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CHAPTER

3

SEAFLOOR HABITATS

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Introduction

Effective marine resource management and conservation begins with knowing the types, amounts, and spatial distribution of resources (Walker and Gilliam 2013).

The seafloor habitats of the South Atlantic Bight are the foundation of the region's extensive biodiversity. Sandy habitats on the Continental Shelf sustain important fishery species such as tilefish, flounder, scallops, and penaeid shrimp. Rocky outcrops that punctuate the shelf provide substrate for a wealth of sponges, corals, and algae. Like coral reefs, these "live" rocky reefs support varied assemblages of mollusks and crustaceans, and sustain economically valuable fisheries of snapper, grouper, grunt, and porgy. South of Cape Canaveral, a drowned coral reef creates a ridge system parallel to the shoreline of Florida where shallow water coral reefs harbor a myriad of reef species. The Florida reef tract encompasses 6,000 patch reefs and coral ridge formations, the only system of shallow reef-building corals in the continental U.S. Seaward of the shelf, the Continental Slope is interrupted by the relatively flat Blake Plateau that separates the inshore slope from the deep offshore Blake Escarpment that plunges to 3,000 m (9,842 ft) at its base. The rock outcrops of the Blake Plateau are colonized by deep-sea sponges and corals, and in some places the corals have formed significant mound and ridge systems up to 150 m (492 ft) tall. These coral mounds support associated sponges, other cnidarians, mollusks, polychaetes, crustaceans, echinoderms, and fishes (adapted from Fautin et al. 2010).

The distributions and life histories of seafloor organisms are related to the physical environment. Individual species are sensitive to variations in light, depth, sediment size, temperature, salinity, and other abiotic factors. They may be attached to hard substrates, embedded in soft sediment, or freely moving. For example, filter feeders, abundant in shallow sandy sediment, strain suspended matter directly from the water column, while deposit feeders that rely on settling detritus are most abundant in fine-grained mud. Natural rock substrate and reefs are often colonized by algae, sponges, corals, and bryozoans, which in turn support a large diversity of fish (SAFMC 1998). Mobile species such as sea stars, crabs, snails and demersal fish search the seafloor for prey.

Extensive surveys of the benthic invertebrate communities of the South Atlantic Continental Shelf suggest that these habitats are teeming with life. Surveys have found an average of 3,000 individual organisms per square meter with a range of 275 to 23,650 individuals per square meter (Wenner et al. 1983; Wenner et al. 1984; Hyland et al. 2006; Fraser and Sedberry 2008; Cooksey et al. 2010). Samples taken in Gray's Reef National Marine Sanctuary found the density of individual organisms per square meter to range from 4,958 (inner shelf) to 5,901 (mid-shelf) to 1,550 (outer shelf; Hyland et al.2006).

The taxonomic diversity of invertebrate species in the South Atlantic Continental Shelf region is estimated at 2,434 species, with mollusks (698 spp.), crustaceans (696), annelids (400) and cnidarians (362) making up the majority of the taxa (Fautin et al.2010). Cooksey et al. (2010) found a total of 462 benthic taxa on the shelf exclusive of estuaries, with polychaetes and crustaceans representing the majority of the taxa. The fauna of the oceanic region is poorly known because of the difficulty of sampling. However, the rock outcrops of the Blake Plateau are colonized by a wide variety of deep-sea sponges and corals, with many other associated invertebrates and fishes (Ross and Nizinski 2007).

The South Atlantic Bight supports an estimated 1,200 fish species including an extensive and diverse demersal fish fauna (Fautin et al. 2010). Fin fish associated with reef and rock substrate habitats have been well studied in the region (Sedberry et al. 2006; Rowe and Sedberry 2006; Schobernd and Sedberry 2009) and systematically sampled for over 30 years by the Marine Resources Monitoring Assessment and Prediction program (MARMAP, Reichert 2009), whose mission is to determine distribution, relative abundance, and critical habitat of economically and ecologically important fishes of the South Atlantic. Prevalent and abundant in the region, especially on hard substrate, are: bank sea bass, black sea bass, gag, gray triggerfish, knobbed porgy, red grouper, red porgy, red snapper, sand perch, scamp, scup, spottail pinfish, spotted moray, tomtate, vermilion snapper, and white grunt (Sedberry and Van Dolah 1984; Wenner and Sedberry 1989; Van Dolah et al. 2011).

This report provides the results of The Nature Conservancy's three-year effort to define the types, amounts, and spatial distribution of seafloor habitats across the South Atlantic Bight using the most recent information on bathymetry, seafloor topography, sediment grain size, and hardbottom. This project is not the first to map the seafloor of the South Atlantic. The challenge of mapping seafloor habitats has produced an extensive body of research both within the South Atlantic and in other marine regions (Table 3.1). We were grateful that many of the authors of previous classifications agreed to participate on the steering committee to review and guide this project, allowing us to integrate and upgrade a substantial body of existing work with additional data and newer mapping techniques.

There is no agreed-upon approach for classifying seafloor habitats, although many have been proposed (see reviews in National Estuarine Research Reserve System 2000 and Lund and Wilbur 2007). In the United States, the Coastal and Marine Ecological Classification Standard (CMECS) has been adopted as a federal standard for classifying and describing coastal and marine ecological systems (FGDC 2012). CMECS is not a list of habitat types but a language for describing components of the seafloor at various scales using a consistent vocabulary. This flexible approach allows features mapped at a variety of scales to be crosswalked to CMECS. For readers interested in how our results relate to CMECS we include a complete crosswalk in Appendix 1. Methods for crosswalking mapped seafloor features to CMECS were developed for the Northwest Atlantic Marine Ecoregional Assessment (Anderson et al. 2010) which used the same mapping protocols as this project (Weaver et al. 2013).

Our goal was to build on the considerable sampling, mapping, and classification work completed by others for many parts of the South Atlantic to produce a regional map of seafloor habitats using consistent and repeatable methods. Many organizations freely contributed data to this effort, and a team of scientists familiar with the seafloor of the South Atlantic Bight served as a scientific review committee (Box 3.1). Comments on the methods and preliminary results were collected via meetings, webinars, individual phone calls, and written responses. Each dataset and derived product was carefully reviewed, but a full accuracy assessment was not completed and cross-validation using independent datasets is ongoing. The assessment was developed to guide conservation decisions and aid in marine spatial planning. We anticipate that updated reports will be produced as the research matures.

Box 3.1. Seafloor Habitats Technical Team Members

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Geography of the Study Area

The South Atlantic Bight marine region, as the SABMA project defines it, extends southward from North Carolina's James River to the Florida Keys. Seaward it encompasses the continental shelf, the shelf-slope break, and the deepwater plateaus and terraces that reach to the Blake Escarpment, 5000 m (3.1 mi) below sea level (Figure 3.1). The large, 37,550,000 hectare (145,000 mi^2) region divides naturally into three sub-regions that include all of the Carolinian and the Floridian regions (Spalding et al. 2007), and part of the Virginian region. For planning purposes, The Conservancy calls the latter the "mid-Atlantic Bight" (Figure 3.1).

<u>The mid-Atlantic Bight.</u> This analysis addresses the southern end of the mid-Atlantic Bight/Virginian ecoregion, starting at the James River in Virginia and running south to Cape Hatteras. The region is centered on the 105-km (65-mile) wide Continental Shelf running from the Virginia/North Carolina coastline to the shelf-slope break. The shelf averages 25 m (82 ft) in depth, growing deeper eastward until it reaches 100 m (328 ft) at the shelf edge and then drops to 1,000 m (3,281 ft) at the steep escarpment and deep canyons of the slope break.

The coastal edge of the region is dominated by large estuaries like Pamlico Sound which contains a huge expanse of sea grass and tidal marsh. Not all of the mid-Atlantic Bight is covered by this study; the Chesapeake Bay and Delaware Bay estuaries, for example, are in this region but outside the extent of the South Atlantic Bight.

The Carolinian Region forms the central portion of the study area. The west side is dominated by the large shallow Continental Shelf, 64 to 137 km (40 to 85 miles) wide and 5 to 100 m (16 to 328 ft) deep. It is underlain in places by a hard limestone pavement where corals and other species form diverse colonies. At the shelf edge, the slope drops to 200 m (650 ft) and flattens out into two wide plateaus: the smaller and shallower Charleston Bump at a depth of 200-600 m (650-1,970 ft), and the larger Blake Plateau at 600-750 m (1,970-2,460 ft) depth. The Blake Plateau covers almost 518 km^2 (200 mi^2) and is flanked on its eastern side by the Blake Escarpment, a steep slope that drops to 5,000 m (3.1 mi) in depth. The escarpment and its two deepwater spurs (Blake Spur and McAlinden Spur) mark the eastern edge of the ecoregion. The southernmost end of the region is marked by Florida’s cape Canaveral, and the deepwater zone is bounded by the exclusive economic zone (EEZ), a zone prescribed by the United Nations Convention on the Law of the Sea over which a state has special rights over the exploration and use of marine resources, including energy production from water and wind.

The Floridian Region extending from Cape Canaveral to the Keys is a narrow linear region of terraces and coral reefs. The shallow Continental Shelf is a relatively modest feature constricted to 11.3 km (7 mi) at its narrowest and about 64.3 km (40 mi) at it is widest. The shelf-break drops to 200 m (656 ft) in depth and is then broken up by relatively flat terraces: the Miami Terrace, the Pourtales Terrace, and the Tortuga Terrace reaching a depth of 750 m (2,460 ft).

Table 3.1. A review of literature on seafloor classifications and approaches that informed our methods

Physical/ Biological	Ecological Associations	Species	Data Type/ Comments	Example References
temperature	community composition	benthic macro-invertebrates		Theroux & Wigley 1998
substrate	soft sediment	demersal fish	sampling; correlational analyses done separately for each group	Wenner 1983 Miller & Richards 1980 Vandolah 1984
		benthic macro-		Hyland et al. 2006 Cooksey et al. 2010
	hardbottom	demersal fish, benthic macro-invertebrates	trawl samples, benthic grabs/submersible transects	Wenner et al. 1980 Van Dolah et al. 2011 Sedberry et al. 2006 Reichert et al. 2009 Wenner & Sudbury 1989 Quattrini & Ross 2006
	coral reef	demersal fish, benthic macro-invertebrates	bottom trawls samples	Chiappone & Sullivan 1994 SAFMC 1998
habitat complexity	species abundance community composition	demersal fish	video transects	Anderson & Yoklavich 2007
	species diversity	benthic macro-invertebrates	benthic grabs, photographs, fine-scale sediment heterogeneity	Kostylev et al. 2001 Serrano & Preciado 2007 Etter & Grassle 1992
			literature review	Levin et al. 2001
	species richness & total abundance	demersal fish	visual surveys	Charton & Perez Ruzafa 1998
depth	organism density & community composition	benthic macro-invertebrates & demersal fish	benthic grabs; correlational analyses done separately for each group	Stevenson et al. 2004
		Combination		
depth + temperature + substrate	species assemblages & abundance, benthic ‘seascapes’	demersal fish abiotic	bottom trawl; single species assessments, abiotic sampling	Mahon et al. 1998 DeLong & Collie 2004 CLF/WWF 2006

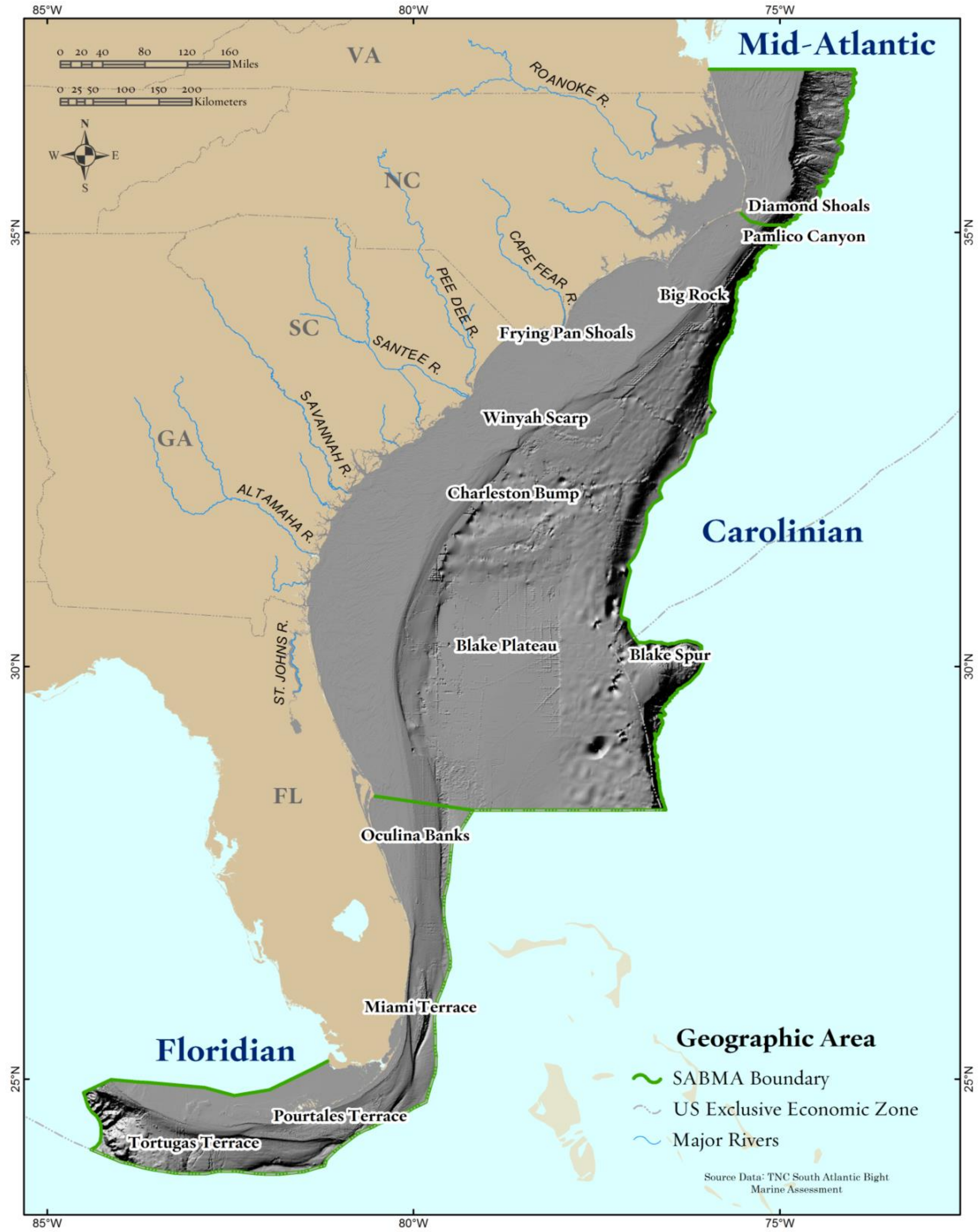


Figure 3.1. Geography and subregions of the South Atlantic Bight marine region

Methods and Results

We characterized the seafloor using three geophysical variables that define its structure: bathymetry (depth), seabed forms (topography), and substrate (texture and hardness). These factors are relatively stable over time and space, and have been shown to correlate with the distribution and abundance of demersal fish and benthic organisms (Table 3.1). They change at slower rates than water column conditions such as temperature and salinity, collectively forming the enduring physical template of the seafloor. For each variable we created a spatially comprehensive dataset using the highest quality data that was regionally available. The individual and combined datasets were used to create a mapping framework (Ecological Marine Units) to explore how the biota of the region corresponded to the physical environment.

Data on each physical factor were compiled from many sources; the techniques used to create a comprehensive map are discussed below. There was a dramatic difference in the density of information available for the Continental Shelf versus the oceanic region eastward of the shelf-slope break. Consequently, there was often a difference in data resolution (coarser in the deepwater areas) and in the number of data points available for confirming patterns between these two areas. Our approach was to use the best available data for the shelf and the best available for the deepwater region even if this created a lack of consistency between the two sections.

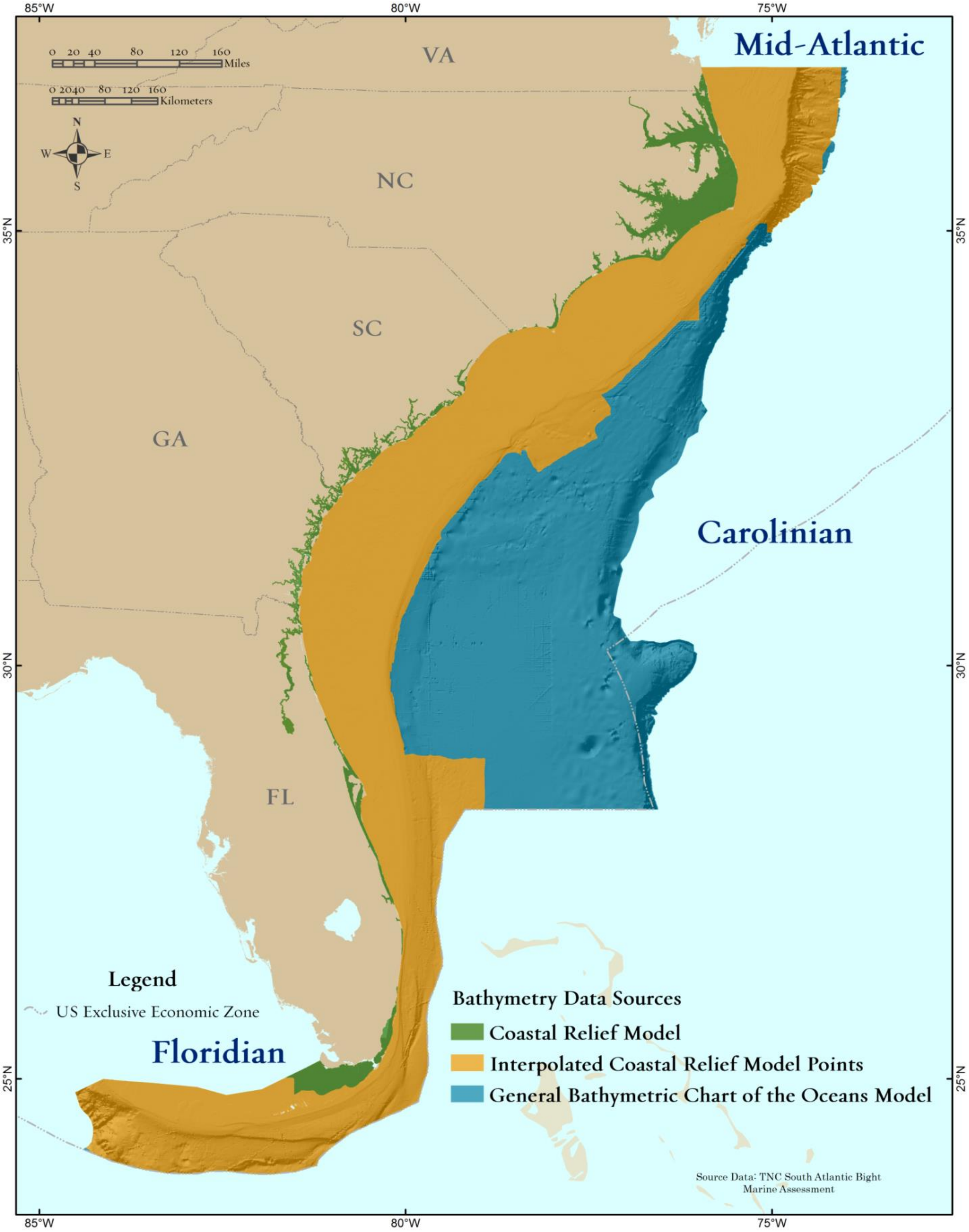
Bathymetry

Seafloor depth affects the temperature, pressure, light availability, circulation patterns, and chemistry of benthic environments, and it can be a limiting factor for many species. To characterize depth across the whole study region, we compiled millions of depth sounding points and then interpolated them to form a continuous grid. Our primary data source was the National Geophysical Data Center's (NGDC) Coastal Relief Model (CRM) depth soundings. The soundings were from hydrographic surveys completed between 1851 and 1965, and from survey data acquired digitally on National Ocean Service (NOS 2008) survey vessels since 1965 that are stored in the NOS Hydrographic Database. We interpolated the bathymetry directly from the 4.7 million sounding points, after evaluating CRM's bathymetric surface model and finding data inconsistencies that would not support the accurate derivation of slope. To create a single bathymetry grid for the entire region, we merged the re-interpolated grid with an existing high-quality grid for the estuaries and a coarser scale grid for oceanic areas not covered by the data points.

Mapping Methods

Our bathymetry map was created from three datasets: in estuaries we used the NGDC CRM, in the oceanic section of the Carolinian we used the General Bathymetric Chart of the Oceans (GEBCO), and for the remainder of the region we used a re-interpolated grid created from NGDC's depth soundings (Figure 3.2). For the re-interpolation, we prepared the CRM soundings dataset by paring down the original set of 8.4 million points to include only the points collected after the 1950s. This reduced the data point total to 4.7 million, covering the entirety of the mid-Atlantic and Floridian regions and the Continental Shelf area of the Carolinian region (excluding the estuaries, Figure 3.2). We interpolated the points in ArcGIS 10 using kriging to create a continuous surface. We tested a variety of cell sizes and search radii on samples of the dataset and decided on a spherical model, with a cell size of 90 m^2 and a search radius of 36 cells. After each test run, we created a slope grid from the products and visually assessed it for obvious data artifacts. Some problems in the slope grid were caused by a false six-decimal precision in the sounding depth. To correct for this, we rounded the sounding values to one decimal place which eliminated many of the false slopes. When we were satisfied with the results of the test areas, we created a map for the whole region by dividing the geography into six smaller overlapping subsets and combined the successful runs into one bathymetry grid for the region. In offshore areas, we conducted a density analysis on the raw points in order to determine which areas we needed to fill in with data from the GEBCO grid. We used the modeled NGDC CRM in all estuaries.

We created a seamless regional dataset by adding oceanic and estuary data to the newly interpolated offshore bathymetry grid. In the oceanic portion of the Carolinian region (east of the Continental Shelf) that was outside the range of the CRM points, we obtained 810 m^2-resolution data from the GEBCO. The resolution of the dataset was purportedly at 90 m^2; however, a slope grid created for this area revealed that each area of nine by nine grid cells had the same depth value across all of the cells, indicating that the resolution of the grid was actually 810 m^2. To create a smooth grid we aggregated the grid up from 90 m^2 cells to 810 m^2 cells and resampled the aggregated 810 m^2 grid back to 90 m^2 cells, averaging the values. We then calculated a focal mean for the new 90 m^2 grid to smooth out the values, resulting in an approximate 90 m^2 grid. We filled in all estuaries with the NGDC CRM. We merged these two datasets with the newly interpolated bathymetry grid to create one 90 m bathymetry grid for the whole region.



Source Data: TNC South Atlantic Bight Marine Assessment

Figure 3.2. Distribution of the three source datasets used for creating the bathymetry grid

Bathymetry Zones

Demersal fish and invertebrate communities typically occur within a particular bathymetry range. Fish such as lookdown, menhaden, and black sea bass are typically found in shallow water (less than 30 m (98 ft) deep). In contrast, fish such as the scaleless dragonfish, duckbill eel, and lightfish thrive in depths over 600 m (1,968 ft). Over the past fifty years, researchers have identified a number of different depth zones that correspond to changes in species composition or ecological processes Table 3.2). Some schemes are based on specific habitats such as rock substrates or soft sediments (Table 3.2, rows 6-10), and others are characterized by the distribution of benthic invertebrates, particularly corals, that have also been well studied with respect to depth (Table 3.2, rows 11-15). The Continental Shelf is much better studied than the deeper oceanic habitat. Deepwater corals (e.g., *Lophelia pertusa* and *Enallopsammia profunda*) have been the subject of several inventories (Ross and Nizinski 2007) but most deepwater seafloor habitats are poorly surveyed. For example, Blake and Grassle (1994) reported that of the 1,202 invertebrate species they collected on the Blake Plateau beyond the 600 m depth line, 43% were new to science.

Depth zones can also be characterized by dominant ecological process. The inner shelf is controlled by tidal currents, river runoff, local wind, and seasonal atmospheric changes. The mid shelf zone is dominated by winds but also influenced by the Gulf Stream. Stratification of the mid shelf water column changes seasonally with mixed conditions generally characterizing fall and winter, and vertical stratification prevailing during spring and summer (SAFMC 2009). Strong stratification allows the upwelled waters near the seafloor to advance closer to shore, while at the same time facilitating offshore spreading of lower salinity water in the surface layer. The outer shelf, terminating at the steep shelf-slope break, is controlled primarily by the Gulf Stream. Recognizing these differences, CMECS (FGDC 2012) bases their benthic depth zone modifier on ecological processes (Appendix 1). The modifier was developed to describe general "zones in which surf or ocean swell influences bottom communities, lower limits of vegetation, and overall photic ability and temperature" at a global scale. This modifier was not specifically developed to describe regional patterns of biodiversity; however, the zones are similar to those derived from biotic patterns (Table 3.2):

- Infralittoral: shallow (0-5 m)
- Infralittoral: deep (5-30 m)
- Circalittoral (30-200 m)
- Mesobenthic (200-1,000 m)
- Bathybenthic (1,000-4,000 m)
- Abyssalbenthic (4,000-6,000 m)
- Hadalbenthic (>6,000 m)

IDENTIFYING BATHYMETRY ZONES FOR SABMA

To identify biologically relevant depth zones for the South Atlantic region, we examined two recent depth zone proposals (Table 3.2, rows 2-3): the CMECS process-based classification and the depth zones recommended by the South Atlantic Fisheries Independent Management (SAFIM) group (Williams and Carmichael 2009). We combined these two proposals into one set of depth thresholds (30, 70, 140, 200, 600, and 1,000 meters) and evaluated how well these thresholds separated different fish communities by examining the species–depth relationships in the following four regional datasets:

Collections by the Exploratory Fishing Vessels Oregon, Silver Bay, Combat, and Pelican (USFWS, Bullis and Thompson 1965): Trawl and dredge surveys from the late 1950s in the southwestern North Atlantic. (4,792 samples in SABMA; 513 spp.; depth range 3 to 8,284 m; years 1956 – 1960; FL,GA,SC,NC)

Marine Resources Monitoring Assessment and Prediction: Isaacs-Kidd Midwater Trawl 1979 (Reichert 2010) (1,053 samples in SABMA; 16,825 records; 529 spp.; depth range 9 to 686 m; years 1973-1980; FL,GA,SC,NC).

Marine Resources Monitoring Assessment and Prediction: Chevron Trap data (MARMAP, Reichert 2009): Chevron trap data (7,885 samples in SABMA; hardbottom only; 24 spp.; depth range 15 to 101 m; years 1989-2012; GA,SC,NC).

National Marine Fisheries Service (NMFS 2009): Spring and fall bottom trawl surveys. (4,712 samples in SABMA; 560 spp.; depth range 6 to 1,160 m; years 1968 – 2006; SC, NC)

The USFWS Exploratory Vessels report, our base dataset, was the most geographically and bathymetrically extensive, covering North Carolina (1,407 samples), South Carolina (460 samples), Georgia (460 samples) and Florida (2,771 samples), and ranging in depth from 3 to 8,284 m. The aim of the regional exploratory program was to inventory fishery resources in the western Atlantic; it included a gross faunal survey with identifications performed by many different taxonomic specialists. The standard gear for bottom exploration was 40 foot shrimp trawls, but a large variety of commercial type fishing equipment was used: shrimp trawls, fish trawls, midwater trawls, scallop and clam dredges, seines and lampara nets, longlines, and handlines. Material was also collected at night-light dip-netting stations. Specific cruise objectives varied from general reconnaissance of unknown and unexplored areas to detailed commercial evaluations of a range of food or scrap fish.

The NMFS and MARMAP datasets were amenable to detailed quantitative analysis, while the USFWS dataset was not. The NMFS data is based on trawl surveys performed over a 40-year period, but was only available for the mid-Atlantic Bight and a portion of the northern Carolinian region. The MARMAP trawl data were collected by offshore surveys in the 1970s that collected a few hundred species; the data set is comparable to the NEFSC survey conducted by MARMAP in the South Atlantic. The MARMAP trap data also come from a long term sampling program that uses chevron traps to sample hardbottom substrates often under-sampled in the trawl surveys. We used the information from these surveys to augment the USFWS study and analyzed each independently to determine relevant depth zones.

For the NMFS and MARMAP trap datasets we performed exploratory quantitative analysis to determine species-depth thresholds. First, we clustered the sample data into groups based on species composition, and then we used a classification tree to identify the depth zones that best separated the groups from each other. For the cluster analysis, we performed hierarchical clustering on each individual dataset (flexible beta, beta = -0.25) using both presence/absence data (Jaccard distance matrix) and abundance data (Bray Curtis distance matrix) for individual species. An additional divisive partitioning analysis (TWINSPAN) was performed on the NMFS trawl data to obtain a more thorough sorting of the presence/absence data as the initial identification of twenty clusters assigned 96% of the data to a single one.

To identify depth zones, all samples were assigned to their respective cluster group and attributed with the depth at which the sample was taken. A classification tree analysis was then run with each cluster group as the response variable and sampling depth as the predictor variable. The MARMAP and NMFS data were analyzed separately and the resulting depth thresholds were compared using all five runs (Table 3.3). There was considerable consistency across the runs: the first split averaged 34.6 m across all the datasets and the second split averaged 20.2 m. The NMFS data had a third split at 68 m, and the TWINSPAN analysis identified a deep water split at 213 m in its initial three breaks. The results provided evidence to support the SAFIM workshop proposal of breaks at 30 m and 70 m, and for the CMECS process-based thresholds of 30 m and 200 m.

Using the USFWS vessel data augmented by the other three datasets we next examined individual species distribution patterns to determine whether we could identify sets of species that were typical of each zone. For this analysis, we organized the survey data by the potential depth zones then calculated the percent of each species' distribution found across each zone (Table 3.4). Most proposed zones each had at least 17-152 species found mainly in the zone (i.e., had more than two-thirds of their sampled locations in the zone): 0-30 m (99 species), 30-70 m (71 species), 70-200 m (40 species), 200-600 m (152 species), and 600-1,000 m (17 species). The exception was the 70-140 m zone which had only two “restricted” species: saddle bass and big-eyed frogfish. Therefore, we dropped the 140 m threshold, collapsing it into the broader 70-200 m zone. The other exception was the 1,000+ m zone for which we had very few samples and only 11 species detected, none of them restricted to the zone. Because there was no information to support or dispute the 1,000 meter threshold, we retained the threshold to match the CMECS process-based classification. Ultimately, we recognized six depth zones that were similar to the SAFIM zones and match or nest within CMECS thresholds (Figures 3.3-3.6).

Table 3.2. Comparison of depth zones used in recent studies

		Depth (meters)															
Depth Zones	**Source**	**0-10**	**10-20**	**20-30**	**30-40**	**40-50**	**50-60**	**60-70**	**70-80**	**80-90**	**90-100**	**100-150**	**150-200**	**200-250**	**250-300**	**300-350**	**350-600**
SABMA-TNC	Combat/Oregon/ Silver Bay/Pelican NMFS/MARMAP data	Infralittoral 0-30			Shallow Circalittoral 30-70				Deep Circalittoral 70-200					Shallow Mesobenthic 200-600			Deep Meso 600-1000
SAFIM Workshop	Williams & Carmichael 2009	0-30			30-70				70-140			>140					
CMECS depth modifiers	FGDC 2012	0-30 Infralittoral			30-200 Circalittoral									200-1000 Mesobenthic			
Process based	SAFMC 2009	0-20 IS		20-40 Mid shelf		41-75 OS											
Fisheries zone	SAFMC 2009	<18 coastal		18-55 open shelf			55-183 Shelf edge										
Live bottom	SC DNR Website 2014		15-31 Blackfish		31-55 Snapper		55-110 Shelf edge					110-183 Lower shelf					
Live bottom/sponge - coral habitats	Miller and Richards 1980	<18	18-55				55-183										
Fish in Sponge - coral habitat	Wenner 1983 (M&R 79)	<18 nearshore	18-55 open shelf				55-183 offshore										
Demersal fish - live bottom	Sedberry and Van Dolah 1984		16-22 IS	25-38 MS		47-67 OS											
Demersal fish - sand	Wenner et al. 1980		11-22	26-41					70-155						254-338		
Hardbottom	Deaton et al. 2010			20-40			50-200 outer shelf reefs								>250		
Sponge - coral habitat	Wenner 1983 cluster groups			18-29	37-44, 42-46												
Florida offshore reefs	SAFMC 2009	5-8 inner	9-15 mid	18-30 outer													
Deepwater & Black corals	SAFMC 2009							65-103 Black Corals								350-500	>600
Oculina colonies	SAFMC 2009	3-50 solitary colonies							70-100 contiguous								
Patch reef Elkhorn	SAFMC 2009I	0-15															

Table 3.3. Comparison of depth thresholds for the five classification groups and two data sources. Our goal was to determine if the data supported any of the thresholds proposed in the literature (Table 3.2), particularly those from CMECS or the SAFIM workshop. In our analysis the first split at about 15 m (row 1) was ignored because it was based primarily on differences in species abundances not composition. Rows 2 and 3 suggested a faunal change somewhere around 24-41 m (avg. 32 m) which roughly matched the zones proposed by several of the studies and supported the idea of a transition zone around 30 m. The two deeper splits were close enough to proposed SAFM and CMECS splits that they could be rounded to 70 m and 200 m respectably.

NMFS Data			MARMAP Data				
TWINSPAN Presence/ Absence	Cluster Presence/ Absence	Cluster Abundance	Cluster Presence Absence	Cluster Abundance	Avg.	Simplified	Final
		-14 m		-16.5 m	-15.3 m	-	-
-22 m	-23 m	-23 m	-25.5 m	-28.5 m	-24.4 m	-32 m	-30 m
-41 m	-38 m		-42.5 m		-40.5 m		
	-68 m	-68 m			-68 m	-68 m	-70 m
-213 m					-213 m	-213 m	-200 m

Table 3.4. Common fish by bathymetry zones based on USFWS vessel data. For each species the table shows the total number caught followed by the proportion of the total found in each depth zone. This table shows species with more than 5 individuals and >66% of their locations in one depth zone. The last two columns indicate whether the patterns in the NOAA, MARMAP trap (MM Trap) and MARMAP trawl (MM Trawl) data agree with the vessel data.

Scientific Name	Common Name	Total	0-30 m	30-70 m	70-200 m	200-600 m	600-1000 m	1000+	NMFS	MM Trap	MM Trawl
Selene vomer	Lookdown	13	1.00						Agree		Agree
Chloroscombrus chrysurus	Atlantic Bumper	10	1.00						Agree		Agree
Sphyraena borealis	Northern Sennet	9	1.00						Agree		Agree
Vomer setapinnis	Moonfish	8	1.00								
Astroscopus y-graceum	Southern Stargazer	5	1.00								
Bagre marinus	Gafftopsail Catfish	5	1.00						Agree		
Paralichthys lethostigma	Southern Flounder	5	1.00						Agree		Agree
Opisthonema oglinum	Atlantic Thread Herring	33	0.97	0.03					Agree		Agree
Peprilus paru	Harvestfish	19	0.95	0.05							
Cynoscion regalis	Atlantic Weakfish	24	0.92	0.08					Agree		Agree
Menticirrhus saxatilis	Northern Kingfish	9	0.89	0.11					Agree		Agree
Symphurus plagiusa	Blackcheek Tonguefish	9	0.89	0.11					Agree		Agree
Galeichthys felis	Sea catfish	8	0.88	0.13							
Larimus fasciatus	Banded Drum	8	0.88	0.13					Agree		Agree
Torpedo andersoni	Florida Torpedo	7	0.86			0.14					
Scophthalmus aquosus	Windowpane	20	0.85	0.15					Agree		Agree
Orthopristis chrysoptera	Pigfish	19	0.84	0.16					Agree		Agree
Chaetodipterus faber	Atlantic Spadefish	30	0.83	0.17					Agree		Agree
Rypticus saponaceus	Greater Soapfish	5	0.80	0.20							
Stenotomus chrysops	Scup	19	0.79	0.21					Agree	Agree	Agree
Pomatomus saltatrix	Bluefish	28	0.79	0.14		0.07			Agree		Agree

Table 3.4 continued. Common fish by bathymetry zones based on USFWS vessel data. For each species the table shows the total number caught followed by the proportion of the total found in each depth zone. This table shows species with more than 5 individuals and >66% of their locations in one depth zone. The last two columns indicate whether the patterns in the NOAA, MARMAP trap (MM Trap) and MARMAP trawl (MM Trawl) data agree with the vessel data.

Scientific Name	Common Name	Total	0-30 m	30-70 m	70-200 m	200-600 m	600-1000 m	1000+	NMFS	MM Trap	MM Trawl
Scomberomorus maculatus	Spanish Mackerel	18	0.78	0.17		0.06			Agree		Agree
Micropogon undulatus	Atlantic Croaker	48	0.75	0.21	0.04						
Sphoeroides maculatus	Northern Puffer	16	0.75	0.13	0.06	0.06			Agree	Agree	Agree
Seriola zonata	Banded Rudderfish	14	0.71	0.14		0.14			Agree		Agree
Leiostomus xanthurus	Spot	46	0.70	0.11	0.11	0.04		0.04	Agree		Agree
Paralichthys dentatus	Summer Flounder	36	0.69	0.25				0.06	Agree		Agree
Alectis ciliaris	African pompano	19	0.68	0.21	0.05	0.05					
Raja eglanteria	Clearnose Skate	28	0.68	0.21	0.11				Agree		Agree
Ogcocephalus radiatus	Polka-dot batfish	8		1.00							
Balistes carolinensis	Grey trigger fish	7		1.00							
Apogon maculatus	Flamefish	5		1.00					Disagree		
Mycteroperca bonaci	Black Grouper	5		1.00					Agree		
Bathystoma rimator	Tom-tate	10	0.10	0.90							
Eucinostomus argenteus	Spotfin Mojarra	6	0.17	0.83					Disagree		Disagree
Fistularia petimba	Red Cornetfish	6		0.83	0.17				Agree		Agree
Prionotus ophryas	Bandtail Searobin	6		0.83	0.17				Agree		Agree
Equetus lanceolatus	Jackknife-Fish	23	0.17	0.83					Agree		Agree
Chaetodon sedentarius	Reef Butterflyfish	15	0.13	0.80	0.07				Agree		Agree
Holocanthus isabelita	Blue angelfish	10	0.10	0.80		0.10					
Apogon pseudomaculatus	Twospot Cardinalfish	5	0.20	0.80					Agree		Agree
Chromis enchrysura	Yellowtail Reeffish	5	0.20	0.80							Agree

Table 3.4 continued. Common fish by bathymetry zones based on USFWS vessel data. For each species the table shows the total number caught followed by the proportion of the total found in each depth zone. This table shows species with more than 5 individuals and >66% of their locations in one depth zone. The last two columns indicate whether the patterns in the NOAA, MARMAP trap (MM Trap) and MARMAP trawl (MM Trawl) data agree with the vessel data.

Scientific Name	Common Name	Total	0-30 m	30-70 m	70-200 m	200-600 m	600-1000 m	1000+	NMFS	MM Trap	MM Trawl
Lutjanus campechanus	Northern Red Snapper	14	0.14	0.79		0.07				Agree	
Sphoeroides spengleri	Bandtail Puffer	17	0.18	0.76		0.06			Agree		Agree
Sphoeroides dorsalis	Marbled Puffer	24	0.08	0.75	0.17				Agree		Agree
Trachurus lathami	Rough Scad	14	0.21	0.71		0.07			Disagree		Disagree
Lepophidium jeannae	Mottled Cusk-Eel	7		0.71	0.29				Disagree		Disagree
Psenes regulus	Spotted Driftfish	7	0.14	0.71	0.14						
Rhomboplites aurorubens	Vermilion Snapper	65	0.22	0.69	0.06	0.03			Agree	Agree	Agree
Trachinocephalus myops	Snakefish	34	0.26	0.68	0.03	0.03			Agree		Agree
Ancylopsetta dilecta	Three-Eye flounder	7			0.86	0.14			Agree		Agree
Antennarius radiosus	Big-eyed frogfish	6		0.17	0.83				Agree		
Pronotogrammus spp.	Bass (unidentified)	5		0.20	0.80						
Prionotus alatus	Spiny searobin	13			0.77	0.15	0.08		Agree		Agree
Zenopsis ocellata	John Dory	13	0.08		0.77	0.15					
Macroramphosus scolopax	Longspine snipefish	14	0.07	0.21	0.71						Agree
Chaetodon aya	Bank butterflyfish	10	0.10	0.10	0.70	0.10			Agree		
Laemonema barbatulum	Smallscale mora	41				1.00			Agree		Agree
Peristedion gracile	Slender searobin	20				1.00			Disagree		Disagree
Parasudis truculenta	Longnose greeneye	13				1.00			Agree		
Foetorepus agassizii	Spotfin dragonet	10				1.00					

Table 3.4 continued. Common fish by bathymetry zones based on USFWS vessel data. For each species the table shows the total number caught followed by the proportion of the total found in each depth zone. This table shows species with more than 5 individuals and >66% of their locations in one depth zone. The last two columns indicate whether the patterns in the NOAA, MARMAP trap (MM Trap) and MARMAP trawl (MM Trawl) data agree with the vessel data.

Scientific Name	Common Name	Total	0-30 m	30-70 m	70-200 m	200-600 m	600-1000 m	1000+	NMFS	MM Trap	MM Trawl
Urophycis chesteri	Longfin hake	9				1.00			Agree		
Argyropelecus affinis	Slender hatchetfish	7				1.00					
Nezumia aequalis	Common Atlantic grenadier	6				1.00					
Chascanopsetta lugubris	Pelican flounder	5				1.00					
Chlorophthalmus chalybeius	Greeneye	28				0.96	0.04				
Helicolenus dactylopterus	Blackbelly rosefish	48		0.02	0.02	0.96			Agree		Agree
Zenion hololepis	Dwarf dory	22				0.95	0.05				Agree
Chaunax pictus	Pink frogmouth	110	0.01	0.01		0.94	0.05				
Galeus arae	Roughtail catshark	47	0.04			0.94	0.02				
Gadella maraldi	Common gadela	14			0.07	0.93					
Polymetme corythaeola	Rendezvous fish	9				0.89	0.11				
Lophiomus sp.	Goosefish (unidentified)	19		0.05	0.11	0.84					
Diapterus spp.	Mojarra	11		0.09	0.09	0.82					
Sternoptyx diaphana	Diaphanous hatchetfish	16			0.06	0.81	0.13				
Glossanodon pygmaeus	Pygmy argentine	8			0.25	0.75					Disagree
Peristedion miniatum	Armored searobin	7			0.29	0.71					Agree

Table 3.5. Final bathymetry zones. Species are from Bullis and Thompson (1965). Numbers in parentheses indicate the total number of species found and the number of species with >66% of their locations in one depth zone.

		Depth	
		Zone	**Taxa (Examples to 350 m based on USFWS Vessel**
Depth (meters)	**0-30**	Infralittoral (Nearshore Shelf and Estuaries)	**Fish: (215 species / 99 restricted)** lookdown, Atlantic bumper, northern sennet, moonfish, southern stargazer, gaff topsail catfish, southern flounder, American shad, Atlantic menhaden Invertebrates: Atlantic brief squid, blue crab, fire sponge, green sea urchin, notched sand dollar, banded sea star, penaeid shrimp
	30-70	Shallow Circalittoral (Mid Shelf)	**Fish: (232 species / 71 restricted)** Examples: polka-dot Batfish, grey Trigger fish, flame fish, black grouper, sharp nose puffer, flying gurnard, black-winged sea robin, tom-tate Invertebrates: arrow squid, Atlantic surf clam, crusting bryzoan, hydranths, sponges, and mantis shrimp
	70-200	Deep Circalittoral (Outer Shelf & Shelf Edge)	**Fish: (185 species /40 restricted)** yellowfin bass, jambeau, broad flounder, highfin scorpionfish, spiny flounder, three-eye flounder, big-eyed frogfish, spiny searobin Invertebrates: Atlantic rock crab, boreal asterias, brown rock shrimp, Cancer crab coarsehand lady crab, *Oculina*, brown-striped brittlestar
	200-600	Shallow Mesobenthic (Shelf/Slope break - Charleston Bump)	**Fish: (251 species /152 restricted)** offshore hake, white hake, freckled skate, deepwater dab, fourbeard rockling, goosefish, slim flounder, fawn cusk-eel, spotted hake Invertebrates: northern shortfin squid, Jonah crab, cancer crab, rock shrimp, squat lobsters, *Lophelia pertusa*, black corals, glass sponges
	600-1000	Deep Mesobenthic (Blake Plateau)	**Fish: (56 species / 17 restricted)** Cuban pygmy skate, smooth-head, scaleless dragonfish, duckbill eel, lightfish, snake mackerel Invertebrates: Polychaetes , deepwater corals (*Lophelia* and *Enallopsammia)*
	1000 - 5000	Bathybenthic/ Abyssal	**Fish: (11/0)** Not well sampled. Species with some proportion caught in this zone include: Pacific snake-eel, dusky flounder, spotted hake, dolphin

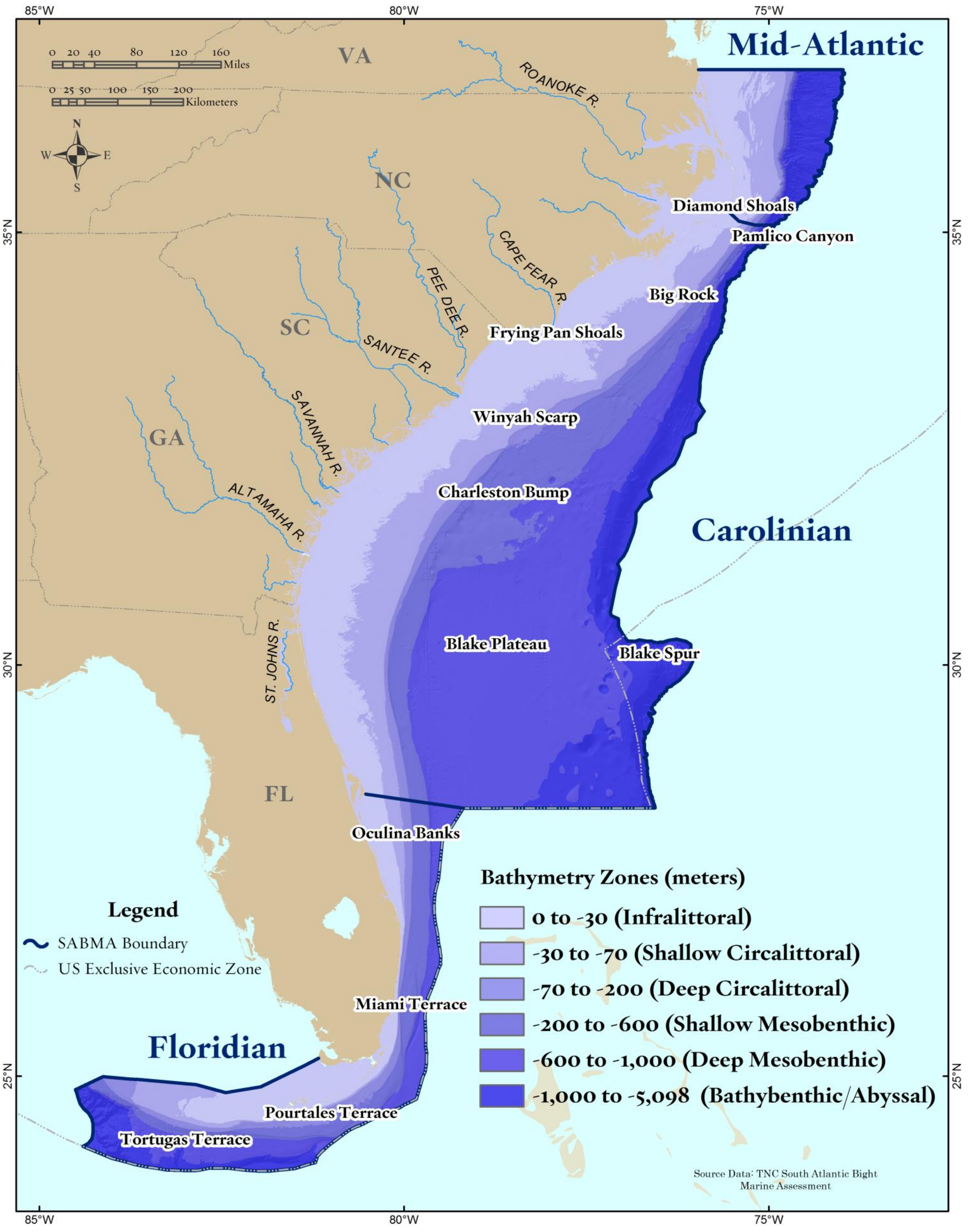
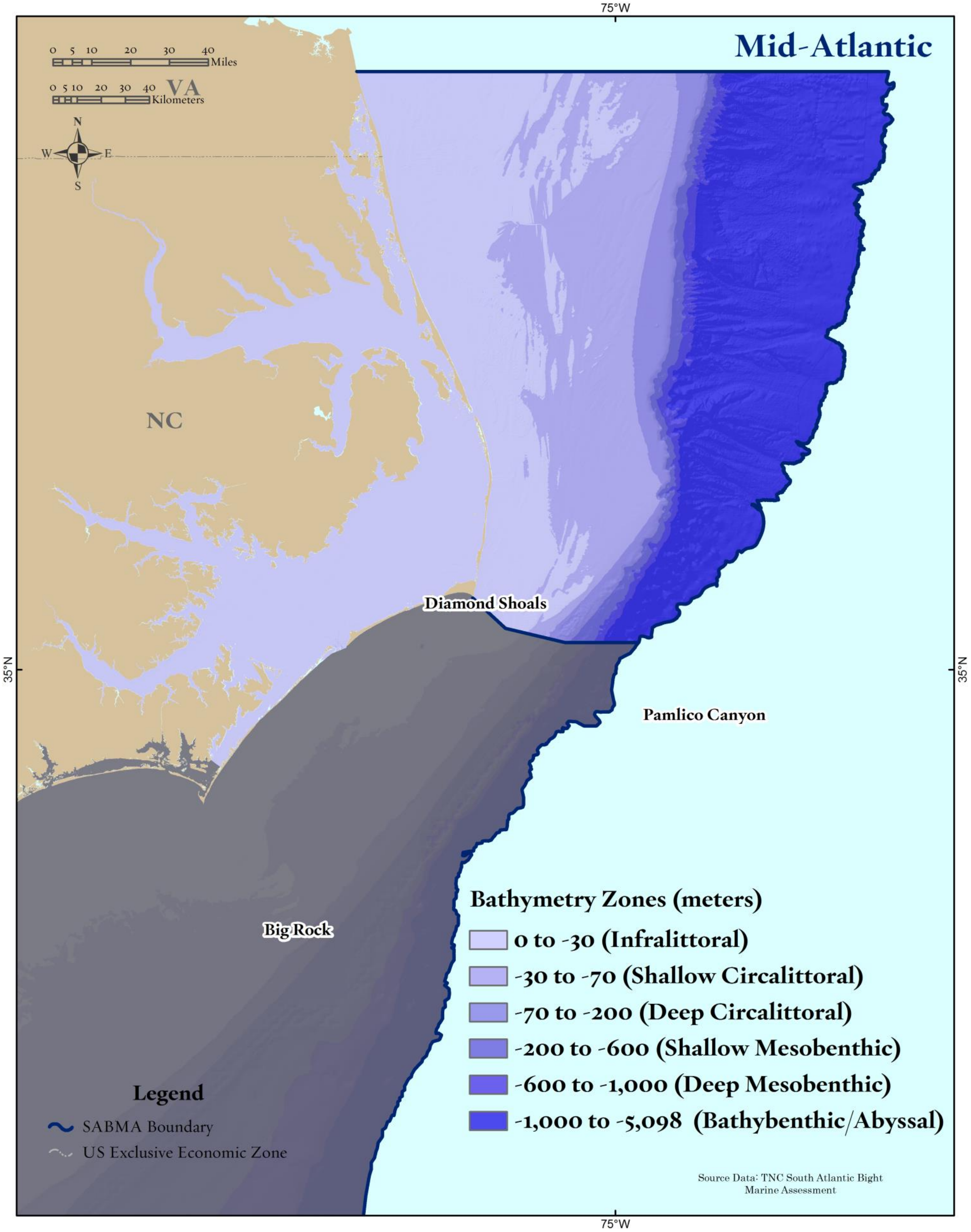
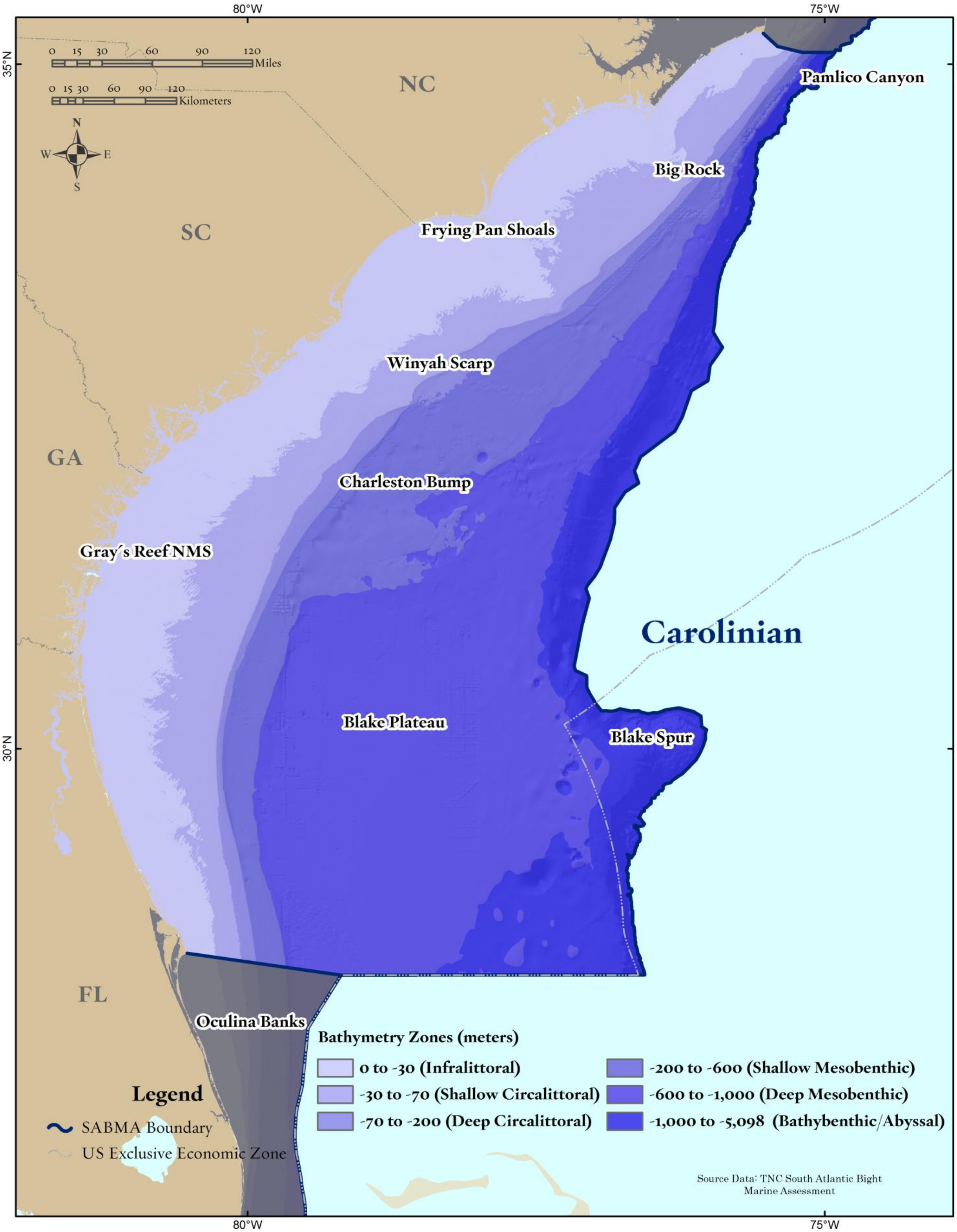


Figure 3.3. Depth zones of the South Atlantic Bight marine region. See subregional maps on following pages.



Source Data: TNC South Atlantic Bight Marine Assessment

Figure 3.4. Depth zones of the mid-Atlantic subregion



Source Data: TNC South Atlantic Bight Marine Assessment

Figure 3.5. Depth zones of the Carolinian subregion

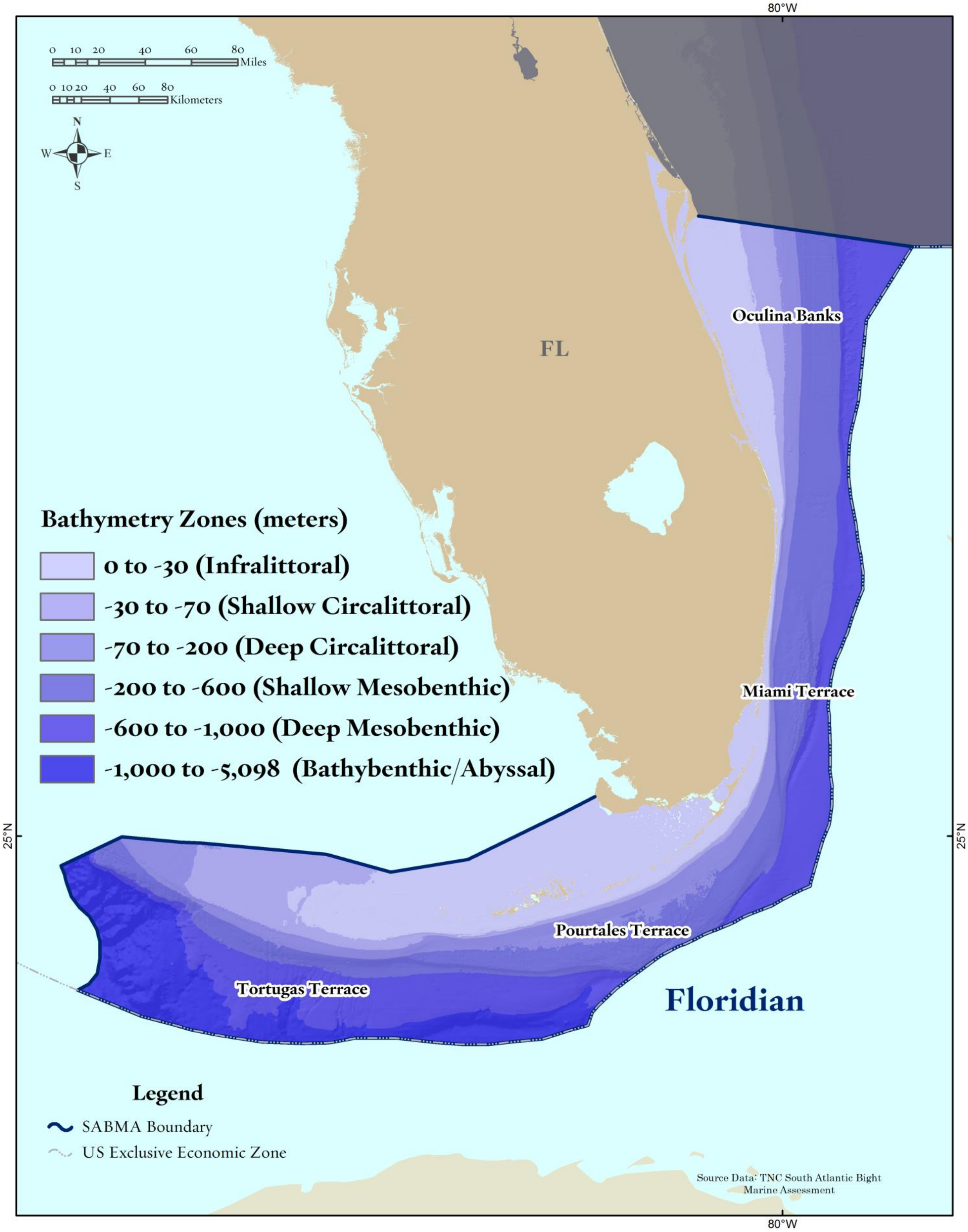


Figure 3.6. Depth zones of the Floridian subregion

Seabed Topographic Forms

Topography influences the distribution of oceanic processes and seafloor habitats. The South Atlantic seafloor is characterized by a variety of large and small scale geomorphic features. The wide, flat Continental Shelf is patterned with shoal fields, sediment waves, ridges, trenches, channels, and depressions. The oceanic region east of the shelf-slope break forms a deepwater basin marked by plateaus, terraces, canyons, slopes, and spurs. Our goal was to characterize and map seafloor topography in a systematic way relevant to the scale of distribution of seafloor organisms. The units that emerge from this analysis – the seabed forms – represent depositional and erosional environments that typically differ in fluvial processes, sediment types, and species composition (Wigley and Theroux 1981).

To develop the data layer of seabed forms, we started with the interpolated bathymetry surface, using new techniques to calculate the relative topographic position and degree of slope of each seafloor cell. From this information we described different seabed forms such as a flat surface raised above its surroundings (a shoal) or a narrow slope bottom surrounded by steep slopes (a canyon bottom). Mapping methods are described below and were based on Anderson et al. (2010) which were derived from Fels and Zobel (1995). Like the bathymetry data, cell resolution was 90 m^2 for most of the region, but 810 m^2 for the deepwater section of the Carolinian.

Relative Position

To derive relative topographic position of any given cell we evaluated the elevation differences between that cell and the surrounding cells within a specified search radius. For example, if the model cell was, on average, higher than the surrounding cells, then it was considered to be closer to the ridge top (a more positive seabed position value). Conversely, if the model cell was, on average, lower than the surrounding cells then it was considered closer to the slope bottom (a more negative seabed position value).

The relative position value was the mean of the distance-weighted elevation differences between a given point and all other model points within a specified search radius. The search radius was set at 61 cells after examining the effects of various distances to find a radius that would discern both subtle sand waves on the coastal shelf and deep canyons on the slope. Position was grouped into five classes:

CLASS NAME	Mean Elevation Difference
❖ Lowest	(< -30)
❖ Low	(-30 to -5)
❖ Mid	(-5 to 5)
❖ Upper	(5 to 30)
❖ Uppermost	(> 30)

Slope

Degree of slope was used to differentiate between steep features (slopes and canyons) and flat features (banks, shoals, depressions). Slope was calculated as the difference in elevation between two neighboring cells, expressed in degrees. After examining the distribution of slopes across the region, slopes were grouped according to the following thresholds:

MODEL SLOPE *(90 m^2 cell)*	**NAME *(Approximate actual slope)***
❖ 0° - 0.04°	Depression (0°)
❖ 0.04° - 0.08°	Flat
❖ 0.05° - 0.8°	Gentle slope
❖ 0.8° - 8.0°	Slope
❖ > 8.0°	Steep slope (35°-45°)

The cutoffs were averaged over a 90 m^2 cell or larger and thus do not correspond exactly with slope degrees calculated at a finer scale. For example, canyon walls reported as 35°-45° slope correspond to only > 8.0° category for the 90 m cells. We combined slope and relative position to create 30 possible seabed forms which were then simplified into eleven named types from “upper flat” to “low scarp” (Table 3.6 and Table 3.7, Figures 3.7-3.10).

Each individual cell was assigned to a unique seabed form. Visually, groups of seabed forms may cluster to define larger scale forms; for example, the shelf shows a marked ridge-and-swale topography. At the shelf break, the seabed forms delineate a discontinuous series of sloped terraces that drop off into steep slopes with submarine canyons, or to the flat Blake Plateau, or deep Straits of Florida.

Relation to CMECS

The seabed topographic units are the basic building blocks of the CMECS “Geoforms” (Appendix 1). For instance, the geoform named “ridge” is composed of an upper position flat flanked by steep slopes on two sides, while the reverse geoform, “canyon” is characterized by a low position flat flanked by two steep slopes. Creating named geoforms out of the various seabed topographic forms is a step that we have not completed, but readers will recognize many characteristic geoforms on the accompanying maps because the seabed forms aggregate to produce larger recognizable features.

Table 3.6. Shelf Region: cutoffs and thresholds for the seabed forms. These forms were created using 90 meter bathymetry data.

Section	SLOPE CATEGORY (90 m)	POSITION	NAME
Shelf	Flat	Highest	Upper Flat
Shelf	Flat	High	Upper Flat
Shelf	Flat	Mid	Mid Flat
Shelf	Flat	Low	Low Flat
Shelf	Flat	Lowest	Depression
Shelf	Sloping	Highest	Upper Slope
Shelf	Sloping	High	Upper Slope
Shelf	Sloping	Mid	Mid Slope
Shelf	Sloping	Low	Low Slope
Shelf	Sloping	Lowest	Bottom Slope
Shelf	Steeply Sloping	Highest	Upper Scarp
Shelf	Steeply Sloping	High	Upper Scarp
Shelf	Steeply Sloping	Mid	Mid Scarp
Shelf	Steeply Sloping	Low	Low Scarp
Shelf	Steeply Sloping	Lowest	Low Scarp

SEABED FORM	**CHARACTERISTIC GEOFORM**
❖ depression	*(shelf valley channel, depression, trench)*
❖ low flat	*(valley, flat)*
❖ mid flat	*(shelf , plateau, flat terrace)*
❖ high flat	*(bank, shoal, flat)*
❖ upper slope	*(ledge, slope)*
❖ mid slope	*(slope, sediment wave)*
❖ low slope	*(fan, terrace)*
❖ slope bottom	*(slope)*
❖ upper scarp	*(ledge)*
❖ mid scarp	*(canyon, scarp, steep slopes)*
❖ lower scarp	*(canyon, trench)*

Table 3.6. Oceanic Region: cutoffs and thresholds for the seabed forms. These oceanic forms were created using 810 m bathymetry data. We tried to match the patterns found in the 90 m data used for the shelf as closely as possible, but doing so often necessitated different cutoffs due to the coarse scale of the data.

SECTION	SLOPE CATEGORIES	POSITION	NAME
Deep	Flat	Highest	Upper Flat
Deep	Flat	High	Upper Flat
Deep	Gently Sloping	Highest	Upper Flat
Deep	Flat	Mid-position	Mid Flat
Deep	Gently Sloping	Mid-position	Mid Gentle Slope
Deep	Flat	Low	Low Flat
Deep	Flat	Lowest	Low Flat
Deep	Sloping	High	Upper Slope
Deep	Sloping	Highest	Upper Slope
Deep	Sloping	Mid-position	Mid Slope
Deep	Sloping	Low	Low Slope
Deep	Sloping	Lowest	Low Slope
Deep	Sloping	Lowest	Slope Bottom
Deep	Steeply Sloping	Highest	Upper Scarp
Deep	Steeply Sloping	High	Upper Scarp
Deep	Steeply Sloping	Mid-position	Mid Scarp
Deep	Steeply Sloping	Low	Low Scarp
Deep	Steeply Sloping	Lowest	Low Scarp
Deep	Vertical	Highest	High Ledge
Deep	Vertical	High	High Ledge
Deep	Vertical	Mid-position	Mid Ledge
Deep	Vertical	Low	Canyon Bottom
Deep	Vertical	Lowest	Canyon Bottom

SEABED FORM	**CHARACTERISTIC GEOFORMS**
❖ depression	(*shelf valley channel, depressions, trenches*)
❖ low flat	(*valley, flat)*
❖ mid flat	(*shelf , plateaus, flat terraces*)
❖ mid gentle slopes	*(flat)*
❖ high flat	(*bank, shoal, flat*)
❖ upper slope	(*ledge*)
❖ mid slope	(*slope, sediment wave*)
❖ low slope	*(fan, terraces)*
❖ slope bottom	*(slope)*
❖ upper scarp	*(ledge)*
❖ mid scarp	(*canyon, steep slope*
❖ lower scarp	*(canyon, trench)*
❖ high ledge	*(ledge)*
❖ mid ledge	*(ledge)*
❖ canyon bottom	*(canyon)*

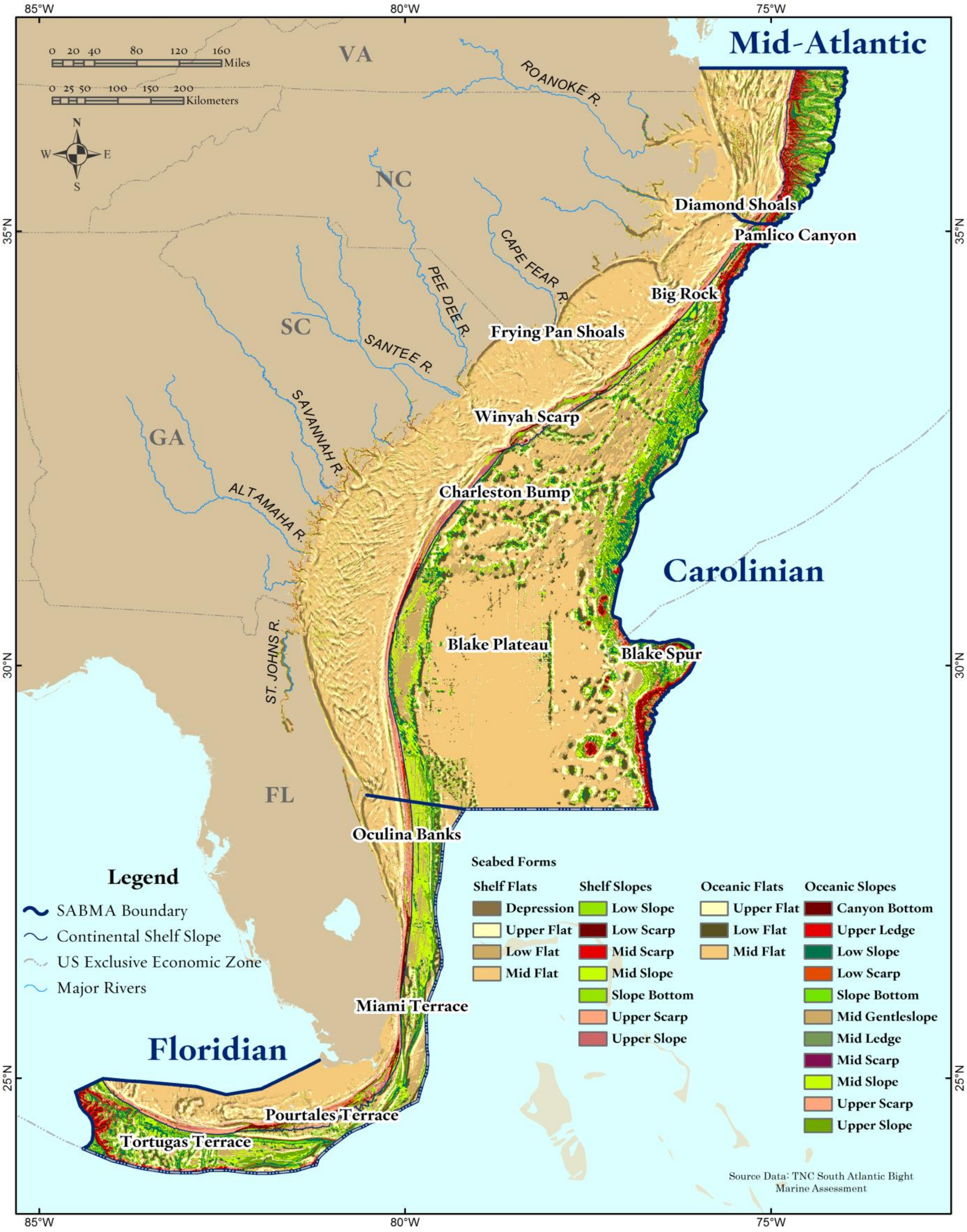


Figure 3.7. Seabed forms of the South Atlantic Bight marine region. See subregional maps on the following pages.

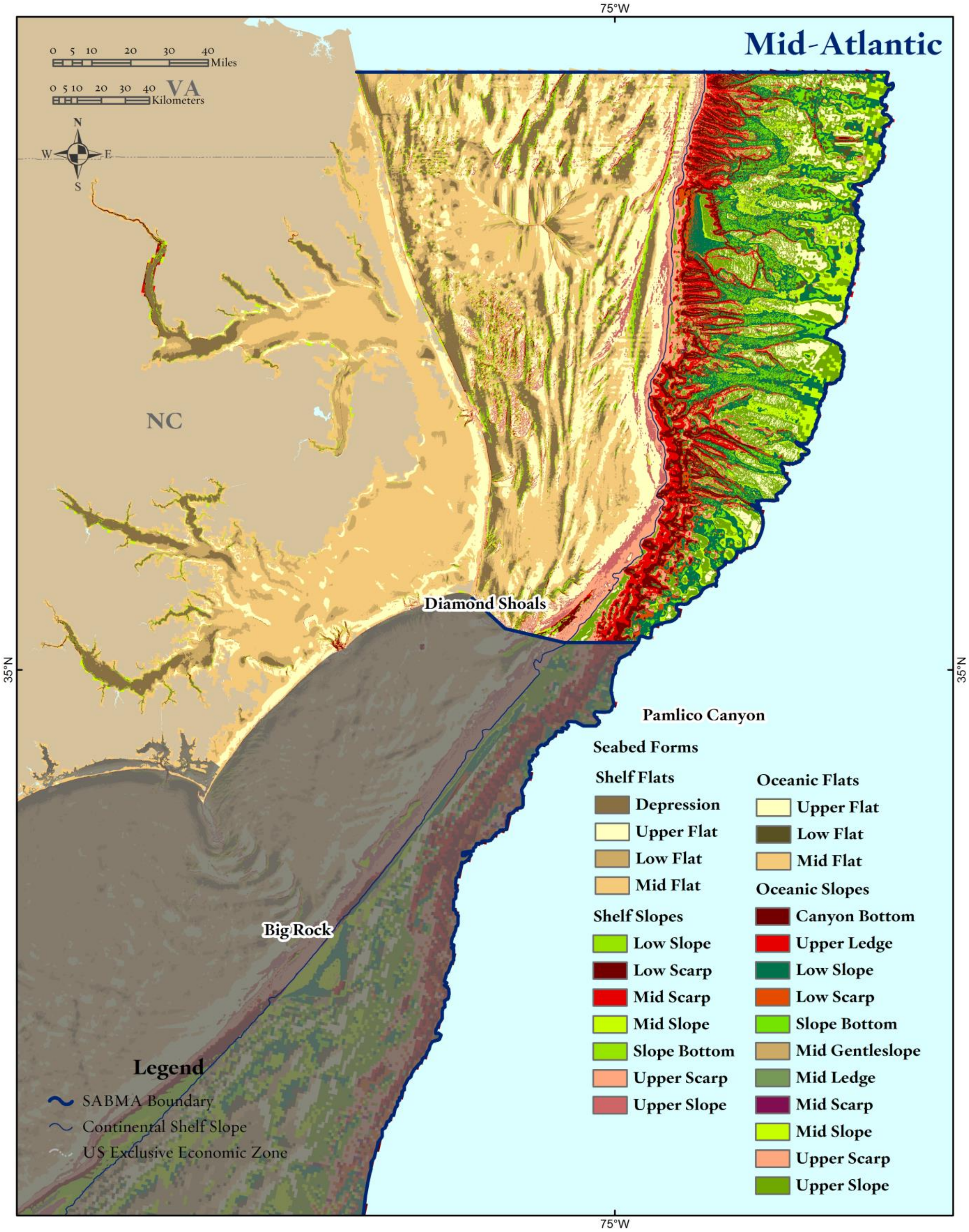


Figure 3.8. Seabed forms of the mid-Atlantic subregion

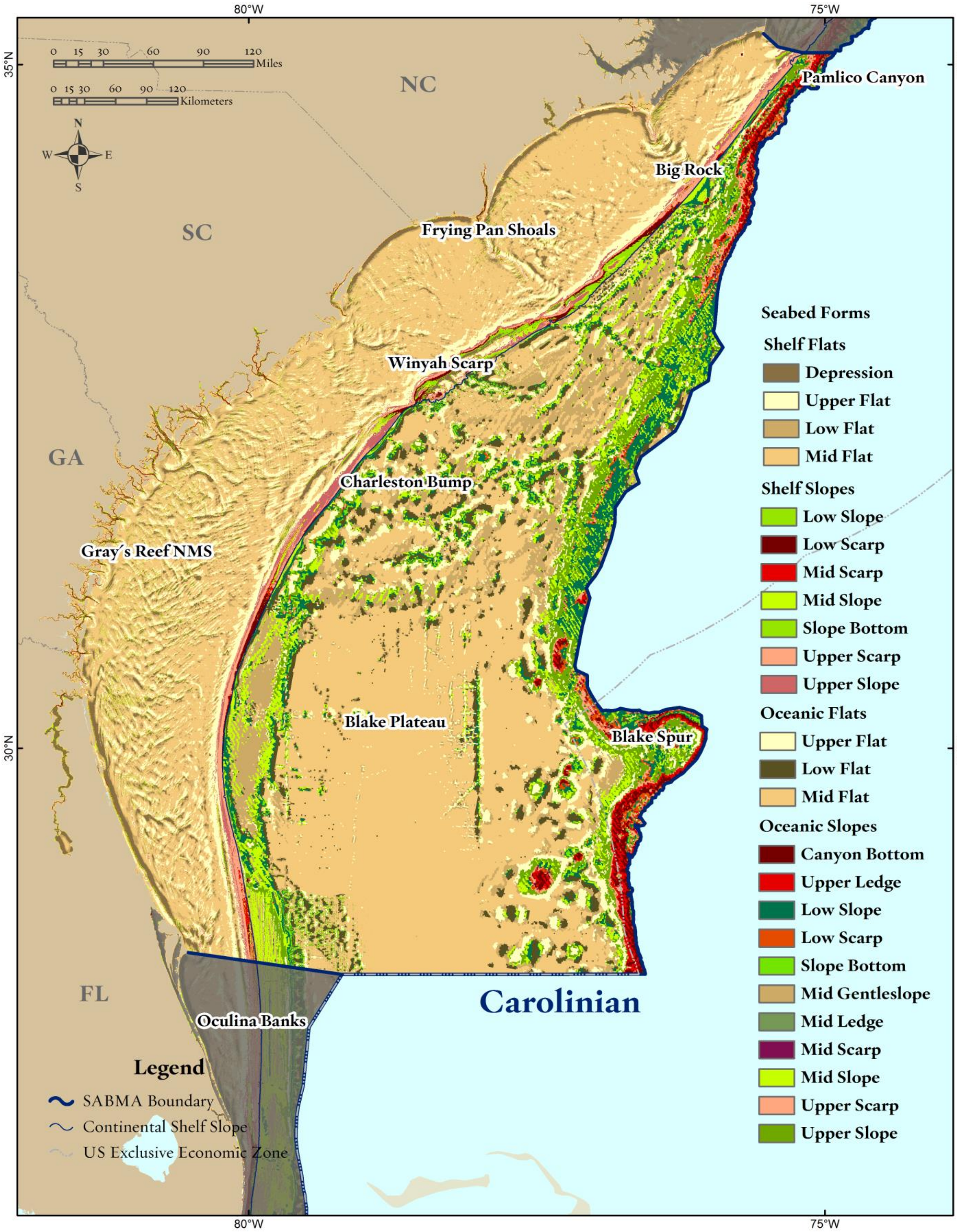


Figure 3.9. Seabed forms of the Carolinian subregion

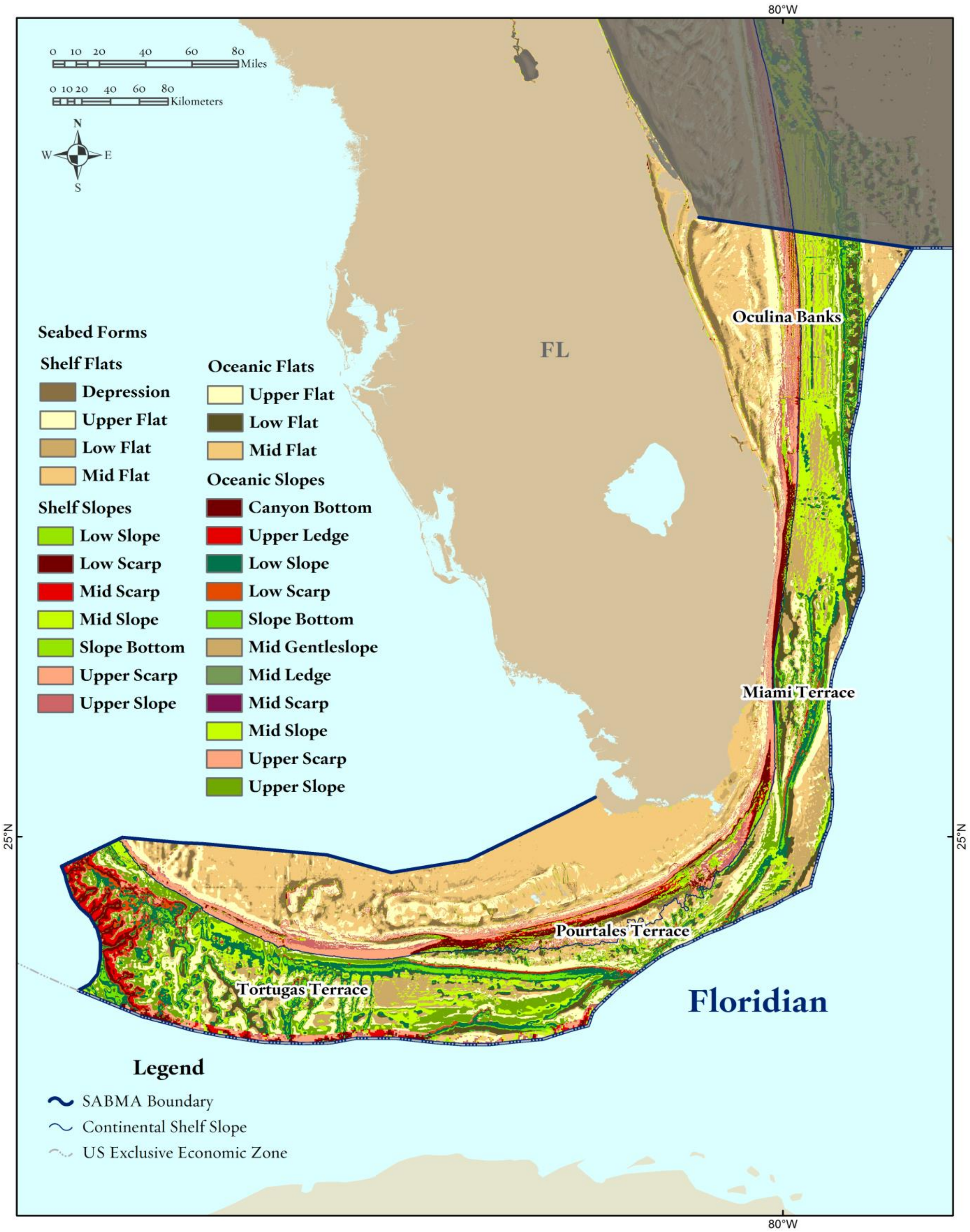
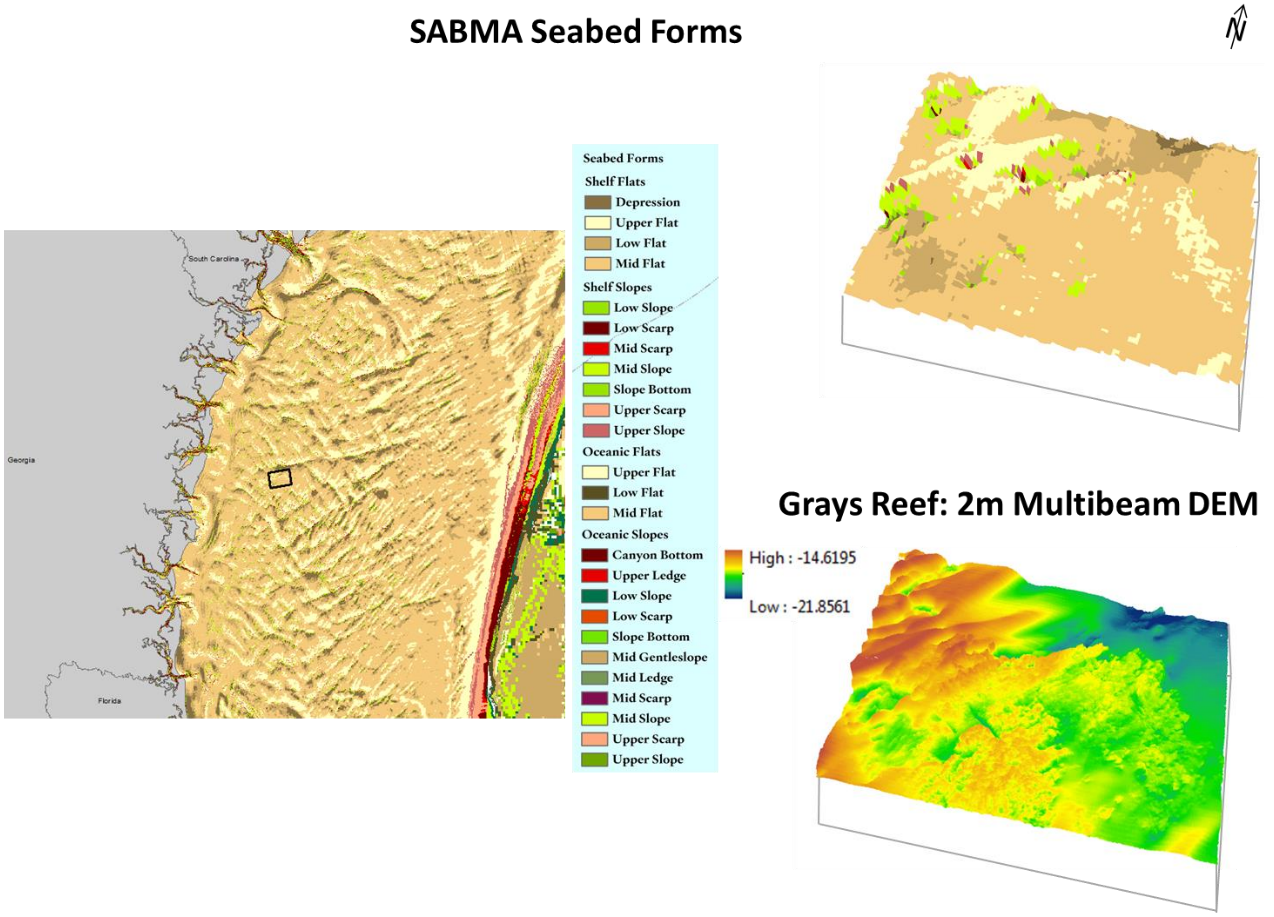


Figure 3.10. Seabed forms of the Floridian subregion

Comparison of the 90 m Seabed forms with Multibeam Data

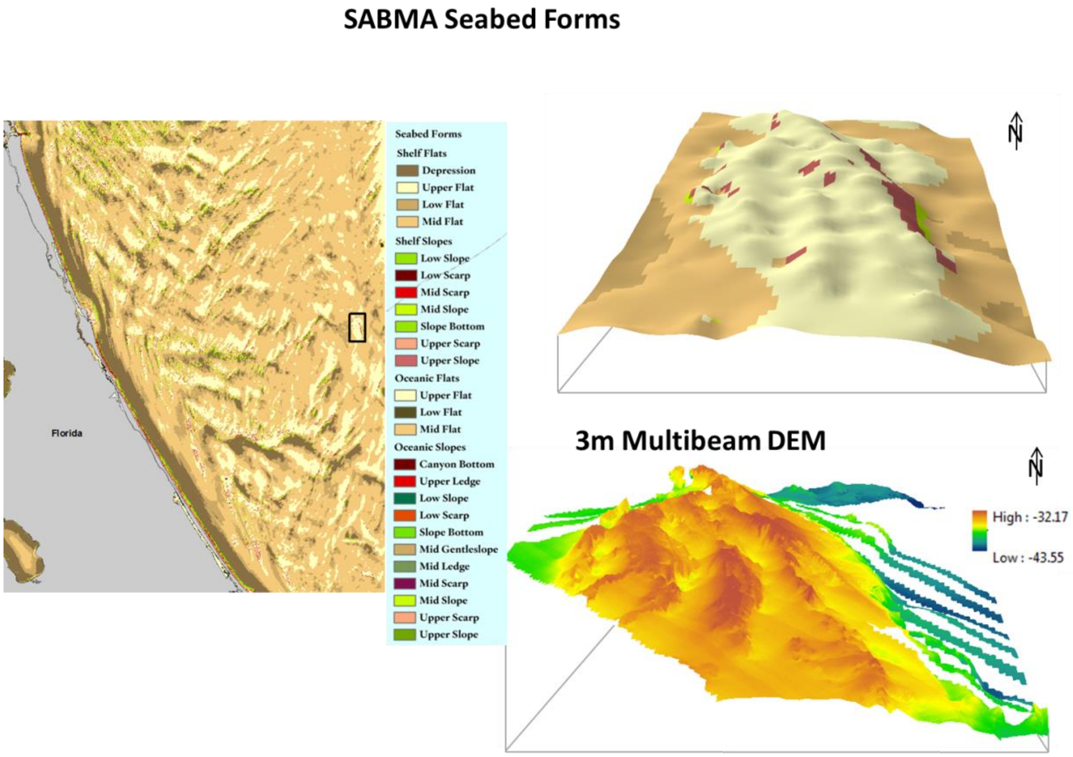
To understand the strengths and limitations of the seabed form dataset we examined four test areas where we had fine scale 1-4 m Digital Elevation Models (DEM) created from multibeam bathymetric data (Figure 3.11-3.14).

The figures compare the seabed forms developed at a 90 m resolution with the seafloor topography mapped at a 1 to 4 m resolution. In general, the 90 m resolution accurately maps the larger and more dramatic features but misses the small-scale topographic diversity. For example, for Gray's Reef (Figure 3.11), the low depressions (multibeam - blue) are picked up by the seabed forms (dark brown), and the upper flats (multibeam - red) are also picked up (white) along with the larger slopes (green and red). However, much of the fine patterning shown in the flats (multibeam - green) is lost in the 90 m seabed forms.



Source: NOAA Ship Whiting 2001

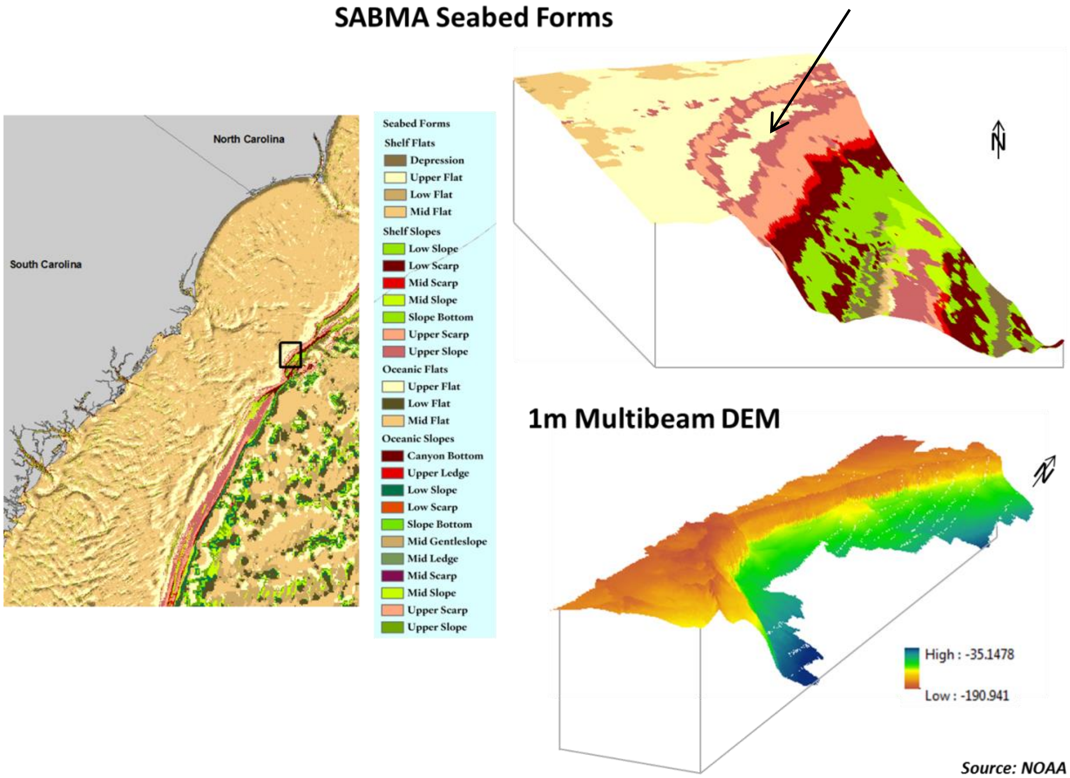
Figure 3.11. Multibeam data for Gray's Reef. The multibeam DEM shows a low depression (blue) with gentle slopes to the east (red) and steeper slopes to the north (green). These same features can be seen in the coarse 90 m seabed forms.


SABMA Seabed Forms

3m Multibeam DEM

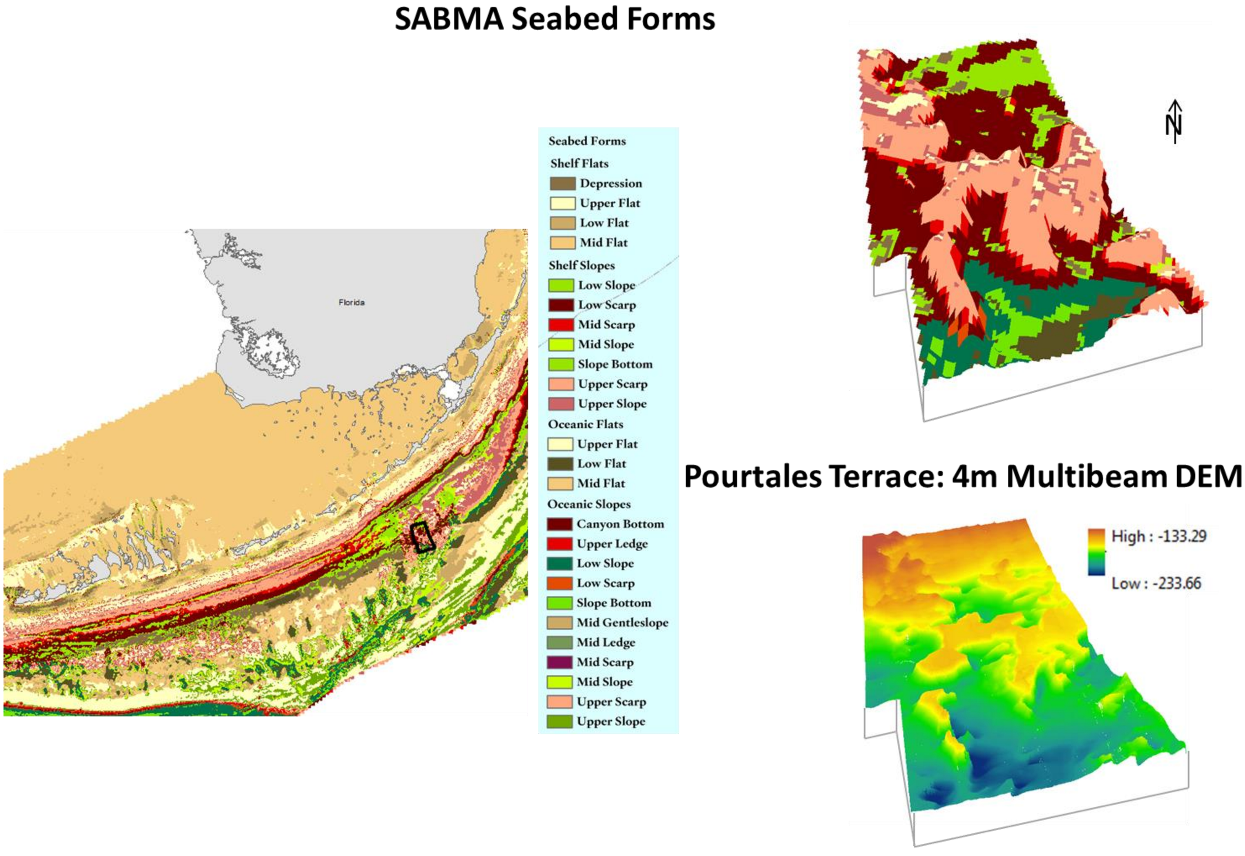
Source: NMFS SEFIS

Figure 3.12. Multibeam data for the outer edge of the Continental Shelf. The multibeam data shows a raised seabed form with small slopes that can also be seen in the 90 m data.



Source: NOAA

Figure 3.13. Multibeam data for the Shelf-Slope break. Where the multibeam shows a linear ridge, the seabed forms show a linear high position "flat" flanked by slopes on both sides. The linear ridge apparent in the multibeam data is mapped as a narrow linear flat flanked by slopes in the 90 m data (arrow). The steeper slopes off the shelf-slope break are visible at both scales.



Source: NOAA Ship Nancy Foster 2011 multibeam

Figure 3.14. Multibeam data for Pourtales Terrace. The multibeam data shows a large dissected plateau surrounded by slopes and this is also apparent in the seabed forms.

Seafloor Substrates

The South Atlantic seafloor is a mix of soft sediment and hardbottom that collectively offers a range of habitats for benthic invertebrates and demersal fish. Unconsolidated soft sediments of clay, silt, sand, and fine gravel form the majority of the seafloor while hardbottom formed by natural rock and reef substrates is distributed patchily throughout the region. The latter vary from flat limestone “pavements,” to small outcrops, to vertical slopes with up to 10 m of relief, and they are often hot spots of diversity. The hard substrate provides a stable surface for colonizing species such as algae, sponges, corals, and bryozoans, and the hard structure creates refuge habitat for fish. We mapped soft sediments using interpolations of sample points to create a continuous soft sediment map. To delineate hardbottom we used observed rock substrate points and reef locations in conjunction with the seabed forms to create a map of estimated hardbottom areas. The final substrate map overlays the hardbottom on the soft sediment. Methods used to map the two substrates are discussed separately below.

Soft Sediment

To create the soft sediment dataset, sediment samples for the United States portion of the region were obtained from usSEABED, an innovative system that brings an assortment of spatially-explicit quantitative and descriptive sediment data together in a unified database (Reid et al. 2005). The information includes textural, geophysical, and compositional characteristics of points collected from the seafloor. The data coverage extends seaward across the Continental Shelf and slope, and combines more than 150 different data sources containing over 200,000 data points for the Atlantic/Gulf and Caribbean regions. A unique feature of the database is the use of data mining and processing software to extend the coverage of information in areas where data is more descriptive than quantitative (details in Reid et al. 2005). The usSEABED dataset provided 9,965 usable points for the South Atlantic and we supplemented it with other non-overlapping point locations from three sources: Florida Fish and Wildlife Conservation Commission Fish and Wildlife Research Institute (FWRI) Fisheries-Independent Monitoring (FIM) Program (15,994 points), Carteret Sand Search Cores (155 points), and South Carolina Department of Natural Resources (3,821 points), for a total or 29,935 points (Figure 3.15). These datasets were used with permission from the original sources.

USSEABED (Number of Records = 9,965)

We compiled the Atlantic/Gulf and Caribbean datasets and extracted all points within 10 km of the South Atlantic Bight boundary, keeping both extracted and parsed points. We removed records that did not contain usable information on sediment grain size or that were rock substrate (Shepherd Code = Solid and grain size = -99). A large number of locations had multiple records associated with a single point. For these records we gave priority to extracted data (measured) over parsed data (qualitatively estimated). If multiple extracted points were given, we used the mode grain size, and if there was no mode we used the lowest extracted grain size value. We used the same criteria when only parsed data were present. The final dataset of 9,965 unique points was converted to a shapefile with two fields for grain size: Phi and millimeters.

FLORIDA FISH AND WILDLIFE CONSERVATION COMMISSION (FWRI 2013) FIM PROGRAM (N = 15,994)

Data were exported to csv files from SAS datasets with qualitative attributes for the grain sizes. We converted the dataset to a shapefile and retained only records that had latitude and longitude values and that were coded as Sand or Mud. We assigned the sand records a value of 0.239 mm (the average sand value of usSEABED sand points within 1 km of these points). We assigned the mud records a value of 0.0025 mm which is the break point between clay and silt classes on the Wentworth scale (Wentworth 1922). All locations with multiple records that had conflicting bottom type values (sand and mud) were removed and those that agreed were reduced to one record/location and used along with the other unique records for a unique location.

These locations were also checked against the usSEABED data to verify there were no duplicate points between the two datasets.

<u>2011 CARTERET SAND SEARCH CORES</u> (N = 155)
Description of data was provided as an Excel spreadsheet. We converted the data to a shapefile and confirmed that there were no duplicate points with the usSEABED data. We used the geology description field (sand or silt) that was available for most records, and assigned these a sediment size based on the average usSEABED value for the equivalent sediment type (e.g., sand or silt). Records with no substrate description were removed.

<u>SOUTH CAROLINA DEPARTMENT OF NATURAL RESOURCES/ARMY CORPS</u> (N = 3,821)
This dataset was for South Carolina only and contained a location (latitude and longitude) and Phi size for each record. We added a calculated value for millimeters and confirmed that there were no duplicate points with the usSEABED data.

The final substrate dataset consisted of 29,935 points. The density of data points was highly skewed toward nearshore environments with no points occurring for large sections of the Blake Plateau region (Figure 3.15). To highlight this issue, a Voronoi analysis was used to create a polygon around each data point such that all the space within each polygon was closer to the central point than to any other data point (Figure 3.16-3.17).

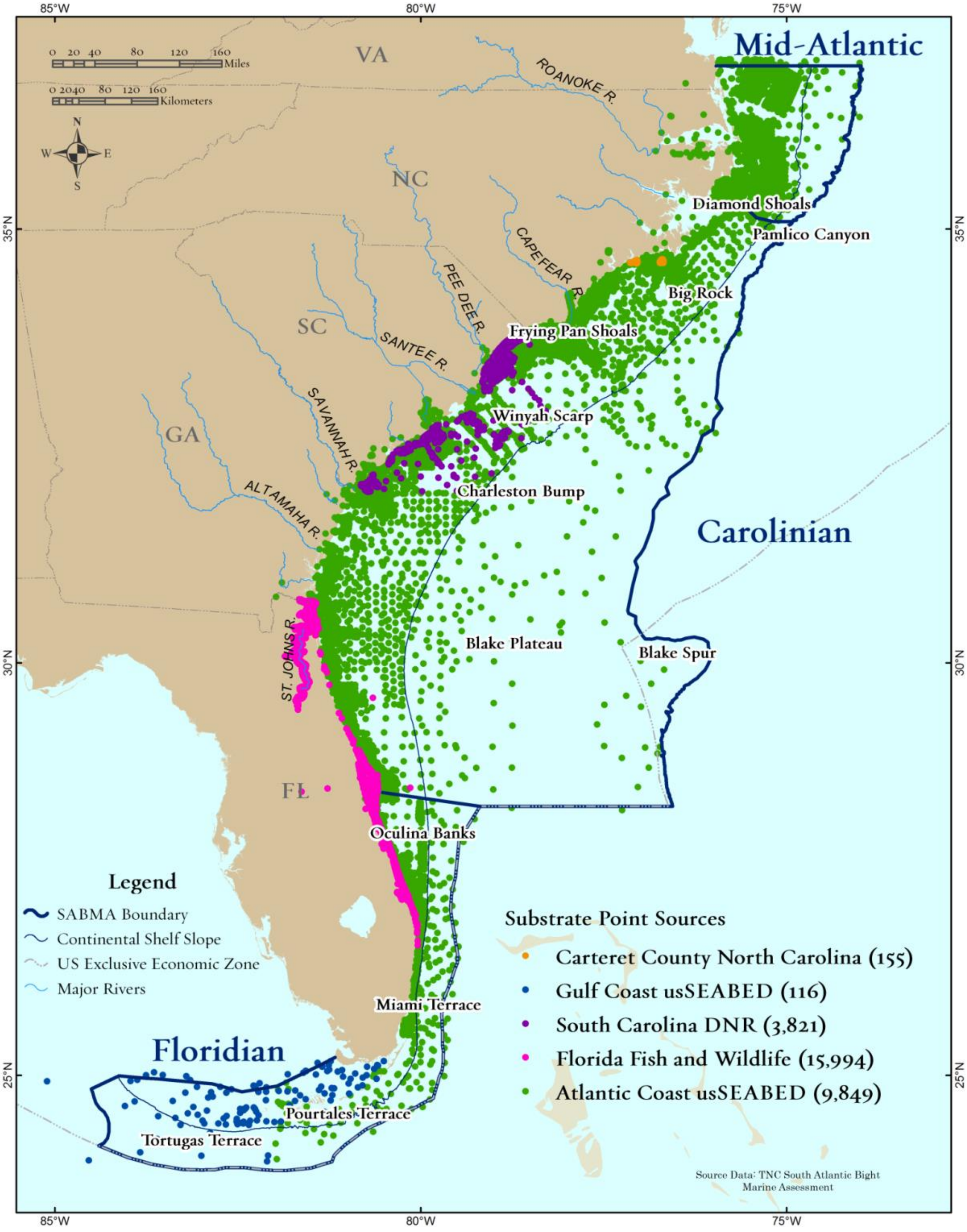
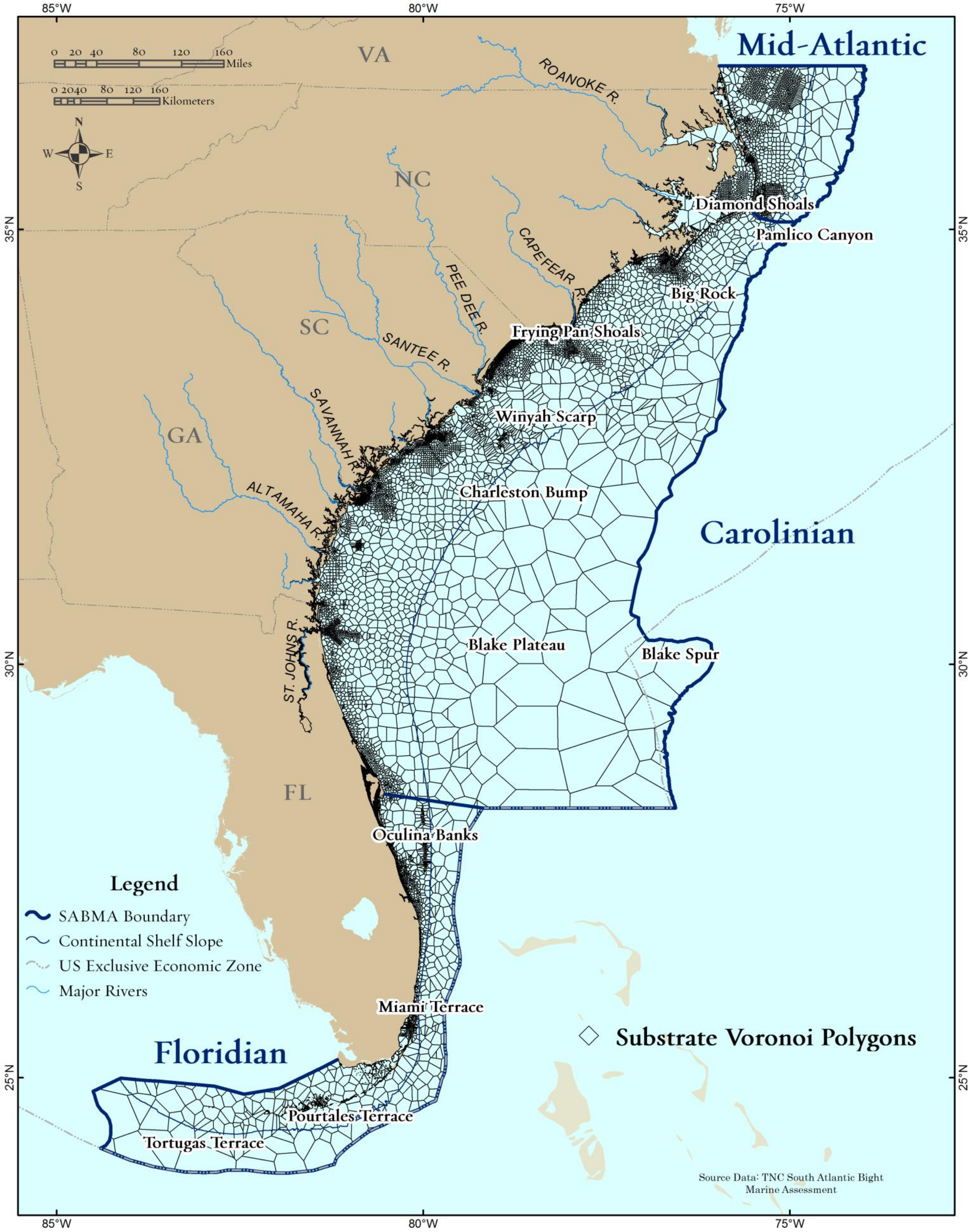


Figure 3.15. Distribution of the 29,935 soft sediment source data points in the South Atlantic Bight marine region



Source Data: TNC South Atlantic Bight Marine Assessment

Figure 3.16. Distribution of soft sediment data in the South Atlantic Bight marine region displayed as Voronoi polygons

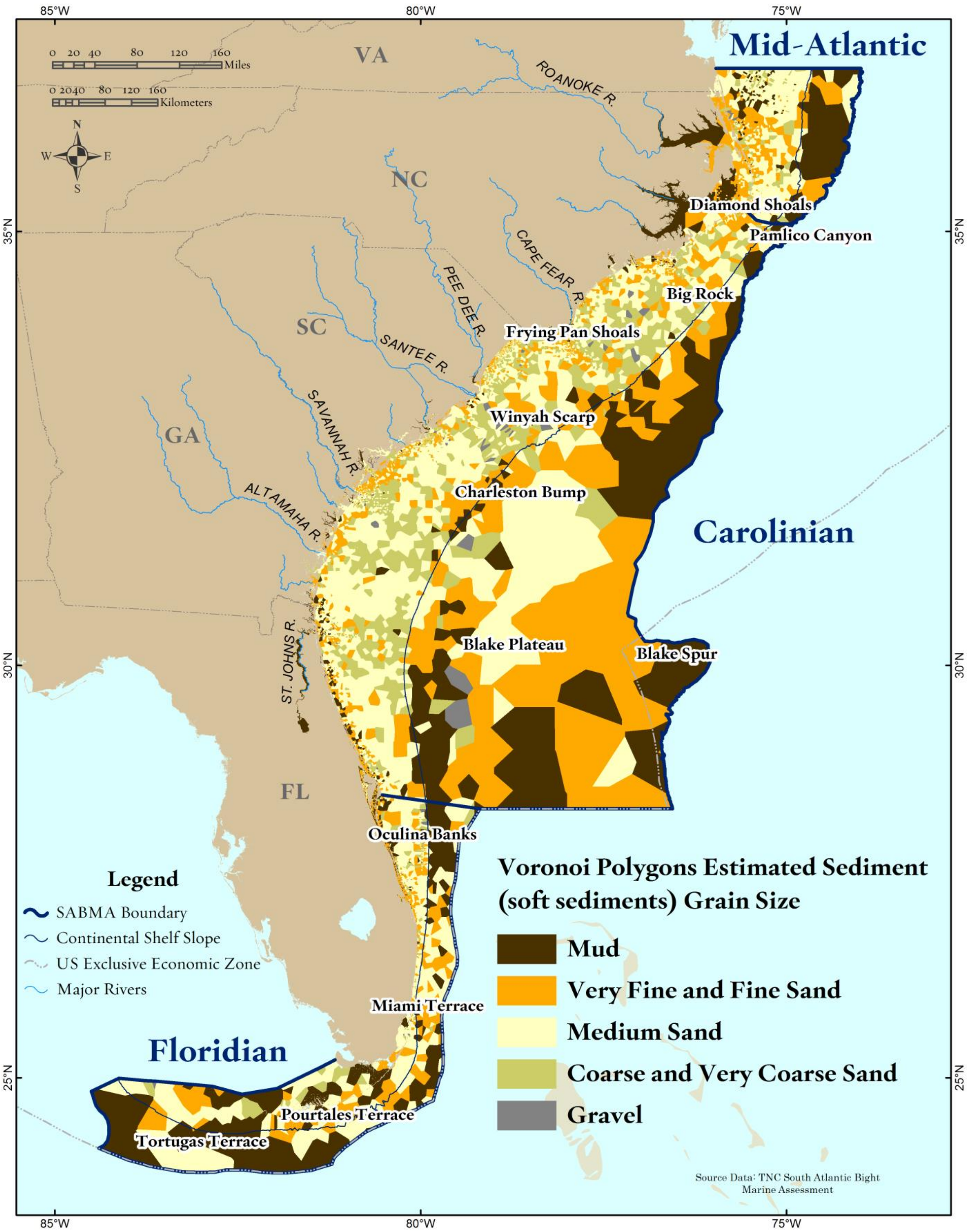


Figure 3.17. Distribution of soft sediment data in the South Atlantic Bight marine region displayed as Voronoi polygons colored by their sediment size class

We interpolated the sediment data using the following parameters: ordinary kriging, spherical semivariogram, variable search radius type using three points with no maximum distance, and an output cell size of 90 m. Kriging provides consistent results across areas that have been sparsely and densely sampled, and it provides an estimation of error (Figure 3.18). The resulting grids created by this method had a strong correlation with the Voronoi grids whereas using more than three points caused considerable smoothing and apparent warping of the raw data patterns. Thus the kriging interpolation resembled the Voronoi map with smoother surfaces and more realistic looking shapes.

GRAIN SIZE CLASSES

The ecology of unconsolidated sandy substrates that characterize the majority of the Continental Shelf is less studied than that of the uncommon (but more biologically diverse) rock substrates. However, the benthic fauna of sand and silt is a key component of seafloor ecosystems, playing a vital role in detrital decomposition, nutrient cycling, and energy flow to higher trophic levels (Hyland et al. 2006). None of the studies we reviewed (Frankenberg 1971; Frankenberg and Leiper 1977; Hopkinson 1985; Tenore 1985) related benthic composition directly to grain size but several focused on larger structure. For example, Kendall et al. (2005) separated flat sand plains from rippled sand on the Georgia Bight. On the shelf, water temperatures vary widely over the year, and the sediments are subject to strong tidal and wind-driven scour, thus most species are mobile and/or surface dwellers that can withstand unstable sediment conditions (Tenore 1985).

We used the Wentworth (1922) scale for the classification of sediments (Table 3.8). Our initial goal was to map all classes. However, because much of the sediment grain size data were derived from qualitative assessments with categorical information, we were unable to accurately distinguish the finer separations within any major category except sand. Even for sand, we could not determine some of the finer splits with confidence. Thus, we mapped the following five categories with confidence (Figures 3.19-3.22):

❖ Mud (Clay/Silt)	0 – 0.063 mm
❖ Very fine to fine sand	0.063 – 0.25 mm
❖ Medium sand	0.25 – 0.5 mm
❖ Coarse to very coarse sand	0.5 – 2 mm
❖ Gravel	> 2 mm

Results of the interpolations reveal the Continental Shelf alternates between medium sand and coarse sand in a regular pattern. Oceanic regions and shallow estuaries are both dominated by fine sands and silt (Figures 3.19-3.22).

Table 3.7. Grain size and sediment class names (Wentworth 1922)

Grain Size (mm)		Class
0	0.001	Fine clay
0.001	0.002	Medium clay
0.002	0.004	Coarse clay
0.004	0.008	Very fine silt
0.008	0.016	Fine silt
0.016	0.031	Medium silt
0.031	0.063	Coarse silt
0.063	0.125	Very fine sand
0.125	0.25	Fine sand
0.25	0.5	Medium sand
0.5	1	Coarse sand
1	2	Very coarse sand
2	4	Very fine pebbles (granules)
4	8	Fine pebbles
8	16	Medium pebbles
16	32	Coarse pebbles
32	86	Very coarse pebbles to cobbles

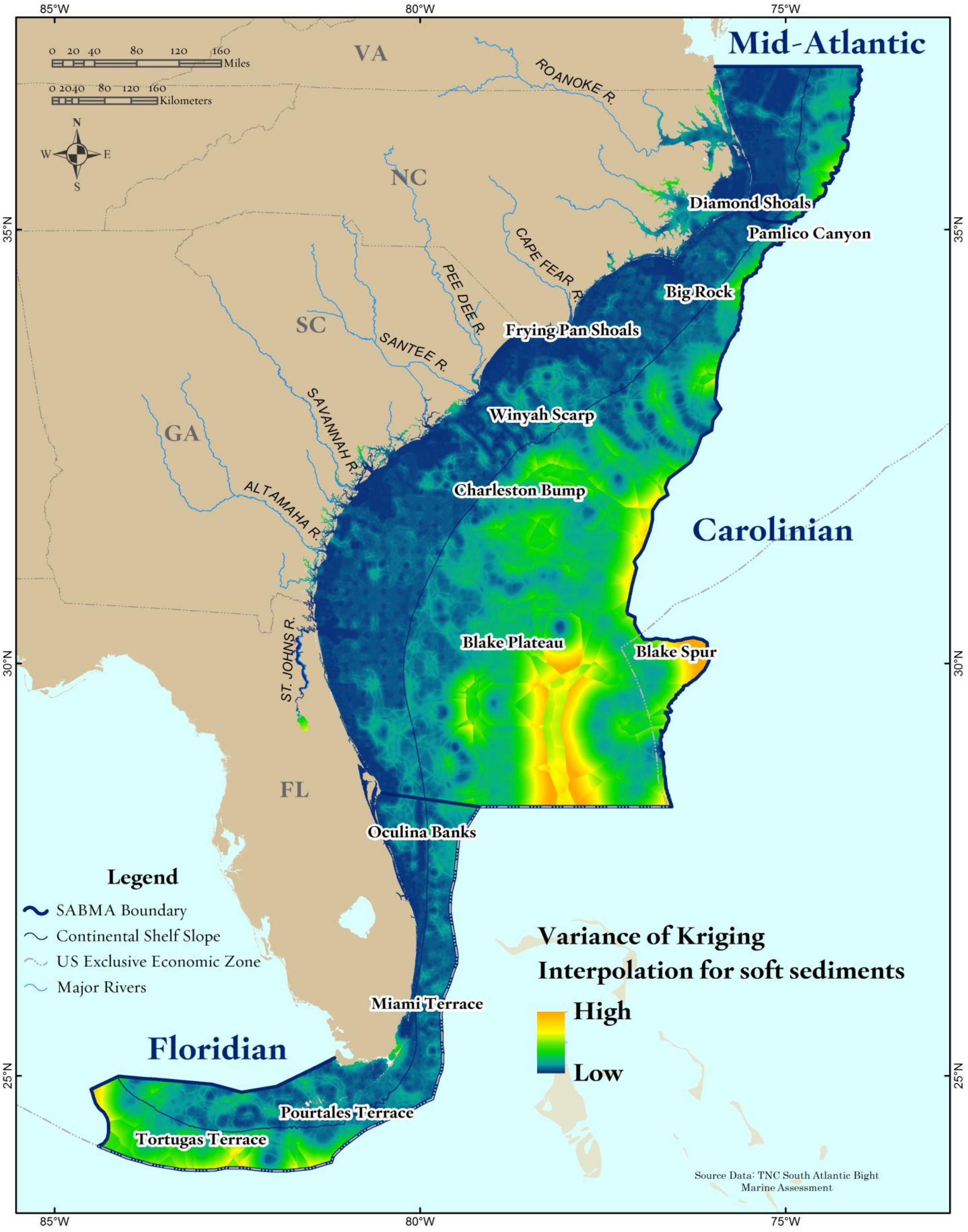


Figure 3.18. Kriging variance of soft sediments in the South Atlantic Bight marine region

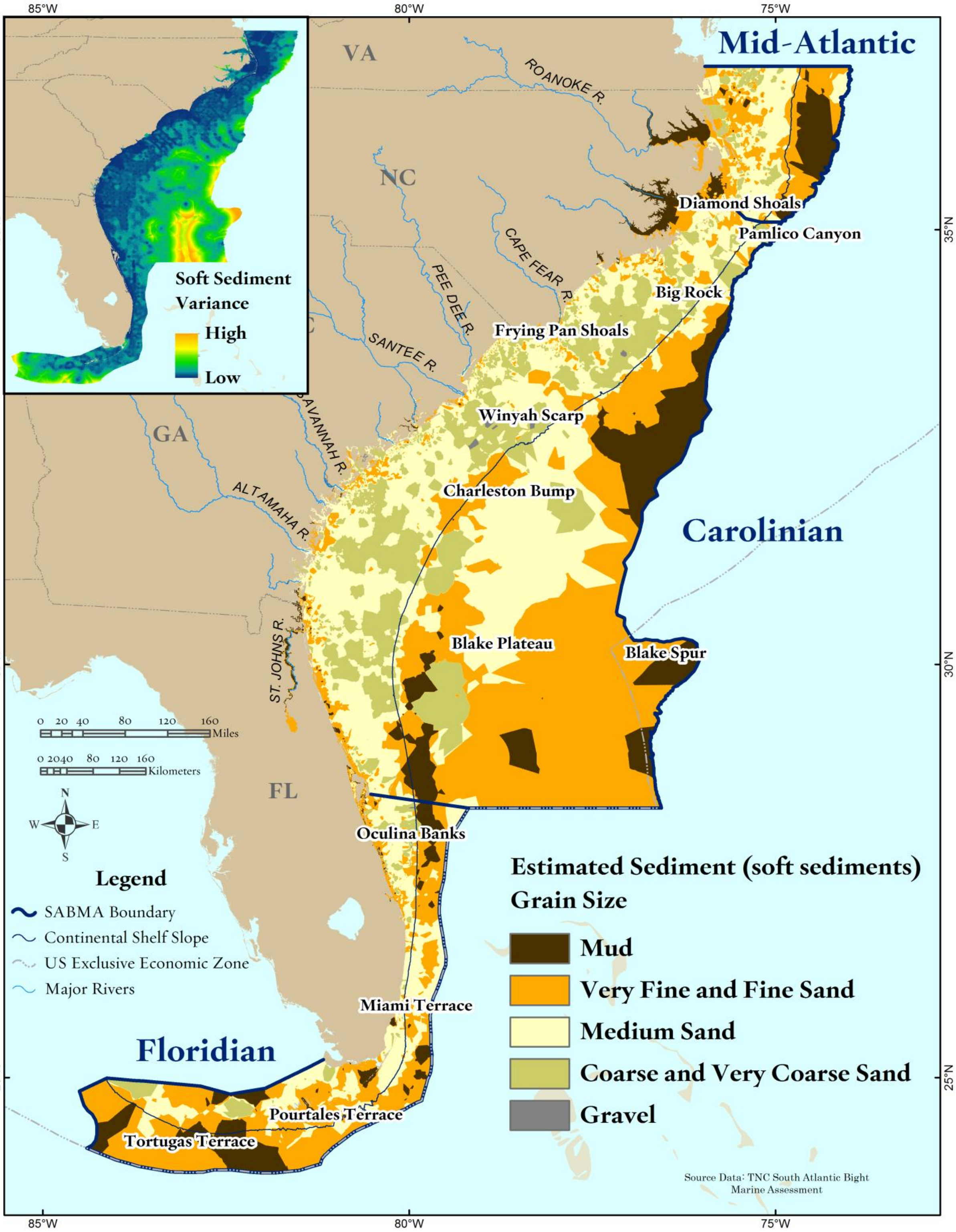


Figure 3.19. Distribution of soft sediments in the South Atlantic Bight marine region. See subregional maps on the following pages.

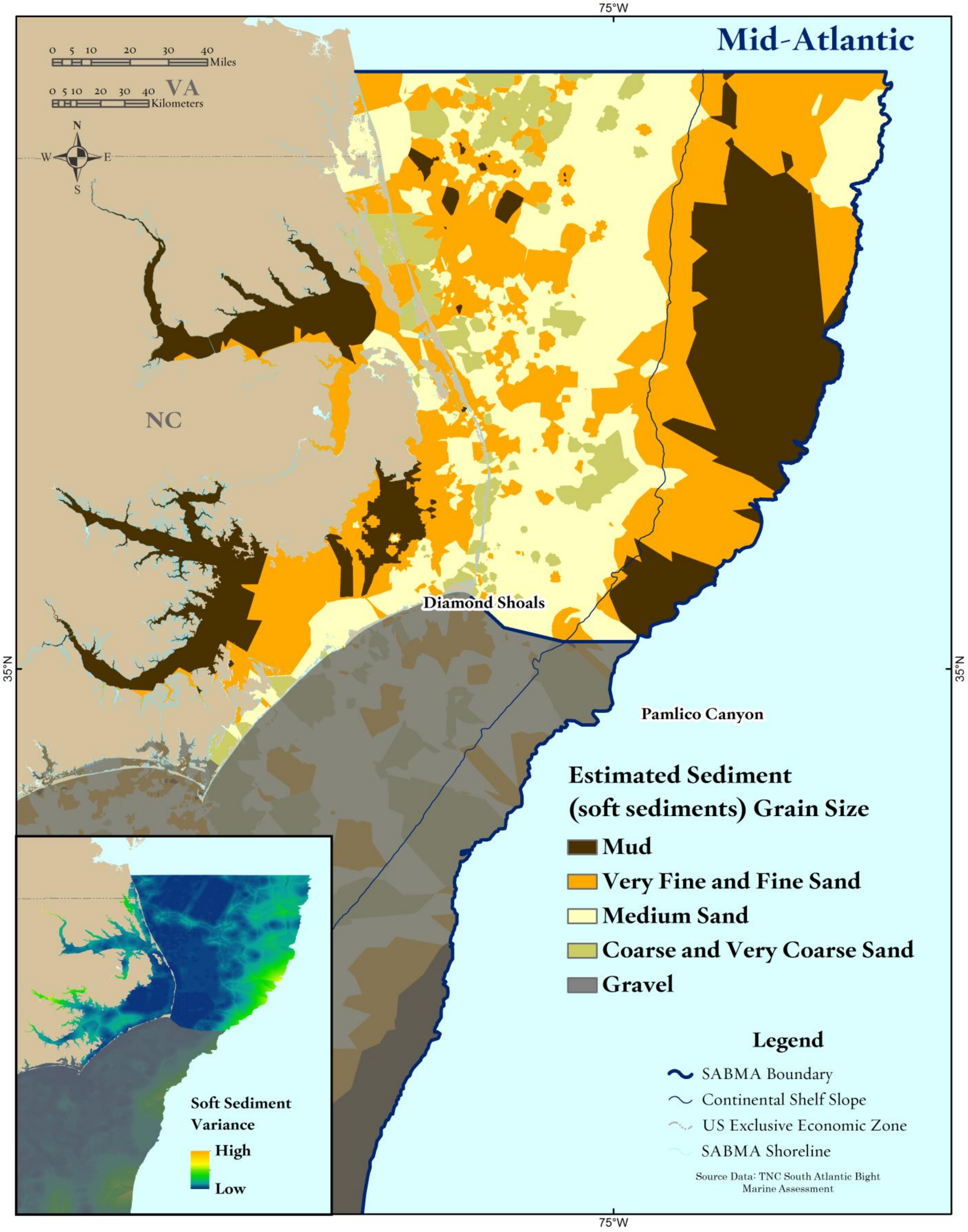
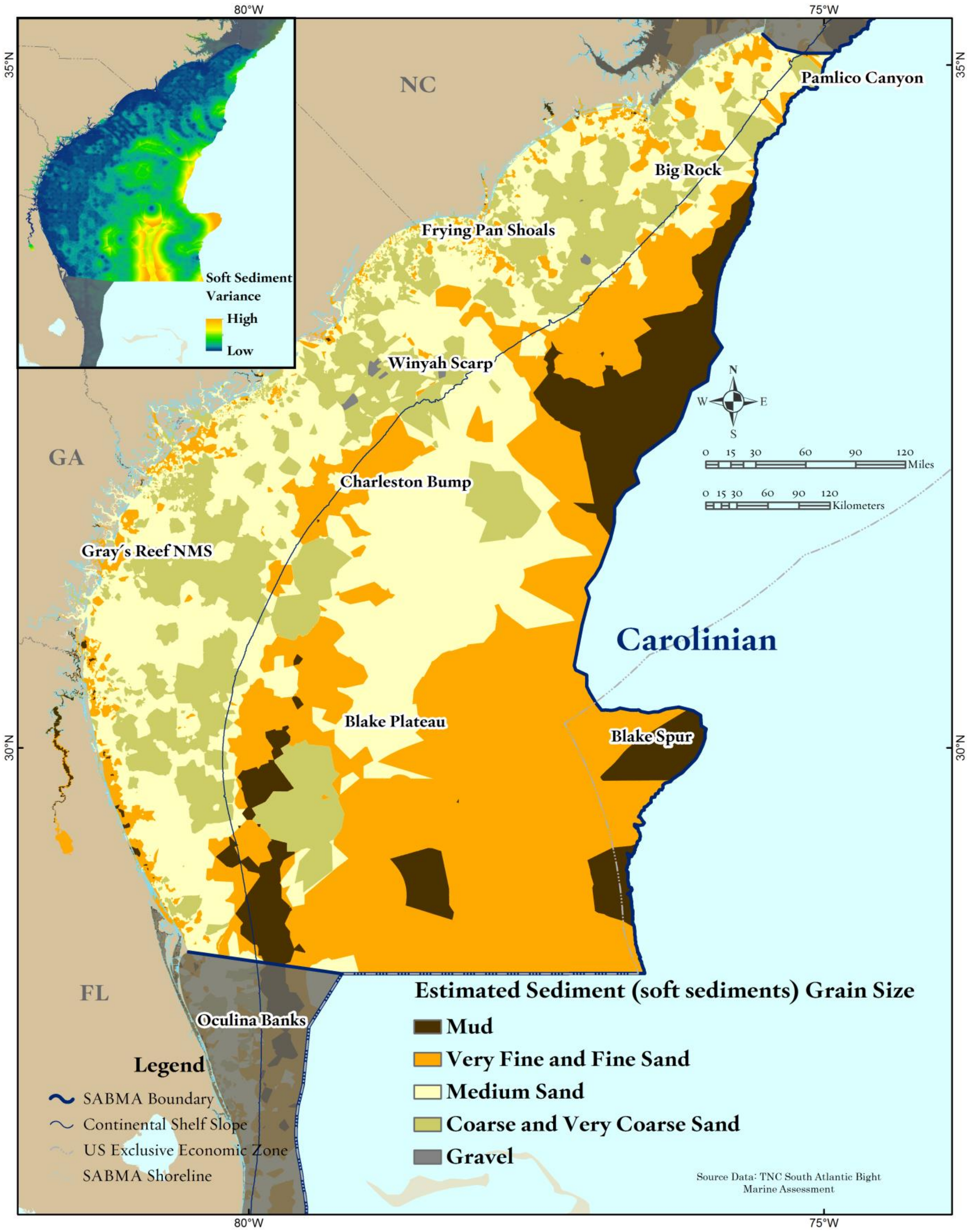


Figure 3.20. Distribution of soft sediments in the mid-Atlantic subregion



Source Data: TNC South Atlantic Bight Marine Assessment

Figure 3.21. Distribution of soft sediments in the Carolinian subregion

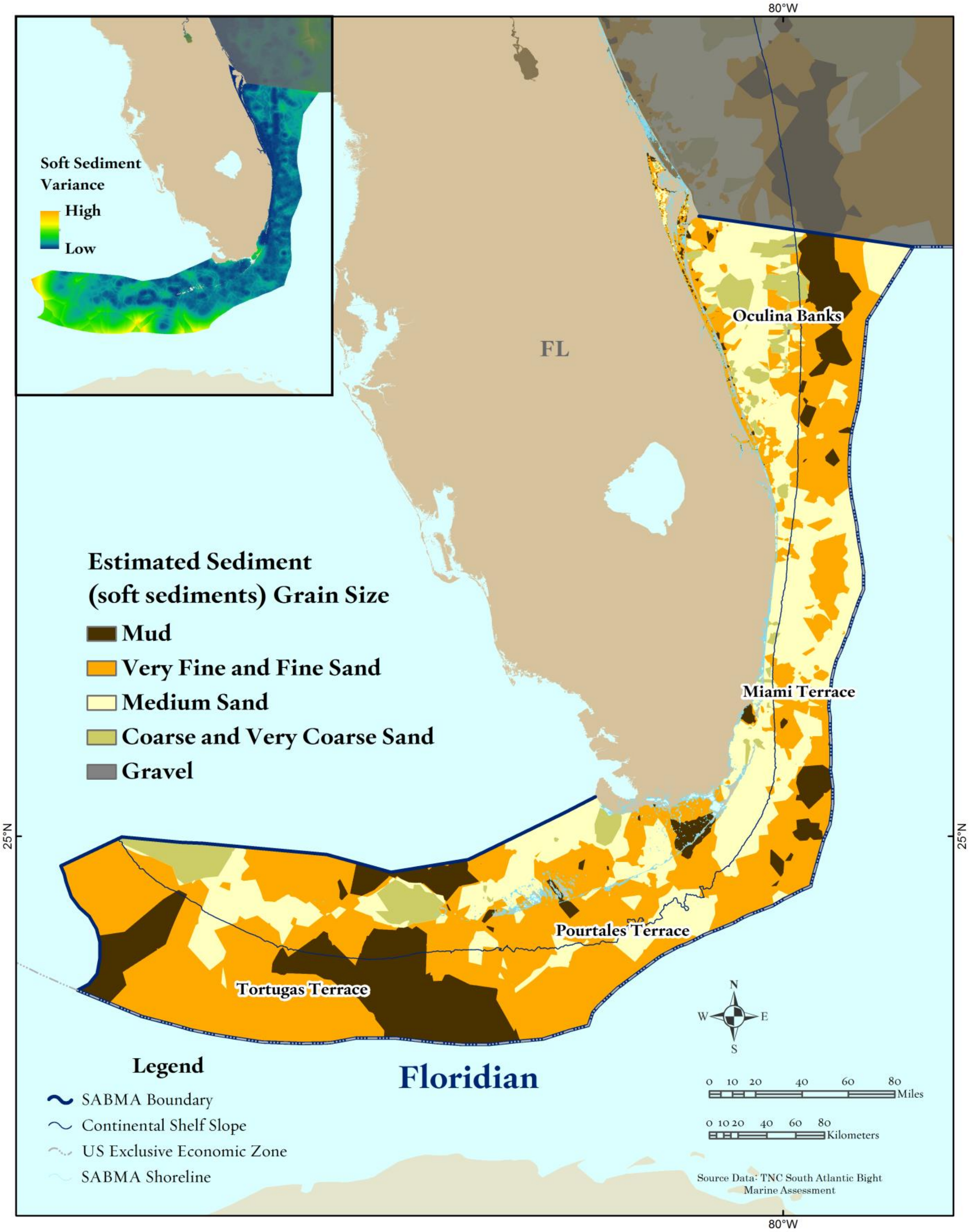


Figure 3.22. Distribution of soft sediments in the Floridian subregion

Hardbottom: Rock Substrate and Coral Reef

Natural rock substrates are areas of rock or consolidated sediment that provide stable substrate for colonization by corals, sponges, algae, bryozoans and other invertebrates. Colonized rock substrate, known as "rocky reef," "faunal beds" or "live-bottom" offers food and shelter to a large variety of organisms, from mollusks and annelids to sea turtles and demersal fish. The degree to which a reef is colonized varies with topography, currents, light availability, and location, but even uncolonized rocky reef is important as fish refuge habitat. Studies have shown that rock substrate areas support a more diverse and abundant demersal fish fauna than the surrounding unconsolidated sand and silt substrates. In the South Atlantic, rock substrate features vary from low-relief pavement dominated by corals, sponges, hydroids, bryozoans, and ascidians to high relief outcrops, ledges, ridges, boulder fields, and scarps dominated by sponges and gorgonian corals (Wenner et al. 1983).

Coral reefs are a specific type of hardbottom where the substrate itself is produced by living organisms (i.e., biogenic substrate). Stony corals may dominate a hardbottom habitat or be present as individual colonies within a community of sponges or macroalgae. In the Floridian region, shallow water coral reefs and coral communities occur in depths generally less than 40 m (130 ft). In some areas, reef-building corals form extensive structures and dominate the reef biota, while in other areas non-reef building corals colonize geologically derived hard substrates and may be a less dominant component of the benthic communities. Coral communities support a wide array of finfish, invertebrates, plants, and microorganisms. In deeper waters, large elongate mounds called deepwater banks, hundreds of meters in length, often support a rich fauna compared to adjacent areas, and coral mounds up to 150 m (490 ft) tall have been found on the Blake Plateau (Ross and Nizinski 2007; Fautin et al. 2010).

DATA SOURCES

Although there are large reefs in the Floridian region, much of the hardbottom habitat is small and patchy. In order to create a consistent map of hardbottom habitat across the whole South Atlantic, we compiled data from many different sources and applied analysis methods specifically developed to map areas where we were most confident that habitat was present. Below we describe the sources and types of spatially explicit hardbottom data and the methods we used to generate the final hardbottom maps. A complete list of all the datasets used in this analysis is included in Appendix 2.

POLYGON DATA SOURCES

Hardbottom polygons from the SABMA benthic hardbottom database (TNC 2013) were selected (n = 33,861) as were 201 hardbottom polygons from a recent benthic mapping effort in Florida (Walker and Gilliam 2013). Four polygons of the current Oculina Banks Habitat Area of Particular Concern (HAPC), one final polygon for the proposed Oculina Bank HAPC northern extension, and one polygon for an alternative western extension of the Oculina Bank HAPC were obtained and used to estimate the distribution of Oculina Bank hardbottom.

POINT DATA SOURCES

Chevron trap data from 1990 to 2013 from the SCDNR/NOAA Marine Resources Monitoring, Assessment and Prediction (MARMAP) Program database (Reichert 2009) were converted to point locations (n=7,885). After discussion with experts in the South Atlantic system, we reviewed the hardbottom point data from the original SEAMAP (2001) hardbottom database (n=4,466) and removed all points unless the point had been obtained from video, closed circuit TV, or the MARMAP program. In addition, MARMAP trap points for the years 1990-1996 were removed as they were duplicated in the larger 1990-2013 MARMAP dataset described above. After these refinements, the original SEAMAP hardbottom dataset was reduced from 4,466 points to 2,120 points.

Information on coldwater coral observations from seven spatially-explicit coral datasets (Fautin 2011; Woods Hole 2012; Scanlon et al. 2010; Partyka et al. 2007; Freiwald et al. 2005; Watling and Auster 2005; Skidaway Institute of Oceanography 2004) was compiled, and key fields were standardized across all the databases. All observations that contained soft substrate species, dead specimens, and incomplete species information were removed from the combined coral dataset, as were identical overlapping points. With multiple databases, there were often duplicate observations that did not spatially coincide due to slight locational coordinate differences. The distance from each point to all other points in the combined coral database was calculated and then used in a series of queries to identify likely duplicates based on species information, date, and distance. After the above processing steps, there were 1,167 hard substrate coral observations remaining from the original 3,577 points.

Each unique source for point data in the SABMA benthic hardbottom database that had not previously been in the original SEAMAP hardbottom database and was not in the coldwater coral databases described above (n=6,155) was also reviewed. Points that were based on the presence of obligate reef species rather than direct observance of hardbottom were removed from the dataset (n=219).

In addition, hardbottom points from the various usSEABED sediment datasets (n=49) were reviewed and only those that occurred on sloped seabed forms were retained (n=11). The resultant point dataset contained 5,898 points.

LINE DATA SOURCES

Trawl polylines from the SEAMAP Bottom Mapping Project database that recorded the presence of hardbottom habitat somewhere along the trawl and were less than or equal to 1.58 km in length were converted to their original start and end points using the start and stop longitude and latitude values. As the actual location of hardbottom was not captured in the dataset, we used a length threshold to avoid using very long trawls where the actual hardbottom occurrence could be a large distance from the start and/or end point. We used 1.58 km in length as this was the mean plus one standard deviation of the trawl lengths and was similar to the 1 and 2 km confidence zones used in the pavement and slope analyses described below. Any end points that overlapped with start points (i.e., a new trawl began at the end point of the previous trawl) were removed to avoid inflating the subsequent point density analysis conducted with the hardbottom points. These processing steps resulted in 3,802 trawl points for use in the hardbottom analysis.

All hardbottom points derived from the above sources were merged into one dataset containing a total of 20,872 points. A year flag was created to assign all points to one of the following three classes: 1) no date information (n=1,509), 2) historic data from the 1800s to the 1950s (n=40), and 3) current data from 1960 to present (n=19,323). Finally, as experts noted that commercially-identified hardbottom points beyond the shelf slope break often capture deepwater canyon features, we flagged all points from commercial data sources (n=2,584) with a value of 1 in the "COMM_PT" field.

MAPPING METHODS

We mapped four categories of hardbottom based on location and degree of relief. In reality, these types intergrade and their associated biota overlaps considerably.

- **Hardbottom Slope:** High relief rock or hard substrate associated with ledges and slopes, excluding the upper continental shelf edge
- **Hardbottom Upper Shelf Edge:** High relief rock or hard substrate associated with the upper portion of the steep continental shelf edge to a depth of -100 m

- **Hardbottom Pavement:** Low relief hard substrate composed of consolidated carbonate sands and coral rubble often encrusted with coralline algae and small coral colonies

- **Patchy Hardbottom (corals, sponges and/or rock):** Patches of low relief pavement-like hardbottom composed of sandstone or consolidated carbonate sands with sponges and soft corals. The mapped areas are regions with high concentrations of patchy hardbottom. Small isolated hardbottom patches are not shown.

HARDBOTTOM SLOPE

This analysis identified likely rock substrate habitat underlying high relief features such as ledges and scarps. First, all sloping seabed forms (e.g., slope, scarp, and ledge) were selected from the 90 m grid of seabed topographic forms previously described. The cells from all the selected seabed forms that were immediately adjacent or diagonal to each other were grouped together to create contiguous sloping seabed forms. The blocks of seabed forms were then converted to polygons and individual seabed forms that were within 500 m of a hardbottom point location were selected (n = 1,119). The selected seabed forms were often long linear ridges that extended far beyond the known hardbottom occurrences. To distinguish the areas where we had high confidence that hardbottom was present we created confidence zones based on the hardbottom point data. A "high confidence" zone was created by selecting the portion of a sloping seabed form within 1 km of a known hardbottom point. Next, a "probable" hardbottom zone was created by selecting the portion of each seabed form greater than 1 km and less than or equal to 2 km from a hardbottom point occurrence. The minimum and maximum year of the point data used to derive the confidence zones was spatially assigned to each hardbottom slope polygon when date information was available. We designated all sloping seabed form areas greater than 2 km from a confirmed hardbottom occurrence as "potential" hardbottom habitat, and we designated all slope forms that were not within 500 m of a hardbottom point as "possible" hardbottom slopes. For all slope forms, the underlying classification (e.g., oceanic mid scarp, shelf mid scarp, etc.) was retained and is available in the final dataset. *Only the **high confidence** and **probable confidence** areas are shown in the maps and used in the substrate and ecological marine unit synthesis.*

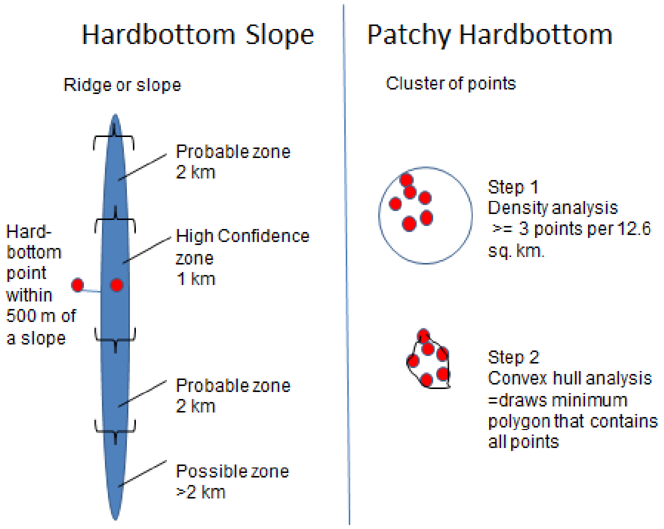


Figure 3.23. Diagram of hardbottom mapping methods. The diagram illustrates the method for determining high confidence and probable zones for hardbottom slopes and high density areas for patchy hardbottom.

HARDBOTTOM UPPER SHELF EDGE

Fish community data from deep shelf-edge hardbottom are limited but include at least 117 species (Quattrini and Ross 2006). The Continental Shelf forms an almost continuous feature and consequently the shelf polygon was represented as a long continuous polygon that ran the full extent of the project area. We processed this large formation separately from the other slopes using the following steps. Bathymetry data was used to divide the shelf into two depth zones. The first zone, referred to as the upper slope, constitutes the portion of the shelf with depth values shallower than -100 m and is the zone of the shelf most likely to have hardbottom habitat. The second zone is the lower slope and occurs at depths of -100 m and deeper. For those portions of the upper shelf for which confirmed hardbottom point data existed, confidence zones were created using the same approach as previously described for the seabed slope analysis. The confidence zones were defined for both the lower and upper slope segments of the outer shelf; however only the upper slope areas are included here (lower slope areas were classified as “hardbottom slopes”). When temporal data were available, the minimum and maximum year of the point data used to derive the confidence zones was attributed to the combined depth and confidence zone polygons. The seabed form types that comprise the upper shelf were retained and are available in the final dataset. *Only the **high confidence** and **probable confidence** areas are shown in the maps and used in the substrate and ecological marine unit synthesis.*

PATCHY HARDBOTTOM (CORALS, SPONGES AND/OR ROCK

Patches of low relief pavement-like hardbottom composed of sandstone or consolidated carbonate sands occur throughout the region; our goal was to map areas with high concentrations of these features. In the Floridian ecoregion, patchy hardbottom was mapped directly and we obtained polygons from Florida Marine Research Institute (FMRI 2000) showing its distribution. Outside of the Floridian region we estimated the extent and shape of patchy hardbottom concentrations using a density analysis applied to the individual hardbottom points (Figure 3.23). To delineate concentrations of patchy hardbottom, we conducted point density analyses using all the hardbottom points collected since 1960 that were not within 500 m of the selected high relief seabed forms used for mapping hardbottom slopes (n = 13,454). In the analysis, density was calculated for all points in a circle with a 1 km radius around each 90 m grid cell. The gridded output was then classified into high density areas by selecting all cells with at least three points in the 3.14 km^2 circular neighborhood. That is, all cells with a density value greater than or equal to 0.96 were selected and coded as high density hardbottom areas. Our assumption was that we could have high confidence that actual hardbottom exists in areas where three confirmed points occurred in close proximity. The high density/high confidence point density areas were converted to polygons with unique identification numbers. A spatial analysis was conducted to assign the hardbottom points to the density polygons with which they intersected. The hardbottom points thus each had a value to identify to which density polygon they belonged. Next, a convex hull was used to generate the minimum bounding polygon for hardbottom points with the same polygon density ID value. For convex hulls with only two or fewer points or with multiple points that closely overlapped, the resultant minimum bounding area was a narrow line that we subsequently buffered by 150 m in an attempt to create a more ecologically meaningful boundary. For all the patchy hardbottom areas, the minimum and maximum year of the point data used to derive the boundaries (when information was available) was attributed to the polygons. The final dataset had a total of 353 high density/high confidence patchy hardbottom areas with an average area of 223 ha. We performed a second analysis to identify larger "probable" areas; a 2 km radius was used to define the circular neighborhood but *only the* ***high density/high confidence*** *areas are shown in the maps and used in the substrate and ecological marine unit synthesis.*

Hardbottom Pavement

Low relief hard "pavement" composed of consolidated carbonate sands and coral rubble is found in the Florida Keys behind fringing or barrier reefs. The extensive consolidated substrate is often encrusted with coralline algae and small coral colonies, and is quite different than patchy flat pavement-like hardbottom off the Carolinas and Georgia. In the Floridian subregion we used polygon data provided by the Fish and Wildlife Research Institute (FMRI 2000) to map the hardbottom pavement. The data also contained information as to whether the pavement was colonized or uncolonized.

ISOLATED HARDBOTTOM (NOT SHOWN)

All rock substrate points that were not used in the slope, upper shelf, or patchy hardbottom analyses (n = 896) were buffered by 150 m and defined as isolated hardbottom occurrences. These isolated points are not included in the dataset or shown on the maps because we did not have high confidence that they represent actual hardbottom locations.

CORAL REEFS

Shallow water coral reefs exist in the Floridian subregion where stony corals form reef structures. Offshore reefs reflect an assemblage of hard corals, soft corals, and sponges that is relatively consistent along Southeast Florida (Blair and Flynn 1989). Coral reefs tend to have clear ecological zonation. They are concentrated in southeast Florida where the distribution pattern between Cape Canaveral and Key Biscayne consists of an inner reef in approximately 4 to 8 m of water, a middle patch reef zone in about 9 to 15 m of water, and an outer reef in approximately 18 to 30 m of water (Duane and Meisburger 1969; Goldberg 1973; Courtenay et al. 1974; Lighty et al. 1978; Jaap 1984). These reef zones are separated by areas of sand or sand and rubble. A unique deep/cold-water coral reef system, the Oculina Bank, occurs off the Central Florida coast. This diverse deepwater ecosystem is dominated by the ivory tree coral, *Oculina varicosa*, which thrives in cooler waters. Found as deep as 100 m on the shelf edge, the corals form thickets of white branches that are home to hundreds of different kinds of invertebrates and provide essential habitat for many commercial fish species. *Oculina* occurs elsewhere in the region but not to the extent and abundance that it does in this unique area. *Lophelia* reefs occur in deep water zones (> 1000 m) east of the shelf-slope break in the Carolinian subregion, but the locations of these reefs are not mapped.

Coral reefs intergrade with rock substrate which, when colonized, can have coral reef biota as a less dominant component of diverse benthic assemblages. When non-reef building corals are dominant on rock substrate they form the hardbottom slopes of rocky ledges or the patchy hardbottom described above for low relief areas. In each case, species composition may vary depending on water depth and associated parameters (light, temperature, etc.) and geography.

To map coral reefs, we obtained a comprehensive set of polygons of coral reefs, rock substrate, and related features from several recent benthic mapping efforts in Florida (FMRI 2000; Walker 2012; Walker and Gilliam 2013). The various sources used slightly different classification systems and we aggregated all polygons into several broad types following the recommendations of the Florida

System for Classifying Estuarine and Marine Environments (SCHEME; Madley et al. 2002) while retaining the original attributes. The following scheme was used to simplify the many attributes associated with the coral reef polygons across all the sources:

- **Platform Reef**: reef consisting of hardened substrate of unspecified relief formed by the deposition of calcium carbonate by reef-building corals. This group includes coral reef and colonized rock substrate, linear reef, reef terrace, spur and groove reef, nearshore reef, offshore reef, and associated remnants and reef rubble.
- **Patch Reef**: irregularly distributed clusters of corals and associated biota along the coast of the Florida Keys. This class includes aggregated patch reef, aggregate reef, and individual patch reef.
- **Oculina Bank**: deeper water reefs off the Florida coast dominated by *Oculina varicosa*.
- **Hardbottom Pavement**: low relief solid carbonate rock, colonized or uncolonized by organisms. Colonized occurrences have macroalgae, hard coral, gorgonians and other sessile invertebrates, often dense enough to obscure the substrate.

In the final processing step, all the data types and results from the various data sources were merged to create a shapefile of hardbottom and reef substrate areas in the study area. Although hardbottom types may overlap and are typically covered with a thin veneer of soft substrate such as sand or mud, we mapped the final classes giving precedence to reefs over hardbottom, and hardbottom over soft sediment. The final maps show seven classes with the last four found only in the Floridian subregion:

- **Hardbottom Slope:** High relief hardbottom associated with ledges and slopes
- **Hardbottom Upper Shelf Edge:** High relief hardbottom associated with the upper shelf edge to -100 m
- **Patchy Hardbottom (corals, sponges and/or rock):** Concentrations of patchy low relief pavement-like hardbottom composed of sandstone or consolidated carbonate sands with sponges and soft corals.
- **Hardbottom Pavement:** Low relief hard substrate composed of consolidated carbonate sands
- **Platform Reef:** reef structures composed of coral forming organisms
- **Patch Reef:** irregularly distributed clusters of corals
- **Oculina Bank:** reefs dominated by *Oculina varicosa*

Related attributes in the dataset not included in the maps include: isolated hardbottom, possible and potential hardbottom slope, and potential patchy hardbottom. Results for the region and subregions are shown in Figures 3.24-3.27 and were then integrated with the soft sediment maps giving precedence to hardbottom over soft sediments (Figures 3.28-3.31).

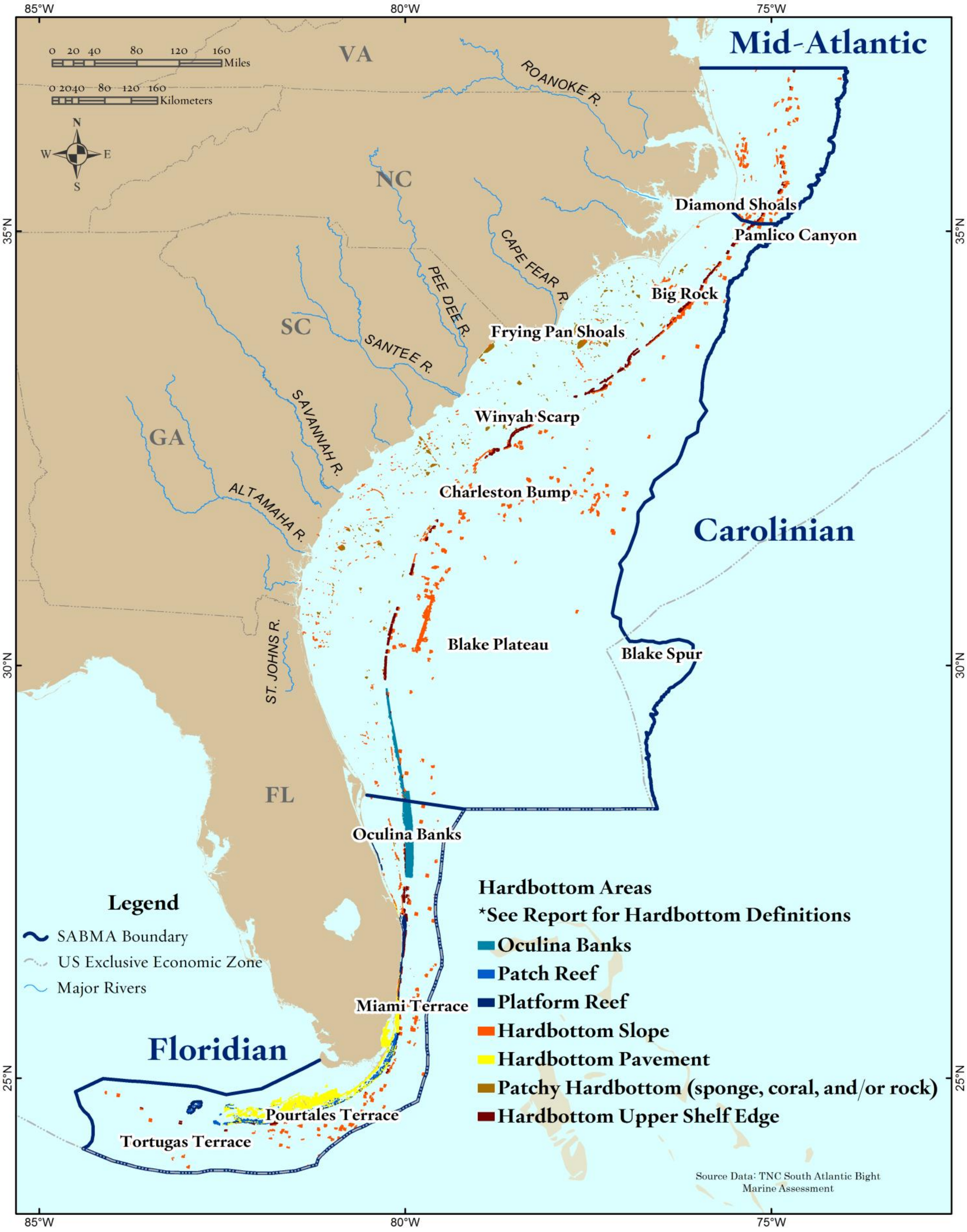


Figure 3.24. Hardbottom in the South Atlantic Bight. The map shows the hardbottom and reef locations. See subregional maps on the following pages.

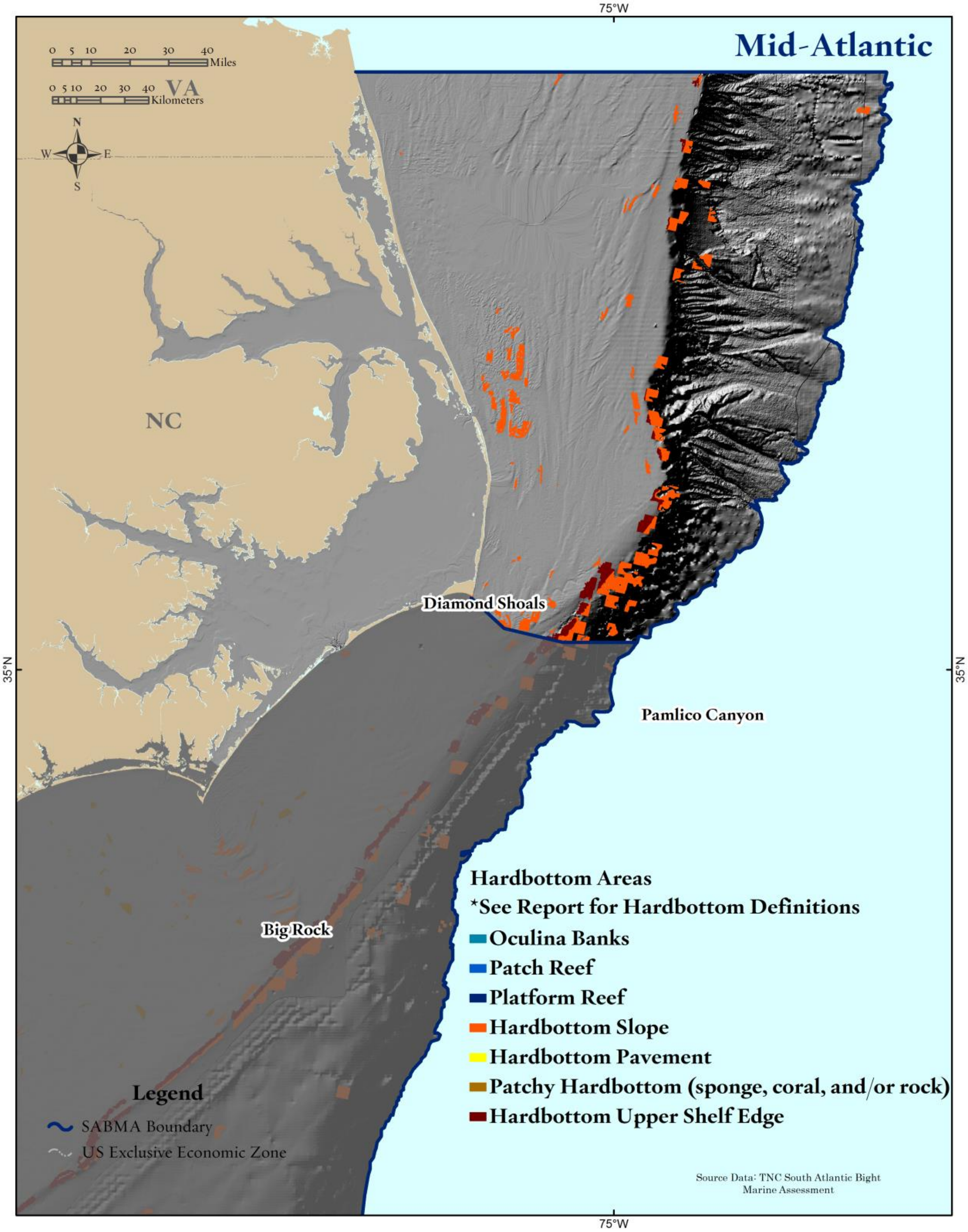


Figure 3.25. Hardbottom areas in the mid-Atlantic subregion. The map shows the location of hardbottom and corals over a hillshade map.

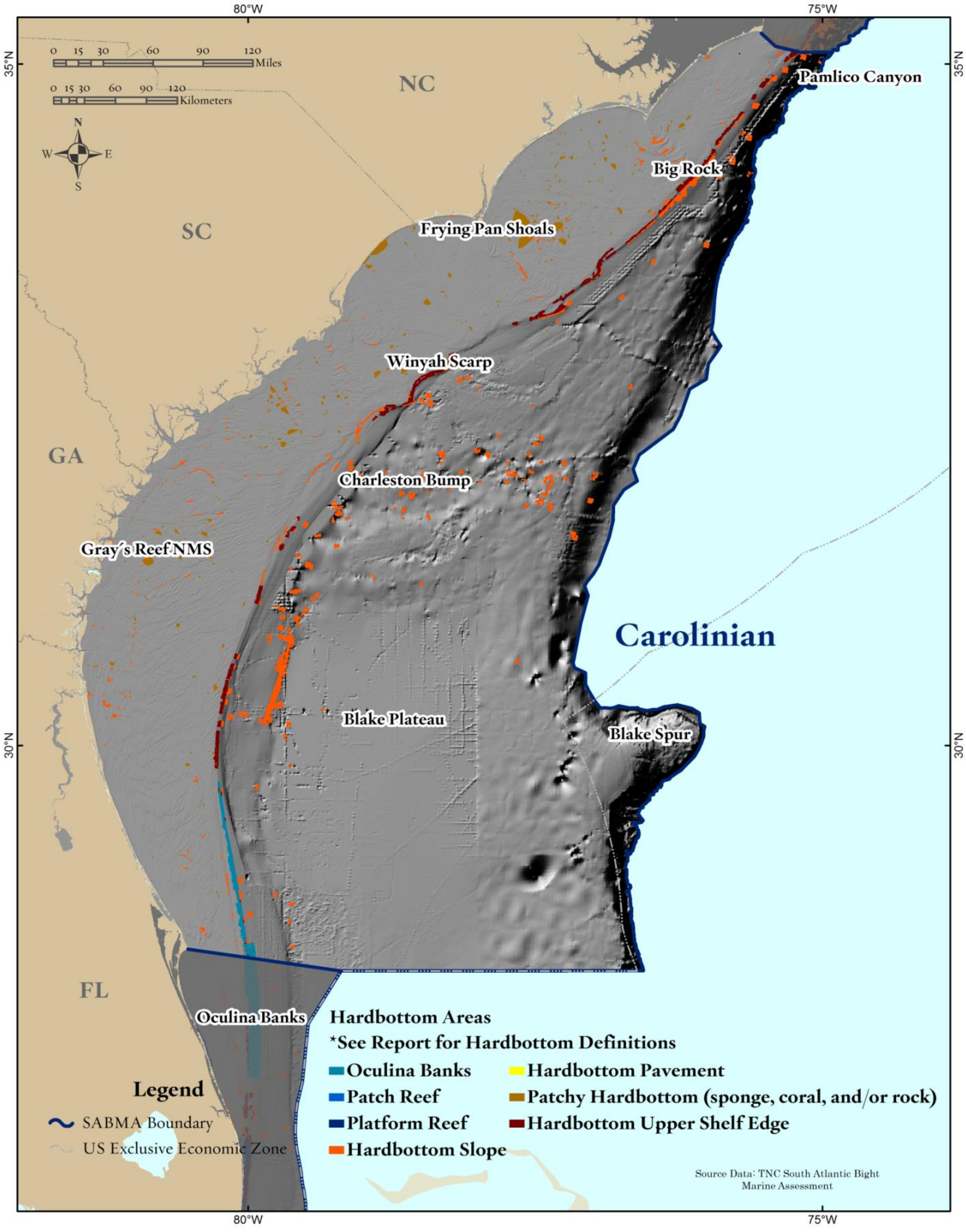


Figure 3.26. Hardbottom areas in the Carolinian subregion overlaid on a hillshade map. The map shows the location of hardbottom and corals over a hillshade map.

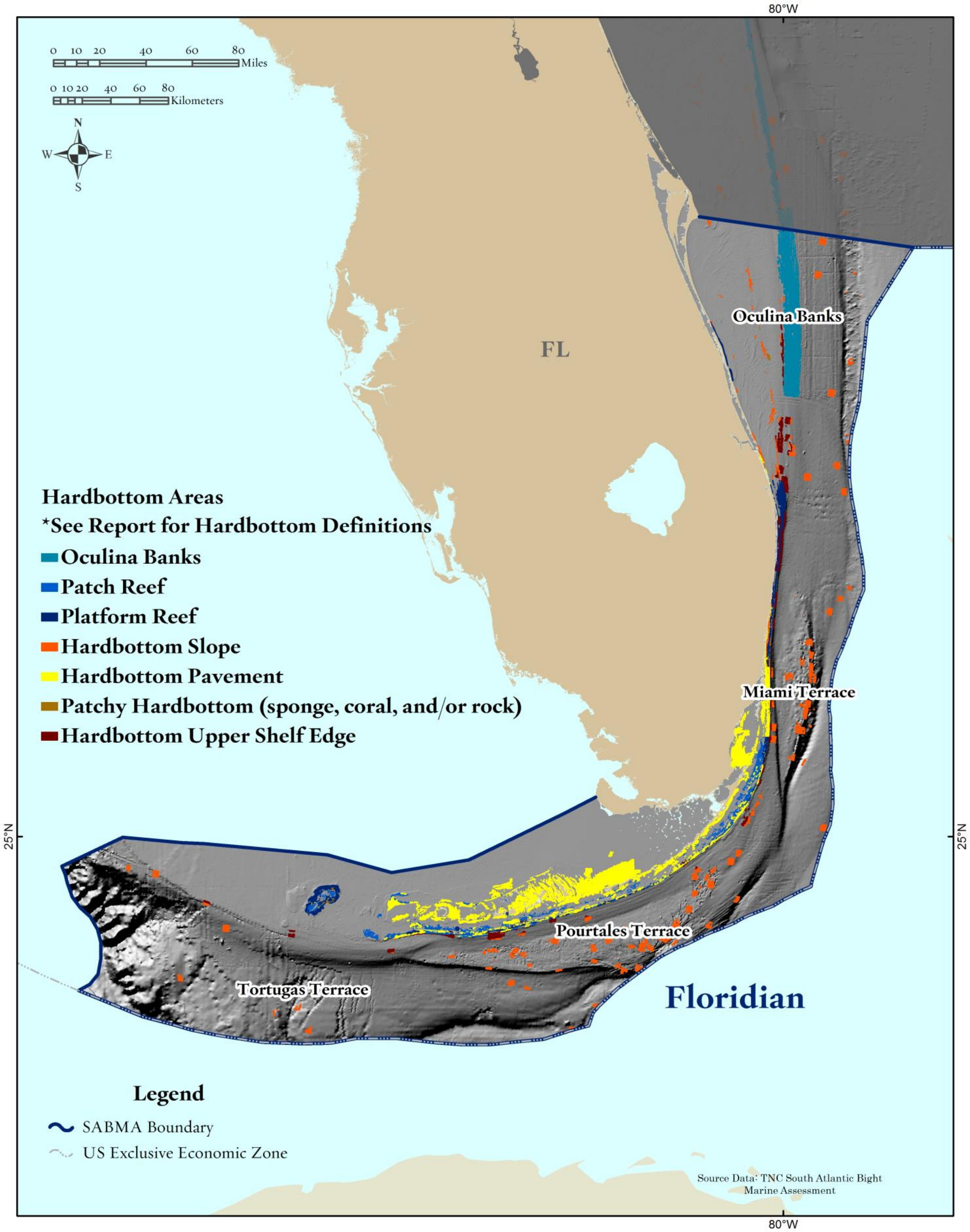
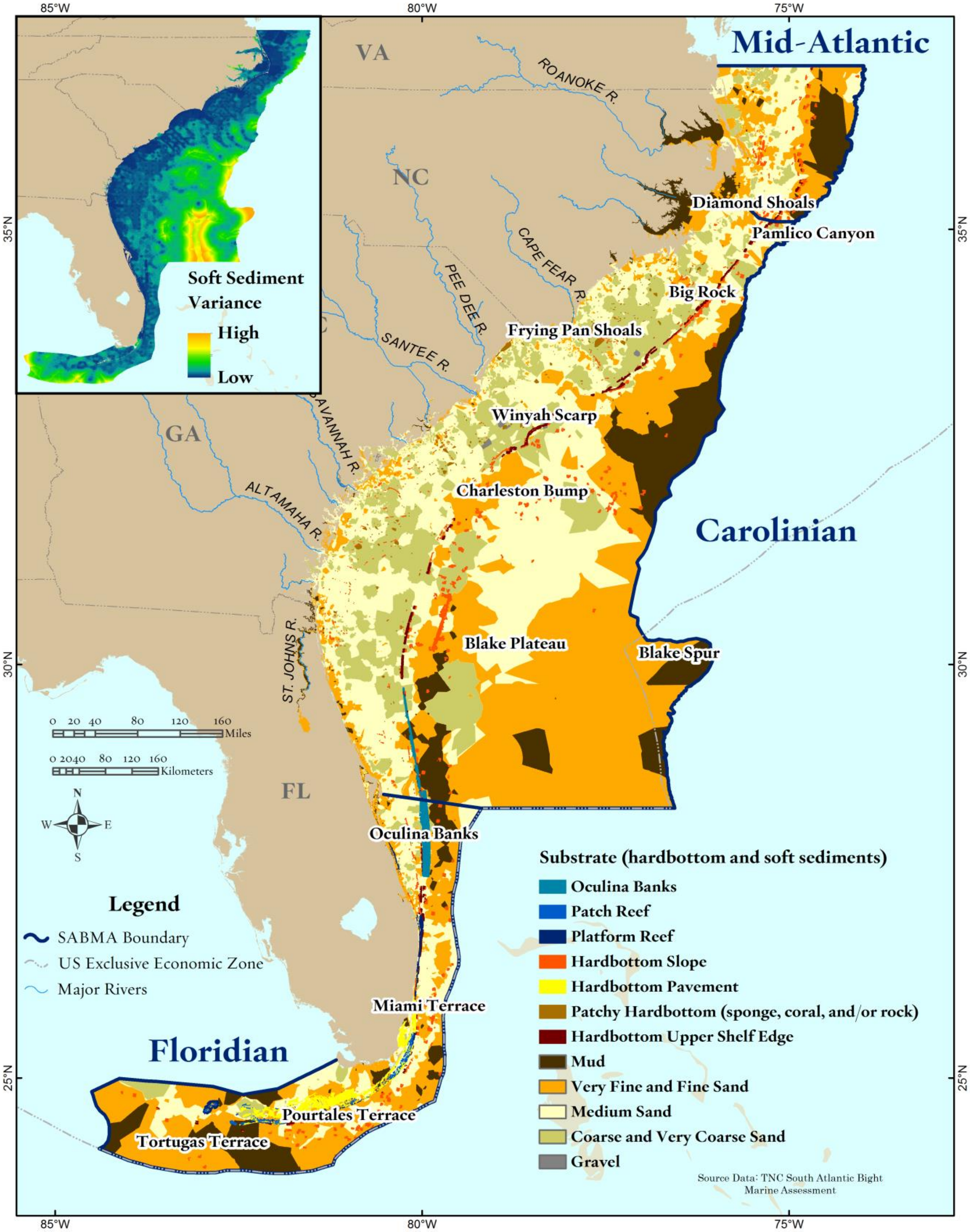


Figure 3.27. Hardbottom areas in the Floridian subregion. The map shows hardbottom and reef types on top of a hillshade map.



Source Data: TNC South Atlantic Bight Marine Assessment

Figure 3.28. Integrated hardbottom and soft sediment substrate in the South Atlantic Bight. See subregional maps on the following pages.

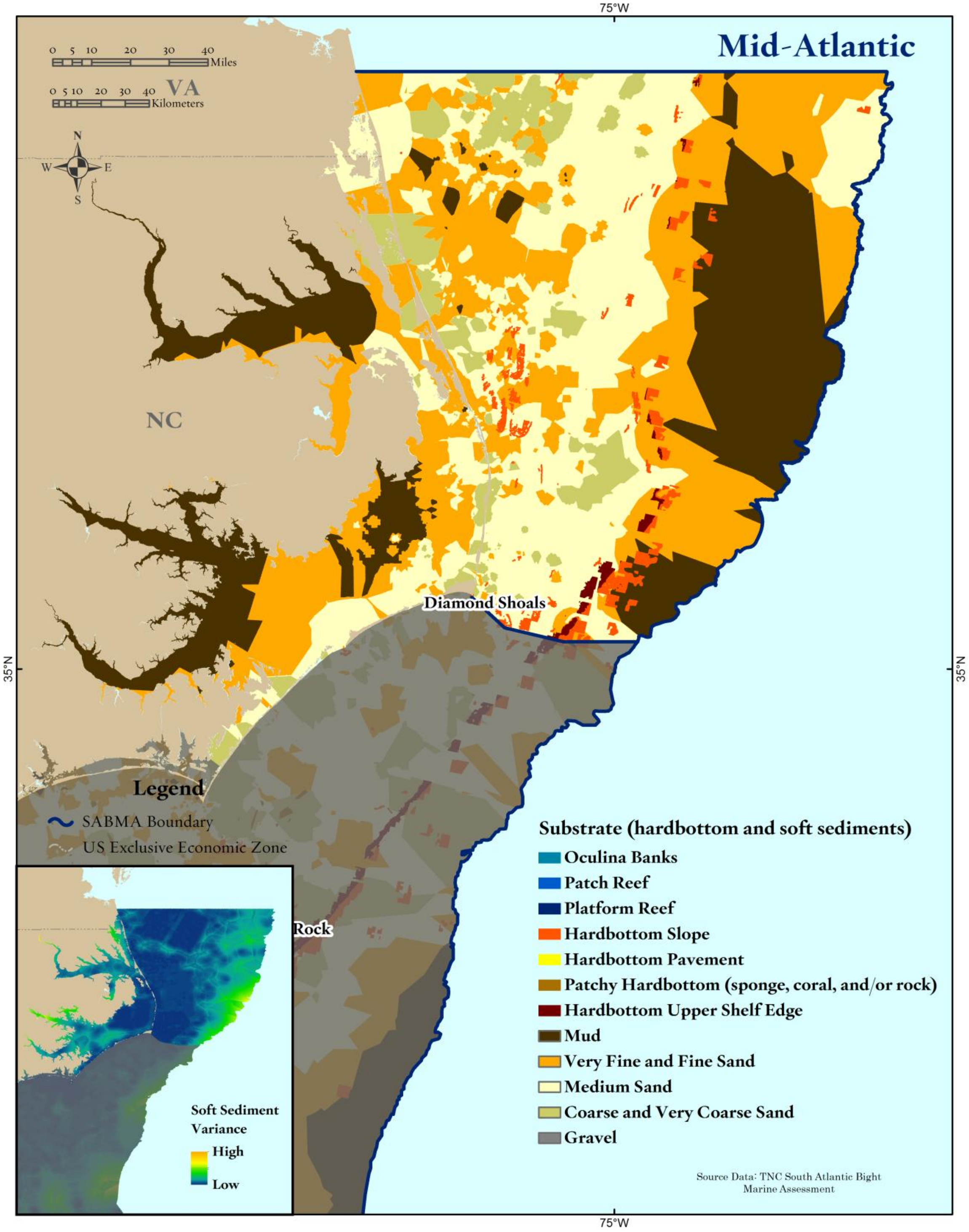


Figure 3.29. Integrated hardbottom and soft sediment substrate in the mid-Atlantic subregion

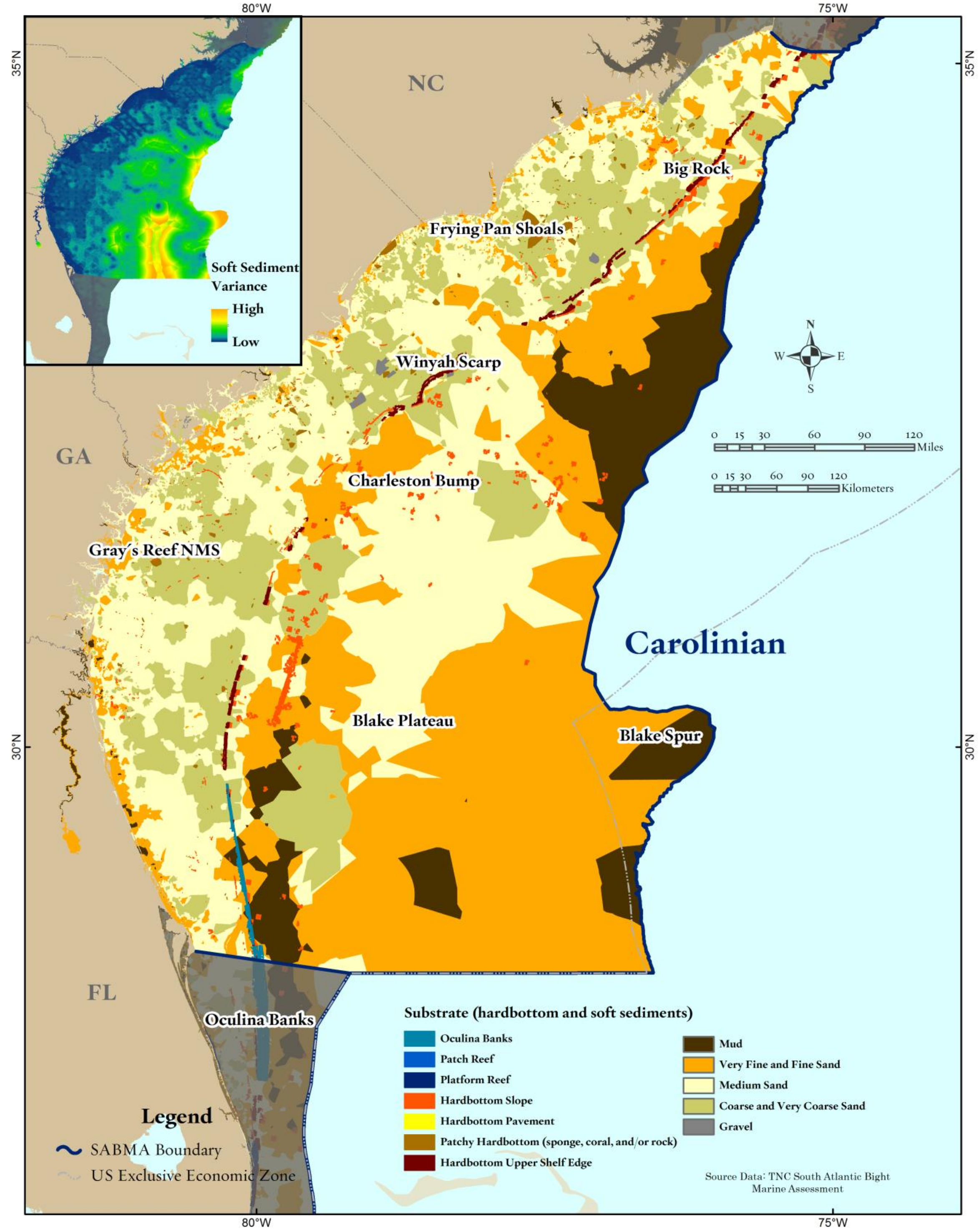
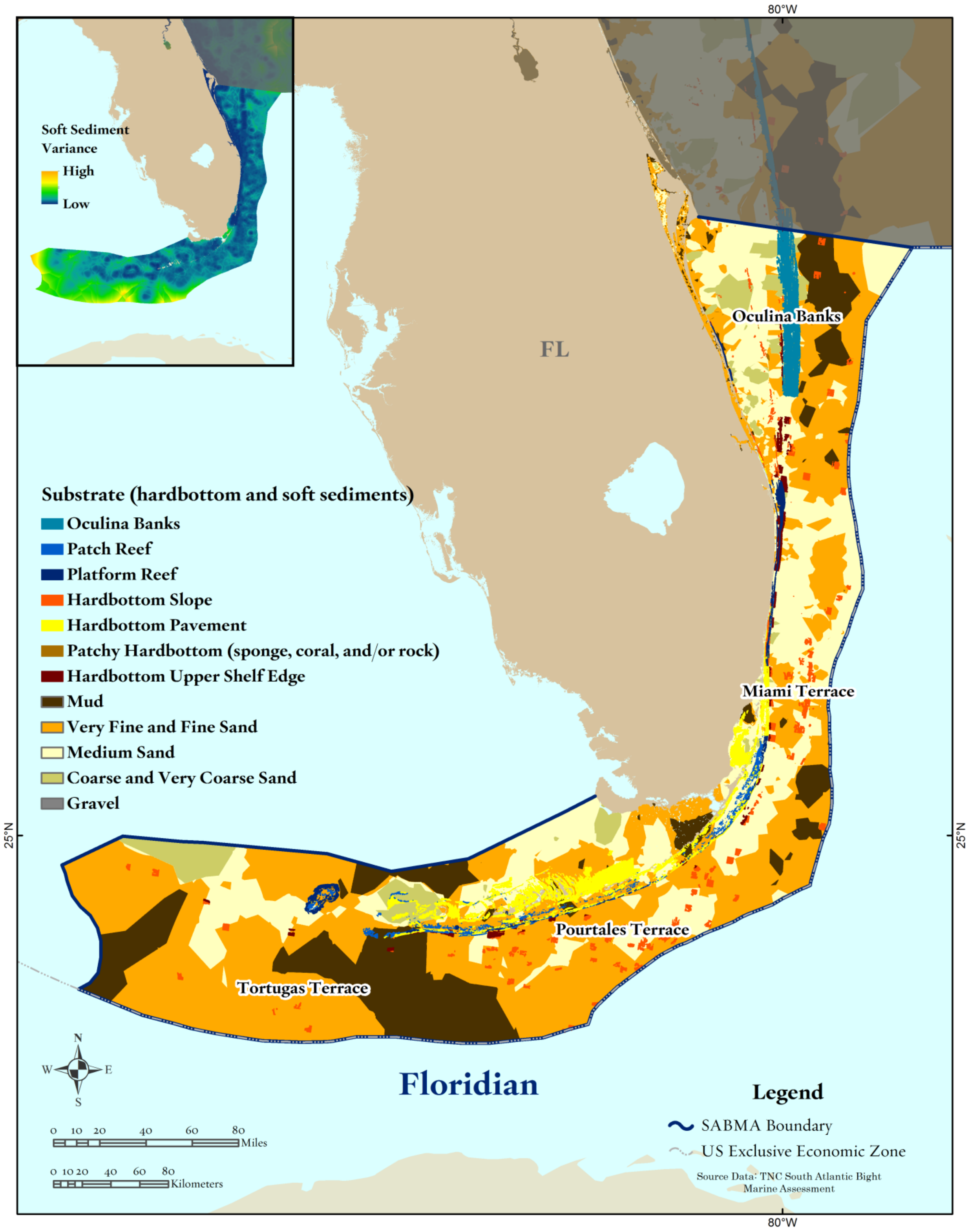


Figure 3.30. Integrated hardbottom and soft sediment substrate map in the Carolinian subregion



Source Data: TNC South Atlantic Bight Marine Assessment

Figure 3.31. Integrated hardbottom and soft sediment substrate map in the Floridian subregion

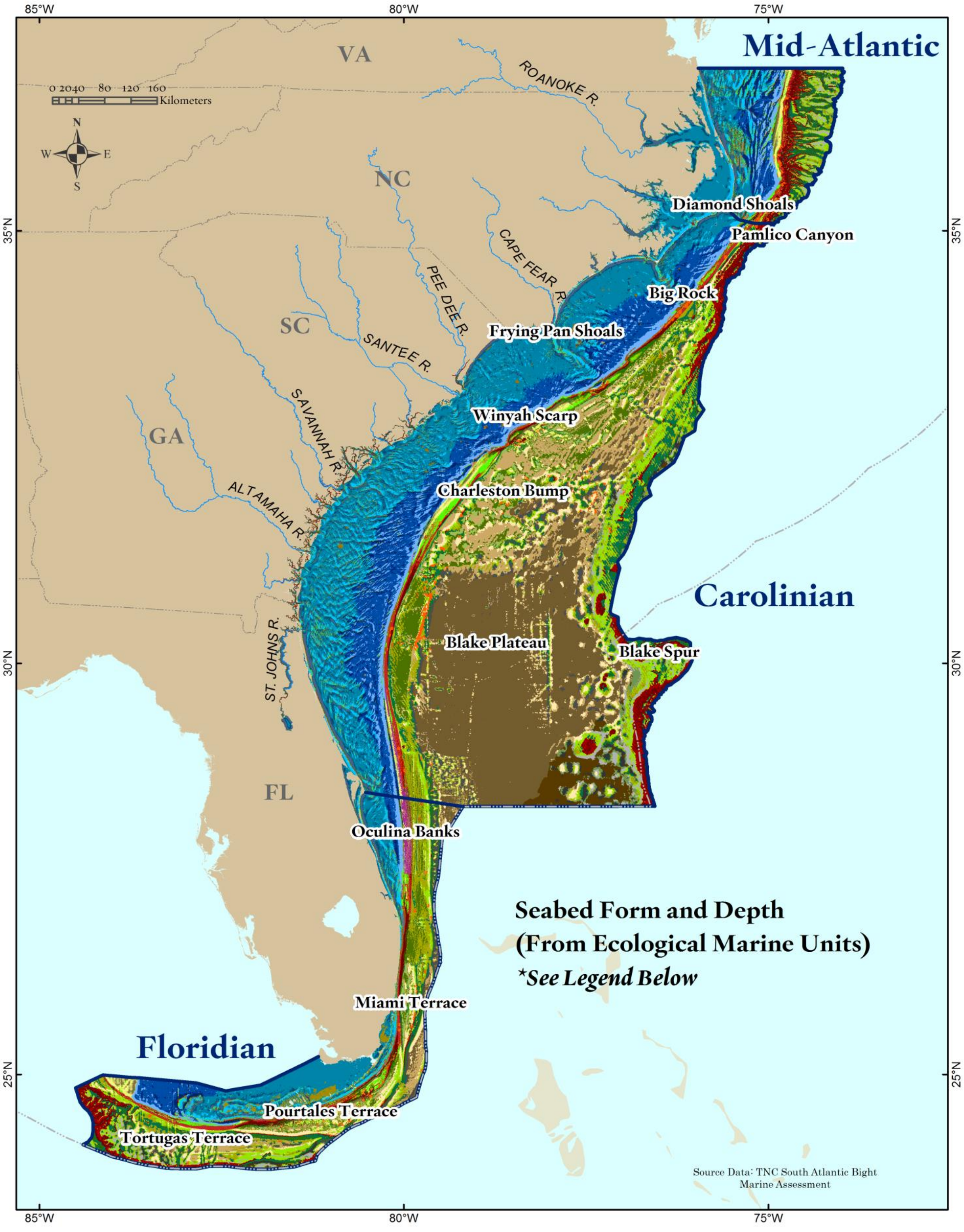
Ecological Marine Units

We combined and integrated the bathymetry, seabed forms, and substrate information into a single map and data layer that we termed Ecological Marine Units (EMUs). The EMUs represent the physical structure of the South Atlantic Bight which can be used to approximate the distribution of benthic habitats. To create the EMUs, each cell was given a code based on all of its properties determined from the previous analyses. The coding scheme used 1000s for depth, 100s for substrate, and 10s for seabed form (Table 3.9). For example: 1113 = Infralittoral mud depression and 4621 = Mesobenthic hardbottom upper slope.

Table 3.9. Ecological Marine Units: components and codes. DCode = depth code, SCode = substrate code, and SBCode = seabed form code

D Code	Depth Zone	S Code	Substrate Class	SB Code	Seabed Form
1000	Infralittoral (0-30 m)	100	Mud	10	upper flat
2000	Shallow Circalittoral (30-70 m)	200	Fine Sand	11	mid flat
3000	Deep Circalittoral (70-200 m)	300	Medium Sand	12	low flat
4000	Shallow Mesobenthic (200-600 m)	400	Coarse Sand	13	depression
5000	Deep Mesobenthic (600-1000 m)	500	Gravel	21	upper slope
6000	Bathybenthic/Abyssal (1000+ m)	600	Hardbottom Slope	22	mid slope
		700	Hardbottom Upper Shelf	23	low slope
		800	Hardbottom Pavement	24	slope bottom
		900	Reef	25	mid gentle-slope
		000	Patchy Hardbottom	31	upper scarp
				32	mid scarp
				33	low scarp
				41	upper ledge
				42	mid ledge
				43	canyon bottom
				50	platform reef
				60	patch reef
				80	Oculina bank

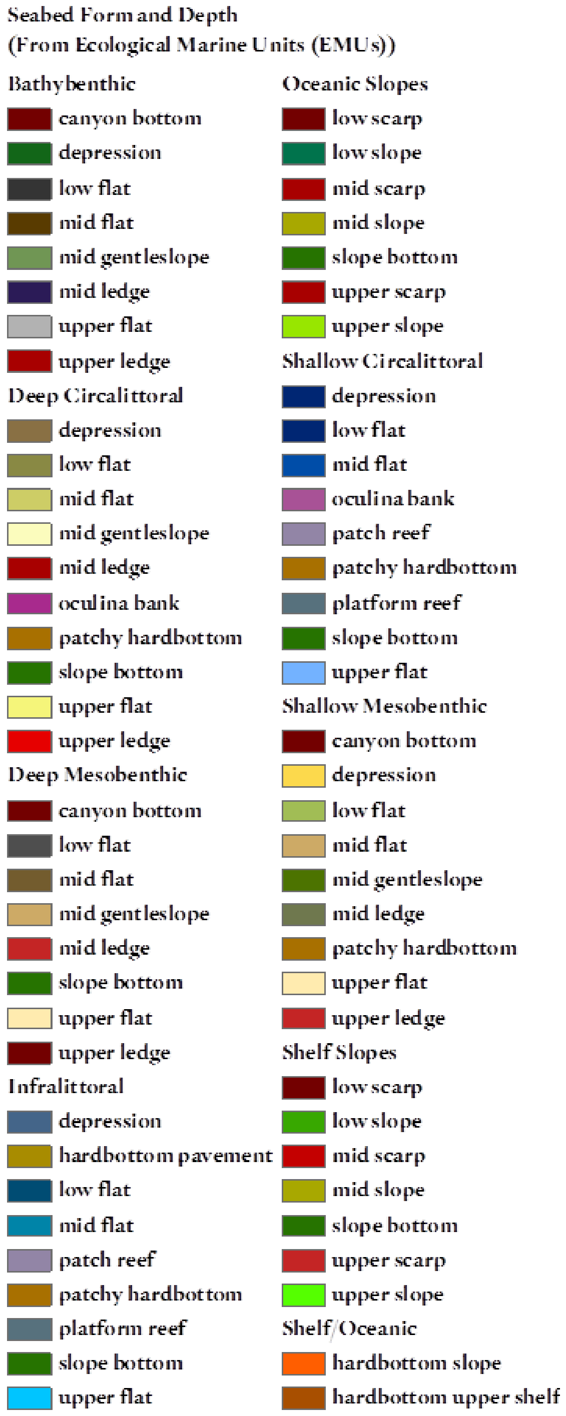
The combined EMUs are displayed on the maps using color changes to represent changes in bathymetry zones, with blues for the Continental Shelf (infralittoral, circalittoral) and browns for the oceanic zone (mesobenthic, bathybenthic). Within each zone, low position seabed forms are darker in color and high position forms are lighter. Slopes are uniformly shown as green and scarps as red. Hardbottom is shown in orange or orange-brown, and reefs are in purples. The first set of maps (Depth and Seabed form from EMUs) shows only the depth zone, seabed forms and hardbottom for the region and the three subregions (Figures 3.32–3.36). The second set of maps (the complete EMUs) is similar but has an overlay showing mud, coarse sand and gravel areas. Areas with no overlay are composed of fine to medium sand (Figures 3.37-3.40).



Seabed Form and Depth
(From Ecological Marine Units)
See Legend Below

Source Data: TNC South Atlantic Bight Marine Assessment

Figure 3.32. Seabed form and depth (from Ecological Marine Units) of the South Atlantic Bight: depth zones, seabed forms and hardbottom



Seabed Form and Depth
(From Ecological Marine Units (EMUs))

Bathybenthic
- 🟥 canyon bottom
- 🟩 depression
- ⬛ low flat
- 🟫 mid flat
- 🟩 mid gentleslope
- 🟪 mid ledge
- ⬜ upper flat
- 🟥 upper ledge

Deep Circalittoral
- 🟫 depression
- 🟫 low flat
- 🟨 mid flat
- 🟨 mid gentleslope
- 🟥 mid ledge
- 🟪 oculina bank
- 🟧 patchy hardbottom
- 🟩 slope bottom
- 🟨 upper flat
- 🟥 upper ledge

Deep Mesobenthic
- 🟥 canyon bottom
- ⬛ low flat
- 🟫 mid flat
- 🟫 mid gentleslope
- 🟥 mid ledge
- 🟩 slope bottom
- 🟨 upper flat
- 🟥 upper ledge

Infralittoral
- 🟦 depression
- 🟨 hardbottom pavement
- 🟦 low flat
- 🟦 mid flat
- 🟪 patch reef
- 🟧 patchy hardbottom
- 🟦 platform reef
- 🟩 slope bottom
- 🟦 upper flat

Oceanic Slopes
- 🟥 low scarp
- 🟩 low slope
- 🟥 mid scarp
- 🟨 mid slope
- 🟩 slope bottom
- 🟥 upper scarp
- 🟩 upper slope

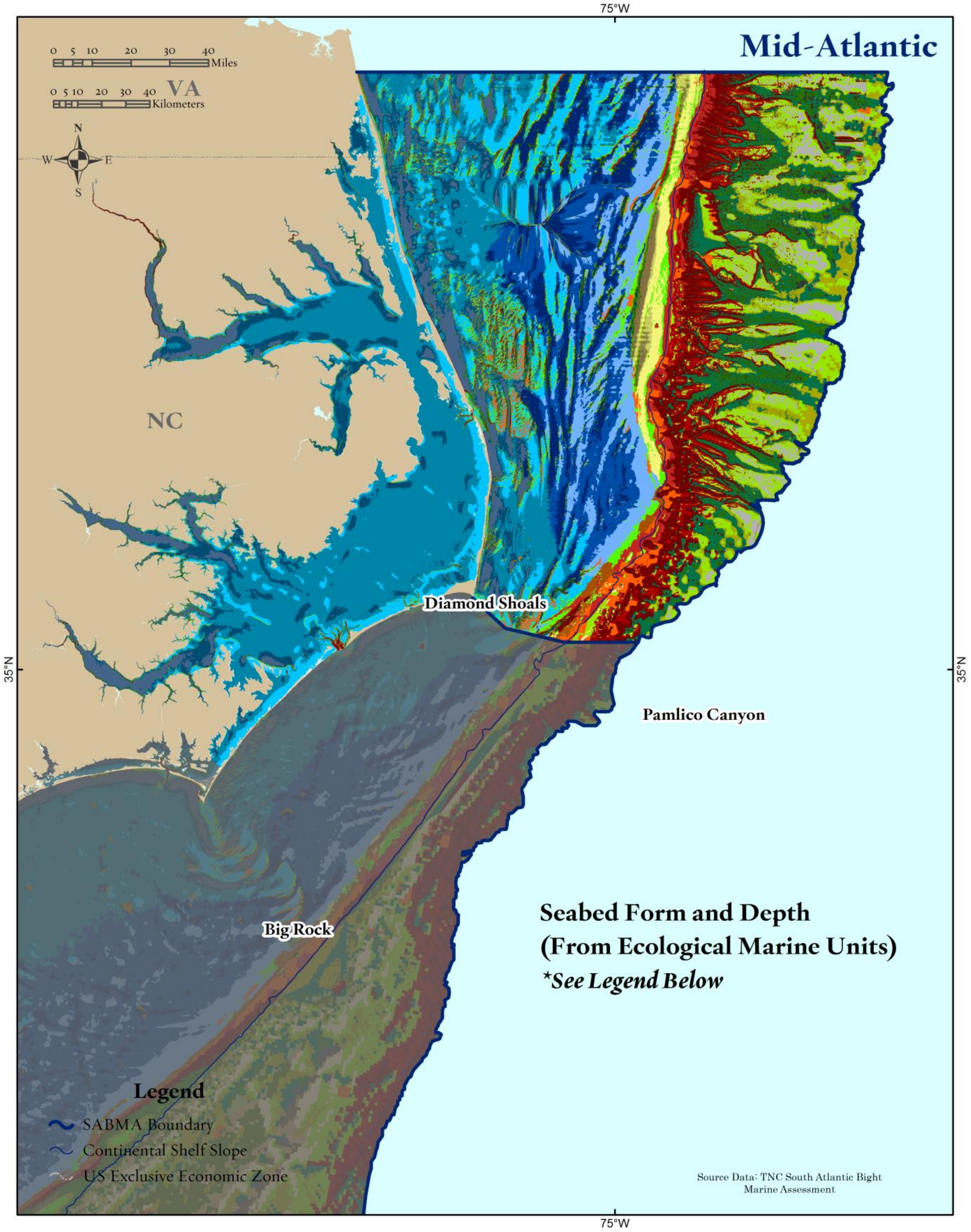
Shallow Circalittoral
- 🟦 depression
- 🟦 low flat
- 🟦 mid flat
- 🟪 oculina bank
- 🟪 patch reef
- 🟧 patchy hardbottom
- 🟦 platform reef
- 🟩 slope bottom
- 🟦 upper flat

Shallow Mesobenthic
- 🟥 canyon bottom
- 🟨 depression
- 🟩 low flat
- 🟫 mid flat
- 🟩 mid gentleslope
- 🟩 mid ledge
- 🟧 patchy hardbottom
- 🟨 upper flat
- 🟥 upper ledge

Shelf Slopes
- 🟥 low scarp
- 🟩 low slope
- 🟥 mid scarp
- 🟨 mid slope
- 🟩 slope bottom
- 🟥 upper scarp
- 🟩 upper slope

Shelf/Oceanic
- 🟧 hardbottom slope
- 🟧 hardbottom upper shelf

Figure 3.33. Legend for seabed form and depth (from Ecological Marine Units): seabed forms and hardbottom organized within depth zones



Source Data: TNC South Atlantic Bight Marine Assessment

Figure 3.34. Seabed form and depth (from Ecological Marine Units) of the mid-Atlantic subregion: depth zones, seabed forms and hardbottom

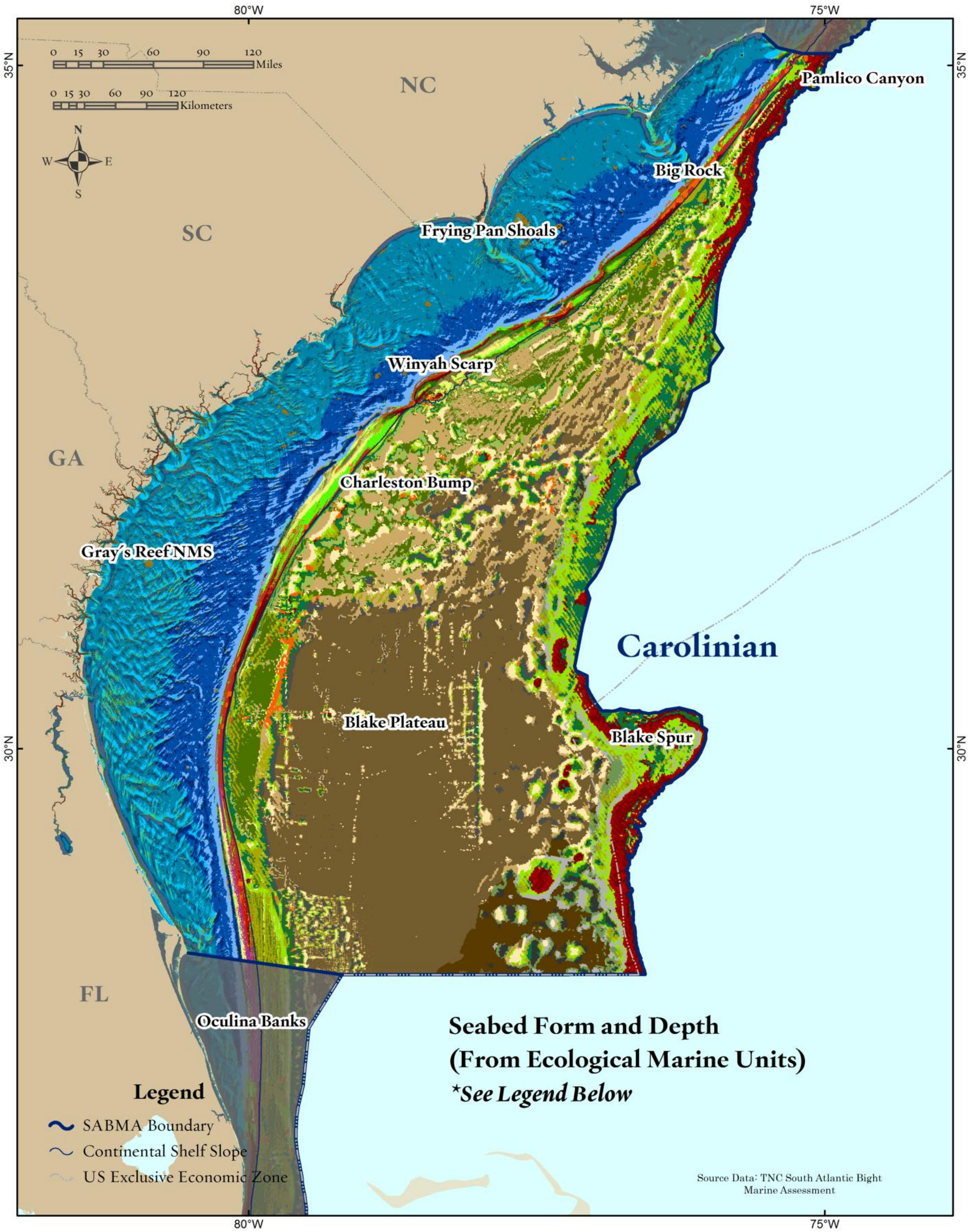


Figure 3.35. Seabed form and depth (from Ecological Marine Units of the Carolinian subregion: depth zones, seabed forms and hardbottom

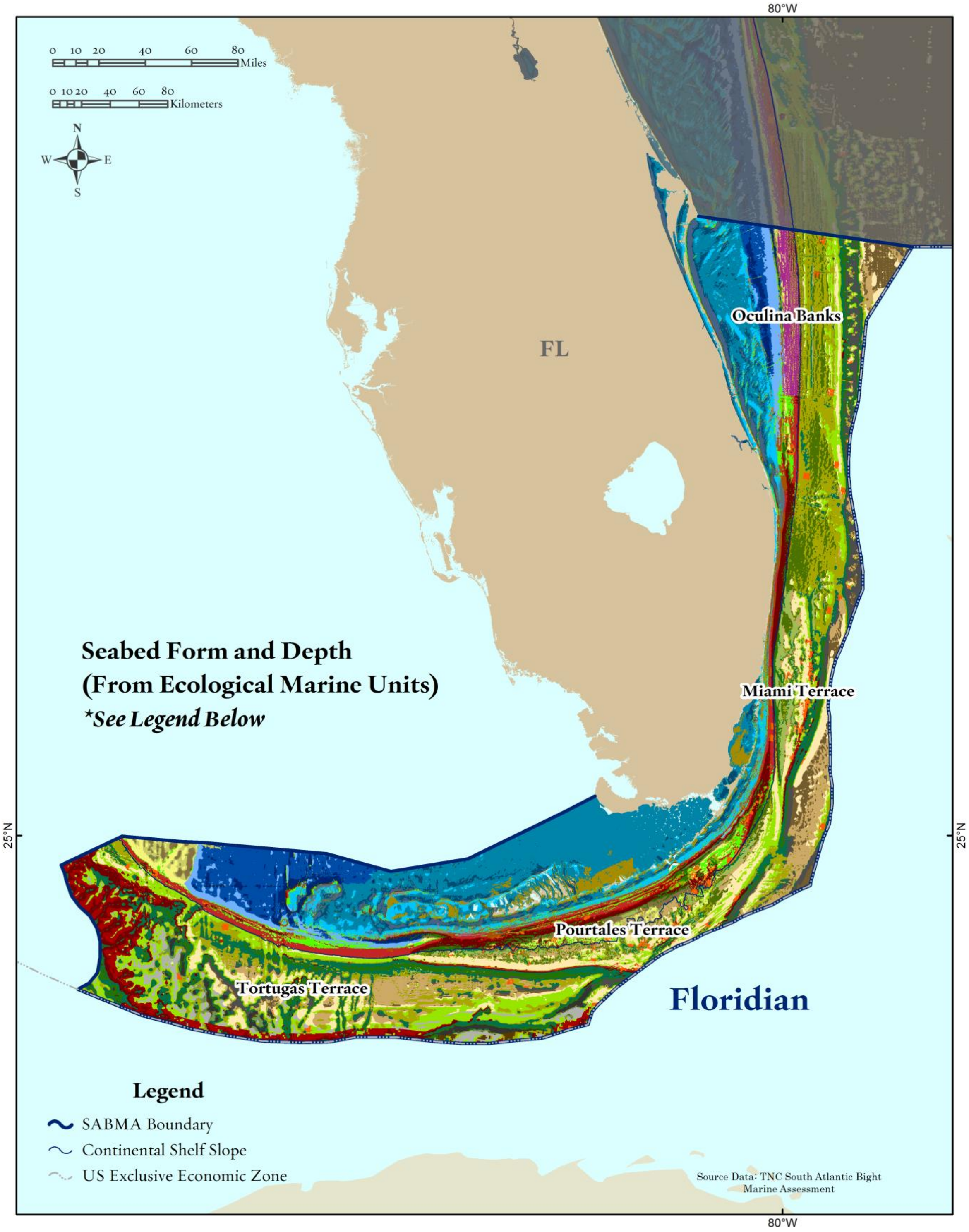
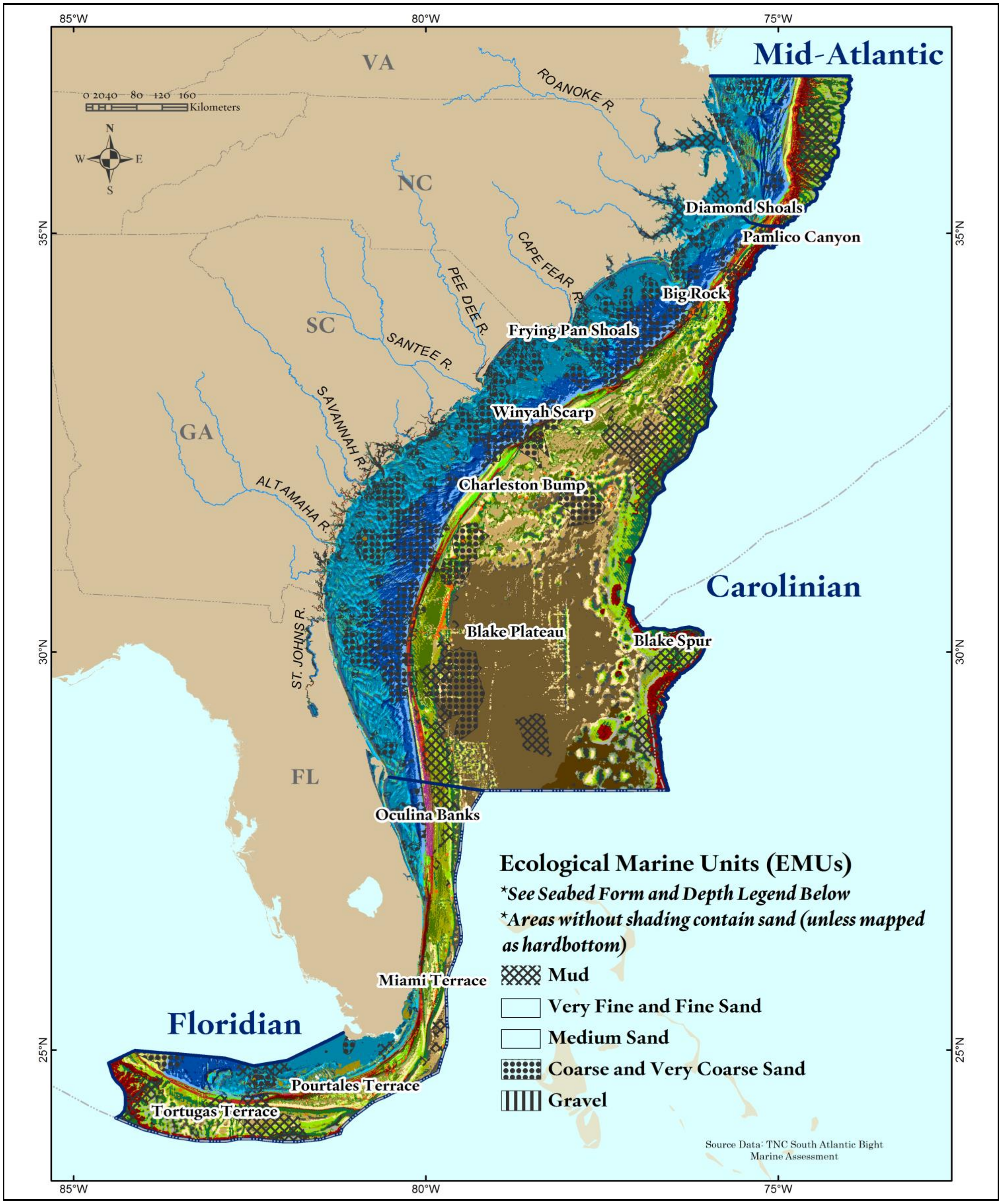


Figure 3.36. Seabed form and depth (from Ecological Marine Units of the Floridian subregion: depth zones, seabed forms and hardbottom



Source Data: TNC South Atlantic Bight Marine Assessment

Figure 3.37. Ecological Marine Units of the South Atlantic Bight: depth zones, seabed forms and hardbottom, with soft substrate overlaid. Areas that are fully transparent are medium to fine sand.

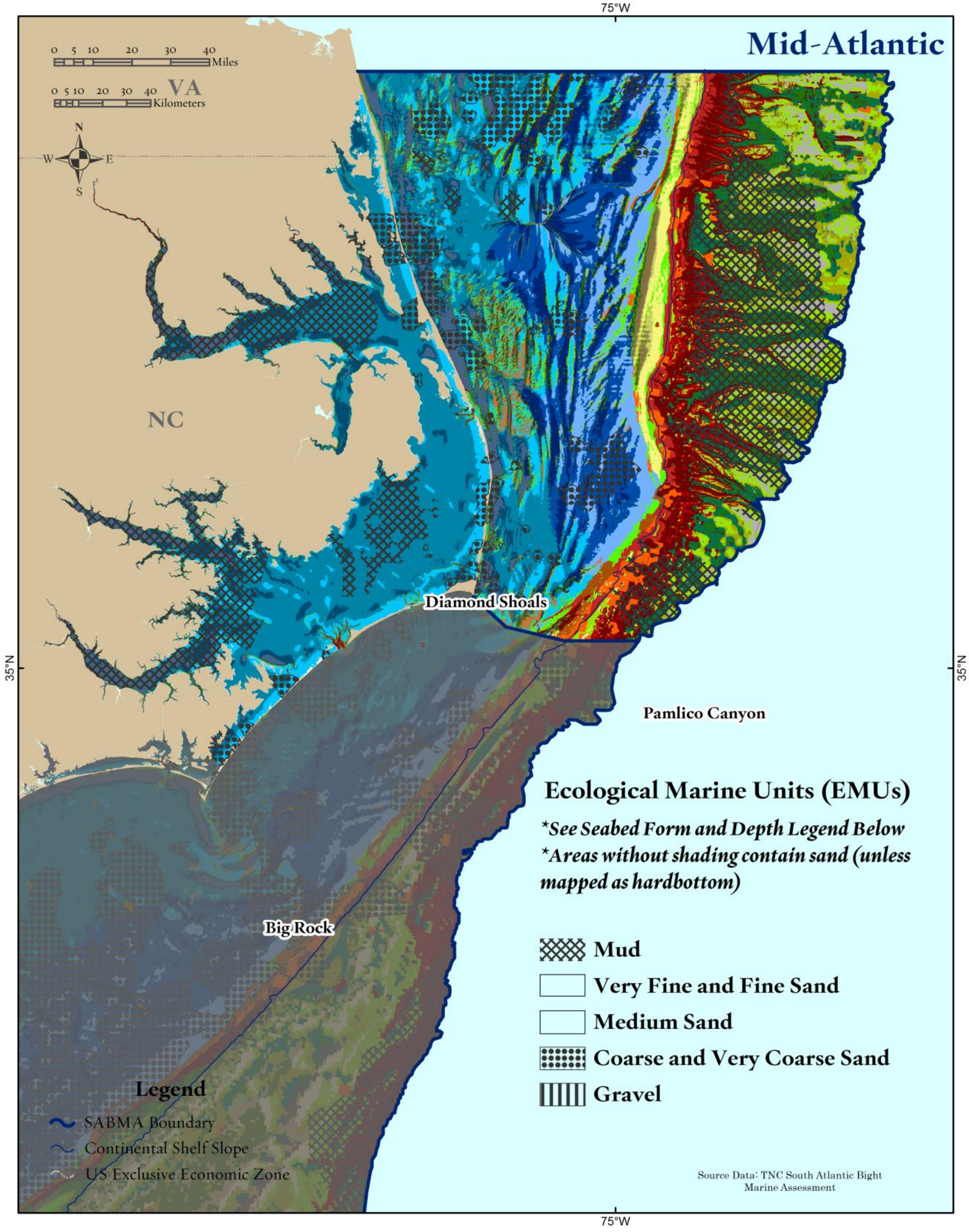


Figure 3.38. Ecological Marine Units of the mid-Atlantic subregion: depth zones, seabed forms, hardbottom and soft sediment

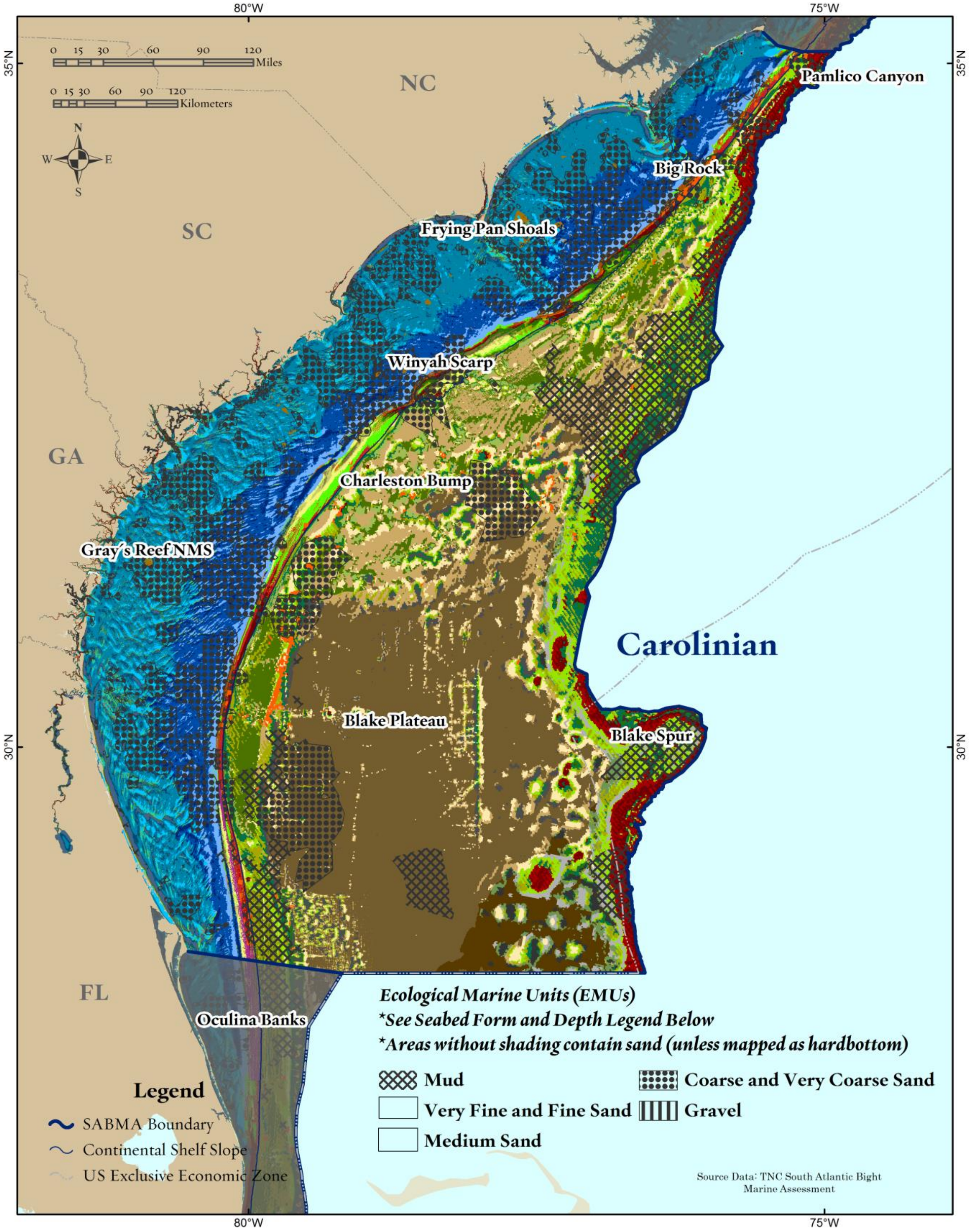
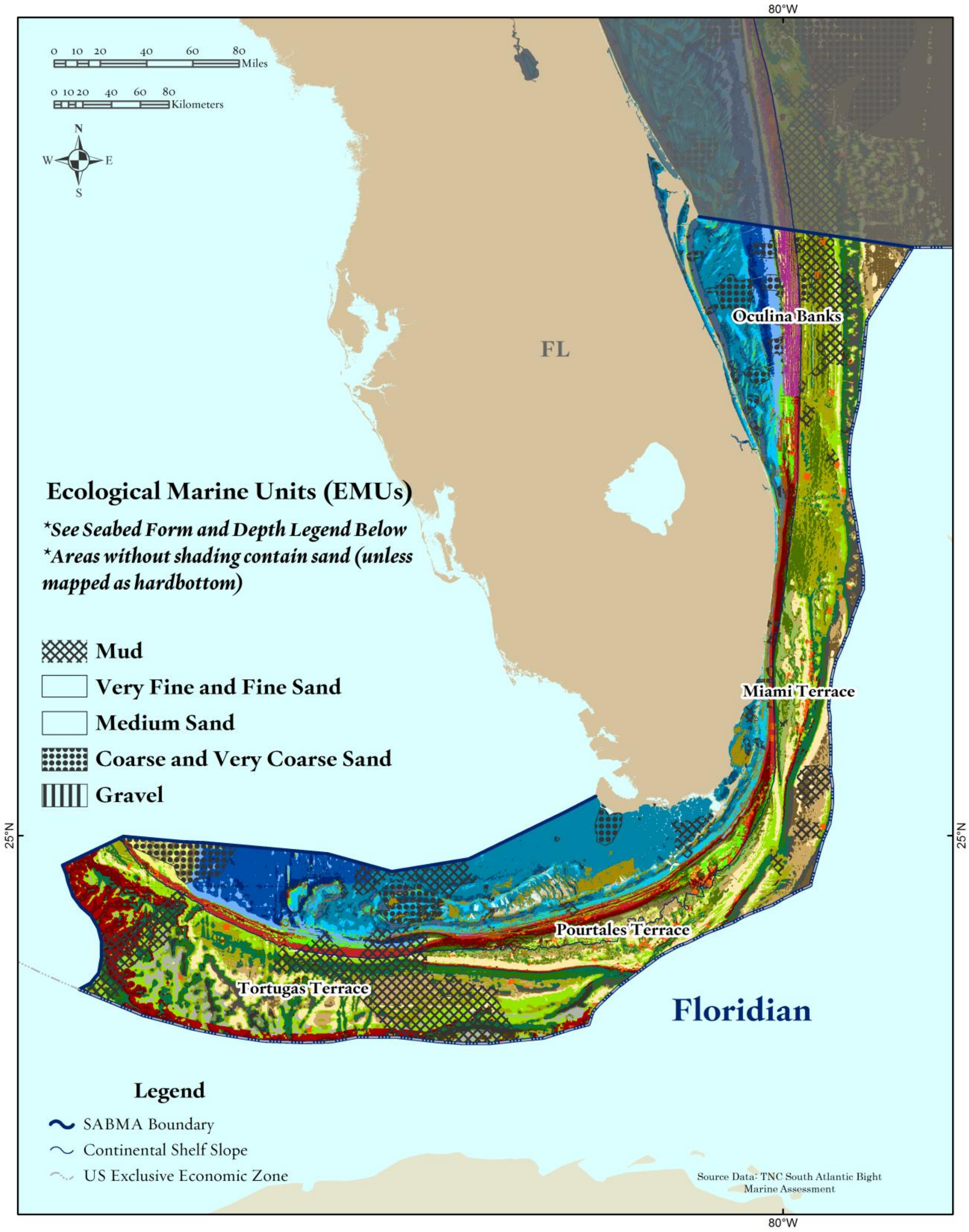


Figure 3.39. Ecological Marine Units of the Carolinian subregion: depth zones, seabed forms, hardbottom, and soft sediment



Source Data: TNC South Atlantic Bight Marine Assessment

Figure 3.40. Ecological Marine Units of the Floridian subregion: depth zones, seabed forms, hardbottom, and soft sediment

Human Interaction and Threats

(This section is condensed from Fautin et al. 2010 except where noted)

South Atlantic seafloor habitats are sensitive to a range of alterations from increased sea temperature and ocean acidification to overfishing and dredging. Extensive coastal development has impacted the habitats of estuarine species and estuarine-dependent stages of offshore species. Nonselective fishing gear, invasive species, and changing environmental factors make management for sustainable fisheries and conservation of biodiversity a challenge. Coral reefs are in decline worldwide as global change and concomitant ocean acidification and sea level rise degrade these nearshore habitats.

Fisheries in the region target the highly diverse assemblage of reef fishes associated with hardbottom substrates or coral reefs. Overfishing has depleted populations of top-level demersal predatory fishes such as snappers and groupers, and fishing pressure and demand remain high. These depletions, combined with fishing gear effects, likely impact the health of associated reef species such as algae, invertebrates, and other vertebrates. Management efforts are largely aimed at restoring sustainable stocks of individual species rather than the ecosystem as a whole, and the interactions among reef species are poorly understood. Decades of fishing on reef fish spawning aggregations have resulted in declining abundance, although recent protection of spawning sites has reversed this trend for mutton snapper (Burton et al. 2005) and may be effective for other species. Finally, there is concern about the large populations of the invasive lionfish (Pterois spp.) now present in some reef areas. Because lionfish have no predators in this system and they prey on small fishes, including new recruits, their impact on endemic fish population recovery and restoration could be substantial.

Reef-forming corals of the Florida Keys are declining (National Marine Sanctuary Program 2007), their poor condition resulting from combined effects of coastal development, overfishing, ship groundings, temperature increases, and water quality degradation from terrestrial, marine, and atmospheric pollution. The National Marine Fisheries Service is now evaluating the status of 82 species of stony coral that the Center for Biological Diversity has asked to be listed as threatened or endangered under the Endangered Species Act. These include *Montastrea* spp., which form large colonies and are important in building reefs of the Florida Keys, and *Oculina varicosa*, which occurs on deep reefs in the region. New coral species and assemblages are likely to be discovered in deep water sponge and coral fauna of the Blake Plateau.

Sediment dredging occurs in nearshore sand flats, shoals, and shoal-ridge complexes. Michel et al. (2013) studied the effects and provided recommendations to limit the physical and biological impacts of dredging on seafloor habitats. These include: dredging only on shoals with a large height to depth ratio, dredging only in actively accreting areas, and using rotational dredging (or removing materials in bands) to leave untouched sediment in- between to provide a local source of benthic infauna for recolonization. They encourage dredgers to maintain shoal geometry by following natural contours, limiting the depth and amount of removal to less than 10% per shoal, and avoiding removal from the crest in order to maintain nursery habitat. If hardbottom habitat or coral reefs occur in the vicinity of the shoal they suggest that vessels restrict anchoring or drilling to avoid these features.

Management and Conservation

The South Atlantic region has been the subject of substantial conservation efforts including three National Marine Sanctuaries (NMS), 53 Habitat Areas of Particular Concern (HAPC), and eight deepwater Marine Protected Areas (MPA). The designation of reef areas as no-fishing zones has been successful in restoring populations of top-level predatory fishes in the Florida Keys (Kramer and Heck 2007), and recent implementation of small areas where bottom fishing is not allowed show promise for restoring predators in those areas as well.

The region contains three National Marine Sanctuaries. Monitor, the nation’s first marine sanctuary was established in 1975 to protect the shipwreck of the USS Monitor. Gray's Reef, designated in 1981, protects a 5,700-hectare (22 mi^2) stretch of natural rocky reef and hardbottom on the Continental Shelf off the Georgia coast. The Florida Keys, established in 1990, protects 751,000 hectares (2,900 square miles) of waters surrounding the Florida Keys and includes the world’s third largest barrier reef, extensive seagrass beds, mangrove-fringed islands, and more than 6,000 species.

The 53 Habitat Areas of Particular Concern (HAPC) have been designated for deepwater corals, sargassum, and essential fish habitat. To safeguard the importance and uniqueness of deep water coral habitats in the South Atlantic, the South Atlantic Fisheries Management Council designated five areas, encompassing more than 59,000 km^2 (23,000 mi^2), as Coral Habitat Areas of Particular Concern (C-HAPC) in 2010. Management measures to help protect these sensitive habitats include a prohibition on the use of fishing gear (bottom longline, bottom and mid-water trawl, dredge, pot, and trap), anchoring by fishing vessels, and possession of deep water coral. Oculina Bank, designated in 1984 by the council, closed 9,320 hectares (36 square miles) on the upper slope off Florida to trawling, dredging, longlining, and trapping to protect banks of ivory tree coral (*Oculina varicosa*; Ross and Nizinski 2007). Ten years later, the council created the Experimental Oculina Research Reserve, closing the area to all bottom fishing indefinitely in order to protect spawning reef fishes, restore reef fish stocks, and protect sensitive habitat that includes at least 350 invertebrate species (Ross and Nizinski 2007; Reed 2002). The large Deep Sea Coral C-HAPC includes a substantial portion of deep water area (more than 400 m^2 (4,300 ft^2), and has been approved to protect banks of the coral *Lophelia* and other coral banks on the Blake Plateau and the Straits of Florida.

The smaller HAPCs are mostly focused on protecting essential habitat for particular fish species. The designated habitats include: sandy shoals (e.g., Cape Lookout, Cape Fear), estuaries (e.g., Ace Basin, Indian River lagoon), and hardbottom or shelf habitat (e.g., Fathom Ledge, Big Rock, The Point, Charleston Bump). These designations are expected to have positive impacts on the conservation of biodiversity, although they vary widely in their degree of protection. Some HAPCs, such as the Charleston Bump complex, have seasonal fisheries closures.

Eight Marine Protected Areas (MPAs) were established by the SAFMC in 2009 to protect a portion of the long-lived, deep water, snapper and grouper species such as snowy grouper, speckled hind, and blueline tilefish. These MPAs consist of eight no-bottom-fishing zones on the outer Continental Shelf between southern North Carolina and the Florida Keys that range in size from 2,070 to 38,850 hectares (8 to 150 square miles). They all encompass natural habitat except for one area off Charleston, South Carolina, that was established to create a deep water artificial reef. These small areas are aimed at protecting deepwater reef species and providing areas where a natural reef ecosystem can function. The small MPAs in the region will be useful in providing data on how no-take zones established for the conservation of habitat and restoration of fishery species affect sustainable fisheries and biodiversity.

The region's estuarine resources are partially protected by five National Estuary Research Reserves. These include the four linked sites in North Carolina (from Currituck Banks south to Masonboro Island), North Inlet-Winyah Bay and ACE Basin in South Carolina, Sapelo Island in Georgia, and Guana Tolomato Matanzas in northeast Florida. These areas comprise large shallow sounds and other estuarine lagoons and tidal creeks, relatively pristine saltmarsh, mangrove and other wetlands, subtidal seagrass and oyster beds, and upland maritime forest.

The many small HAPCs and the dispersed nature of the seafloor habitats characterized in this study (hardbottom, coral mounds, shoal, ridges, sand waves) suggest a crucial role for multi-objective ocean planning. The maps and data provided in this report, in conjunction with the SAFMC's mapped HAPCs and essential fish habitats, offer a strong spatial foundation for characterizing the region's key habitats and processes. We encourage agencies such as the Bureau of Ocean Energy Management and the Army Corps of Engineers to incorporate this information into their planning and permitting for dredging, offshore mineral mining, oil and gas development and leasing, alternative energy development, and state-based wind energy siting to ensure the conservation of marine diversity.

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