A Classification Scheme for Mapping the Shallow-water Coral Ecosystems of Southern Florida

Version 3.2
20 June 2008

"Systems of classification are not hatracks, objectively presented to us by nature. They are dynamic theories developed to express particular views about the history of organisms.

Gould, SJ 1987 In Hatracks and Theories, Natural History **96**(3).

Introduction

A hierarchical classification scheme is being developed to define and delineate the benthic habitats associated with southern Florida's shallow-water (generally, less than 30 m depth) coral ecosystems. The hierarchical scheme allows users to expand or collapse the thematic detail of the resulting map to suit their needs. This is an important aspect of the scheme as it provides a "common language" to compare and contrast digital maps derived from various remote sensing platforms. ***The ability to apply any component of this scheme is dependent on being able to identify and delineate a given feature in remotely sensed imagery and assess the accuracy of the resulting benthic habitat map.*** Furthermore, the hierarchical structure of the scheme enables users to add habitat categories to the resulting GIS-based maps.

A tropical coral ecosystem is composed of both habitats and structural zones. Benthic habitats found in a coral ecosystem include unconsolidated sediments (e.g., sand and mud); mangrove; submerged vegetation (e.g., seagrass and algae); hermatypic coral reefs and associated colonized hard bottom habitats (e.g., spur and groove, individual and aggregated patch reefs, and gorgonian-colonized pavement and bedrock); and uncolonized hard bottom (e.g., reef rubble and uncolonized bedrock). Typical structural zones include the Reef Crest, Forereef, Bank/Shelf, and Lagoon (Rohmann et al., 2005).

The development of the classification scheme is influenced by many factors including: the requirements of the Florida coral ecosystem conservation and management community; NOS's coral ecosystem mapping experience in the Florida Keys and U.S. Caribbean; existing classification schemes for the U.S. Caribbean, and Pacific and Hawaiian Islands (Holthus and Maragos 1995; Gulko 1998; Allee et al. 2000) and other coral reef systems (Kruer 1995; Reid and Kruer 1998; Lindeman et al. 1998; Sheppard et al. 1998; Vierros 1997; Chauvaud et al. 1998; Mumby et al. 1998; Kendall et al. 2001); the minimum mapping unit (MMU - 0.4 hectare or 4,046 sq m for visual imagery interpretation) previously used for mapping; and the spatial and spectral limitations of the imagery used to derive the maps.

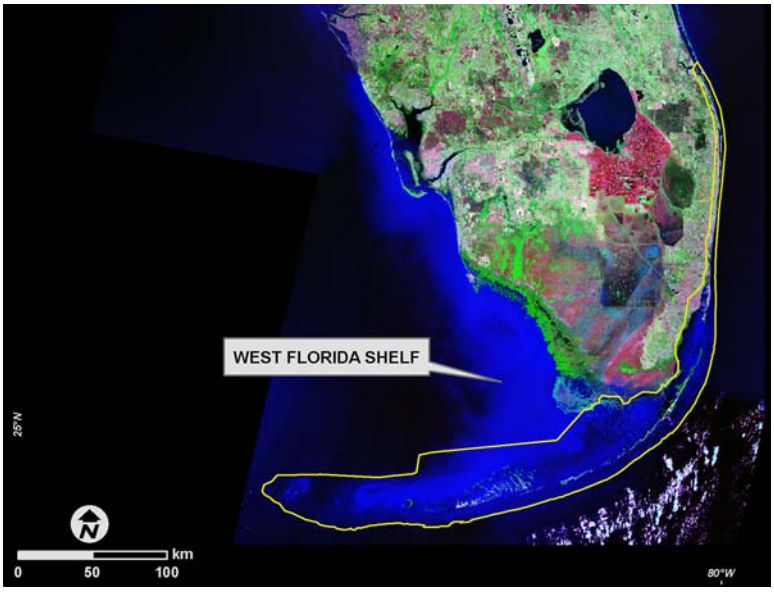


Figure 1. The yellow polygon delineates the approximately 13,000 sq km priority shallow-water benthic habitat mapping area of southern Florida.

The Florida Fish and Wildlife Research Institute, in partnership with the U.S. EPA's Gulf of Mexico Program, developed a benthic habitat scheme. That scheme, a System for Classification of Habitats in Estuarine and Marine Environments (SCHEME) for Florida was used to develop this scheme (Madley et al., 2002). The categories of habitats described in SCHEME have been linked to the habitat categories in this scheme and are shown in **Bold**.

This scheme was prepared using input from coral reef biologists, mapping experts, and resource managers familiar with southern Florida's coral ecosystems. The scheme will be modified based on feedback provided during its' application during actual mapping activities to ensure that each category describes the intended habitats and zones encountered in the field as accurately as possible.

Using the capabilities provided by the GIS, each polygon identified in the coral ecosystem landscape can be assigned three attributes. Each polygon can be assigned to a zone (e.g., fore reef), which denotes its' cross sectional location relative to emergent features (see Figure 2 on page 4). Each polygon can be assigned a geomorphological structure attribute, which denotes the physical structure (e.g., pavement) associated with its' underlying composition within the coral ecosystem. Finally, each polygon can be assigned a biological cover attribute, which denotes the type of biological cover (e.g., seagrass) found on the geomorphological structure of the location within the coral ecosystem.

The Coral Ecosystem Classification Scheme

Coral Ecosystem Geomorphological Structures

Structure Types - Fourteen distinct and non-overlapping geomorphological structure types have been described that can be mapped by visual interpretation of the IKONOS imagery. Habitats or features that cover areas smaller than the 0.4 ha MMU are not considered. For example, sand halos surrounding patch reefs are too small to be mapped independently. Structure refers only to predominate physical structural 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 (Unconsolidated Sediment; Coral Reef and Hardbottom; Other Delineations; and Unknown), to thirteen detailed classes (Sand; Mud; Spur and Groove; Individual or Aggregated Patch Reef; Aggregate Reef; Scattered Coral/Rock in Unconsolidated Sediment; Pavement; Rock/Boulder (volcanic and carbonate); Reef Rubble; Pavement with Sand Channels; Artificial; Land; and Unknown).

Unconsolidated Sediment

Sand: Coarse sediment typically found in areas exposed to currents or wave energy. Sand is associated with several zones including shoreline intertidal, bank/shelf, ridges and swales, and forereef. **(12 – Sand; 13 – Mixed Fine; 14 – Mixed Coarse; 15 – Granule)**

Mud: Fine sediment often associated with river discharge or the build-up of organic material in areas sheltered from high-energy waves and currents. Mud is associated with several zones including shoreline intertidal, and lagoon **(11 – Mud)**

Sand

Mud

(continued on next page)

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

Spur and Groove: Habitat 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 (see below) and are separated from each other by 1-5 meters of sand or hard-bottom (grooves), although the height and width of these elements may vary considerably. This habitat type typically occurs in the forereef zone. **(31121 – High Relief Spur and Groove**)

Individual or Aggregated Patch Reef: Coral formations that are isolated from other coral reef formations by sand, seagrass, or other habitats and that may or may not have organized structural axis relative to the contours of the shore, lagoon, bank/shelf, and ridges and swales zones.

Individual Patch Reef: Distinctive single patch reefs that are larger than or equal to 625 sq m (0.0625 ha). **(3121 – Individual Patch Reef; 3125 – Pinnacles)**

Aggregate Patch Reefs: Clustered patch reefs that individually are too small (less than the 0.4 ha MMU) or are too close together to map separately. **(3124 – Aggregated Patch Reefs (including Halo areas if present))**

Aggregate Reef: High relief lacking sand channels of spur and groove. **(3111 – Linear Reef; 32 – Mollusk Reefs; 33 – Annelid Reefs (i.e., Sabellariid reefs))**

Spur and Groove

Individual Patch Reef

Aggregate Patch Reefs

Scattered Coral/Rock in Unconsolidated Sediment: Primarily sand or seagrass bottom with scattered rocks or small, isolated coral heads that are too small to be delineated individually (i.e. smaller than individual patch reef). **(313 – Patchy Coral and/or Rock in Unconsolidated Bottom)**

Pavement: Flat, low-relief, solid carbonate rock with coverage of macroalgae, hard coral, zoanthids, and other sessile invertebrates that are dense enough to begin to obscure the underlying surface. **(342 – Pavement (i.e., low relief hardbottom))**

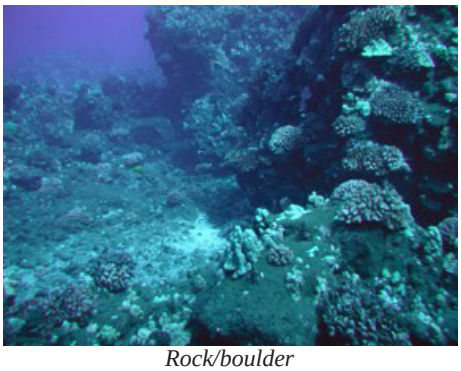
Scattered coral/rock in unconsolidated sediment

Pavement

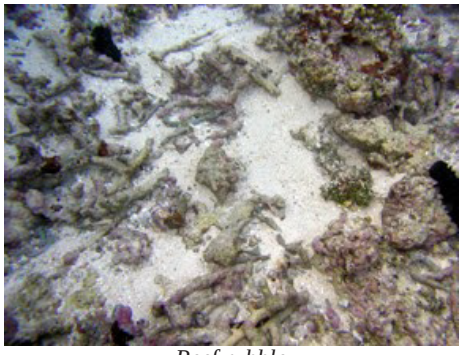
Rock/Boulder: Solid carbonate blocks and/or boulders or volcanic rock. **(16 – Pebble; 17 – Cobble; 341 – Bedrock)**

Reef Rubble (volcanic and carbonate): Dead, unstable coral rubble often colonized with filamentous or other macroalgae. This habitat often occurs landward of well-developed reef formations in the reef crest, ridges and swales, or back reef zone. **(3113 – Reef Rubble)**

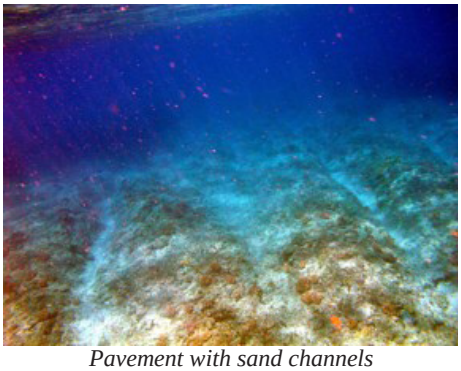
Pavement with Sand Channels: Habitats of pavement with alternating sand/surge channel formations that are oriented perpendicular to the reef crest or ridges and swales zone. The sand/surge channels of this feature have low vertical relief relative to spur and groove formations and are typically erosional in origin. This habitat type occurs in areas exposed to moderate wave surge such as the forereef zone. **(31122 – Low Relief Spur and Groove)**



Rock/boulder



Reef rubble



Pavement with sand channels

Other Delineations

Artificial: Man-made habitats such as submerged wrecks, large piers, submerged portions of rip-rap jetties, and the shoreline of islands created from dredge spoil. **(Modifier A – Artificial)**

Land: Terrestrial features above the spring high tide line. **(6 – Land)**

Unknown: Zone, Cover, and Structural feature that is not interpretable due to turbidity, cloud cover, water depth, or other interference. **(7 – Unknown)**

Artificial

Land

Unknown

Coral Ecosystem Zones

Zone Types - Twelve mutually exclusive zones can be identified from land to open water corresponding to typical insular shelf and coral reef geomorphology. Figure 2 (next page) is a cross-sectional diagram showing the generalized locations of most of these zones. The zones include: Shoreline Intertidal; Lagoon; Bank/Shelf; Back Reef; Ridges and Swales; Reef Crest; and Forereef.; Five zones not included in the diagram are Vertical Wall, Bank/Shelf Escarpment, Channel, Dredged, and Unknown. Zone refers only to each benthic community's location and does not address substrate or cover types that are found within. A brief description of each zone is provided, starting on the next page.

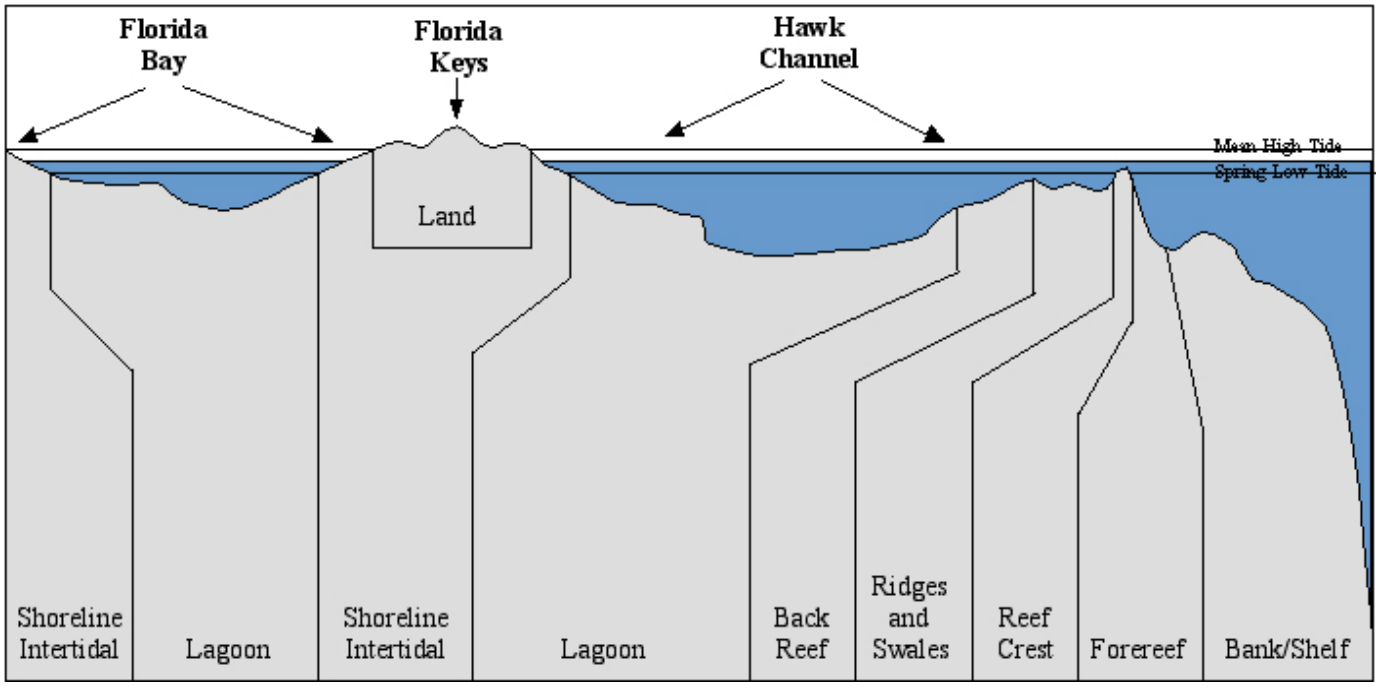


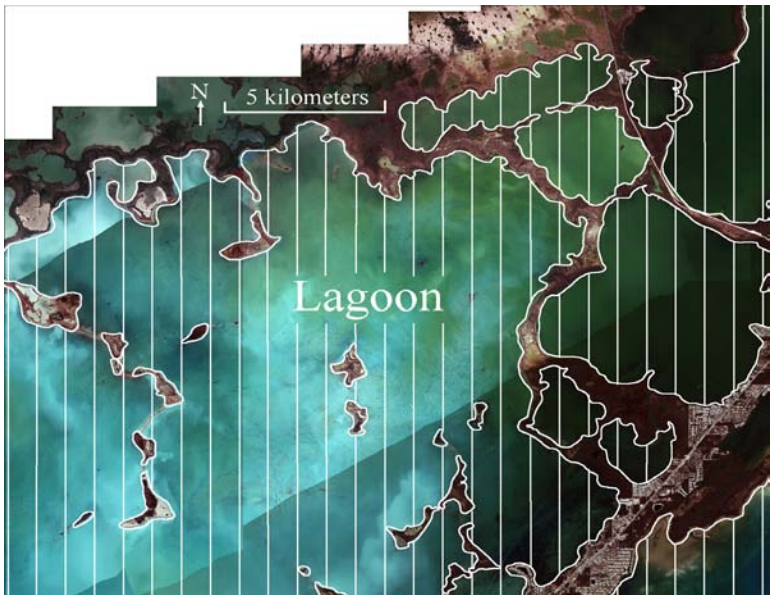
Figure 2. A diagram depicting a generalized cross-section of the Florida Keys and associated zones.

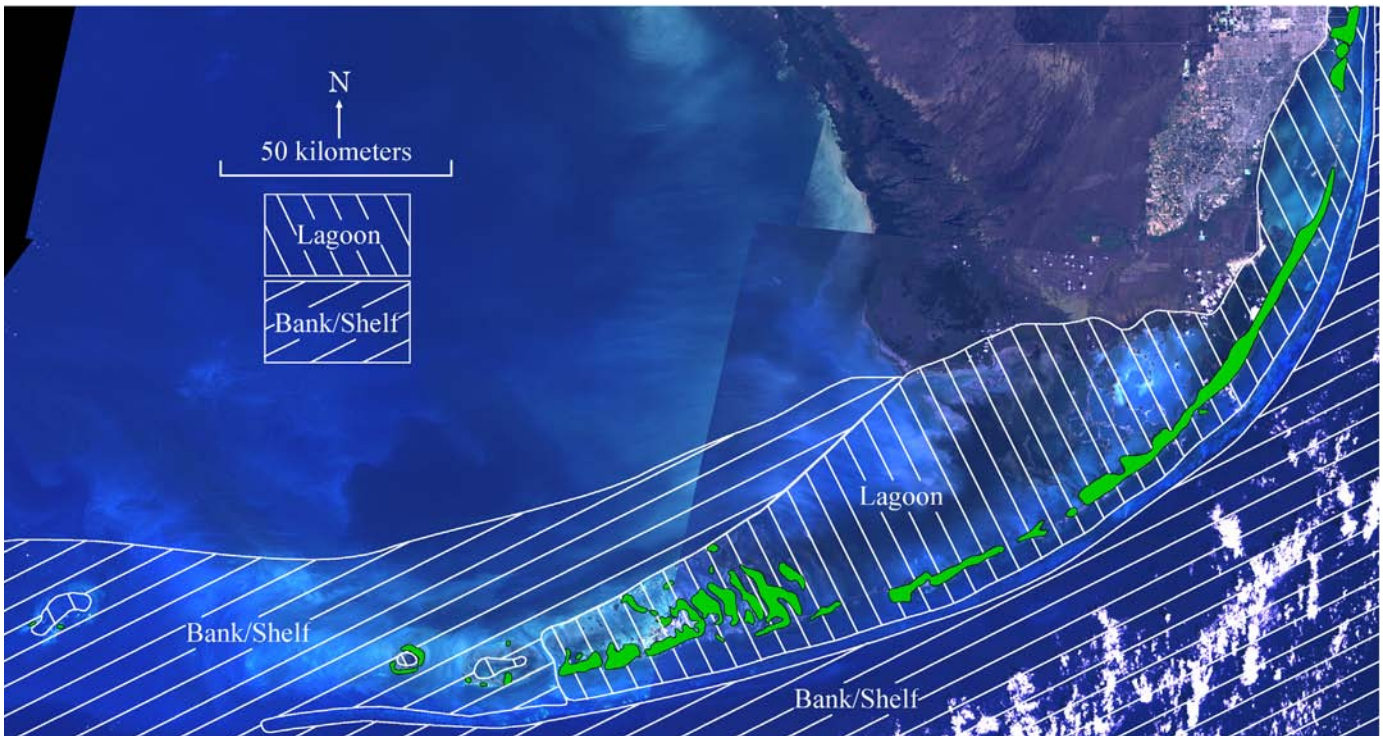
Shoreline Intertidal: Area between the mean high water line (or landward edge of emergent vegetation, such as Red Mangrove, when present) and lowest spring tide level (excluding emergent segments of barrier reefs). Typically, this zone is narrow due to the small tidal range in southern Florida. **(Modifier Z2 – Intertidal)** Typical biological cover types found in this zone:

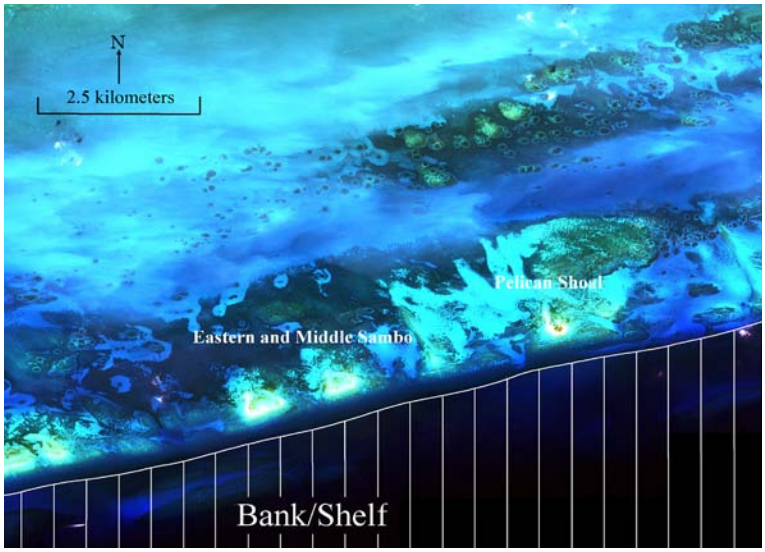
* Emergent Vegetation
* Uncolonized

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 found in the Bank/Shelf zone and can be interconnected by tidal exchange or riverbed channels and passes. See next figure showing Lagoon and Bank/Shelf locations. **(No equivalent)** Typical biological cover types found in this zone:

* Sand
* Seagrass
* Macroalgae
* Emergent Vegetation
* Patch Reef

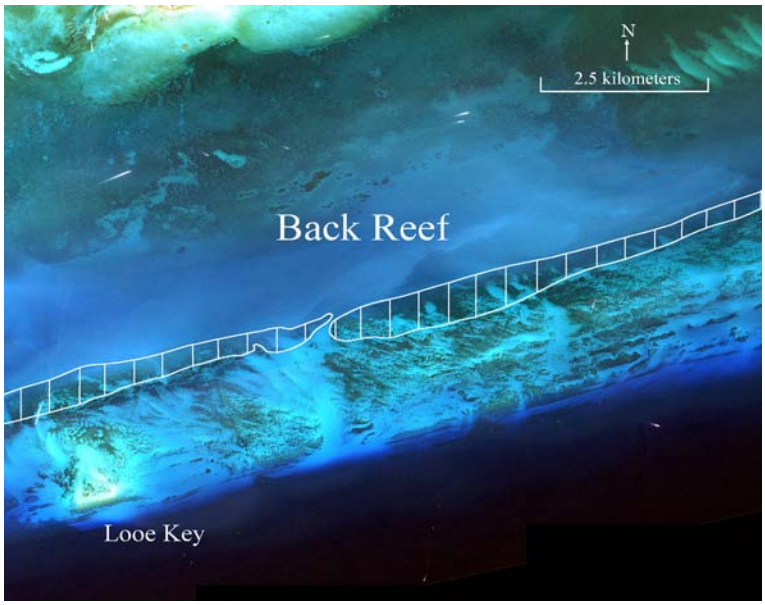






Bank/Shelf: A deep water (relative to the shallow water in a lagoon) area typically extending offshore from the seaward edge of the Forereef to the beginning of the escarpment where the shelf drops off into deep, oceanic water. The Bank/Shelf is generally the platform between the Forereef and deep ocean water or between the Shoreline Intertidal zone and open ocean if no Reef Crest is present. **(No equivalent)** Typical biological cover types found in this zone:

* Sand
* Live Coral
* Seagrass
* Macroalgae

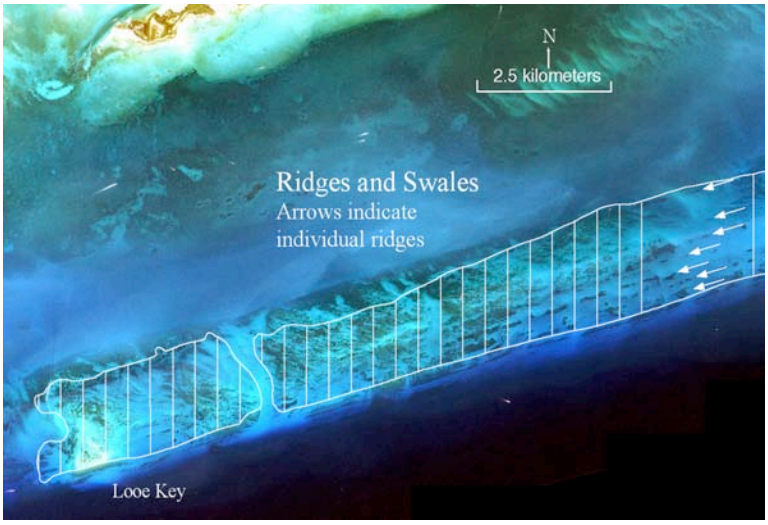


Back Reef: Area between the bank/shelf and the ridge and swale or reef crest zone. This zone is present when a bank/shelf, ridges and swales, or reef crest zone exist. **(No equivalent)** Typical biological cover types found in this zone:

* Live Coral
* Seagrass
* Macroalgae
* Encrusting/Coralline Algae
* Turf Algae

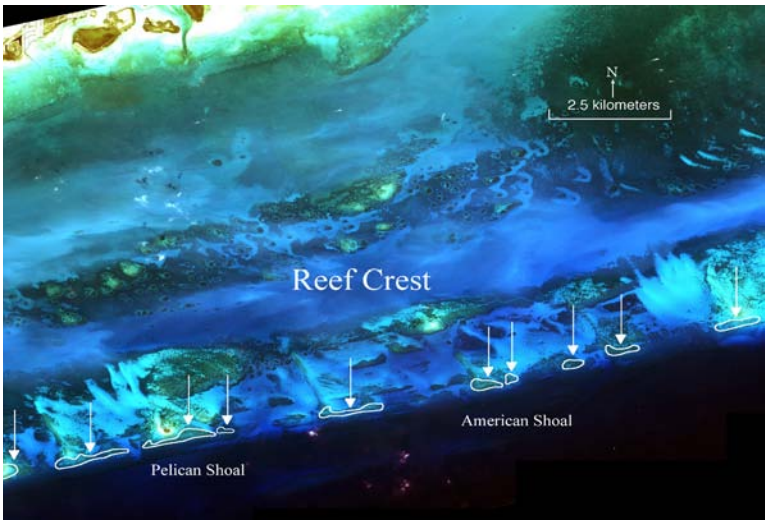
Ridges and Swales: An area of numerous thin, narrow, discontinuous bands of coral ridges and leeward sand and sediment-filled swales. Debris and reef-rubble fields behind many of the reefs may obscure these margin-parallel seabed features. This zone extends for an estimated 200 km along the shelf from the Key Largo to Halfmoon Shoal and is discontinuous due to topography, inconsistent responses of coral reefs to changing sea level, and from varying effects of the physical environment on reefs and sediments. **(No equivalent)** Typical biological cover types found in this zone:

* Live Coral



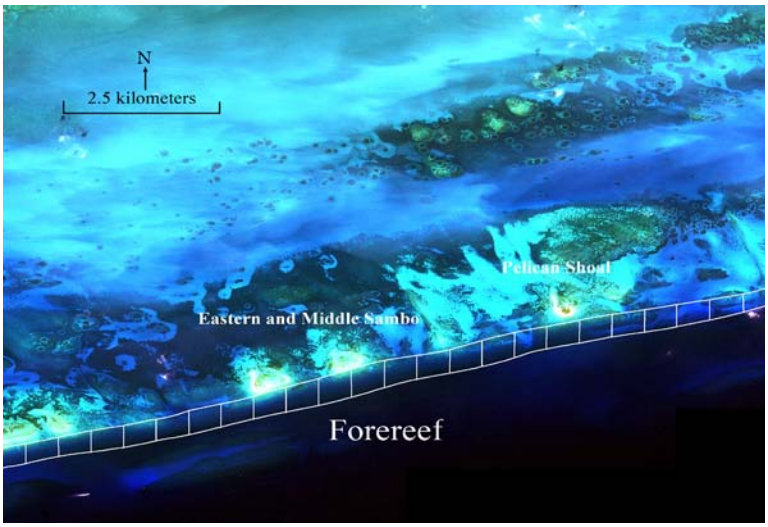
Reef Crest: The flattened, emergent (especially during low tides) or nearly emergent segment of a reef. This zone lies between the Ridge and Swale and Forereef zones. Breaking waves will often be visible in aerial images at the seaward edge of this zone. **(Modifier Z2 – Intertidal)** Typical biological cover types found in this zone:

* Live Coral
* Encrusting/Coralline Algae



Forereef: An 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 forming an emergent reef crest but still having a seaward-facing slope that is significantly greater than the slope of the bank/shelf are also designated as Forereef. **(No equivalent)** Typical biological cover types found in this zone:

* Live Coral
* Encrusting/Coralline Algae



Channel: Naturally occurring channels that often cut across several other zones. **(Modifier E – Submerged tidal canals)** Typical biological cover types found in this zone:

* Live Coral
* Seagrass
* Macroalgae
* Turf Algae
* Emergent Vegetation

Dredged: Area in which natural geomorphology is disrupted or altered by excavation or dredging. **(Modifier F – Dredged/Excavation)** Typical biological cover types found in this zone:

* Live Coral
* Seagrass
* Macroalgae
* Turf Algae
* Emergent Vegetation
* Unknown

Vertical Wall: Area with near-vertical slope from shore to shelf or shelf escarpment. This zone is typically narrow and may not be distinguishable in remotely sensed imagery, but is included because it is recognized as a biologically important feature. **(No equivalent)** Typical biological cover types found in this zone:

* Live Coral
* Encrusting/Coralline Algae

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 aerial images. This zone is designated to capture the transition from the shelf to deep waters of the open ocean. **(No equivalent)** Typical biological cover types found in this zone:

* Live Coral

Unknown: Zone, Cover, and Structural feature that is not interpretable due to turbidity, cloud cover, water depth, or other interference. **(7 – Unknown)**

Coral Ecosystem Biological Cover

Biological Cover Types - Sixteen distinct and non-overlapping biological cover types can be identified that may be mapped through visual interpretation of the IKONOS imagery. Typically, habitats or features that cover areas

smaller than the 0.4 hectare MMU are not considered. The two exceptions are: 1) patch reefs in Hawk Channel with an area greater than 625 sq m (0.0625 ha); and 2) islands with an area greater that 1000 sq m (0.1 ha). Cover type refers only to predominate biological component colonizing the surface of the feature and does not address location (e.g., on the shelf or in the lagoon). The cover types are defined in a collapsible hierarchy ranging from six major classes (live coral, seagrass, macroalgae, encrusting coralline algae, turf algae, emergent vegetation, uncolonized, and unknown), combined with a density modifier representing the percentage of the predominate cover type (10%-<50%: sparse; 50%-<90%: patchy; 90%-100%: continuous).

The assignment of Habitat Cover and Cover Modifier categories to the map is a stepwise progression from Live Coral to Seagrass to Macroalgae, etc, until the Uncolonized category is reached. The Stepwise progression also proceeds from Live Coral-Continuous to Live Coral-Patchy to Live Coral-Sparse before jumping to the Seagrass category. The Stepwise progression would then proceed from Seagrass-Continuous to Seagrass-Patchy to Seagrass-Sparse before jumping to the Macroalgae category, etc. As a result, there will be cases where, for example, a habitat polygon may exhibit ~25% seagrass and ~75% macroalgae and will be classified as Seagrass-Sparse rather than Macroalgae-Patchy, even though the dominant seafloor cover is macroalgae.

Biological Cover categories that can be readily and accurately interpreted will be assigned, as feature attributes, to habitat polygons during the initial visual interpretation process. *In-situ* data from both the visual interpretation activity and local research and monitoring will be used to determine Biological Cover attributes of feature polygons during the map production process. During this process, the *Live Coral*, *Macroalgae*, *Encrusting/Coralline Algae*, and *Turf Algae* cover categories will be assigned as preliminary feature attributes. Draft map products showing coral ecosystem zone, structure, and the *Seagrass* biological cover will be reviewed for overall accuracy using standard map accuracy techniques. A peer review process will be used to determine accuracy of the *Live Coral*, *Macroalgae*, *Encrusting/Coralline Algae*, and *Turf Algae* biological cover features shown on draft maps and whether or not they should be included in the final map product.

Live Coral: Substrates colonized by sponges, octocorals, and hexacorals and have at least 10% live coral cover.

Hexacorals

Octocorals

Continuous Coral: Live coral covering 90% or greater of the substrate. 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 (generally less than 0.4 ha). **(No equivalent)**

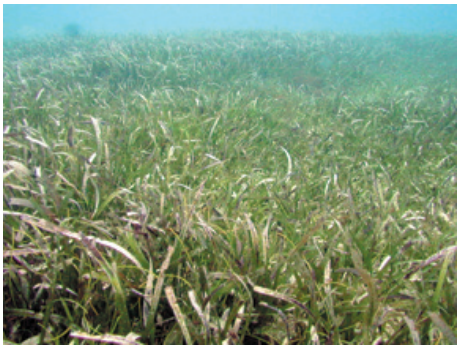
Patchy Coral: Discontinuous live coral with breaks in coverage that is too diffuse, irregular, or result in isolated patches that are too small (generally smaller than the 0.4 ha MMU) to be mapped as continuous coral. Overall live coral cover is estimated at 50%-<90% of the bottom. **(No equivalent)**

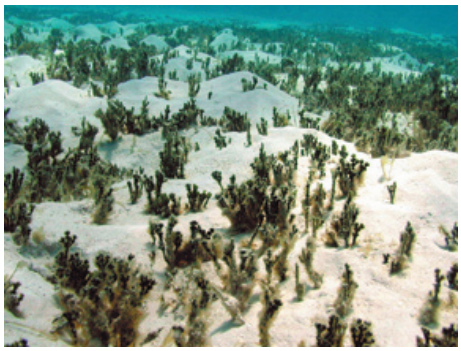
Sparse Coral: Discontinuous live coral with breaks in coverage that is too diffuse, irregular, or result in isolated patches that are too small (smaller than the 0.4 ha MMU) to be mapped as patchy coral. Overall live coral cover is estimated at 10%-<50% of the bottom. **(No equivalent)**

Representative Hexacoral Species:	Representative Octocoral Species
Acropora cervicornis	*Briareum asbestinum*
Acropora palmate	*Eunicea succinea*

Acropora spp.
Agaricia spp.
Montastrea annularis
Lophelia prolifera
Oculina varicose
Porites porites
Porites spp.
Gorgonia ventalina
Leptogorgia virgulata
Plexaura flexuosa
Plexaura homomalla
Plexaurella spp.
Pseudoplexaura spp.
Pseudopterogorgia spp.

Seagrass: Habitat with 10 percent of more of seagrass (e.g., Halophila sp.).


Seagrass


Macroalgae

Continuous Seagrass: Seagrass community covering 90 percent or greater of the substrate. May include blowouts of less than 10 percent of the total area that are too small to be mapped independently (less than the MMU). **(211 – Continuous Submerged Rooted Vegetation SRV)**

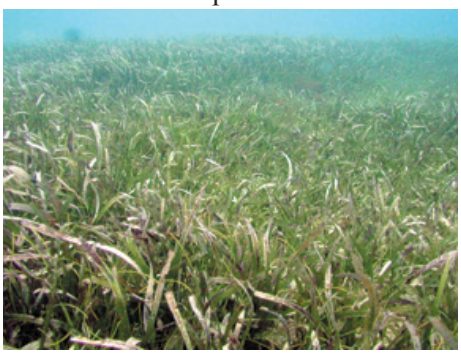
Patchy Seagrass: Discontinuous seagrass community with breaks in coverage that are too diffuse, irregular, or result in isolated patches that are too small (smaller than the 0.4 ha MMU) to be mapped as continuous seagrass. Overall cover is estimated at 50%-<90% of the bottom. **(2111 - Dense patches of SRV in a matrix of continuous, sparse SRV)**

Sparse Seagrass: Discontinuous seagrass community with breaks in coverage that are too diffuse, irregular, or result in isolated patches that are too small (smaller than the 0.4 ha MMU) to be mapped as patchy seagrass. Overall cover is estimated at 10%-<50% of the bottom. **(212 – Discontinuous SRV)**

Representative Seagrass Species:
Thalassia testudinum
Halodule wrightii
Halophila decipiens
Halophila johnsonii
Syringodium filiforme
Halophila engelmanni

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


Macroalgae


Seagrass

Continuous Macroalgae: Macroalgae covering 90 percent or greater of the substrate. May include blowouts of less than 10 percent of the total area that are too small to be mapped independently (less than the 0.4 ha MMU). **(2211 - Continuous attached macroalgae)**

Patchy Macroalgae: Discontinuous macroalgae with breaks in coverage that are too diffuse, irregular or

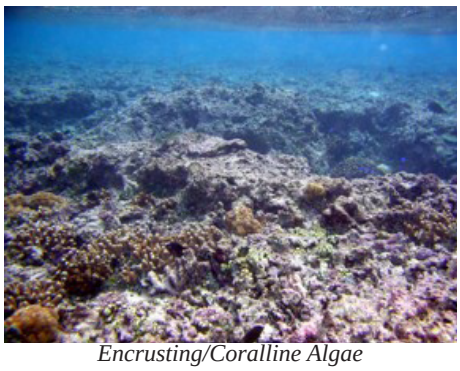
result in isolated patches that are too small (smaller than the 0.4 ha MMU) to be mapped as continuous macroalgae. Overall cover is estimated at 50%-<90% of the bottom. **(22111 - Dense patches of attached macroalgae in a matrix of continuous, sparse macroalgae**)

Sparse Macroalgae: Discontinuous macroalgae with breaks in coverage that are too diffuse, irregular, or result in isolated patches that are too small (smaller than the MMU) to be mapped as patchy macroalgae. Overall cover is estimated at 10%-<50% of the bottom. **(2212 - Discontinuous attached macroalgae)**

Representative Species:

Caulerpa spp.	*Laurencia spp.*	*Halimeda spp.*
Dictyota spp.	*Lobophora variegata*	

Encrusting/Coralline Algae: An area with 10 percent or greater coverage of any combination of numerous species of encrusting or coralline algae. May occur along reef crest, in shallow back reef, relatively shallow waters on the bank/shelf zone, and at depth.



Encrusting/Coralline Algae

Continuous Coralline Algae: Coralline algae covering 90 percent or greater of the substrate. May include blowouts of less than 10 percent of the total area that are too small to be mapped independently (less than the 0.4 ha MMU). **(No equivalent)**

Patchy Coralline Algae: Discontinuous coralline algae with breaks in coverage that are too diffuse, irregular, or result in isolated patches too small (smaller than the 0.4 ha MMU) to be mapped as continuous coralline algae. Overall cover is estimated at 50%-<90% of the bottom. **(No equivalent)**

Sparse Coralline Algae: Discontinuous coralline algae with breaks in coverage that are too diffuse, irregular, or result in isolated patches too small (smaller than the 0.4 ha MMU) to be mapped as patchy coralline algae. Overall cover is estimated at 10%-<50% of the bottom. **(No equivalent)**

Representative Species:
Porolithon gardineri

Turf Algae: A community of low lying species of marine algae composed of any or a combination of algal divisions dominated by filamentous species lacking upright fleshy macroalgal thali.

Turf Algae

Continuous Turf Algae: Turf algae covering 90 percent or greater of the substrate. May include blowouts of less than 10 percent of the total area that are too small to be mapped independently (less than the 0.4 ha MMU). **(No equivalent)**

Patchy Turf Algae: Discontinuous Turf algae with breaks in coverage that are too diffuse, irregular, or result in isolated patches too small (smaller than the 0.4 ha MMU) to be mapped as continuous Turf algae. Overall cover is estimated at 50%-<90% of the bottom. **(No equivalent)**

Sparse Turf Algae: Discontinuous Turf algae with breaks in coverage that are too diffuse, irregular, or result in isolated patches too small (smaller than the 0.4 ha MMU) to be mapped as patchy Turf algae. Overall cover is estimated at 10%-<50% of the bottom. **(No equivalent)**

Representative species:

Sargassum spp.	*Dictyota spp.*	*Avrainvellea spp.*
Rhipocephalus spp.	*Cladophora spp.*	*Batophora spp.*

Digenia spp. *Chondria spp.* *Laurencia spp.*
Gracilaria spp. *Caulerpa spp.* *Halimeda spp.*

Emergent Vegetation: Emergent habitat composed primarily of *Rhizophora mangle* (red mangrove) and other species. Generally found in areas sheltered from high-energy waves. This habitat type is usually found in the shoreline/intertidal or reef flat zone. **(4 – Tidal Marsh; Modifier M – Mat algae; N – Attached macroalgae)**


Emergent Vegetation

Marsh: Habitat dominated by marsh species such as *Spartina spps*. or *Saliconia spps*.

Mangrove: Habitat dominated by mangrove species *Rhizophora mangle* (red mangrove), *Avicennia germinans* (black mangrove), *Laguncularia racemosa* (white mangrove), and *Conocarpus erectus* (buttonwood).

Representative species:
Avicennia germinans *Salsola kali* *Spartina alterniflora*
Laguncularia racemosa *Distichlis spicata* *Juncus roemerianus*
Rhizophora mangle *Batis maritima* *Spartina patens*
Conocarpus erectus *Cladium mariscoides* *Vallisneria americana*
Ruppia maritime *Salicornia virginica*

Uncolonized: Substrates not covered with a minimum of 10% of any of the above biological cover types. This habitat is usually on sand or mud structures. Overall uncolonized cover is estimated at 90%-100% of the bottom. **(18 – Detrital floor)**

Unknown: Zone, Cover, and Structural feature that is not interpretable due to turbidity, cloud cover, water depth, or other interference. **(7 – Unknown)**


Uncolonized

For more information about this classification scheme or the southern Florida shallow-water coral ecosystem mapping project, please contact:

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