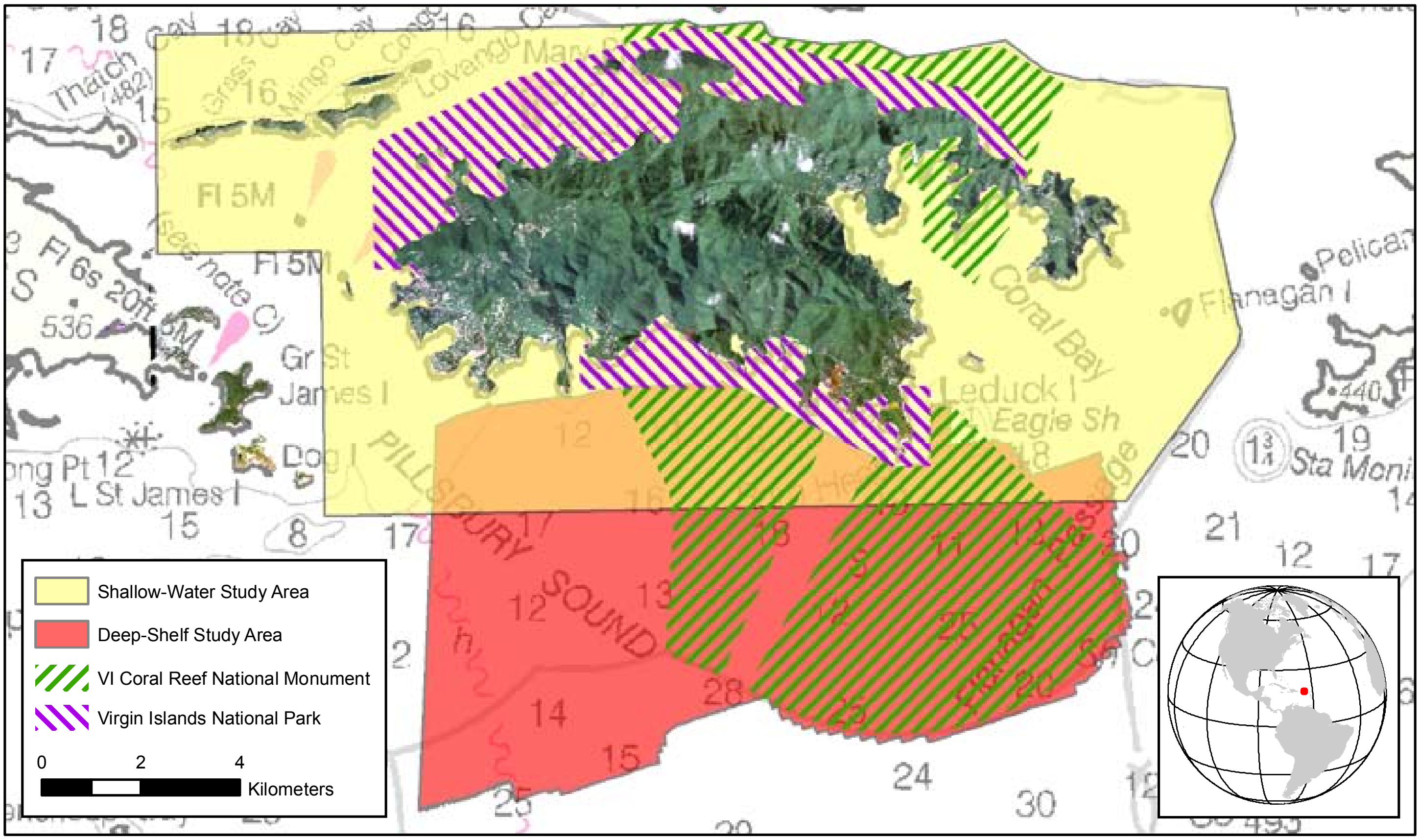
TABLE OF CONTENTS

List of Tables

List of Figures

INTRODUCTION

NOAA's Center for Coastal Monitoring and Assessment - Biogeography Branch has developed analytical protocols used for mapping benthic habitats throughout all U.S. jurisdictions, States, and Territories, including the U.S. Caribbean. NOAA, in partnership with the U.S. National Park Service (NPS), has generated spatially resolved benthic habitat mapping products of the coral reef ecosystems surrounding St. John, U.S. Virgin Islands. The synthesis of existing geospatial data and collection of new data provides the most contemporary compilation of remotely sensed and *in situ* data within the network of NPS-managed marine ocean parks. These products provide a fine-scale assessment of the status, abundance, and distribution of marine habitats of St. John. This effort equips NPS with increased technical capacity for ocean exploration, management, and stewardship. Potential applications include use as a spatial framework for sampling design, improved assessment of human-use impacts, and other marine spatial planning activities.



Overview of St. John, U.S. Virgin Islands with U.S. National Park Service management boundaries and mapping effort extents.

As part of President Bush's U.S. Ocean Action Plan, the NPS developed an Ocean Park Stewardship Action Plan to focus organizational and scientific capacity on conserving marine, estuarine, and Great lakes resources. The Plan strives to prevent the loss of productive fisheries, habitats, and wildlife, and continue to conserve ocean resources and recreational activities for park visitors. NPS manages and protects more than 250,000 acres of coral reef in ten National Park units, two of which are located in St. John, USVI. The Virgin Islands Coral Reef National Monument includes 12,708 acres of submerged lands within 3 miles off the coast of St. John. These waters contain some of the most biologically rich and economically important coral ecosystems in the U.S. Caribbean, supporting a diverse and complex system of coral reefs, shoreline mangrove forests, and seagrass beds. Additionally, the Virgin Islands National Park includes 5,650 acres of submerged federal lands to protect and conserve a rich, but fragile coral reef seascape. As part of the ocean stewardship effort, the Ocean Park Stewardship Action Plan calls to improve scientific capacity in order to better understand ocean ecosystems and human influence. This includes providing improved products and characterizations to better inform resource managers of current resource inventories and benthic habitat distributions.

The NOAA/NPS joint study to map the benthic habitats of St. John has resulted in a suite of products. The project deliverables include:

- Primary data sources, including satellite and airborne imagery, ground validation field data, and accuracy assessment field data,
- Derived datasets, including GIS files of benthic habitats and shoreline,
- Classification manual,
- Description of the specific methods used to create the habitat maps, and
- Assessment of the thematic accuracy of the maps.

CHAPTER 1: BENTHIC HABITAT CLASSIFICATION SCHEME

A habitat classification scheme is a structured system of arranging habitat types into defined groups or classes based on ecological characteristics. The initial task in any mapping effort is to clearly identify these classes and describe their attributes. The scheme is used to guide the delineation and definition of habitats throughout the map creation process. Furthermore, it is critical for map users to have an understanding of how a classification system is structured and the definitions of each class. This knowledge allows users to determine the appropriate uses and limitations of a map.

The St. John habitat classification scheme defines benthic communities on the basis of four primary coral reef ecosystem attributes: 1) broad geographic zone, 2) geomorphological structure type, 3) dominant biological cover, and 4) degree of live coral cover. A hierarchical structure of describing features at varying levels of detail was used so that numerous detailed habitats are encompassed by more broadly defined habitat classes. This hierarchy provides users with the ability to expand and collapse the detail of the habitat map to suit their needs. Every feature in the benthic habitat map is assigned a designation from each level of the scheme (Figure 1.1). The ability to apply any component of this scheme is dependent on being able to identify and delineate a given feature in remotely sensed imagery and assess the accuracy of the resulting benthic habitat map.

Geographic Zone
- Land
- Salt Pond
- Shoreline Intertidal
- Lagoon
- Reef Flat
- Back Reef
- Reef Crest
- Fore Reef
- Bank/Shelf
- Bank/Shelf
- Escarpment
- Channel
- Dredged
- Unknown

Geomorphological Structure
- Coral Reef and Hard Bottom
  - Rock Outcrop
  - Boulder
  - Aggregate Reef
  - Individual Patch Reef
  - Aggregated Patch Reefs
  - Spur and Groove
  - Pavement
  - Pavement with Sand Channels
  - Reef Rubble
  - Rhodoliths
  - Unknown
- Unconsolidated Sediment
  - Sand
  - Mud
  - Sand with Scattered Coral & Rock
  - Unknown
- Other Delineations
  - Land
  - Artificial
  - Unknown

Biological Cover

Major Cover
- Algae
- Live Coral
- Coralline Algae
- Mangrove
- Seagrass
- No Cover
- Unknown

Percent Major Cover
- 10% - <50%
- 50% - <90%
- 90% - 100%
- Unknown

Coral Cover

Percent Coral Cover
- 0% - <10%
- 10% - <50%
- 50% - <90%
- 90% - 100%
- Unknown

Figure 1.1. The classification scheme defines benthic habitats with four primary attributes (described by separate boxes) and several hierarchical levels of classification therein.

1.1. COMPARISON TO PREVIOUS NOAA HABITAT CLASSIFICATION SCHEMES

Many important factors were considered in the development of the habitat classification scheme including: requests of the management community, existing classification schemes for coastal ecosystems, quantitative *in situ* habitat data, minimum mapping unit (MMU) and spectral limitations of remotely sensed imagery (Kendall et al. 2001). The habitat classification scheme used in St. John was based on the evolution of schemes developed by NOAA in efforts to map the U.S. Caribbean and Pacific Islands (Kendall et al. 2001, Battista et al. 2007a, and Battista et al. 2007b).

The fundamental difference in the St. John scheme, as compared to other NOAA coral reef classification schemes, was the deviation from coral-centric classification rules to a biological dominance scheme in which benthic habitats were classified based on the dominant biological cover type present on each feature. In previous NOAA coral reef classification schemes, the biological cover component was assigned to a step-wise progression to first capture the presence of live coral and then attempt to classify any other biological cover if coral was not present. In other words, during map creation the interpreter would assign a polygon to the *Live Coral* biological cover class if there was 10% or greater live coral cover even if the polygon was predominantly covered by another biological cover type. For example, a patch reef covered by 15% live coral and 85% turf algae would be described in the previous classification schemes as *Live Coral* 10% - <50%. This approach often mislead map users in overstating the degree of live coral cover at the expense of the more prevalent biological cover type.

In NOAA's new St. John habitat classification scheme, there were no formal hierarchal classification rules; instead biological cover was described as the dominant cover type on each feature of the map. The importance of always describing the percent cover of live coral was maintained in the St. John scheme by the introduction of a new map attribute *Percent Coral Cover*. This attribute describes the percent live coral cover for every feature at the scale of diver observation in the water, with no regard to dominant biological cover (Figure 1.2). It is important to note that *Percent Coral Cover* refers only to the hardbottom component of any mapped polygon. For instance, an area of sand with some small scattered coral heads in it could be classified as *10% - <50%* live coral cover even though 90% of the polygon is bare sand.

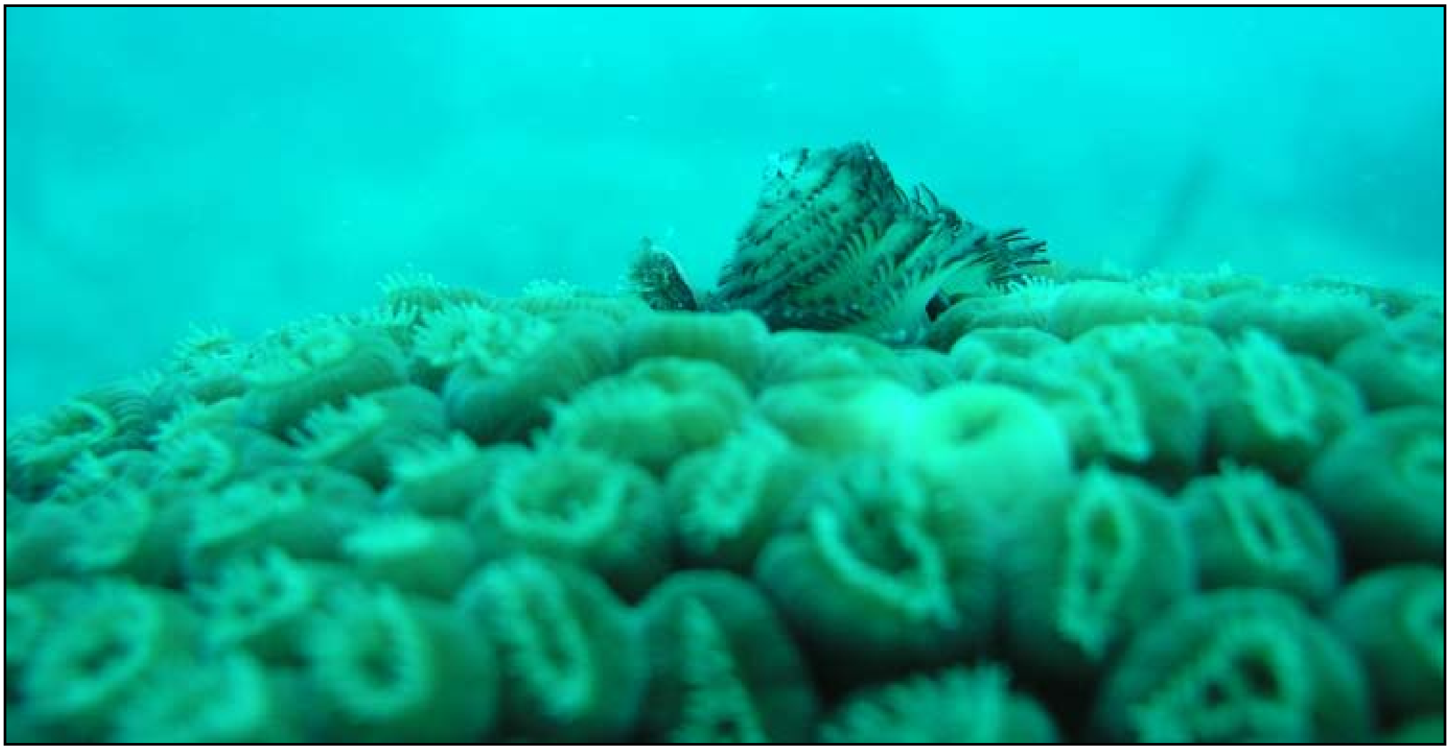


Figure 1.2. The crown of a Christmas Tree Worm (*Spirobranchus giganteus*) protrudes from a colony of Great Star Coral (*Montastraea cavernosa*) on the south shore of St. John.

Every unique combination of classification attributes was provided a distinct identifier in the *UniqueID* field. *UniqueID* consists of an 8-digit number string with each position in the string corresponding to a specific map attribute. See Figure 1.3 for a schematic that defines each attribute's position in the *UniqueID*. Within each attribute, different classifications were assigned discrete codes. Through the assembly of these successive codes, it is possible to summarize all the information for a polygon feature solely based on the *UniqueID*.

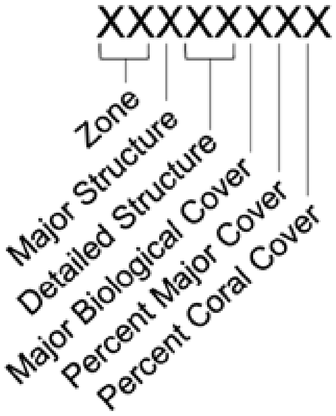


Figure 1.3. Schematic of each attribute's position in the *UniqueID* code of the classification scheme.

1.2. GEOGRAPHIC ZONES

Thirteen mutually exclusive zones can be identified from shore to shelf edge corresponding to typical insular shelf and coral reef geomorphology. These zones include: *Land, Salt Pond, Shoreline Intertidal, Reef Flat, Lagoon, Back Reef, Reef Crest, Fore Reef, Bank/Shelf, Bank/Shelf Escarpment, Channel, Dredged,* and *Unknown*. Figures 1.4 - 1.6 illustrate zone types across typical cross-sections when the reef feature is either separated from shore by a lagoon (Figure 1.4), fringing the shore (Figure 1.5), or not emergent (Figure 1.6). Zone refers only to each benthic community's location and does not address substrate or biological cover types that are found within. For example, the lagoon zone may include patch reefs, sand, or reef rubble; however, these are considered structural elements that may or may not occur within the lagoon zone and therefore, are not used to define it at this level in the scheme (Kendall et al. 2001). A brief description of each zone is provided in the following text.

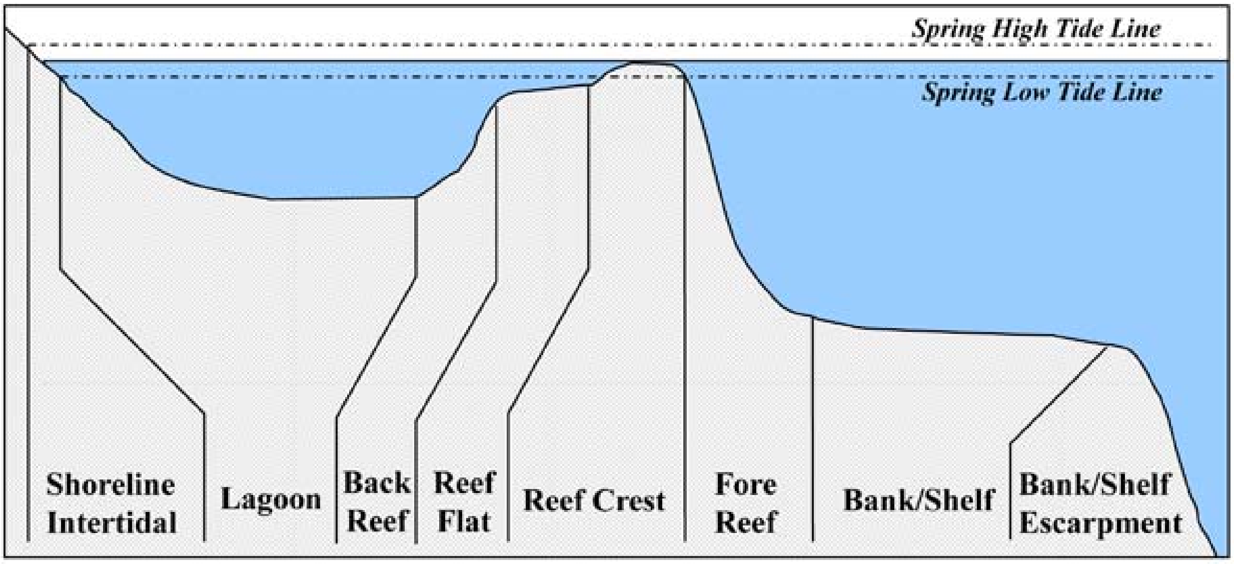


Figure 1.4. Cross-section of zone types where a barrier reef is present. Reef is separated from the shore by a relatively wide, deep lagoon.

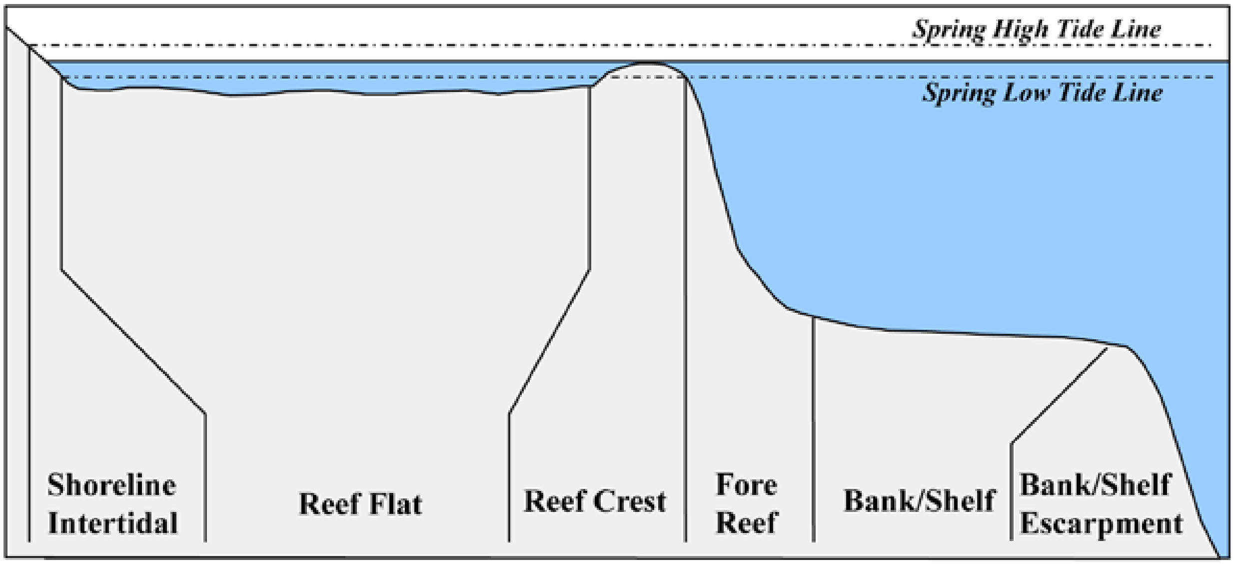


Figure 1.5. Cross-section of zone types where a fringing reef is present. Reef platform is continuous with the shore.

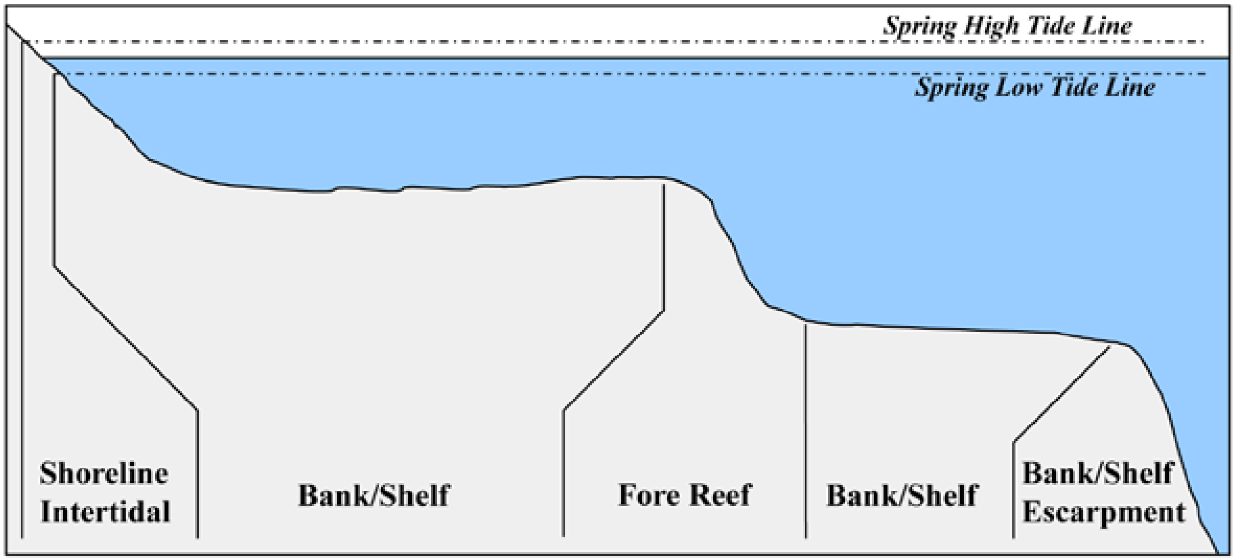


Figure 1.6. Cross-section of zone types where no emergent reef crest is present.

Land (ID Code = 10)
Terrestrial features at or above the spring high tide line. Shoreline delineations describing the boundary between land and submerged zones are established at the wrack line where possible or the wet line at the time of imagery acquisition (Figure 1.7).

Figure 1.7. Depiction of shoreline delineations on unconsolidated (left) and rocky (right) coastlines. A red line highlights each shoreline on orthophotography.

Salt Pond (11)
Enclosed area just landward of the shoreline with a permanent or intermittent flooding regime of saline to hypersaline waters (Figure 1.8).

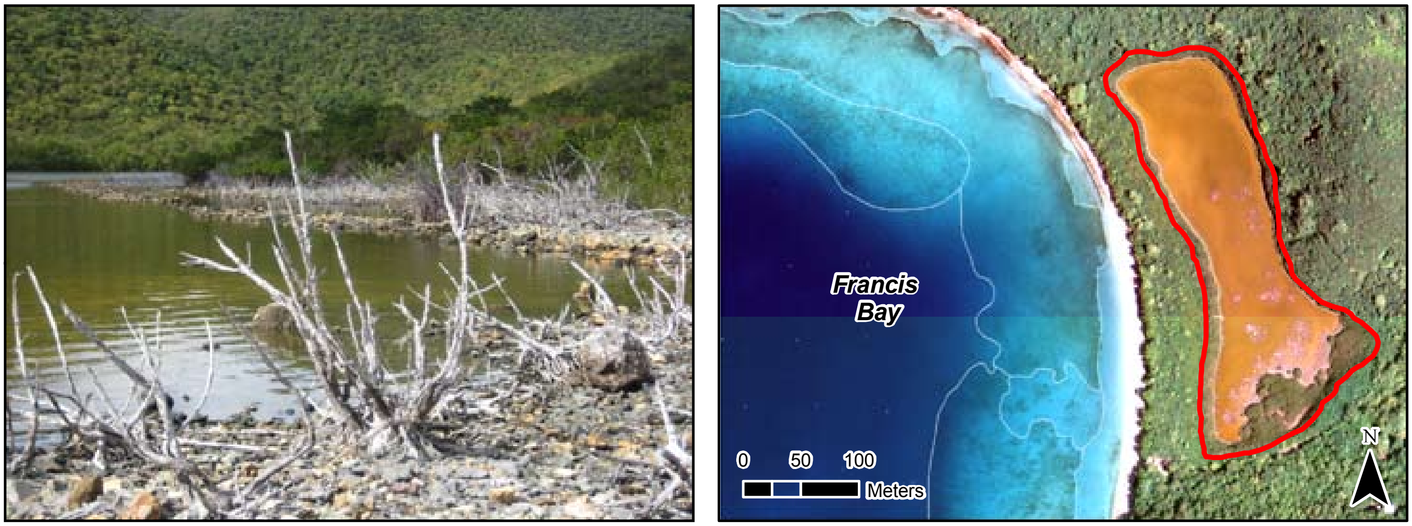


Figure 1.8. Depictions of the *Salt Pond* zone just inshore of Europa Bay (left) and Francis Bay (right). A red polygon outlines the feature on orthophotography.

Shoreline Intertidal (12)
Area between the spring high tide line (or landward edge of emergent vegetation when present) and lowest spring tide level. Emergent segments of barrier reefs are excluded from this zone. Typically, this zone is narrow due to the small tidal range in the U.S. Virgin Islands (Figure 1.9). While present island-wide, the feature is often too narrow to be mapped on steep shorelines due to the scale of the imagery and the MMU.

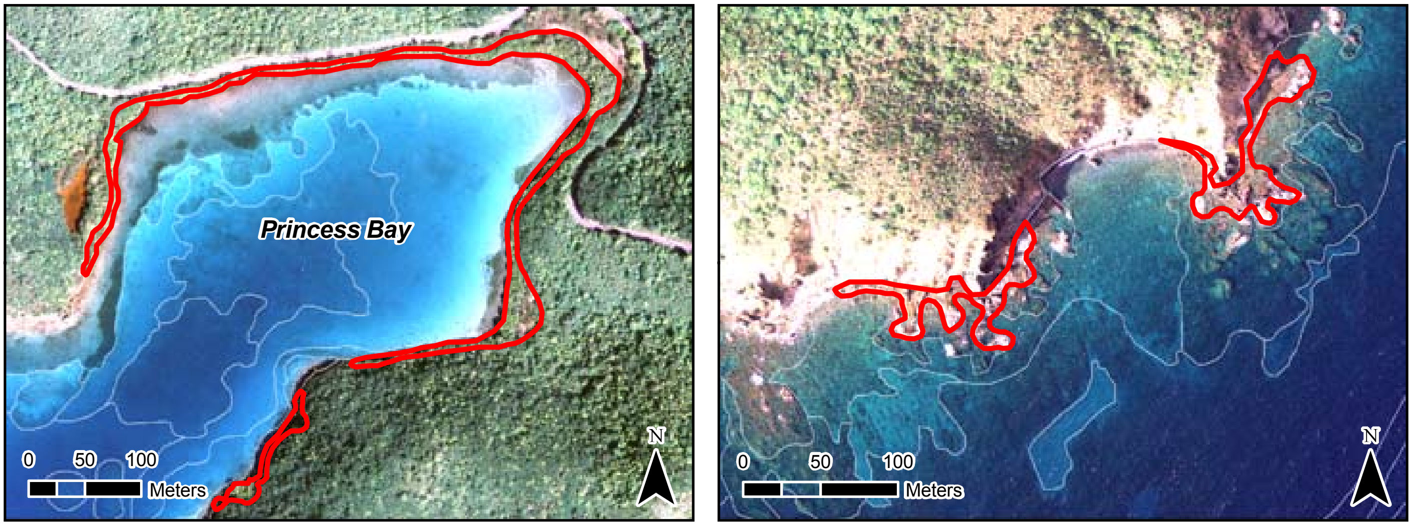


Figure 1.9. Representation of two different types of *Shoreline Intertidal* zones. A low energy mangrove shoreline (left) and a high energy rocky shoreline (right) on the east end of St. John.

Lagoon (13)
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 typically protected from the high-energy waves commonly experienced on the *Bank/Shelf* and *Reef Crest* zones (Figure 1.10). Typical lagoons are rare in St. John, however embayments with limited open ocean exchange restricted by nearly continuous reef crests are included in the *Lagoon* zone.

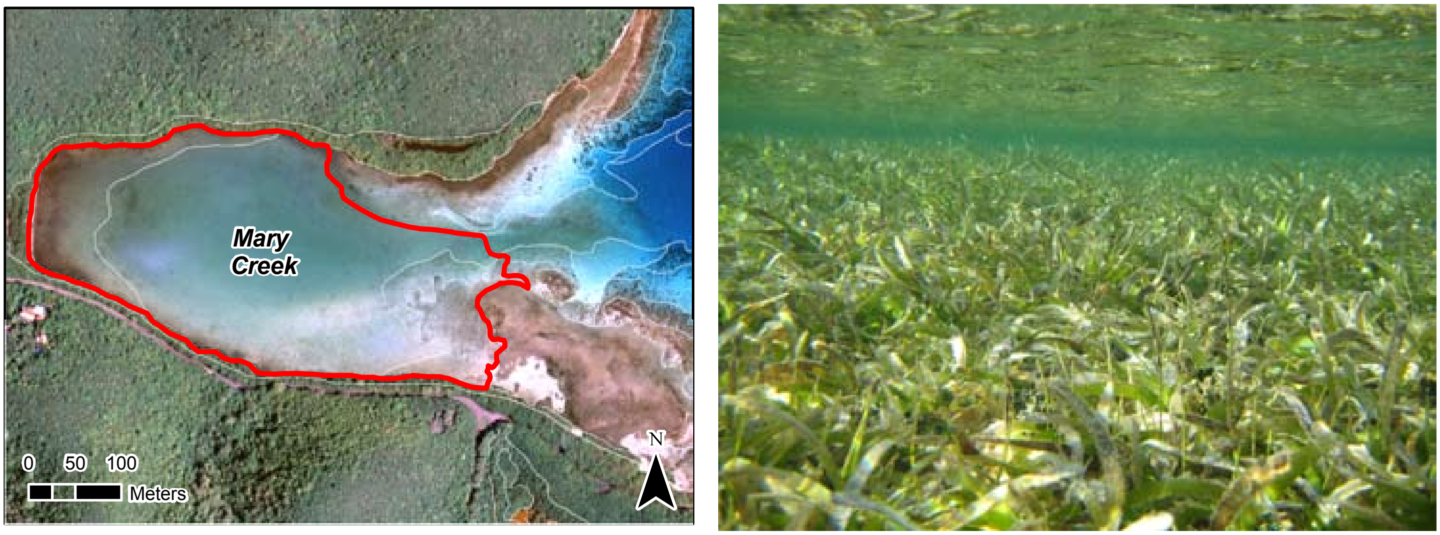


Figure 1.10. View of the *Lagoon* zone on orthophotography at Mary Creek. A red polygon outlines the feature. An example of a seagrass bed located in a shallow *Lagoon*.

Reef Flat (14)
Shallow, semi-exposed area of little relief between the *Shoreline Intertidal* zone and the *Reef Crest* of a fringing reef. This broad, flat area often exists just landward of a *Reef Crest* and may extend to the shoreline or drop into a *Lagoon*. This zone is protected from the high-energy waves commonly experienced on the *Bank/Shelf* and *Reef Crest* zones (Figure 1.11).

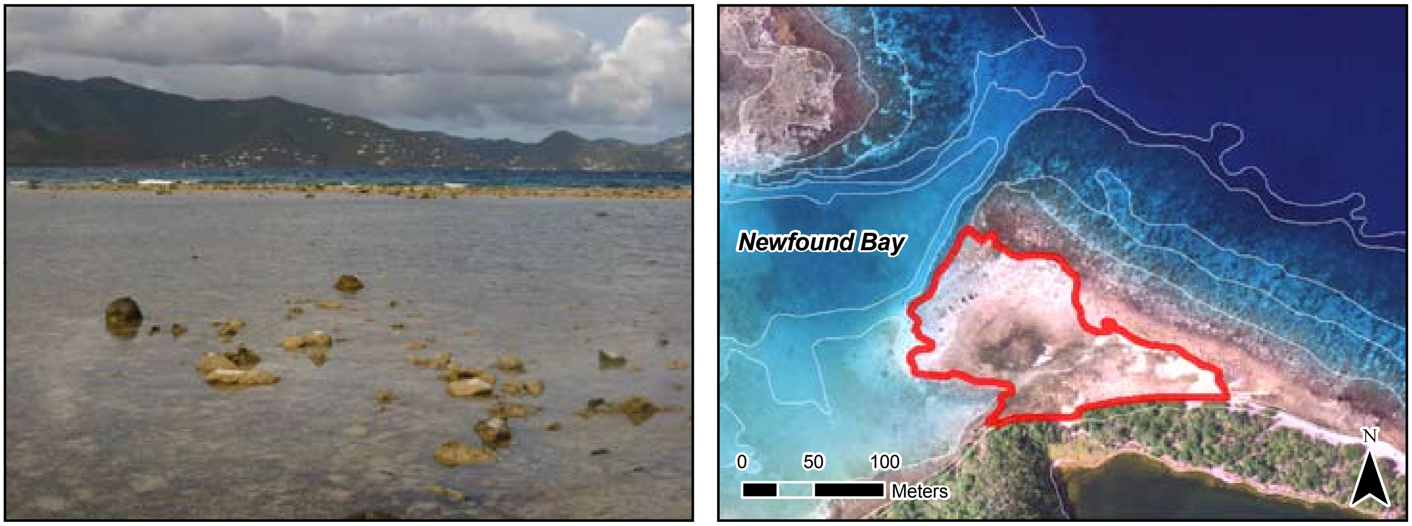


Figure 1.11. Depictions of the *Reef Flat* zone in Newfound Bay from the shoreline and from orthophotography. A red polygon outlines the feature.

Back Reef (15)
Area just landward of a *Reef Crest* that slopes downward towards the seaward edge of a *Lagoon* floor or *Bank/Shelf*. This zone is present only when a *Reef Crest* exists.

Reef Crest (16)
The flattened, emergent (especially during low tides) or nearly emergent segment of a reef. This zone of high wave energy lies between the *Fore Reef* and *Back Reef* or *Reef Flat* zones. Breaking waves are often visible in overhead imagery at the seaward edge of this zone (Figure 1.12).

Fore Reef (17)
Area along the seaward edge of the *Reef Crest* that slopes into deeper water to the landward edge of the *Bank/Shelf* platform. Features not associated with 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* (Figures 1.5 and 1.12).

Bank/Shelf (18)
Deeper water area (relative to the shallow water in a lagoon) extending offshore from the seaward edge of the *Fore Reef* or shoreline to the beginning of the escarpment where the insular shelf drops off into deep, oceanic water. If no *Reef Crest* is present, 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 (Figure 1.12).

Figure 1.12. A series of orthophotographs illustrating the transition from *Reef Crest* to *Fore Reef* to *Bank/Shelf* zones at Lagoon Point. Each zone is depicted in color on the respective map.

Bank/Shelf Escarpment (19)
This zone begins on the oceanic edge of the *Bank/Shelf*, where depth increases rapidly into deep, oceanic water and exceeds the depth limit of features visible in optical imagery around St. John. This zone is intended to capture the transition from the shelf to deep waters of the open ocean.

Channel (20)
Naturally occurring channels that often cut across several other zones.

Dredged (21)
Area in which natural geomorphology is disrupted or altered by excavation or dredging (Figure 1.13).

Figure 1.13. View of the *Dredged* zone on orthophotography at the shipping dock of Turner Bay. A red polygon outlines the feature on orthophotography.

Unknown (99)
Zone indistinguishable due to turbidity, cloud cover, water depth, or other interference with an optical signature of the seafloor.

1.3. GEOMORPHOLOGICAL STRUCTURE TYPES

Sixteen distinct and non-overlapping geomorphological structure types were identified that can be mapped by visual interpretation of remotely sensed imagery. Habitats or features that cover areas smaller than the MMU are not considered. For example, sand halos surrounding patch reefs are often too small to be mapped independently. Structure refers only to predominant physical composition of the feature and does not address location (e.g., on the shelf or in the lagoon). The structure types are defined in a collapsible hierarchy ranging from four major classes (*Coral Reef and Hardbottom, Unconsolidated Sediment, Other Delineations,* and *Unknown*), to sixteen detailed classes (*Rock Outcrop, Boulder, Spur and Groove, Individual Patch Reef, Aggregated Patch Reefs, Aggregate Reef, Reef Rubble, Pavement, Pavement with Sand Channels, Rhodoliths, Sand, Mud, Sand with Scattered Coral and Rock, Artificial, Land,* and *Unknown*).

<u>Coral Reef and Hardbottom</u> (1)
Areas of both shallow and deep-water seafloor with solid substrates including bedrock, boulders and deposition of calcium carbonate by reef building organisms. Substrates typically have no sediment cover, but a thin veneer of sediment may be present at times especially on low relief hardbottoms. Detailed structure classes include *Rock Outcrop, Boulder, Spur and Groove, Individual Patch Reef, Aggregated Patch Reefs, Aggregate Reef, Reef Rubble, Pavement, Pavement with Sand Channels,* and *Rhodoliths*.

Rock Outcrop (30)
A primarily continuous exposure of solid carbonate blocks or volcanic rock extending offshore from the island bedrock. Includes large rock boulders greater than 3 m in diameter (Figure 1.14).

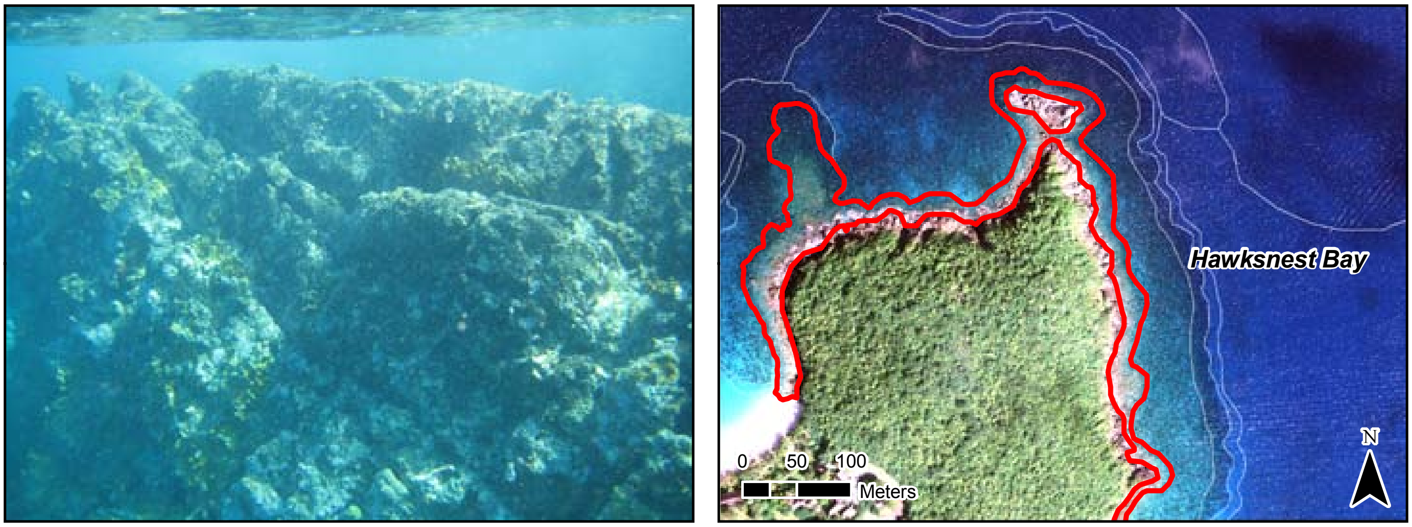


Figure 1.14. Depictions of *Rock Outcrop* structure on the west side of the mouth of Hawksnest Bay. A red polygon outlines the feature on orthophotography.

Boulder (31)

Aggregation of loose carbonate or volcanic rock fragments that have been detached and transported from their native beds (Figure 1.15). Individual boulders range in diameter from 0.25 – 3 m as defined by the Wentworth scale (Wentworth 1922).

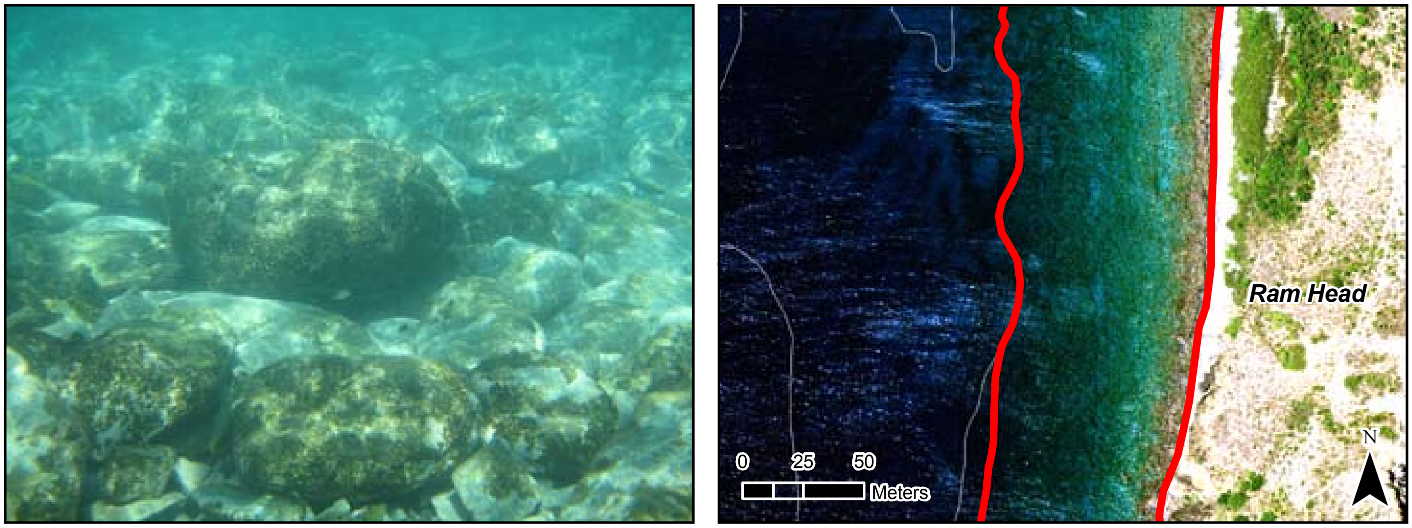


Figure 1.15. Depictions of *Boulder* structure on the west side of Ram Head. A red polygon outlines the feature on orthophotography.

Aggregate Reef (10)

Continuous, high-relief coral formation of variable shapes lacking sand channels of *Spur and Groove*. Includes linear reef formations that are oriented parallel to shore or the shelf edge (Figure 1.16). This class is used for such commonly referred to terms as linear reef, fore reef or fringing reef.

Figure 1.16. Depictions of *Aggregate Reef* structure in Privateer Bay. A red polygon outlines the feature on orthophotography.

Individual Patch Reef (11)
Patch reefs are coral formations that are isolated from other coral reef formations by bare sand, seagrass, or other habitats and that have no organized structural axis relative to the contours of the shore or shelf edge. They are characterized by a roughly circular or oblong shape with a vertical relief of one meter or more in relation to the surrounding seafloor (Figure 1.17). *Individual Patch Reefs* are larger than or equal to the MMU.

Aggregated Patch Reefs (12)
Having the same defining characteristics as an *Individual Patch Reef*. This class refers to clustered patch reefs that individually are too small (less than the MMU) or are too close together to map separately. Where aggregated patch reefs share sand halos, the halo is included in the polygon (Figure 1.17).

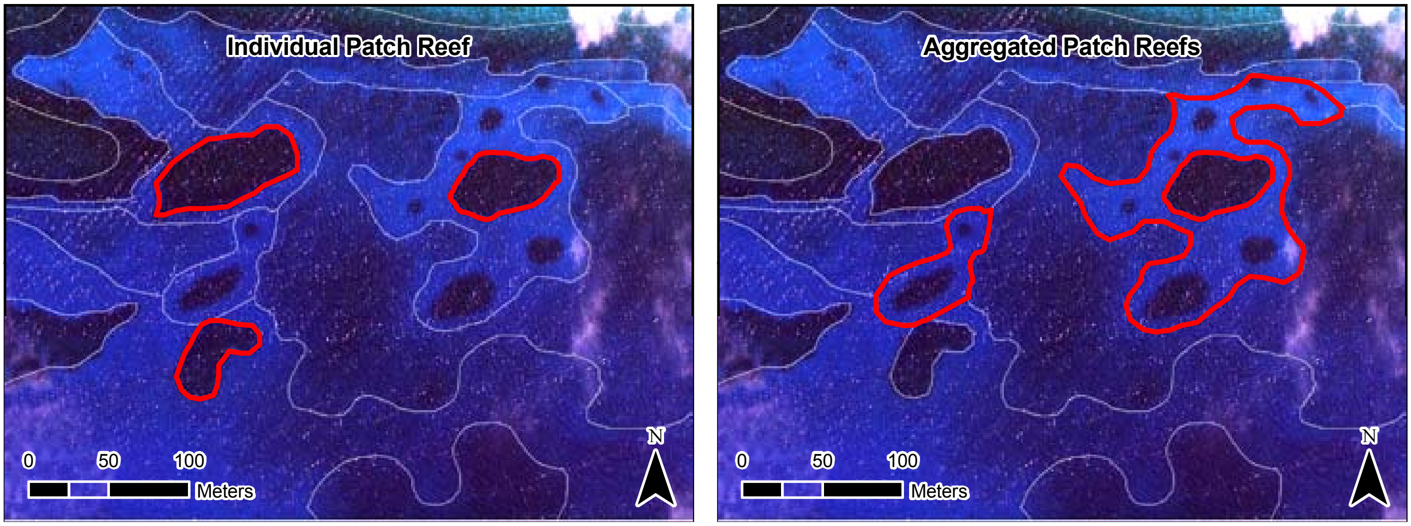


Figure 1.17. Comparison of patch reef delineations south of Johnsons Reef. Due to the influence of minimum mapping units, patch reefs of the same complex are designated by either *Individual Patch Reef* (left) or *Aggregated Patch Reefs* (right). Red polygons outline the features on orthophotography.

Spur and Groove (13)
Structure having alternating sand and coral formations that are oriented perpendicular to the shore or reef crest. The coral formations (spurs) of this feature typically have a high vertical relief (approximately 1 meter or more) relative to pavement with sand channels and are separated from each other by 1-5 meters of sand or hardbottom (grooves), although the height and width of these elements may vary considerably (Figure 1.18). This habitat type typically occurs in the *Fore Reef* or *Bank/Shelf Escarpment* zone.

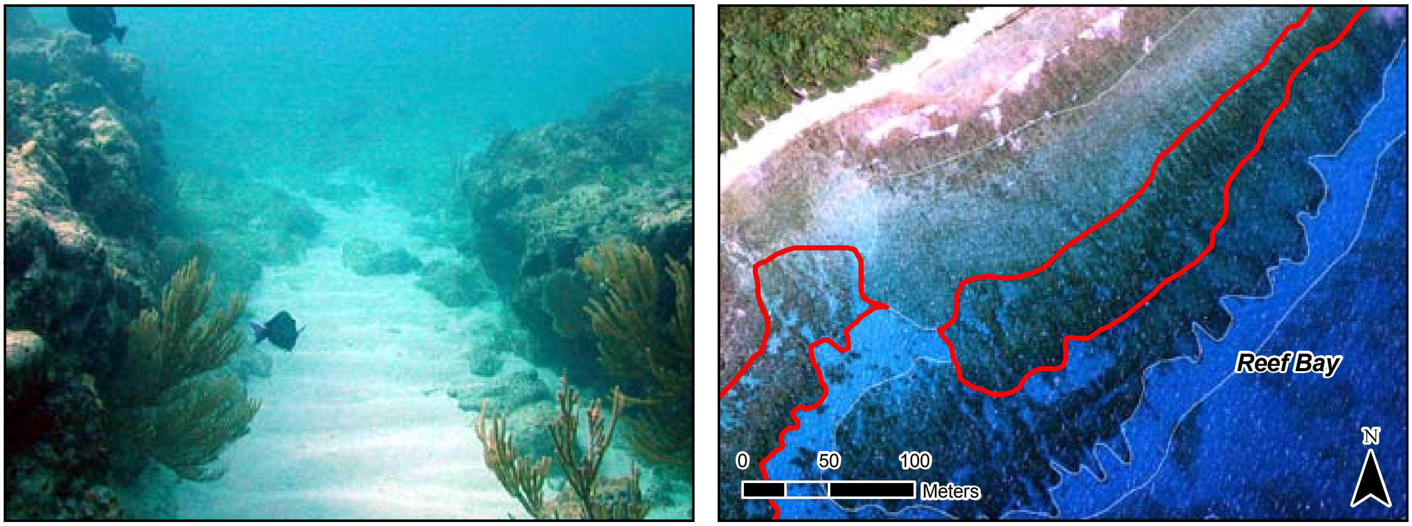


Figure 1.18. Depictions of *Spur and Groove* structure on the west side of Reef Bay. A red polygon outlines the feature on orthophotography.

Pavement (14)

Flat, low-relief, solid carbonate rock with coverage of algae, hard coral, gorgonians, zooanthids or other sessile vertebrates that are dense enough to partially obscure the underlying surface. On less colonized Pavement features, rock may be covered by a thin sand veneer or turf algae (Figure 1.19).

Figure 1.19. Several views of *Pavement* structure in St. John. The overhead representation outlined by red polygons illustrates the often irregular shape. Also, *Pavement* may be colonized by a variety of marine flora.

Pavement with Sand Channels (15)

Habitats of pavement with alternating sand/surge channel formations that are oriented perpendicular to the *Reef Crest* or *Bank/Shelf Escarpment*. The sand/surge channels of this feature have low vertical relief (approximately less than 1 meter) relative to *Spur and Groove* formations and are typically erosional in origin. This habitat type occurs in areas exposed to moderate wave surge such as the *Bank/Shelf* zone (Figure 1.20).

Figure 1.20. Depictions of *Pavement with Sand Channels* off Turner Point in Coral Bay. A red polygon outlines the feature on orthophotography.

Reef Rubble (16)
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, Back Reef* or *Reef Flat* zones. Less often, *Reef Rubble* can occur in low density aggregations on broad offshore sand areas (Figure 1.21).

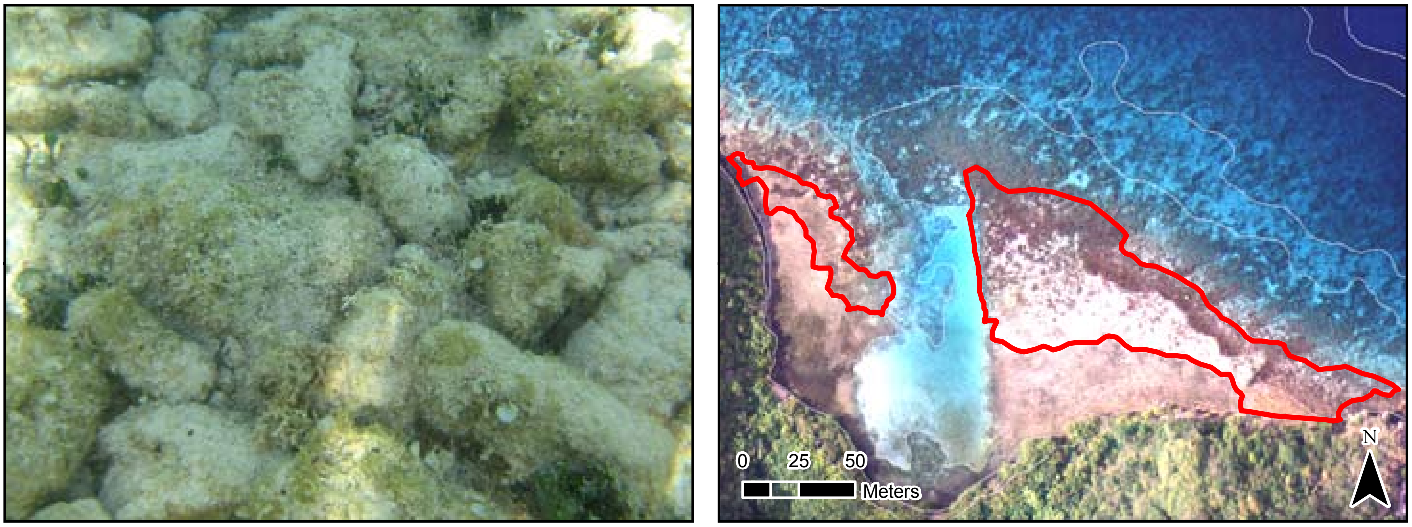


Figure 1.21. Depictions of inshore *Reef Rubble* structure behind a reef crest on St. John's East End. Red polygons outline the features on orthophotography.

Rhodoliths (17)
Aggregation of cylindrical, discoidal, or irregular shaped calcareous nodules averaging approximately 6 cm in diameter. These unattached fragments are colonized by successive layers of coralline red algae. Commonly found in offshore topographic depressions (Figure 1.22).

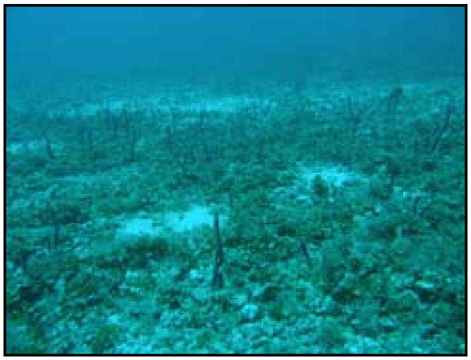


Figure 1.22. Typical rhodolith bed off the south shore of St. John characterized by growth of fleshy macroalgae and sponges.

<u>Unconsolidated Sediment</u> (2)
Areas of the seafloor consisting of small particles (<.25 m) with less than 10% cover of large stable substrate. Detailed structure classes of softbottom include *Sand, Mud,* and *Sand with Scattered Coral and Rock*.

Sand (18)
Coarse sediment typically found in areas exposed to currents or wave energy (Figure 1.23). Particle sizes range from 1/16 – 256 mm, including pebbles and cobbles (Wentworth 1922).

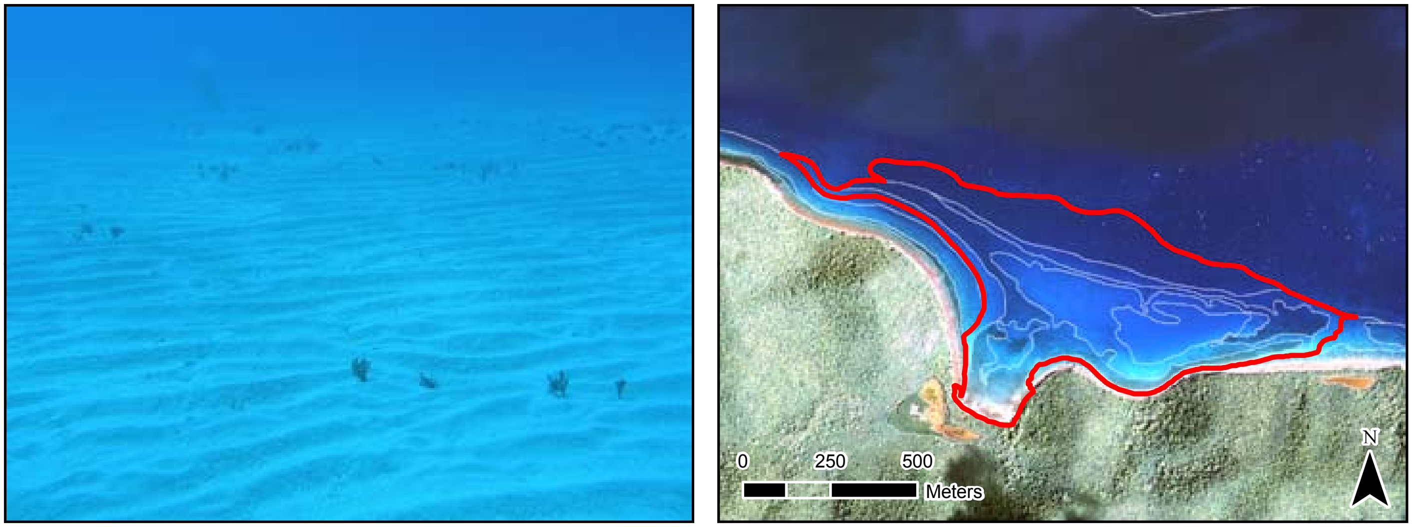


Figure 1.23. Depictions of *Sand* as a structure on the northeast shore of St. John. The overhead representation described by a red polygon includes Sand with no biological cover (lighter), as well as with seagrass and algae (darker).

Mud (19)
Fine sediment often associated with river discharge and build-up of organic material in areas sheltered from high-energy waves and currents (Figure 1.24). Particle sizes range from <1/256 – 1/16 mm (Wentworth 1922).

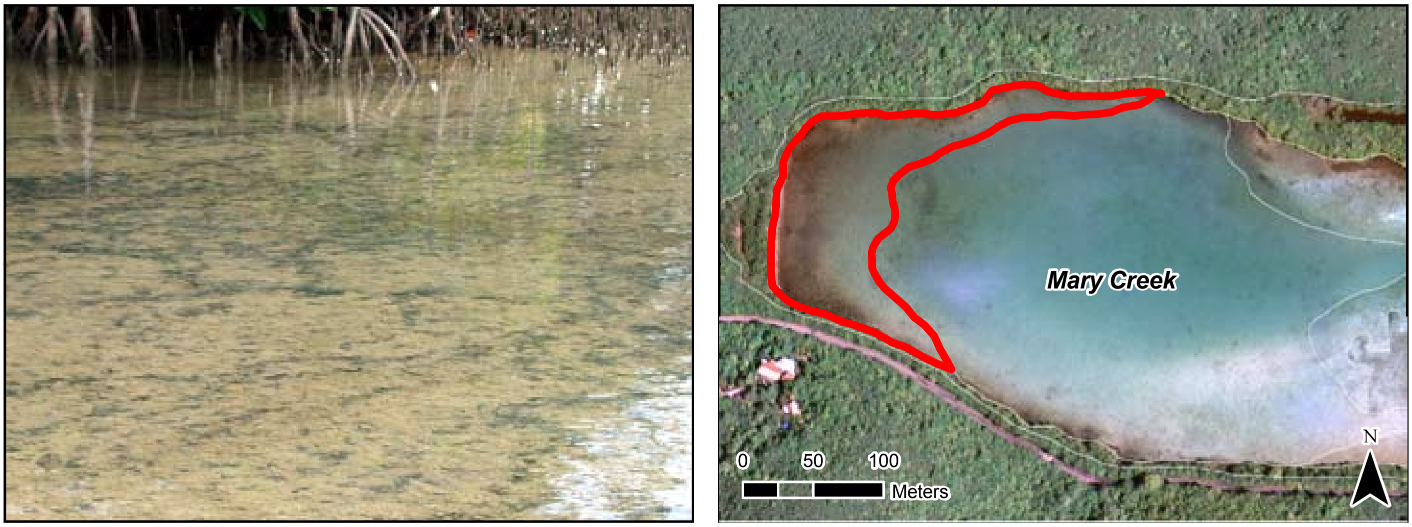


Figure 1.24. Depictions of *Mud* as a structure in the back of Mary Creek. A red polygon outlines the feature on orthophotography.

Sand with Scattered Coral and Rock (20)
Primarily sand bottom with scattered rocks or small, isolated coral heads that are too small to be delineated individually (i.e., smaller than individual patch reef) (Figure 1.25). If the density of small coral heads is greater than 10% of the entire polygon, this structure type is described as *Aggregated Patch Reefs*.

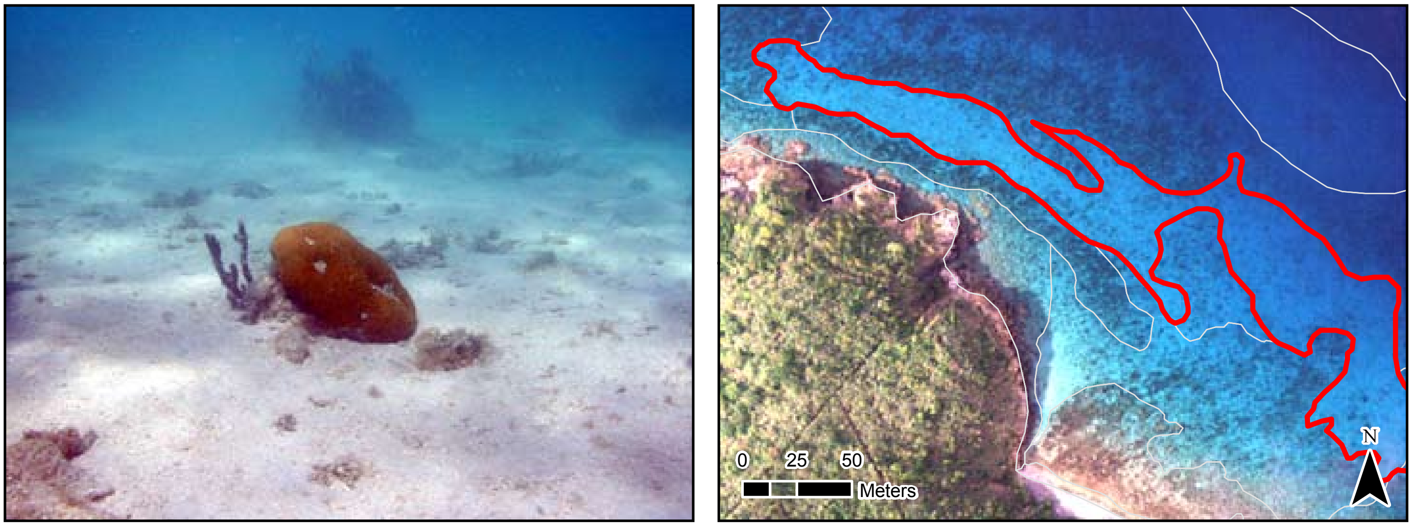


Figure 1.25. Depictions of *Sand with Scattered Coral and Rock* structure near East End Bay. Notice that coral aggregations and rock are either too small or sparse to be delineated as *Aggregated Patch Reefs*. A red polygon outlines the feature on orthophotography.

<u>**Other Delineations**</u> (3)
Any other type of structure not classified as *Coral Reef and Hardbottom* or *Unconsolidated Sediment*. Usually related to the terrestrial environment and/or anthropogenic activity. Detailed structure classes include *Land* and *Artificial*.

Land (21)
Terrestrial features at or above the spring high tide line.

Artificial (22)
Man-made habitats such as submerged wrecks, large piers, submerged portions of rip-rap jetties, and the shoreline of islands created from dredge spoil (Figure 1.26).

Unknown (9)
Major structure indistinguishable due to turbidity, cloud cover, water depth, or other interference with an optical signature of the seafloor.

Unknown (99)
Detailed structure indistinguishable due to turbidity, cloud cover, water depth, or other interference with an optical signature of the seafloor.

Figure 1.26. Representation of *Artificial* structure (outlined in red on orthophotography) at the docks in Cruz Bay.

1.4 BIOLOGICAL COVER CLASSES

Eighteen distinct and non-overlapping biological cover classes were identified that could be mapped through visual interpretation of remotely sensed imagery. Cover classes refer only to the dominant biological component colonizing the surface of the feature and do not address location (e.g., on the shelf or in the lagoon) or structure type. Habitats or features that cover areas smaller than the MMU were not considered. The cover types are defined in a collapsible hierarchy ranging from eight major classes (*Algae, Seagrass, Live Coral, Mangrove, Coralline Algae, No Cover, Unclassified* and *Unknown*), combined with a modifier describing the distribution of the dominant cover type throughout the polygon (*10%-<50%, 50%-<90%,* and *90%-100%*).

It is important to reinforce that the modifier represents a measure of the level of patchiness of the biological cover at the scale of delineation and not the density observed by divers in the water. For example, a seagrass bed can be described as covering 90%-100% of a given polygon, but may have sparse densities of shoots when observed by divers. Figure 1.27 aids interpreter's visual estimation of patchiness in assigning percent cover.

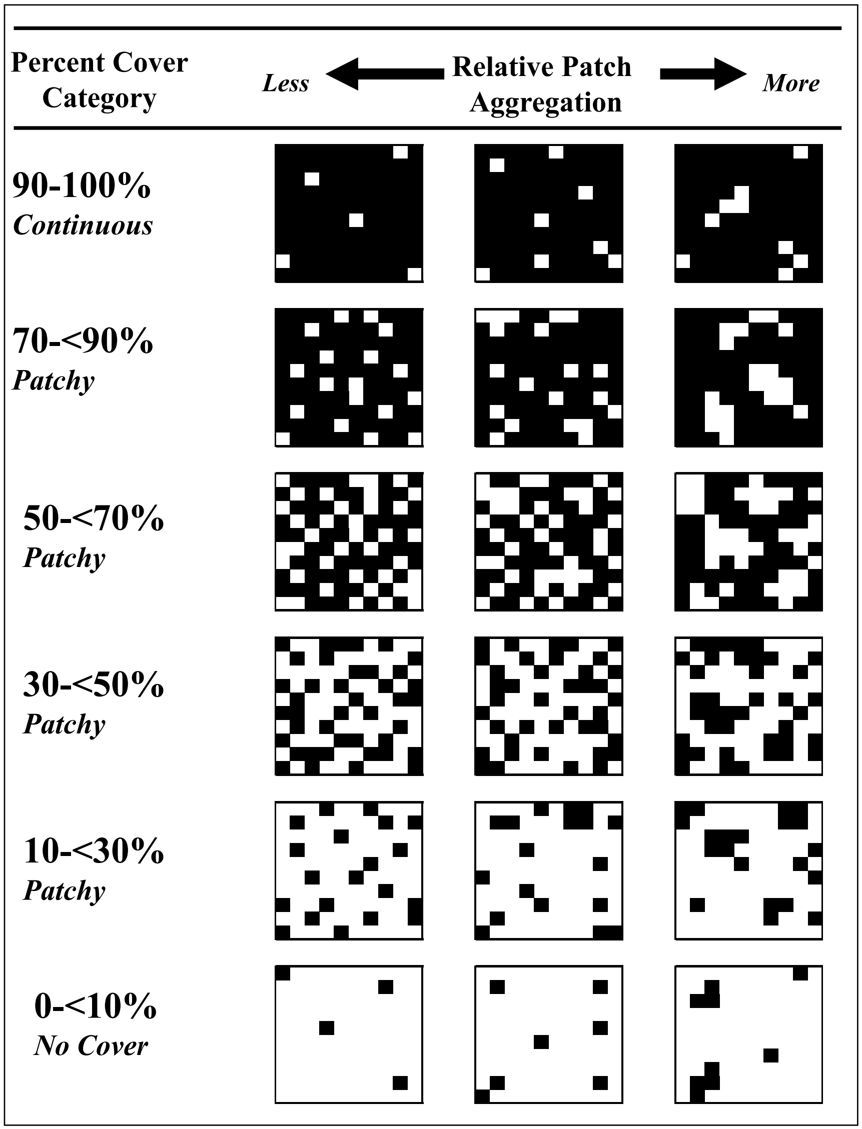


Figure 1.27. Guidance chart to understand visual interpreter's estimation of patchiness in assigning percent cover. Note that each large square denotes a minimum mapping unit.

Major Cover

Algae (1)

Substrates with 10% or greater distribution of any combination of numerous species of red, green, or brown algae. May be turf, fleshy or filamentous species. Occurs throughout many zones, especially on hardbottoms with low coral densities and softbottoms in deeper waters of the *Bank/Shelf* zone (Figure 1.28).

Figure 1.28. Depictions of *Algae* dominated habitats. Underwater pictures illustrate the different algal covers on soft and hardbottoms. A red polygon outlines the feature on orthophotography.

Seagrass (2)

Habitat with 10% or more of the mapping unit dominated by any single species of seagrass (e.g. *Syringodium* sp., *Thalassia* sp., and *Halophila* sp.) or a combination of several species (Figure 1.29).

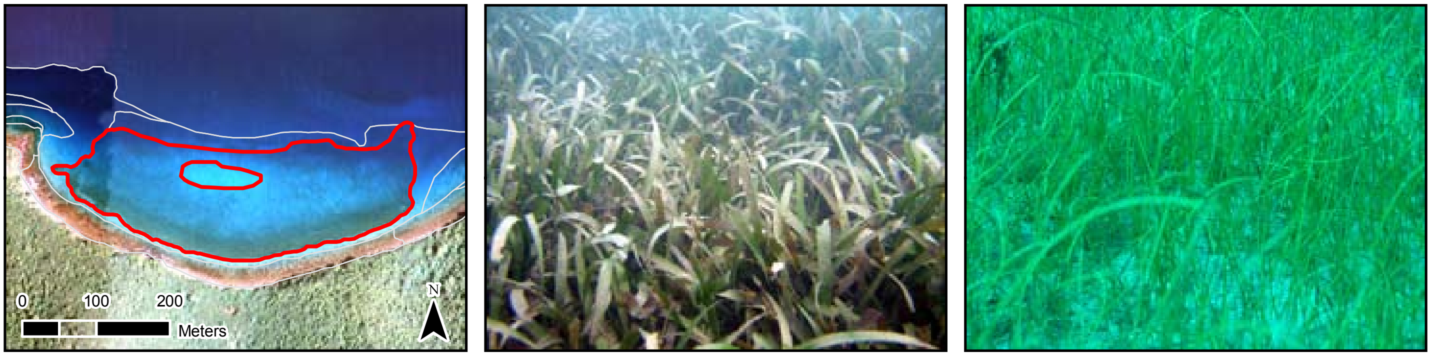


Figure 1.29. Extensive *Seagrass* beds, such as that east of Leinster Point, cover softbottoms around the island. Turtle Grass (*Thalassia testudinum*) (left) and Manatee Grass (*Syringodium filiforme*) (right) are both common. A red polygon outlines the feature on orthophotography.

Live Coral (3)

Substrates colonized with 10% or greater live reef building corals and other organisms including scleractinian corals (e.g., *Acropora* sp.) and octocorals (e.g., *Briareum* sp.) (Figure 1.30).

Figure 1.30. In some instances, *Live Coral* may be the dominant biological cover on St. John's habitats. Underwater pictures display both homogenous octocoral and scleractinian coral dominated environments. A red polygon outlines the feature on orthophotography.

Mangrove (4)

This habitat is comprised of semi-permanently, seasonally or tidally flooded coastal areas occupied by any species of mangrove (Figure 1.31). Mangrove trees are halophytes; plants that thrive in and are especially adapted to salty conditions. In the Virgin Islands there are three species of mangrove trees: red mangrove (*Rhizophora mangle*), black mangrove (*Avicennia germinans*), and white mangrove (*Laguncularia racemosa*); another tree, buttonwood (*Conocarpus erectus*) is often associated with the mangrove formation. Red mangrove grows at the water's edge and in the tidal zone. Black mangrove and white mangrove grow further inland in areas where flooding occurs only during the highest tides. Generally found in areas sheltered from high-energy waves. This habitat type is usually found in the *Shoreline Intertidal* zone.

Figure 1.31. Red mangroves (*Rhizophora mangle*) cover much of St. John's sheltered coastlines (left), while extensive mangrove complexes develop in low-lying areas inland from the shoreline (right). Red polygons outline the features on orthophotography.

Coralline Algae (5)

An area with 10% or greater coverage of any combination of numerous species of encrusting or coralline algae (Figure 1.32). May occur along reef crest, in shallow back reef, relatively shallow waters on the bank/shelf zone, and at depth. Broad enough coverage to constitute dominant biological cover in a MMU is particularly rare in the U.S. Caribbean.

Figure 1.32. Underwater photograph of a *Coralline Algae* dominated environment.

No Cover (6)

Substrates not covered with a minimum of 10% of any of the other biological cover types. This habitat is usually found on sand or mud bottoms. Overall, *No Cover* is estimated at 90%-100% of the bottom with the possibility of some very low density biological cover (Figure 1.33).

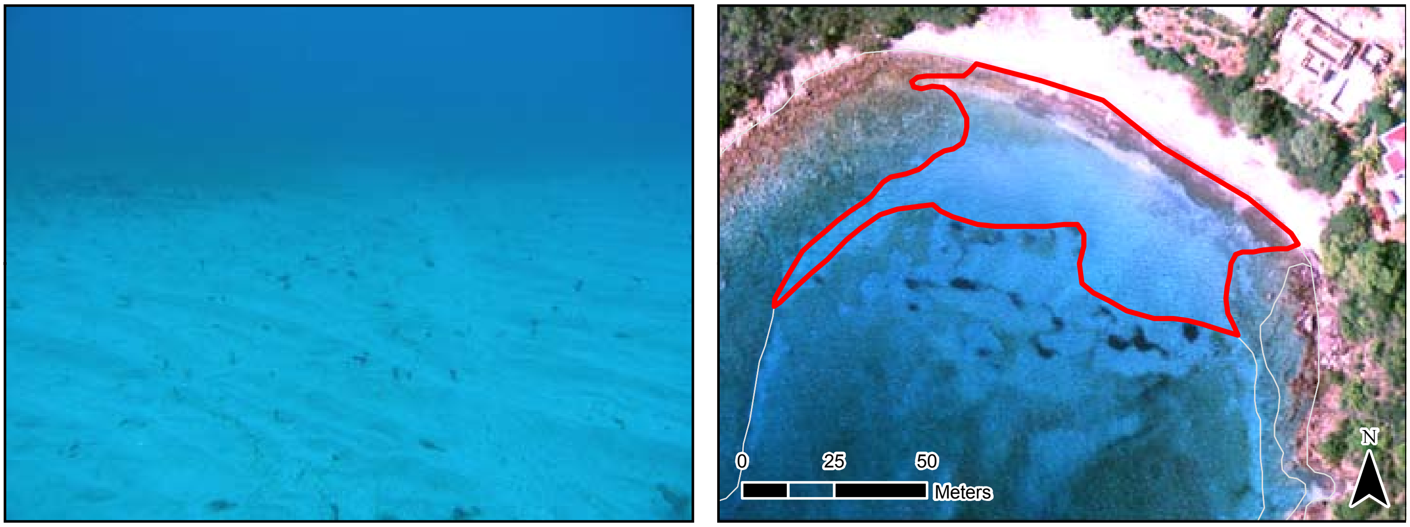


Figure 1.33. Depictions of benthic habitats with *No Cover*. Illustrated in the underwater photograph (left), *No Cover* may include some biological cover as long as it comprises less than 10% of the bottom.

Unclassified (7)

A different biological cover type, such as upland, deciduous forest, that is not included in this habitat classification scheme dominates the area. Most often used on polygons defined as *Land* with terrestrial vegetation.

Unknown (9)

Biological cover is indistinguishable due to turbidity, cloud cover, water depth, or other interference with an optical signature of the seafloor.

Percent Major Cover

10% - <50% (2)
Discontinuous cover of the major biological type with breaks in coverage that are too diffuse to delineate or result in isolated patches of a different dominant biological cover that are too small (smaller than the MMU) to be mapped as a different feature. Overall cover of the major biological type is estimated at 10% - <50% of the polygon feature (Figure 1.34).

50% - <90% (3)
Discontinuous cover of the major biological type with breaks in coverage that are too diffuse to delineate or result in isolated patches of a different dominant biological cover that are too small (smaller than the MMU) to be mapped as a different feature. Overall cover of the major biological type is estimated at 50% - <90% of the polygon feature (Figure 1.34).

90% - 100% (4)
Major biological cover type with nearly continuous (90-100%) coverage of the substrate (Figure 1.34). May include areas of less than 90% major cover on 10% or less of the total area that are too small to be mapped independently (less than the MMU).

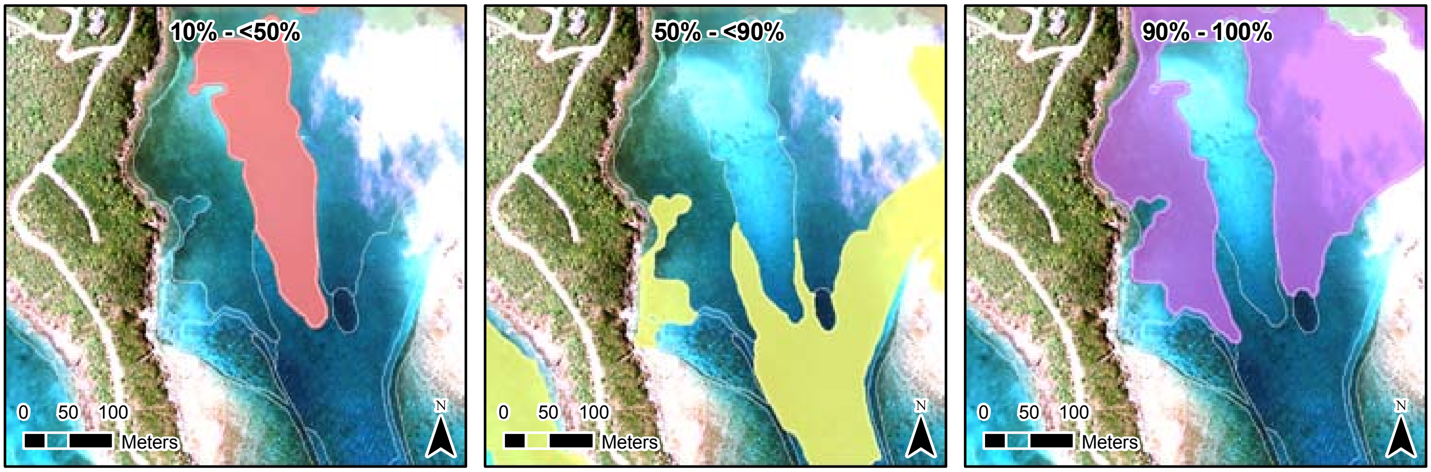


Figure 1.34. Representation of the three percent major cover modifiers (10% - <50%, 50% - <90%, 90% - 100%) using a seagrass bed in Fish Bay as an example. Each zone is depicted in color on the respective map.

Not Applicable (5)
An estimate of percent cover is not appropriate for this particular major biological cover class. Regularly accompanies the use of *Unclassified* as the major biological cover.

Unknown (9)
Percent estimate of the biological cover is indistinguishable due to turbidity, cloud cover, water depth, or other interference with an optical signature of the seafloor.

1.5. LIVE CORAL COVER CLASSES

Four distinct and non-overlapping percent live coral classes were identified that can be mapped through visual interpretation of remotely sensed imagery. This attribute is an additional biological cover modifier used to maintain information on the percent cover of live coral, both scleractinian and octocorals (Figure 1.35), even when it is not the dominant cover type. In order to provide resource managers with additional information on this cover type of critical concern, four range classes were used (*0% - <10%, 10% - <50%, 50% - <90%,* and *90% - 100%*). Hardbottom features are classified into these range classes based on the amount of combined scleractinian and octocoral present in a polygon. Distinction of scleractinian coral versus octocoral was limited by the current state of remote sensing technology and could not be separated in the *Live Coral Cover* modifier.

Figure 1.35. Both scleractinian and octocorals are considered when defining live coral cover. Typical corals of St. John include the scleractinian boulder coral (*Montastraea annularis*) and several octocorals including sea fans (*Gorgonia sp.*).

Unlike the biological cover modifier, live coral cover describes the percent coverage on hardbottom features at the observed fine-scale (i.e., diver scale), not the distribution at the scale of delineation. For this reason, extensive *in situ* data is critical to correct attribution of the live coral cover modifier. The observed fine-scale used for live coral cover assessment was approximately 1 m to 3 m off the bottom feature and its associated field of view. As a result of these varying scales of interpretation, the percent biological cover and percent live coral cover modifiers are not additive properties within the same mapping unit. In many cases, they will sum to greater than 100%. For example, an aggregate reef can have continuous (90%-100%) cover of algae throughout a mapping unit, as well as 10%-50% density of coral at the fine-scale. It is important to note that *Percent Coral Cover* refers only to the hardbottom component of any mapped polygon. For instance, an area of sand with some small scattered coral heads in it could be classified as *10% - <50%* live coral cover even though 90% of the polygon is bare sand.

0% - <10% (1)
Live coral cover of less than 10% of hardbottom substrate at a scale several meters above the seafloor (Figure 1.36).

10% - <50% (2)
Live coral cover between 10% and 50% of hardbottom substrate at a scale several meters above the seafloor (Figure 1.37).

50% - <90% (3)
Live coral cover between 50% and 90% of hardbottom substrate at a scale several meters above the seafloor.

90% - 100% (4)
Continuous live coral consisting of 90% or greater cover of the hardbottom substrate at a scale several meters above the seafloor.

Not Applicable (5)
An estimate of percent live coral cover is not appropriate for this particular feature. Only occurs in areas describing the terrestrial environment.

Unknown (9)
Percent estimate of coral cover is indistinguishable due to turbidity, cloud cover, water depth, or other interference with an optical signature of the seafloor.

Figure 1.36. An example of the presence of live coral in the 0% - 10% cover range.

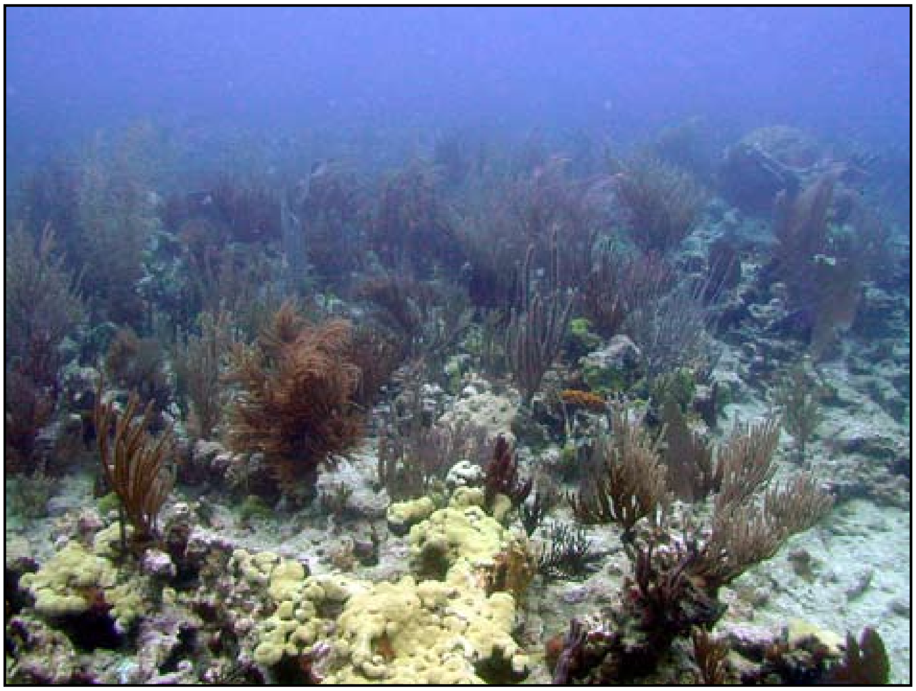


Figure 1.37. An illustration of live coral, primarily gorgonian, in the 10% - 50% cover range.

LITERATURE CITED

Battista, T.A., Costa, B.M., and S.M. Anderson, S.M. 2007a. Shallow-Water Benthic Habitats of the Main Eight Hawaiian Islands (DVD). NOAA Technical Memorandum NOS NCCOS 61, Biogeography Branch. Silver Spring, MD.

Battista, T.A., Costa, B.M., and S.M. Anderson, S.M. 2007b. Shallow-Water Benthic Habitats of the Republic of Palau. NOAA Technical Memorandum NOS NCCOS 59, Biogeography Branch. Silver Spring, MD.

Kendall, M.S., C.R. Kruer, K.R. Buja, J.D. Christensen, M. Finkbeiner, R.A. Warner and M.E. Monaco. 2001. Methods Used to Map the Benthic Habitats of Puerto Rico and the U.S. Virgin Islands. NOAA Technical Memorandum NOS NCCOS CCMA 152. Silver Spring, MD.

Wentworth, C.K. 1922. A Scale of Grade and Class Terms for Clastic Sediments. Journal of Geology. 30 (5): 377-392.

CHAPTER 2: BENTHIC HABITAT MAP CREATION

Figure 2.1. Blue Chromis (*Chromis cyanea*) aggregate over a mixed hardbottom of hydrocorals, octocorals and scleractinian corals.

Benthic habitat maps of the nearshore marine environment of St. John, U.S. Virgin Islands were created through visual interpretation of remotely sensed imagery. Remotely sensed imagery, including color orthophotography and IKONOS satellite imagery, proved to be an excellent source from which to derive the location, extent and attributes of marine habitats. NOAA scientists were able to accurately and reliably delineate the boundaries of features on digital imagery using a Geographic Information System (GIS) and a custom extension to ArcGIS 9.3 that enabled easy delineation and attribution of bottom features. Field investigations were conducted from small marine vessels in order to ground validate the spectral signature created by the myriad submerged features in the marine environment (Figure 2.1). Once digital maps were produced, experts with local knowledge of the coral reef ecosystem of St. John were consulted at an on-site workshop and their feedback was incorporated into the final maps. Through this process, natural resource managers and researchers are provided with spatially and thematically accurate maps of marine features and their ecological characteristics.

2.1 GENERAL MAPPING APPROACH

NOAA Biogeography Branch's approach to shallow-water benthic habitat mapping of coral reef ecosystems was a six-step process:

1. Imagery Acquisition – The first step in map creation was the acquisition and processing of a comprehensive dataset of remotely sensed imagery. All imagery was geo-positioned to ensure acceptable spatial accuracy in the mapping product. In the case of St. John, two separate data types were used (color orthophotography and IKONOS satellite imagery) in order to capture the full mappable extent using remote sensing techniques.

2. Habitat Boundary Delineation – A first draft of the benthic habitat map was generated by delineating all features that could be identified by visual inspection of the remotely sensed imagery. During the creation of this first draft, the interpreter placed discrete points on the map that were difficult to distinguish and that warranted further field investigation. These sites were labeled as "ground validation" positions.

Figure 2.2. U.S. National Park Service vessel *Acropora* was used to conduct field work in support of habitat map development.

3. Ground Validation – NOAA field scientists explored the ground validation locations with a suite of assessment techniques depending on the conditions at each site. A combination of underwater video, free diving, snorkeling and surface observations were used to survey the ecological characteristics at each location (Figure 2.2). This information was analyzed and the initial maps were edited to generate a second draft map improved by the field observations.

4. Expert Review – The second draft map was then reviewed by local marine biologists, coral reef scientists and resource managers at a one-day workshop in Cruz Bay, St. John. Comments were integrated into the map products to generate a final draft map.

5. Accuracy Assessment – An independent team of NOAA scientists not associated with map creation, conducted field investigations at pre-defined locations to assess the classification accuracy of the final draft map. Locations were generated with a stratified random sampling design that allowed for a statistically rigorous assessment of map accuracy.

6. Final Products Creation – A final benthic habitat map for St. John was generated by correcting any inaccuracies revealed by the accuracy assessment. Additionally, all associated datasets, including GIS files, field video and metadata were packaged and provided to project partners and the public.

2.2 REMOTELY SENSED IMAGERY

Remotely sensed imagery is a valuable tool for natural resource managers and researchers since it provides an excellent record of the location and extent of seafloor habitats. Typically, feature detection of seafloor habitats in the U.S. Caribbean is possible from the shoreline to water depths of approximately 30 meters, depending on water clarity and sea state. Benthic habitat maps of St. John, USVI were created through visual interpretation of remotely sensed imagery. Habitat boundaries were delineated around unique signatures in the orthorectified imagery corresponding to habitat types in the classification scheme described in Chapter 1. Two different remote sensors were used to collect overhead imagery of St. John:

1. ADS40 digital photography, and
2. IKONOS multispectral satellite imagery

Digital Orthophotography

An orthophoto is remotely sensed image data in which displacement of features in the image caused by terrain relief and sensor orientation have been mathematically removed. Orthophotography combines the image characteristics of a photograph with the geometric qualities of a map. After an image has been orthorectified, visual interpreters can accurately and reliably delineate the boundaries of features in the imagery as they appear on the computer monitor using a software interface. Through this process, natural resources managers and researchers are provided with spatially accurate maps of habitats and other features visible in the imagery.

True-color digital orthophotography obtained with an ADS40 digital sensor was the primary imagery source used for delineating benthic habitats of St. John. As described in Table 2.1 imagery was obtained in September and October of 2007 to produce orthophotos with a one foot ground sample distance (GSD). Flight height was maintained at 8,650 ft above ground level throughout the acquisition effort and was collected at 30% sidelap. Imagery was collected by 3001, Inc. under contract to the U.S. Army Corps of Engineers and was later provided to NOAA for this mapping effort. 3001, Inc. reported 1:4,800 scale RMSE accuracy of 1.25 m, but NOAA calculations with known ground control locations resulted in RMSE accuracy of 2.15 m. For a more complete description of the product please see the metadata report included with the project deliverables.

Table 2.1. Acquisition dates of imagery used for creation of the benthic habitat maps. Notice the two remote sensing platforms used and the corresponding individual scene names.

	IMAGE ID	ACQUISITION DATE
Orthophotography	18064-C4-01-03	10/22/2007
	18064-C4-05-07	10/10/2007
	18064-C4-09-10	9/7/2007
	18064-C7-02-04	10/22/2007
	18064-C7-06-08	10/10/2007
	18064-C7-10-12	9/7/2007
IKONOS	304713_0000000	2/23/2000
	184799_0010000	12/26/2005
	191555_0000000	9/18/2005
	191556_0000000	9/18/2005

IKONOS Satellite Imagery

At limited locations throughout the mapping area, the digital orthophotography was not suitable for habitat delineation; in which case, IKONOS multispectral satellite imagery was used as a replacement. Four IKONOS scenes with varying acquisition dates (Table 2.1) were obtained to supplement mapping efforts. The IKONOS satellite, owned and operated by GeoEye Inc., provided commercially available panchromatic (black and white) and four-band multispectral (blue, green, red and near-infrared) imagery. The panchromatic imagery had a 1 m pixel dimension and the multispectral imagery had a 4 m pixel dimension. The IKONOS imagery was acquired in 11 km wide swaths that were mosaicked together to produce complete images covering the area of interest.

Unlike the orthophotos obtained from the U.S. Army Corps of Engineers, the IKONOS imagery required additional processing to ensure suitability for shallow-water benthic mapping. The following four processing steps were completed in order for each image and are described in detail in subsequent text:

1. Geo-positioned with satellite ephemeris data and supplemental ground control,
2. Corrected for terrain displacement,
3. Pan-sharpened, and
4. Removed sun glint.

The IKONOS imagery was purchased in National Imagery Transmission Format (NITF) with the associated Rational Polynomial Coefficients, also known as RPCs or satellite ephemeris data. When using image analysis software capable of reading NITF files and associated RPCs, the positioning error of uncorrected imagery typically approaches 15 m, but after positioning to ephemeris data, the final positioning error is reduced to only a few meters of error. Geo-referencing of the imagery was performed using PCI OrthoEngine module. The NITF IKONOS imagery were orthorectified using the Rational Functions extracted from the NITF, then further supplemented with stereo ground control point positioning using a robust polynomial math model through bundle adjustment of all the satellite scenes.

Figure 2.3. Geodetic marker from NOAA's National Geodetic Survey that was used as a ground control point.

Fixed ground features visible in the IKONOS imagery (Figure 2.3) were selected for ground control points (GCPs) to be used in geo-referencing the imagery; in other words, link the image pixels to a real world coordinate system such as Universal Transverse Mercator. NOAA scientists occupied multiple locations throughout St. John using L1 Trimble GeoXT mapping grade GPS. GPS observations were adjusted using the continuously-operating base station (VITH CORS) located in St. Thomas, USVI. NOAA obtained points with a wide distribution throughout the imagery whenever possible, as it 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. IKONOS scene *304713_0000000* presented a difficult task in fine-scale positioning efforts because it was primarily over open water where ground control points were not available. In this case, image to image tie-points were used to further co-register the imagery with other better positioned scenes. Tie points are distinct features, such as street intersections, piers, coral heads, reef edges, and bridges, which were visible in overlap areas of each image. These features were precisely aligned between scenes, thus providing exterior orientation control to co-register the scene.

Terrain displacement was corrected for in the orthrectification bundle adjustment using the U.S. Geological Survey's Digital Elevation Model (DEM) generated from airborne LiDAR data (Figure 2.4).

Figure 2.4. Oblique view of U.S. Geological Survey's Digital Elevation Model used to correct terrain displacement during orthorectification process.

PCI OrthoEngine Pansharpening module was employed to create a high-resolution color image to be used for visual interpretation by NOAA scientists. Pan-sharpening, also known as image fusion, is the concept of compiling multiple images into a composite product, which maintains the spectral signatures of the input color images while enhancing the spatial features with the input panchromatic image. It was applied to the IKONOS imagery to increase the spatial resolution of the 4 m multispectral data to the panchromatic data resolution of 1 m.

Furthermore, image enhancements were conducted on the positioned and pan-sharpened imagery to remove specular reflection from the sea surface. Reflection of solar radiation on non-flat water surfaces often results in areas of bright white sun glint in remotely sensed imagery. Typically, sun glint forms bands of white along wave edges on the windward side of nearshore environments. Sun glint can obscure bottom features and should be removed before habitat delineation. The method for removal of sun glint described in Hedley et al. (2005) was applied to the IKONOS imagery.

2.3 HABITAT BOUNDARY DELINEATION AND ATTRIBUTION

As described by BAE Systems (2007), traditional methods of stereoplotter digitizing of photo interpreted habitat classes have gradually been replaced by the increased access and functionality of GIS software for on-screen “head’s up” digitizing. GIS-based techniques have several distinct advantages, including:

- Elimination of intermediate steps required to go from hardcopy to digital maps, which reduces slight distortions in habitat boundaries,
- Enhanced productivity in map creation due to gained efficiency,
- Development of a dynamic link between habitat delineations and the associated attributes in a database, and
- Increased analytical capabilities through the use of spatial analysis routines in the GIS.

St. John’s benthic habitat map and mapping methods were developed using ESRI’s ArcGIS 9.3 (ESRI 2008) and an ArcGIS extension created by NOAA’s Biogeography Branch, the Habitat Digitizer Extension (NOAA 2009). The Habitat Digitizer Extension is a GIS tool designed to use a hierarchical classification scheme to delineate features by visually interpreting geo-referenced images. The extension allowed the interpreter to create the custom classification scheme described in Chapter 1, digitize polygons using standard ArcGIS editing tools, and attribute the features using a dialog containing the created scheme. The extension allowed for rapid delineation and attribution of polygons, which significantly improved the efficiency of map creation.

The Habitat Digitizer Extension allowed several critical digitizing parameters to be set in advance that standardized the habitat map output. The Minimum Mapping Unit (MMU) restriction was set to 1,000 m² (0.25 acre). St. John mapping efforts mark the first time NOAA coral reef ecosystem maps have been generated at an MMU of less than 4,000 m² (1 acre). This reduction was in response to the coral reef management community’s interest in having finer resolution maps to make resource management decisions with. However, there were still features visible in the imagery, such as patch reefs (Figure 2.5), which were smaller than the MMU and were not included as individual features in the map.

Figure 2.5. Many individual patch reefs were smaller than the minimum mapping unit and resulted in aggregation with other habitat classes.

Digitizing scale was set to 1:2,000 and a computer generated message informed the interpreter if polygon creation was being initiated at any other scale. The interpreter was allowed to zoom in and out to varying scales when assessing an area, but always returned to 1:2,000 before boundary delineation. Qualitative experimentation results adapted from Kendall et al. (2001) indicated that digitizing at this scale optimized the tradeoff between positional accuracy of lines and time spent digitizing. Given the higher spatial resolution of imagery and reduced MMU for St. John mapping, a reduction of digitizing scale to 1:2,000 from 1:6,000 in Kendall et al. (2001) and 1:4,000 in Battista et al. (2007) was warranted. In general, line placement conducted while zoomed in at fine 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.

Habitat boundary delineation and attribution techniques were adopted from Kendall et al (2001): Using the Habitat Digitizer, habitat boundaries were delineated around spectral signatures of particular color and texture patterns in the remotely sensed imagery that corresponded to habitat types in the classification scheme described in Chapter 1 (Figure 2.6). 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 boundary polygon. Another technique was to draw one large polygon around a feature of similar type and then split it down into smaller, more specific polygons; which was often the case with seagrass beds of varying percent covers. Each new polygon was attributed with the appropriate habitat designation according to the classification scheme. It was believed that the positional accuracy of polygon boundaries was similar to that of the source imagery since delineations were performed directly on the remotely sensed imagery.

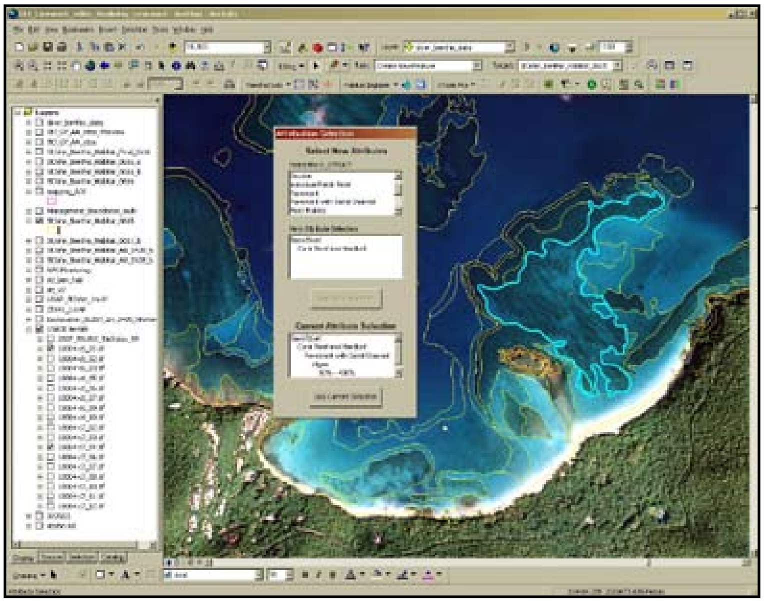


Figure 2.6. NOAA Biogeography Branch's Habitat Digitizer Extension (NOAA 2009) was used to attribute map polygons with all components of the habitat classification scheme.

Brightness, contrast and color stretching of the source imagery were often manipulated in ArcGIS 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. Additional ancillary datasets were consulted to improve the understanding of particular areas. These data types included previously-completed habitat maps (Kendall et al. 2001, Mumby 2001, Beets et al. 1986), bathymetry, nautical charts, and imagery from different time periods.

2.4 GROUND VALIDATION

The creation of high-quality benthic habitat maps required extensive field work to enhance accuracies of habitat attribution and, to a lesser degree, habitat delineation. Following the generation of an initial draft benthic habitat map, a team of NOAA field scientists explored selected locations to verify existing habitat information on the seafloor. These "ground validation" (GV) sites were targeted by the interpreter to satisfy one of the following two objectives:

1. Explore areas in the imagery with confusing or difficult to determine spectral signatures, or
2. Establish a transect moving from shore to deeper waters to better understand habitat transitions in a given area. These transects are important because a single habitat type may provide a different signature depending on water depth and sea state.

Numerous GV locations were established while the photo interpreter was generating the draft habitat map. Before field work began, a subset of these initial GV sites was reduced to only priority locations that could be completed during a two-week field mission. Geographic coordinates were extracted for these sites and uploaded into Garmin GPS 76 WAAS-enabled hand-held devices. The remaining sites were retained and were later assessed with the GV field dataset to update these omitted confusing areas where field data may have been similar.

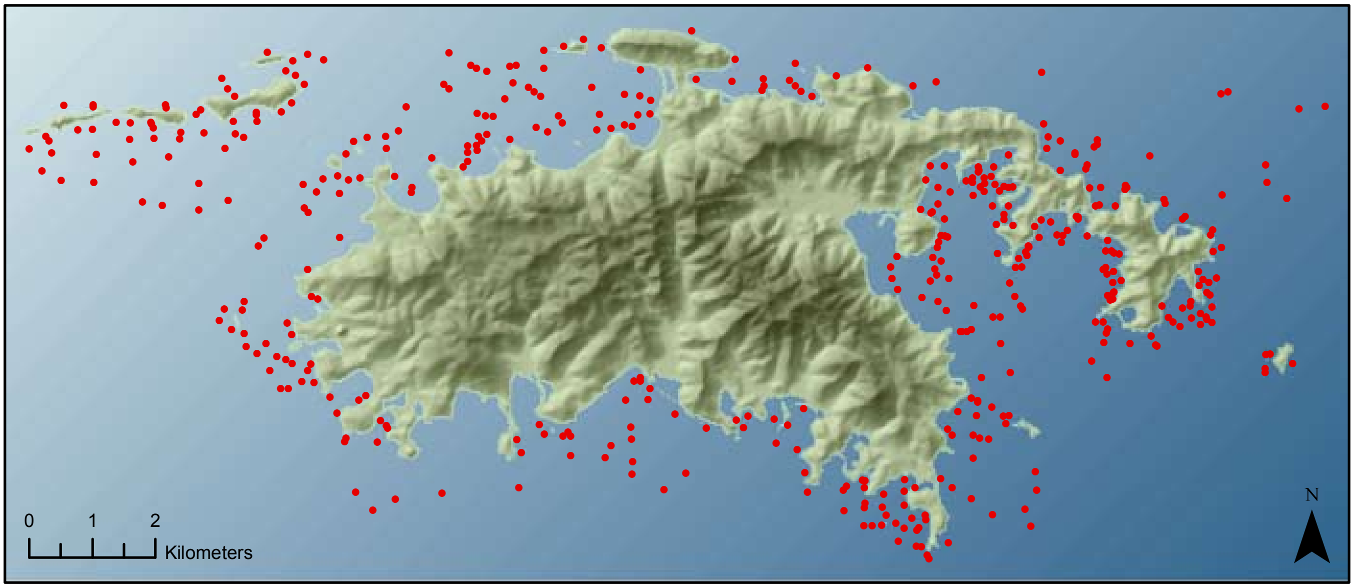


Figure 2.7. Red dots depict the location of the 444 ground validation sites visited during the mapping process to determine habitat information.

Data were collected on 444 GV sites (Figure 2.7) over a two-week field mission from January 5-16, 2009 aboard National Park Service small research vessels. At the start of every morning, the boat captain selected a general region to begin the day's work. Most often this consisted of starting in areas typically prone to more challenging sea conditions and moving to inshore, more protected areas as the day progressed. Navigating to field locations was accomplished using a Garmin GPS 76 device with the uploaded GV site coordinates. The boat captain maneuvered the vessel to within 5 m of the target location and made every effort to maintain that location without jeopardizing crew and equipment safety. Once on site, NOAA scientists would simultaneously deploy a SeaViewer Sea-Drop 950 camera and begin logging a waypoint on a Trimble GeoXT GPS receiver (Figure 2.8). The drop camera reached the bottom in approximately 5 - 10 seconds and bottom imagery was recorded to mini-digital video tapes using a Sony Walkman video recorder. The camera operator adjusted the camera position to get a downward view at approximately 2 m from the bottom and a side view of the habitat at each location. This allowed for accurate measurements of percent biological cover and a broader sense of the structure at each site. No attempt was made to standardize the amount of bottom time the camera would capture in order to avoid the confusion of viewing multiple habitat types. In fact, it was often advantageous for the vessel to drift across habitat transitions, thus allowing the interpreter to understand the ecotone at many locations. Position logging in the

Figure 2.8. Operation of field equipment, including the underwater video camera and GPS receivers.

Trimble receiver was optimized to plot every epic (i.e., position) along a waypoint. This allowed for accurate depiction of the vessels drift line at a single GV location and was utilized in subsequent assessment of the data.

While the video camera was capturing bottom imagery, an observer viewed the video real-time on a Panasonic Toughbook aboard the survey vessel. They categorized each site according to the levels of the habitat classification scheme: major and detailed geomorphological structure, major biological cover, percent major biological cover and percent coral cover. Data was entered into a custom data dictionary generated in Trimble Pathfinder Office software and loaded onto the Trimble data logger. Field sheets representing an exact replicate of the digital data dictionary were also populated as back-up to the digital classification information.

The preceding description of field data collection was the preferred method, as it provided the most reliable data. Of the 444 sites occupied during ground validation, 427 were assessed with the underwater drop camera. However, environmental conditions and boat safety issues, such as close proximity to shore, precluded 17 sites from being assessed with this preferred method. In those cases, several other field assessment methods were used, including snorkeling, free diving and visual inspection from the vessel. Field scientists documented these GV sites with digital pictures to maintain a visual record of the location.

Water-proof field maps illustrating the draft habitat map and source imagery were used on-board the survey vessel to facilitate comparison of signatures in the imagery to actual habitats at each site. In many cases, suggestions on boundary delineation and habitat classifications were made directly on the field maps with permanent marker. For instance, if a fringing mangrove (Figure 2.9) area was passed en route to the next GV location, a note was drawn on the map depicting an approximate boundary. This effort provided even more information to improve the draft map in addition to the GV sites.


Figure 2.9. Presence of fringing mangroves were often noted from the survey vessel on field maps.

Trimble Pathfinder Office software was used to post process and differentially correct the raw GPS data to the Continually Operating Reference System (CORS) station at St. Thomas, U.S. Virgin Islands (VITH). Precise GPS positions and the associated classification data were viewed in a GIS to enhance the accuracy of the draft benthic habitat map. Polygon boundaries and habitat classifications were revised where field data necessitated changes.

2.5 EXPERT REVIEW

Before the draft map was considered final and ready for accuracy assessment, a panel of local experts reviewed the maps at an Expert Review Workshop. Local marine biologists, coral reef scientists and resource managers assembled at National Park Service facilities in Cruz Bay, St. John for a one-day workshop on March 31, 2009. NOAA produced tabloid-sized hardcopy atlases of the entire mapped area for the review. Experts were asked to comment on the habitat classification scheme, habitat boundary delineations and polygon attributes of the draft maps in order to improve the quality and accuracy of the final map products. Table 2.2 shows the list of attendees and their affiliation.

Table 2.2. Expert review workshop participants and their affiliations.

Attendee Name	Affiliation
Rafe Boulon	National Park Service – St. John
Jeff Miller	National Park Service – St. John
Caroline Rodgers	U.S. Geological Survey – St. John
Ron Hill	NOAA Fisheries – Galveston
Tyler Smith	University of the Virgin Islands
Jeremiah Blondeau	University of the Virgin Islands
Mark Monaco	NOAA Biogeography Branch – Silver Spring
Adam Zitello	NOAA Biogeography Branch – Silver Spring

The workshop resulted in the following key recommendations:

- Attendees agreed that assigning a percent live coral modifier to each mapping unit was useful,
    - Change attribute name from Coral Density to Coral Cover to avoid confusion with the more traditional use of density

- Concern was expressed over the combining of scleractinian and octocorals when assigning the Coral Cover modifier,
    - It was explained that distinguishing between these coral types using photo-interpretation is quite difficult, if not impossible
    - NOAA Biogeography committed to exploring the feasibility of distinguishing between the coral types, possibly using *in situ* monitoring data
    - However, it was agreed that this information was not to be part of the products of this effort

- Possibly include a new structure type that describes the transition between aggregate reef and aggregated patch reefs,
    - In order to describe aggregate reefs with sand patches intermixed that are smaller than the MMU (dis continuous in nature, but still constituting a single feature)
    - A suggested type name: Aggregated Coral Heads

- Improve habitat classification scheme manual,
    - Define polygon patchiness and how it relates to percent cover
    - Should include more photographs of structure and biological covers to improve understanding beyond text descriptions (Figure 2.10)
    - Provide flow diagram of how the classification process is conducted for an example mapping unit
    - In text descriptions, include actual site locations in St. John where structure and cover types exist as illustrations for those familiar with St. John

- Avoid use of terms hard and soft coral, instead use scleractinian and octocoral

- Explore explicitly linking *in situ* monitoring data with the final map product

- As part of the final report, compare the new map to the previous NOAA map for St. John
    - Possibly in the number of acres of certain categories, polygons and other critical map statistics

- The atlas maps were difficult to utilize for review
    - Frames should be adjusted so that breaks minimize interruption of features
    - Low print quality made it difficult to read the colors on the maps, especially with blue background
    - A possible solution would be to use solid colors instead of transparency

Figure 2.10. Mangroves are a common biological cover along the protected coastlines of St. John.

2.6 GIS QUALITY CONTROL

All GIS deliverable products generated throughout the mapping process were closely examined for error. Particular attention was given to polygon geometry of the benthic habitat map and attribution of both the habitat map and GV and AA field GIS datasets. Multipart, sliver and void polygons were all removed using standard ArcGIS Spatial Analyst tools. Two custom ArcGIS extensions were employed to identify the following conditions:

1. Adjacency – polygons that shared a common boundary and exact attribute combination that were delineated separately (Buja 2008a)

2. Overlap – polygons sharing the same geographic space, thus violating mutual exclusion (Buja 2008b)

Errors resulting from either of these GIS routines were corrected on draft maps and eliminated in the final product.

A review of habitat boundaries by a NOAA staff member not involved in imagery interpretation concluded that all areas mapped as *Unknown* were indeed indistinguishable on the source imagery.

A visual inspection of attributes on a feature-by-feature basis was conducted to correct for any misspellings or illogical attribute combinations. These types of errors were minimal; as the use of the Habitat Digitizer Extension standardized the process of populating GIS attribute tables. In the rare instances where manual attribution was required, particular attention was given to control these processes. The aforementioned visual inspection accounted for any potential errors.

GIS data from this work were determined to be topologically clean and free of attribution errors. In addition, metadata summaries were prepared in an FGDC-compliant format for all GIS products that were supplied during final delivery (Figure 2.11).

Figure 2.11. A Southern Stingray (*Dasyatis americana*) moves across a sand and algae bottom in St. John.

LITERATURE CITED

BAE Systems. 2007. Mapping of Benthic Habitats for the Main Eight Hawaiian Islands. On Battista, T.A., Costa, B.M., and S.M. Anderson, S.M. 2007. Shallow-Water Benthic Habitats of the Main Eight Hawaiian Islands (DVD). NOAA Technical Memorandum NOS NCCOS 61, Biogeography Branch. Silver Spring, MD.

Battista, T.A., B.M. Costa, and S.M. Anderson, S.M. 2007. Shallow-Water Benthic Habitats of the Republic of Palau. NOAA Technical Memorandum NOS NCCOS 59, Biogeography Branch. Silver Spring, MD.

Beets, J., L. Leewand, and E.S. Zullo. 1986. Marine community descriptions and maps of bays within the Virgin Islands National Park/Biosphere Reserve. Biosphere Reserve Research Report Number 2, National Park Service. 118 pp.

Buja, K. 2008a. (Online). Find adjacent features. ESRI Support Center. http://arcscripts.esri.com/details.asp?dbid=15805. Accessed March 2009.

Buja, K. 2008b. (Online). Find overlapping polygons. ESRI Support Center. http://arcscripts.esri.com/details.asp?dbid=15198. Accessed March 2009.

ESRI. 2008. ArcGIS 9.3. Redlands, CA: Environmental Systems Research Institute. Available: http://www.esri.com/.

Hedley, J.D., A.R. Harborne and P.J. Mumby. 2005. Simple and robust removal of sun glint for mapping shallow-water benthos. International Journal of Remote Sensing 26(10): 2107 – 2112.

Kendall, M.S., C.R. Kruer, K.R. Buja, J.D. Christensen, M. Finkbeiner, R.A. Warner and M.E. Monaco. 2001. Methods Used to Map the Benthic Habitats of Puerto Rico and the U.S. Virgin Islands. NOAA Technical Memorandum NOS NCCOS CCMA 152. Silver Spring, MD.

Mumby, P. 2001. Habitat Mapping of St. Thomas and St. John. University of Exeter, UK. On Khaled bin Sultan Living Oceans Foundation: http://www.livingoceansfoundation.org/. [Accessed December 2008].

NOAA. 2009. Habitat Digitizer Extension. NOAA Biogeography Branch. Silver Spring, MD. Available: http://ccma.nos.noaa.gov/products/biogeography/digitizer/welcome.html.

Buja, K. 2008a. (Online). Find adjacent features. ESRI Support Center. http://arcscripts.esri.com/details.asp?dbid=15805. Accessed March 2009.

Buja, K. 2008b. (Online). Find overlapping polygons. ESRI Support Center. http://arcscripts.esri.com/details.asp?dbid=15198. Accessed March 2009.

ESRI. 2008. ArcGIS 9.3. Redlands, CA: Environmental Systems Research Institute. Available: http://www.esri.com/.

Kendall, M.S., C.R. Kruer, K.R. Buja, J.D. Christensen, M. Finkbeiner, R.A. Warner and M.E. Monaco. 2001. Methods Used to Map the Benthic Habitats of Puerto Rico and the U.S. Virgin Islands. NOAA Technical Memorandum NOS NCCOS CCMA 152. Silver Spring, MD.

Mumby, P. 2001. Habitat Mapping of St. Thomas and St. John. University of Exeter, UK. On Khaled bin Sultan Living Oceans Foundation: http://www.livingoceansfoundation.org/. [Accessed December 2008].

NOAA. 2009. Habitat Digitizer Extension. NOAA Biogeography Branch. Silver Spring, MD. Available: http://ccma.nos.noaa.gov/products/biogeography/digitizer/welcome.html.

CHAPTER 3: ASSESSMENT OF CLASSIFICATION ACCURACY

A comprehensive assessment was conducted to evaluate the thematic accuracy of the St. John benthic habitat map. Thematic accuracy was characterized for major and detailed geomorphological structure, major and detailed biological cover, and percent coral cover classifications (see Chapter 1 for classification scheme description).

3.1. FIELD DATA COLLECTION

Target locations for the accuracy assessment (AA) procedure were determined by an iterative, GIS-based, stratified random sampling technique to ensure that all bottom classifications would be assessed. Based on guidelines from other recent accuracy assessment analyses (Battista et al. 2007a, 2007b), a minimum of 25 points were assigned to each of the 13 detailed structure classes within the draft habitat map. An additional 175 points were distributed based on the proportion of area of each detailed structure class in the map. Points were randomly placed within each class using Hawth's Analysis Tools (Beyer 2004) in ArcGIS at a minimum distance of 50 m apart. The minimum distance was selected to ensure there would be no overlap between surveys. No buffer from polygon edges was used. Next, the number of points that fell within each detailed primary cover class was calculated. Where necessary, additional points were randomly added and re-distributed from classes with many points to ensure that there was a minimum of 25 points within each detailed cover class, with the exception of live coral, due to the small number of polygons in the draft map that received this classification. These steps resulted in a total of 520 sample target locations.

Data were collected over a two-week field mission from February 9-20, 2009. Sample locations were navigated to using a hand-held Garmin 76 WAAS-enabled GPS unit. Underwater video from a SeaViewer Sea-Drop 950 camera was taken at each site, provided the location was safely accessible by the survey vessel (Figure 3.1). A weight was tied to the bottom of the camera to help lower the camera to the bottom, and the camera operator adjusted the camera position to get a downward and side view of the habitat at each location. Video length depended on the habitat type and vessel drift and ranged from approximately 30 seconds to two minutes. Videos of large, homogeneous sand habitats were generally short while heterogeneous hardbottom habitats, especially edges, were typically longer. While the video was being recorded, GPS waypoints were recorded on board the vessel using a Trimble GeoXT GPS receivers. At least three epics (i.e., points) were logged at each site, but this number was generally much higher and depended on the satellite signal, length of the video clip, current speed and vessel drift. This resulted in a string of epics that tracked boat position at each site. An observer categorized each site according to the video for each level of the map classification scheme: major/detailed geomorphological structure, major/detailed biological cover, and percent coral. Data was entered into a custom data dictionary on the Trimble data logger and recorded on waterproof data sheets. Videos were recorded to tape using a Sony Walkman video recorder, and converted to digital video clips using Final Cut Pro software.

Figure 3.1. Picture of the field crew deploying drop camera (left) and camera approaching bottom (right).

Not all sites were accessible by survey vessel and the drop camera. Shallow, nearshore sites were surveyed by snorkel. Sites were categorized in the same way, but in lieu of drop camera video, a digital camera in an underwater housing was used to take pictures. Mangrove target locations were generally assessed from the boat after approaching the target as close as possible, and were again documented with digital pictures. In these situations, an exact GPS waypoint could not be taken at the survey site. A few targets were inaccessible using either of these methods due to high surf or unsafe sea conditions and were not surveyed. In addition, several sites that were targeted in inland mangrove lagoons were inaccessible by road and could not be surveyed. In a few cases, poor sea conditions or turbidity precluded a positive classification of the habitat, and these points were removed from the analysis. A total of 481 sites were sufficiently surveyed to be included in the accuracy assessment (Figure 3.2). An additional five survey sites were successfully surveyed, but fell outside the boundaries of the final benthic habitat map.

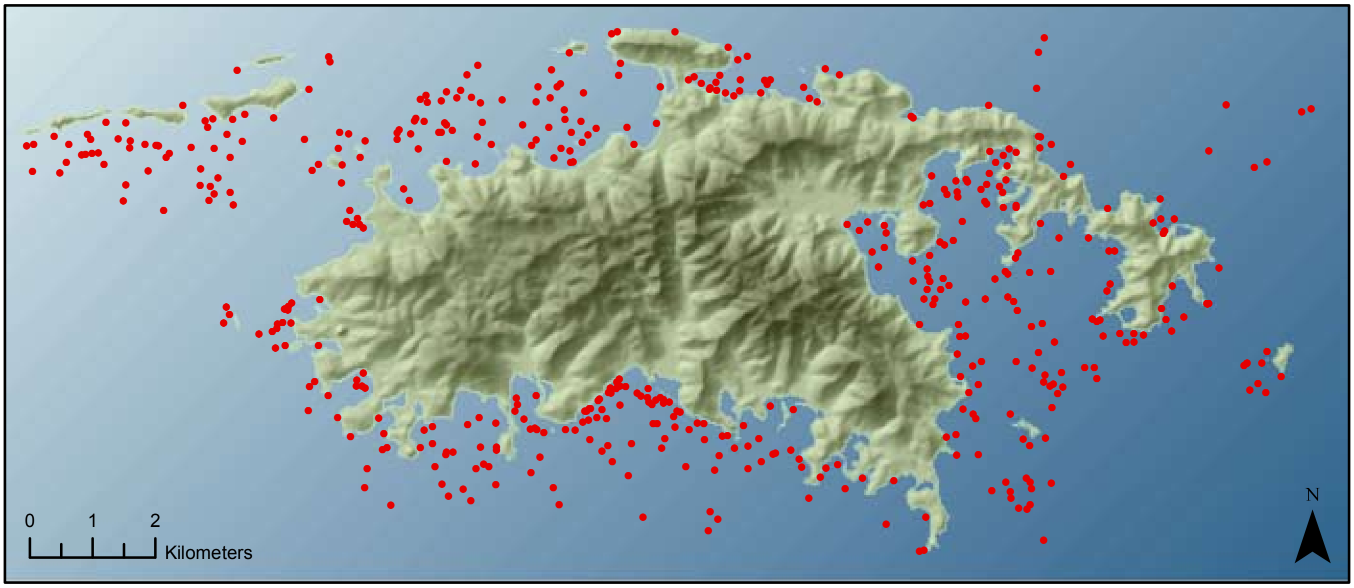


Figure 3.2. Red dots depict the location of the 481 sites visited to obtain habitat information for assessment of thematic map accuracy.

3.2. EVALUATION OF ASSESSMENT DATA

The GPS data were processed using Trimble Pathfinder software. GPS data, which were originally recorded as code phase signals, were differentially post-processed to the Continually Operating Reference System (CORS) station at St. Thomas, U.S. Virgin Islands (VITH). The true positional accuracy of individual epics was determined to be within 1 m for 96% of the points. For each survey site, individual epics were averaged to generate an "average" GPS point. The GPS data were then exported and plotted in ArcGIS along with the corresponding field notes. In most cases, the average point was a sufficient representation of the survey site; however in cases where the survey was conducted along or crossed a polygon edge, the average GPS point did not always fall into the polygon that was assessed. In these cases, the survey point was shifted to the portion of the transect and polygon that was classified (Figure 3.3). For sites where no Trimble data was collected (e.g., sites surveyed by snorkel), the target GPS point was used.

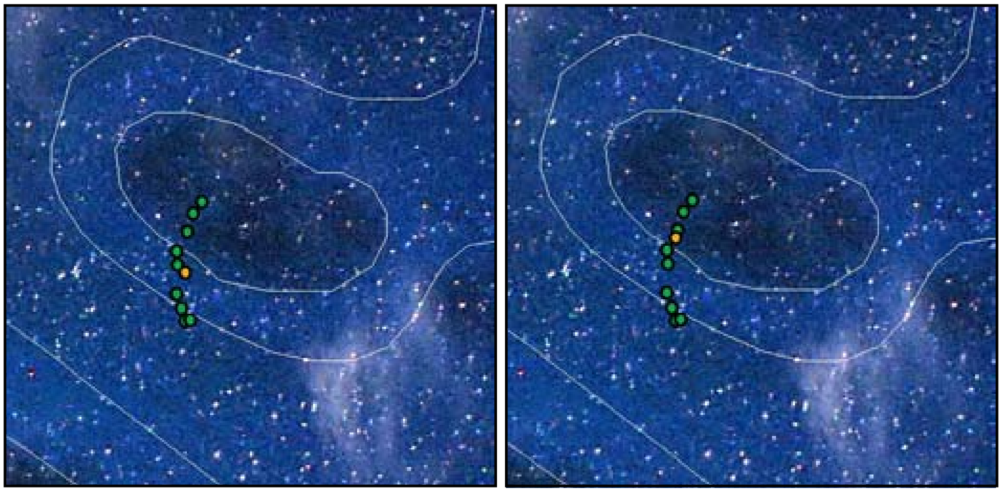


Figure 3.3. Example of case where survey track line, represented by the green points, crossed more than one habitat type/polygon. Although the "average" point (orange) fell in sand (left), the adjacent individual patch reef was the polygon that was actually assessed, therefore the point was shifted slightly north (right).

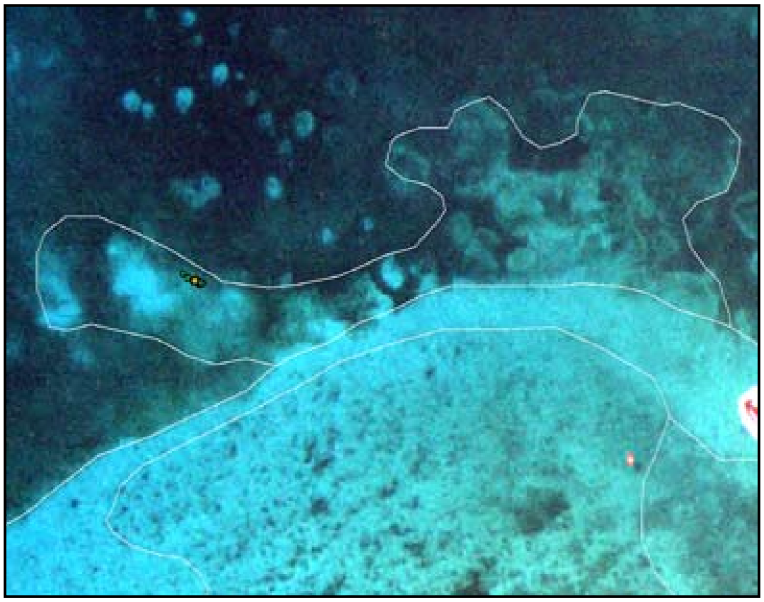


Figure 3.4. Example of case where video survey was conducted over an area of continuous seagrass, but examination of the imagery revealed that patchiness of the polygon was 50% - <90%.

Prior to analysis, each video clip and digital picture was re-analyzed and viewed in concert with the benthic habitat map overlaid on the orthophotography. It should be noted that all analysis at this stage was made by a photointerpreter independent of the scientist who created the map. Patchiness of the biological cover was assessed at the polygon level, and hence it was often necessary to adjust the classifications that were initially recorded in the field to reconcile the differences between the video and map scales. For example, a site may have been classified as continuous seagrass based on the video clip alone, but if the patchiness of the polygon was actually only 50% - <90% upon examination of the imagery, the patchiness for the survey point was changed to 50% - <90% (Figure 3.4). Similar adjustments were sometimes necessary to correctly characterize detailed structure. For example, heterogeneous hardbottom classes, such as pavement with sand channels, could not always be correctly classified from the video alone. In other cases, additional information on the position, size and shape of hardbottom features was needed to determine whether the structure should be classified as aggregate reef or a patch reef (either individual or part of an aggregated patch reef feature if below the MMU).

Following these adjustments, data were then spatially joined to the benthic habitat layer to extract the map classification for each point. Sites that differed between field notes and map classification were evaluated both in GIS and from video to determine possible source of disagreement. At this stage, additional special cases were identified that were a product of the differences in scale between the video data and imagery. For example, there were several occurrences where the survey video documented sand with no cover, but the point was located within a heterogeneous polygon that was mapped as sand with patchy *Seagrass* or *Algae*, *Sand with Scattered Coral and Rock*, or *Aggregated Patch Reefs* that could only be perceived at the broad scale of the aerial photography. For these cases, the points were only classified for structure based on both the video and imagery. Since the mapped polygon cover was not observed in the accuracy assessment video, they were not included in the assessment of biological cover.

In some cases, the patchiness of biological cover within softbottom polygons could not be determined from the imagery due to turbidity. These polygons were primarily located within Coral Bay and were mapped with advice from the expert review workshop. Accuracy assessment points that fell within these polygons were handled in two ways. First, as described above, points that would otherwise have been classified as *No Cover* were removed from the analysis of biological cover and analyzed for structure only. If algal or seagrass cover was documented in the video, these points were included for major cover (e.g., *Seagrass* or *Algae*) but their patchiness was classified as *Unknown* because it cannot be estimated from the remotely sensed imagery and they were not included in the detailed cover analysis. In total, 24 sites were excluded in the major biological cover analysis and an additional 15 sites were excluded from the detailed biological cover analysis for one of the reasons described above.

Percent coral cover was classified for both hardbottom and softbottom habitats; however it is defined as the percent coral cover on the hardbottom substrate within that polygon (see Chapter 1). If a site was determined to be located within a hardbottom polygon but no hardbottom was seen in video (e.g., *Aggregated Patch Reefs*), coral cover could not be sufficiently assessed at that site. Hence, such sites were not included in the error matrix for percent coral cover.

Following this process, 481 points were included in the accuracy assessment analysis for major and detailed structure, 457 for major biological cover, 442 for detailed biological cover, and 475 for percent coral cover.

3.3. ANALYSIS OF THEMATIC ACCURACY

The thematic accuracy of the St. John benthic habitat map was characterized in several ways from these data. Error matrices were computed for the attributes major and detailed geomorphological structure, major and detailed biological cover, and percent coral cover. Overall accuracy, producer's accuracy, and user's accuracy were computed directly from the error matrices (Story and Congalton 1986). The error matrices were constructed as a square array of numbers arranged in rows (map classification) and columns (accuracy assessment, or ground-truthed classification). The overall accuracy (P_o) was calculated as the sum of the major diagonal (i.e. correct classifications, divided by the total number of accuracy assessment samples).

The producer's and user's accuracies were calculated to characterize the classification accuracy of individual map categories. The producer's accuracy (omission/exclusion error) is a measure of how well the mapper classified a particular habitat (e.g., the percentage of times that substrate ground-truthed as sand was correctly mapped as sand). The user's accuracy (commission/inclusion error) is a measure of how often map polygons of a certain habitat type were classified correctly (e.g., the percentage of times that a polygon classified as sand was actually ground-truthed as sand). Each diagonal element was divided by the column total to yield a producer's accuracy and by the row total to yield a user's accuracy.

In addition, the Tau coefficient (T_e), a measure of the improvement of classification accuracy over a random assignment of map units to map categories (Ma and Redmond 1995), was calculated. As the number of categories increases, the probability of random agreement (P_r) diminishes, and T_e approaches P_o. Values of T_e were calculated as follows:

$$\text{Tau coefficient} = T_e = (P_o - P_r) / (1 - P_r),$$

where $P_r = 1/r$. The variance of Tau (Ma and Redmond 1995) was calculated as:

$$\text{Variance of Tau coefficient} = \sigma_r^2 = P_o(1 - P_o) / n(1 - P_r)^2$$

Confidence intervals were then calculated for each Tau coefficient at the 95% confidence level (1-α), using the following generalized form:

$$95\%\ \text{CI} = T_e \pm Z_{\alpha/2}(\sigma_r^2)^{0.5}$$

While stratification ensures adequate evaluation of all map categories, it has the undesired effect of introducing bias into the error matrix (Hay 1979; Card 1982). A minimum number of sites were targeted within each mapping category, which caused rare map categories to be sampled at a greater rate than common map categories. For example, although *Sand* habitat comprised 44% of the map area, only 23% of the target points were allocated for this habitat. Conversely, *Aggregated Patch Reefs* comprised only 1% of the map area, but received 5% of the allocated target sample points. The bias introduced by differential sampling rates was removed using the method of Card (1982), which utilizes the known map marginal proportions, i.e. the proportional areas of map categories relative to the total map area. The map marginal proportions were calculated as the area of each map category divided by the total mapped area of the St. John benthic habitat map. The map marginal proportions were also utilized in the computation of confidence intervals for the overall, producer's, and user's accuracies (Card 1982; Congalton and Green 1999). This method was also used in the recent accuracy assessment of the NOAA Florida Keys benthic habitat map (Walker and Foster 2009).

The known map marginal proportions (π_j) were computed from the GIS layer of the draft benthic habitat map for each of the four error matrices (major and detailed geomorphological structure, major and detailed biological cover), by dividing the area of each category by the total map area. Marginal proportions were not computed for the percent coral cover matrix, as this would have required an estimate of the percent hardbottom within each polygon to truly estimate the area of live coral. The map areas were exclusive to categories present in the error matrix. For the example of detailed structure category sand, π_j was 0.44 (23.3 km^2/53.4km^2). The individual cell probabilities, i.e. the product of the original error matrix cell values and π_j, divided by the row marginal (total map classifications per category), were computed for the off-diagonal elements using the following equation:

Individual cell probabilities = $\hat{P}_{ij} = \pi_j n_{ij} / n_{-j}$

The relative proportions of the cell values within a row of the error matrix were unaffected by this operation, but the row marginals were forced to the known map marginal proportions (i.e. the row total of a particular habitat now equaled the fraction of map area occupied by that habitat, instead of the total number of accuracy assessment points). The estimated true marginal proportions (p_i) were computed as the sum of individual cell probabilities down each column of the error matrix.

The π_j-adjusted overall, producer's, and user's accuracies were then computed from the new error matrix, now populated by individual cell probabilities. The values of the π_j-adjusted overall and producer's accuracies differ by design from those of the original error matrix, as they have been corrected for the areal bias introduced by the stratified random sampling protocol. The user's accuracy, in contrast, is not affected. The variances and confidence intervals of the overall, producer's, and user's accuracies were then computed from the following set of equations (Card 1982; Walker and Foster 2009):

Overall Variance = $V(\hat{P}_c) = \sum_{i=1}^{r} p_{ii}(\pi_i - p_{ii})/n_i)$

Overall Confidence Interval = CI = $\hat{P}_c \pm 2[V(\hat{P}_c)]^{1/2}$

Producer's Variance = $V(\hat{\theta}_{ii}) = p_{ii} p_i^{-4} [p_{ii} \sum_{j \neq i}^{r} p_{ij}(\pi_j - p_{ij})/n_{-j} + (\pi_i - p_{ii})(p_i - p_{ii})^2 / n_{i-j}]$

Producer's Confidence Interval = CI = $\hat{\theta}_{ii} \pm 2[V(\hat{\theta}_{ii})]^{1/2}$

User's Variance = $V(\hat{\lambda}_{ii}) = p_{ii}(\pi_i - p_{ii}) / \pi_i^2 n_i$

User's Confidence Interval = CI = $\hat{\lambda}_{ii} \pm 2[V(\hat{\lambda}_{ii})]^{1/2}$

3.4 ACCURACY ASSESSMENT RESULTS AND DISCUSSION

Major Geomorphological Structure

Error matrices for major geomorphological structure are displayed in Tables 3.1 and 3.2. The overall accuracy (P_o) at the major geomorphological structure level was 96% (Table 3.1). The Tau coefficient for equal probability of group membership is 0.941 ± 0.026 (α=0.05). The error matrix in Table 3.2 is populated by the individual cell probabilities (p_{ij}), which in review are the product of the original error matrix cell values (Table 3.1) and the map marginal proportions, divided by the row marginal of the original matrix (i.e., total map classifications per category). The adjusted overall accuracy, corrected for bias using the true map marginal proportions, was 96.7 (±1.7)% (α=0.05). The user's and producer's accuracies were similarly high for both hard and softbottom habitats (Table 3.2).

Table 3.1. Error matrix for major geomorphological structure.

		Accuracy Assessment (i)				
		Hard	**Soft**	**Other**	**n_{-j}**	**User's Accuracy (%)**
Map data (j)	**Hard**	**291**	8	0	299	**97.3%**
	Soft	10	**171**	1	182	**94.0%**
	Other	0	0	**0**	0	**n/a**
	n_{i-}	301	179	1	n=481	
	Producer's Accuracy (%)	**96.7%**	**95.5%**	**n/a**	**P_o = 96.0%**	
					T_e =	**0.921 ± 0.035**

Detailed Geomorphological Structure

Error matrices for detailed geomorphological structure are displayed in Tables 3.3 and 3.4. The overall accuracy (P_o) at the detailed geomorphological structure level was 85.7%, with a Tau coefficient (T_e) of 0.846 ± 0.034 (α=0.05) (Table 3.3). The adjusted overall accuracy, corrected for bias using the true map marginal proportions, improved slightly to 88.8 (±2.9)% (α=0.05), because the classes that covered the most area were also the most correctly interpreted.

Table 3.2. Error matrix for major geomorphological structure, using individual cell probabilities. The overall accuracy and producer's accuracy were corrected for bias using the true map marginal proportions.

		Accuracy Assessment (i)					
		Hard	**Soft**	**Other**	**$\pi_{\cdot j}$**	**User's Accuracy (%)**	**User's CI (±%)**
Map data (j)	**Hard**	**0.484**	0.010	0	0.494	**97.9%**	**1.6%**
	Soft	0.021	**0.484**	0.001	0.506	**95.6%**	**3.0%**
	Other	0	0	**0**	n/a	**n/a**	**n/a**
	p_i	0.505	0.494	0.001	π=1		
	Producer's Accuracy (%)	**95.8%**	**97.9%**	**n/a**	**P_o = 96.7%**		
	Producer's CI (±%)	**2.8%**	**1.6%**	**n/a**	**CI(±) = 1.7%**		

Adjusted user's accuracy was above 70% for all categories with the exception of the *Spur and Groove* and *Mud* categories, which had a calculated user's accuracy of 60.0% and 63.9%, respectively (Table 3.4). Five of the fifteen points mapped as *Spur and Groove* ware validated as *Pavement with Sand Channels*. Three of these points were located within the same polygon, along with two points that were positively classified as *Spur and Groove*. Since the difference in the two classifications is primarily determined by the relief of the hard substrate, it is possible that varying degrees of relief within individual polygons contributed to this error. Often these two bottom types occur adjacent to each other and represent a continuum in range of relief rather than clearly distinct classes. Twelve of

Table 3.3. Error matrix for detailed geomorphological structure.

		Accuracy Assessment (i)															
		Aggregate Reef	**Aggregate Patch Reef**	**Individual Patch Reef**	**Spur and Groove**	**Pavement**	**Pav w/ Sand Channels**	**Rock Outcrop**	**Boulder**	**Reef Rubble**	**Rhodolith**	**Sand w/ SCR**	**Sand**	**Mud**	**Land**	**$n_{\cdot j}$**	**User's Accuracy (%)**
Map data (j)	**Aggregate Reef**	**38**		1		6			1							46	**82.6%**
	Aggregate Patch Reef		**28**	1								1				30	**93.3%**
	Individual Patch Reef			**9**												9	**100.0%**
	Spur and Groove				**9**	1	5									15	**60.0%**
	Pavement	1		1		**59**				2						63	**93.7%**
	Pav w/ Sand Channels				1	3	**27**									31	**87.1%**
	Rock Outcrop	1			1			**34**	2							38	**89.5%**
	Boulder					1		2	**10**							13	**76.9%**
	Reef Rubble	1				1				**24**		2	5			33	**72.7%**
	Rhodolith	1								1	**19**					21	**90.5%**
	Sand w/ SCR		4			2						**15**				21	**71.4%**
	Sand	1				1				2		4	**117**			125	**93.6%**
	Mud												12	**23**	1	36	**63.9%**
	Land															0	**n/a**
	$n_{i\cdot}$	43	32	12	11	74	32	36	13	29	19	22	134	23	1	n=481	
	Producer's Accuracy (%)	**88.4%**	**87.5%**	**75.0%**	**81.8%**	**79.7%**	**84.4%**	**94.4%**	**76.9%**	**82.8%**	**100.0%**	**68.2%**	**87.3%**	**100.0%**	**n/a**	**P_o =**	**85.7%**

T_e = 0.846 ± 0.034

the 36 survey sites mapped as *Mud* were ground-truthed as Sand, the majority of which were located in the Coral Bay vicinity. *Sand* and *Mud* habitats in this area were often difficult to distinguish since the substrate composition was often a mixture of fine and coarse sediment rather than clearly separate and distinct classes. For example, sand was sometimes covered with a thin layer of silt.

Categories with the lowest adjusted producer's accuracy were *Individual Patch Reef, Sand with Scattered Coral and Rock, Spur and Groove,* and *Reef Rubble* (Table 3.4). In all cases, there was a high degree of variance, and two of the categories (*Individual Patch Reef* and *Spur and Groove*) were relatively undersampled compared to the other map categories. There were several reasons why the resulting number of samples in these two categories were fewer than planned, including inaccessibility, different classifications in the final map compared to the draft map, and inadvertent sampling of an adjacent polygon. Patch reef and spur and groove features were often small and/or narrow, so the probability of drifting into an adjacent habitat tended to be more frequent than with larger features. Several points ground-truthed as *Sand with Scattered Coral and Rock* (Figure 3.5) were mapped as habitats that were similar in structure (i.e. *Sand, Reef Rubble* and *Aggregated Patch Reefs*).

Figure 3.5. Sand with scattered coral and rock was occasionally confused with other geomorphological structure types composed of varying combinations of hard and softbottoms.

Table 3.4. Error matrix for detailed geomorphological structure, using individual cell probabilities. The overall accuracy and producer's accuracy were corrected for bias using the true map marginal proportions.

	Accuracy Assessment (i)																
Map data (j)	**Aggregate Reef**	**Aggregate Patch Reef**	**Individual Patch Reef**	**Spur and Groove**	**Pavement**	**Pav w/ Sand Channels**	**Rock Outcrop**	**Boulder**	**Reef Rubble**	**Rhodolith**	**Sand w/ SCR**	**Sand**	**Mud**	**Land**	**$\pi_{\cdot j}$**	**User's Accuracy (%)**	**User's CI (±%)**
Aggregate Reef	0.0576		0.0015		0.0091			0.0015							0.070	**82.6%**	**11.18%**
Aggregate Patch Reef		0.0199	0.0007								0.0007				0.021	**93.3%**	**9.11%**
Individual Patch Reef			0.0045												0.005	**100.0%**	**0.00%**
Spur and Groove				0.0042	0.0005	0.0023									0.007	**60.0%**	**25.30%**
Pavement	0.0025		0.0025		0.1478				0.0050						0.158	**93.7%**	**6.14%**
Pav w/ Sand Channels				0.0018	0.0053	0.0480									0.055	**87.1%**	**12.04%**
Rock Outcrop	0.0008			0.0008			0.0271	0.0016							0.030	**89.5%**	**9.96%**
Boulder					0.0011		0.0021	0.0106							0.014	**76.9%**	**23.37%**
Reef Rubble	0.0014				0.0014				0.0325		0.0027	0.0068			0.045	**72.7%**	**15.51%**
Rhodolith	0.0043								0.0043	0.0812					0.090	**90.5%**	**12.81%**
Sand w/ SCR		0.0048			0.0024						0.0179				0.025	**71.4%**	**19.72%**
Sand	0.0035				0.0035				0.0070		0.0140	0.4087			0.437	**93.6%**	**4.38%**
Mud												0.0148	0.0284	0.0012	0.044	**63.9%**	**16.01%**
Land															n/a	**n/a**	**n/a**
$p_{i\cdot}$	0.070	0.025	0.009	0.007	0.171	0.050	0.029	0.014	0.049	0.081	0.035	0.430	0.028	0.001	π=1		
Producer's Accuracy (%)	**82.3%**	**80.6%**	**49.0%**	**62.0%**	**86.4%**	**95.4%**	**92.7%**	**77.3%**	**66.6%**	**100.0%**	**50.8%**	**95.0%**	**100.0%**	**n/a**	**P_o =**	**88.8%**	
Producer's CI (±%)	14.6%	14.2%	31.5%	36.5%	6.3%	3.3%	8.8%	21.6%	20.6%	0.0%	21.7%	2.0%	0.0%	n/a	**CI(±) =**	**2.9%**	

Major Biological Cover

Error matrices for major biological cover are displayed in Tables 3.5 and 3.6. The overall accuracy (P_o) at the major biological cover level was 93.7%, with a Tau coefficient (T_e) of 0.921 ± 0.045 (α=0.05). The adjusted overall accuracy, corrected for bias using the true map marginal proportions, was similar at 93.0 (±2.4)% (α=0.05).

Accuracy was high for all major cover levels. The category with the lowest producer's and user's accuracy was *Live Coral*, but the number of accuracy assessment points in this category was too few to robustly assess this category. The low sample size was due to the rarity of polygons mapped where coral was mapped as the dominant cover. However, a better assessment of the accuracy of mapped coral cover will be discussed in the section *Percent Coral Cover*. The other major source of producer's error was in the *Seagrass* category, due to the misclassification as *Algae*.

Table 3.5. Error matrix for major biological cover.

		Accuracy Assessment (i)						
		Algae	**Live Coral**	**Mangrove**	**Seagrass**	**No Cover**	**$n_{.j}$**	**User's Accuracy (%)**
Map data (j)	**Algae**	**316**	1		12	2	331	**95.5%**
	Live Coral	2	**5**				7	**71.4%**
	Mangrove			**15**		1	16	**93.8%**
	Seagrass	6			**65**		71	**91.5%**
	No Cover	5				**27**	32	**84.4%**
	$n_{i.}$	**329**	**6**	**15**	**77**	**30**	n=457	
	Producer's Accuracy (%)	**96.0%**	**83.3%**	**100.0%**	**84.4%**	**90.0%**	**P_o = 93.7%**	
								T_e = 0.921 ± 0.045

Table 3.6. Error matrix for major biological cover, using individual cell probabilities. The overall accuracy and producer's accuracy were corrected for bias using the true map marginal proportions.

		Accuracy Assessment (i)							
		Algae	**Live Coral**	**Mangrove**	**Seagrass**	**No Cover**	**$\pi_{.j}$**	**User's Accuracy (%)**	**User's CI (±%)**
Map data (j)	**Algae**	**0.7089**	0.0020		0.0272	0.0076	0.746	**95.1%**	**2.4%**
	Live Coral	0.0047	**0.0085**				0.013	**64.3%**	**36.2%**
	Mangrove			**0.0060**		0.0004	0.006	**93.8%**	**12.1%**
	Seagrass	0.0147			**0.1322**		0.147	**90.0%**	**7.1%**
	No Cover	0.0137				**0.0741**	0.088	**84.4%**	**12.8%**
	$p_{i.}$	0.742	0.010	0.006	0.159	0.082	π=1		
	Producer's Accuracy (%)	**95.5%**	**81.2%**	**100.0%**	**83.0%**	**90.3%**	**P_o = 93.0%**		
	Producer's CI (±%)	**2.1%**	**33.7%**	**0.0%**	**9.4%**	**9.2%**	**CI(±) = 2.4%**		

Detailed Biological Cover

Error matrices for detailed biological cover are displayed in Tables 3.7 and 3.8. The overall accuracy (P_o) at the detailed biological cover level was 81.7%, with a Tau coefficient (T_e) of 0.798 ± 0.040 (α=0.05). The adjusted overall accuracy, corrected for bias using the true map marginal proportions, was similar at 81.0 (±3.1)% (α=0.05).

The greatest source of confusion at the detailed biological cover level was degrees of patchiness within *Algae* and *Seagrass* categories. For example, the adjusted user's and producer's accuracy of the *Seagrass 10%-<50%* were 16.7% and 10.8%, respectively (Table 3.8). Of the 12 sites mapped as *Seagrass 10%-<50%*, 10 were interpreted to have 50%-<90% patchiness in the accuracy assessment. However, it should be noted there were fewer sites surveyed within the 10% - <50% algae and seagrass categories than planned. As described in the methods, sites that were surveyed in a sand patch of a polygon that was mapped as patch vegetation were not included in the analysis, because the available information was insufficient to identify the major cover in the polygon. Many of these sites that were consequently removed were located in polygons that were mapped as submerged vegetation with a patchiness of 10% - <50%, contributing to the final lower sampling size in these categories. It is possible that a revised sampling technique, such as more points per polygon or a longer transect, is necessary to fully characterize heterogeneous habitats.

Table 3.7. Error matrix for detailed biological cover.

Map data (j)	Accuracy Assessment (i)												
	Algae 10% - <50%	Algae 50% - <90%	Algae 90% - 100%	Live Coral 50% - <90%	Live Coral 90% - 100%	Mangrove 50% - <90%	Mangrove 90% - 100%	Seagrass 10% - <50%	Seagrass 50% - <90%	Seagrass 90% - 100%	No Cover 90% - 100%	$n_{\cdot j}$	User's Accuracy (%)
Algae 10% - <50%	**16**	3						2	1		1	23	**69.6%**
Algae 50% - <90%	9	**71**	9					1				90	**78.9%**
Algae 90% - 100%	2	16	**180**	1				1	2	1	1	204	**88.2%**
Live Coral 50% - <90%				**2**								2	**100.0%**
Live Coral 90% - 100%		1	1	3								5	**0.0%**
Mangrove 50% - <90%												0	**n/a**
Mangrove 90% - 100%						1	**14**				1	16	**87.5%**
Seagrass 10% - <50%								**2**	10			12	**16.7%**
Seagrass 50% - <90%			2						**22**	1		25	**88.0%**
Seagrass 90% - 100%		1	3						2	**27**		33	**81.8%**
No Cover 90% - 100%	4	1									**27**	32	**84.4%**
$n_{i\cdot}$	31	93	195	6	0	1	14	6	37	29	30	n=442	
Producer's Accuracy (%)	**51.6%**	**76.3%**	**92.3%**	**33.3%**	**n/a**	**0.0%**	**100.0%**	**33.3%**	**59.5%**	**93.1%**	**90.0%**	**P_o = 81.7%**	
												T_e =0.798 ± 0.040	

Table 3.8. Error matrix for detailed biological cover, using individual cell probabilities. The overall accuracy and producer's accuracy were corrected for bias using the true map marginal proportions.

Map data (j)	Accuracy Assessment (i)													
	Algae 10% - <50%	Algae 50% - <90%	Algae 90% - 100%	Live Coral 50% - <90%	Live Coral 90% - 100%	Mangrove 50% - <90%	Mangrove 90% - 100%	Seagrass 10% - <50%	Seagrass 50% - <90%	Seagrass 90% - 100%	No Cover 90% - 100%	$\pi_{\cdot j}$	User's Accuracy (%)	User's CI (±%)
Algae 10% - <50%	**0.0901**	0.0169						0.0113	0.0056		0.0056	0.130	**69.6%**	**19.2%**
Algae 50% - <90%	0.0214	**0.1692**	0.0214					0.0024				0.214	**78.9%**	**8.6%**
Algae 90% - 100%	0.0039	0.0315	**0.3544**	0.0020				0.0020	0.0039	0.0020	0.0020	0.402	**88.2%**	**4.5%**
Live Coral 50% - <90%				**0.0014**								0.001	**100.0%**	**0.0%**
Live Coral 90% - 100%		0.0024	0.0024	0.0071								0.012	**0.0%**	**0.0%**
Mangrove 50% - <90%												0.000	**n/a**	**n/a**
Mangrove 90% - 100%						0.0004	**0.0056**				0.0004	0.006	**87.5%**	**16.5%**
Seagrass 10% - <50%								**0.0019**	0.0094			0.011	**16.7%**	**21.5%**
Seagrass 50% - <90%			0.0034						**0.0374**	0.0017		0.042	**88.0%**	**13.0%**
Seagrass 90% - 100%		0.0028	0.0085						0.0056	**0.0762**		0.093	**81.8%**	**13.4%**
No Cover 90% - 100%	0.0110	0.0027									**0.0741**	0.088	**84.4%**	**12.8%**
$p_{i\cdot}$	0.126	0.226	0.390	0.010	0.000	0.000	0.006	0.018	0.062	0.080	0.082	π=1		
Producer's Accuracy (%)	**71.3%**	**75.0%**	**90.9%**	**13.5%**	**n/a**	**0.0%**	**100.0%**	**10.8%**	**60.3%**	**95.4%**	**90.3%**	**P_o = 81.0%**		
Producer's CI (±%)	**11.6%**	**8.6%**	**4.1%**	**8.4%**	**n/a**	**n/a**	**0.0%**	**16.0%**	**14.8%**	**6.2%**	**13.0%**	**Ci(±) = 3.1%**		

As mentioned previously, seagrass and algae on softbottom habitats were sometimes mapped incorrectly. This is to be expected, as it can be difficult to distinguish between the two in remotely sensed imagery. In addition, there is often a mix of vegetation types rather than a homogeneous seagrass or algae field.

Percent Coral Cover

The error matrix for percent coral cover is displayed in Table 3.9. The overall accuracy (P_o) at the detailed biological cover level was 85.7%, with a Tau coefficient (T_e) of 0.809 ± 0.042 (α=0.05). As mentioned previously, a second matrix using the true map marginal proportions, was not computed for percent coral cover.

Table 3.9. Error matrix for major geomorphological structure and percent coral.

		Accuracy Assessment (i)					
		Softbottom, Coral <10%	Softbottom, Coral 10% - <50%	Hardbottom, Coral <10%	Hardbottom, Coral 10% - <50%	$n_{.j}$	User's Accuracy (%)
Map data (j)	Softbottom, Coral <10%	**171**		**6**		177	**96.6%**
	Softbottom, Coral 10% - <50%			**3**		3	**0.0%**
	Hardbottom, Coral <10%	**9**		**172**	**24**	205	**83.9%**
	Hardbottom, Coral 10% - <50%			**26**	**64**	90	**71.1%**
	$n_{i.}$	179	0	207	88	n=475	
	Producer's Accuracy (%)	**95.0%**	**n/a**	**83.1%**	**72.7%**	**P_o = 85.7%**	
						T_e = 0.809 ± 0.042	

Only two of the possible coral categories were present in the map and accuracy assessment data (*<10%* and *10%-<50%*). Accuracy was very high for the softbottom habitats, where a low amount of coral is to be expected. There was lower accuracy for percent coral on hardbottom habitats. The decision between <10% and 10% - <50% is often difficult to determine, especially if there is a mix of octocorals and sclerectinians. Since percent coral cover was recorded at all sites regardless of whether it was the dominant cover type, this is a better measure of coral accuracy than is found under *Major Biological Cover*.

3.5 CONCLUSIONS

Although the classification schemes are not directly comparable due to region-specific categories, the level of accuracy for detailed structure was similar to that of other recent NOAA benthic habitat maps in the Florida Keys (86.2% [91.5% adjusted], Walker and Foster 2009), Palau (90.0%, Battista et al. 2007b), and the Main Hawaiian Islands (90.0%, Battista et al. 2007a).

Comparisons with other accuracy assessments at the biological cover level are difficult due to the differences in the classification scheme. Previous mapping efforts utilized a hierarchical classification scheme to characterize biological cover, in comparison to the dominance based scheme used here.

In comparison to the other aforementioned accuracy assessments, which were conducted in a subset, or test area, of their respective habitat maps, the relative small size of the St. John benthic habitat map enabled the entire mapping area to be included in the accuracy assessment. As a result, we were able to capture the full diversity of habitats in the survey (Figure 3.6) and produce a spatially comprehensive evaluation of the thematic accuracy.

Figure 3.6. Juvenile Bluehead Wrasses (*Thalassoma bifasciatum*) gather around a colony of *Montastraea sp.*

LITERATURE CITED

Battista, T.A., Costa, B.M., and S.M. Anderson, S.M. 2007a. Shallow-Water Benthic Habitats of the Main Eight Hawaiian Islands (DVD). NOAA Technical Memorandum NOS NCCOS 61, Biogeography Branch. Silver Spring, MD.

Battista, T.A., Costa, B.M., and S.M. Anderson, S.M. 2007b. Shallow-Water Benthic Habitats of the Republic of Palau. NOAA Technical Memorandum NOS NCCOS 59, Biogeography Branch. Silver Spring, MD.

Beyer, H.L. 2004. Hawth's Analysis Tools for ArcGIS. Available at http://www.spatialecology.com/htools.

Card, D.H. 1982. Using known map categorical marginal frequencies to improve estimates of thematic map accuracy. Photogrammetric Engineering and Remote Sensing 48: 431-439.

Cohen, J. 1960. A coefficient of agreement for nominal scale. Educational and Psychological Measurement 20: 37-46.

Congalton, R.G. and K. Green. 1999. Assessing the Accuracy of Remotely Sensed Data: Principles and Practices. CRC/Lewis Press, Boca Raton, FL. 137 pp.

Ma, Z. and R.L. Redmond. 1995. Tau coefficients for accuracy assessment of classification of remote sensing data. Photogrammetric Engineering and Remote Sensing 61: 435-439.

Steel, G.D. and J.H. Torrie. (1960) Principles and Procedures of Statistics. McGraw-Hill Book Company, Inc., New York. 481 pp.

Story, M. and R. Congalton. (1986) Accuracy assessment: A user's perspective. Photogrammetric Engineering and Remote Sensing 52: 397-399.

Walker, B.K. and G. Foster. 2009. Final Report: Accuracy Assessment and Monitoring for NOAA Florida Keys mapping: AA ROI-1 (near American Shoal). National Coral Reef Institute, Nova Southeastern University, Dania Beach, FL. 32 pp.

This page intentionally left blank.

CHAPTER 4: CONCLUSION

NOAA's Biogeography Branch, with support from the U.S. National Park Service, has completed benthic habitat mapping and subsequent field validation and accuracy assessment of the nearshore marine environment of St. John, U.S. Virgin Islands. An independent accuracy assessment revealed successful overall map accuracies of over 90% for major structure and cover classes, and over 80% for detailed structure and cover classes. As a result, these digital map products can be used with confidence by scientists and resource managers for a multitude of different applications (Figure 4.1). The scientific and management communities have used previous NOAA benthic habitat maps to structure monitoring programs, support management decisions, and establish and manage marine conservation areas in coral reef ecosystems.

Figure 4.1. A NOAA diver characterizes seagrass habitat during a monitoring mission in St. John.

The final delivery consisted of the benthic habitat maps in several formats and all ancillary data generated in support of map creation. These items are listed in Table 4.1 with a description of the format type and quantity when appropriate.

Table 4.1. Final deliverable items of NOAA's St. John benthic habitat mapping effort. Additional information is given on the item type and a quantitative descriptor.

Item	Format	Quantity
Benthic Habitat Map	GIS	1,940 polygons
Source Imagery	GIS	
Map Atlas	PDF	
Interactive Map Project	On-line	
Ground Validation Dataset	GIS	444 locations
Accuracy Assessment Dataset	GIS	481 locations
Video of Bottom Imaging	Quicktime Movie	807 videos
Final Report	PDF	
FGDC-compliant Metadata for GIS Files	Text	

4.1 MAP SUMMARY STATISTICS

An area of 131.49 km² was considered during the mapping process; of which, 78.05 km² were designated as *Unknown* due to water depth and clarity issues. The remaining 53.44 km² were described by 1,939 polygons corresponding to the structure and biological cover types of the habitat classification scheme outlined in Chapter 1.

Of these 53.44 km², *Unconsolidated Sediment* and *Coral Reef and Hardbottom* each accounted for 26.71 km² of Major Structure type (Table 4.2). Equivalence in area of *Unconsolidated Sediment* and *Coral Reef and Hardbottom* was not an intentional design element; rather, it was an unforeseen coincidence. Together, *Unconsolidated Sediment* and *Coral Reef and Hardbottom* account for 98.98% of Major Structure type; the remaining 0.02% corresponds to *Artificial* structures. The 0.01 km² of *Artificial* type is located in Cruz Bay at the ferry dock and NPS boat dock.

Detailed Structure map summary statistics highlight the composition of Major Structure types (Table 4.2). *Coral Reef and Hardbottom* is subdivided into ten Detailed Structure categories, while *Unconsolidated Sediment* is segmented into three. Note in Table 4.2, that Detailed Structure percentages are derived from total mapped area, not within the corresponding Major Structure classification.

Table 4.2. Area summary of major geomorphological structure classes and the subsets of detailed structure classes.

MAJOR STRUCTURE	AREA (km²)	PERCENT AREA	DETAILED STRUCTURE	AREA (km²)	PERCENT AREA
Coral Reef and Hardbottom	26.71	49.99	Rock Outcrop	1.62	3.03
			Boulder	0.74	1.39
			Aggregate Reef	3.74	6.99
			Individual Patch Reef	0.25	0.47
			Aggregated Patch Reef	1.49	2.79
			Spur and Groove	0.33	0.61
			Pavement	8.74	16.35
			Pavement with Sand Channels	2.68	5.02
			Reef Rubble	2.36	4.41
			Rhodoliths	4.77	8.93
Unconsolidated Sediment	26.71	49.99	Sand	22.98	43.00
			Mud	2.33	4.37
			Sand with Scattered Coral and Rock	1.40	2.62
Other Delineations (Land excluded)	0.01	0.02	Artificial	0.01	0.02
Total	53.44	100		53.44	100

Sand is the most common detailed structure type, accounting for 43% of the total mapped area (Figure 4.2). *Mud* and *Sand with Scattered Coral and Rock* are considerably less common *Unconsolidated Sediment* types, accounting for 4.37% and 2.62% respectively. At 16.35% of total area, *Pavement* is the second most dominant structure type overall and the predominant detailed structure type within *Coral Reef and Hardbottom*. Other common structure types are *Rhodoliths*, which account for 8.93% of total area, and *Aggregate Reef*, which contributes to 6.99% of total area. Although ecologically significant, patch reefs, in the form of *Individual Patch Reefs* and *Aggregated Patch Reefs*, only comprise just over 3% of all the nearshore habitat of St. John.

Biological Cover map summary statistics (Figure 4.3) reveal that the overwhelmingly dominant Major Cover is *Algae*, which accounts for 74.28% of the 53.44 km² study area (Table 4.3). About half of the 39.69 km²

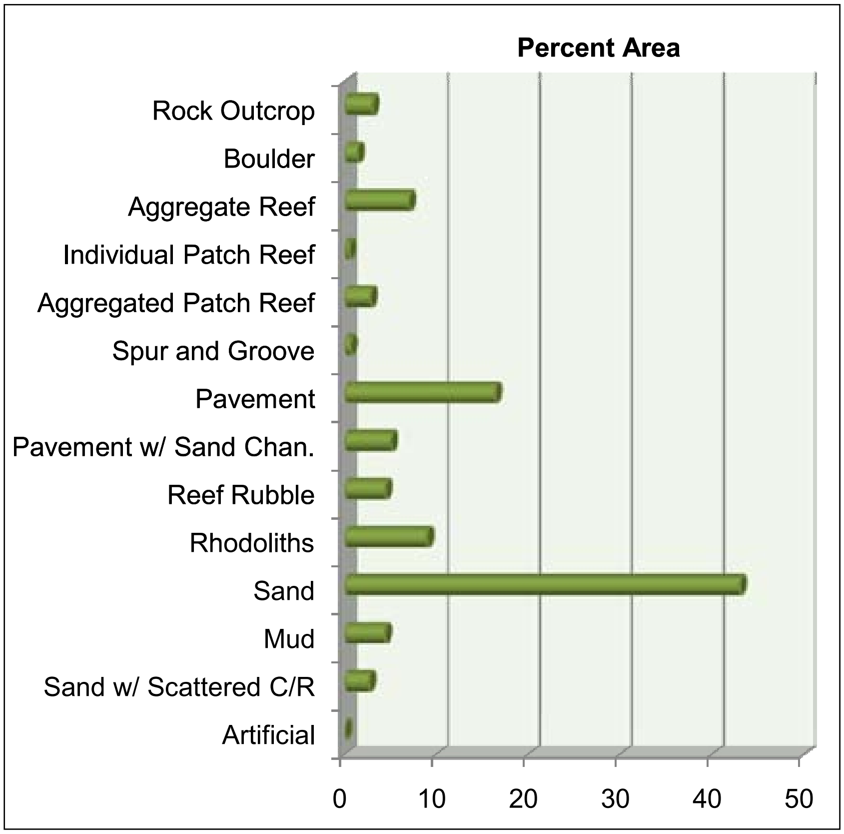


Figure 4.2. Chart illustrating the percent cover of each detailed geomorphological structure type for the entire St. John mapping area. *Sand* being the most common structure type and *Pavement* the most common hardbottom type.

of algal dominance is covered by a continuous distribution (*90% - 100%*). This is in large part due to the inclusion of turf algae as a mapped species, since much of St. John's hardbottom is covered by turf in the absence of live coral. At 14.68%, *Seagrass* is the second most common Major Cover type. Areas with *No Cover* account for 8.84% of the total area. *Live Coral* and *Mangrove* are rare Major Covers; the former constitutes 1.51% and the latter 0.66% of the study area. Although live coral colonies exist throughout the St. John seascape, the total area of features dominated by live coral cover was only 0.81 km^2. Coralline Algae was not found to be a Major Cover within the study area.

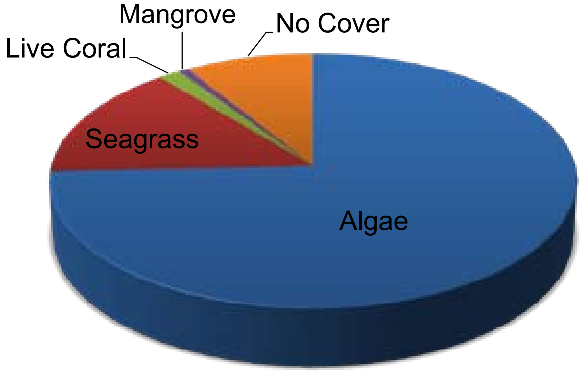


Figure 4.3. Chart depicting the prevalence (~ 75%) of *Algae* as the dominant biological cover type in the mapped area of St. John.

Map summary statistics suggested that almost all of the total mapped area is comprised of less than 50% coral cover (Table 4.4). There are 9.29 km^2 exhibiting a Percent Coral Cover of *10% to <50%*. These areas account for 17.39% of the study area, while 82.59%, or 44.12 km^2, have less than 10% coral cover. Furthermore, Coral Cover does not exceed 50% within any single minimum mapping unit of the study area. For this, it is important to remember the influence of minimum mapping units in the habitat mapping process. It was observed that some areas of St. John are comprised of greater than 50% coral cover, but these areas were not large enough to be mapped with a minimum mapping unit of 1,000 m^2.

Table 4.3. Summary of areas for each biological cover and respective percent cover modifier mapped in St. John.

MAJOR COVER	AREA (km^2)	PERCENT AREA	PERCENT COVER	AREA (km^2)	PERCENT AREA
Algae	39.69	74.28	10% - <50%	7.16	13.40
			50% - <90%	12.07	22.59
			90% - 100%	20.46	38.30
Seagrass	7.85	14.68	10% - <50%	0.48	0.89
			50% - <90%	2.47	4.63
			90% - 100%	4.90	9.17
Live Coral	0.81	1.51	10% - <50%	0.12	0.23
			50% - <90%	0.10	0.19
			90% - 100%	0.58	1.09
Mangrove	0.35	0.66	10% - <50%	0.01	0.01
			50% - <90%	0.01	0.02
			90% - 100%	0.34	0.63
Coralline Algae	0	0	10% - <50%	0	0
			50% - <90%	0	0
			90% - 100%	0	0
No Cover	4.73	8.84	90% - 100%	4.73	8.84
Artificial	0.01	0.02	N/A	0.01	0.02
Total	**53.44**	**100.00**		**53.44**	**100.00**

4.2 COMPARISON TO PREVIOUS NOAA HABITAT MAPS OF ST. JOHN

The 2009 benthic habitat mapping effort described in this report marks the second such effort NOAA has conducted to map the shallow-water coral reef ecosystems of St. John, USVI. The Kendall et al. (2001) digital benthic habitat maps of St. John were a significant improvement over previous paper copy maps (Beets et al. 1986). However, as the complexities of resource management and the capabilities of mapping techniques developed over the past

Table 4.4. Area summary of percent coral cover for St. John habitats.

PERCENT CORAL COVER	AREA (m^2)	AREA (km^2)	PERCENT AREA
0 - <10%	44,131,783	44.13	82.59
10% - <50%	9,293,135	9.29	17.39
50% - <90%	0.00	0.00	0.00
90% - 100%	0.00	0.00	0.00
N/A	10,548	0.01	0.02
Total	**53,435,466**	**53.44**	**100.00**

decade, the management and scientific communities have required benthic habitat maps with greater spatial and thematic detail. In response to these requests, NOAA, in cooperation with the U.S. National Park Service, has completed new fine-scale habitat maps that reflect the most current conditions at the Virgin Islands Coral Reef National Monument, Virgin Islands National Park and the surrounding waters. Components of this new mapping product include an expanded habitat classification scheme (as described in Chapter 1), smaller minimum mapping units, more recent imagery, and improved positional accuracy (Table 4.5).

Table 4.5. Comparison of basic map characteristics between a previous NOAA effort (2001) and the current maps of St. John (2009).

		NOAA MAPPING EFFORT	
MAP		2001	2009
	Source Imagery Date	1999	2007
	Scale of Delineation	1:6,000	1:2,000
	Minimum Mapping Unit (m²)	4,046	1,000
	Positional Accuracy (m)	4.31 (+/- 5.2)	2.15 (+/- 0.7)
FEATURE			
	Number of Polygons	537	1,939
	Mean Polygon Area (m²)	173,971	53,378
	Sum of Polygon Edges (km)	1,137	2,303
	Mean Polygon Edge (km)	2.12	1.19

NOAA's revised approach to mapping nearshore coral reef ecosystems has provided significant advantages to better represent the natural environment. As displayed in Table 4.5, the 2009 maps were created with finer-scale mapping standards in both scale of delineation and minimum mapping unit. The map interpreter delineated polygon boundaries at a scale of 1:2,000, which is three times as spatially resolute as that of the 1:6,000 of the 2001 mapping effort. In addition, the source imagery of the 2009 habitat maps had a pixel resolution of 0.3 m, as compared to the 2.4 m resolution imagery used by Kendall et al. (2001). These factors resulted in enhanced line accuracy and line detail as more vertices were able to be created along the same amount of line distance with a more detailed view of the seafloor.

A reduction in MMU from approximately 4,000 m² to 1,000 m² in the 2009 mapping effort, had a large impact on the final content of the habitat map product. The smaller minimum mapping unit resulted in over three times as many polygons and about three times as small average polygon area (Table 4.5). Figure 4.4 illustrates the influence of minimum mapping unit on the delineation of patch reefs outside of Reef Bay. Smaller patch reefs that were formerly too small to map individually (< 4,046 m²), under the 2001 standards, are delineated as separate polygons in the 2009 habitat map. Additionally, reduced MMUs allow for more accurate depictions of other patchy environments, as patches were more readily delineated. For instance, large pavement areas formerly mapped as homogeneous hardbottom are now depicted as pavement with smaller sand patches intermixed throughout the broader polygon. The true heterogeneous nature of many marine features was more accurately mapped due to the reduction in minimum mapping unit.

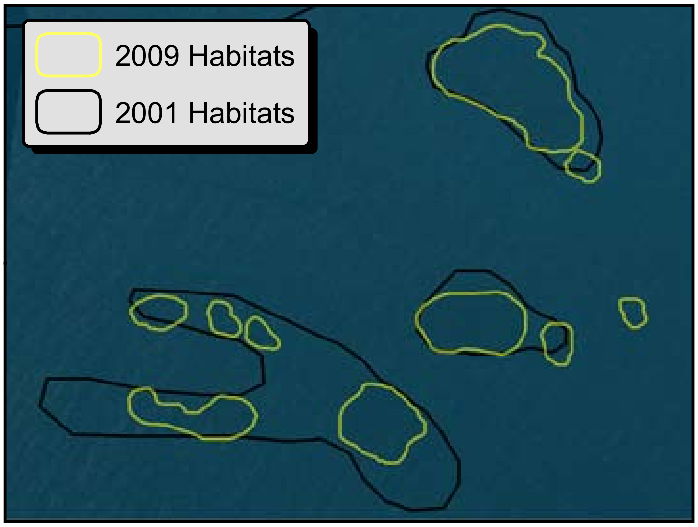


Figure 4.4. Comparison of 2001 and 2009 NOAA habitat boundaries to illustrate the influence of minimum mapping unit on the delineation of patch reefs outside of Reef Bay.

Marine systems are recognized as dynamic, and subject to changes ranging from a single storm event to long-term ecological shifts due to climate change. It was essential for NOAA to use the most current, available source imagery from which to generate the new benthic habitat maps. High resolution orthophotography collected in late 2007 afforded a more recent depiction of the habitats of St. John, as opposed to the 1999 aerials used in Kendall et al. (2001).

It is well documented that St. John has experienced changes in the coral environment, particularly live coral cover, over the past decade (Waddell and Clarke 2008). NOAA's 2009 mapping effort supports this conclusion on softbottom habitats as well. In comparison to Kendall et al. (2001), preliminary spatial comparisons have indicated that seagrass growth has increased dramatically in areas off the coast of St. John. For instance, softbottoms covered by seagrass in Rendezvous Bay have increased from 0.22 km² in 1999 to 0.74 km² in 2007 (Figure

4.5). Growth of 0.52 km² of seagrass in a 1.23 km² embayment, such as Rendevous Bay, over an 8 year period is significant development of submerged aquatic vegetation. The present map results indicate that other bays on the south shore, including Reef Bay, Europa Bay and Little Lameshur Bay, have experienced similar trends in seagrass growth.

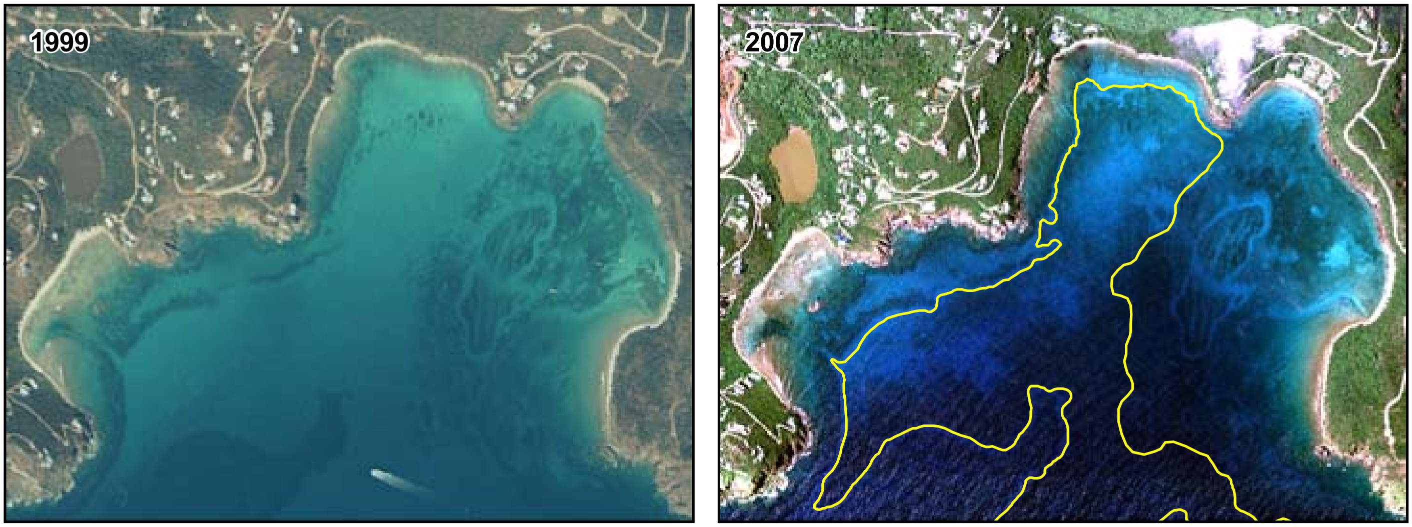


Figure 4.5. Imagery time-series of Rendezvous Bay depicting growth of seagrass beds between 1999 (left) and 2007 (right). The yellow polygon outlines the area of new seagrass growth.

Beyond the changes in mapping technique and standards, NOAA's 2009 effort marked a significant alteration of the benthic habitat classification scheme used to map other coral reef ecosystems. As outlined in *Chapter 1.1 Comparison to Previous NOAA Habitat Classification Schemes*, treatment of the biological cover classification has evolved over the years. In Kendall et al. (2001), biological cover was not explicitly stated for each feature in the map. Instead, the specific biological cover type was only reported for softbottoms colonized by submerged aquatic vegetation. For example, sand bottoms with patchy seagrass were fully reported in the old scheme. However, linear reefs colonized by a mix of turf algae and gorgonians were only classified as *Linear Reef*, with no reference to biological cover. Moreover, the Kendall et al. (2001) scheme made no reference to the amount of live coral cover present on polygon features (Figure 4.6). In contrast, the 2009 effort described the percentage of live coral cover in ranges for every seafloor feature. Other differences exist between the habitat classification scheme used in 2001 and that of 2009; including division of some structure types into more detailed groups. For instance, *Colonized Bedrock* was subdivided into *Rock Outcrop* and *Boulder,* with an associated dominant biological cover. These differences in habitat classification scheme make a direct comparison between NOAA-generated, St. John habitat maps difficult. An analysis comparing both maps is beyond the scope of this report, but should be considered in future efforts.

Overall, the transition to the current version of NOAA's dominance habitat classification scheme from previous iterations was a success. As described in *Chapter 3.5 Conclusions*, the 85.7% accuracy achieved for detailed structure in NOAA's 2009 St. John benthic habitat maps was similar to that of other recent NOAA benthic habitat maps in the Florida Keys (86.2%, Walker and Foster 2009), Palau (90.0%, Battista et al. 2007b), and the Main Hawaiian Islands (90.0%, Battista et al. 2007a). This indicates that the needs of coral reef managers and scientists for a dominance based classification scheme were met, with no loss in thematic map accuracy.

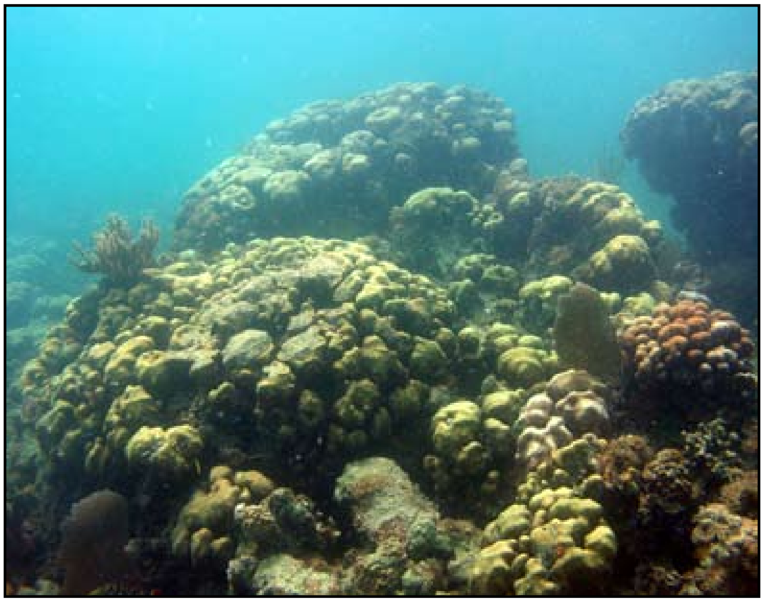


Figure 4.6. A large colony of boulder coral (Montastraea annularis) may have varying percentages of live coral cover.

4.3 PROJECT DELIVERABLES

The NOAA and NPS collaborative effort to map the benthic habitats of St. John resulted in a suite of products. These products were provided directly to NPS project partners by data drive and are available to the public on a NOAA Biogeography Branch website devoted to this mapping effort (http://ccma.nos.noaa.gov/ecosystems/coralreef/benthic_usvi.html). The project deliverables include:

- Benthic habitat maps in GIS format,
- Remotely sensed imagery, including satellite and airborne imagery,
- Underwater video of ground validation and accuracy assessment field sites, including GIS files of their locations,
- Classification manual (contained in this report),
- Description of the specific methods used to create the habitat maps (contained in this report),
- Assessment of the thematic accuracy of the maps (contained in this report),
- FGDC-compliant metadata for all GIS products,
- Map atlas panels in PDF format, and
- An interactive, web-based map that allows users to query and display all spatial datasets and underwater video.

4.4 FUTURE U.S. VIRGIN ISLANDS MAPPING ACTIVITIES

NOAA’s Biogeography Branch is undertaking an effort to develop similar habitat maps of the moderate depth area (20 m – 55 m) south of St. John, including the Mid-Shelf Reef. The same habitat classification scheme from the shallow-water maps will be applied to habitat maps derived from acoustic data collected with a multibeam echosounder (MBES). The Biogeography Branch has developed a semi-automated classification technique, combining object and pixel-based approaches to classify acoustic data. The moderate depth mapping area begins at the deepest edge of the shallow-water mapping described in this report (see figure in Introduction). Integration of the shallow-water mapping with the moderate depth mapping will provide NPS and others with one seamless habitat map derived from two different technologies.

Upon completion of the moderate depth mapping effort, the Biogeography Branch, in collaboration with NOAA’s Coastal Services Center, will implement a translation of the NOAA dominance habitat classification scheme for coral ecosystems (described in Chapter 1) to the Coastal and Marine Ecological Classification Standard (CMECS) (Madden et al. 2009). CMECS is a national-scale classification scheme that describes an aquatic setting and provides additional detail through five underlying components that describe different aspects of the relevant ecology. Project partners will evaluate the “cross-walking” of these two classification schemes to determine the ability of CMECS to capture the needs of the coral reef management and scientific communities currently described in NOAA’s scheme.

Using the knowledge gained from the St. John integrated mapping effort, the Biogeography Branch will conduct a similar approach to St. Croix, U.S. Virgin Islands. The project includes acquisition of acoustic data and production of benthic habitat maps for the Buck Island Reef National Monument (BUIS) and the Salt River Bay National Historical Park and Ecological Reserve (SARI) (Figure 4.7). While NOAA and NPS have collaboratively conducted extensive habitat mapping and biological monitoring inside and outside parts of BUIS and SARI, funding and vessel access has never afforded the opportunity to conduct complete bathymetric and seafloor characterization within all of the marine protected areas (MPA). The Biogeography Branch proposes to conduct small boat operations using acoustic systems which are ideally suited to mapping the remaining shallow areas, to produce integrated shallow to deep water bathymetric and habitat maps within the MPA’s.

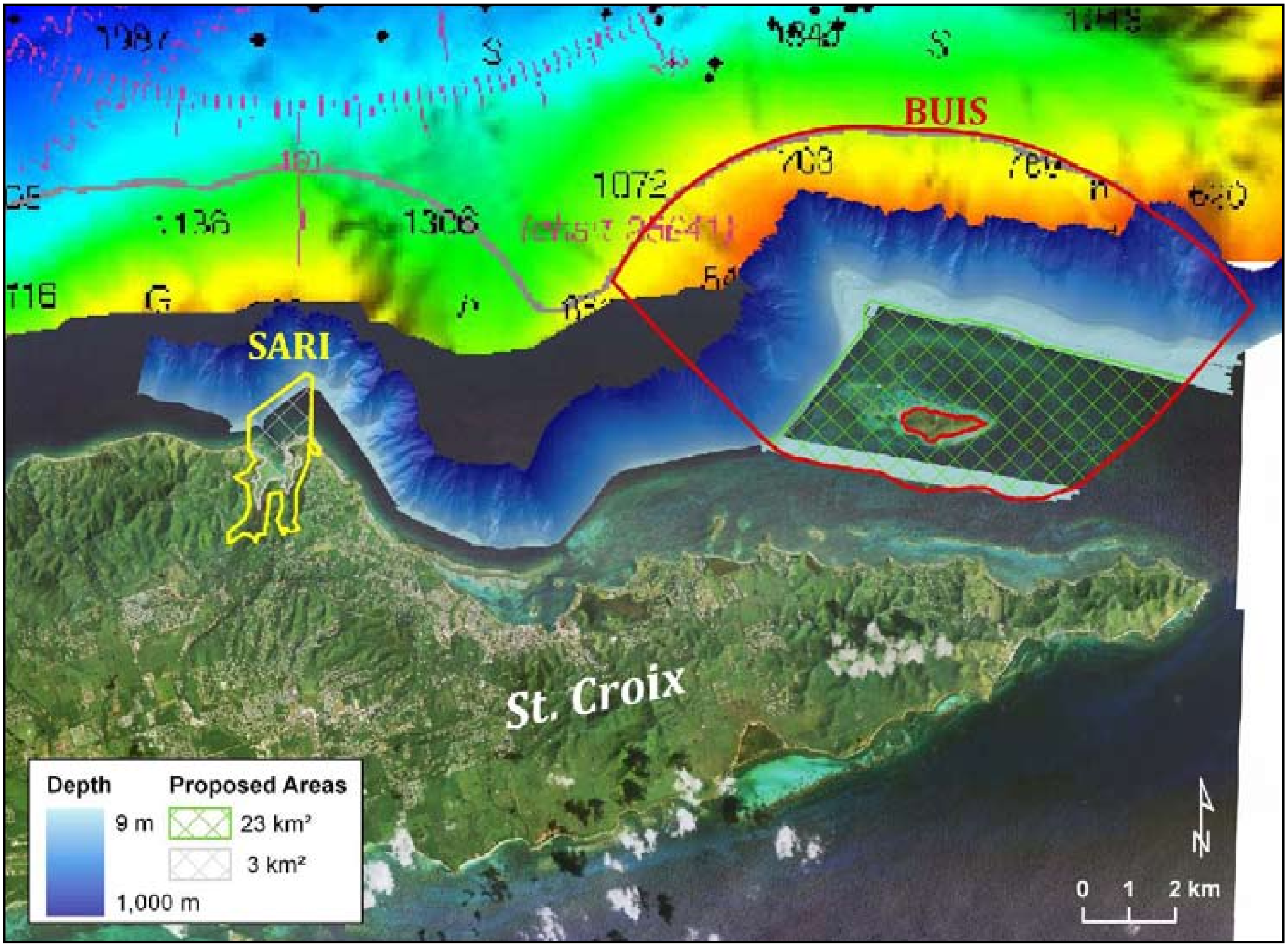


Figure 4.7. Seafloor mapping of Buck Island Reef National Monument and Salt River Bay National Historical Park and Ecological Reserve and adjacent areas of St. Croix, USVI. Previously collected acoustic data is displayed with management boundaries and proposed mapping areas.

LITERATURE CITED

Battista, T.A., B.M. Costa, and S.M. Anderson, S.M. 2007a. Shallow-Water Benthic Habitats of the Main Eight Hawaiian Islands (DVD). NOAA Technical Memorandum NOS NCCOS 61, Biogeography Branch. Silver Spring, MD.

Battista, T.A., B.M. Costa, and S.M. Anderson. 2007b. Shallow-Water Benthic Habitats of the Republic of Palau. NOAA Technical Memorandum NOS NCCOS 59, Biogeography Branch. Silver Spring, MD.

Beets, J., L. Leewand, and E.S. Zullo. 1986. Marine community descriptions and maps of bays within the Virgin Islands National Park/Biosphere Reserve. Biosphere Reserve Research Report Number 2, National Park Service. 118 pp.

Kendall, M.S., C.R. Kruer, K.R. Buja, J.D. Christensen, M. Finkbeiner, R.A. Warner, and M.E. Monaco. 2001. Methods Used to Map the Benthic Habitats of Puerto Rico and the U.S. Virgin Islands. NOAA Technical Memorandum NOS NCCOS CCMA 152. Silver Spring, MD.

Madden, C.J., K. Goodin, R.J. Allee, G. Cicchetti, C. Moses, M. Finkbeiner, D. Bamford. 2009. Coastal and Marine Ecological Classification Standard, Version III. NOAA and NatureServe. 109 pp.

Waddell, J.E. and A.M. Clarke (eds.). 2008. The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2008. NOAA Technical Memorandum NOS NCCOS 73. Biogeography Branch. Silver Spring, MD. 569 pp.

Walker, B.K. and G. Foster. 2009. Final Report: Accuracy Assessment and Monitoring for NOAA Florida Keys mapping: AA ROI-1 (near American Shoal). National Coral Reef Institute, Nova Southeastern University, Dania Beach, FL. 32 pp.

ACKNOWLEDGEMENTS

Funding for this study was provided by the U.S. National Park Service. This report would not have been possible without the numerous people who shared their data, information and time throughout this process. We appreciate the support of Park Service staff including Jeff Cross, Rafe Boulon and Jeff Miller, as well as Caroline Rodgers from the U.S. Geological Survey. Also, NPS boat captains, Dave Sapio and Jessica Hornbeck, were critical in maintaining a safe and productive field effort. An expression of thanks goes to NOAA's CCMA and CRCP for the ability to provide the labor necessary to complete this mapping effort. As always, the entire Biogeography Branch provided endless support. Thanks to Jamie Higgins for organizing the content of this report into what you see before you. Many thanks to Kim Woody for answering the many questions that came up during the mapping process. Finally, Charlie Menza and Zach Hecht-Leavitt were instrumental in acquiring and processing field data and their work is greatly appreciated.

United States Department of Commerce

Gary Locke
Secretary

National Oceanic and Atmospheric Administration

Jane Lubchenco
Administrator

National Ocean Service

John H. Dunnigan
Assistant Administrator