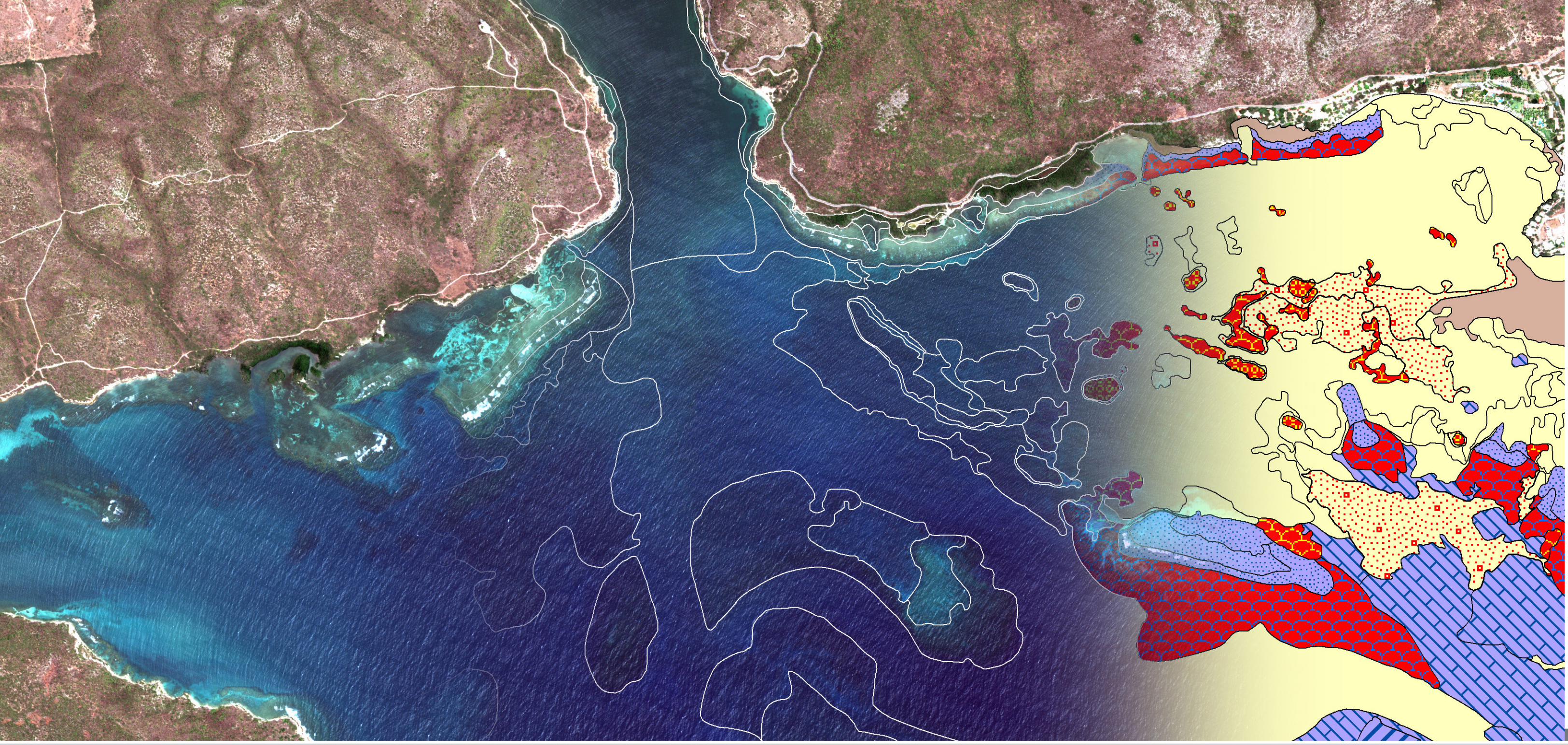
Shallow-Water Benthic Habitats of Southwest Puerto Rico



NOAA National Centers for Coastal Ocean Science
Center for Coastal Monitoring and Assessment

Laurie J. Bauer

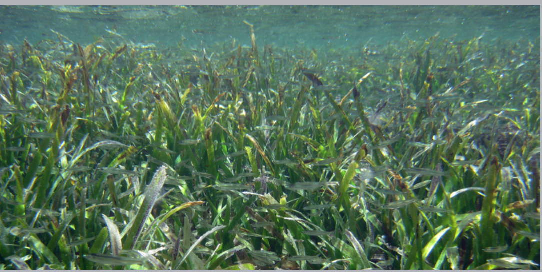
Kimberly Edwards

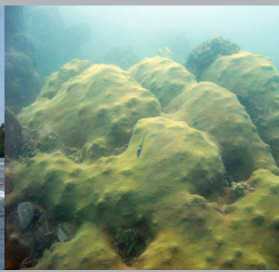
Matthew S. Kendall

Kimberly K.W. Roberson

Sam Tormey

Timothy A. Battista



November 2012

NOAA TECHNICAL MEMORANDUM NOS NCCOS 155

NOAA NCCOS Center for Coastal Monitoring and Assessment

CITATION

Bauer, L.J., K. Edwards, K.K.W. Roberson, M.S. Kendall, S. Tormey, and T.A. Battista. 2012. Shallow-water benthic habitats of Southwest Puerto Rico. NOAA Technical Memorandum NOAA NOS NCCOS 155. Silver Spring, MD.

ACKNOWLEDGEMENTS

Many thanks to Captain Angel Nazario (*Aquanauta*) and his assistant Joel (Joito) Rivera for providing safe passage to our sites and for their assistance in the field. Will Sautter assisted in the processing of video data. Thanks to Alicia Clarke, Lisamarie Carrubba, Bryan Costa, and Gustav Kagesten for providing helpful comments and editorial assistance. Thanks to Ken Buja for designing the southwest Puerto Rico BIOMapper. Funding for this work was provided by NOAA's Coral Reef Conservation Program, in part through a proposal submitted by the National Marine Fisheries Service Caribbean Field Office. Government contract labor was provided by CSS-Dynamac of Fairfax, Virginia under NOAA contract number DG133C11CO0019.

Shallow-Water Benthic Habitats of Southwest Puerto Rico

Prepared by the:
Biogeography Branch
Center for Coastal Monitoring and Assessment (CCMA)
NOAA/NOS/National Centers for Coastal Ocean Science
Silver Spring, MD, USA

November 2012

Authors:
Laurie J. Bauer
Kimberly Edwards
Kimberly K.W. Roberson
Matthew S. Kendall
Sam Tormey
Timothy A. Battista

NOAA Technical Memorandum NOS NCCOS 155

United States Department of Commerce	National Oceanic and Atmospheric Administration	National Ocean Service
Rebecca Blank Acting Secretary	Jane Lubchenco Administrator	David Kennedy Assistant Administrator

ABOUT THIS DOCUMENT

This report describes the creation and assessment of a shallow-water benthic habitat map of southwest Puerto Rico, including the regions of Guánica/La Parguera and Finca Belvedere. The Guánica work was conducted by NOAA's National Centers for Coastal Ocean Science, Center for Coastal Monitoring and Assessment's (CCMA), Biogeography Branch as a component of a baseline assessment in support of watershed restoration efforts in the Guánica Bay watershed. The Guánica Bay project represents a collaborative effort between multiple agencies including CCMA, NOAA's Coral Reef Conservation Program and Restoration Center, U.S. Department of Agriculture's Natural Resource and Conservation Service, and the Center for Watershed Protection. In addition, the work was conducted in coordination with and support by the NOAA Fisheries Caribbean Field Office, which is working to characterize the marine environment adjacent to two natural reserves, the Bosque Estatal de Guánica and the Reserva Natural Finca Belvedere.

This project was funded by NOAA's Coral Reef Conservation Program. The products provide an update to a region of NOAA's existing benthic habitat maps of Puerto Rico and the U.S. Virgin Islands (Kendall et al., 2001) and are part of NOAA's ongoing efforts to map and assess coral reef ecosystems in the U.S. Caribbean.

For more information on this effort, please visit http://ccma.nos.noaa.gov/ecosystems/coralreef/benthic_swpr.aspx, or direct questions and comments to:

Chris Caldow, Biogeography Branch Chief
Center for Coastal Monitoring and Assessment
NOAA National Centers for Coastal Ocean Science
1305 East West Highway
SSMC 4, N/SCI-1
Silver Spring, MD 20910
Phone: (301) 713-3028
E-mail: Chris.Caldow@noaa.gov

TABLE OF CONTENTS

INTRODUCTION

This report describes the creation and assessment of benthic habitat maps for shallow-water (<30m) marine environments of the Guánica/Parguera and Finca Belvedere Natural Reserve in southwest Puerto Rico (Figure 1). The objective was to provide spatially-explicit information on the habitat types, biological cover and live coral cover of the region's coral reef ecosystem. These fine-scale habitat maps, generated by interpretation of 2010 satellite imagery, provide an update to NOAA's previous digital maps of the U.S. Caribbean (Kendall et al., 2001) for these areas.

Updated shallow-water benthic habitat maps for the Guánica/Parguera region are timely in light of ongoing restoration efforts in the Guánica Bay watershed. The bay is served directly by one river, the Rio Loco, which flows intermittently and more frequently during the rainy season. The watershed has gone through a series of manipulations and alterations in past decades, mainly associated with agricultural practices, including irrigation systems, in the upper watershed. The Guánica Lagoon, previously situated to the north of the bay, was historically the largest freshwater lagoon in Puerto Rico and served as a natural filter and sediment sink prior to the discharge of the Rio Loco into the Bay. Following alterations by the Southwest Water Project in the 1950s, the Lagoon's adjacent wetland system was ditched and drained; no longer filtering and trapping sediment from the Rio Loco. Land use in the Guánica Bay/Rio Loco watershed has also gone through several changes (CWP, 2008). Similar to much of Puerto Rico, the area was largely deforested for sugar cane cultivation in the 1800s, although reforestation of some areas occurred following the cessation of sugar cane production (Warne et al., 2005). The northern area of the watershed is generally mountainous and is characterized by a mix of forested and agricultural lands, particularly coffee plantations. Closer to the coast, the Lajas Valley Agricultural Reserve extends north of Guánica Bay to the southwest corner of the island.

The land use practices and watershed changes outlined above have resulted in large amounts of sediment being distributed in the Rio Loco river valley (CWP, 2008). Storm events and seasonal flooding also transport large amounts of sediment to the coastal waters. The threats of upstream watershed practices to coral reefs and the nearshore marine environment have been gaining recognition. Guánica Bay, and the adjacent marine waters, has been identified as a "management priority area" by NOAA's Coral Reef Conservation Program (CRCP, 2012). In a recent Guánica Bay watershed management plan, several critical issues were outlined in regards to land-based sources of pollution (LBSP; CWP, 2008). These include: upland erosion from coffee agriculture, filling of reservoirs with sediment, in-stream channel erosion, loss of historical Guánica lagoon, legacy contaminants and sewage treatment (CWP, 2008). The plan recommended several management actions that could be taken to reduce impacts of LBSP, which form the basis of Guánica watershed restoration efforts.

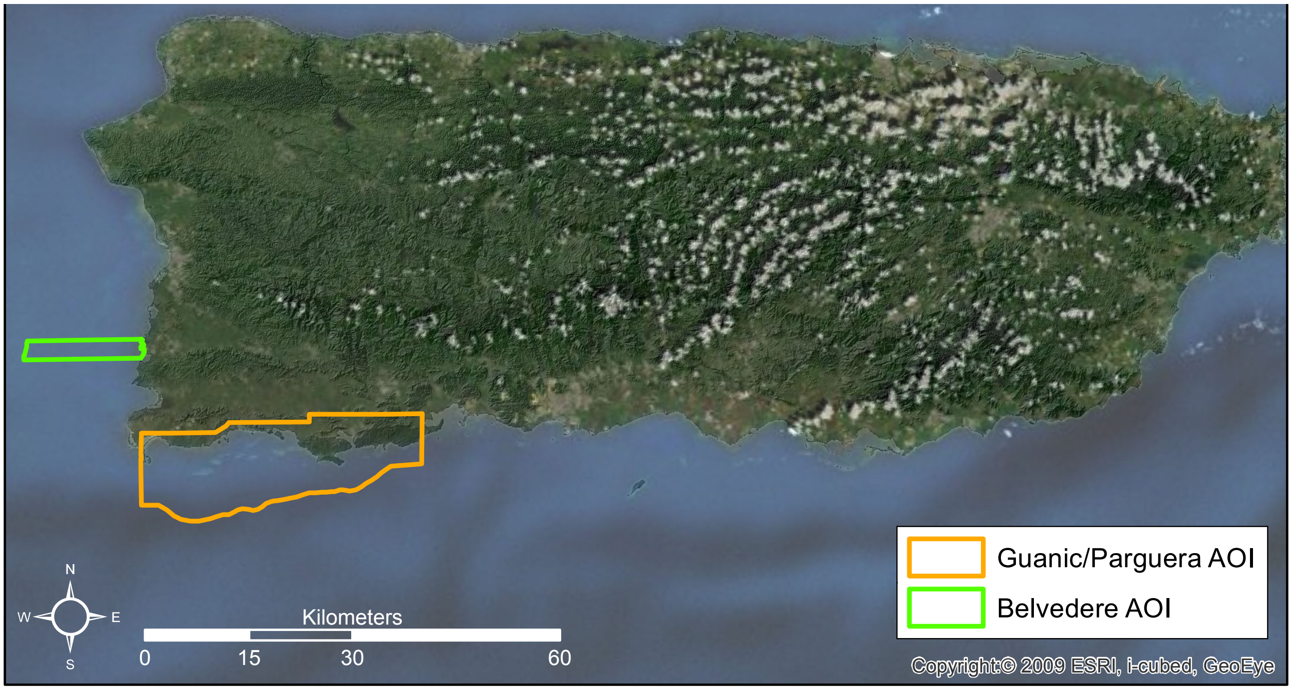


Figure 1. Location of Guanica/Parguera and Belevdere areas of interest (AOI) in southwest Puerto Rico.

The Guánica watershed restoration project is a multi-disciplinary, multi-faceted effort with numerous federal and territorial partners, including NOAA's National Centers for Coastal Ocean Science (NCCOS), NOAA's Coral Reef Conservation Program, NOAA's Restoration Center, USDA's Natural Resources Conservation Service and the Center for Watershed Protection. Current and proposed restoration projects in the watershed include the restoration of the historic Guánica Lagoon and adjacent coastal wetlands, conversion of sun grown to shade grown coffee, sewage treatment upgrades and stabilization of the Rio Loco river channel. A primary objective of these restoration activities is to reduce nutrient and sediment loading into the marine environment, with the ultimate goal of improving coral reef health.

In order to measure the effectiveness of restoration efforts, it is critical that baseline data be collected to which potential future changes can be compared. An ecological characterization of the Guánica Bay region is being conducted and will serve as a baseline assessment with which the success of these efforts can be evaluated. Updated fine-scale benthic habitat maps will support this effort and allow for potential future changes in the spatial distribution of habitats and benthic cover to be evaluated following completion of the restoration activities.

Additionally, this work supports ongoing efforts to characterize benthic habitats and human uses in marine protected areas (MPAs) of Puerto Rico, particularly those identified by the Department of Natural and Environmental Resources (DNER) as priority watershed areas (L. Carrubba, personal communication). Two of these priority areas include the Guánica Dry Forest Natural Reserve (Bosque Estatal de Guánica), located adjacent to and east of Guánica Bay, and the Finca Belvedere Natural Reserve (Reserva Natural Finca Belvedere) on the west coast of Puerto Rico. Through coordination with and support from the NOAA Fisheries Caribbean Field Office, the study area was expanded to include the extent of the marine environment adjacent to both reserves.

The Finca Belvedere Natural Reserve was established in 2002 and covers a coastal area of ~256 acres of wetlands and mangroves (DRNA, 2002). The mangroves serve as a rookery for a variety of native, migratory, and residential bird species, and the marine extension of the reserve contains a diverse array of habitats, including seagrass beds and coral reefs (DRNA, 2002). The reserve is bordered by the densely populated town of Puerto Real. Similar to the Guánica/Parguera region, there has been concern regarding the effects of LBSP on the wetlands and the adjacent marine ecosystem. Leakage of septic tanks is a widespread problem, a significant percentage of which are located in proximity to the wetlands or Puerto Real Bay (Norat and Mattei, 2006). In a recent study of non-point source fecal pollution in southwestern Puerto Rico, a gradient was detected across the shelf, with the most turbid, polluted survey sites located in Puerto Real adjacent to Finca Belvedere (Bonkosky et al., 2008). Ongoing research efforts by Puerto Rico DNER are focusing on potential impacts of land-based sources of sediment on nearshore marine ecosystems in the Belvedere-Puerto Real coastal areas.

This report consists of four primary components: 1) a description of the benthic habitat classification scheme used to classify habitats, 2) a discussion of the techniques used for map creation, 3) an assessment of map accuracy, and 4) a summary of map statistics, habitat distributions and deliverables. The maps will be used by managers and scientists for planning, research and monitoring activities, and will support the management and conservation of the watershed and coastal marine waters of Guánica, Belvedere, and greater southwest Puerto Rico. The benthic habitat map and a suite of associated products are available to the public on the NCCOS Center for Coastal Monitoring and Assessment (CCMA) Biogeography Branch web site devoted to this mapping effort (http://ccma.nos.noaa.gov/ecosystems/coralreef/Guánica.aspx).

BENTHIC HABITAT CLASSIFICATION SCHEME

The habitat classification scheme defines benthic habitats based on five attributes: 1) broad geographic zone; 2) geomorphological structure type; 3) dominant biological cover; 4) amount of live coral cover; and 5) percent hardbottom. Every feature in the benthic habitat map is assigned a designation from each level of the scheme (Table 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.

Many factors were considered in the development of this 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 the southwest Puerto Rico map 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,b). The scheme used here was also used in the recent mapping of Vieques, Puerto Rico (Bauer et al., 2010) and Jobos Bay, Puerto Rico (Costa et al., 2011).

Table 1. The classification scheme used to classify benthic habitats in the Guanica/Parguera and Belvedere regions of southwest Puerto Rico.

Geographic Zone	**Geomorphological Structure**	**Biological Cover**	**Percent Hardbottom**
Land	Coral Reef and Hardbottom	**Major Cover**	
Salt Pond	Rock/Boulder	Algae	0% - <10%
Shoreline Intertidal	Aggregate Reef	Seagrass	10% - <30%
Lagoon	Individual Patch Reef	Live Coral	30% - <50%
Reef Flat	Aggregated Patch Reefs	Mangrove	50% - <70%
Back Reef	Spur and Groove	No Cover	70% - <90%
Reef Crest	Pavement	Unknown	90% - 100%
Fore Reef	Pavement with Sand Channels		Unknown
Bank/Shelf	Reef Rubble	**Percent Major Cover**	
Bank/Shelf-Escarpment	Rhodoliths	10% - <50%	
	Unknown	50% - <90%	
Channel	Unconsolidated Sediment	90% - 100%	
Dredged	Sand	Unknown	
Unknown	Mud	**Percent Coral Cover**	
	Sand with Scattered Coral and Rock	0% - <10%	
	Unknown	10% - <50%	
	Other Delineations	50% - <90%	
	Land	90% - 100%	
	Artificial	Unknown	
	Unknown		

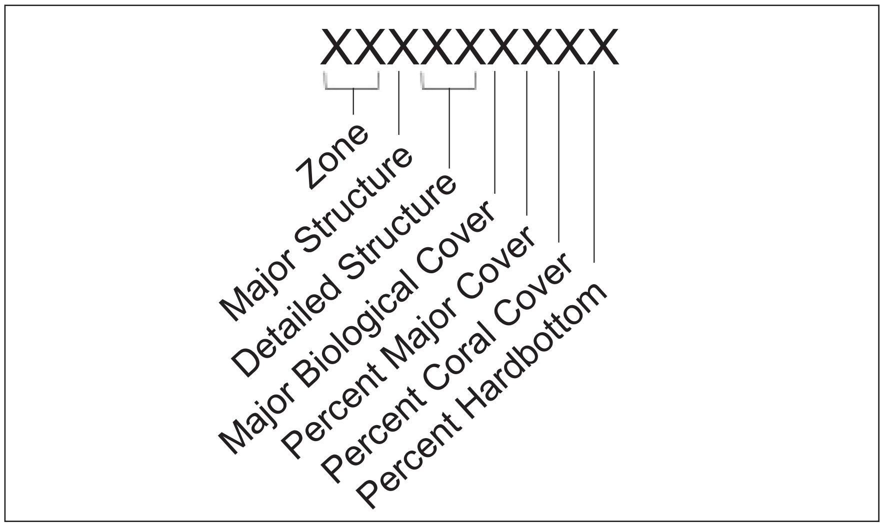


Figure 2. Schematic of each attribute's position in the Unique ID *code of the classification scheme.*

The primary difference between the new scheme and the one used by Kendall et al. (2001) in the previous mapping of southwest Puerto Rico is the separation of biological cover from habitat structure and additional detailed classes. Dominant biological cover, live coral cover and percent hardbottom were not identified in the previously used scheme. In NOAA's new southwest Puerto Rico habitat classification scheme, biological cover was described simply as the dominant cover type on each feature of the map. Percent cover of live coral was mapped separately in the southwest Puerto Rico scheme by the introduction of an additional map attribute *Percent Coral Cover*. This attribute describes the percent live coral cover (includes "hard" scleractinians and "soft" gorgonians) for every feature. 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 patch reefs in it could be classified as 10% - <50% live coral cover even though 90% of the polygon is bare sand.

Every unique combination of classification attributes was provided a distinct identifier in the *Unique ID* field of the GIS layer. *Unique ID* consists of an eight-digit number string with each position in the string corresponding to a specific map attribute (Figure 2). Within each attribute, different classifications were assigned discrete numbers.

Geographic Zones

Thirteen mutually exclusive zones can be identified from land to open water corresponding to typical insular shelf and coral reef geomorphology. These zones include: *Land, Salt Pond, Shoreline Intertidal, Lagoon, Reef Flat, Back Reef, Reef Crest, Fore Reef, Bank/Shelf, Bank/Shelf Escarpment, Channel, Dredged* and *Unknown*. Figures 3-5 illustrate zone types across typical cross-sections of the island shelf when the reef feature is either separated from shore by a lagoon (Figure 3), fringing the shore (Figure 4) or not emergent (Figure 5). Zone refers only to each benthic community's location and does not address substrate or biological cover types that are found within. A brief description of each zone is provided in the following text.

Land

Terrestrial features at or near the spring high tide line (Figure 6). 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. (Unique ID = 10)

Salt Pond

Enclosed area just landward of the shoreline with a permanent or intermittent flooding regime of saline to hypersaline waters. (Unique ID = 11)

Shoreline Intertidal

Area between the spring high tide line (or landward edge of emergent vegetation when present) and lowest spring tide level. Typically, this zone is narrow due to the small tidal range in Puerto Rico (Figure 7). 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. (Unique ID = 12)

Lagoon

Shallow area (relative to the deeper water of the bank/shelf) between the *Shoreline Intertidal* zone and the *Back Reef* of a reef or a barrier island. This zone is typically protected from the high-energy waves commonly experienced on the *Bank/Shelf* and *Reef Crest* zones (Figure 8). (Unique ID = 13)

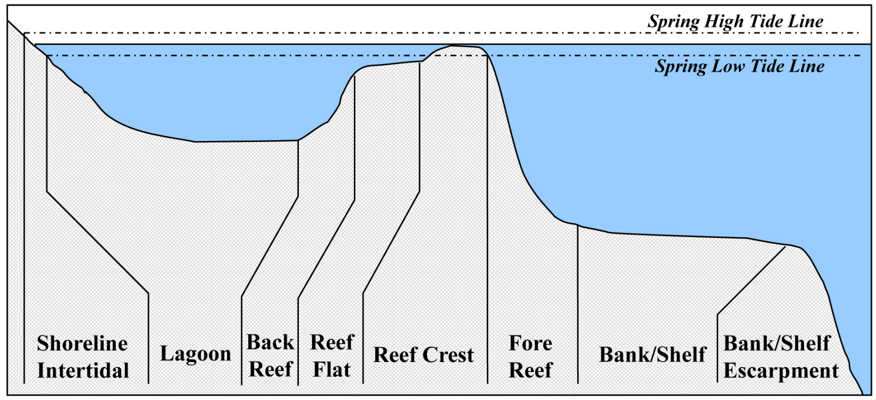


Figure 3. Cross-section of zone types where a barrier reef is present. Reef is separated from the shore by a relatively wide, deep lagoon.

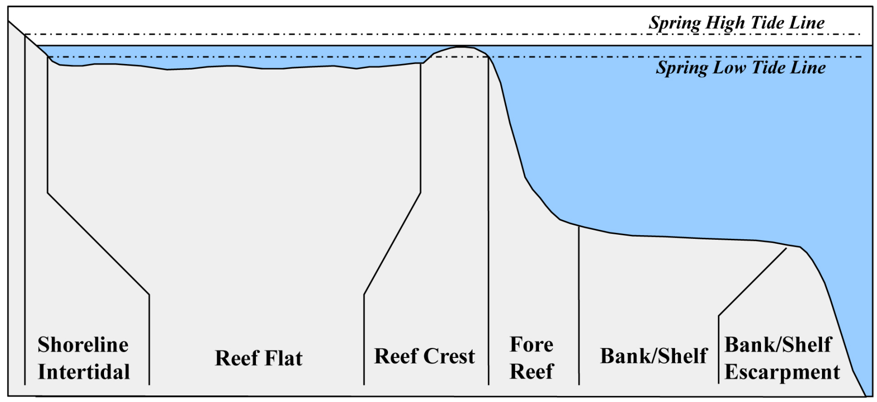


Figure 4. Cross-section of zone types where a fringing reef is present. Reef platform is continuous with the shore.

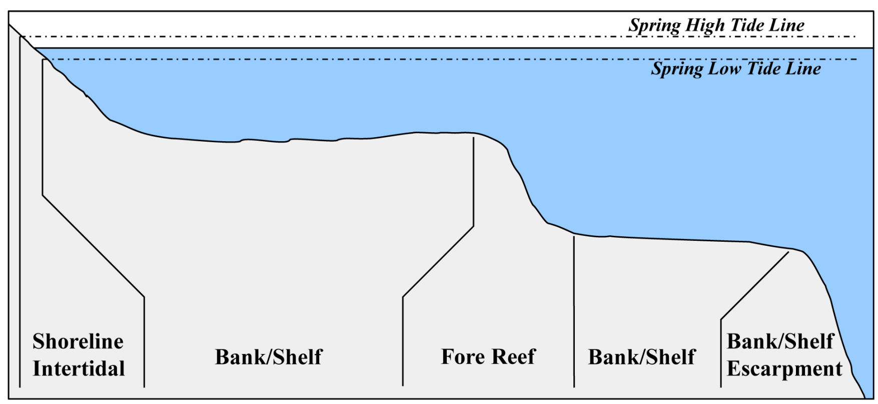


Figure 5. Cross-section of zone types where no emergent reef crest is present.

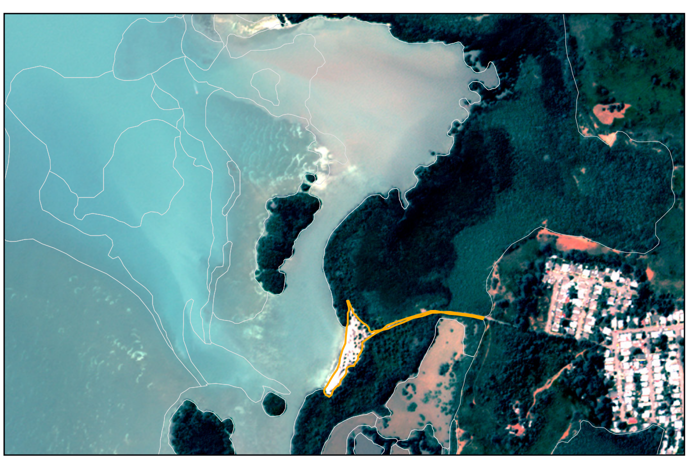


Figure 6. View of the Land *zone on satellite imagery. An orange polygon outlines the features.*

Figure 7. View of Shoreline Intertidal *zone on satellite imagery. An orange polygon outlines the features.*

Reef Flat
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 often somewhat protected from the high-energy waves commonly experienced on the *Bank/Shelf* and *Reef Crest* zones (Figure 9). (Unique ID = 14)

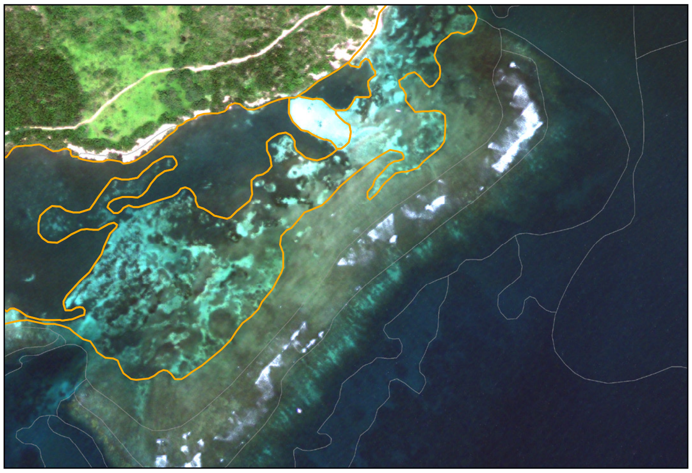


Figure 8. View of the Lagoon *zone on satellite imagery. An orange polygon outlines the feature.*

Figure 9. View of the Reef Flat *zone on satellite imagery. An orange polygon outlines the feature.*

Back Reef
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 (Figure 10). (Unique ID = 15)

Reef Crest
The flattened, emergent (especially during low tides) or nearly emergent segment of a reef. This high wave energy zone 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 10). (Unique ID = 16)

Fore Reef
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* (Figure 10). (Unique ID = 17)

Figure 10. A series of satellite images illustrating the transition from Back Reef *(left) to* Reef Crest *(middle) to* Fore Reef *(right) zones. Orange polygons outline the zone on the respective map.*

Bank/Shelf
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. (Unique ID = 18)

Bank/Shelf Escarpment
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. This zone is intended to capture the transition from the shelf to deep waters of the open ocean. (Unique ID = 19)

Channel
Naturally occurring channels that often cut across several other zones (Figure 11). (Unique ID = 20)

Dredged
Area in which natural geomorphology is disrupted or altered by excavation or dredging. (Unique ID = 21)

Figure 11. View of the Channel *zone on satellite imagery. Orange polygons outline the features on satellite imagery.*

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

Geomorphological Structure Types

Fifteen distinct and non-overlapping geomorphologic structure types were described that can be mapped by visual interpretation of remotely-sensed imagery. Habitats or features that cover areas smaller than the MMU were not considered. For example, sand halos surrounding patch reefs are often too small to be mapped independently. Structure refers only to predominate 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 15 detailed classes (*Rock/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*).

Coral Reef and Hardbottom

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 lack a thick sediment cover, but a thin veneer of sediment may be present at times. Detailed structure classes within this category include *Rock/Boulder, Spur and Groove, Individual Patch Reef, Aggregated Patch Reefs, Aggregate Reef, Reef Rubble, Pavement, Pavement with Sand Channels* and *Rhodoliths*. (Unique ID = 1)

Rock/Boulder
A primarily continuous exposure of solid carbonate blocks or volcanic rock extending offshore from the island bedrock or aggregation of loose carbonate or volcanic rock fragments that have been detached and transported from their native beds (Figure 12). Individual boulders range in diameter from 0.25 – 3 m as defined by the Wentworth scale (Wentworth, 1922). (Unique ID = 33)

Aggregate Reef
Continuous, high-relief coral formation of variable shapes lacking sand channels of *Spur and Groove*. Includes linear coral formations that are oriented parallel to shore or the shelf edge (Figure 13). This class is used for such commonly referred to terms as linear reef, fore reef or fringing reef. (Unique ID = 10)

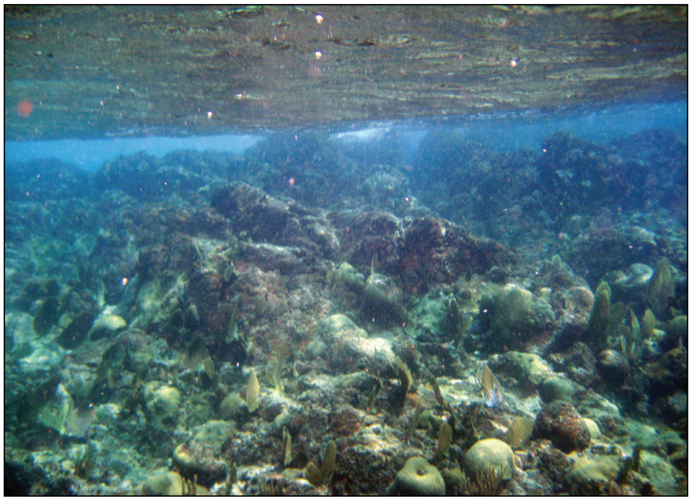
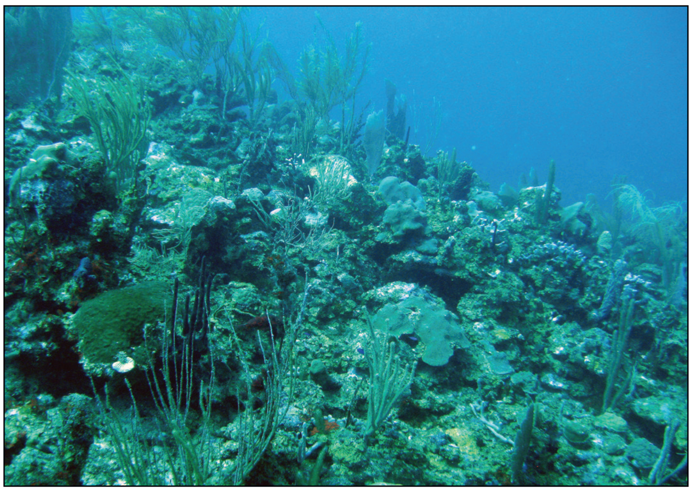


Figure 12. Depictions of Rock/Boulder *structure in Puerto Rico. An orange polygon outlines the feature on satellite imagery.*



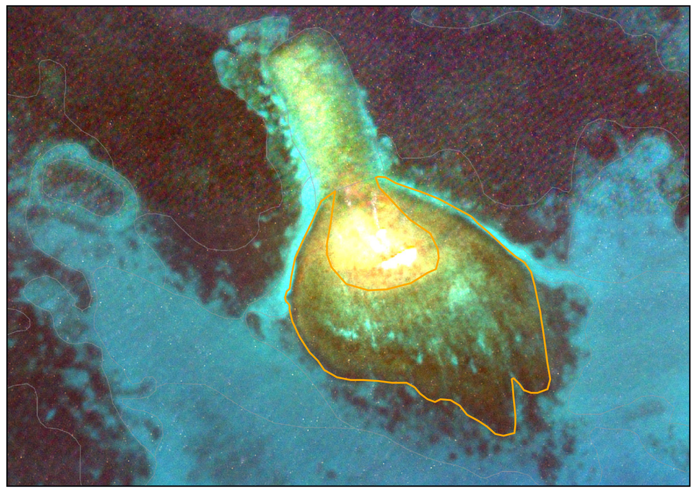


Figure 13. Depictions of Aggregate Reef *structure in Puerto Rico. An orange polygon outlines the feature on satellite imagery.*

Individual Patch Reef
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 14). *Individual Patch Reefs* are larger than or equal to the MMU. (Unique ID = 11)

Aggregated Patch Reefs
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 14). (Unique ID = 12)

Spur and Groove
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 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 15). This habitat type typically occurs in the *Fore Reef* or *Bank/Shelf Escarpment* zone. (Unique ID = 13)

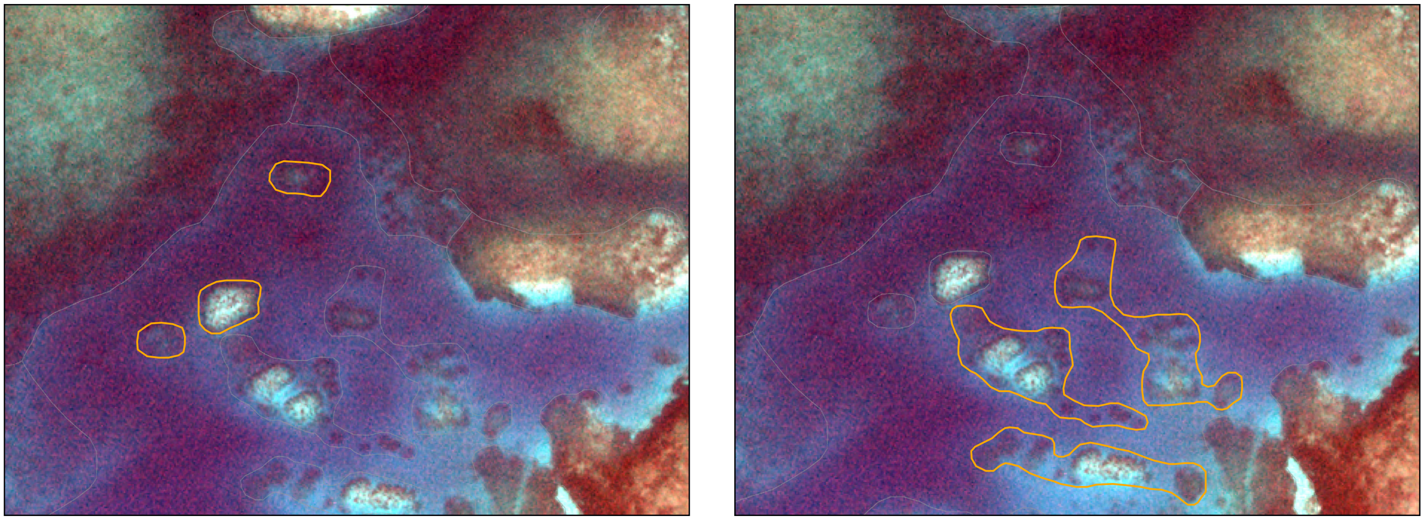


Figure 14. Comparison of patch reef delineations. Due to the influence of MMU, patch reefs of the same complex are designated by either Individual Patch Reef *(left) or* Aggregated Patch Reefs *(right). Orange polygons outline the features on satellite imagery.*

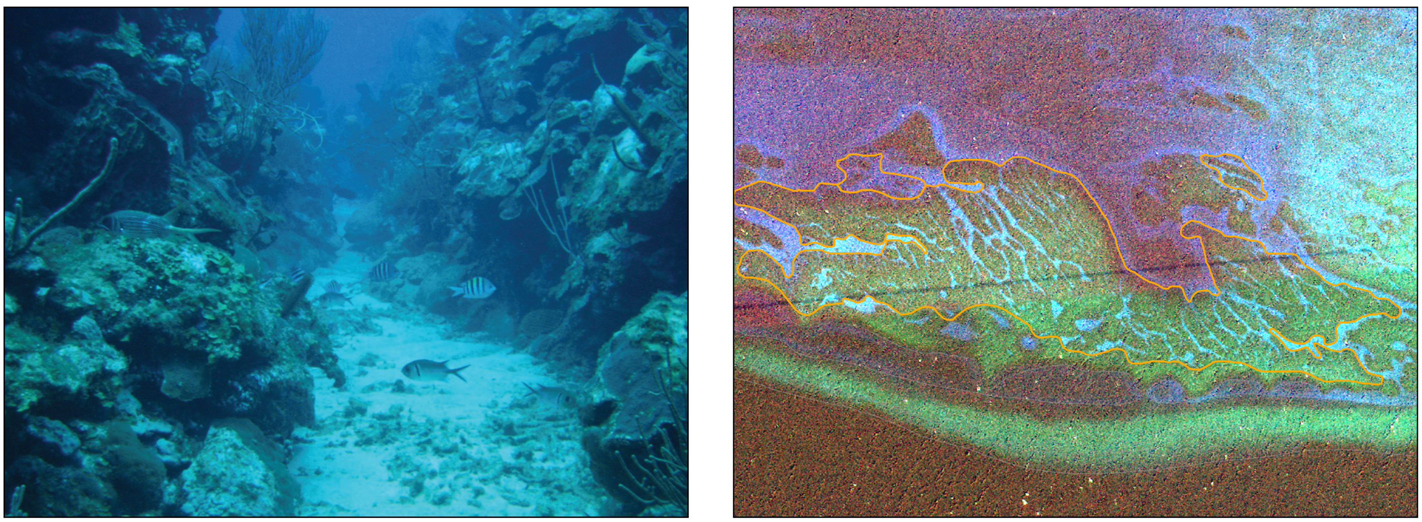


Figure 15. Depictions of Spur and Groove *structure. Orange polygons outline the features on satellite imagery.*

Pavement

Flat, low-relief, solid carbonate rock in regularly broad areas with coverage of algae, hard coral, gorgonians, zooanthids or other sessile vertebrates that are dense enough to partially obscure the underlying surface (Figure 16). On less colonized *Pavement* features, rock may be covered by a thin sand veneer or turf algae. (Unique ID = 14)

Pavement with Sand Channels

Habitats of pavement with alternating sand/surge channel formations that are oriented perpendicular to the shore or *Bank/Shelf Escarpment*. The sand/surge channels of this feature have low vertical relief relative to *Spur and Groove* formations. This habitat type occurs in areas exposed to moderate wave surge such as the *Bank/Shelf* zone (Figure 17). (Unique ID = 15)

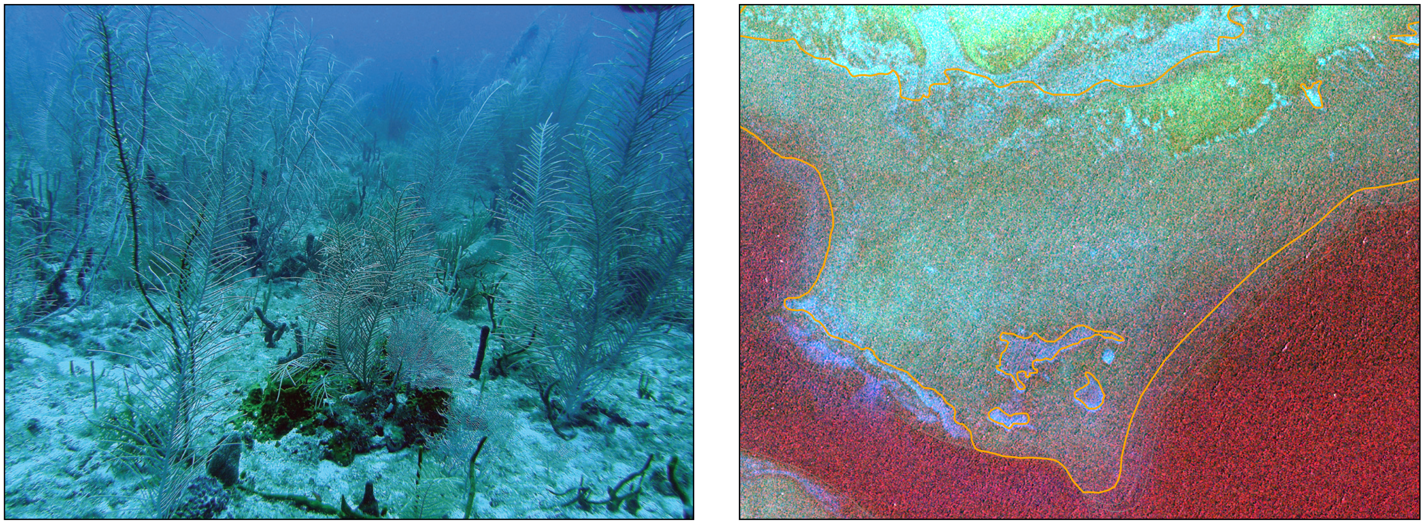


Figure 16. Depictions of Pavement *structure. Orange polygons outline the features on satellite imagery.*

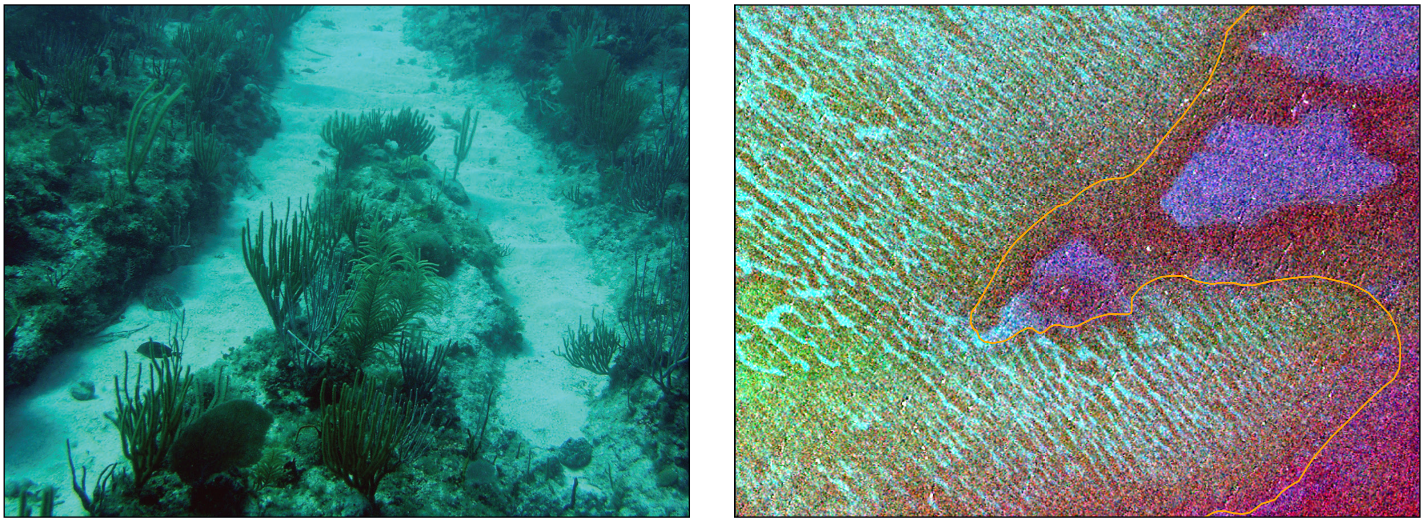


Figure 17. Depictions of Pavement with Sand Channels *structure. An orange polygon outlines the feature on satellite imagery.*

Reef Rubble

Dead, unstable coral rubble often colonized with turf, filamentous or other macroalgae. This habitat often occurs landward of well developed reef formations in the *Reef Crest, Back Reef* or *Reef Flat* zones (Figure 18). Less often, *Reef Rubble* can occur in low density aggregations on broad offshore sand areas. (Unique ID = 16)

Rhodoliths

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. (Unique ID = 17)

Unconsolidated Sediment

Areas of the seafloor consisting of small particles with less than 10% cover of large stable substrate. Detailed structure classes of softbottom include *Sand*, *Mud*, and *Sand with Scattered Coral and Rock*. (Unique ID = 2)

Sand

Coarse sediment typically found in areas exposed to currents or wave energy (Figure 19). Particle sizes range from 1/16 – 256 mm, including pebbles (Wentworth, 1922). (Unique ID = 18)

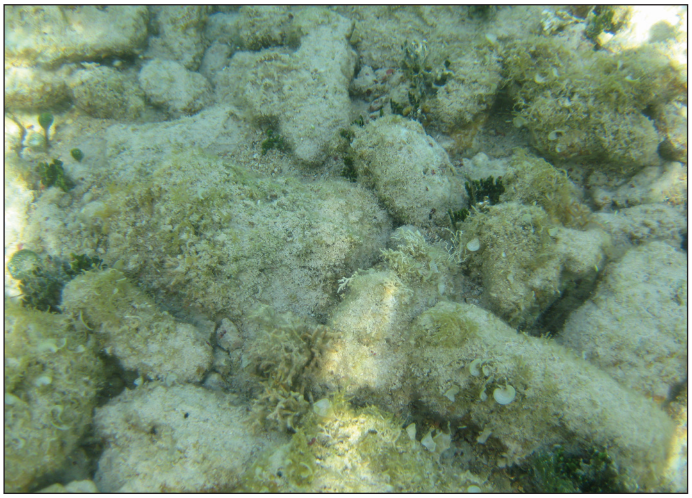
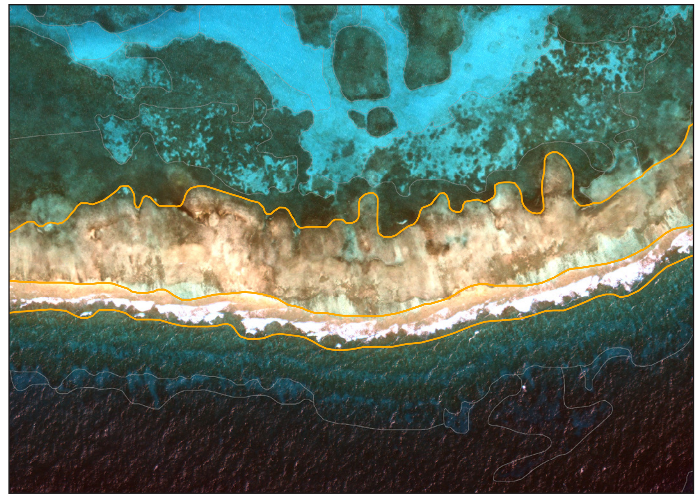



Figure 18. Depictions of Reef Rubble *structure. Orange polygons outline the features on satellite imagery.*

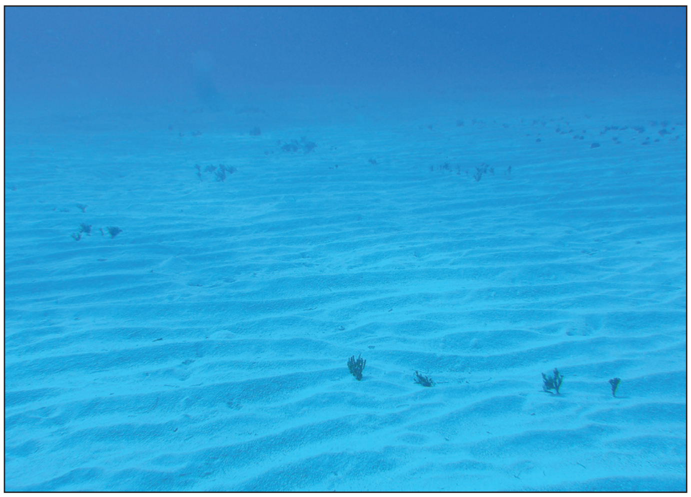



Figure 19. Depictions of Sand *structure. The features outlined by orange polygons include* Sand *with no biological cover (lighter), as well as with seagrass and algae (darker).*

Mud

Fine sediment often associated with river discharge and build-up of organic material in areas sheltered from high-energy waves and currents (Figure 20). Particle sizes range from <1/256 – 1/16 mm (Wentworth, 1922). (Unique ID = 19)

Sand with Scattered Coral and Rock

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 21). If the density of small coral heads is greater than 10% of the entire polygon, this structure type is described as *Aggregated Patch Reefs*. (Unique ID = 20)

Other Delineations

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*. (Unique ID = 3)

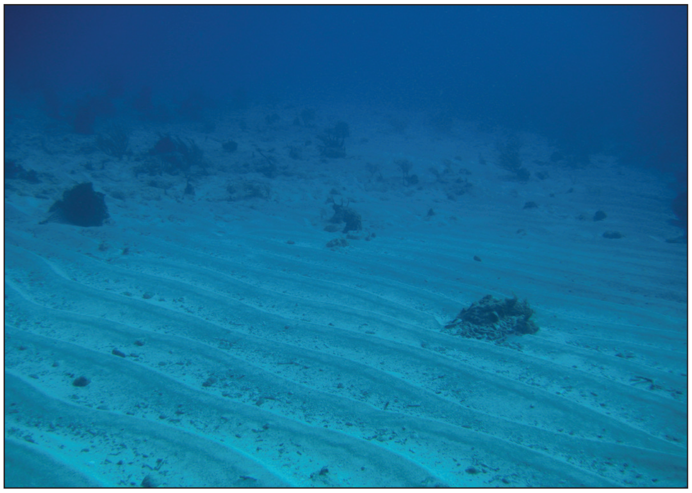
Land

Terrestrial features at or near the spring high tide line. (Unique ID = 21)

Artificial

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

Figure 20. Depictions of Mud *structure. Orange polygons outline the features on satellite imagery.*



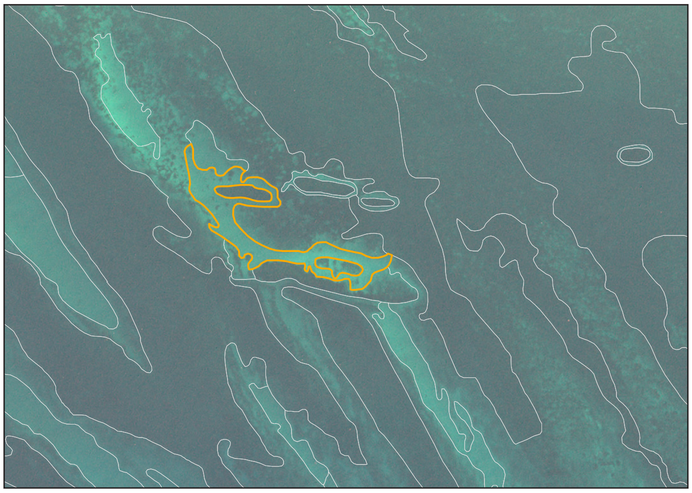


Figure 21. Depictions of Sand with Scattered Coral and Rock *structure. An orange polygon outlines the feature on satellite imagery.*

Unknown

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

Unknown

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

Biological Cover Classes

Eighteen distinct and non-overlapping biological cover classes were identified that can be mapped through visual interpretation of remotely-sensed imagery. Cover classes refer only to the biological component colonizing the surface of the feature and does not address zone or structure type. Habitats or features that cover areas smaller than the MMU were not considered. The cover types are defined as seven major classes (*Algae, Seagrass, Live Coral, Mangrove, No Cover, Unclassified* and *Unknown*), combined with a modifier describing the distribution of the dominant cover type throughout the mapping unit (*10%-<50%, 50%-<90%, 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/cameras in the water. For example, a seagrass bed can be described as having 90%-100% biological cover, but have sparse shoot densities when observed by divers or video. Figure 22 is a visual aid used by mappers to estimate patchiness.

Major Cover

Algae

Substrates with 10% or greater distribution of any combination of numerous species of red, green or brown algae. May be turf, fleshy, coralline or filamentous species. Occurs throughout many zones, especially on hard bottoms with low coral densities and soft bottoms in deeper waters on the *Bank/Shelf* zone (Figure 23). (Unique ID = 1)

Seagrass

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 24). (Unique ID = 2)

Live Coral

Substrates colonized with 10% or greater live reef building corals and other organisms including scleractinian (e.g., *Acropora sp.*) and octocorals (e.g., *Briareum sp.*; Figure 25). This category is rare in the U.S. Caribbean. (Unique ID = 3)

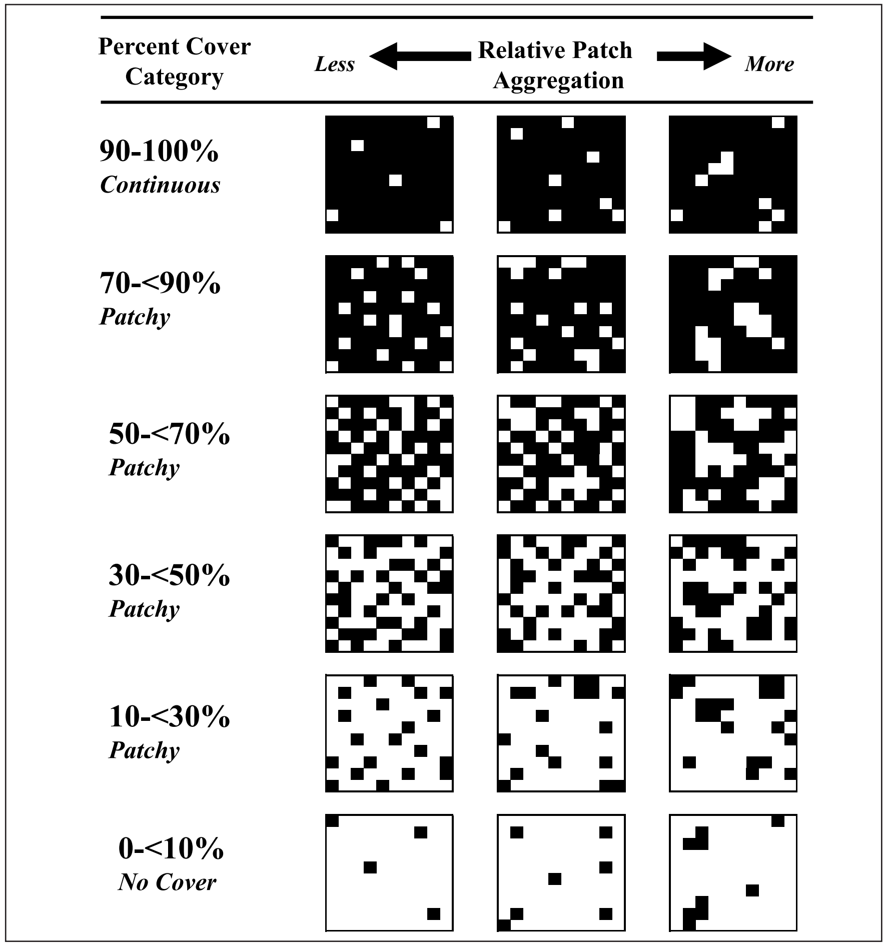


Figure 22. Guidance chart to aid visual interpreter's estimation of patchiness in assigning percent cover. Note that each large square denotes a MMU.

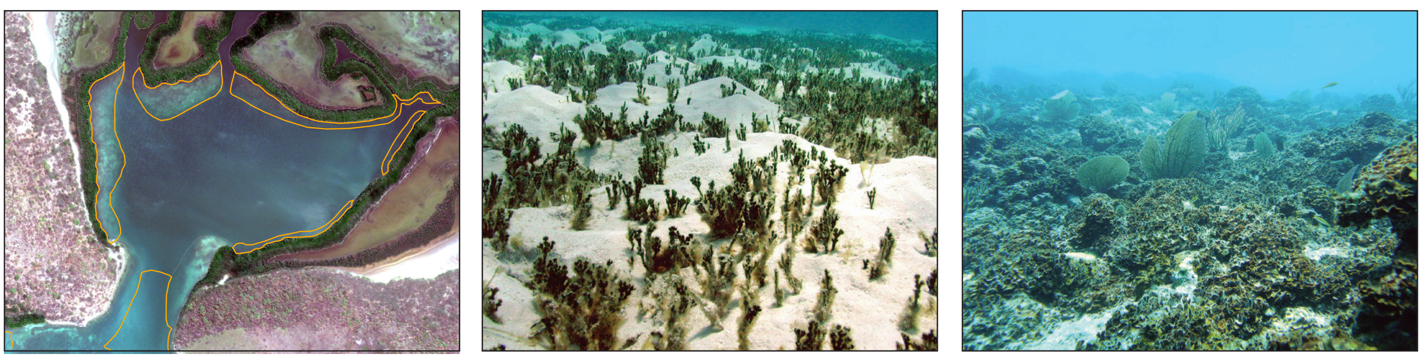


Figure 23. Depictions of Algae *dominated habitats. Orange polygons outline algal-dominated features in Puerto Rico. Underwater pictures illustrate the different algal covers on unconsolidated sediment (middle) and hardbottom (right).*

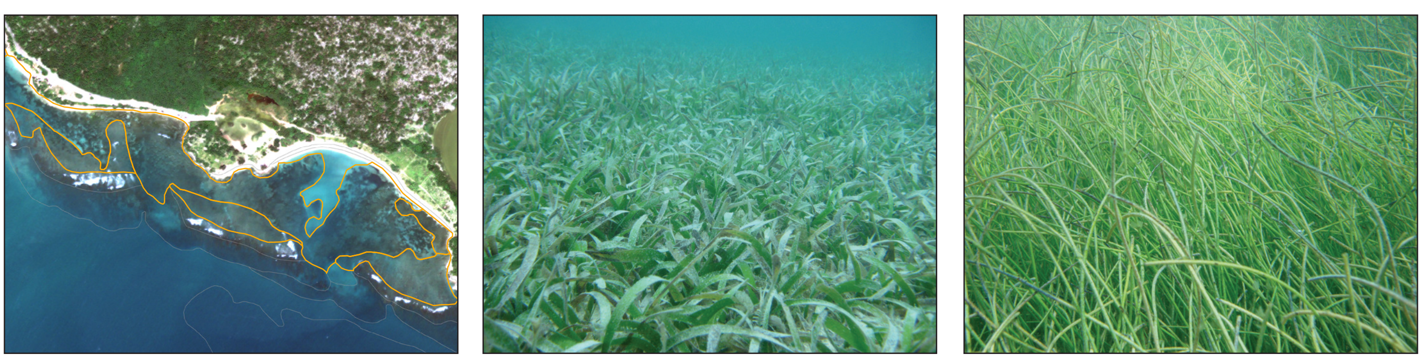


Figure 24. Extensive Seagrass *beds are prevalent in southwest Puerto Rico. Orange polygons outline the features on satellite imagery. Turtle Grass (*Thalassia testudinum*; middle) and Manatee Grass (*Syringodium filiforme*; right) are both common.*

Mangrove

Mangrove habitat is comprised of semi-permanently, seasonally or tidally flooded mangrove vegetation formations that grow near the sea (Figure 26). Mangrove trees are halophytes; plants that thrive in and are especially adapted to salty conditions. In Puerto Rico 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 mangrove habitats along the coast. Generally found in areas sheltered from high-energy waves, including along rivers, on coral cays, around salt flats and coastal lagoons. This habitat type is usually found in the *Shoreline Intertidal* zone. (Unique ID = 4)

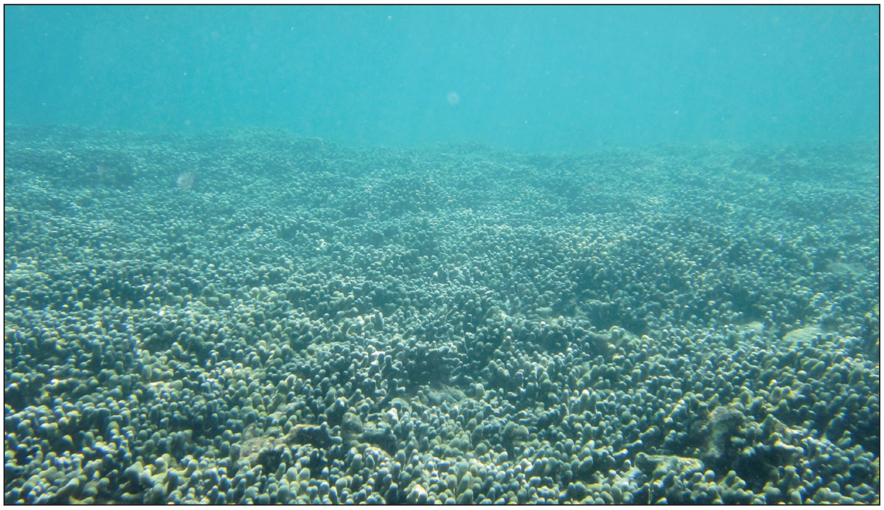


Figure 25. Although coral-dominated habitats were rare in southwest Puerto Rico, this reef flat, characterized by extensive cover of Porites porites*, was an exception.*

No Cover

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 27). (Unique ID = 6)

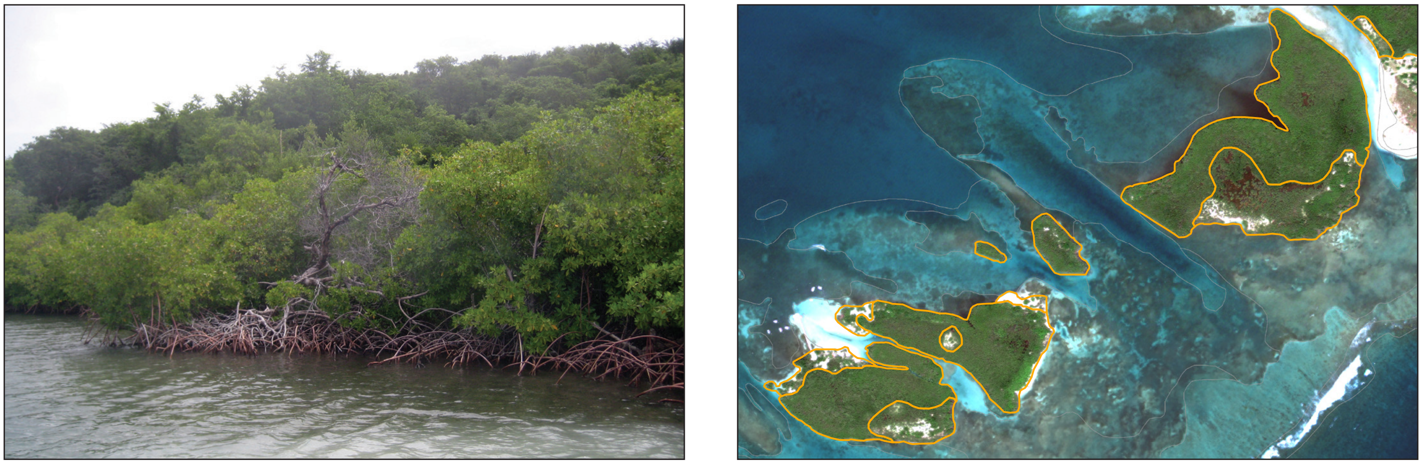


Figure 26. Depictions of Mangrove *cover. Orange polygons outline the features on satellite imagery.*

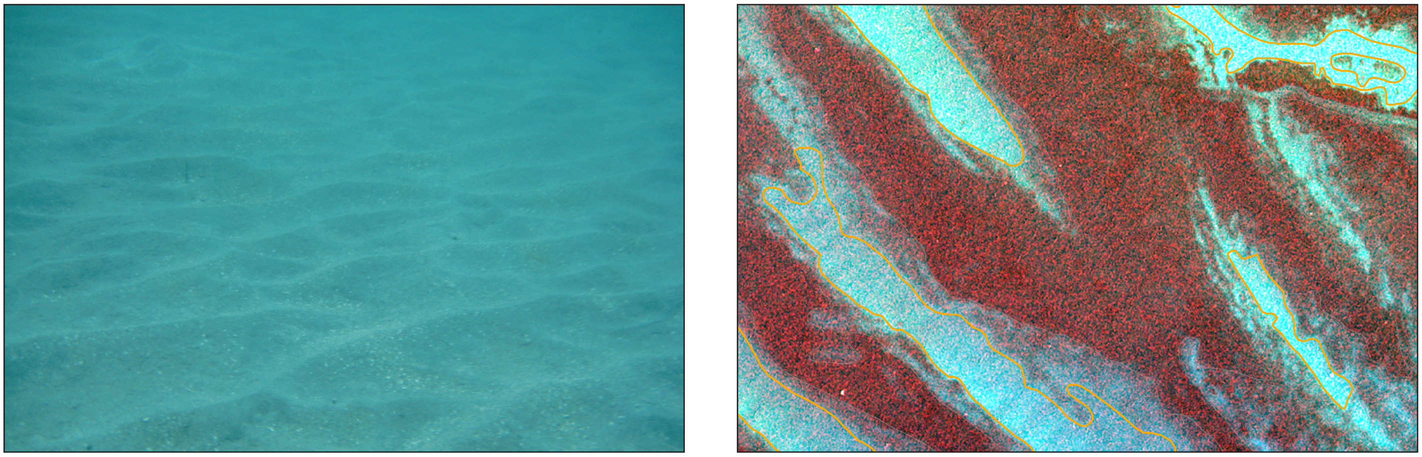


Figure 27. Depictions of sand with No Cover. Orange polygons outline the features on satellite imagery.

Unclassified
A different biological cover type, such as upland, deciduous forest, that is not included in this habitat classification scheme. Most often used on polygons defined as *Land* with terrestrial vegetation. (Unique ID = 7)

Unknown
Biological cover is indistinguishable due to turbidity, cloud cover, water depth or other interference with an optical signature of the seafloor. (Unique ID = 9)

Percent Major Cover

Patchy 10% - <50%
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 28). (Unique ID = 2)

Patchy 50% - <90%
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 28). (Unique ID = 3)

Continuous 90% - 100%
Major biological cover type covering 90% or greater of the substrate (Figure 28). 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). (Unique ID = 4)

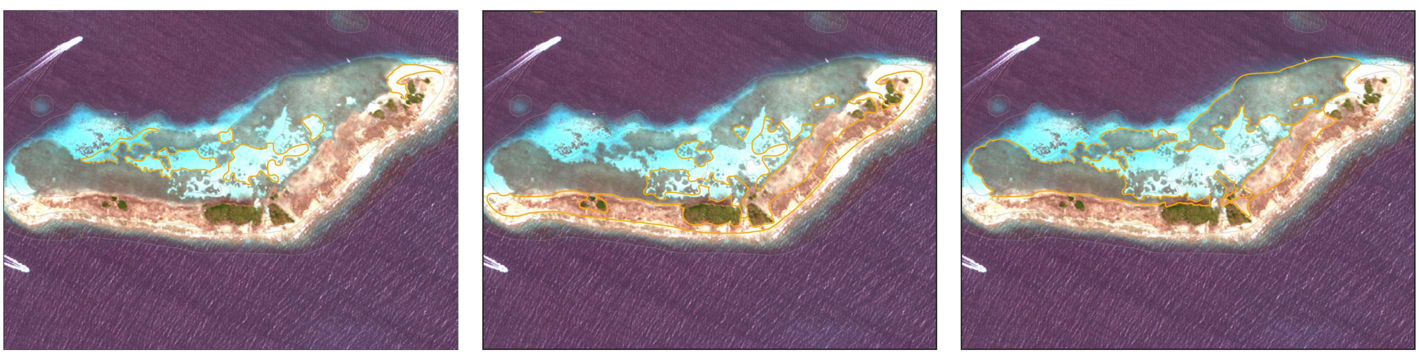


Figure 28. Representation of the three percent major cover modifiers (left to right: 10% - <50%, 50% - <90%, 90% - 100%) using a seagrass bed as an example. Orange polygons outline the features on satellite imagery.

Not Applicable
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. (Unique ID = 5)

Unknown
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. (Unique ID = 9)

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 and ground-truthing. This attribute is an additional biological cover modifier used to maintain information on the percent cover of live coral, both scleractinian and octocorals (Figure 29), 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%, 90% - 100%). Distinction of scleractinian coral versus octocoral (i.e., hard versus soft coral) was limited by the current state of remote sensing technology and could not be separated in the Live Coral Cover modifier.

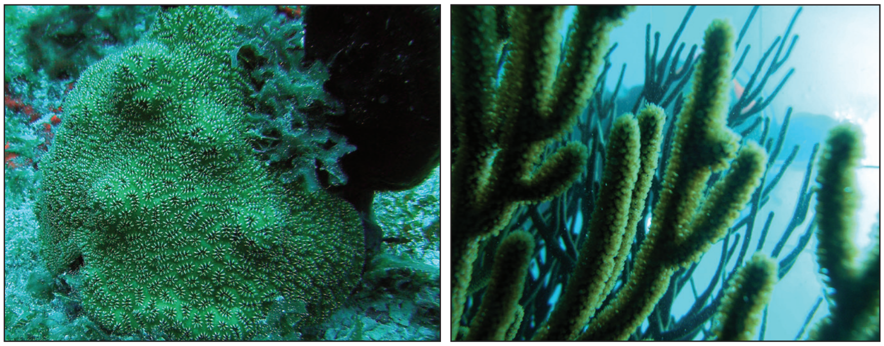


Figure 29. Both scleractinian (left) and octocorals (right) were included when estimating percent live coral cover.

Live coral cover describes the percent coverage on hardbottom features at a fine-scale (i.e., 1-3 meters off the seafloor), not the distribution at the scale of delineation, as was the case for dominant biological cover. For this reason, extensive *in situ* data is necessary. Also, Percent Live Coral Cover refers only to the hardbottom component of any mapped polygon. For instance, an area of sand with some scattered coral and rock in it could be classified as 10% - <50% live coral cover even though 90% of the polygon is bare sand.

0% - <10%
Live coral cover of less than 10% of hardbottom substrate observed from 1-3 meters above the seafloor (Figure 30). (Unique ID = 1)

10% - <50%
Live coral cover between 10% and 50% of hard bottom substrate observed from 1-3 meters above the seafloor (Figure 30). (Unique ID = 2)

50% - <90%
Live coral cover between 50% and 90% of hard bottom substrate observed from 1-3 meters above the seafloor (Figure 30). (Unique ID = 3)

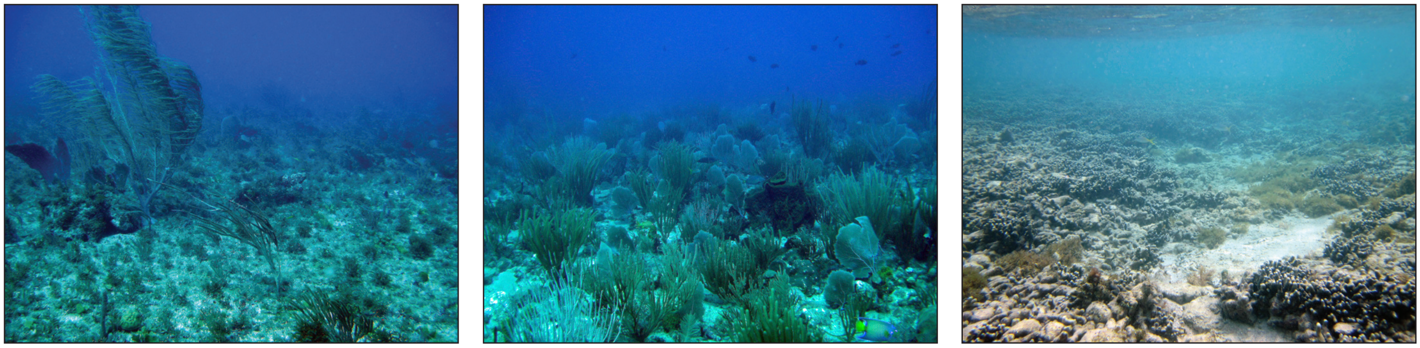


Figure 30. Illustration of live coral in the 0<10% (left), and 10% - 50% (middle) and 50% - 90% cover range.

90% - 100%
Continuous live coral consisting of 90% or greater cover of the hard bottom substrate observed from 1-3 meters above the seafloor. (Unique ID = 4)

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

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

Percent Hardbottom Classes

An additional modifier was attributed to all polygons (except *Land*) to describe the percentage of hardbottom within that polygon. Several of the detailed structure types are heterogeneous in nature (e.g., *Aggregated Patch Reefs*, *Pavement w/ Sand Channels*, *Spur and Groove*), and the purpose of this modifier was to provide additional information about these structure types. It is expected that this will be useful in field survey planning when knowledge of the likelihood of encountering reef/hardbottom in an area is desired, or in estimating the actual amount of hardbottom in a polygon or mapped area. As with percent cover, Figure 22 was used as an aid to estimate the percent hardbottom in a polygon.

0% - <10%
Less than 10% of the structure within the polygon is hard substrate. All polygons attributed as *Unconsolidated Sediment* would have this designation. (Unique ID = 1)

10% - <30%
Hardbottom substrate between 10% and 30% of the polygon. (Unique ID = 2)

30% - <50%
Hardbottom substrate between 30% and 50% of the polygon. (Unique ID = 3)

50% - <70%
Hardbottom substrate between 50% and 70% of the polygon. (Unique ID = 4)

70% - <90%
Hardbottom substrate between 70% and 90% of the polygon. (Unique ID = 5)

90% - <100%
Hardbottom substrate between 90% and 100% of the polygon. (Unique ID = 6)

Not Applicable
An estimate of percent hardbottom is not appropriate for this particular feature. Regularly occurs in areas describing the terrestrial environment. (Unique ID = 7)

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

MAP CREATION

Benthic habitat maps of the nearshore marine environment of the southwest Puerto Rico region were created by visual interpretation of remotely sensed imagery. Remotely sensed imagery, including GeoEye satellite imagery and color orthophotography, proved to be an excellent source from which to derive the edges, extent and attributes of marine habitats. Boundaries of features were delineated on digital imagery using a Geographic Information System (GIS) and a custom extension to ArcGIS 9.3 that enabled easy attribution of bottom features. Field investigations were conducted from small marine vessels in order to ground validate the spectral signature created by the myriad of submerged features of the marine environment. Once digital maps were produced, an assessment of thematic map accuracy was conducted.

General Mapping Approach

NOAA's approach to 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 the southwest Puerto Rico region, two separate data types were used (GeoEye satellite imagery and color orthophotography) to capture the full mappable extent using optical techniques.

2. Habitat Boundary Delineation – A draft 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 field investigation. These sites were referred to 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. This information was analyzed and the initial maps were edited to generate a second draft map.

4. Expert Review – The second draft map was then distributed to local marine biologists, resource managers, and other experts for review. Comments were integrated into the map products to generate a third draft map.

5. Accuracy Assessment – Field investigations were conducted at pre-defined locations to assess the accuracy of the third draft map. Locations were generated with a stratified random sampling design that allowed for a statistically rigorous assessment of map accuracy. An independent NOAA scientist, not associated with map creation, classified the video and conducted the analysis.

6. Final Products Creation – A final benthic habitat map for the southwest Puerto Rico region was generated by correcting inaccuracies identified 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.

Imagery Acquisition and Processing

Remote sensing 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. Generally, feature detection of seafloor habitats is possible from the shoreline to water depths of approximately 30 meters, depending on water clarity. The GeoEye-1 satellite imagery employed here provides precise and robust data with spectral and spatial resolutions suitable for shallow water benthic mapping. The GeoEye-1 satellite, owned and operated by GeoEye, provides commercially available panchromatic (black and white) and multispectral (blue/green/red/near-infrared) imagery. The panchromatic imagery has a 0.41 m pixel resolution and the multispectral imagery has a 1.65 m pixel resolution.

GeoEye imagery was collected for the southwest Puerto Rico region in 2010. Due to software-imagery compatibility limitations, the NCCOS CCMA Biogeography Branch processed the raw GeoEye imagery into two distinct data products useful in benthic habitat mapping: pansharpened imagery and deglinted multispectral imagery.

First, ENVI 4.6.1 software was used to derive a high-resolution, pansharpened and georeferenced dataset. For each scene, ENVI’s “Pan Sharpening” tool created a full-color image at the panchromatic band’s resolution (0.41 m). This image fusion tool merges the spectral signatures of the input color bands while using the panchromatic band to enhance the spatial features, two useful outcomes for the photointerpreter. Subsequently, geo-referencing was performed using ENVI’s “Orthorectify GeoEye-1 with Ground Control” module. The ground control points (GCPs) were fixed ground features visible in the imagery that are used along with the satellite’s ephemeris data to link the image pixels to a coordinate system. NOAA scientists occupied and logged these points using a L1 Trimble GeoXT mapping grade GPS unit, and accuracy was enhanced by adjusting to the continuously-operating base station (PRMI CORS) located on Magueyes Island, Puerto Rico. Due to the difficulty of obtaining precise positions for submerged features, only ground control points for terrestrial features were collected. Also as part of this module, terrain displacement was corrected for using the U.S. Geological Survey’s Digital Elevation Model (DEM). Once individually orthorectified, the scenes from each acquisition were geographically matched tightly to one another using ENVI’s “Warp From GCPs: Image to Image” tool. The “tie points” that were used as GCP’s for this step were not occupied. They were simply distinct features – such as street intersections, piers, recreation field delineations and bridges – which were visible in overlap areas of two given images. The pansharpened, georeferenced and co-registered imagery provided high-resolution, full-color datasets for the cartographer.

Another complication of seafloor mapping with passive optical imagery is that the reflection of solar radiation on non-flat 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. The glint can obscure bottom features and should be removed before habitat delineation. However software-imagery compatibility constraints prevented the NCCOS CCMA Biogeography Branch from deglinting the pansharpened scenes, so an alternate workflow was developed using PCI Geomatica 10.3. The PCI "OrthoEngine" module was used to merge the four multispectral bands into a single file, which was subsequently georeferenced in "OrthoEngine" using the same GCP's and DEM mentioned above. The scenes from each acquisition were then co-registered using analogous tie points discernible in the multispectral imagery. The lower-resolution (1.65 m) datasets were then deglinted in PCI's "Focus" using the band ratio methodology described by Hedley et al. (2005).

During the mapping process, the cartographer used both the pansharpened and deglinted multispectral imagery to guide benthic habitat mapping. The finer-resolution pansharpened imagery was used as the primary source for delineation when possible; however in areas of heavy glint, the deglinted imagery was more often referenced.

Digital orthophotos for southwest Puerto Rico were the secondary imagery source used for delineating benthic habitats. Imagery was collected by 3001, Inc. under contract to the U.S. Army Corps of Engineers, in September and October of 2007 to produce orthophotos with a one foot ground sample distance. Flight height was maintained at 8,650 ft above ground level throughout the acquisition effort and was collected at 30% sidelap. As the data were collected primarily for terrestrial purposes, the coverage of the marine environment varied between photos. However, the high-resolution imagery was often very useful for delineating nearshore features.

Habitat Boundary Delineation and Attribution

The southwest Puerto Rico benthic habitat map and mapping methods were developed using ESRI's ArcGIS 9.3 (ESRI, 2008) and an ArcGIS extension created by NOAA, the Habitat Digitizer Extension (Buja, 2008a). 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 previously, 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 in order to standardize the map output. The MMU restriction was set to 1,000 m^2 (~0.25 acre). In contrast, NOAA's previous maps of Puerto Rico and the U.S. Virgin Islands were created with a one acre MMU, or 4,047 m^2 (Kendall et al., 2001). This reduction was in response to the coral reef management community's interest in having finer resolution maps to make resource management decisions. However, there were still features visible in the imagery, such as patch reefs, which were smaller than the MMU and were not included as individual features in the map.

The digitizing scale was set to 1:3,000. The interpreter was allowed to zoom in and out to varying scales when assessing an area, but always returned to 1:3,000 before boundary delineation. Qualitative experimentation results adapted from Kendall et al. (2001) indicated that digitizing at this scale optimized the trade-off between positional accuracy of lines and time spent digitizing. 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. In addition, the resolution of the imagery often influences the digitizing scale. For example, when zooming in on a feature, there becomes a scale at which the feature becomes less distinct. Although the smaller pixel size of the orthophotos could have allowed mapping at a finer scale, as in Zitello et al. (2009), who used a 1:2,000 scale, 1:3,000 was more appropriate for the lower resolution GeoEye-1 imagery.

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 (Figure 31). 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 polygons, an approach often used for seagrass beds of varying patchiness. 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.

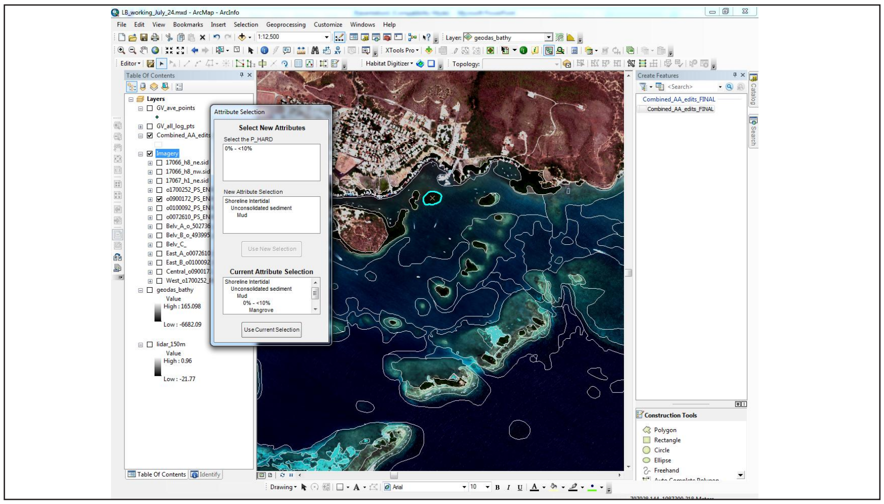


Figure 31. The NCCOS CCMA Biogeography Branch's Habitat Digitizer Extension (Buja, 2008a) was used to attribute map polygons with all components of the habitat classification scheme.

Brightness, contrast and histogram 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), bathymetry nautical charts and imagery from different time periods.

Ground Validation

The creation of high-quality benthic habitat maps requires field work to enhance accuracies of habitat attribution and habitat delineation. Following the generation of an initial draft benthic habitat map, a team of NOAA scientists explored selected field locations to verify habitat type. 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 land to sea 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 selected while the photo interpreter was generating the draft habitat map. Geographic coordinates were extracted for these sites and uploaded into Garmin GPS 76 WAAS-enabled hand-held devices. Data were collected on 511 GV sites (Figure 32) over a 10-day field mission in March 2011. Of this total, 126 were located within the Belvedere region and 385 were located in the Parguera/Guánica region. At each survey location, 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 deploy a SeaViewer Sea-Drop 950 camera and begin logging waypoints on a Trimble GeoXT GPS receiver. The drop camera reached the bottom in approximately 5-10 seconds and bottom imagery was recorded to a digital video recorder (DVR). 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 fact, it was often advantageous for the vessel to drift across habitat transitions. Position logging in the Trimble receiver

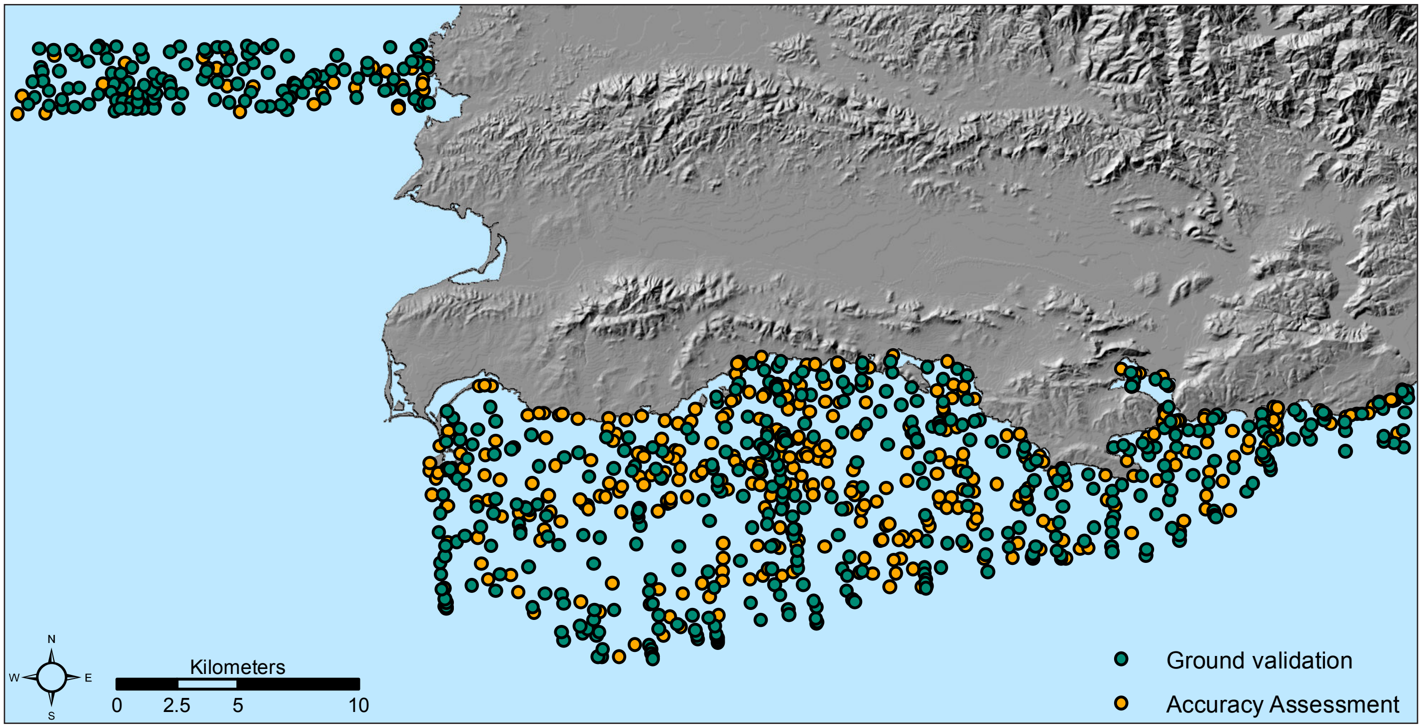


Figure 32. Spatial distribution of the ground validation and accuracy assessment sites visited during the 2011 field missions.

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

While the video camera was recording, an observer viewed the video real-time on the DVR 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.

Of the 511 sites occupied during ground validation, 467 were assessed with the underwater drop camera. Shallow, nearshore sites that were inaccessible by the survey vessel 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.

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 Puerto Rico 5 (PURS). The digital videos were reviewed and 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.

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

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

ACCURACY ASSESSMENT

Thematic accuracy of the benthic maps was characterized for major and detailed geomorphological structure, major and detailed biological cover, percent hardbottom and percent coral cover.

Collection of Field Data

Sites for the accuracy assessment procedure were determined through a stratified random sampling technique. Funding and logistical constraints indicated that 416 sites could be included (Figure 32). Points were initially distributed based on the proportion of area occupied by each of the 12 detailed structure categories in a draft benthic map. Classes that covered a large proportion of the total area but are easy to interpret had some points redistributed to other bottom classifications. For example, sand comprised ~46% of the mapped area and could therefore have received half of the assessment effort. Experience has shown, however, that *Sand* is relatively easily and accurately mapped (>90% correct; Battista et al., 2007a; Walker and Foster, 2009; Zitello et al., 2009). Therefore, the assessment effort was redistributed to other important bottom types such as *Aggregate Reef,* and *Spur and Groove* that covered less area (7 and 4% of the study area). Survey effort was raised to a minimum of 20 points per classification category to more adequately assess all bottom types.

Data were collected during a field mission from June 21 to July 1, 2012. Navigation to sample locations was conducted using GPS. Underwater video was taken at each site, provided the location was safely accessible by the survey vessel. 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, a string of GPS waypoints were recorded on board the vessel. At least three positions 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 positions that tracked boat movement at each site. Video at each site was categorized for major/detailed geomorphological structure, major/detailed biological cover, percent hardbottom and percent coral cover.

Very shallow, nearshore sites were often not accessible by the survey vessel and video camera system and therefore were surveyed using snorkeling gear and a digital camera. Mangrove sites were generally assessed from the boat or land after approaching the target as close as possible.

Evaluation of Assessment Data

The GPS positions were determined to have a positional accuracy of <1 m for most points. For each survey site, multiple GPS positions were combined 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 some cases vessel drift caused the survey to cross polygon edges. In these cases, the “average” survey point was shifted to the portion of the transect and polygon that was intended to be assessed.

Each video clip or digital picture was viewed in concert with the benthic habitat map and the remote sensing imagery of each site. All analysis at this stage was made by a photointerpreter independent of the scientist who created the benthic 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 in which the site occurred was actually only 50% - <90% upon examination of the imagery, the patchiness for the survey point was changed to 50% - <90%. 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 if the vessel/video did not drift over a sand channel. 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*.

Following these adjustments, the map classification underlying each point was extracted. Sites that differed between field notes and map classification were further evaluated both in GIS and from video to determine possible sources of disagreement. At this stage, mismatches between GPS and map attributes that were a product of the differences in scale between the video data and imagery rather than errors in classification were identified. 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 remote sensing imagery. 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.

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. 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, 410 points were included in the accuracy assessment analysis for major and detailed structure, 397 for major biological cover, 396 for detailed biological cover, 412 for percent hard bottom and 408 for percent coral cover (Figure 32).

Analysis of Thematic Accuracy

The thematic accuracy of the benthic 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, percent hard bottom, 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 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 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 cell in the matrix was divided by the column total (n_{i-}) to yield a producer's accuracy and by the row total (n_{-j}) 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 categories, was calculated. As the number of categories increases, the probability of random agreement (Pr) diminishes, and T_e approaches P_o. See Ma and Redmond (1995) for mathematical equations.

Redistribution of sampling effort caused rare but important map categories to be sampled at a greater rate than common map categories. Such allocation is necessary for reasonable assessment of individual map categories but introduced bias when assessing overall accuracy (Hay, 1979; Card, 1982). The bias introduced by differential sampling rates was removed using the method of Card (1982), which utilizes the proportional areas of each map category relative to the total map area. The category proportions were also utilized in the computation of confidence intervals (CI) for the overall, producer's, and user's accuracies (Card, 1982; Congalton and Green, 1999). This approach was modeled after Walker and Foster (2009), who recently conducted an accuracy assessment of a benthic map of the Florida Keys.

The category proportions (π_j) were computed from the GIS layer of the draft benthic habitat map by dividing the area of each category by the total map area. Proportions were not computed for the percent coral cover matrix. Due to the way percent coral cover was estimated, doing so would have required an adjustment by the percent hardbottom, and there was insufficient sample size of all combinations of the percent coral and percent hardbottom categories. The individual cell probabilities were computed as the product of the original error matrix cell values and π_j, divided by the total number of assessment points per category ($n_{\cdot j}$).

The relative proportions of the cell values within a row of the error matrix were unaffected by this operation, but the row total of a particular category now equaled the fraction of map area occupied by that category (π_j), instead of the total number of accuracy assessment points within it ($n_{\cdot j}$). The estimated true proportions (p_i) of each map category given the observed classification errors were computed as the sum of individual cell probabilities down each column of the error matrix.

The π_j-adjusted overall and producer's accuracies were then computed from the new error matrix. The values of the π_j-adjusted overall and producer's accuracies differ from those of the original error matrix, as they have been corrected for the areal bias introduced by stratified random sampling and the effort redistribution 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 using the equations of Card (1982).

Accuracy Assessment Results and Discussion

Major Geomorphological Structure

Error matrices for major geomorphological structure are displayed in Table 2 for the simple tally of assessment points and Table 3 for the unbiased values of producers and overall accuracy corrected by category proportions. The overall accuracy (P_o) when calculated by a simple tally of correct points was 95.4% (Table 2). The Tau coefficient was 0.907 ± 0.041. Adjusted overall accuracy, corrected for bias using the map category proportions, was 93.6 (±2.5)% (Table 3). The user's and producer's accuracies were similarly high for both hard and softbottom habitats (Table 3).

Table 2. Error matrix for major geomorphological structure.

Map data (j)	Accuracy Assessment (i): Hard	Soft	$n_{\cdot j}$	User's Acc. (%)
Hard	**218**	10	228	**95.6%**
Soft	9	**173**	182	**95.1%**
$n_{i\cdot}$	227	183	n=410	
Producer's Accuracy (%)	**96.0%**	**94.5%**	**P_o =**	**95.4%**
			T_e =	**0.907 ± 0.041**

Table 3. Error matrix for major geomorphological structure, using individual cell probabilities. The overall accuracy and producer's accuracy were corrected for bias using the category proportions.

Map data (j)	Accuracy Assessment (i): Hard	Soft	$\pi_{\cdot j}$	User's Acc. (%)	User's CI (±%)
Hard	**0.372**	0.032	0.404	**92.1%**	**3.6%**
Soft	0.032	**0.564**	0.596	**94.7%**	**3.3%**
p_i	0.404	0.596	π=1		
Producer's Accuracy (%)	**92.2%**	**94.6%**	**P_o =**	**93.6%**	
Producer's CI (±%)	**4.5%**	**2.3%**	**CI(±) =**	2.5%	

Detailed Geomorphological Structure

Error matrices for detailed geomorphological structure are displayed in Table 4 for the simple tally of assessment points and Table 5 for the unbiased values of producers and overall accuracy corrected by category proportions. The overall accuracy (P_o) when calculated by a simple tally of correct points was 82.9%, with a Tau coefficient (T_e) of 0.814 ± 0.397 (Table 4). The adjusted overall accuracy, corrected for bias using the category proportions, was similar at 81.7 (±4.8)% (Table 5).

Table 4. Error matrix for detailed geomorphological structure.

Accuracy Assessment (i)

Map data (j)	Aggregate Reef	Aggregate Patch Reef	Individual Patch Reef	Spur and Groove	Pavement	Pav w/ Sand Channels	Rock/Boulder	Reef Rubble	Rhodolith	Sand w/ SCR	Sand	Mud	$n_{\cdot j}$	User's Accuracy (%)
Aggregate Reef	**26**				3								29	**89.7%**
Aggregate Patch Reef		**27**									2		29	**93.1%**
Individual Patch Reef		2	**32**										34	**94.1%**
Spur and Groove	3			**11**									14	**78.6%**
Pavement		3			**21**	2				3	3		32	**65.6%**
Pav w/ Sand Channels				4	3	**25**							32	**78.1%**
Rock/Boulder							**30**				1		31	**96.8%**
Reef Rubble	4	1			1			**19**	1	1			27	**70.4%**
Rhodolith													0	**n/a**
Sand w/ SCR		2			1	1				**20**	8		32	**62.5%**
Sand		1	1		1			1	1	1	**73**	5	84	**86.9%**
Mud											10	**56**	66	**84.8%**
$n_{i\cdot}$	33	36	33	15	30	28	30	20	2	25	97	61	n=410	
Producer's Accuracy (%)	**78.8%**	**75.0%**	**97.0%**	**73.3%**	**70.0%**	**89.3%**	**100.0%**	**95.0%**	**0.0%**	**80.0%**	**75.3%**	**91.8%**	**P_o =**	**82.9%**

T_e = 0.814 ± 0.397

Table 5. Error matrix for detailed geomorphological structure. The overall accuracy and producer's accuracy were corrected for bias using the category proportions.

Accuracy Assessment (i)

Map data (j)	Aggregate Reef	Aggregated Patch Reef	Individual Patch Reef	Spur and Groove	Pavement	Pav w/ Sand Channels	Rock/Boulder	Reef Rubble	Rhodolith	Sand w/ SCR	Sand	Mud	$\pi_{\cdot j}$	User's Accuracy (%)	User's CI (±%)
Aggregate Reef	0.0662				0.0076								0.074	**89.7%**	**11.31%**
Aggregated Patch Reef		0.0270									0.0020		0.029	**93.1%**	**9.41%**
Individual Patch Reef		0.0004	0.0060										0.006	**94.1%**	**8.07%**
Spur and Groove	0.0097			0.0355									0.045	**78.6%**	**21.93%**
Pavement		0.0148			0.1036	0.0099				0.0148	0.0148		0.158	**65.6%**	**16.79%**
Pav w/ Sand Channels				0.0097	0.0073	0.0608							0.078	**78.1%**	**14.62%**
Rock/Boulder							0.0011				0.0000		0.001	**96.8%**	**6.35%**
Reef Rubble	0.0019	0.0005			0.0005			0.0091	0.0005	0.0005			0.013	**70.4%**	**17.58%**
Rhodolith													0.000	**n/a**	**n/a**
Sand w/ SCR		0.0021			0.0010	0.0010				0.0209	0.0084		0.033	**62.5%**	**17.12%**
Sand		0.0055	0.0055		0.0055			0.0055	0.0055	0.0055	0.3992	0.0273	0.459	**86.9%**	**7.36%**
Mud											0.0156	0.0875	0.103	**84.8%**	**8.83%**
$p_{i\cdot}$	0.078	0.050	0.011	0.045	0.126	0.072	0.001	0.015	0.006	0.042	0.440	0.115	π=1		
Producer's Accuracy (%)	**85.1%**	**53.7%**	**52.2%**	**78.5%**	**82.5%**	**84.8%**	**100.0%**	**62.6%**	**0.0%**	**50.2%**	**90.7%**	**76.2%**	**P_o =**	**81.7%**	
Producer's CI (±%)	11.1%	21.4%	49.7%	16.5%	11.2%	16.3%	0.0%	46.9%	n/a	24.6%	4.1%	15.9%	**CI(±) =**	**4.8%**	

Accuracies for individual map categories must be interpreted cautiously due to the low sample sizes (<15 points). User's accuracy was above 70% for 9 of the 12 categories (Table 5). Categories with relatively low accuracies that were evaluated by an adequate number of points were *Pavement* (65.6%) and *Sand with Scattered Coral and Rock* (62.5%). Both these categories had relatively large confidence intervals. *Pavement* was confused with several other bottom types. *Sand with Scattered Coral and Rock* was most often misclassified simply as *Sand*, a very similar bottom type that often occurs adjacent to areas with scattered coral or rock. *Mud* and *Sand* had high accuracy but were occasionally confused with each other. This often occurred in *Mangrove* habitats where ground truthing of substrate types is difficult.

Major Biological Cover

Error matrices for major biological cover are displayed in Table 6 for the simple tally of assessment points and Table 7 for the unbiased values of producers and overall accuracy corrected by category proportions. The overall accuracy (P_o) when calculated by a simple tally of correct points was 87.9%, with a Tau coefficient (T_e) of 0.849 ± 0.049 (Table 6). The adjusted overall accuracy, corrected for bias using the map category proportions, was lower but well within acceptable limits at 84.6 (±4.0)% (Table 7). *Mangrove* was always mapped correctly. User's accuracy was acceptable for all other classes with an adequate number of assessment points. Reciprocal errors in mapping seagrass and algae beds were the most common error in cover because these categories are commonly intermixed. Accuracy of mapped coral cover will be discussed in the section Percent Coral Cover (see page 27).

Table 6. Error matrix for major biological cover.

	Accuracy Assessment (i)						
	Algae	Live Coral	Mangrove	Seagrass	No Cover	$n_{.j}$	User's Acc. (%)
Algae	**228**	1		13	5	247	**92.3%**
Live Coral				1		1	**0.0%**
Mangrove			**39**			39	**100.0%**
Seagrass	15			**64**	3	82	**78.0%**
No Cover	4			6	**18**	28	**64.3%**
$n_{i.}$	**247**	**1**	**39**	**84**	**26**	n=397	
Producer's Accuracy (%)	**92.3%**	**0.0%**	**100.0%**	**76.2%**	**69.2%**	P_o =	**87.9%**
						T_e =	**0.849 ± 0.049**

Table 7. Error matrix for major biological cover. The overall accuracy and producer's accuracy were corrected for bias using the category proportions.

Map data (j)	Accuracy Assessment (i)							
	Algae	Live Coral	Mangrove	Seagrass	No Cover	$\pi_{.j}$	User's Acc. (%)	User's CI (±%)
Algae	**0.5489**	0.0024		0.0343	0.0169	0.602	**91.1%**	**3.6%**
Live Coral				0.0016		0.002	**0.0%**	**0.0%**
Mangrove			**0.0189**			0.019	**100.0%**	**0.0%**
Seagrass	0.0374			**0.1815**	0.0092	0.228	**79.6%**	**8.9%**
No Cover	0.0207			0.0310	**0.0930**	0.145	**64.3%**	**18.1%**
$p_{i.}$	0.607	0.002	0.019	0.248	0.119	π=1		
Producer's Accuracy (%)	**90.4%**	**0.0%**	**100.0%**	**73.1%**	**78.1%**	P_o =	**84.6%**	
Producer's CI (±%)	**4.0%**	**0.0%**	**0.0%**	**10.3%**	**11.6%**	CI(±) =	**4.0%**	

Detailed Biological Cover

Error matrices for detailed biological cover are displayed in Table 8 for the simple tally of assessment points and Table 9 for the unbiased values of producers and overall accuracy corrected by category proportions. The overall accuracy (P_o) when calculated by a simple tally of correct points was 80.1%, with a Tau coefficient (T_e) of 0.781 ± 0.043 (Table 8). The adjusted overall accuracy, corrected for bias using the map category proportions, was similar at 76.7 (±2.8)% (Table 9).

Table 8. 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%	**29**	4						3	1		4	41	**70.7%**
Algae 50% - <90%	4	**139**	11					1	6	1	1	163	**85.3%**
Algae 90% - 100%		10	**31**	1						1		43	**72.1%**
Live Coral 50% - <90%									1			1	**0.0%**
Live Coral 90% - 100%												0	**n/a**
Mangrove 50% - <90%						**12**						12	**100.0%**
Mangrove 90% - 100%							**27**					27	**100.0%**
Seagrass 10% - <50%	1	4	3					**15**	1		1	25	**60.0%**
Seagrass 50% - <90%		1	2					1	**19**	1	2	26	**73.1%**
Seagrass 90% - 100%			3							**27**		30	**90.0%**
No Cover 90% - 100%	2	2						3	1	2	**18**	28	**64.3%**
$n_{i\cdot}$	36	160	50	1	0	12	27	23	29	32	26	n=396	
Producer's Accuracy (%)	**80.6%**	**86.9%**	**62.0%**	**0.0%**	**n/a**	**100.0%**	**100.0%**	**65.2%**	**65.5%**	**84.4%**	**69.2%**	**P_o =**	**80.1%**
												T_e =	**0.781 ± 0.043**

Table 9. Error matrix for detailed biological cover. The overall accuracy and producer's accuracy were corrected for bias using the category 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 Acc. (%)	User's CI (±%)
Algae 10% - <50%	**0.1070**	0.0148						0.0111	0.0037		0.0148	0.151	**70.7%**	**14.2%**
Algae 50% - <90%	0.0086	**0.2972**	0.0235					0.0021	0.0128	0.0021	0.0021	0.348	**85.3%**	**5.6%**
Algae 90% - 100%		0.0239	**0.0740**	0.0024						0.0024		0.103	**72.1%**	**13.7%**
Live Coral 50% - <90%									0.0016			0.002	**0.0%**	**0.0%**
Live Coral 90% - 100%												0.000	**0.0%**	**n/a**
Mangrove 50% - <90%						**0.0042**						0.004	**100.0%**	**0.0%**
Mangrove 90% - 100%							**0.0189**					0.019	**100.0%**	**0.0%**
Seagrass 10% - <50%	0.0024	0.0096	0.0072					**0.0360**	0.0024		0.0024	0.060	**60.0%**	**19.6%**
Seagrass 50% - <90%		0.0034	0.0068					0.0034	**0.0647**	0.0034	0.0068	0.089	**73.1%**	**17.4%**
Seagrass 90% - 100%			0.0080							**0.0716**		0.080	**90.0%**	**11.0%**
No Cover 90% - 100%	0.0103	0.0103						0.0155	0.0052	0.0103	**0.0930**	0.145	**64.3%**	**18.1%**
$p_{i\cdot}$	0.128	0.359	0.119	0.002	0.000	0.004	0.019	0.068	0.090	0.090	0.119	π=1		
Producer's Accuracy (%)	**83.4%**	**82.7%**	**61.9%**	**0.0%**	**n/a**	**100.0%**	**100.0%**	**52.8%**	**71.6%**	**79.7%**	**78.1%**	**P_o =**	**76.7%**	
Producer's CI (±%)	**11.4%**	**6.1%**	**11.4%**	**0.0%**	**n/a**	**0.0%**	**0.0%**	**19.2%**	**14.2%**	**15.1%**	**12.7%**	**CI(±) =**	**2.8%**	

Percent Hardbottom

Error matrices for percent hardbottom are displayed in Table 10 for the simple tally of assessment points and Table 11 for the unbiased values of producers and overall accuracy corrected by category proportions. The overall accuracy (P_o) when calculated by a simple tally of correct points was 90.0%, with a Tau coefficient (T_e) of 0.878 ± 0.035 (Table 10). The adjusted overall accuracy, corrected for bias using the map category proportions, was 89 (±2.4)% (Table 11). Greatest sources of error for sites with a majority of hardbottom (i.e. >50%) were between adjacent categories (e.g., site mapped as 70-90% hardbottom was actually 90-100%). Sites with very little hardbottom (0-10%) experienced a wider range of errors but were still mapped with very high accuracy overall.

Percent Coral Cover

The error matrix for percent coral cover is displayed in Table 12. The overall accuracy (P_o) was 86%, with a Tau coefficient (T_e) of 0.819 ± 0.043. As mentioned previously, a second matrix using the map category proportions could not be computed for percent coral cover.

Live coral 50 – 90% occurred very rarely in the map and accuracy assessment data. Accuracy was very high for the softbottom habitats, where a low amount of coral is expected. There was lower, but still very acceptable, accuracy for percent coral on hardbottom habitats. The decision between <10% and 10% -<50% was often difficult to determine, especially where there was a mix of octocorals and scleractinians.

Table 10. Error matrix for percent hardbottom.

Map data (j) \ Accuracy Assessment (i)	0% - <10%	10% - <30%	30% - <50%	50% - <70%	70% - <90%	90% - 100%	$n_{.j}$	User's Acc. (%)
0% - <10%	**173**		3	1	2	3	182	**95.1%**
10% - <30%		**4**		1		1	6	**66.7%**
30% - <50%	1		**11**				12	**91.7%**
50% - <70%	5		4	**10**	3	1	23	**43.5%**
70% - <90%	1			**2**	**91**	3	97	**93.8%**
90% - 100%	3			3	**5**	**81**	92	**88.0%**
$n_{i.}$	**183**	**4**	**18**	**17**	**101**	**89**	n=412	
Producer's Accuracy (%)	**94.5%**	**100.0%**	**61.1%**	**58.8%**	**90.1%**	**91.0%**	P_o =	**90.0%**

T_e = 0.878 ± 0.035

Table 11. Error matrix for percent hardbottom. The overall accuracy and producer's accuracy were corrected for bias using the category proportions.

Map data (j) \ Accuracy Assessment (i)	0% - <10%	10% - <30%	30% - <50%	50% - <70%	70% - <90%	90% - 100%	$\pi_{.j}$	User's Acc. (%)	User's CI (±%)
0% - <10%	**0.5664**		0.0098	0.0033	0.0065	0.0098	0.596	**95.1%**	**3.2%**
10% - <30%		**0.0054**	0.0000	0.0013		0.0013	0.008	**66.7%**	**38.5%**
30% - <50%	0.0014		**0.0150**				0.016	**91.7%**	**16.0%**
50% - <70%	0.0094		0.0075	**0.0189**	0.0057	0.0019	0.043	**43.5%**	**20.7%**
70% - <90%	0.0020			**0.0041**	0.1845	0.0061	0.197	**93.8%**	**4.9%**
90% - 100%	0.0046			0.0046	**0.0076**	**0.1230**	0.140	**88.0%**	**6.8%**
$p_{i.}$	0.574	0.000	0.025	0.012	0.199	0.139	π=1		
Producer's Accuracy (%)	**98.6%**	**n/a**	**60.4%**	**158.8%**	**92.9%**	**88.5%**	P_o =	**89.0%**	
Producer's CI (±%)	**1.2%**	**n/a**	**27.7%**	**141.8%**	**5.3%**	**8.5%**	CI(±) =	**2.4%**	

Table 12. Error matrix for percent live coral cover.

Map data (j) \ Accuracy Assessment (i)	Softbottom, Coral <10%	Softbottom, Coral 10% - <50%	Hardbottom, Coral <10%	Hardbottom, Coral 10% - <50%	Hardbottom, Coral 50% - <90%	$n_{.j}$	User's Accuracy (%)
Softbottom, Coral <10%	**172**		**8**	**2**		182	**94.5%**
Softbottom, Coral 10% - <50%						0	**n/a**
Hardbottom, Coral <10%	**7**		**93**	**15**	**2**	117	**79.5%**
Hardbottom, Coral 10% - <50%	**2**		**19**	**82**	**3**	106	**77.4%**
Hardbottom, Coral 50% - <90%	**1**				**2**	3	**66.7%**
$n_{i.}$	182	0	120	99	7	n=408	
Producer's Accuracy (%)	**94.5%**	**n/a**	**77.5%**	**82.8%**	**28.6%**	P_o =	**86.0%**

T_e = 0.819 ± 0.043

Conclusions

The results indicate that all levels of map data for Guánica/Parguera and Belvedere have acceptable accuracy percentages and are suitable for a wide range of scientific and management applications. Classification errors were primarily between similar habitats such as *Sand* and *Sand with Scattered Coral and Rock* which often lack clear separation when adjacent to each other. Other common errors included *Mud* and *Sand* which often grade into each other and occur in mixtures, *Seagrass* and *Algae* which often occur in mixed beds; and between adjacent categories of percent hardbottom and coral cover. 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 Vieques, (78.0 % [88.8% adjusted] Bauer and Kendall, 2010), St. John, US Virgin Islands (86%, [89% adjusted]; Zitello et al., 2009), the Florida Keys (86% [92% adjusted]; Walker and Foster, 2009), Palau (90%; Battista et al., 2007b), and the Main Hawaiian Islands (90%; Battista et al., 2007a). For additional details on accuracy assessment methods and computational details see the references in the literature cited section.

SUMMARY STATISTICS AND CONCLUSIONS

A total of 343.11 km^2 of marine habitat were mapped in the entire study area. The Belvedere study region accounted for 48.58 km^2 of this total, while the Parguera/Guánica region accounted for the remaining 293.27 km^2. Due to the differences between these two regions, summary statistics were computed for each region individually.

Table 13. Summary of structure types in the Belvedere study area.

MAJOR STRUCTURE	AREA (km^2)	PERCENT AREA	DETAILED STRUCTURE	AREA (km^2)	PERCENT AREA
Coral Reef and Hardbottom	5.23	10.77	Rock/Boulder	0	0
			Aggregate Reef	1.97	4.06
			Individual Patch Reef	0.1	0.21
			Aggregated Patch Reefs	0.12	0.25
			Spur and Groove	0	0
			Pavement	2.95	6.07
			Pavement with Sand Channels	0	0
			Reef Rubble	0.08	0.16
			Rhodoliths	0	0
Unconsolidated Sediment	43.34	89.23	Sand	41.53	85.50
			Mud	1.57	3.23
			Sand with Scattered Coral and Rock	0.25	0.51
Other Delineations (Land excluded)	0	0	Artificial	0	0
Total	**48.57**	**100**		**48.57**	**100**

The majority of the Major Structure within Belvedere is comprised of Unconsolidated Sediments (43.34 km^2; Table 13) with Coral Reef and Hardbottom constituting a smaller portion of the benthic structure (5.23 km^2). Summary statistics for the Detailed Structure highlight the composition of the Major Structure types (Table 13). Note that Detailed Structure percentages are derived from total mapped area, not within the corresponding Major Structure classification. *Sand* is the dominant Detailed Structure type at 85.5% of the total mapped area (Table 13; Figure 33). *Mud* and *Scattered Coral and Rock* constitute a much smaller portion of the *Unconsolidated Sediment* category (3.23% and 0.51% of the total mapped area, respectively). *Pavement* (6.07%) accounts for the second most dominant Detailed Structure overall, as well as the dominant cover within the *Coral Reef and Hardbottom* structure. The other common hardbottom structure type is *Aggregate Reef* at 4.06% of the mapped area. The remaining structure types are either present at <1%, such as: *Aggregated Patch Reefs* (0.25%), *Individual Patch Reefs* (0.21%), and *Reef Rubble* (0.16%); or completely absent from the mapped region, such as: *Spur and Groove, Rock/Boulder, Pavement with Sand Channels, Artificial* and *Rhodoliths*.

Table 14. Summary of major biological cover types in the Belvedere study area.

MAJOR COVER	AREA (km^2)	PERCENT AREA	PERCENT COVER	AREA (km^2)	PERCENT AREA
Algae	5.41	11.14	Continuous (90% - 100%)	2.07	4.27
			Patchy (50% - <90%)	3.02	6.21
			Patchy (10% - <50%)	0.32	0.66
Seagrass	8.70	17.90	Continuous (90% - 100%)	3.16	6.51
			Patchy (50% - <90%)	0.95	1.96
			Patchy (10% - <50%)	4.58	9.42
Mangrove	1.03	2.13	Continuous (90% - 100%)	0.85	1.76
			Patchy (50% - <90%)	0.11	0.23
			Patchy (10% - <50%)	0.07	0.13
Live Coral	0.44	0.91	Continuous (90% - 100%)	0.002	0.00
			Patchy (50% - <90%)	0.44	0.90
			Patchy (10% - <50%)	0.00	0.00
No Cover	21.98	45.26	Continuous (90% - 100%)	21.98	45.26
Unknown	11.01	22.67	Unknown	11.01	22.67
Total	**48.58**	**100**		**48.58**	

No Cover dominates the Major Cover type as 45.26% of the region is characterized by primarily *Sand* or *Mud* with *No Cover* (Table 14). Among the remaining biological cover constituents, *Seagrass* dominated with 17.90% of the mapped area, followed by *Algae* at 11.14% (Table 14). However, it should be noted that beds of submerged vegetation are often a mix of *Seagrass* and *Algae*, and distinguishing between the two in aerial imagery can be difficult. *Mangrove*, a less common dominant cover, constitutes 2.13% of the mapped area. Live *Coral* was designated as the major cover type for 0.91% of the mapped area. A large portion of the study area was mapped as *Unknown* major cover (22.67%), where the biological cover could not be determined due to turbidity or imagery issues (Figure 34).

Table 15. Summary of percent live coral in the Belvedere study area.

PERCENT CORAL COVER	AREA (km²)	PERCENT AREA
0% - <10%	35.32	72.72
10% - <50%	1.80	3.71
50% - <90%	0.44	0.91
Unknown	11.01	22.67
Total	**48.58**	**100**

The majority of the mapped area (72.72%) is characterized by 0-10% coral cover, while 3.71% of the mapped area has Percent Coral cover of 10%-<50% (Table 15; Figure 35). Less than 1% of the mapped area contains coral cover exceeding 50%. Areas of high coral were located on aggregate reef. It is important to remember the influence of the MMU in the habitat mapping process when considering these values. It is possible that some areas of Belvedere are comprised of greater than 50% coral cover, but these areas were not large enough to be mapped with a contiguous MMU of 1,000 m².

The Belvedere region contains several watersheds feeding into the nearshore waters, causing high turbidity from sediment outflow. Situated along the west coast of Puerto Rico, prevalent wind action and high currents also cause high turbidity in the region. These combined factors prohibited distinguishing the benthic cover

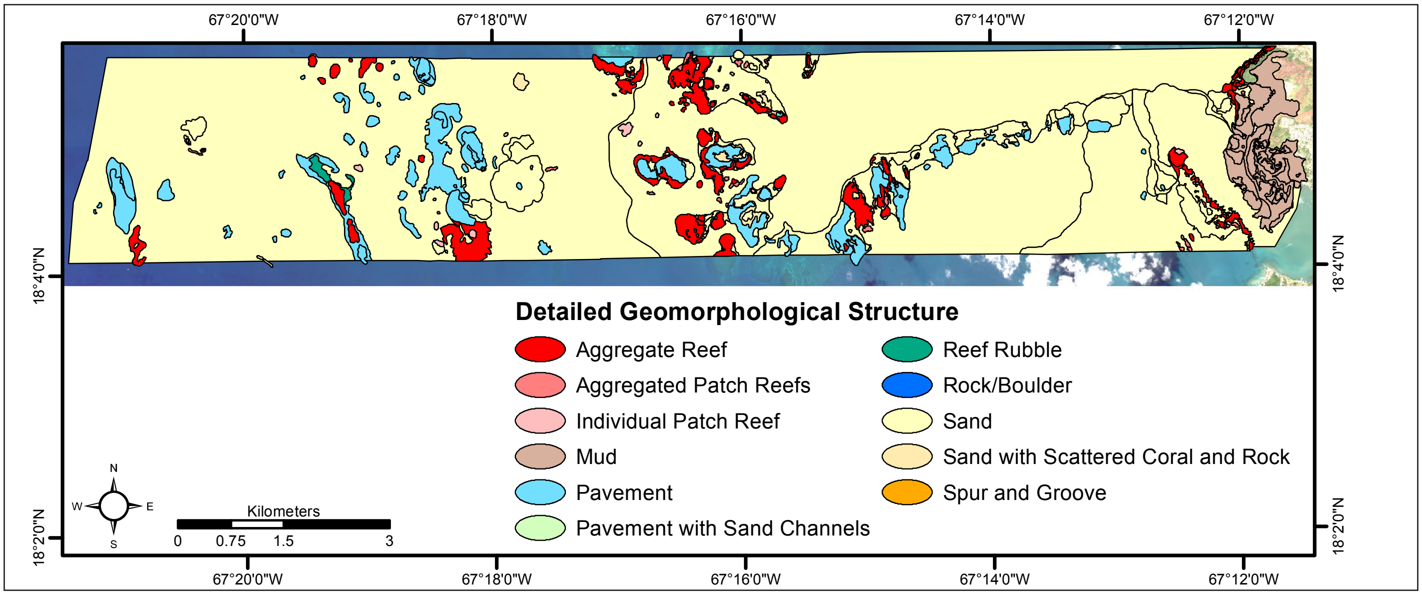


Figure 33. Detailed geomorphological structure in the Belvedere study area.

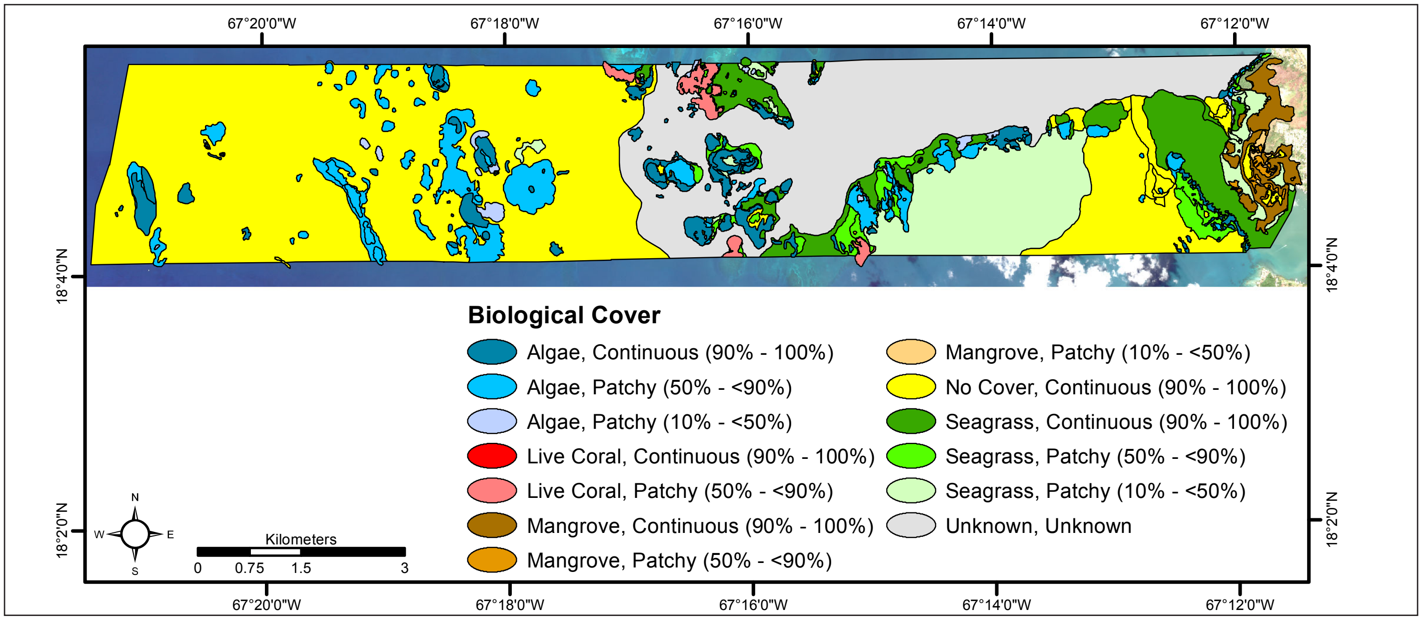


Figure 34. Major biological cover in the Belvedere study area.

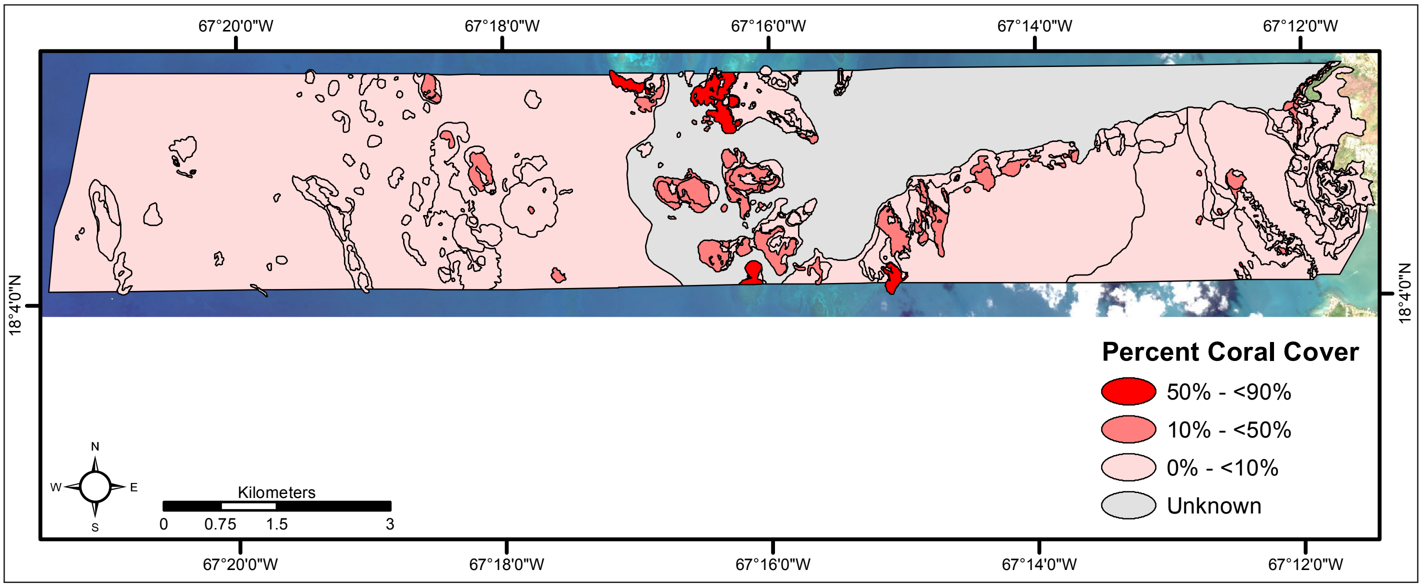


Figure 35. Percent coral cover in the Belvedere study area.

within in a large area of deeper soft sediments offshore of Belvedere. High turbidity was present in multiple imagery collects. Alternative remote-sensing techniques (e.g., side-scan sonar or multibeam) may be necessary to fully characterize this area.

Table 16. Summary of structure types in the Guanica/Parguera study area.

MAJOR STRUCTURE	AREA (km²)	PERCENT AREA	DETAILED STRUCTURE	AREA (km²)	PERCENT AREA
Coral Reef and Hardbottom	133.19	45.42	Rock/Boulder	0.39	0.13
			Aggregate Reef	26.63	9.08
			Individual Patch Reef	2.06	0.70
			Aggregated Patch Reefs	10.23	3.49
			Spur and Groove	13.24	4.51
			Pavement	51.58	17.59
			Pavement with Sand Channels	25.01	8.53
			Reef Rubble	4.05	1.38
			Rhodoliths	0	0
Unconsolidated sediment	160.08	54.58	Sand	110.70	37.75
			Mud	33.55	11.44
			Sand with Scattered Coral and Rock	15.83	5.40
Other Delineations	0	0	Artificial	0	0
Total	**293.27**	**100**		**293.27**	**100**

While the Belvedere study area was dominated by soft sediments, the composition of major structure types in the Guánica/Parguera study area was more evenly divided, with *Coral Reef and Hardbottom* comprising 45.42% of the study area (Table 16). *Sand* was the most common detailed structure type overall, comprising 37.75%, followed by *Pavement* at 17.59% (Table 16). *Unconsolidated Sediments* are most common in the nearshore environment, including Guánica Bay and the La Parguera lagoon (Figure 36). An extensive reef complex, a mix of both low rugosity (*Pavement, Pavement with Sand Channels*) and high-rugosity (*Aggregate Reef, Spur and Groove*) hardbottom, ranges the entire length of the bank-shelf in the study area. *Patch Reefs* (both *Individual* and *Aggregated*) comprise a smaller percentage of the hardbottom in the study area but are distributed widely throughout the shelf.

Algae was most commonly mapped as the major cover type in the Guánica/Parguera study area, comprising two-thirds of the mapped area (Table 17; Figure 37). In particular algae, whether as macroalgae or turf algae, was most often the major cover on *Coral Reef and Hardbottom*, while only a small portion of the study area (0.05%) was mapped with *Live Coral* as the major cover. *Seagrass* beds of various patchiness levels are prevalent in the nearshore area and overall encompass about one-quarter of the mapped area. The most extensive seagrass bed encompasses the shallow, protected waters that stretch from La Parguera west to Cabo Rojo.

While *Live Coral* was rarely mapped as the major cover, there were exceptions. High density *Porites porites* fields were occasionally present in *Back Reef/Reef Flat* environments, including south of Cayos de Caña Gorda. Areas with *No Cover* account for 19.04% of the total area.

Table 17. *Summary of major biological cover types in the Guanica/Parguera study area.*

MAJOR COVER	AREA (km²)	PERCENT AREA	PERCENT COVER	AREA (km²)	PERCENT AREA
Algae	194.91	66.46	Continuous (90% - 100%)	33.33	11.36
			Patchy (50% - <90%)	111.86	38.14
			Patchy (10% - <50%)	49.72	16.95
Sea-grass	72.02	24.56	Continuous (90% - 100%)	22.59	7.70
			Patchy (50% - <90%)	28.98	9.88
			Patchy (10% - <50%)	20.45	6.97
Man-grove	7.15	2.44	Continuous (90% - 100%)	5.39	1.84
			Patchy (50% - <90%)	1.29	0.44
			Patchy (10% - <50%)	0.48	0.16
Live Coral	0.15	0.05	Continuous (90% - 100%)	0.00	0.00
			Patchy (50% - <90%)	0.15	0.05
			Patchy (10% - <50%)	0.00	0.00
No Cover	19.04	6.49	Continuous (90% - 100%)	19.04	6.49
Un-known	0.001	0.00	Unknown	0.001	0.001
Total	**293.27**	**100**		**293.27**	**100**

The majority (79%) of the Guánica/Parguera study area was mapped with *0% - <10% Coral Cover* (Table 18; Figure 38). Polygons with 10% - <50% coral cover most commonly coincided with high rugosity reef types, or in areas with high cover of gorgonians. The only polygons that exceeded 50% coral cover were the aforementioned *P. porites* reefs. It is possible that additional areas are comprised of greater than 50% coral cover but were smaller than the MMU of 1,000 m².

Table 18. *Summary of percent live coral in the Guanica/Parguera study area.*

PERCENT CORAL COVER	AREA (km²)	PERCENT AREA
0% - <10%	231.76	79.03
10% - <50%	61.36	20.92
50% - <90%	0.15	0.05
Unknown	0	0.00
Total	**293.27**	**100**

The 2012 mapping effort described in this report marks the second such effort NOAA has conducted to map shallow water marine benthic habitats of southwest Puerto Rico. Components of the new mapping product that mark an improvement over Kendall et al. (2001) include an expanded habitat classification scheme, smaller MMU and more recent aerial imagery. The previous NOAA map of southwest Puerto Rico was created using 1999 imagery with an MMU of one acre (~4047 m²), while the new map was created with imagery collected in 2006-2008 with an MMU of 1,000 m². In addition, within the extent area used for this mapping effort, a larger total area was mapped than in the previous mapping effort. For example, some areas that were mapped as unknown in the previous effort were able to be delineated in the new map due to better remote sensing imagery. In the Guanica/Parguera study area, 198.65 km² of marine habitat were mapped in the 2001 effort. The 293.27 km² mapped here represent an approximately 50% increase in total area mapped. In particular, the southwest portion of the offshore reef complex south of La Parguera that was not mapped in the previous effort was able to be mapped in the 2012 efforts. In the Belvedere study area, the percent increase was even greater; 13.15 km² of marine habitat were mapped in the 2001 effort, compared to 48.58 km² here. However, it should be noted that of the 48.58 km², 11.01 km² were unable to be classified for biological cover. Improvements are still needed to fully classify the turbid, deeper areas of the shelf in this region.

Periodic re-mapping of an area can serve as an important monitoring tool. Future mapping of southwest Puerto Rico can be used to monitor changes in the benthic habitats in the Parguera/Guánica region following restoration efforts in the Guánica Bay watershed. One of the major goals of these restoration efforts is to reduce input of sediments, nutrients and contaminants into the marine environment. Reduction in these terruginous inputs could have several potential effects on the marine habitats, e.g. improved water clarity would likely benefit growth of seagrass and corals. It is recommended that a similar classification scheme and MMU be utilized in future mapping efforts to allow for quantitative comparisons between time periods.

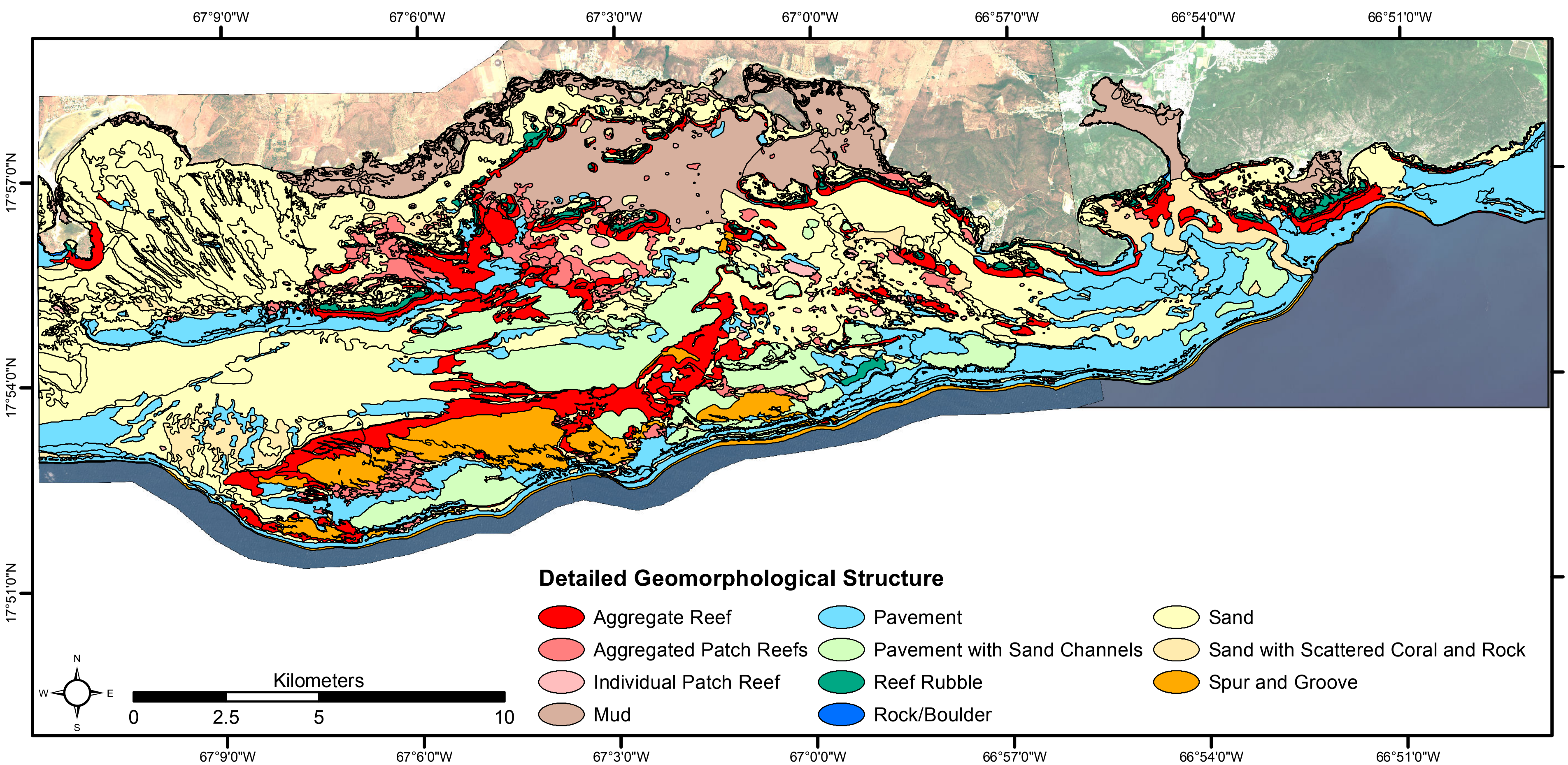


Figure 36. Detailed geomorphological structure in the Guanica/Parguera study area.

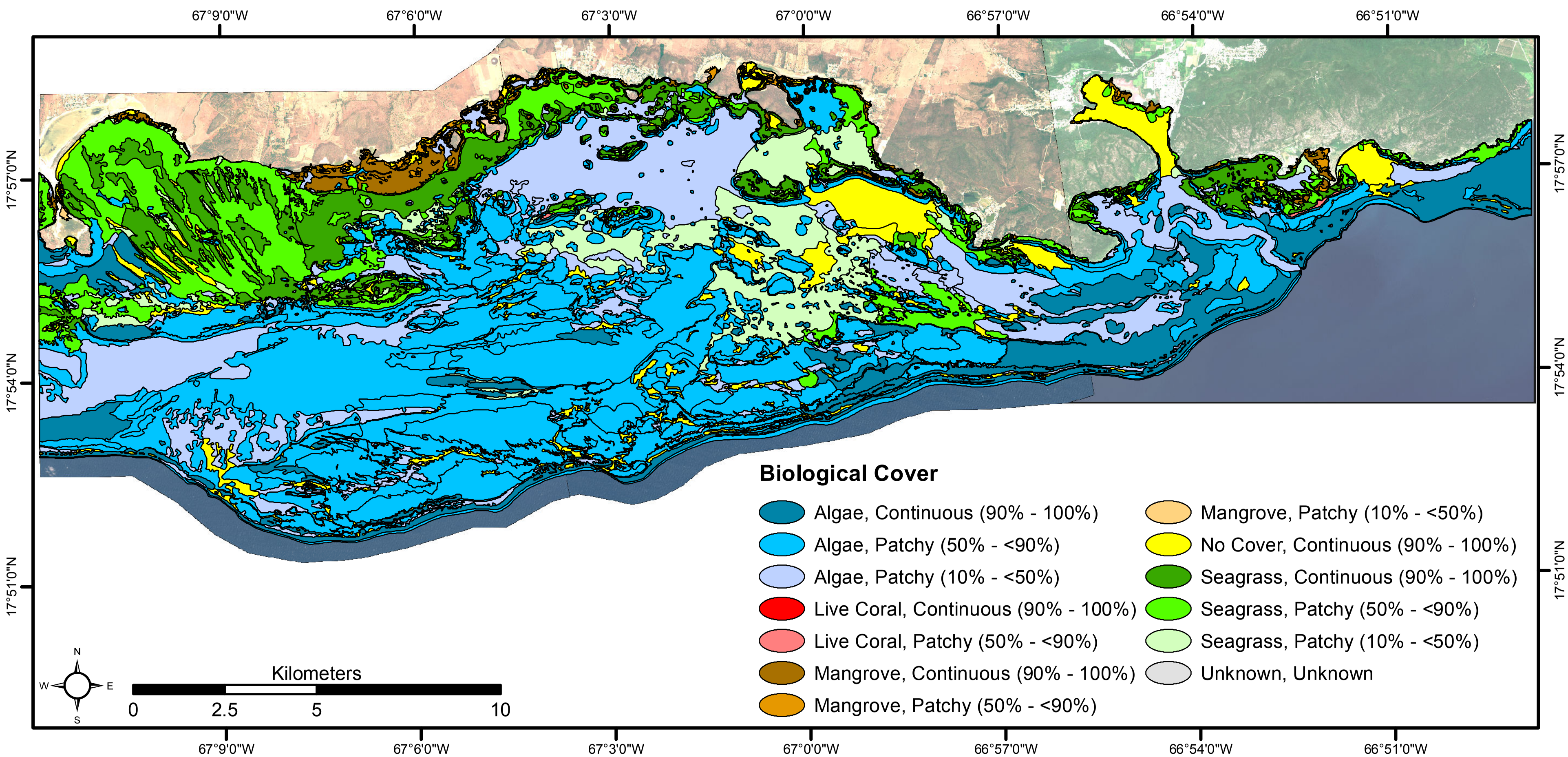


Figure 37. Major biological cover in the Guanica/Parguera study area.

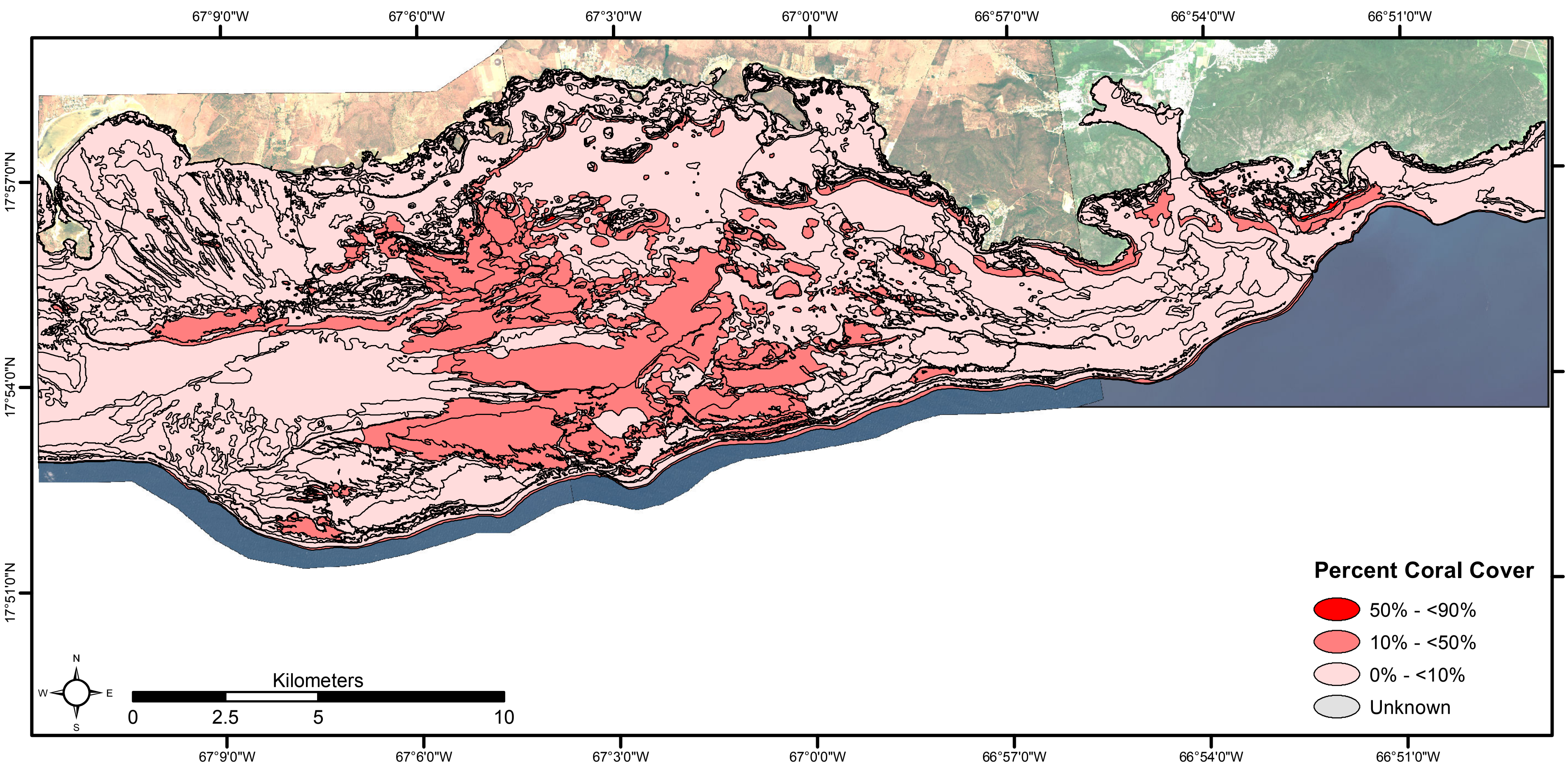


Figure 38. Percent coral cover in the Guanica/Parguera study area.

PROJECT DELIVERABLES

A suite of products associated with the southwest Puerto Rico benthic habitat map are available to the public on a NCCOS CCMA Biogeography Branch's web site. The project deliverables include:

- Benthic habitat maps in GIS format,
- 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, and
- An interactive, web-based map that allows users to query and display all spatial datasets and underwater video (http://ccma.nos.noaa.gov/explorer/biomapper/biomapper.html?id=SWPR).

LITERATURE CITED

Battista, T.A., B.M. Costa, and S.M. Anderson. 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 (DVD). NOAA Technical Memorandum NOS NCCOS 59. Silver Spring, MD.

Bauer, L.J. and M.S. Kendall (eds.). 2010. An ecological characterization of the marine resources of Vieques, Puerto Rico Part II: Field studies of habitats, nutrients, contaminants, fish, and benthic communities. NOAA Technical Memorandum NOS NCCOS 110. Silver Spring, MD. 174 pp.

Bonkosky, M., E.A. Hernández-Delgado, B. Sandoz, I.E. Robledo, J. Norat-Ramírez, and H. Mattei. 2008. Detection of spatial fluctuations of non-point source fecal pollution in coral reef surrounding waters in southwestern Puerto Rico using PCR-based assays. Marine Pollution Bulletin. doi:10.1016/j.marpolbul.2008.09.008.

Buja, K. 2008a. (Online). Habitat digitizer extension for ArcGIS, version 5. NOAA Biogeography Branch. Silver Spring, MD. Available at: http://ccma.nos.noaa.gov/products/biogeography/digitizer/.

Buja, K. 2008b. (Online). Find adjacent features. ESRI Support Center. Available at: http://arcscripts.esri.com/details.asp?dbid=15805. Last accessed July 2009.

Buja, K. 2008c. (Online). Find overlapping polygons. ESRI Support Center. Available at: http://arcscripts.esri.com/details.asp?dbid=15198. Last accessed July 2009.

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.

Carrubba, L. NOAA National Marine Fisheries Service. Boquerón, Puerto Rico. Personal Communication.

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.

Costa, B, L. Bauer, and P. Mueller. 2011. Shallow-water benthic habitats of Jobos Bay. In: D.R. Whitall et al., (eds.). A baseline assessment of the ecological resources of Jobos Bay, Puerto Rico. NOAA Technical Memorandum NOS NCCOS 133. Silver Spring, MD. 188 pp.

Coral Reef Conservation Program (CRCP). 2012. Land-based sources of pollution implementation plan, FY 2011-FY 2015. Available at: http://coralreef.noaa.gov/aboutcrcp/resources/pdfs/crcp_implementation_plan.pdf.

Council for Watershed Protection (CWP). 2008. Guánica Bay Watershed Management Plan. Prepared for NOAA's Coral Reef Program, Office of Ocean Coastal and Resource Management and Departmento de Recursos Naturales y Ambientales, Estado Libre Asociado de Puerto Rico.

DRNA (Departmento de Recursos Naturales y Ambientales). 2002. Documento de Designación Reserva Natural Belvedere. Secretaría Auxiliar de Planificación Integral, División de Planificación de Recursos Terrestres. 43 pp.

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

Hay, A.M. 1979. Sampling designs to test land-use map accuracy. Photogrammetric Engineering and Remote Sensing 45: 529-533.

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. 45 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.

Norat, J. and H. Mattei. 2006. Inventory of septic tanks as a source of pollution in groundwater and coral reefs in the Belvedere Natural Reserve in Western Puerto Rico. Final report submitted to the Department of Natural Resources of the Commonwealth of Puerto Rico.

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.

Warne, A.G., R.M.T. Webb, and M.C. Larsen. 2005. Water, sediment, and nutrient discharge characteristics of rivers in Puerto Rico, and their potential influence on coral reefs: U.S. Geological Survey Scientific Investigations Report 2005-5206, 58 pp.

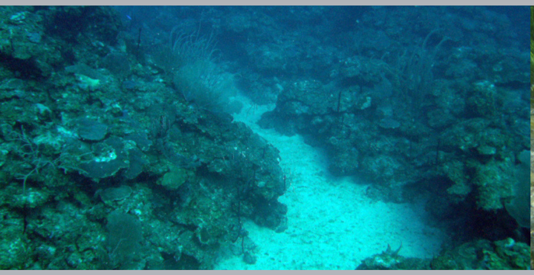
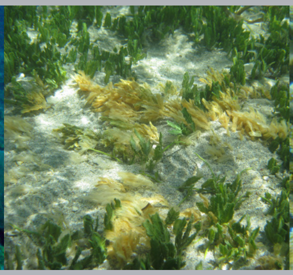
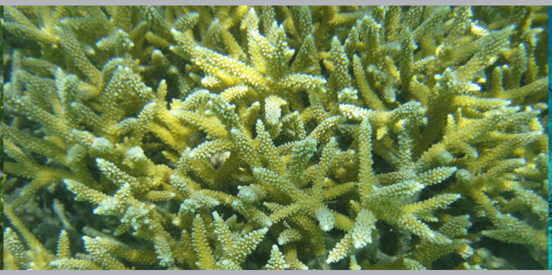
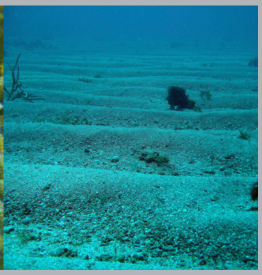
Wentworth, C.K. 1922. A scale of grade and class terms for clastic sediments. Journal of Geology 30(5): 377-392.

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

U.S. Department of Commerce
Rebecca Blank, *Acting Secretary*

National Oceanic and Atmospheric Administration
Jane Lubchenco, *Under Secretary for Oceans and Atmosphere*

National Ocean Service
David M. Kennedy, *Assistant Administrator for Ocean Service and Coastal Zone Management*

The mission of the National Centers for Coastal Ocean Science is to provide managers with scientific information and tools needed to balance society's environmental, social and economic goals. For more information, visit: **http://www.coastalscience.noaa.gov/**.