Appendix C: Mapping Methods

Fish communities and associated benthic community surveys are greatly aided by benthic habitat maps. Many fish communities are strongly linked to particular benthic habitats and consequently habitats can be used in a stratified sampling design to improve sampling efficiency (Ault et al., 1999, 2005; Menza et al., 2007). Many types of benthic habitat maps exist, ranging from maps devised from a single benthic variable (e.g., depth) to complicated integrators of geomorphology, biological cover and geographical zonation. In this report we produced several different benthic habitat maps for sampling and analysis.

Map # 1

In 2006, a benthic habitat map devised from bathymetric slope was used to stratify sample selection. The sampling domain was also divided into two geographic locations (i.e., east bank, west bank) resulting in four exhaustive and mutually-exclusive strata which covered the shallow coral caps (Figure C1). Bathymetric slope was anticipated to be a covariate of several fish community metrics, because distinct species had been sighted along the steep perimeter of the coral caps (sanctuary staff, pers. comm.) and because it was thought to be a covariate of dominant coral type (e.g., plate coral, head coral, rubble). To divide the survey domain according to slope, areas of high (steep) and relatively low (flat or gently sloping) slopes were programmatically delineated from half-meter resolution bathymetric models (source: sanctuary staff) in a geographic information system (GIS). Models were first smoothed using a 5 x 5 m (10 x 10 cell) nearest neighborhood filter to reduce noise. Then the Slope function in ArcGIS' spatial analyst extension was used to produce a slope surface. This function defined the slope of each raster cell by the maximum rate of change between the cell and its neighbors. Lower slope values indicate flatter habitat and higher values indicate steeper habitat. Areas having a slope greater than 35° were considered steep, while the remainder of area was considered flat or gently sloping. A minimum mapping unit of 100 m^2 was used and thus distinct slope regions smaller than this area were incorporated into surrounding strata.

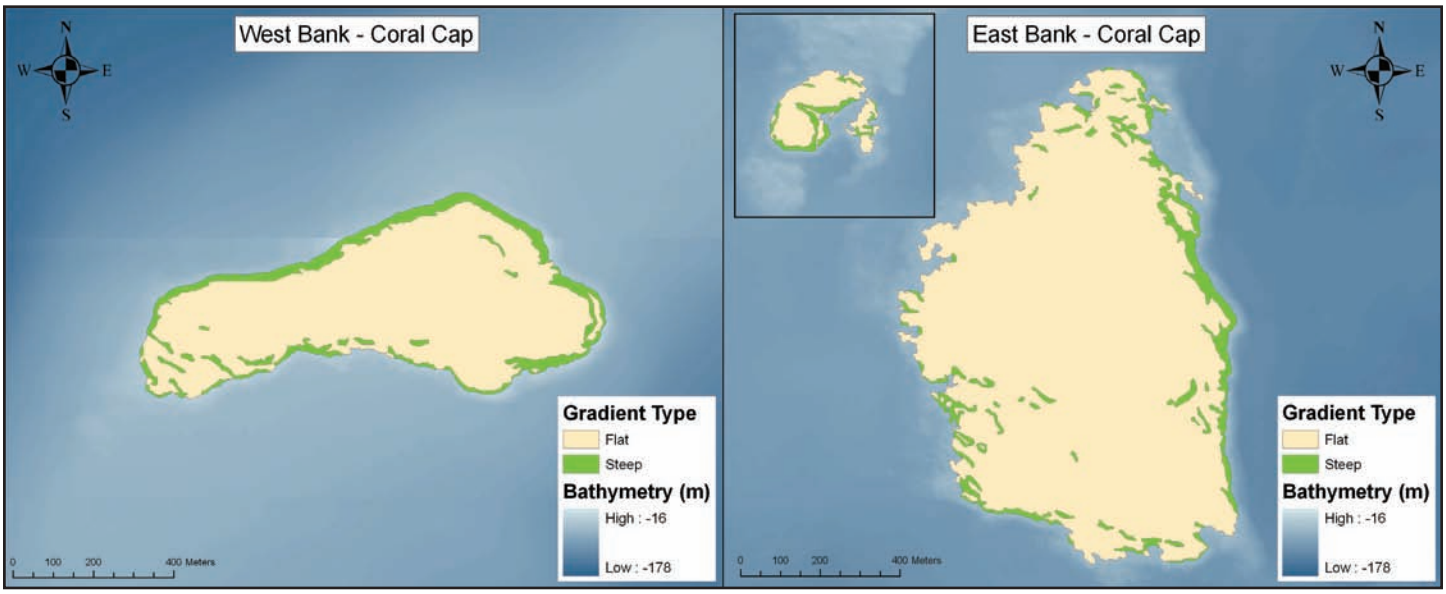

Figure C1. Benthic habitat maps of the West Bank and East Bank coral caps devised from gradient delineations.

Map # 2

After the field mission in 2006, a second benthic habitat map was developed, based on diver observations. Divers noted at least two distinct coral cover types were present on the coral caps and these cover types were each associated with different fish assemblages. The spatial patterns and bathymetric complexity of these cover types suggested that the classification method and spatial scale of analysis used to generate Map #1 were inadequate and required adjustment.

Two distinct cover types, low-relief coral and high-relief coral, were delineated for the new map. Differentiation among these cover types was accomplished using visual interpretation of a half-meter resolution slope surface. The slope surface was identical to the one used to develop the first benthic habitat map, but did not implement a smoothing filter prior to computation of slope, and was not assessed programmatically. Instead, cover was digitized using heads up display on a monitor.

Preliminary visual examination of the slope surface revealed three distinct spatial patterns. High-relief coral habitat was characterized by a relatively large variance of slope per unit area and low-relief coral habitat was characterized by a relatively low variance. A third habitat type consisted of almost no variance and represented areas of flat terrain, probably consisting of sand and little, if any, coral. Diver data revealed low-relief coral habitat consisted of a mixture of *Madracis* coral and rubble (Figure C2a), and high-relief coral habitat was a mixture of boulder and plate corals (Figure C2b).

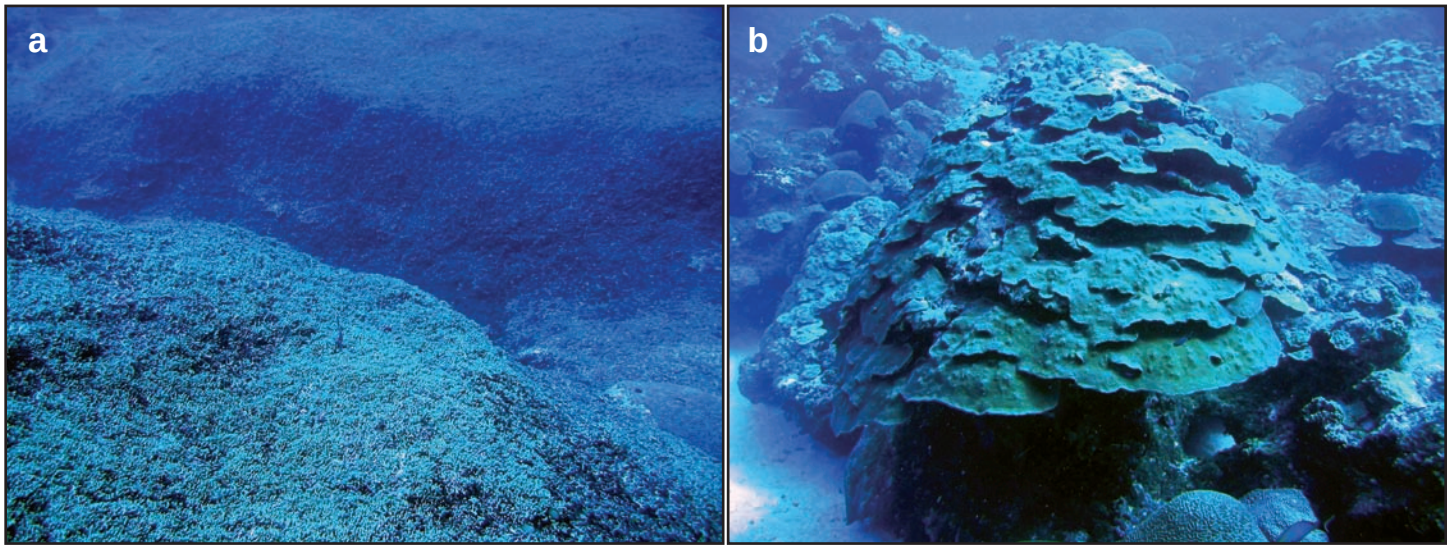

Figure C2. Underwater photos of (a) low-relief coral habitat and (b) high-relief coral habitat.

The benthic habitat map was produced by digitizing contiguous areas of coral cover types which were greater than 2,000 m^2 (i.e., the minimum mapping unit [MMU]) in a GIS (Figure C3). A value of 2000 m^2 was used for the MMU, because this was the spatial scale at which fish and benthic habitat data were collected (i.e., 25 m long transect at random bearing from point; area = π x 252, approximately 2,000 m^2). Areas of habitat with almost no variance in slope were all smaller than the MMU and consequently absorbed within surrounding habitat types.

Approximately 88% of the shallow coral cap area (consisting of EB and WB) was classified as high-relief coral habitat; the remaining 12% was classified as low-relief coral habitat (Figure C4). If the flat sand habitats were incorporated they would have made up less than 1% of the area. The majority of the low-relief coral habitat was at the edges of the corals caps and among deeper depths (mean depth 30 m WB and 31 m EB) compared with high-relief habitats (mean depth 25 m both banks). Strata area was also quite different with substantially smaller regions located in the low-relief strata (0.01 km^2 WB and 0.13 km^2 EB) compared to high-relief (0.34 km^2 WB and 0.62 km^2 EB). This new map was one of the layers used to develop the 2007 sampling design, but should not be confused with the sampling design itself.

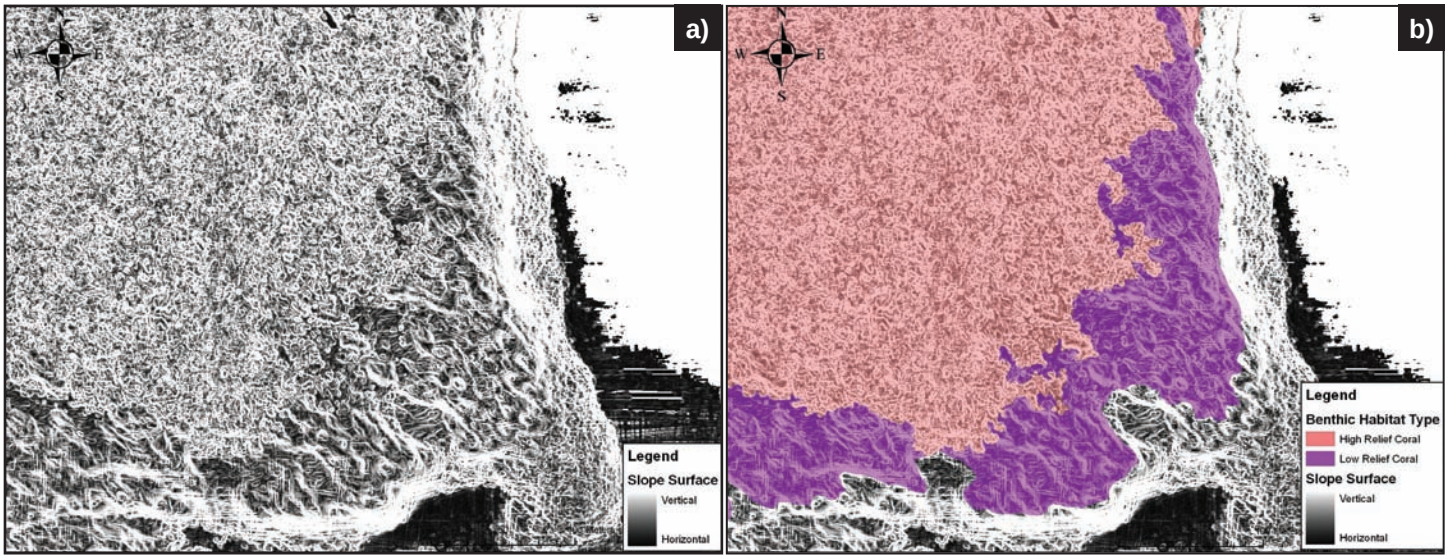

Figure C3. a) Process used to delineate benthic habitat types from slope surface; b) distinct spatial patterns of slope were used to map low-relief and high-relief coral habitats.

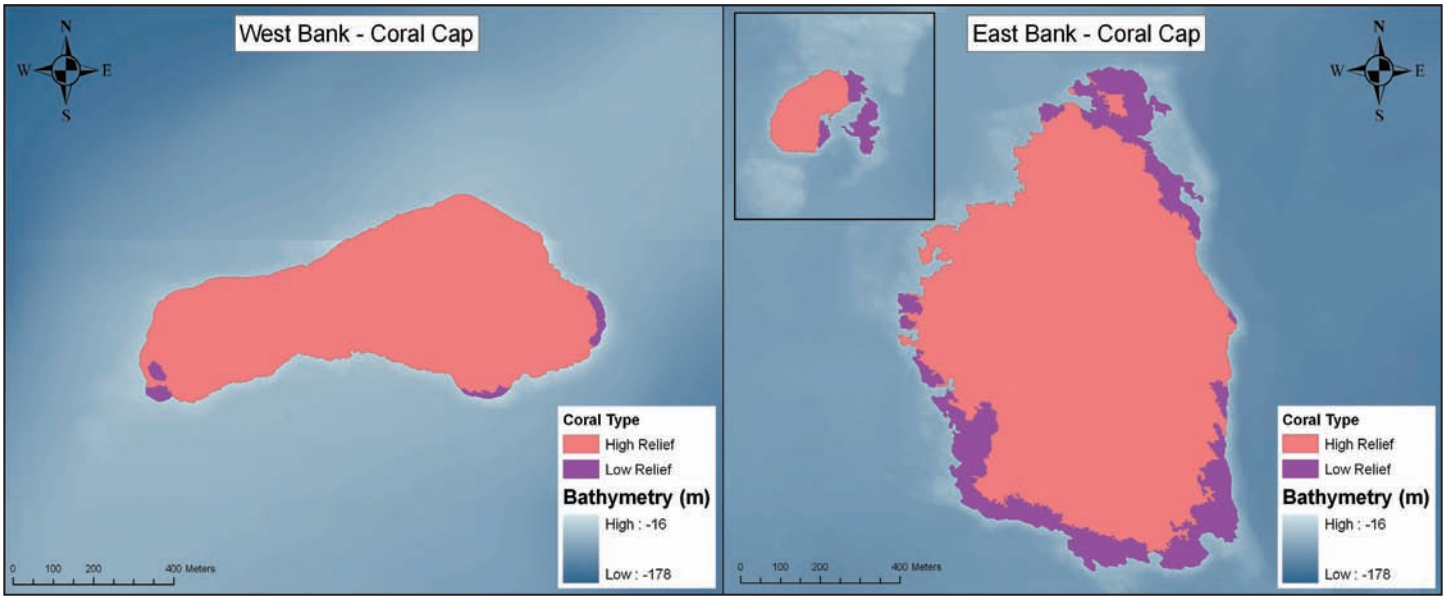

Figure C4. Benthic habitat maps of the West Bank and East Bank coral caps devised from coral habitat delineations.

Map # 3

In 2007, a stratified sampling design which used a regular network of points as sampling units was developed. Each point was the centroid of a square measuring 50 x 50 m and all of which exhaustively covered the coral caps. Several different environmental variables within each square were used to classify the corresponding sampling units, including coral cover type.

To integrate the coral cover type map (Map # 2) into the sampling design, each sampling unit was designated as either high- or low-relief coral habitat (Figure C5; the corresponding squares are used to visualize sampling unit classifications). In essence, the characterized sampling units became another version of the benthic habitat map defined by coral cover. Sampling units were classified by the cover type with the most area within a 25 m radius circle centered on the sampling unit (area approximately 2,000 m^2). The circle was used, because fish and benthic measurements are taken inside the circle (25 m long transect at random bearing from sampling unit). Although this procedure blurs the limits of coral cover types, it also allows sampling units to be updated easily. Updates may be needed if coral cover designations were initially interpreted incorrectly, coral cover type changes over time or new types are needed.

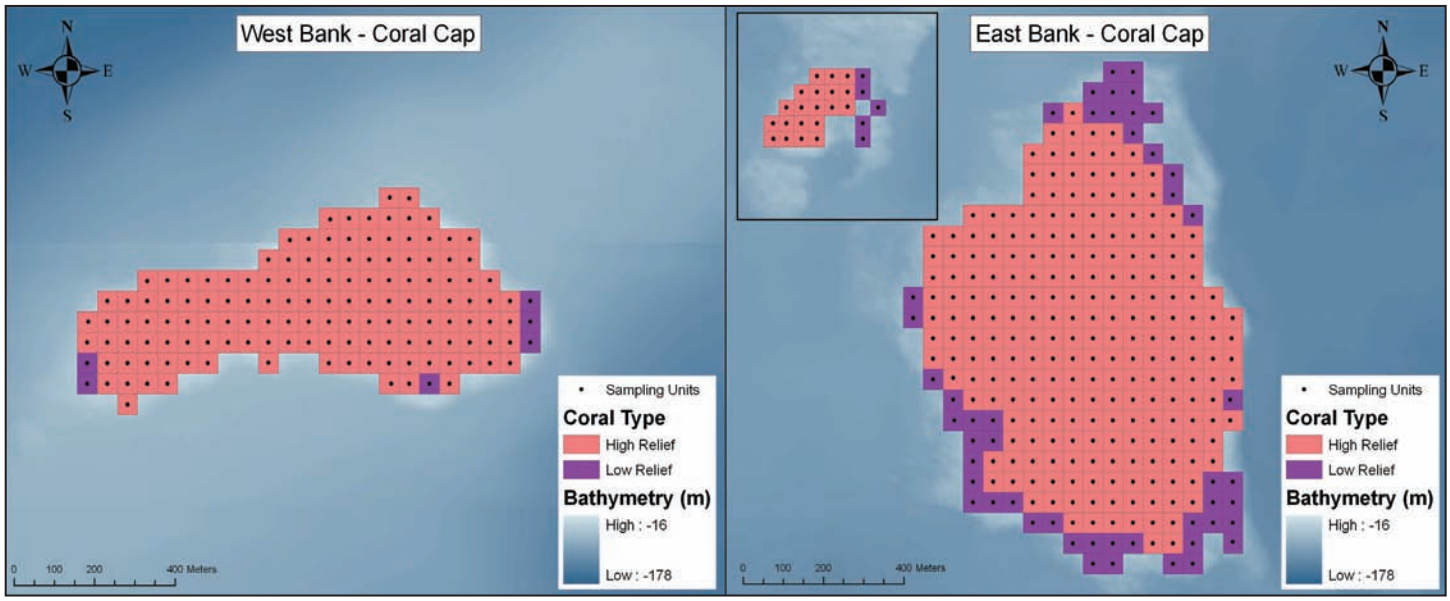

Figure C5. Benthic habitat maps of the West Bank and East Bank coral caps devised from coral habitat delineations within sampling units.

Accuracy of the benthic habitat map was assessed by *in situ* data collection during the 2007 sampling mission. Divers were asked to estimate the percentage of low- and high-relief coral habitat within the 25 m radius circle centered on the sampling unit. Habitat designations were made based on the majority of area within the circle. The designation was made independent of the stratification scheme and of subsequent measurements used in the characterization of fish and benthic habitat.

It was anticipated that over 70 sites would be used to assess the accuracy of the map, but severe weather prematurely canceled the mission and resulted in data collection at only 32 sites. All surveyed sites were on the southern portion of the east bank coral cap. The spatial bias among data means the reference data are not representative of the entire mapped area (east and west banks) and must be interpreted with this in mind. The incorporation of additional data from the northern portion of the east bank and west bank may alter map accuracy.

Table C1. Error matrix for accuracy assessment.

		Predicted		
	Habitat Type	**Low-Relief**	**High-Relief**	**User's Accuracy**
Reference	Low-Relief	7	1	88%
	High-Relief	1	23	96%
	Producer's Accuracy	88%	96%	

Overall accuracy of the cover type map was 94% (Table C1; kappa=0.73). Only two errors were identified, one for each cover type. These errors were adjacent to each other in a transition zone and included both cover types at each site (Figure C6). The most plausible explanations for these errors are mistakes in processing reference data for map production (visual interpretation of slope surface) positional error or diver interpretation error.

The benthic habitat map should be reassessed whenever possible. As mentioned previously, the use of a gridded map allows simple updates when new data become available or management objectives change.

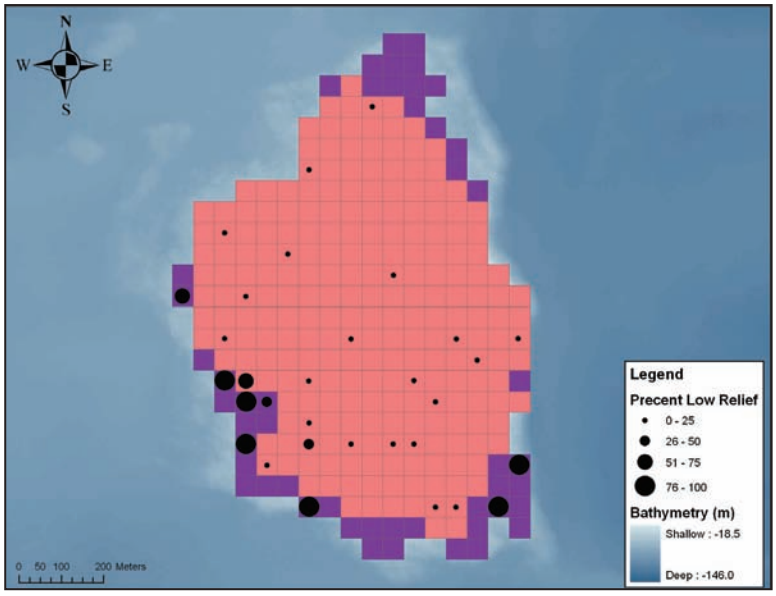

Figure C6. Accuracy assessment of coral cover type map. Graduated symbols represent percent low-relief coral cover recorded by scuba divers within a 25 m radius circle surrounding sampling units.

Map # 4

Three environmental variables were compiled to produce the strata used in the 2007 field mission (StRS; see Section 2.6.1 for details). The map of strata is a benthic habitat map which integrates coral cover type, geographic location and depth (Figure C7). The arrangement of sampling units and the method for coral cover type designation were the same as defined for Map # 3. Sampling units were differentiated according to depth by the maximum depth within a 25 m radius circle centered on the sampling unit. Units with a maximum depth greater than 31 m were considered deep, whereas those units less than 31 m were shallow. Groupings generated by the new environmental variables were not assessed for accuracy because they were not based on interpretation, but rather bathymetric surfaces having assumed negligible positional error.

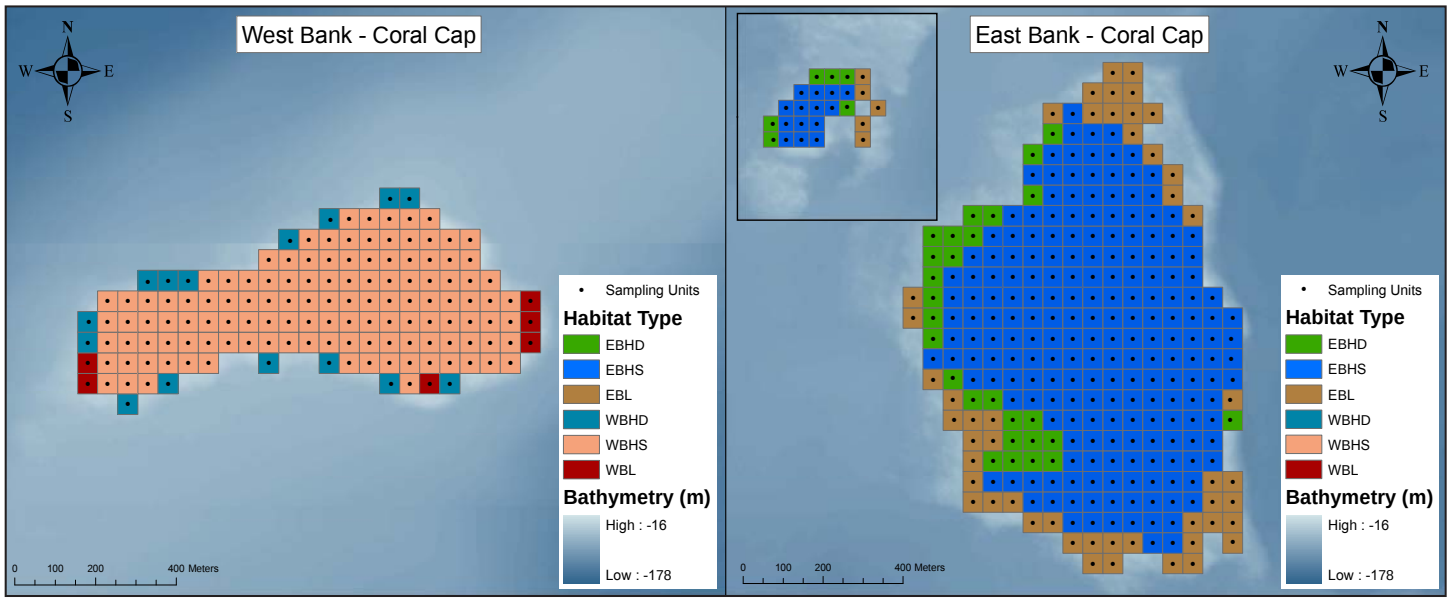

Figure C7. Benthic habitat maps of the West Bank and East Bank coral caps. Maps shows sampling unit stratum designations based on coral habitat type, geographic location and depth. Sampling units are points. Surrounding squares are used to visualize sampling unit classifications.