CHAPTER 2: BENTHIC HABITAT MAP CREATION

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.

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

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.

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.

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

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.

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.

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

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.

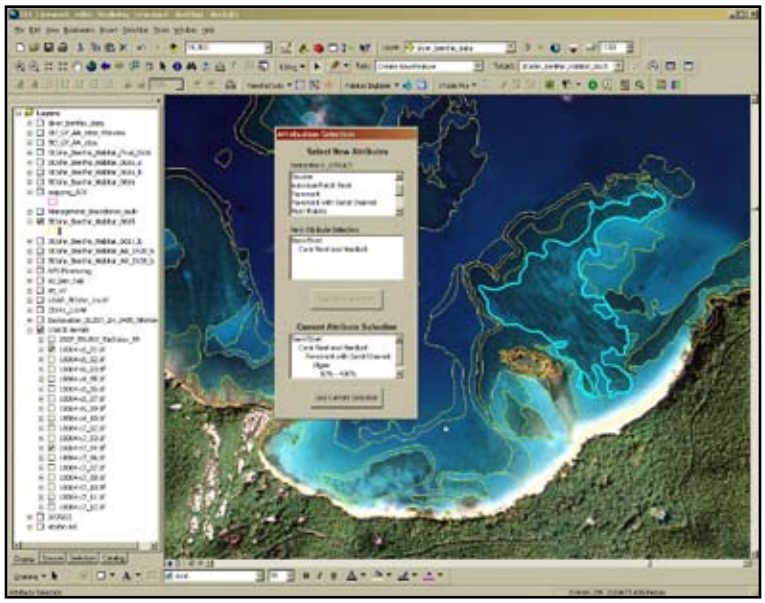

Figure 2.6. NOAA Biogeography Branch's Habitat Digitizer Extension (NOAA 2009) was used to attribute map polygons with all components of the habitat classification scheme.

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.

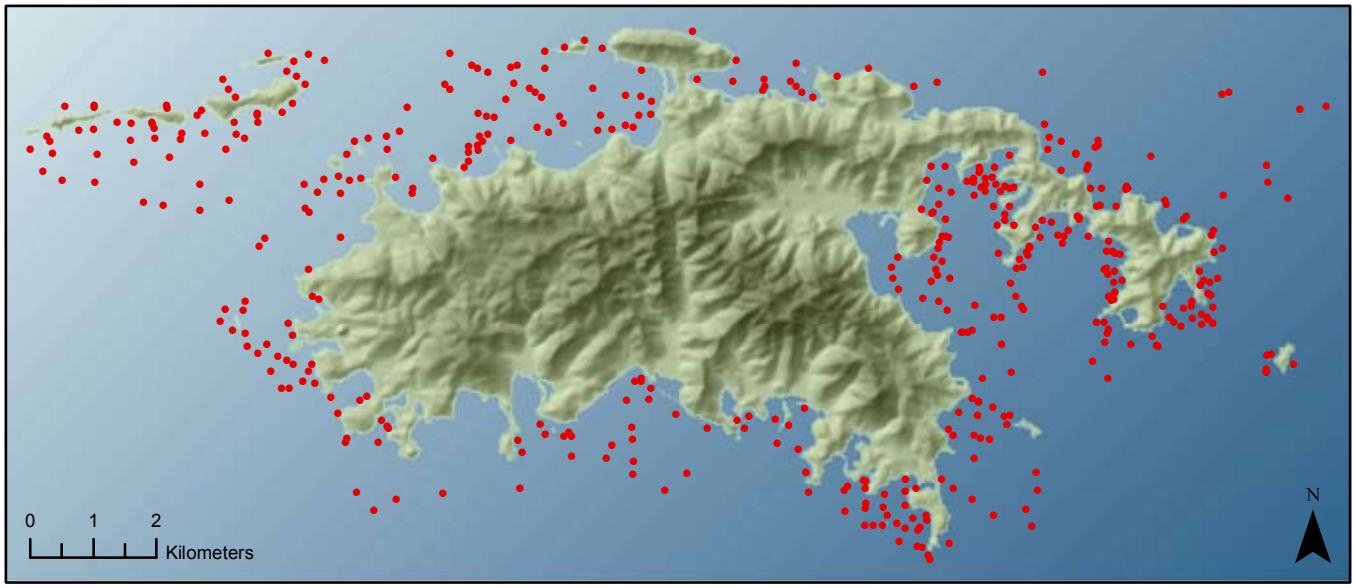

Figure 2.7. Red dots depict the location of the 444 ground validation sites visited during the mapping process to determine habitat information.

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,
  - o 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,
  - o It was explained that distinguishing between these coral types using photo-interpretation is quite difficult, if not impossible
  - o NOAA Biogeography committed to exploring the feasibility of distinguishing between the coral types, possibly using *in situ* monitoring data
  - o 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,
  - o 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)
  - o A suggested type name: Aggregated Coral Heads

- Improve habitat classification scheme manual,
  - o Define polygon patchiness and how it relates to percent cover
  - o Should include more photographs of structure and biological covers to improve understanding beyond text descriptions (Figure 2.10)
  - o Provide flow diagram of how the classification process is conducted for an example mapping unit
  - o 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
  - o Possibly in the number of acres of certain categories, polygons and other critical map statistics

- The atlas maps were difficult to utilize for review
  - o Frames should be adjusted so that breaks minimize interruption of features
  - o Low print quality made it difficult to read the colors on the maps, especially with blue background
  - o 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.

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