

## Appendix B: Shoreline to Shelf Edge Benthic Maps of Tutuila, American Samoa

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### INTRODUCTION

Accurate maps of coral reef ecosystems are a critical component of reef science and management. Mesophotic reefs around Tutuila, American Samoa make up the majority of the area of coral reef ecosystems around the island but have not been comprehensively mapped and classified like their shallow water counterparts (see NOAA NCCOS 2005). To meet this need we created benthic maps of the mesophotic reef ecosystems and edge matched them to the existing shallow water maps to produce a comprehensive shoreline to shelf edge map of benthic features.

### METHODS

Benthic features were visually interpreted from sonar imagery collected by the Pacific Islands Benthic Habitat Mapping Center (PIBHMC) (downloaded from <http://www.soest.hawaii.edu/pibhmc/>). Primary datasets used during map production were bathymetry and backscatter. Additional image datasets derived from these primary sources were also used during interpretation and included slope, rugosity, contours, and hillshade.

Areas of consistent tone and texture in the sonar imagery were identified visually by toggling among the various sonar datalayers. Boundaries were drawn around these contiguous sonar signatures using the Habitat Digitizer Extension to ArcGIS 9.0 (<http://ccma.nos.noaa.gov/products/biogeography/digitizer/welcome.html>). All features were delineated at a scale of 1:10,000. The minimum mapping unit (MMU- size of the smallest feature to be delineated) was restricted to 4,000 m<sup>2</sup> to be consistent with benthic maps recently produced for shallow water areas (NOAA NCCOS 2005).

Benthic features with consistent sonar signatures were attributed based on a classification scheme modified from the recently completed "Benthic Habitats of American Samoa, Guam, and CNMI" (NOAA NCCOS 2005). The scheme was originally designed for use with color satellite imagery. The spatial properties of the satellite and sonar imagery (i.e. 5 m bathymetry and 1 m back scatter grid resolution for sonar imagery versus 4 m color and 1 m black and white grid resolution for IKONOS satellite imagery) and scales of mapping were similar (i.e. on-screen digitizing scale was 1:10K for sonar imagery and 1:6K for satellite imagery, MMU was 4,000 m<sup>2</sup> for both data sources). Sonar signatures were primarily ground truthed using video transect data from a towed camera system which was supplemented with drop camera video on specific features. Video transect data was collected between 2002 and 2006 and obtained from PIBHMC (Bare et al. 2010). Supplemental drop camera data was collected in May 2010 and consisted of 119 sites on features in between the video transects. Each site was characterized by ~2 minutes of video for a total of ~4 hours of seafloor imagery.

A key goal was to create comprehensive maps of the coral reef ecosystem of Tutuila from the shoreline to the shelf edge. The extent of the sonar data was approximately from the insular shelf edge to the base of the fringing reefs around Tutuila, however, in places it did not cover all the way to the shelf edge, include the base of fringing reefs (lower fore reef), or necessarily include 100% coverage throughout the shelf. Gaps between sonar swaths on the shelf were simply ignored during digitizing since they were typically narrow and occurred in regions of relatively homogenous seafloor. To fill in gaps in coverage at the shelf edge, the 100 fathom isobath from NOAA Navigational Chart #83484 was overlaid in the GIS and used to assist in digitizing placement of the shelf edge polygon. The gap in coverage between the sonar data and the shoreline was filled using maps from the 2005 Benthic Habitats of American Samoa, Guam and CNMI data CD (NOAA NCCOS 2005). The satellite base maps (NOAA NCCOS 2005) were edge matched to sonar based maps principally along the seaward edge of the fore reef, a feature often visible in both sonar and satellite imagery. The shallow water map was generally clipped out in regions of overlap due to the higher interpretability of the sonar imagery of this zone relative to the satellite imagery.

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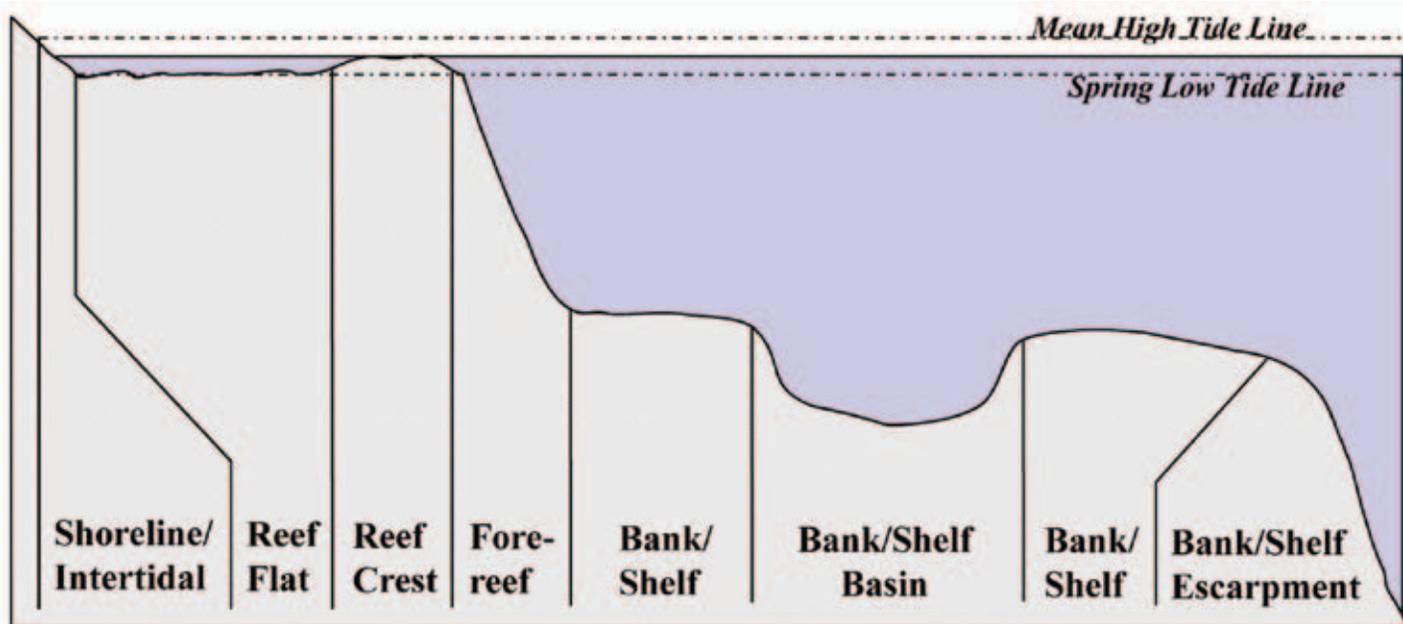
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## Classification Scheme

The classification scheme defined benthic habitats based on four attributes: 1) shelf zone, 2) general geomorphological structure, 3) detailed structure, and 4) percent hardbottom. Every feature in the benthic habitat map was assigned a designation from each level of the scheme. We customized the classification scheme to be compatible with, 1) the available sonar data for American Samoa, and 2) the existing benthic maps of shallow reefs for American Samoa (NOAA NCCOS 2005). The primary differences between this scheme and the one used to map shallow reefs of Tutuila were that biological cover was not mapped whereas percent hardbottom was. These changes were necessary to the scheme due to the differences in sonar and satellite imagery.

### Zones

Thirteen mutually exclusive zones were identified from land to deep ocean corresponding to typical insular shelf and coral reef geomorphology. These zones included: Land, Shoreline Intertidal, Reef Flat, Lagoon, Back Reef, Reef Crest, Fore Reef, Bank/Shelf, Bank/Shelf Basin, Bank/Shelf Escarpment, Channel, Dredged, and Unknown. **Figure B.1** illustrates zone types across a typical cross-section of the island shelf. Zone refers only to each benthic community's location and does not address substrate or structure types that are found within. For example, the Lagoon zone may include patch reefs, sand, and reef rubble; however, these are considered structural elements that may or may not occur within the lagoon zone and therefore, are not used to define it. Note that some zone categories exist only in the nearshore map (NOAA NCCOS 2005; e.g. shoreline/intertidal and reef crest) and others only exist in the sonar based portion of the map (e.g. bank/shelf escarpment and bank/shelf basin). See NOAA NCCOS (2005) and Bare et al. (2010) for additional cross sectional figures and example photographs of each zone type.



**Figure B.1.** Cross section of Zones.

### Land

Terrestrial features at or near the spring high tide line. The shoreline is based on the official digital shoreline available at the time nearshore mapping was conducted (NOAA NCCOS 2005). As a result many of the land polygons may be smaller than the MMU used to delineate marine features.

### Shoreline Intertidal

Area between the spring high tide line (or landward edge of emergent vegetation when present) and lowest spring tide level. Emergent segments of reefs are excluded from this zone and instead are defined below as Reef Crest. Typically, this zone is narrow due to the small tidal range in Tutuila. While present island-wide, the feature is often too narrow to be mapped on steep shorelines due to the scale of the imagery and the MMU.

### *Lagoon*

Shallow area (relative to the deeper water of the bank/shelf) between the Shoreline Intertidal zone and the Back Reef of a reef. This zone is typically protected from the high-energy waves commonly experienced on the Bank/Shelf and Reef Crest zones.

### *Reef Flat*

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

### *Back Reef*

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

### *Reef Crest*

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

### *Fore Reef*

Area along the seaward edge of the Reef Crest that slopes into deeper water to the landward edge of the Bank/Shelf platform. This feature is often referred to locally as the reef slope. Features not associated with an emergent Reef Crest but still having a seaward-facing slope that is significantly greater than the slope of the Bank/Shelf are also designated as Fore Reef.

### *Bank/Shelf*

Deeper water area (relative to the shallow water in a lagoon or reef flat) extending offshore from the seaward edge of the Fore Reef or shoreline to the beginning of the escarpment where the insular shelf drops off into deep, oceanic water. If no Reef Crest is present, the Bank/Shelf is the flattened platform between the Fore Reef and deep open ocean waters or between the Shoreline Intertidal zone and open ocean.

### *Bank/Shelf Basin*

Broad depressions of deeper water occurring in the Bank/Shelf. These features are surrounded by well defined inflections in bathymetry up to the relatively less deep waters of the Bank/Shelf.

### *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 sonar imagery around Tutuila. This zone is intended to capture the inflection point of the shelf to deep waters of the open ocean.

### *Channel*

Naturally occurring channels that often cut across several other zones.

### *Dredged*

Area in which natural geomorphology is disrupted or altered by excavation or dredging.

### *Pinnacle*

High relief features occurring in or adjacent to Bank/Shelf Basin that are capped by coral reef or hard bottom.

### *Unknown*

Zone indistinguishable due to gaps between swaths in sonar imagery or due to turbidity, cloud cover, water depth, or other interference in satellite imagery.

## Geomorphological Structures

Fifteen distinct and non-overlapping geomorphologic structure could be mapped by visual interpretation of sonar imagery. Structure refers only to predominate physical composition of the feature and does not address location (see Zone for shore to shelf edge location). The structure types are defined in a collapsible hierarchy ranging from four major classes (Coral Reef and Hardbottom, Unconsolidated Substrate, Other Delineations, and Unknown), to fifteen detailed classes listed and defined below. See NOAA NCCOS (2005) for example photographs and satellite images of each classification.

### *Coral Reef and Hardbottom*

Solid substrates including bedrock, boulders, and reef building organisms. A thin veneer of sediment may be present. Detailed classes within this category include Aggregate Reef, Individual Patch Reef, Aggregated Patch Reefs, Spur and Groove, Pavement, Pavement with Sand Channels, Pavement with Patch Reefs, Reef Rubble, and Rock/Boulder.

#### Aggregate Reef

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

#### Individual Patch Reef

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

#### Aggregated Patch Reefs

These features have the same defining characteristics as an Individual Patch Reef. However, this class refers to clustered patch reefs that individually are too small (less than the MMU) or are too close together to map separately. Where aggregated patch reefs share sand halos, the halo is included in the polygon.

#### Spur and Groove

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

#### Pavement

Flat, low-relief, solid rock in broad areas often with partial coverage of sand, algae, hard coral, gorgonians, zooanthids or other sessile invertebrates.

#### Pavement with Sand Channels

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

#### Pavement with Patch Reefs

Habitats of pavement with occasional patch reef formations that make up less than 10% of the area of the polygon. This habitat type occurs nested in pavement areas on the Bank/Shelf zone.

### Reef Rubble

Dead, unstable coral rubble often colonized with turf, filamentous, calcareous, or encrusting macroalgae. This habitat often occurs landward of well developed reef formations in the Reef Crest, Back Reef or Reef Flat zones due to storm waves piling up dead coral. Reef Rubble can also occur in offshore areas due to diseased or physically impacted reef communities.

### Rock/Boulder

Large, irregularly shaped carbonate blocks or volcanic rock often extending offshore from the island bedrock or headlands. Can also occur as aggregations of loose rock fragments that have been detached and transported from their native beds. Individual boulders often range in diameter from 0.25 – 3 m.

### *Unconsolidated Substrate*

Areas of the seafloor consisting of small, unattached or uncemented particles with less than 10% cover of large stable substrate. Detailed structure classes of softbottom include Sand, Mud, Sand with Scattered Coral and Rock, and Algal Plain.

#### Sand

Coarse sediment typically found in areas exposed to currents or wave energy.

#### Mud

Fine sediment often associated with stream discharge and build-up of organic material in areas sheltered from high-energy waves and currents.

#### Sand with Scattered Coral and Rock

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

#### Algal Plain

Low relief (<~0.25 m) substrate composed of a mixture of sand, live halimeda, halimeda sand, fleshy macroalgae, and rhodoliths. Relative abundance of these compositional elements is highly variable over scales of a few meters.

### *Other Delineations*

Any other type of structure not classified as Coral Reef and Hardbottom or Unconsolidated Sediment. Usually related to the terrestrial environment and/or anthropogenic activity. Detailed structure classes include Land, Artificial, and Emergent Vegetation.

#### Land

Terrestrial features at or near the spring high tide line.

#### 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.

#### Emergent Vegetation

This category includes all species of mangroves regardless of canopy density. This class was not used the sonar derived map for obvious reasons but was retained in the classification scheme due to its occurrence in nearshore maps.

*Unknown*

Major structure indistinguishable due to data gaps from turbidity, cloud cover, water depth, ship orientation, line spacing, or other interference with an interpretable signature of the seafloor.

## Unknown

Detailed structure indistinguishable as above.

*Percent Hardbottom*

Seven classes were used to denote the approximate proportion of each polygon occupied by hard bottom substrate. A polygon encompassing several patch reefs that were too small to be delineated individually is actually comprised of some area of patch reefs and some background structure such as sand. This category includes both “living” hard bottom such as patch reefs as well as “abiotic” features such as pavement and rock/boulder. This attribute can be used to estimate the combined amount of coral reef and hard bottom around the island based on the area of each polygon.

## &lt;10%

Used for all sand, mud, and sand with scattered coral and rock polygons.

## 10-30%

Used for some aggregated patch reef polygons and other discontinuous features.

## 30-50%

Used for some aggregated patch reef polygons and other discontinuous features.

## 50-70%

Used for some aggregated patch reef polygons and other discontinuous features.

## 70-90%

Used for some aggregated patch reef polygons, pavement, and other discontinuous features.

## 90-100%

Used for most individual patch reef, pavement, aggregate reef polygons, and other continuous features.

## 10-90%

This broad category was used for algal plain polygons due to the high variability in Rhodolith coverage of this bottom type which was not interpretable in the sonar imagery. Rhodoliths are hard algal nodules with ~5-10 cm diameter that are not cemented to the seafloor. They can form highly variable coverage from sparse (a few per square meter) to a nearly continuous cover over sand substrates.

**RESULTS**

The map product from this work is available for download from the NOAA/NOS/NCCOS/CCMA/ Biogeography Branch website at <http://ccma.nos.noaa.gov/about/biogeography/>.

## ACKNOWLEDGEMENTS

Sonar data and towed camera imagery are essential tools for mapping coral reef ecosystems at this depth and are the basis of this mapping project in deeper waters. These data were collected and made available for this project by staff at the Pacific Islands Benthic Habitat Mapping Center and NOAA's NMFS/PIFSC/Coral Reef Ecosystem Division. We are particularly grateful to John Rooney, Alica Bare, and Kerry Grimshaw for obtaining and navigating those datasets. Laurie Bauer, Kim Roberson, Kevin Grant, Chris Caldow, and Ken Buja were instrumental in collecting additional ground validation data. Ken Buja provided help with the habitat digitizer and with sewing the shallow and deep water maps together.

## REFERENCES

Bare AY, Grimshaw KL, Rooney J, Sabater MG, Fenner D, Carroll B. 2010. Mesophotic communities of the insular shelf at Tutuila, American Samoa. *Coral Reefs* 29:369-377.

NOAA NCCOS (National Centers for Coastal Ocean Science). 2005. Shallow-water benthic habitats of American Samoa, Guam, and the Commonwealth of the Northern Mariana Islands (CD-ROM). NOAA Technical Memorandum NOS-NCCOS 8, Biogeography Team. Silver Spring, MD.



## Addendum to Appendix B: Shoreline to Shelf Edge Benthic Maps of Tutuila, American Samoa

### Thematic Accuracy Assessment

Thematic accuracy of the portion of the benthic maps derived from sonar (described in Appendix B) was assessed using video data collected on the insular shelf of Tutuila. The results of an accuracy assessment for the shallow-water portion of the maps are available in NOAA NCCOS 2005. Video data were collected by DMWR using a Seaviewer drop camera system in support of a fisheries assessment project. These data were collected independently of map production. Videos were acquired within randomly selected 500 m grid cells around Tutuila. Only video files that provided a good view of the sea floor, had GPS tracking or could be linked back to grid cell coordinates, and consisted of one unambiguous video clip (several consisted of multiple clips from different locations apparently spliced together) were used in this assessment. Of the videos provided, 77 met acceptable quality control standards. Videos were evaluated in the context of the MMU and features in the sonar imagery from which maps were derived and then scored according to the major and detailed structure categories of the classification scheme. Video observations were compared to map attributes at drop camera sites and used to produce error matrices. Overall accuracy ( $P_o$ ) and Tau ( $T_o$ ) were calculated. Matrices consisting of omission (user's accuracy) and commission (producer's accuracy) errors by category for both the major (Table 1) and detailed map classifications (Table 2) are provided. For a complete discussion of error matrix terms and interpretation see NOAA NCCOS (2005) or Congalton and Green (1999).

Table 1. Accuracy of major structure classifications. Cell entries denote the number of sites correctly and incorrectly classified within each category.

	Accuracy Assessment (i)		n <sub>j</sub>	User's Accuracy (%)
	Hard	Soft		
Hard	9	2	11	82%
Soft	0	66	66	100%
n <sub>i</sub>	9	68	n=77	
Producer's Accuracy (%)	100%	97%	$P_o =$	97.4%
			$T_o =$	0.948 ± 0.07

Both hard and soft bottom categories were mapped with a highly acceptable level of thematic accuracy, although sample size was small for hard bottom. Over 97% (75 of the 77) of sites surveyed in the accuracy assessment were mapped correctly at the level of major structure in the classification scheme.

Table 2. Accuracy of detailed structure classifications. Cell entries denote the number of sites correctly and incorrectly classified within each category.

		Accuracy Assessment (i)																
		Aggregate Reef	Aggregate Patch Reef	Individual Patch Reef	Spur and Groove	Pavement	Pav w/ Sand Channels	Rock Outcrop	Boulder	Reef Rubble	Algal Plain	Sand w/ SCR	Sand	Mud	Land	n <sub>i</sub>	User's Accuracy (%)	
	Aggregate Reef	1									1					2	50.0%	
	Aggregate Patch Reef		7								1					8	87.5%	
	Individual Patch Reef			1												1	100.0%	
	Spur and Groove															0	n/a	
Map data (j)	Pavement															0	n/a	
	Pav w/ Sand Channels															0	n/a	
	Rock Outcrop															0	n/a	
	Boulder															0	n/a	
	Reef Rubble															0	n/a	
	Algal Plain										49		2			51	96.1%	
	Sand w/ SCR															0	n/a	
Sand												13	1		14	92.9%		
Mud													1		1	100.0%		
Land														0	0	n/a		
	n <sub>i</sub>	1	7	1	0	0	0	0	0	0	51	0	15	2	0	n=77		
	Producer's Accuracy (%)	100.0%	100.0%	100.0%	n/a	n/a	n/a	n/a	n/a	n/a	96.1%	n/a	86.7%	50.0%	n/a	P <sub>o</sub> =	93.5%	
																T <sub>e</sub> =	0.93 ± 0.06	

Over 93% (72 of the 77) of sites surveyed in the accuracy assessment were mapped correctly at the level of detailed structure in the classification scheme. Only algal plain and sand had a sufficient number of accuracy assessment sites to consider results at the level of individual categories. Due to limited sample sizes for most categories (in many cases zero samples), accuracy was not corrected for bias resulting from the proportion of map area occupied by the various categories. While these results are very positive and comparable to the high accuracies achieved in other NCCOS mapping projects, a more thorough assessment of the coral reef categories based on additional surveys is advisable.

Literature Cited:

Congalton RG, and K Green. 1999. Assessing the accuracy of remotely sensed data: Principles and Practices. CRC/Lewis Press, Boca Raton, FL 137 pp.

NOAA NCCOS. 2005. Shallow-water benthic habitats of American Samoa, Guam, and the Commonwealth of the Northern Mariana Islands (CD ROM). NOAA Technical Memorandum NOS-NCCOS 8, Biogeography Team. Silver Spring, MD

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