Benthic Habitat Mapping of the Marquesas/Quicksands Area of the Florida Keys

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MARQUESAS/QUICKSANDS BENTHIC HABITAT MAPPING PROJECT

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INTRODUCTION

PURPOSE

Florida is the only state in the continental United States to have extensive shallow coral reef formations near its coasts (FDEP, 2011). These reefs, along with associated benthic habitats characteristic of subtropical ecosystems, extend for approximately 530 km from Martin County, on the Atlantic coast, to the Dry Tortugas, west of Key West, in the Gulf of Mexico. Hardbottom communities, coral reef resources, seagrass beds, and mangroves are also found along the southwest Florida Shelf. The most prolific reef development occurs seaward of the Florida Keys with approximately 6,000 coral reefs between Key Biscayne and Dry Tortugas (FDEP, 2011). Due to deep and often turbid water, there is little information on habitat communities in the area between the Marquesas and Quicksands region, which is the focus of this mapping study (Lidz, et al., 2007) (Figure 1). Shifting sands have prevented extensive reef development throughout much of this area. The various benthic habitats found within the region vary in their overall development, species diversity, and other factors in part due to their geographic location (Lidz, et al., 2007). These extremely diverse habitats provide shelter, food, and breeding sites for a wide variety of commercially and aesthetically important organisms. Ecosystem services derived from these habitats in south Florida include fishing, diving, and tourism.

This report documents the procedures and results of the benthic habitat mapping of the Marquesas and Quicksands region of the Florida Keys. Understanding the scope and extent of benthic habitats is a fundamental component to protecting and conserving these important resources. Benthic habitat mapping is essential for all successful marine management plans and is used as the basis for many management decisions. Information gained from mapping efforts such as this includes identifying essential fish habitat and other ecologically sensitive areas for protection. The benthic mapping products derived from this effort provides an accurate assessment of the abundance and distribution of marine habitats surrounding the Marquesas and the Quicksands region of the Florida Keys. Ultimately, this effort will serve to support more effective management and conservation of ocean resources within the region.

GEOLOGIC HISTORY

The Florida Keys are divided into three distinct sections: the Upper Keys, Middle Keys, and Lower Keys. Generally, the Lower Keys encompass the islands from west of the seven mile bridge to Key West and also include Marquesas and Dry Tortugas. These divisions correspond to orientation, morphology, water depth, and composition. The Upper Keys are oriented almost north-south and buttress against the east-southeast winds. The Middle Keys are oriented northeast-southwest and face directly into the east-southeast winds. The Lower Keys are oriented nearly parallel to the winds, trend nearly east-west and are composed of oolite (Thornberry-Ehrlich, 2005). Water depth is at a maximum in the Middle Keys. As a result, the coral reef development is greatest in the shallower waters of the Upper and Lower Keys (Shinn et al., 1997).

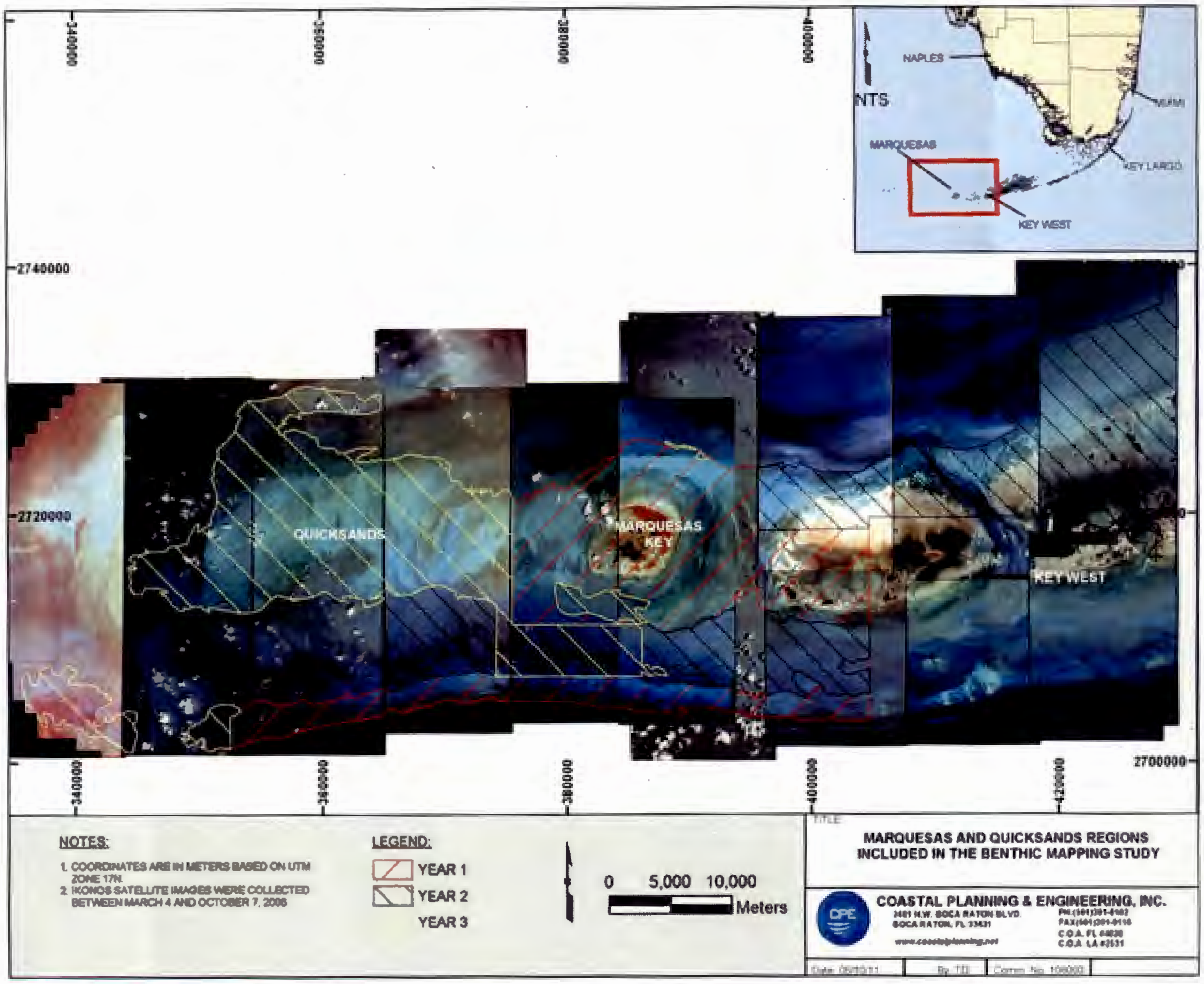

Figure 1. Marquesas and Quicksands regions included in the benthic mapping study. Years 1, 2, and 3 are the respective years that areas were mapped during the 3 year study.

The generally recognized lithologic units in south Florida are the Miami Limestone and the Key Largo Limestone (sometimes called the Miami Formation and the Key Largo Formation, respectively) (Harris, 1975). Rock of the Miami Limestone, which underlies the mainland of southeastern Florida, is generally a cross-bedded oolite and is late Pleistocene in age. The Key Largo Limestone is coralline limestone that formed during the most recent interglacial stage of the Pleistocene Epoch, some 100,000 to 250,000 years ago. The Key Largo Limestone is not exposed in the Lower Keys. However, an oolitic limestone that has been called the Key West Oolite is present. Apparently it is the same rock unit as the Miami Limestone, although the oolitic limestone of the mainland and the Upper Keys is at a somewhat higher elevation than its oolitic limestone of the Lower Keys (Harris, 1975). This Key Largo Limestone was deposited during the same time period as the Key West Oolite, as determined by cores bored in the Lower Keys.

The oolitic-limestone unit present in the Lower Keys extends westward from beneath Key West and underlies the Marquesas Keys and Quicksands areas, which are between Key West and the Dry Tortugas. However, as stated above, the present day coral reefs of the Upper, Middle, and many of the Lower Keys are underlain by what appears to be Key Largo Limestone. Cores drilled in two Holocene reefs north and northwest of the Marquesas Keys recovered rock of the Key Largo Limestone beneath the two 26-foot thick coral reefs. The positions of these coral reefs seem to be coincident with underlying topographic highs consisting of Key Largo Limestone (Harris et al., 1975).

Extensive geophysical data have been collected along the Florida shelf west of the Marquesas Keys (Shinn et al., 1990). Results from bathymetric surveys indicate the presence of a westward-oriented ridge in roughly the shape of a rectangle approximately 10 km wide by 30 km long within this area. Referred to as the Marquesas-Quicksands ridge (Shinn et al., 1990), the ridge is the westward extension of the limestone platform spit on which the chain of Florida Keys is located. The ridge is elevated 10 to 20 m above the shelf, and its south side is 8 to 10 km from the shelf margin bordering the Straits of Florida (Lidz et al., 2007). On the ridge, bedrock ranges from 1 to 12 m below sea level but is generally less than 6 m. Relatively deep (>20 m) waters bound the ridge on three sides: the Tortugas to the north, an unnamed channel to the west, and a backreef lagoon to the south (the westward extension of the Hawk Channel bedrock depression). Boca Grande Channel and the Marquesas Keys mark the east end of the ridge with Boca Grande Key located on the east side of the channel. Though no radiometric ages have been obtained on bedrock from the ridge, the oolite is presumed to be the same age (~125 kya) as that of the lower Florida Keys (Lidz et al., 2007).

Relatively deep non-oolitic carbonate sand deposits overlie the Marquesas-Quicksands ridge in a belt 47 km long by 28 km wide commonly known as the Quicksands (Shinn et al., 1990). This area is located just west of the Marquesas Keys. Some of the sand waves are exposed at low tide. These sand waves are formed by strong reversing tidal currents flowing between the Gulf of Mexico and the Straits of Florida. The waves migrate directly over Pleistocene bedrock to the east, but the deposit thickens to the west and sand waves there overlie non-oolitic Holocene accumulations as thick as 12 m (Shinn et al., 1990). Westward-dipping accretionary bedding indicates that net migration of the sands is to the west, despite north-south movement of tidal currents. Thin-section analyses show the principal component (average 48%) of the well-sorted sands is fragmented plates of species of the green alga Halimeda, followed by particulate coral (average 17%), which increases off the flanks of the main sand body. Short vibracores confirm the presence of cross-bedding (Shinn et al., 1990; Richardson et al., 1997). Similarly, Halimeda sands compose the crescentic islands of the Marquesas Keys (Hudson, 1985). The spit-like shape of the islands and their westward-trending extensions indicate that, like elsewhere on the ridge, sands of the islands are accreting westward.

BENTHIC HABITATS

The Marquesas Keys region encompasses 14 distinct islands that encircle an open basin. Mooney Harbor is located inside this complex and contains shallow sea grass beds dotted with sponges, bomb craters, and serpentine deep water channels (KWNWRSTP, 2011). To the north and east of the Marquesas, extensive sea grass beds are found in one to three meters of water. To the south and southeast of the islands a myriad of coral patch reefs and sponge/hardbottom habitats can be found in three to five meters of water (KWNWRSTP, 2011).

The benthic communities within proximity of the Marquesas and the Quicksands were first explored in 1988 following the installation of five oil exploration test wells between 1959 and 1962. These wells include wells A, B, and C located to the southwest of the Marquesas and south of the Quicksands. Well D/E1 and 826Y are located to the southeast and northeast of the Marquesas, respectively (Figure 2). Water depths at these sites ranged from 5 to 70 m. Benthic surveys were conducted to determine the ecological impact of drilling on the natural communities (Shinn et al., 1989a; Dustan et al., 1991). A variety of techniques were used to assess biological and ecological impacts. At the shallow sites, snorkelers and scuba divers collected sediments, conducted point counts of organisms along chain transects and in quadrats, and probed with a rod to determine gravel and sediment thicknesses. In general, bottom habitats included sand, bedrock, gorgonian hardgrounds, seagrass beds, and coral reefs.

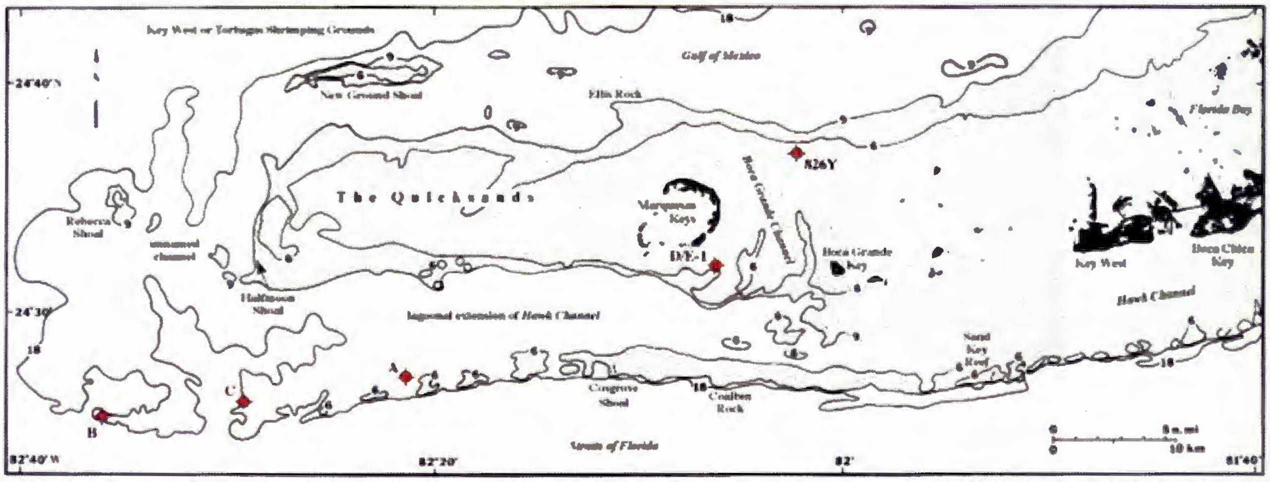

Figure 2. Locations of well sites explored within proximity to the Marquesas and Quicksands (Lidz et al., 2007).

At well site D/E1, results of the benthic study revealed four distinct, concentric bottom habitats: a central cement-bag habitat, pea gravel, sea grass, and a peripheral natural hardbottom. The cement bags, which were relicts of the initial well drilling activity, had created a stable hardbottom that served as an artificial reef colonized by macroalgae and coral (Lidz et al., 2007). The resultant geometric complexity had increased fish diversity, in marked contrast to low diversity and numbers of fish in the surrounding pea-gravel, seagrass, and natural hardbottom gorgonian communities. Gorgonians and large sponges had not colonized the bags. Their absence was thought to result from fish predation (fish were observed nipping at the bags) or leachates emanating from the cement. Fleshy algae dominated the pea-gravel habitat. The pea gravel was initially added to the substrate as a means of stabilizing the drilling platform. A seagrass community populated finer-grained sands at the perimeter of the pea gravel. The natural hardbottom gorgonian community also included sponges, corals, and assorted small reef fishes.

Well site 826Y, the drill site northeast of the Marquesas Keys, was a nearly featureless habitat in 5 m of water subjected to the exceptionally strong tidal currents that keep Boca Grande Channel free of sediment (Shinn et al., 1990). Murky water and rippled, shifting sand has discouraged development of an obvious biological community. However, several tons of drilling debris and limestone core had created an artificial reef-effect. Three species of coral and numerous species of fleshy algae encrusted the debris.

Well sites A, B, and C are located in 11-20 m of water along the shelf edge southwest of the Marquesas Keys, where coral growth is marginal (Jaap, 1984). The paucity of reef development has been attributed to sporadic intrusion of cold Gulf of Mexico waters (Shinn, 1988; Shinn et al., 1989b). Winter storms and hurricanes also impact the area. Twenty-five species of coral and 18 species of gorgonians were found growing on drilling debris surrounding the sand-filled depressions at well site A. Algae and barrel sponges (Xestospongia spp.) also encrusted the debris at this location. Well site C was dominated by a few fleshy algae upon the primarily sandy bottom. The westernmost drill site, site B was drilled upon a rugged-relief, reasonably well developed reef knoll that supported gorgonians, fish, algae, and 17 stony coral species. The bottom community was typical of those usually found on Florida Keys coral reefs (Lidz et al., 2007).

METHODOLOGY

CLASSIFICATION SCHEME

The National Oceanic and Atmospheric Administration's (NOAA) Coral Reef Conservation Program developed a hierarchical classification scheme to define and delineate southern Florida's shallow water (generally less than 30 m depth) benthic habitats (NOAA, 2008). In this scheme, habitats are classified by three (3) major components: structure, zone, and biological cover, along with subdivisions under two of the components to provide further detail: detailed structure and detailed biological cover. Within a GIS framework, this hierarchal system allows a user to view detail as desired by expanding or collapsing thematic details. This classification scheme is illustrated in Table 1 below, adopted from NOAA (2008), and applied in this remote sensing project. The established scheme was maintained so that these mapping results can be incorporated into past and future mapping efforts.

Table 1. Classification scheme for mapping benthic habitats in the Marquesas/Quicksands area of the Florida Keys (adopted from NOAA, 2008).

Major Structure	Detailed Structure	Zone	Major Biological Cover	Detailed Biological Cover	Percentage
Unconsolidated Sediment	Sand	Shoreline Intertidal	Live Coral	Continuous Coral	>90%
		Shoreline Supratidal		Patchy Coral	50-90%
		Lagoon		Sparse Coral	10-50%
	Mud		Seagrass	Continuous Seagrass	>90%
		Bank/Shelf		Patchy Seagrass	50-90%
				Sparse Seagrass	10-50%
Coral Reef and Hardbottom	Spur and Groove	Back Reef	Macroalgae	Continuous Macroalgae	>90%
	Individual or Aggregated Patch Reef			Patchy Macroalgae	50-90%
		Ridges and Swales		Sparse Macroalgae	10-50%
	Aggregate Reef		Encrusting/Coralline Algae	Continuous Coralline Algae	>90%
	Scattered Coral/Rock in Unconsolidated Sediment	Reef Crest		Patchy Coralline Algae	50-90%
				Sparse Coralline Algae	10-50%
	Pavement	Forereef	Turf Algae	Continuous Turf Algae	>90%
	Rock/Boulder			Patchy Turf Algae	50-90%
	Reef Rubble	Channel		Sparse Turf Algae	10-50%
	Pavement with Sand Channels		Emergent Vegetation	Marsh	>90%
		Dredged			50-90%
Other Delineations	Artificial	Vertical Wall		Mangrove	10-50%
	Land	Bank/Shelf Escarpment	Uncolonized	Uncolonized	>90%
Unknown	Unknown	Unknown	Unknown	Unknown	> 90%

The following section outlines and defines the classification types used for the Marquesas/Quicksands Benthic Habitat Mapping Project. Cover types refer only to the predominate biological component colonizing the surface of the seafloor, and are defined in a hierarchy ranging from seven major classes (Table 1), combined with a percent cover modifier (Detailed Biological Cover). More detail on classifications can be found in the photo-interpretation key created for this project (Appendix 1).

Structure

This component describes the physical structure of the polygon within the ecosystem. NOAA's classification scheme defines geomorphic structure using four (4) major structure types and twelve (12) detailed structure types. However, many of these classifications did not apply in the Marquesas/Quicksands mapped area. Classifications that were used in the mapping of this project are described below.

Unconsolidated Sediment

This category includes areas of seafloor containing unconsolidated sediment. Two subclasses of detailed structure fall under this category:

- SAND: coarse sediment usually found in areas exposed to currents or wave energy; sand is a dominant structural element in the Marquesas/Quicksands area.

- MUD: fine grain sediments associated with low energy environments, free from waves and currents; mud can be found in the project area in and around mangroves.

Coral Reef and Hardbottom

Coral reef and hardbottom areas are hardened substrate formed by the deposition of calcium carbonate by reef-building organisms or exposed bedrock. Hardbottom typically has no more than a thin veneer of sediment; however, the Marquesas/Quicksands area is highly dynamic, with continual sand movement. Areas subject to high current and tidal flux may become alternately exposed or buried; this constant flux of sand deposition and thickness determines the biotic cover at the time of sampling.

- INDIVIDUAL OR AGGREGATED PATCH REEF: coral formations characterized by vertical relief of at least one meter and often having a round or oblong shape. Patch reefs are typically located in shallow waters of 10-20 ft (3-6 m) in depth, within the Florida Reef Tract and beyond. They are isolated from other reef formations by bare sand, seagrass or other habitats and have no organized structural axis relative to the contours of the shore or shelf edge. A surrounding ring of sand is often a distinguishing feature; for mapping purposes these sand halos are included with the patch reef in a single polygon. The width of this ring of sand is often determined by the distance that herbivorous fish and other herbivores (including Diadema antillarum) feel is within safe foraging range from the reef. Within the study area, patch reefs are common within Hawk Channel, have the highest relief of any coral reef formation, and typically support the highest biotic cover.

- AGGREGATE REEF: Vast expanses of coral formations that vary in shape and height (but typically high relief), and lack the presence of sand channels are classified as aggregate reefs. They may also include linear formations of coral that grow parallel to the edges of the seafloor shelf. In this locale, this formation is typified by stony corals, interspersed with soft corals and sponges. The reef space below the coral has many holes and cavities well suited for fish and invertebrates to take refuge in.

- PAVEMENT: Pavement is low-relief to flat, solid carbonate rock. The reef pavement surface is often characterized as relatively smooth with low coral coverage and intermittent turf algae coverage. Areas of pavement are often incised by small shore-normal sand channels 0.5 m in depth and width. Common corals found amongst pavement areas include "weedy" corals of the genus Porites and Siderastrea.

- REEF RUBBLE: Reef rubble is often composed of unstable dead branching coral fragments including those of elkhorn (Acropora palmata) and staghorn (Acropora cervicornis) coral. Individual rubble fragments are often encrusted with crustose coralline algae (CCA) which can serve to bind fragments helping to stabilize the rubble zone. Rubble may also be colonized by turf, filamentous or other macroalgae. This habitat usually occurs landward of well developed reef formations in the reef crest, ridges and swales or back reef zone. Well-developed rubble zones were not observed in the Marquesas/Quicksands mapping area.

Other Delineations

- ARTIFICIAL: manmade structures such as bridges, docks and piers.

- LAND: terrestrial features above the spring high tide line.

Unknown

Unknown areas are defined as having indeterminable seafloor composition. In some areas, water turbidity hindered bottom interpretation; however, the primary cause for designation of an area as unknown was cloud cover.

Zones

Geological zones denote cross-sectional location relative to emergent features. NOAA's Coral Reef Conservation Program defined the cross-section of zones typical of the Florida Keys in their 2008 report in which they initially developed the classification scheme that is used in this project (Figure 3, NOAA 2008). Although this figure has been applied to other mapping projects in the Florida Keys, emergent reef crests were not observed in the Marquesas/Quicksands area. Therefore, an alternate zone classification was used based on Figure 4 below; similar logic has been applied to mapping efforts in southeast Florida where no emergent reef crest exists (Walker, 2009).

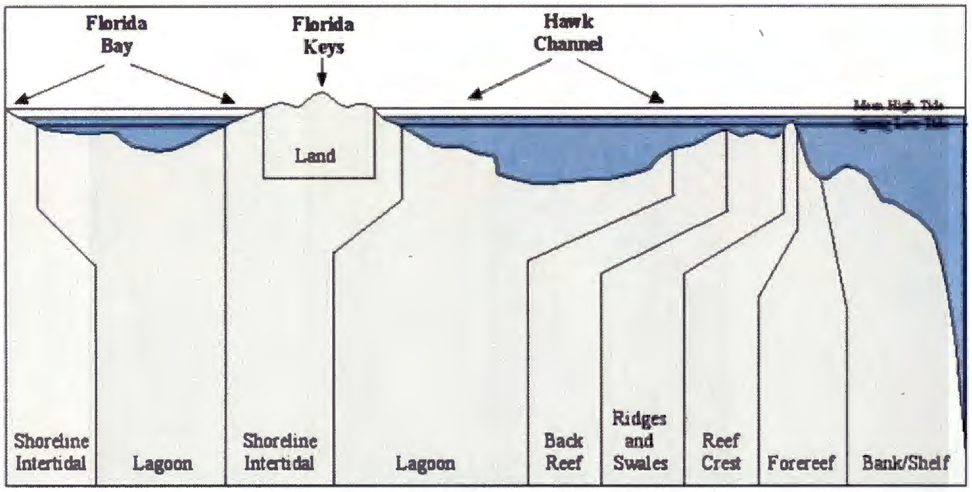

Figure 3. Cross-section of zones typical of the Florida Keys (NOAA, 2008).

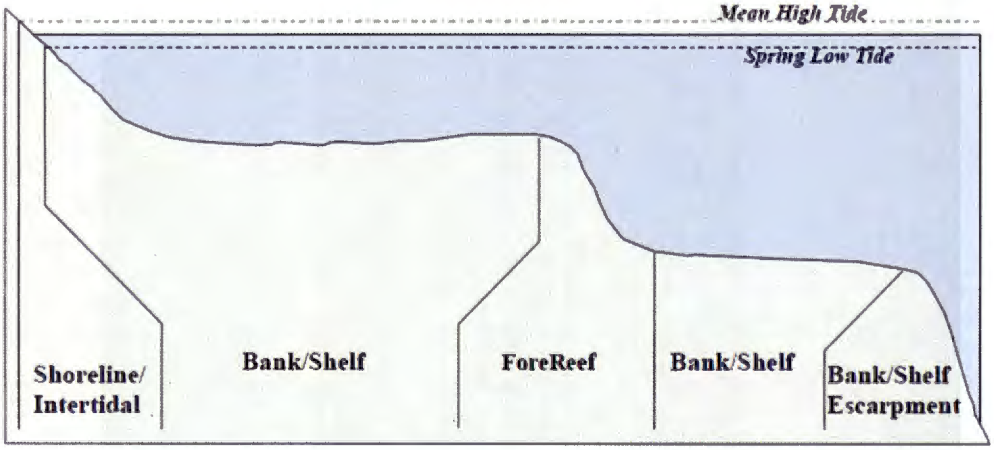

Figure 4. Cross-section of zones where no emergent reef crest is present (Source: Kendall et al., 2001).

NOAA's classification scheme includes 11 Zones; however, as with Detailed Structure classifications, many zone types did not apply in the Marquesas/Quicksands mapped area. As described above, no emergent reef crest was observed, thus precluding the use of mapping zones such as lagoon (with the exception of the area inside the Marquesas Keys), back reef, and reef crest. The majority of the study area was designated bank/shelf, as shown in Figure 2 above. Zones applied in this mapping project are described below.

- SHORELINE INTERTIDAL: The area between the mean high water line, and lowest spring tide level.

- SHORELINE SUPRATIDAL: Any area above the mean high water line; land.

- LAGOON: The shallow area between the shoreline intertidal and backreef or barrier island. No emergent crest was observed in the study area; therefore no backreef designations and thus no lagoon designations were made with the exception of the shallow areas inside the Marquesas Keys.

- BANK/SHELF: The platform between the shoreline/intertidal zone and the open ocean. The majority of the Marquesas/Quicksands mapping area falls within the bank/shelf zone.

- FOREREEF: Typically, the forereef is the area from the seaward edge of the reef crest that slopes into deeper water to the landward edge of the bank/shelf platform. However, no emergent crest is present in the study area; therefore, any area where the seaward facing slope is significantly greater than the slope of the bank/shelf was designated as forereef for this mapping project.

- CHANNEL: A natural trough in the seafloor through which water flows at level higher than the surrounding shallow area. In the mapping area, most channels are lined with uncolonized sand or seagrass. However, within the Quicksands area and Boca Grand Channel, the currents are such that little sediment remains; rather, hardbottom and associated coral reef communities may be present due exposure of the underlying hard structure.

- DREDGED: Areas in which the natural geomorphology is disrupted or altered by excavation of dredging.

Biological Cover

The NOAA classification scheme utilizes eight (8) distinct categories to describe the Major Biological Cover which is further broken down into Detailed Biological Cover categories based on percent cover qualified as "continuous", "patchy" or "sparse" (Table 2).

Table 2. Definition of each Detailed Biological Cover category.

DETAILED BIOLOGICAL COVER	PERCENT AREAL COVER
Continuous	>90%
Patchy	50-90%
Sparse	10-50%

Biological cover is assigned in a step-wise progression from Live Coral to Seagrass to Macroalgae to Encrusting Coralline Algae to Turf Algae to Emergent Vegetation to Uncolonized and finally Unknown. Cover modifiers are also assigned in a step-wise progression from "continuous" to "patchy" to "sparse." Because of this step-wise progression, polygons are not always named for their predominant cover if that cover is lower in the hierarchy than another cover found in that polygon (example: polygon containing 15% seagrass and 85% macroaglae will be classified as Sparse Seagrass rather than Patchy Macroalgae).

Coral

- CONTINUOUS CORAL (>90% COVER): May include areas of less than 90% coral cover on 10% or less of the total area that are too small to be mapped independently. Observed coral cover never exceeded 90% during this mapping project; therefore, no designation of live Continuous Coral cover was assigned to any areas.

- PATCHY CORAL (50% TO 90% COVER): Discontinuous live coral with breaks in coverage that are too diffuse, irregular, or result in isolated patches that are too small to be mapped as continuous coral.

- SPARSE CORAL (10% TO 50% COVER): Discontinuous live coral with breaks in coverage that are too diffuse, irregular, or result in isolated patches that are too small to be mapped as patchy coral.

Seagrass

- CONTINUOUS SEAGRASS (>90% COVER): May include blowouts of less than 10% of the total area that are too small to be mapped independently.

- PATCHY SEAGRASS (50% TO 90% COVER): Discontinuous seagrass community with breaks in coverage that are too diffuse, irregular or result is isolated patches that are too small to be mapped as continuous seagrass.

- SPARSE SEAGRASS (10% TO 50% COVER): Discontinuous seagrass community with breaks in coverage that are too diffuse, irregular, or result in isolated patches that are too small to be mapped as patchy seagrass.

Macroalgae

- CONTINUOUS MACROALGAE (>90% COVER): May include areas of less than 90% macroalgae coverage that are too small to be mapped independently.

- PATCHY MACROALGAE (50% TO 90% COVER): Discontinuous macroalgae with breaks in coverage that are too diffuse, irregular or result in isolated patches that are too small to be mapped independently.

- SPARSE MACROALGAE (10% TO 50% COVER): Discontinuous macroalgae with breaks in coverage that are too diffuse, irregular or result in isolates patches that are too small to be mapped as patchy macroalgae.

Turf Algae

- PATCHY TURF ALGAE (50% TO 90% COVER):Discontinuous turf algae with breaks in coverage that are too diffuse, irregular or result in isolated patches too small to be mapped as continuous turf algae.

- SPARSE TURF ALGAE (10% TO 50% COVER):Discontinuous turf algae with breaks in coverage that are too diffuse, irregular or result in isolated patches too small to be mapped as patchy turf algae.

Mangroves

Generally found in areas sheltered from high-energy waves. The area east of the Marquesas and north of Key West is dotted with small mangrove keys/islands composed primarily of red mangroves (Rhizophora mangle).

Uncolonized

Areas where substrate that is covered with less than 10% of any of the above eight biological cover classes.

Unknown

Classification used when delineation was not possible from aerial imagery, mostly due to cloud cover although turbid or dark water may also obscure interpretation.

Classification Codes

As described above, data were organized by major structure, detailed structure, zone, major biological cover, and detailed biological cover (percentage), respectively. Each polygon was assigned an alphanumeric code (F_CLASS_CO in the attribute table) that represents the interpreted mapping unit and ranges from 1 to 5 digits (with the exception of emergent vegetation, which goes to 6 digits due to a secondary breakdown of detailed cover—marsh or mangrove) (Figure 5). To elaborate, polygons with one digit are unknown areas, while areas of unconsolidated sediment are four digits (no detailed biological cover), and areas of patchy macroalgae are five digits (percentages are linked to detailed biological cover description). The numeric code breaks down as follows for each unit based on Table 1.

1ST NUMBER: MAJOR STRUCTURE
2ND NUMBER: DETAILED STRUCTURE
3RD NUMBER: ZONE
4TH NUMBER: MAJOR BIOLOGIC COVER
5TH NUMBER: DETAILED BIOLOGIC COVER

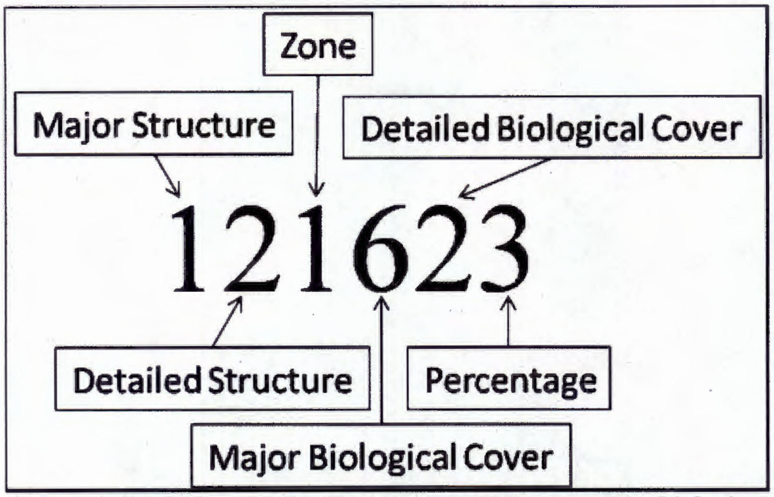

Figure 5. Example of code for less than 50% mangrove biological cover.

Only areas with emergent vegetation have percentages which force the code to six digits. This is because the detailed biological covers for live coral to turf algae (major biological covers 1 through 5) have percentages as a part of the description (Table 1). Figure 5 is an example of less than 50% mangroves which is emergent vegetation and thus requires the six digit code.

MAPPING

The area of interest (AOI) for this study was divided into three sections: Year 1, Year 2, and Year 3 (Figure 1). The original areas were 424 km2, 322 km2, and 274 km2, respectively. However, the total contract area was 1,354 km2. In order to fulfill the required mapping area, additional areas outside the AOI were found by enhancing the Ikonos imagery and analyzing adjacent benthic habitats that appeared suitable for digitizing. After adding in the additional areas, the total digitized area for Year 1 was 422.7 km2, 489.5 km2 for Year 2, and 442.3 km2 for Year 3, for an overall project total of 1354.5 km2.

High-resolution, geo-referenced, pan-sharpened, color IKONOS satellite imagery were used for the mapping. Images were loaded into ArcMap 10 for visual interpretation; all seafloor features visible in the imagery, with the exception of patch reefs, were mapped to the 0.4 ha/~1 ac minimum mapping unit (MMU) specification. Patch reefs were mapped using a 0.0625 ha/0.154 ac MMU. Land, defined as hard features or landward boundary of visible red mangrove extent, was mapped to the 0.1 ha/0.247 ac MMU. Mapping was conducted using heads-up digitizing on a large screen LCD display equipped with a SmartBoard. The SmartBoard allows the operator to view large areas at one time and digitize directly onto the screen. Once each area was preliminarily mapped (habitat polygons created) in GIS, points were created for verification in the field. Areas where interpretation of the satellite imagery was uncertain were assigned a ground validation (GV) point as well as transition areas and areas deemed representative of certain habitat types. The goal of the ground validation was to check every classification type that was mapped from satellite imagery and confirm questionable areas. Each GV point created in GIS was then investigated in the field using the methods described below. Representative images of benthic habitats mapped are in the photo interpretation key attached as Appendix 1.

FIELD METHODS

Ground validation was conducted in the field using a 950 series SeaDrop Camera made by SeaViewer (Photograph 1). The drop-camera was integrated with a Trimble DMS 232 DGPS system linked to a laptop running Hypack navigational software for recording real-time GPS coordinates on the video footage. Where water depth and visibility allowed, some areas were visually inspected from the surface and the nature of the bottom habitat was recorded. Divers entered the water and documented the seafloor with a handheld underwater camera when the seafloor cover type was unclear in the drop-camera feed. Representative footage of each classification type, as well as footage of areas that were undetermined during preliminary mapping, was recorded (Photographs 2 and 3). Eight hundred and sixty nine (869) ground validation (GV) points were collected over three (3) different field campaigns. Videos were collected for 793 of the GV points using the drop camera. Following processing of field data, polygon boundaries and habitat classifications were created or revised where necessary to create a “first draft” map.

Photograph 1. Drop camera used during field investigations.

Photograph 2. Representative screen capture for biological cover classification of Continuous Seagrass.

Photograph 3. Representative screen capture for biological cover classification of Patchy Coral.

ACCURACY ASSESSMENT

In addition to ground validation points, accuracy assessment (AA) points were also collected during field investigations. The AA points were randomly generated in GIS using the ET GeoWizards ESRI tool and then investigated in the field using the drop-camera method described above. A total of 293 AA video points were collected and used to evaluate the thematic accuracy of the "first draft" map. Accuracy was calculated for each of four categories: Major Structure, Detailed Structure, Major Biological Cover, and Detailed Biological Cover. Overall, the accuracy of the Marquesas/Quicksands mapping area was comparable to that of nearby regional mapping accuracies utilizing the same classification scheme. The accuracy assessment for the adjacent NOAA Florida Keys mapping area ROI 2 (Walker and Foster, 2010) is provided in Table 3 below. A more detailed assessment is provided in Appendix 2.

Table 3. Comparison of accuracy assessment results (overall accuracy, Po) to that of nearby NOAA mapping area ROI 2 (Key West; after Walker and Foster, 2010).

	MARQUESAS/QUICKSANDS AOI (P_o)	NOAA ROI 2 (P_o)
MAJOR STRUCTURE	90.8%	88.7%
DETAILED STRUCTURE	87.0%	82.9%
MAJOR BIOLOGICAL COVER	73.7%	68.7%
DETAILED BIOLOGICAL COVER	67.4%	64.7%

RESULTS

Of the 1,354 km2 mapped, polygon totals indicated the majority of Major Structure consisted of Unconsolidated Sediment which accounted for 71.7% of the total mapped area (971.3 km2). Sand accounted for the majority of Detailed Structure (69.9%; 946.8 km2); Pavement accounted for the majority of Detailed Structure within Coral Reef and Hardbottom (20.9%; 282.6 km2). Seagrass was the predominant Biological Cover, accounting for 39.3% (531.6 km2) of the mapped area (Table 4).

Emergent reef crests were not observed in the mapped area (reef crest and spur and groove formations disappear west of Sand Key Reef, where the Marquesas mapping area begins). Therefore, the majority of the mapping area was given the zone classification of "Bank/Shelf" with the exception of the shallow areas inside the Marquesas Keys, which were classified as "Lagoon", and a few offshore areas south of the Marquesas Keys. In these habitat polygons were overlaid on top of areas bathymetric contours; any area where the seaward facing slope was significantly greater than the slope of the bank/shelf (i.e. a sudden increase in water depth on the bathymetric map which typically coincided with a signature change on the imagery) was designated as forereef for this mapping project (Figure 6).

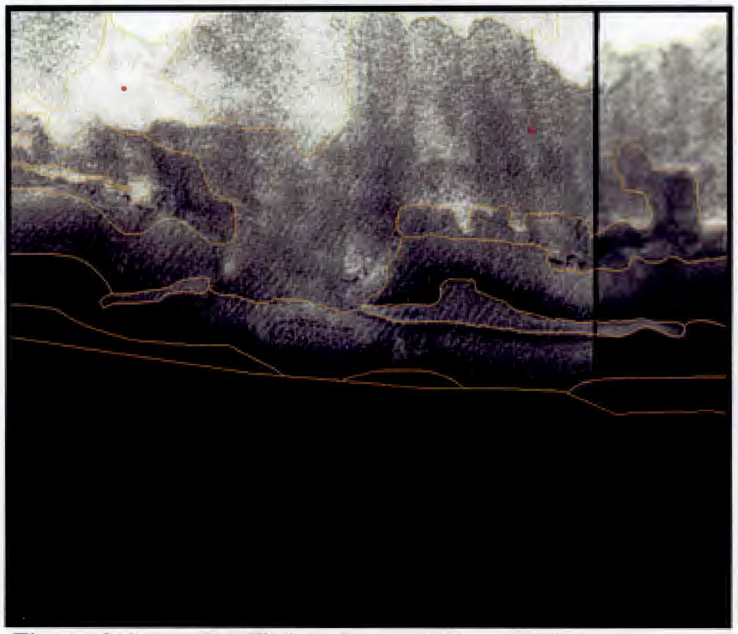

Figure 6. Areas classified as the zone "Forereef."

Table 4. Contribution of each classification type to the overall map area (non-land categories). Major Structure classified as "Other" accounted for <0.01% of the total mapped area (0.2 km2); "Unknown" accounted for 1.5% (20.1 km2).

	UNCONSOLIDATED SEDIMENT	CORAL REEF and HARDBOTTOM	SAND	MUD	IND. or AGG. PATCH REEF	AGGREGATE REEF	PAVEMENT	RUBBLE	LIVE CORAL	SEAGRASS	MACROALGAE	TURF	UNCOLONIZED
MAJOR STRUCTURE	71.7% (971.3 km^2)	26.8% (362.9 km^2)											
DETAILED STRUCTURE			69.9% (946.8 km^2)	1.5% (20.1 km^2)	1.9% (25.6 km^2)	4.0% (54.4 km^2)	20.9% (282.6 km^2)	0.3% (4.7 km^2)					
MAJOR BIOLOGICAL COVER									16.7% (226.7 km^2)	39.3% (531.6 km^2)	12.8% (172.7 km^2)	0.2% (2.43 km^2)	28.6% (387.9 km^2)

DISCUSSION

Relatively large deposits of sand overlie the Marquesas/Quicksands study area, and are influenced by strong reversing tidal currents. This high-energy shallow marine environment results in dynamic and sometimes ephemeral benthic habitats. For example, in several locations, dark signatures observed on the Ikonos imagery that were classified as seagrass or macroalgae cover during preliminary mapping were often discovered to be areas of uncolonized sand in the field, or vice-versa (Figure 7). Based on observations in the field, it is suspected that these areas likely support or supported macroalgae over sandy substrate, and due to seasonal changes or sediment dynamics such as burial and scouring, these communities are likely short-lived or cyclical. This situation introduces assumed error in mapping during accuracy assessment; when mapping ephemeral habitat, particularly when using aged imagery (the Ikonos imagery used in this study was 4-5 years old at the time of mapping), the likelihood of verifying the particular classified habitat during ground-validation in the field is lowered.

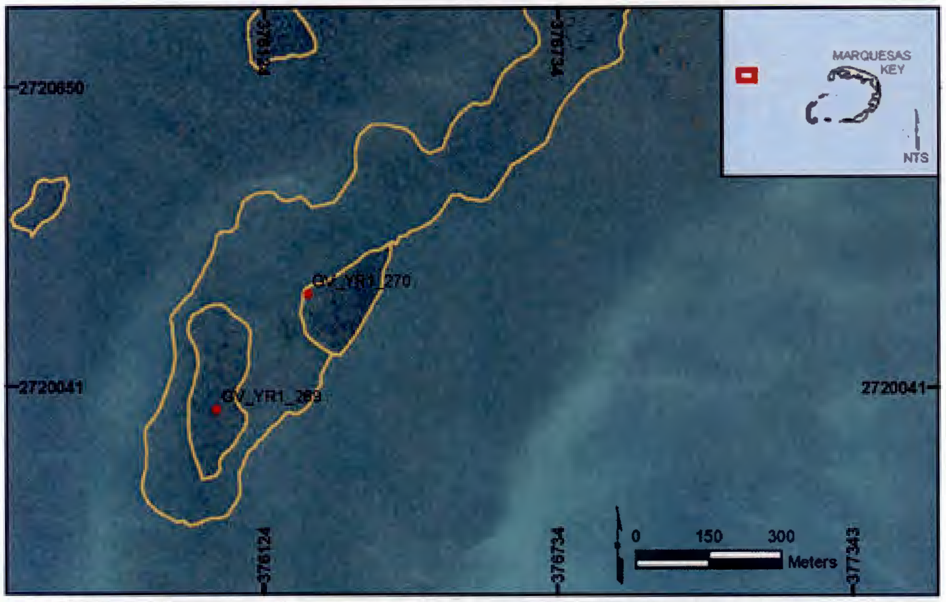

FIGURE 7. Example of suspected "ephemeral" area; the dark signature in the image was classified as macroalgae despite being ground-truthed as uncolonized sediment in the field.

Mixed communities consisting of hardbottom alternating with sandy areas supporting seagrass were frequently observed. These communities ranged from hardbottom-dominated to mostly seagrass with an occasional reef sponge or octocoral. This likely occurs due the dynamic hydrological processes that continually change the sediment thickness over the study area. Strong currents prevent sediment accretion in Boca Grande Channel, which is characterized by a hardbottom community often dominated by macroalgae. However, hardbottom areas that experience sediment accretion for long periods may exhibit seagrass-dominated communities. Once such example of this community is an area southwest of the Marquesas. Pleistocene bedrock in this area is only 4-6 m below current sea level, with sediment thickness ranging between 0 and 3 m (Lidz et al., 2003; Figure 8). Therefore, the thin layers of sediment were classified as "seagrass over pavement" rather than unconsolidated sediment (Figure 9; Photograph 4). Precedent for this classification comes from a thematic benthic map produced by NOAA for the Lower Florida Keys (Key West area), which joins the lower east edge of the Marquesas mapping area near Sand Key Reef.

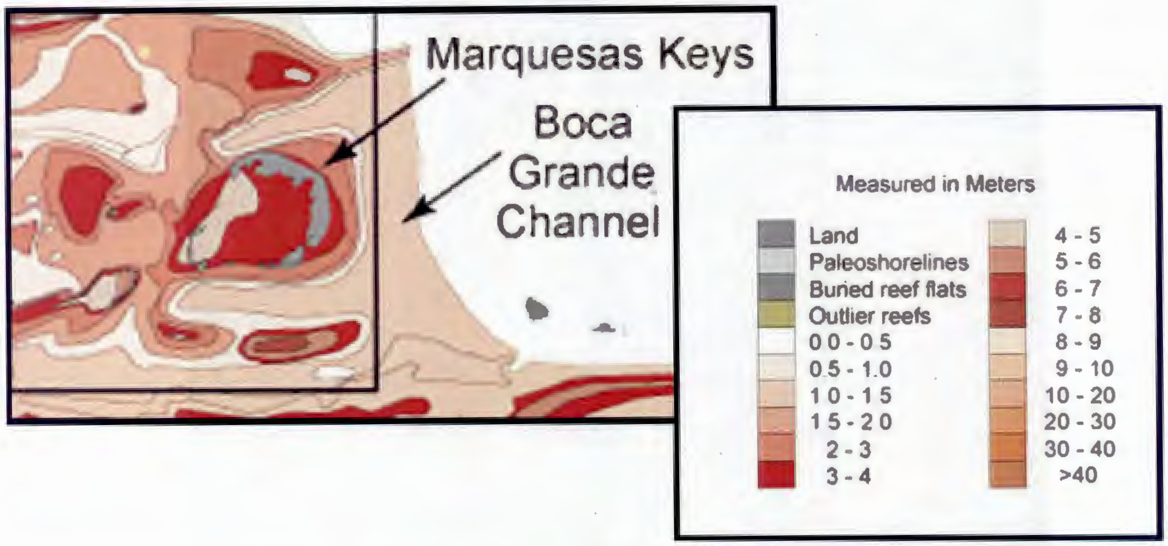

Figure 8. Sediment thickness map of the Marquesas Keys area (from Lidz et al., 2003).

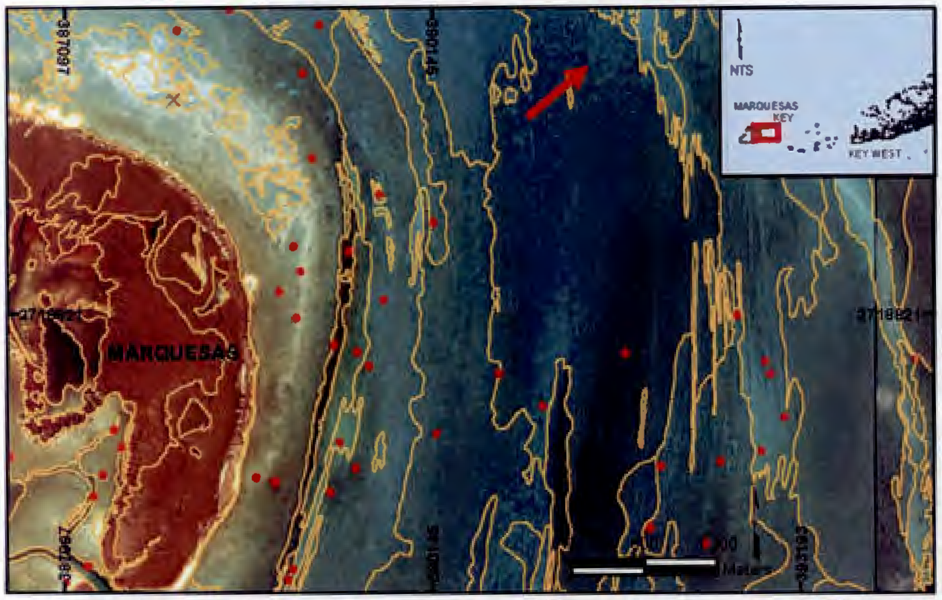

Figure 9. Area southeast of the Marquesas Keys exhibiting "mixed" benthic habitats. Arrow points to Biological Cover classification of "Seagrass" over Detailed Structure classification of "Pavement." Points are locations of ground validation

Photograph 4. "Mixed" benthic habitats. An octocoral is pictured in the foreground surrounded by dense seagrass in the background.

During preliminary GIS mapping, different signatures were isolated as separate polygons even when they were suspected of containing the same habitat or when GV points in the field revealed the same habitat in adjacent polygons (Figure 10).

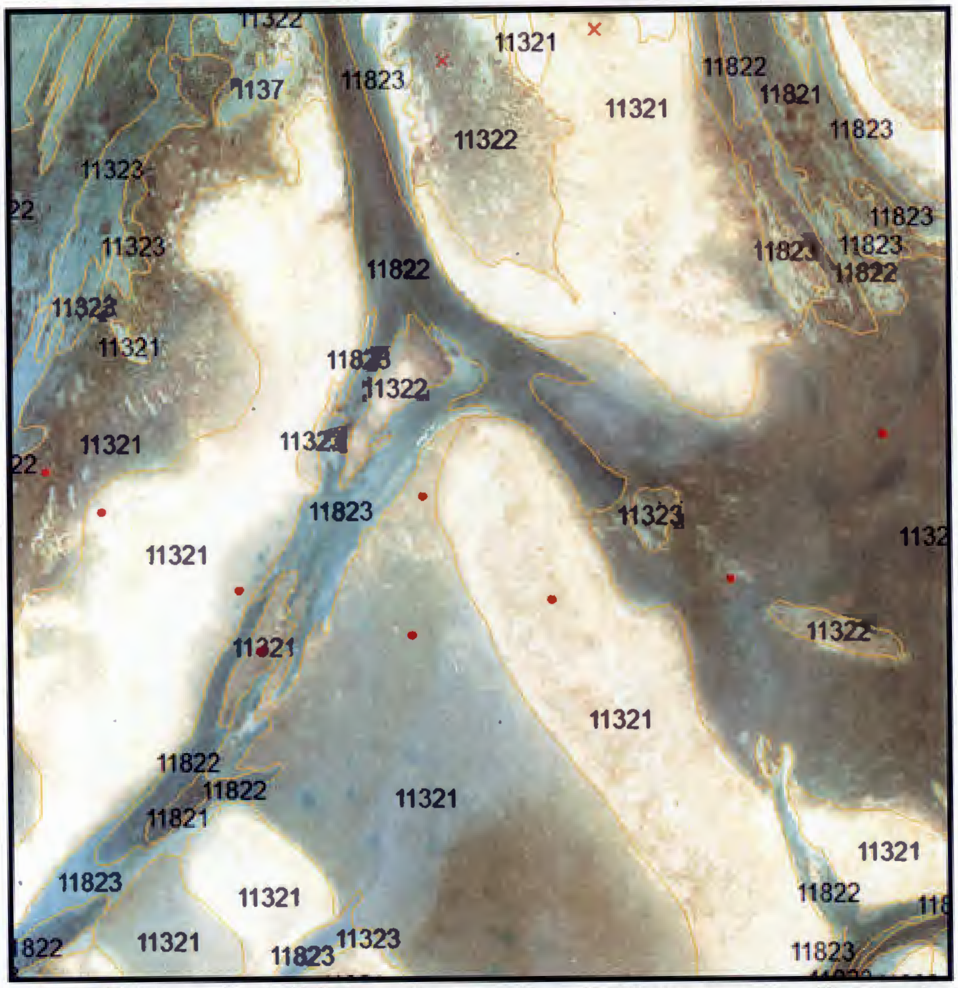

Figure 10. Example of different, adjacent polygons with the same classification due to contrasting signatures in the IKONOS imagery. The five-digit code 11321 indicates continuous seagrass over sandy substrate. Despite supporting identical habitat, the polygons display stark differences in coloration. This could be due to depth, epiphytes growing on the grass blades, water turbidity at the time the imagery was taken, or various other factors.

Some imagery used in the mapping was of poor quality that made accurate delineation of habitats difficult. Images 197742 and 204209 were of notably poor quality. Image 204209 also contained extensive cloud cover. In areas where these image files were all that was available, and especially when cloud cover obscured the underlying benthic signature, the polygon was classified as "Unknown". Figure 11 shows a large area of Hawk Channel that was not mapped due to cloud cover.

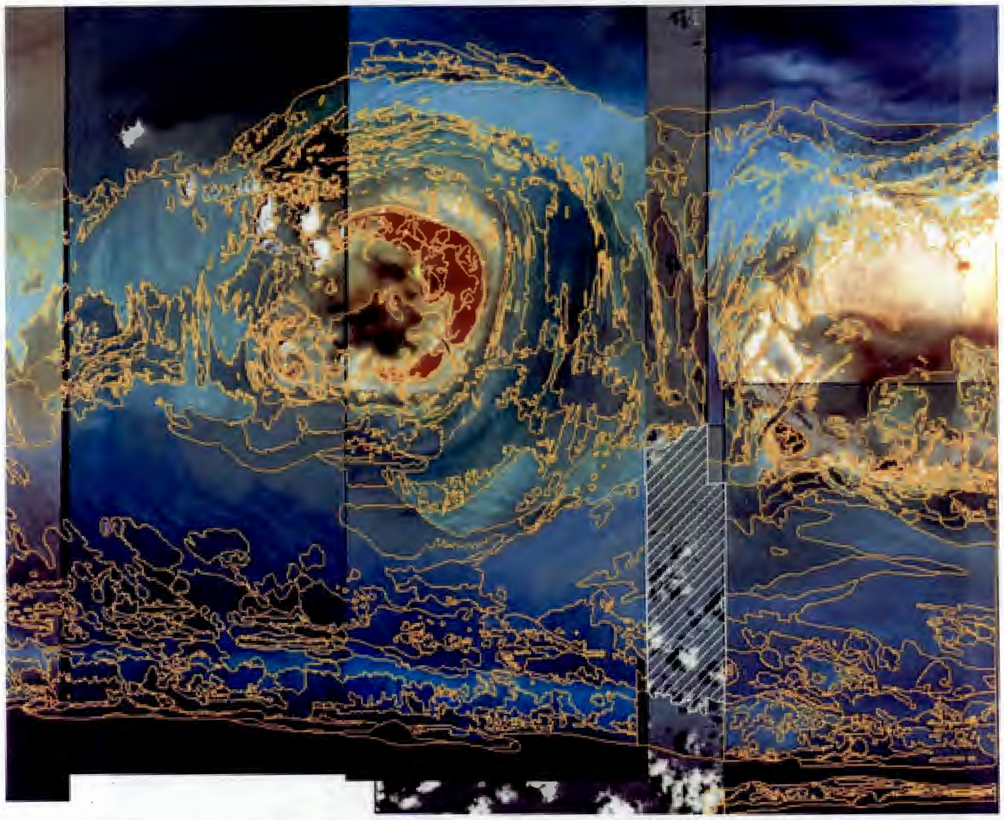

Figure 11. Example of area obscured by cloud cover within Hawk Channel.

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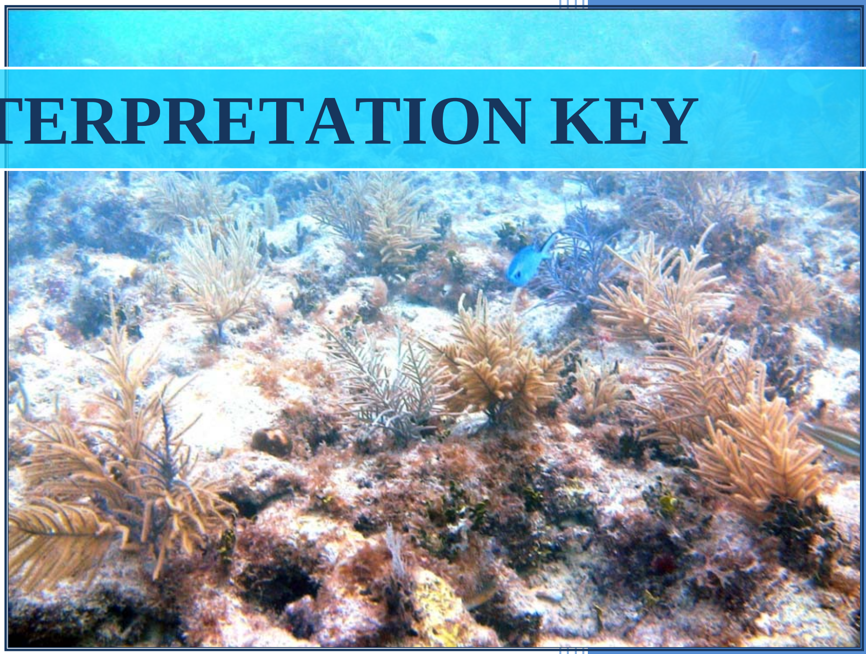
March 2011

PHOTO-INTERPRETATION KEY



Prepared for the Florida Fish & Wildlife Conservation Commission's
Fish & Wildlife Research Institute

Benthic Habitat Mapping of the Marquesas/Quicksands Area of the Florida Keys, Florida

Prepared by:
Coastal Planning & Engineering, Inc.
Boca Raton, Florida

PHOTO-INTERPRETATION KEY
MARQUESAS/QUICKSANDS BENTHIC HABITAT MAPPING PROJECT

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INTRODUCTION

The following is a photo-interpretation (PI) key used to illustrate the classification determinations made during The Marquesas/Quicksands Benthic Habitat Mapping Project. The National Oceanic and Atmospheric Adminsitration's (NOAA's) Coral Reef Conservation Program developed a hierarchical classification scheme to define and delineate southern Florida's shallow water (generally less than 30m depth) benthic habitats (Kendall *et al.(NOAA),* 2001). In this scheme, habitats are classified by three (3) major components: Structure, Zone, and Biological Cover, along with subdivisions under two of the components to provide further detal: Detailed Structure and Detailed Biological Cover. Within a GIS framework, this heirarchal system allows a user to view detail as desired by expanding or collapsing thematic details. This classifcation scheme is illustrated in Table 1 below, adopted from NOAA (2001), and applied in this remote sensing project. Maintaining this established scheme is important so that these mapping results can be incorporated into past and future mapping efforts.

High-resolution, geo-referenced, pan-sharpened, color IKONOS satellite imagery were used for the mapping. All seafloor features visible in the imagery, with the exception of patch reefs, were mapped to the 0.4 ha/~1 ac minimum mapping unit (MMU) specification. Patch reefs were mapped using an approximately 0.0625 ha/0.154 ac MMU. Land, defined as hard features or landward boundary of visible red mangrove extent, was mapped to the 0.1 ha/0.247 ac MMU.

After preliminary mapping was completed for each area using IKONOS imagery in GIS, ground validation was conducted in the field using a 950 series SeaDrop Camera made by SeaViewer. The drop-camera was integrated with a DGPS for recording real-time GPS coordinates on the video footage. Representative footage of each classification type, as well as footage of areas that were undetermined during preliminary mapping, was recorded. Divers entered the water and documented the seafloor with a handheld underwater camera when the seafloor cover type was unclear in the drop-camera feed.

Table 1. Classification scheme for mapping benthic habitats in the Marquesas/Quicksands area of the Florida Keys (adopted from NOAA, 2001).

Major Structure	Detailed Structure	Zone	Major Biological Cover	Detailed Biological Cover	Percentage
Unconsolidated Sediment	Sand	Shoreline Intertidal	Live Coral	Continuous Coral	> 90%
		Shoreline Supratidal		Patchy Coral	50-90%
		Lagoon		Sparse Coral	10-50%
	Mud		Seagrass	Continuous Seagrass	> 90%
		Bank/Shelf		Patchy Seagrass	50-90%
				Sparse Seagrass	10-50%
Coral Reef and Hardbottom	Spur and Groove	Back Reef	Macroalgae	Continuous Macroalgae	> 90%
	Individual or Aggregated Patch Reef			Patchy Macroalgae	50-90%
		Ridges and Swales		Sparse Macroalgae	10-50%
	Aggregate Reef		Encrusting/Coralline Algae	Continuous Coralline Algae	> 90%
	Scattered Coral/Rock in Unconsolidated Sediment	Reef Crest		Patchy Coralline Algae	50-90%
				Sparse Coralline Algae	10-50%
	Pavement	Forereef	Turf Algae	Continuous Turf Algae	> 90%
	Rock/Boulder			Patchy Turf Algae	50-90%
	Reef Rubble	Channel		Sparse Turf Algae	10-50%
	Pavement with Sand Channels		Emergent Vegetation	Marsh	> 90%
		Dredged			50-90%
Other Delineations	Artificial	Vertical Wall		Mangrove	10-50%
	Land	Bank/Shelf Escarpment	Uncolonized	Uncolonized	> 90%
Unknown	Unknown	Unknown	Unknown	Unknown	> 90%

CLASSIFICATIONS

The following section outlines and defines the classification types used for the Marquesas/Quicksands Benthic Habitat Mapping Project. Cover types refer only to the predominate biological component colonizing the surface of the seafloor, and are defined in a hierarchy ranging from seven major classes (see Table 1), combined with a percent cover modifier (*Detailed Biological Cover*). Representative photo-documentation is provided for each cover classification described.

STRUCTURE

This component describes the physical structure of the polygon within the ecosystem. NOAA's classification scheme defines geomorphic structure using four (4) *Major Structure* types and twelve (12) *Detailed Structure* types. However, many of these classifications did not apply in the Marquesas/Quicksands mapped area. Classifications that were used in the mapping of this project are described below.

Unconsolidated Sediment

This category includes areas of seafloor containing unconsolidated sediment. Two subclasses of detailed structure fall under this category:

- **SAND**: coarse sediment usually found in areas exposed to currents or wave energy; sand is a dominant structural element in the Marquesas/Quicksands area

- **MUD**: fine grain sediments associated with low energy environments, free from waves and currents; mud can be found in the project area in and around mangroves

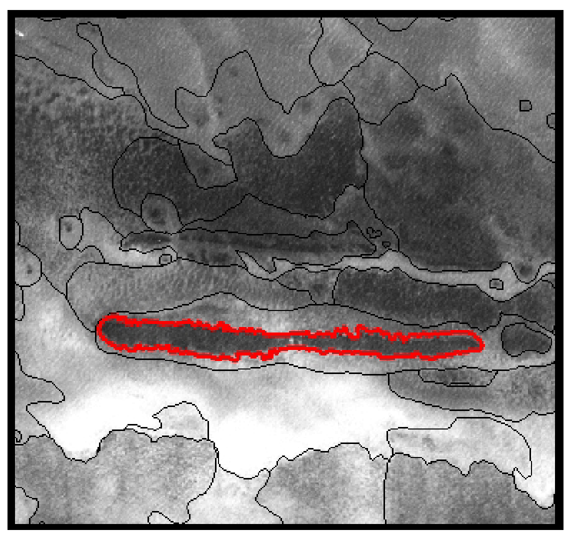
Coral Reef and Hardbottom

Areas of hardened substrate formed by the deposition of calcium carbonate by reef-building organisms or exposed bedrock. Hardbottom typically has no more than a thin veneer of sediment; however, the Marquesas/Quicksands area is highly dynamic, with continual sand movement. Areas subject to high current and tidal flux may become alternately exposed or buried; this constant flux of sand deposition and thickness determines the biotic cover at the time of sampling.

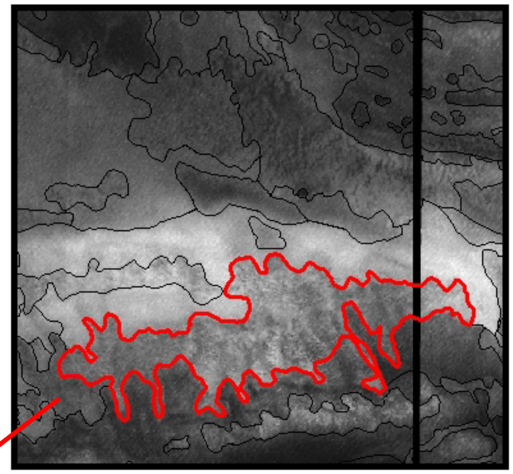
- **INDIVIDUAL OR AGGREGATED PATCH REEF**: coral formations characterized by vertical relief of at least one meter and often having a round or oblong shape. Patch reefs are typically located in shallow waters of 10-20 ft (3-6 m) in depth, within the Florida Reef Tract and beyond. They are isolated from other reef formations by bare sand, seagrass or other habitats and have no organized structural axis relative to the contours of the shore or shelf edge. A surrounding ring of sand is often a distinguishing feature; for mapping purposes these sand halos are included with the patch reef in a single polygon. The width of this ring of sand is often determined by the distance that herbivorous fish and other herbivores (including *Diadema antillarum*) feel is within safe foraging range from the reef. Within the study area, patch reefs are common within Hawk Channel, have the highest relief of any coral reef formation, and typically support the highest biotic cover.

- Each patch reef differs in size, development, and species residing on them. Many patch reefs grow on Pleistocene bedrock whereas others have grown from mud banks. Patch reefs are classified as individual if they are equal to or larger than the minimum mapping unit (MMU) and aggregated when they are clustered too close together to be map individually or are less than the MMU. An aggregate patch reef typically contains a grouping of individual patch reefs of various sizes - generally three to ten in number – that share a common halo and exhibit complete separation between individual reefs. No distinction is made between individual and aggregated patch reefs for this project.

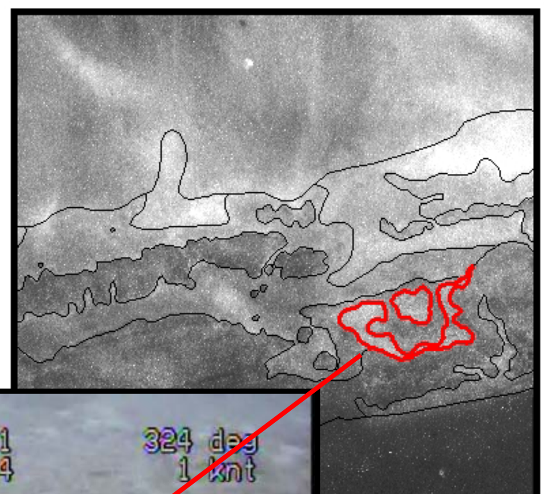
- **AGGREGATE REEF**: Vast expanses of coral formations that vary in shape and height (but typically high relief), and lack the presence of sand channels are classified as aggregate reefs. They may also include linear formations of coral that grow parallel to the edges of the seafloor shelf. In this locale, this formation is typified by stony corals, interspersed with soft corals and sponges. The reef space below the coral has many holes and cavities well suited for fish and invertebrates to take refuge in.



- **PAVEMENT**: Pavement is low-relief to flat, solid carbonate rock. The reef pavement surface is often characterized as relatively smooth with low coral coverage and intermittent turf algae coverage. Areas of pavement are often incised by small shore-normal sand channels 0.5 m in depth and width. Common corals found amongst pavement areas include "weedy" corals of the genus *Porites* and *Siderastrea*.

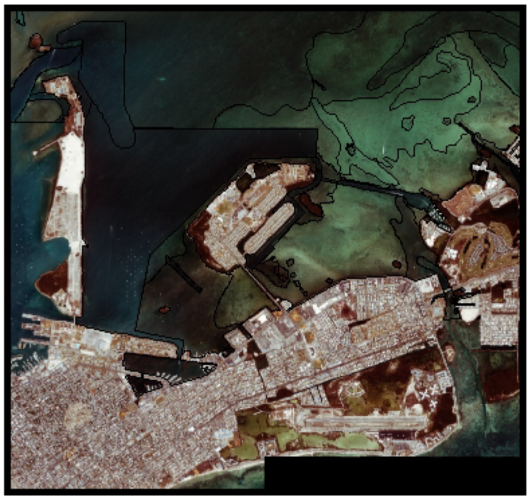


- **REEF RUBBLE**: Reef rubble is often composed of unstable dead branching coral fragments including those of elkhorn (*Acropora palmata*) and staghorn (*Acropora cervicornis*) coral. Individual rubble fragments are often encrusted with crustose coralline algae (CCA) which can serve to bind fragments helping to stabilize the rubble zone. Rubble may also be colonized by turf, filamentous or other macroalgae. This habitat usually occurs landward of well developed reef formations in the reef crest, ridges and swales or back reef zone. Well-developed rubble zones were not observed in the Marquesas/Quicksands mapping area.



Other Delineations

- **ARTIFICIAL**: manmade structures such as bridges, docks and piers.
- **LAND**: terrestrial features above the spring high tide line



Unknown

Unknown areas are defined as having indeterminable seafloor composition. In some areas, water turbidity hindered bottom interpretation; however, the primary cause for designation of an area as unknown was cloud cover.

ZONES

Geological zones denote cross-sectional location relative to emergent features. NOAA's Coral Reef Conservation Program used defined the cross-section of zones typical of the Florida Keys in their 2008 report in which they initially developed the classification scheme that is used in this project (Figure 1 below). Although this figure has been applied to other mapping projects in the Florida Keys, no emergent reef crest was observed in the Marquesas/Quicksands area. Therefore, an alternate zone classification was used based on Figure 2 below; similar logic has been applied to mapping efforts in southeast Florida where no emergent reef crest exists (Walker, 2009).

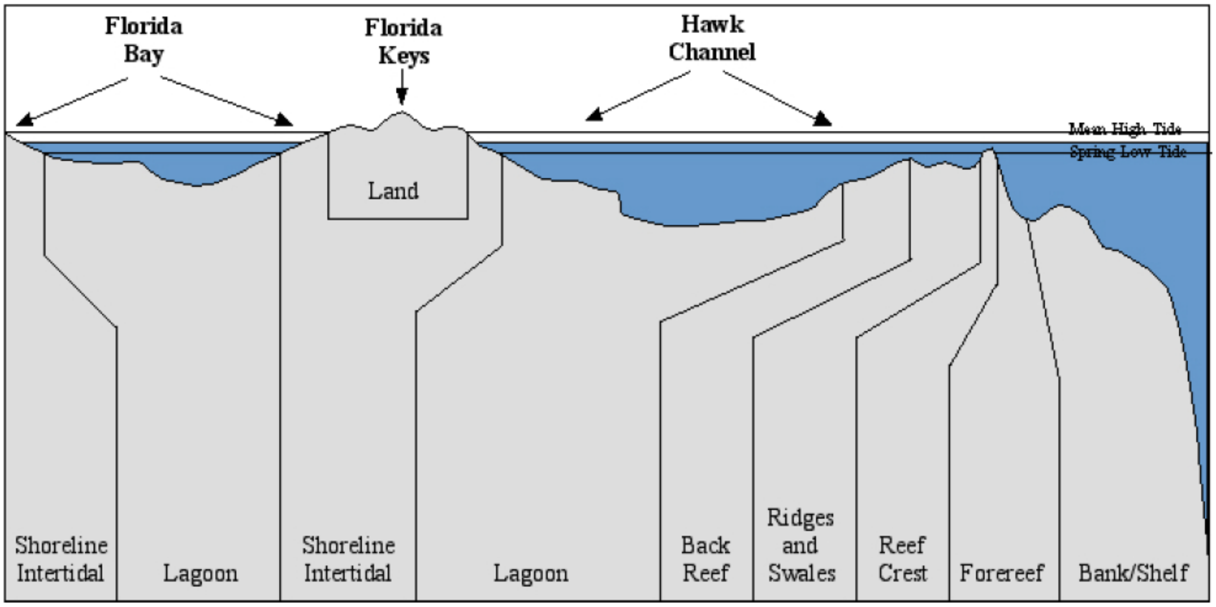


Figure 1. Cross-section of zones typical of the Florida Keys (Source: NOAA, 2008).

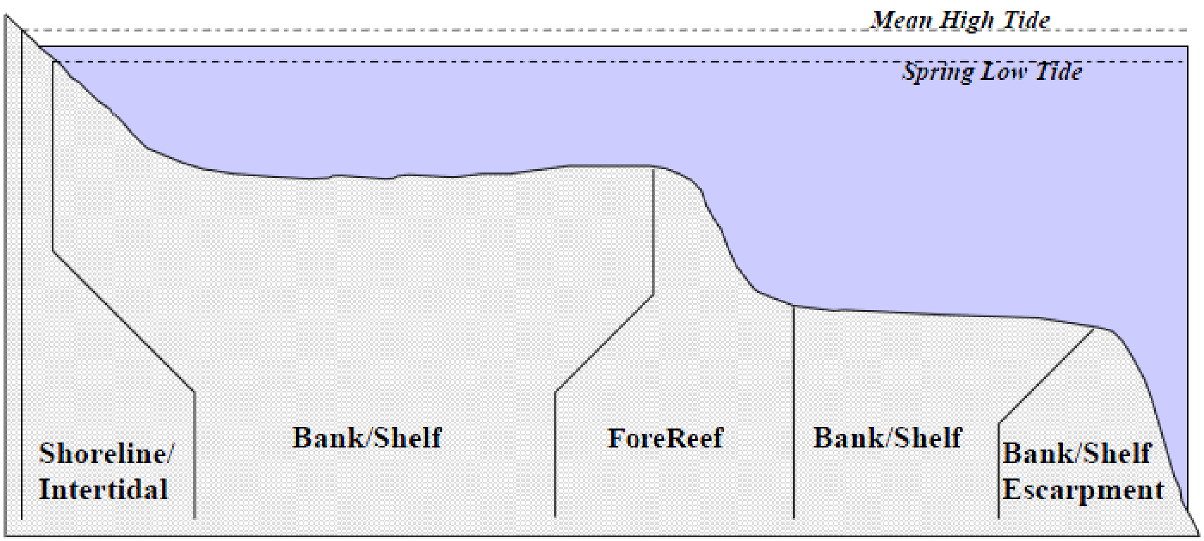
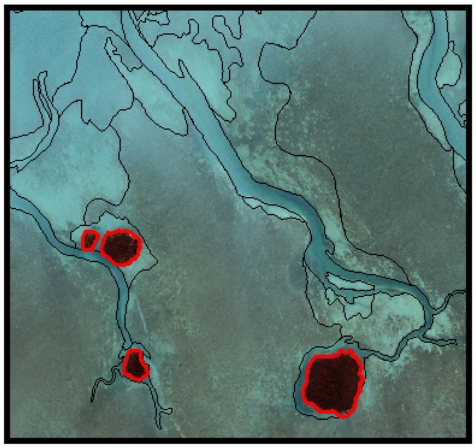


Figure 2. Cross-section of zones where no emergent reef crest is present (Source: NOAA, 2001).

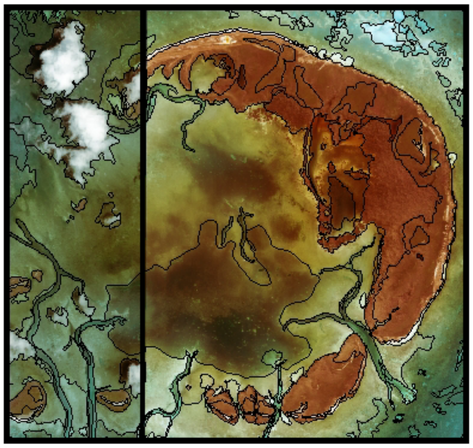
NOAA's classification scheme includes 11 *Zones*; however, as with *Detailed Structure* classifications, many zone types did not apply in the Marquesas/Quicksands mapped area. As described above, no emergent reef crest was observed, thus precluding the use of mapping zones such as *lagoon* (with the exception of the area inside the Marquesas Keys), *back reef*, and *reef crest*. The majority of the study area was designated *bank/shelf*, as shown in Figure 2 above. Zones applied in this mapping project are described below.

- **SHORELINE INTERTIDAL**: the area between the mean high water line, and lowest spring tide level.

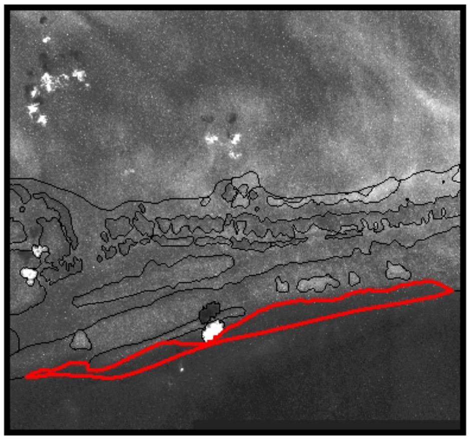


- **SHORELINE SUPRATIDAL**: any area above the mean high water line; land.

- **LAGOON**: the shallow area between the shoreline intertidal and backreef or barrier island. No emergent crest was observed in the study area; therefore no backreef designations and thus no lagoon designations were made with the exception of the shallow areas inside the Marquesas Keys.

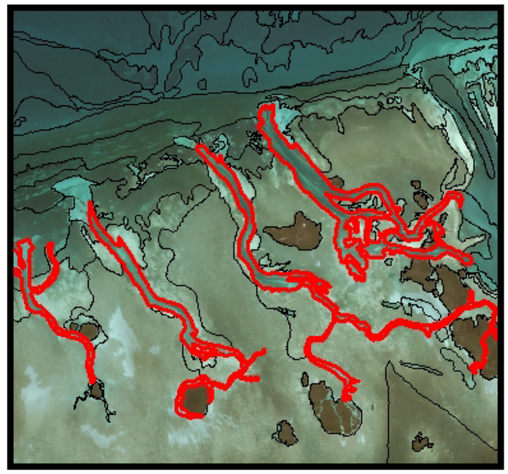


- **BANK/SHELF**: the platform between the shoreline/intertidal zone and the open ocean. The majority of the Marquesas/Quicksands mapping area falls within the bank/shelf zone.



- **FOREREEF**: typically, the forereef is the area from the seaward edge of the reef crest that slopes into deeper water to the landward edge of the bank/shelf platform. However, no emergent crest is present in the study area; therefore, any area where the seaward facing slope is significantly greater than the slope of the bank/shelf was designated as forereef for this mapping project.

- **CHANNEL**: a natural trough in the seafloor through which water flows at level higher than the surrounding shallow area. In the mapping area, most channels are lined with uncolonized sand or seagrass. However, within the Quicksands area and Boca Grand Channel, the currents are such that little sediment remains; rather, hardbottom and associated coral reef communities may be present due exposure of the underlying hard structure.



- **DREDGED**: areas in which the natural geomorphology is disrupted or altered by excavation of dredging.

BIOLOGICAL COVER

The NOAA classification scheme utilizes eight (8) distinct categories to describe the *Major Biological Cover* which is further broken down into *Detailed Biological Cover* categories based on percent cover qualified as "continuous", "patchy" or "sparse" (Table 2).

Table 2. Definition of each *Detailed Biological Cover* category.

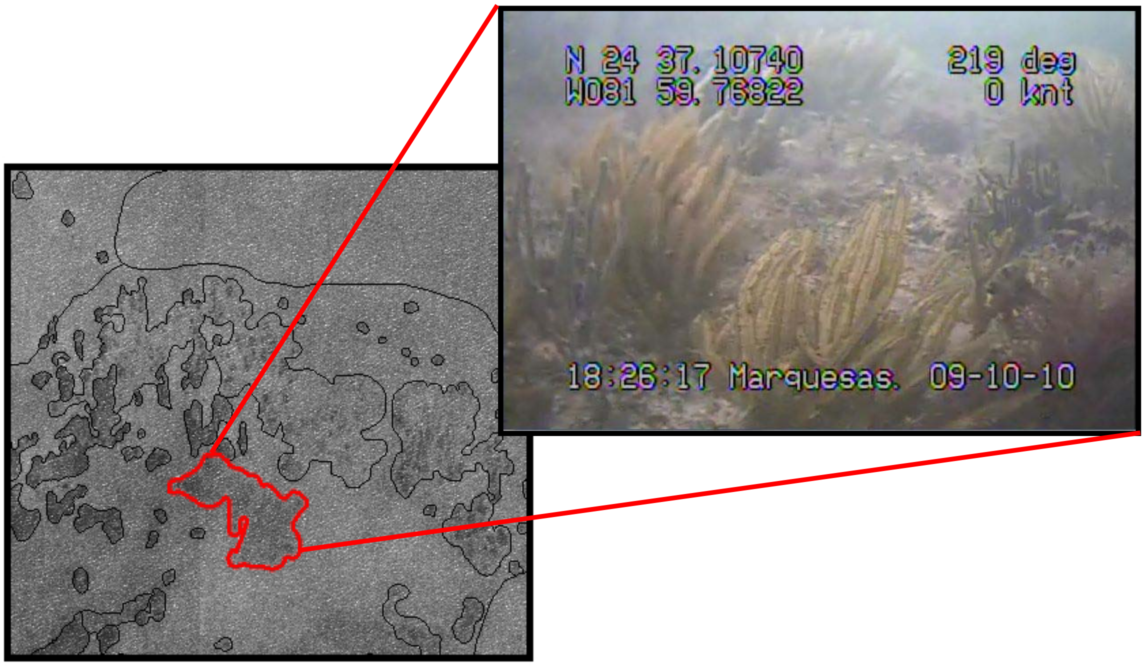
Detailed Biological Cover	Percentage
Continuous	>90%
Patchy	50-90%
Sparse	10-50%

Biological cover is assigned in a step-wise progression from *Live Coral* to *Seagrass* to *Macroalgae* to *Encrusting Coralline Algae* to *Turf Algae* to *Emergent Vegetation* to *Uncolonized* and finally *Unknown*. Cover modifiers are also assigned in a step-wise progression from "continuous" to "patchy" to "sparse". Because of this step-wise progression, polygons are not always named for their predominant cover if that cover is lower in the hierarchy than another cover found in that polygon (example: polygon containing 15% seagrass and 85% macroaglae will be classified as *Sparse Seagrass* rather than *Patchy Macroalgae*).

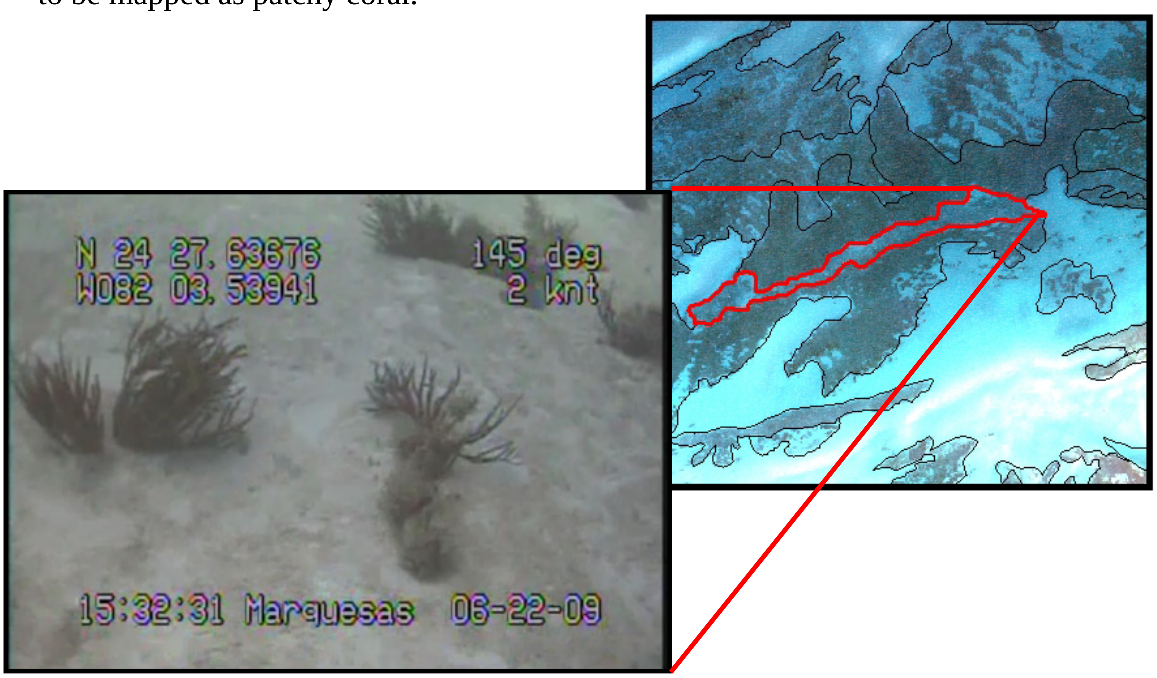
> ***Live Coral*** *is defined as substrates colonized by sponges, octocorals, and hexacorals (stony corals) and have at least 10% live coral cover*

- CONTINUOUS CORAL (>90% cover): may include areas of less than 90% coral cover on 10% or less of the total area that are too small to be mapped independently. Observed coral cover never exceeded 90% during this mapping project; therefore, no designation of live *Continuous Coral* cover was assigned to any areas.

- PATCHY CORAL (50% to 90% cover): discontinuous live coral with breaks in coverage that are too diffuse, irregular, or result in isolated patches that are too small to be mapped as continuous coral.

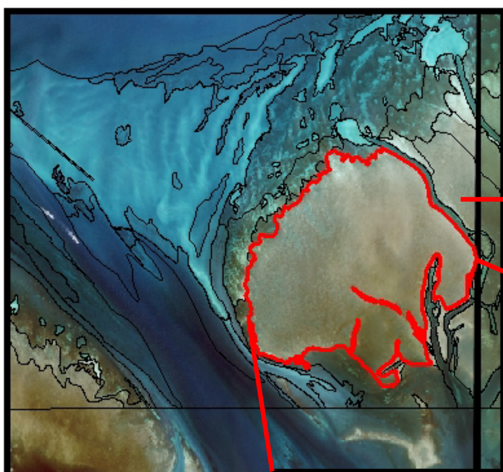


- SPARSE CORAL (10% to 50% cover): discontinuous live coral with breaks in coverage that are too diffuse, irregular, or result in isolated patches that are too small to be mapped as patchy coral.



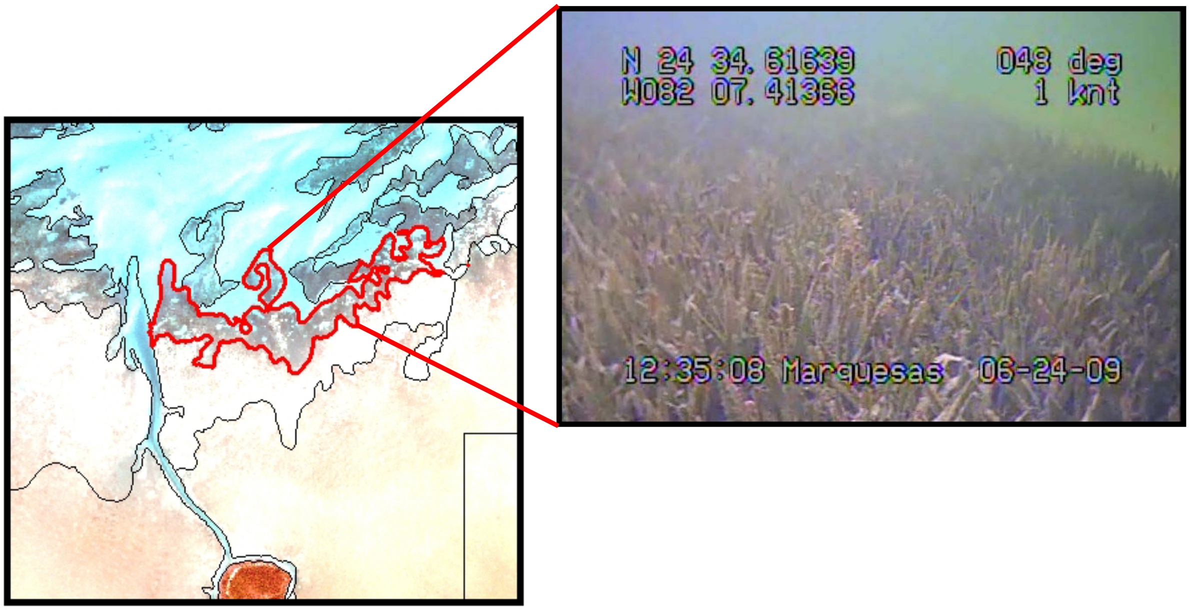
Seagrass *is defined as areas of submerged aquatic vegetation with at least 10% cover by seagrass species*

- CONTINUOUS SEAGRASS (>90% cover): may include blowouts of less than 10% of the total area that are too small to be mapped independently.

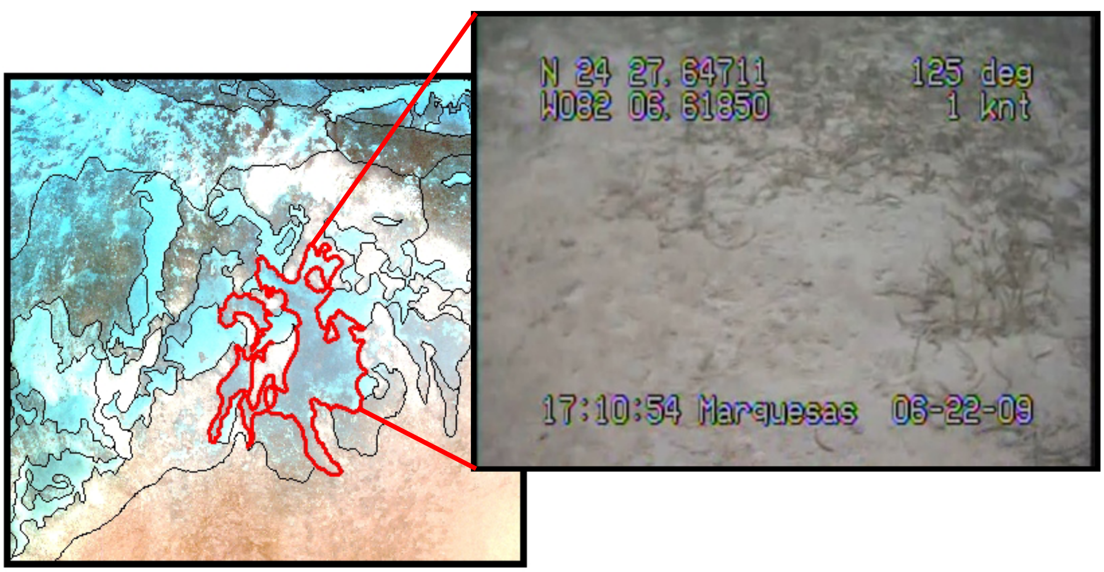


(above-water view)

- PATCHY SEAGRASS (50% to 90% cover): discontinuous seagrass community with breaks in coverage that are too diffuse, irregular or result is isolated patches that are too small to be mapped as continuous seagrass.

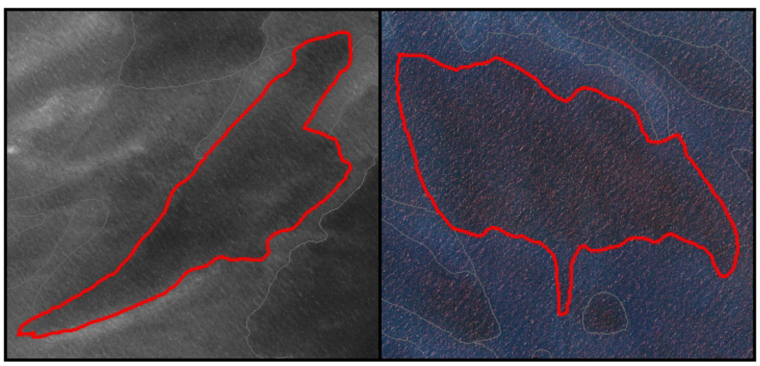


- SPARSE SEAGRASS (10% to 50% cover): discontinuous seagrass community with breaks in coverage that are too diffuse, irregular, or result in isolated patches that are too small to be mapped as patchy seagrass.



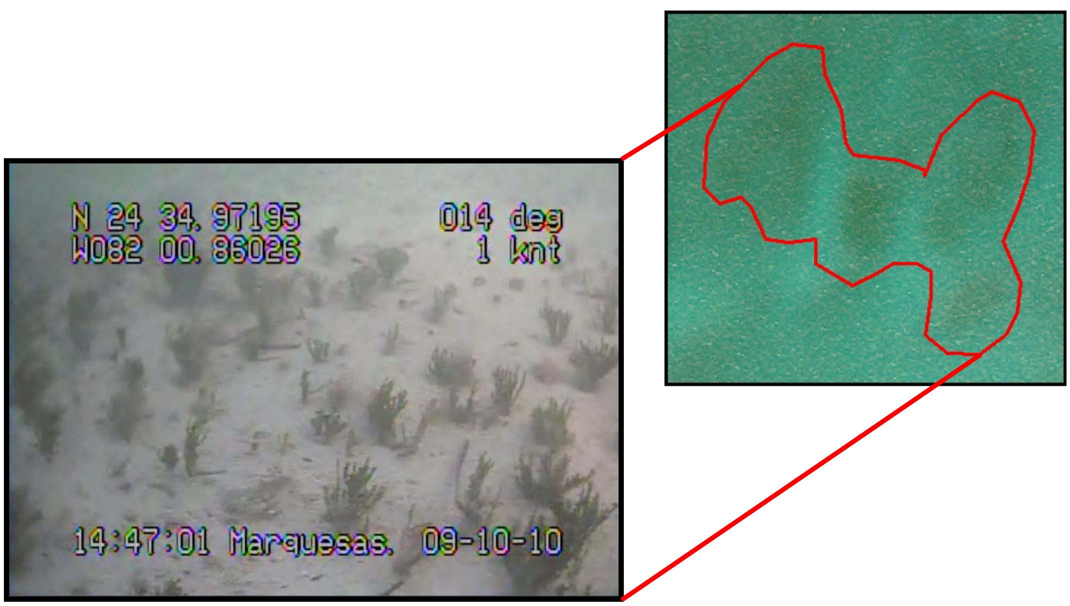
> ***Macroalgae*** *is defined as areas consisting of less than 10% live coral or seagrass and greater than 10% coverage of any combination of species of red, green or brown macroalgae*

- CONTINUOUS MACROALGAE (>90% cover): may include areas of less than 90% macroalgae coverage that are too small to be mapped independently.

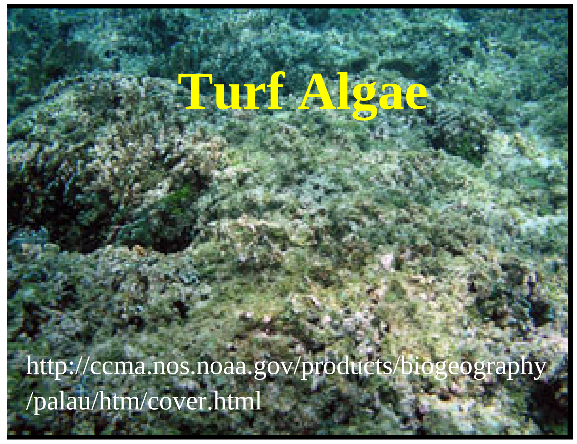


- PATCHY MACROALGAE (50% to 90% cover): discontinuous macroalgae with breaks in coverage that are too diffuse, irregular or result in isolated patches that are too small to be mapped independently.

- SPARSE MACROALGAE (10% to 50% cover): discontinuous macroalgae with breaks in coverage that are too diffuse, irregular or result in isolates patches that are too small to be mapped as patchy macroalgae.



__Turf algae__ are a multispecific assemblage of diminutive, often filamentous, algae that attain a canopy height of only 1 to 10 mm. These microalgal species have a high diversity (>100 species in western Atlantic), although only 30 to 50 species commonly occur at one time. There is a high turnover of individual turf algal species seasonally and only a few species are able to persist or remain abundant throughout the year; however, when observed as a functional group, turf algae remain relatively stable year round.



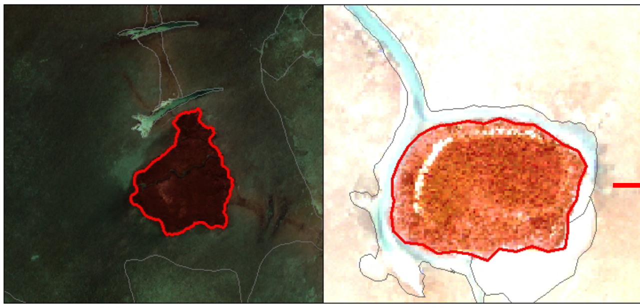
- Continuous Turf Algae (>90% cover): may include areas of bare substrate or differing cover of less than 10% of the total area that are too small to be mapped independently. This category was not used in the mapping area.

- Patchy Turf Algae (50% to 90% cover): discontinuous turf algae with breaks in coverage that are too diffuse, irregular or result in isolated patches too small to be mapped as continuous turf algae.

- Sparse Turf Algae (10% to 50% cover): discontinuous turf algae with breaks in coverage that are too diffuse, irregular or result in isolated patches too small to be mapped as patchy turf algae.

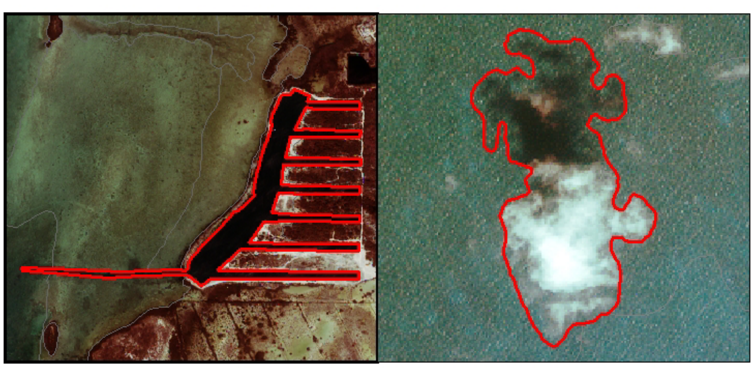
> ***Emergent vegetation*** *in the project area is composed of red mangroves(Rhizophora mangle) and a few other species including black mangroves(Avicennia germinans), white mangroves(Laguncularia racemosa), and buttonwood (Conocarpus erectus).*

Mangroves are generally found in areas sheltered from high-energy waves. The area east of the Marquesas and north of Key West is dotted with small mangrove keys/islands composed primarily of *R. mangle*. The red mangrove grows closest to open water. It has multiple prop roots, which may help to stabilize the surrounding soil and aid in island formation. Black mangroves are found at a higher elevation and do not have prop roots; instead, this species has utilizes pneumatophores for oxygen exchange, which grow up from the roots to above the water level. White mangroves grow closest to shore. This species may have prop roots and/or pneumatophores, depending on conditions where it is growing. The buttonwood grows in shallow, brackish water or on dry land.



(mangroves)

Uncolonized: substrate that is covered with less than 10% of any of the above eight biological cover classes.



Unknown:
classification used when delineation was not possible from aerial imagery, mostly due to cloud cover although turbid or dark water may also obscure interpretation.

REFERENCES

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10600.00

March 30, 2011

Submitted via Email

David Palandro, Ph.D.
Fish and Wildlife Research Institute
100 8th Avenue, SE
St. Petersburg, FL 33701

RE: Marquesas/Quicksands Benthic Habitat Mapping Accuracy Assessment

Dear Dr. Palandro:

Coastal Planning & Engineering, Inc., (CPE) has conducted an internal accuracy assessment to evaluate the thematic accuracy of the draft map deliverable. Results show an accuracy range of 67% to 91%. This range is similar to National Coral Reef Institute's (NCRI) accuracy assessment of NOAA's region of interest (ROI) 2 (Key West). These are positive results given the large temporal difference between the satellite images and the collection of accuracy assessment points.

Point Selection and Field Data Collection

Accuracy assessment (AA) points were randomly generated using ET Geowizards in ArcMap. Initial points were reviewed for proximity to polygon borders that were digitized when interpreting benthic habitats from satellite imagery. To avoid being placed within a habitat transition, points randomly placed closer than 200 ft to a boundary were manually moved further into the randomly selected polygon so that they were at least 200 ft away from the polygon edge. Satellite images were turned off while moving the points to discourage unintentionally biased placement.

AA data were collected during the Years 2 and 3 field mapping events. CPE navigated to each AA point and documented the location using a 950 series SeaViewer SeaDrop camera. Navigation was provided by a Trimble DMS 232 DGPS system linked to a laptop running Hypack and the camera. Camera location, direction and speed were recorded on the video. A total of 293 AA video points were collected (Figure 1).

Evaluation of Data

Several statistical analyses were used to evaluate the benthic habitat map. Error matrices were prepared for each of the four mapping categories: Major Structure, Detailed Structure, Major Biological Cover and Detailed Biological Cover. In each error matrix, the overall producer's and user's accuracies were calculated. The producer's accuracy is a measure of how well the mapper classified a particular habitat. The user's accuracy indicates how often map polygons of a certain habitat type were classified correctly.

Each error matrix was constructed as a square array arranged in rows (map classification) and columns (ground-truthed of accuracy assessment). The overall accuracy was calculated as the sum of the major diagonal/correct classifications, divided by the total number of accuracy assessment samples. Each diagonal element was divided by the column total to yield a producer's accuracy and by the row total to produce a user's accuracy.

Following the creation of each error matrix, the Tau coefficient (T_e), a measure of the improvement of classification accuracy over a random assignment of map units to map categories, was calculated. As the number of categories increases, the probability of random agreement (P_r) decreases, and T_e approaches the overall accuracy, P_o. The Tau coefficient is calculated as follows:

$$T_e = (P_o - P_r)/(1 - P_r)$$

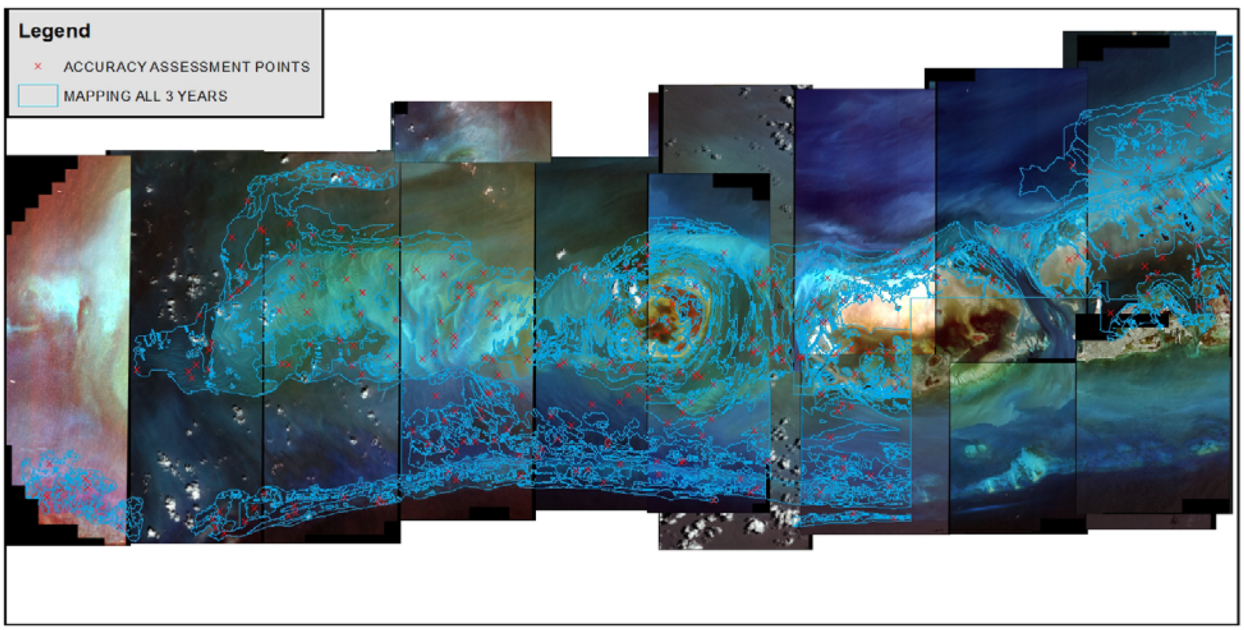

Figure 1. Overview map of Marquesas/Quicksands mapping area and Accuracy Assessment (AA) sampling points.

The map marginal proportions were used to adjust the producer's and overall accuracies for each error matrix. Although stratified random sampling was not used to generate the AA points, rare map categories may have been sampled as frequently as common map categories. Even though a certain category represented only 1% of the total mapped area, it may have received 5% of the total AA sampling points. Utilizing the map marginal proportions or proportional areas of map categories relative to the total mapped area adjusts the overall and producer's accuracies. The known map marginal proportions (π_i) were computed from the GIS layer of the draft benthic habitat map for each of the four error matrices, by dividing the area of each category by the total map area. The areas were exclusive to categories present in the error matrix.

The individual cell probabilities, i.e., the product of the original error matrix cell values and π_i, divided by the row marginal (total map classifications per category), were computed for the off-diagonal elements using the following equation:

$$\widehat{P}=\pi_i n_{ij}/n_{i-}$$

Results

Major Structure

Error matrices for Major Structure category are presented in Tables 1 and 2. The overall accuracy (P_o) for Major Structure was 90.8%. The calculated Tau coefficient (T_e) was 0.816; in other words, the rate of misclassifications at the Major Structure level was 81.6% less than would be expected from random assignment of polygons to categories.

Table 1. Error matrix for Major Structure category.

Map Data (i)	MAJOR STRUCTURE	Accuracy Assessment (j): CORAL REEF AND HARDBOTTOM	Accuracy Assessment (j): UNCOLIDATED SEDIMENT	π_i	User's Accuracy (%)
	CORAL REEF AND HARDBOTTOM	**0.2197**	0.0481	0.2678	**82.0%**
	UNCOLIDATED SEDIMENT	0.0395	**0.6927**	0.7322	**94.6%**
	n_{-j}	0.2592	0.7408	**P_o=91.2%**	
	Producer's Accuracy (%)	**84.8%**	**93.5%**		

Table 2. Error matrix for Major Structure corrected using known map marginal proportions (π_i).

Map Data (i)	MAJOR STRUCTURE	Accuracy Assessment (j): CORAL REEF AND HARDBOTTOM	Accuracy Assessment (j): UNCOLIDATED SEDIMENT	n_{i-}	User's Accuracy (%)
	CORAL REEF AND HARDBOTTOM	**73**	16	89	**82.0%**
	UNCOLIDATED SEDIMENT	11	**193**	204	**94.6%**
	n_{-j}	84	209	*n=293*	
				P_o=90.8%	
	Producer's Accuracy (%)	**86.9%**	**92.3%**	**$T_{e=}$0.816**	

Discrimination between the two categories (Coral Reef and Hardbottom vs. Unconsolidated Sediment) increased after the error matrix cell values were transformed from the original binomial observations to individual cell probabilities, increasing the overall accuracy from 90.8% to 91.2%.

Detailed Structure

Error matrices for Detailed Structure category are presented in Tables 3 and 4. The overall accuracy (P_o) for Detailed Structure was 87.0%. The calculated Tau coefficient (T_e) was 0.838.

Table 3. Error matrix for Detailed Structure category.

Accuracy Assessment (j)

DETAILED STRUCTURE	SAND	MUD	PAVEMENT	PATCH REEF	AGGREGATE REEF	$n_{i\cdot}$	**User's Accuracy (%)**
SAND	**188**	0	10	0	2	200	**94.0%**
MUD	0	**4**	0	0	0	4	**100.0%**
PAVEMENT	13	0	**49**	0	0	62	**79.0%**
PATCH REEF	6	0	3	**1**	0	10	**10.0%**
AGGREGATE REEF	0	0	4	0	**13**	17	**76.5%**
$n_{\cdot j}$	207	4	66	1	15	*n=293*	
Producer's Accuracy (%)	**90.8%**	**100.0%**	**74.2%**	**100.0%**	**86.7%**	**P_o=87.0%** / **T_e=0.838**	

Map Data (i)

Table 4. Error matrix for Detailed Structure corrected using known map marginal proportions (π_i).

Accuracy Assessment (j)

DETAILED STRUCTURE	SAND	MUD	PAVEMENT	PATCH REEF	AGGREGATE REEF	π_i	**User's Accuracy (%)**
SAND	**0.6742**	0	0.0359	0	0.0072	0.7173	**94.0%**
MUD	0	**0.0149**	0	0	0	0.0149	**100.0%**
PAVEMENT	0.0414	0	**0.1560**	0	0	0.1973	**79.0%**
PATCH REEF	0.0121	0	0.0061	**0.0020**	0	0.0202	**10.0%**
AGGREGATE REEF	0	0	0.0118	0	**0.0383**	0.0501	**76.5%**
$n_{\cdot j}$	0.7277	0.0149	0.2097	0.0020	0.0455	**P_o=88.6%**	
Producer's Accuracy (%)	**92.6%**	**100.0%**	**74.4%**	**100.0%**	**84.2%**		

Map Data (i)

After the error matrix cell values were transformed from the original binomial observations to individual cell probabilities, the overall accuracy increased from 87.0% to 88.6%.

Major Biological Cover

Error matrices for Major Biological Cover category are presented in Tables 5 and 6. The overall accuracy (P_o) for Major Biological Cover was 73.7%. The calculated Tau coefficient (T_e) was 0.685.

Table 5. Error matrix for Major Biological Cover category.

Accuracy Assessment (j); rows: *Map Data (i)*

MAJOR BIOLOGICAL COVER	CORAL	SEAGRASS	MACROALGAE	TURF	EMERGENT	UNCOLONIZED	$n_{i\cdot}$	User's Accuracy (%)
CORAL	**34**	5	16	0	0	5	60	**56.7%**
SEAGRASS	6	**90**	10	0	0	6	112	**80.4%**
MACROALGAE	2	6	**28**	0	0	8	44	**63.6%**
TURF	0	0	1	**0**	0	0	1	**0.0%**
EMERGENT	0	0	0	0	**2**	0	2	**100.0%**
UNCOLONIZED	0	3	9	0	0	**62**	74	**83.8%**
$n_{\cdot j}$	42	104	64	0	2	81	*n=293*	
Producer's Accuracy (%)	**81.0%**	**86.5%**	**43.8%**	**0.0%**	**100.0%**	**76.5%**	**P_o=73.7%**	**T_e=0.685**

Table 6. Error matrix for Major Biological Cover corrected using known map marginal proportions (π_i).

Accuracy Assessment (j); rows: *Map Data (i)*

MAJOR BIOLOGICAL COVER	CORAL	SEAGRASS	MACROALGAE	TURF	EMERGENT	UNCOLONIZED	π_i	User's Accuracy (%)
CORAL	**0.1010**	0.0149	0.0475	0	0	0.0149	0.1782	**56.7%**
SEAGRASS	0.0214	**0.3213**	0.0357	0	0	0.0214	0.3998	**80.4%**
MACROALGAE	0.0054	0.0163	**0.0760**	0	0	0.0217	0.1195	**63.6%**
TURF	0	0	0.0029	**0**	0	0	0.0029	**0.0%**
EMERGENT	0	0	0	0	**0.0057**	0	0.0057	**100.0%**
UNCOLONIZED	0	0.0118	0.0353	0	0	**0.2430**	0.2900	**83.8%**
$n_{\cdot j}$	0.1279	0.3642	0.1974	0	0.0057	0.3010	**P_o=75.0%**	
Producer's Accuracy (%)	**79.0%**	**88.2%**	**38.5%**	**0.0%**	**100.0%**	**80.7%**		

After the error matrix cell values were transformed from the original binomial observations to individual cell probabilities, the overall accuracy increased from 73.7% to 75.0%.

Detailed Biological Cover

Error matrices for Detailed Biological Cover category are presented in Tables 7 and 8. The overall accuracy (P_o) for Detailed Biological Cover was 67.4%. The calculated Tau coefficient (T_e) was 0.643.

Table 7. Error matrix for Detailed Biological Cover category.

Accuracy Assessment (j)

DETAILED BIOLOGICAL COVER (*Map Data (i)*)		CORAL		SEAGRASS			MACROALGAE			TURF	EMERGENT		UNCOLONIZED		User's Accuracy (%)
		S	P	S	P	C	S	P	C	S	P	C		$n_{i\cdot}$	
CORAL	S	**15**	3		2		3	3	1				5	32	**46.9%**
	P	2	**14**	1	2		5	2	2				0	28	**50.0%**
SEAGRASS	S	2		**10**				3					6	21	**47.6%**
	P	3	1	3	**32**	3	1	1	1					45	**71.1%**
	C					**42**	3	1						46	**91.3%**
MACROALGAE	S			5	1		**9**						8	23	**39.1%**
	P						6	**9**	2					17	**52.9%**
	C	1	1						**2**					4	**50.0%**
TURF	S							1		**0**				1	**0.0%**
EMERGENT	P										**1**			1	**100.0%**
	C											**1**		1	**100.0%**
UNCOLONIZED					3		8	1					**62**	74	**83.8%**
$n_{\cdot j}$		23	19	19	40	45	35	21	8	0	1	1	81	*n=293*	
Producer's Accuracy (%)		**65.2%**	**73.7%**	**52.6%**	**80.0%**	**93.3%**	**25.7%**	**42.9%**	**25.0%**	**0%**	**100%**	**100%**	**76.5%**	**P_o=67.4%** / **T_e=0.643**	

Table 8. Error matrix for Detailed Biological Cover corrected using known map marginal proportions (π_i).

Accuracy Assessment (j); rows: *Map Data (i)*

DETAILED BIOLOGICAL COVER		CORAL		SEAGRASS			MACROALGAE			TURF	EMERGENT		UNCOLONIZED	πi	User's Accuracy (%)
		S	P	S	P	C	S	P	C	S	P	C			
CORAL	S	**0.049**	0.010	0	0.007	0	0.010	0.010	0.003	0	0	0	0.016	0.104	**46.9%**
	P	0.005	**0.037**	0.003	0.005	0	0.013	0.005	0.005	0	0	0	0	0.074	**50.0%**
SEAGRASS	S	0.009	0	**0.047**	0	0	0	0.014	0	0	0	0	0.028	0.099	**47.6%**
	P	0.009	0.003	0.009	**0.096**	0.009	0.003	0.003	0.003	0	0	0	0	0.135	**71.1%**
	C	0	0	0	0	**0.151**	0.011	0.004	0	0	0	0	0	0.166	**91.3%**
MACROALGAE	S	0	0	0.011	0.002	0	**0.020**	0	0	0	0	0	0.017	0.050	**39.1%**
	P	0	0	0	0	0	0.021	**0.032**	0.007	0	0	0	0	0.060	**52.9%**
	C	0.002	0.002	0	0	0	0	0	**0.005**	0	0	0	0	0.010	**50.0%**
TURF	S	0	0	0	0	0	0	0.002	0	**0**	0	0	0	0.002	**0.0%**
EMERGENT	P	0	0	0	0	0	0	0	0	0	**0.003**	0	0	0.003	**100.0%**
	C	0	0	0	0	0	0	0	0	0	0	**0.002**	0	0.002	**100.0%**
UNCOLONIZED		0	0	0	0.012	0	0.031	0.004	0	0	0	0	**0.243**	0.290	**83.8%**
$n_{\cdot j}$		0.075	0.052	0.070	0.122	0.160	0.109	0.073	0.023	0	0.003	0.002	0.305	**P_o=68.8%**	
Producer's Accuracy (%)		**65.2%**	**70.9%**	**67.7%**	**78.8%**	**94.4%**	**18.0%**	**43.1%**	**20.8%**	**0.0%**	**100.0%**	**100.0%**	**79.7%**		

After the error matrix cell values were transformed from the original binomial observations to individual cell probabilities, the overall accuracy increased from 67.4% to 68.8%.

Discussion

The Major Structure category was mapped with the greatest accuracy with stepwise declining accuracy observed at each category level (Detailed Structure → Major Biological Cover → Detailed Biological Cover). One issue observed during the assessment was that AA points only fell on patch reefs within aggregated patch reef polygons in 1 out of 10 sampling points. Six of those sampling points fell on unconsolidated sediment. While these points count as "misses" for the accuracy assessment, they do not accurately evaluate the classification of those polygons, i.e. sand halos are included around patch reefs and a considerable amount of unconsolidated sediment exists in polygons of aggregated patch reefs. These "misses" indicate the probability of any point landing on a patch reef within an aggregated patch reef polygon based on the density of the patches.

Relatively lower accuracies were observed in the macroalgae classification. The visual signature for macroalgae is often difficult to differentiate from seagrass when viewing the IKONOS satellite imagery. Additionally, macroalgae in the mapping area appears ephemeral (and likely seasonal). This increases the probability of finding uncolonized substrate during ground validation where there was a macroaglae signature in the imagery or vice-versa, especially when there is a large time lapse between the date the imagery was taken and when the ground-validation is conducted. The satellite images utilized for this study were taken in 2006. AA points were collected between September and December 2010.

Overall, the accuracy of the Marquesas/Quicksands mapping area is comparable to that of nearby regional mapping accuracies utilizing the same classification scheme. The accuracy assessment for the adjacent NOAA Florida Keys mapping area ROI 2 (Walker and Foster, 2010) is provided in Table 9 below:

Table 9. Comparison of accuracy assessment results (overall accuracy, P_o) to that of nearby NOAA mapping area ROI 2 (Key West)*.

	Marquesas/Quicksands (P_o)	NOAA ROI 2 (P_o)
Major Structure	90.8%	88.7%
Detailed Structure	87.0%	82.9%
Major Biological Cover	73.7%	68.7%
Detailed Biological Cover	67.4%	64.7%

*from: Walker, B.K. and G.F. Foster, 2010. Final Report: Accuracy Assessment and Monitoring for NOAA Florida Keys mapping ROI 2 (Key West). Prepared for: NOS/NOAA, 37 pp.

Please contact me or Quin Robertson if you have any questions.

Sincerely,

COASTAL PLANNING & ENGINEERING, INC.

Jeffrey L. Andrews, PSM
Vice President

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cc: Kathleen O'Keife, FWRI
Quin Robertson, Ph.D., CPE
Jessica Craft, CPE