STATE OF DEEP CORAL ECOSYSTEMS IN THE NORTHEASTERN US REGION: MAINE TO CAPE HATTERAS

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I. INTRODUCTION

The U.S. Northeast Shelf Large Marine Ecosystem encompasses 260,000 square km and extends from the Gulf of Maine and Georges Bank southward through southern New England waters and the Middle Atlantic Bight to Cape Hatteras. It extends from the coast eastward to the edge of the continental shelf and slope and offshore to the Gulf Stream (Sherman et al. 1996). Some of the specific locations with known occurrences of deep corals include parts of the Gulf of Maine, Georges Bank, as well as a number of canyons that bisect the continental shelf and slope. Deep corals have also recently been collected from the New England Seamount chain; the seamounts are located off the continental shelf, rising above the abyssal plain, and they encompass more than 30 major volcanic peaks extending from Georges Bank southeast for about 1,100 km to the eastern end of the Bermuda Rise (Figure 5.1). Several recent surveys have taken place here, although most of the seamount chain is located outside the 200 nautical mile U.S. Exclusive Economic Zone (EEZ); however, Bear, Physalia, Mytilus, and Retriever Seamounts do occur within the EEZ.

In the U.S. Northeast Shelf Large Marine Ecosystem, deep corals have been noted since the surveys of Verrill in the 19th century (Verrill 1862, 1878a, 1878b, 1879, 1884) and as fisheries bycatch since that period. They also occur off Atlantic Canada on the continental slope and in submarine canyons, and are particularly abundant in the Northeast Channel (Verrill 1922; Deichman 1936; Breeze et al. 1997; MacIsaac et al. 2001; Mortensen and Buhl-Mortensen 2004; Gass and Martin Willison 2005; Mortensen et al. 2005). Many gorgonian corals such as *Paragorgia* have been regularly encountered by fishermen on hard substrate such as boulders, gravel, or rocky outcrops (e.g., Breeze et al. 1997; Leverette and Metaxas 2005).

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This chapter summarizes the current knowledge of deep corals and deep coral communities for the U.S. Northeast Shelf Large Marine Ecosystem, including the diversity of coral species and their distribution, associated species, and habitat preferences. In addition, a summary of current stressors affecting these habitats, and existing conservation and management activities are presented. Gaps in our understanding of deep coral communities and a summary of research priorities that could help fill these gaps are highlighted as a key need to assist in identifying future actions to conserve and manage these vulnerable ecosystems.

However, it should be noted that to our knowledge the northeast region does not have the abundance of large, structure-forming deep corals and deep coral habitats that are present in other regions. Thus, we will confine our discussions to the major gorgonian species such as, for example, *Paragorgia arborea*, *Primnoa resedaeformis*, *Acanthogorgia armata*, and *Paramuricea grandis*, and others, as well as some of the more noteworthy alcyonaceans (soft corals) and scleractinians (stony corals).

II. GEOLOGICAL SETTING

This brief review of the pertinent geological characteristics of the regional systems of the U.S. Northeast Shelf Large Marine Ecosystem, as well as the subsequent section on the oceanographic characteristics, is based on several summary reviews. Literature citations are not included because these are generally

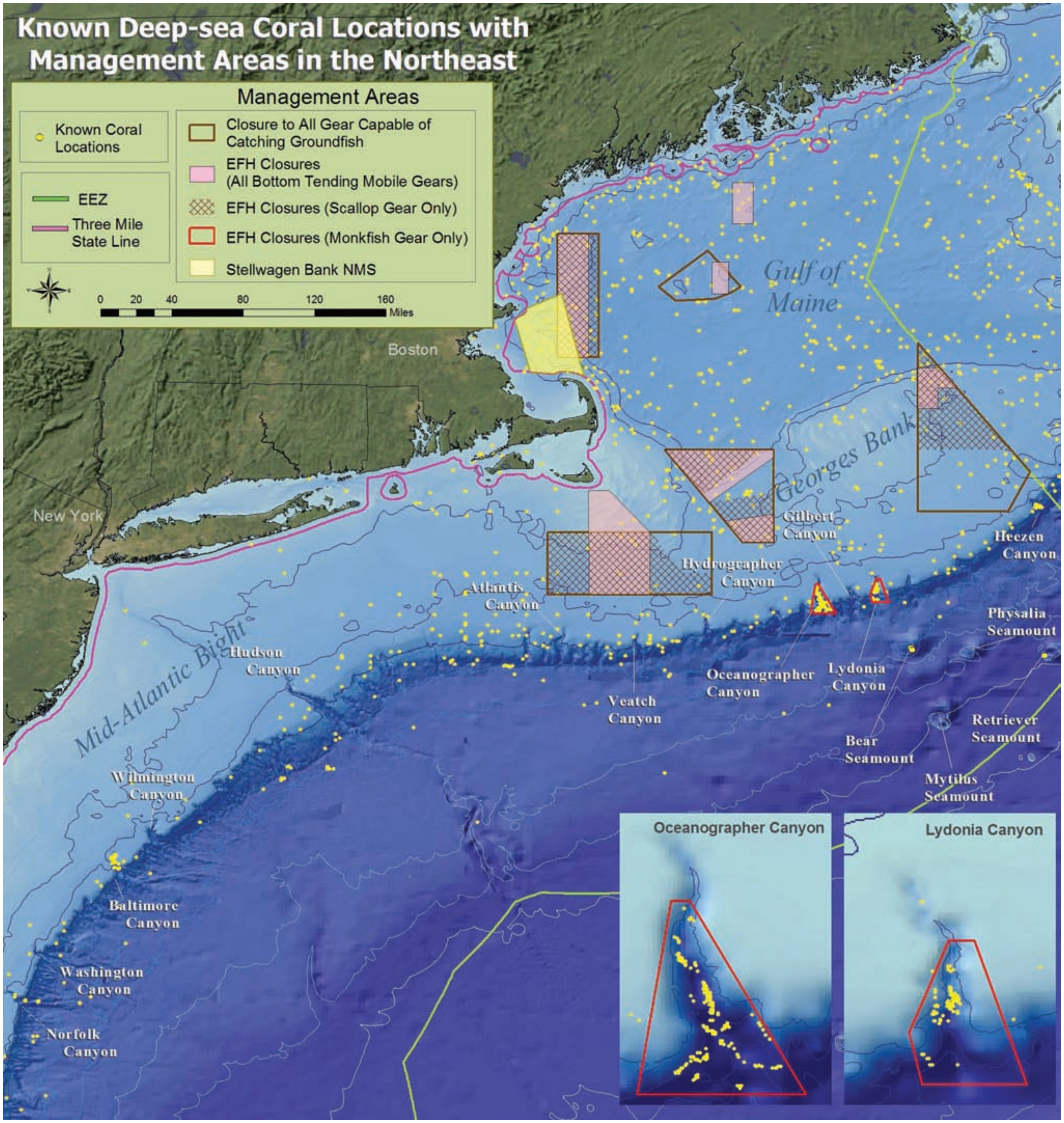


Figure 5.1 Coral Distribution - Deep coral data from the Theroux and Wigley (1998) and the Watling et al. (2003) databases represent known locations of stony, gorgonian, and true soft deep coral species from data ranging from (but not inclusive of) 1870 to the 1990s. This information does not represent all deep coral locations in this region as the U.S. Exclusive Economic Zone has not been extensively surveyed for deep corals. Also, certain deep coral points may no longer be present due to natural and human induced impacts that have occurred since the point was sampled. Essential Fish Habitat (EFH) Closed Areas prohibit the use of mobile bottom-tending gear indefinitely. Northeast Multispecies Closed Areas,indicated in the legend by “Closures to All Gear Capable of Catching Groundfish” prohibit the use of the gear capable of catching groundfish except in portions of the closed areas defined in the Special Access Program during certain times of the year (see NEFMC website). No fishing restrictions exist within the boundaries of the Stellwagen Bank NMS with the exception of the sliver that overlaps both the NEFMC Western Gulf of Maine Groundfish and Western Gulf of Maine Essential Fish Habitat Closed Areas. In addition to the EFH Closed Areas on Georges Bank and in southern New England, Lydonia and Oceanographer Canyons on the continental shelf-break are also considered EFH Closures and were implemented in the Monkfish FMP in 2005. Within these areas, trawling and gillnetting while on a monkfish (*Lophius americanus*, goosefish) days-at-sea (DAS) is prohibited indefinitely to protect the sensitive habitats therein, including deep coral and other structure-forming organisms.

accepted descriptions of the regional systems. Source references include, and more information can be found in: Backus and Bourne (1987), Schmitz et al. (1987), Tucholke (1987), Wiebe et al. (1987), Cook (1988), Stumpf and Biggs (1988), Townsend (1992), Conkling (1995), Brooks (1996), Sherman et al. (1996), Beardsley et al. (1997), Dorsey (1998), Packer (2003), Stevenson et al. (2004), Auster et al. (2005), and Babb (2005).

Gulf of Maine

The Gulf of Maine is a semi-enclosed continental shelf sea of 90,700 sq. km bounded on the east by Browns Bank, on the north by the Scotian Shelf, on the west by the New England states, and on the south by Cape Cod and Georges Bank. It is distinct from the Atlantic, an ecologically separate sea within a sea. The Gulf is characterized by a system of 21 deep basins, moraines, rocky ledges, and banks, with limited access to the open ocean. Sediments in the Gulf of Maine are highly variable and, when coupled with the vertical variation of water properties found in the Gulf, results in a great diversity of benthic habitat types and benthic organisms. Sand, silt, and clay are found throughout the Gulf, with the finer sediments generally found in the deeper basins. Rocky substrates (which include gravel, pebbles, cobbles, and boulders) are found primarily in the Northeast Channel, with other smaller, more variable rocky areas interspersed in the Gulf. Rocky outcrops form significant features, such as Cashes Ledge, and benthic fauna found on these include sponges, tunicates, bryozoans, and hydroids.

Of the 21 deep basins, Jordan (190 m), Wilkinson (190 m), and Georges Basins (377 m), are the largest basins and deepest habitats within the Gulf of Maine. Their great depths resulted from glacial erosion of relatively soft rocks. The bottom sediments of these deep basins are generally very fine, featureless muds, but some gravel may also be found; little or no sediment transport occurs here. Unique invertebrate communities are found on the seafloor, including deep corals, ophiuroids (brittle stars), tube building amphipods, burrowing anemones, and polychaete worms.

Georges Bank

Georges Bank is a shallow (3-150 m depth), elongate extension of the continental shelf that extends from Cape Cod, Massachusetts (Nantucket Shoals) to Nova Scotia (Scotian Shelf) and covers more than 40,000 km^2. It is characterized by a steep slope on its northern edge and a broad, flat, gently sloping southern flank. It is separated from the rest of the continental shelf to the west by the Great South Channel. The central region of the Bank is shallow. Bottom topography on the eastern Bank is characterized by linear ridges in the western shoal areas; relatively smooth, gently dipping sea floor on the deeper, eastern most part, and steeper and smoother topography incised by submarine canyons on the southeastern margin. The sediments vary widely, but are mostly sandy or silty, with coarse gravel and boulders at the northern margins.

At least 70 large submarine canyons occur near the shelf break along Georges Bank and the Mid-Atlantic down to Cape Hatteras, cutting into the slope and occasionally up into the shelf as well. The canyons are typically “v” shaped in cross section, and include features such as steep walls, exposed outcroppings of bedrock and clay, and tributaries. Most canyons may have been formed by mass-wasting processes on the continental slope; some, like the Hudson Canyon (Mid-Atlantic), may have formed because of fluvial drainage. The canyons exhibit a more diverse fauna, topography, and hydrography than the surrounding shelf and slope environments. The diversity in substrata types tends to make the canyons biologically richer than the adjacent shelf and slope.

As mentioned above, the New England Seamount chain extends southeast of Georges Bank for about 1,100 km, rising as much as 4,000 m above the Sohm Abyssal Plain. Of the four seamounts within the U.S. EEZ, Bear Seamount is the closest and rises from a depth of 2,000-3,000 m to a summit that is 1,100 m below the sea surface. The minimum depths of the others are: Physalia (1,848 m), Mytilus (2,269 m), and Retriever (1,819 m). Several other seamounts outside the U.S. EEZ are biologically significant because they rise to relatively shallow depths. Substrate types range from solid basalt to manganese crusts to rock and coral rubble to mixtures of basalt pebbles and sand to fine carbonate oozes. Sediments cover the summits with more exposed rock surfaces on the sides.

Mid-Atlantic Bight

The Mid-Atlantic Bight refers to the region of the continental shelf and slope waters from Georges Bank south to Cape Hatteras, and east to the Gulf Stream. Here the shelf topography is relatively smooth, as depth increases linearly from shore to shelf break, except near submarine canyons. The primary features of the shelf include shelf valleys and channels, shoal massifs, scarps, and sand ridges. The main physiographic feature within the Mid-Atlantic is the Hudson Shelf Valley and Canyon, extending from the inner-continental shelf, at about the 40 m isobath, onto the continental slope. Other significant physiographic features include several other major canyons between Cape May and Cape Charles (Norfolk, Baltimore, Washington, and Wilmington), and the unique oceanography and geology off Cape Hatteras. Sediments over the Mid-Atlantic shelf are fairly uniformly distributed, and are primarily composed of sand, with isolated patches of coarse-grained gravel and fine-grained silt and mud deposits. Sand and gravel deposits vary in thickness from 0-10 m. The sands are mostly medium to coarse grains, with fine sand, silt, and clay in the Hudson shelf valley and on the outer shelf. Mud is rare over most of the shelf, but is common in the Hudson valley. Fine sediment content increases rapidly at the shelf break, which is sometimes called the "mud line," and sediments are 70-100% fines on the slope. The continental slope off Cape Hatteras also receives exceptionally high fluxes of sediment and nutrients that are funneled off the shelf above, helping to account for the high abundance of infaunal organisms found there.

III. OCEANOGRAPHIC SETTING

Gulf of Maine

The Northeast Channel between Georges Bank and Browns Bank leads into Georges Basin, and is one of the primary avenues for water exchange between the Gulf of Maine and Atlantic Ocean. The Gulf has a general counterclockwise nontidal surface current that flows around the margin of the Gulf along the shore. This current is primarily driven by fresh, cold Scotian shelf water that enters from the north and through the Northeast Channel, and freshwater runoff from coastal rivers, which is particularly important in the spring. Dense, relatively warm and saline slope water entering through the Northeast Channel from the continental slope also influences gyre formation. Gulf circulation can vary significantly from year to year due to shelf-slope interactions such as the entrainment of shelf water by Gulf Stream rings, strong winds which can create fast moving currents, and annual and seasonal inflow variations. In the summer, the water in Jordan, Wilkinson, and Georges Basins becomes layered into warm, nutrient-poor surface water; cold, nutrient-rich intermediate water; and cool high-salinity bottom water.

Georges Bank

There is a persistent clockwise gyre around Georges Bank, a strong semidiurnal tidal flow predominantly northwest and southeast, and very strong, intermittent storm-induced currents, which can all occur simultaneously. Tidal currents over the shallow top of the Bank can be very strong, and keep the waters over the Bank well mixed vertically. This results in a tidal front that separates the cool waters of the well-mixed shallows from the warmer, seasonally stratified shelf waters on the seaward and shoreward sides of the Bank. The clockwise gyre is instrumental in distribution of the planktonic community, including larval fish. Georges Bank has a diverse biological community that is influenced by many environmental conditions and is characterized by high levels of primary productivity and, historically, high levels of fish production, which includes such species as *Gadus morhua* (Atlantic cod), *Melanogrammus aeglefinus* (haddock), and *Limanda ferruginea* (yellowtail flounder).

Mid-Atlantic Bight

The shelf and slope waters of the Mid-Atlantic Bight have a slow southwestward flow that is occasionally interrupted by warm core rings or meanders from the Gulf Stream. Slope water tends to be warmer and more saline than shelf water. The abrupt gradient where these two water masses meet is called the shelf-slope front. This front is usually located at the edge of the shelf and touches bottom at about 75-100 m depth of water, and then slopes up to the east toward the surface. It reaches surface waters approximately 25-55 km further offshore. The position of the front is highly variable, and can be influenced by many physical factors.

IV. STRUCTURE AND HABITAT-FORMING DEEP CORALS

As stated in the introduction, the northeast region does not appear to have an abundance of large, structure-forming deep corals and deep coral habitats. Thus, we will confine our discussions primarily to the major deep gorgonian corals as well as to some of the more noteworthy occurrences of alcyonaceans (soft corals) and scleractinians (stony corals), including solitary species or those found in shallower habitats. Records of gorgonians and soft corals are often combined into one database, so for convenience we will be discussing those two orders simultaneously. For a complete list of the deep coral species in this region, see Appendix 5.1.

a. *Stony Corals* (Class Anthozoa, Order Scleractinia)

Cairns and Chapman (2001) list 16 species of stony corals from the Gulf of Maine and Georges Bank to Cape Hatteras (Table 5.1) (See also Cairns 1981). Most of the stony corals in this region are solitary organisms and one species, *Astrangia poculata*, can occur in very shallow water, at depths of only a few meters. Moore et al. (2003, 2004) reported several species of solitary and colonial stony corals on Bear Seamount; one notable solitary species,

Table 5.1. Stony corals from the Gulf of Maine and Georges Bank to Cape Hatteras, based on Cairns and Chapman (2001). *Vaughanella margaritata* has been reported from Bear Seamount of the New England Seamount chain (Moore et al. 2003). Depth ranges are for the western Atlantic only. * = potentially structure-forming colonial species.

Taxon	Distribution	Coloniality	Attachment	Depth (m)
Astrangia poculata (Ellis & Solander, 1786)	Endemic to western Atlantic	colonial	attached	0-263
Caryophyllia ambrosia ambrosia Alcock, 1898	Widespread (cosmopolitan) distribution	solitary	free-living	1487-2286
Caryophyllia ambrosia caribbeana Cairns, 1979	Endemic to western Atlantic	solitary	free-living	183-1646
Dasmosmilia lymani (Pourtales, 1871)	Widespread (cosmopolitan) distribution	solitary	free-living	37-366
Deltocyathus italicus (Michelotti, 1838)	Amphi-Atlantic with a disjunct distribution	solitary	free-living	403-2634
Desmophyllum dianthus (Esper, 1794)	Widespread (cosmopolitan) distribution	solitary	attached	183-2250
Enallopsammia profunda (Pourtales, 1867)*	Endemic to western Atlantic	colonial	attached	403-1748
Enallopsammia rostrata (Pourtales, 1878)*	Widespread (cosmopolitan) distribution	colonial	attached	300-1646
Flabellum alabastrum Moseley, 1873	Amphi-Atlantic with contiguous distribution	solitary	free-living	357-1977
Flabellum angulare Moseley, 1876	Amphi-Atlantic with contiguous distribution	solitary	free-living	2266-3186
Flabellum macandrewi Gray, 1849	Amphi-Atlantic with contiguous distribution	solitary	free-living	180-667
Fungiacyathus fragilis Sars, 1872	Widespread (cosmopolitan) distribution	solitary	free-living	412-460
Javania cailleti (Duch. & Mich., 1864)	Widespread (cosmopolitan) distribution	solitary	attached	30-1809
Lophelia pertusa (L, 1758)*	Widespread (cosmopolitan) distribution	colonial	attached	146-1200
Solenosmilia variabilis Duncan, 1873*	Widespread (cosmopolitan) distribution	colonial	attached	220-1383
Vaughanella margaritata (Jourdan, 1895)	Endemic to northwestern Atlantic	solitary	attached	1267

Vaughanella margaritata, represents the first record of this species since its original description over 100 years ago, and is endemic to the northwest Atlantic (Cairns and Chapman 2001). Other recent expeditions to the New England and Corner Rise Seamounts have also found stony corals (Adkins et al. 2006; Watling et al. 2005; Shank et al. 2006).

b. Black Corals (Class Anthozoa, Order Antipatharia)

Antipatharians are predominantly tropical, but some species are known to occur in the northwest Atlantic. Bushy black coral (*Leiopathes* sp.) has been collected from 1643 m on Bear Seamount (Brugler 2005); it is also found in the collections of the Smithsonian Institution, having been collected in 1883 by the R/V *Albatross* from 1754 m near the same area off Georges Bank. Within the New England Seamount chain, very few associated species have been found living on *Leiopathes* sp. (Brugler 2005). Another black coral, *Cirrhipathes* sp., is also found in the Smithsonian Institution collections, and was also collected in 1883 by the R/V *Albatross* at 262 m off Virginia. Watling et al. (2005) collected at least 8 species of black coral from the seamounts during their 2004 expedition; Brugler and France (2006) observed and collected 15 species of black coral during their 2005 expedition to the New England and Corner Rise Seamounts, including 7 species that they did not previously observe on the seamounts.

c. Gold Corals (Class Anthozoa, Order Zoanthidea)

No records of species from this order have been found in this region.

Table 5.2. List of gorgonians and soft corals known to occur on the northeastern U.S. continental shelf and slope north of Cape Hatteras, from Watling and Auster (2005), with taxonomic changes based on Integrated Taxonomic Information System (ITIS 2006) database/website and S. Cairns (Smithsonian Institution, Washington, D.C., pers. comm.).

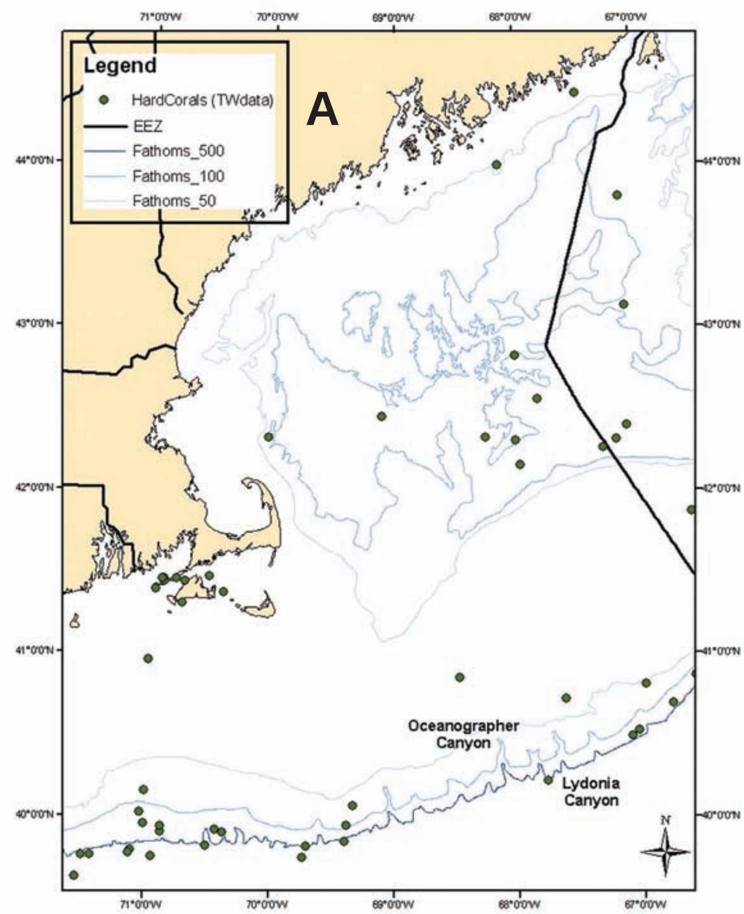
Taxa	Species
Order Gorgonacea	
Acanthogorgiidae	*Acanthogorgia armata* Verrill, 1878
Paramuriceidae	*Paramuricea grandis* Verrill, 1883
	Paramuricea placomus (Linné, 1758)
	Paramuricea n. sp.
	Swiftia casta (Verrill, 1883)
Anthothelidae	*Anthothela grandiflora* (Sars, 1856)
Paragorgiidae	*Paragorgia arborea* (Linné, 1758)
Chrysogorgiidae	*Chrysogorgia agassizii* (Verrill, 1883)
	Iridogorgia pourtalesii Verrill, 1883
	Radicipes gracilis (Verrill, 1884)
Primnoidae	*Narella laxa* Deichmann, 1936
	Primnoa resedaeformis (Gunnerus, 1763)
	Thouarella grasshoffi Cairns, 2006
Isididae	*Acanella arbuscula* (Johnson, 1862)
	Keratoisis ornata Verrill, 1878
	Keratoisis grayi Wright, 1869
	Lepidisis caryophyllia Verrill, 1883
Order Alcyonacea	
Clavulariidae	*Clavularia modesta* (Verrill, 1874)
	Clavularia rudis (Verrill, 1922)
Alcyoniidae	*Alcyonium digitatum* Linné, 1758
	Anthomastus grandiflorus Verrill, 1878
	Anthomastus agassizii Verrill, 1922
Nephtheidae	*Gersemia rubriformis* (Ehrenberg, 1934)
	Gersemia fructicosa (Sars, 1860)
	Capnella florida (Rathke, 1806)
	Capnella glomerata (Verrill, 1869

*d. Gorgonians (*Class Anthozoa, Order Gorgonacea)

The Watling et al. (2003) database obtained records of both gorgonian and true soft coral occurrences from a variety of sources, including Verrill, Deichmann (1936), Hecker and collaborators [e.g.; Hecker (1980, 1990), Hecker and Blechschmidt (1980), Hecker et al. (1980, 1983); see descriptions below], Yale Peabody museum collections, the NEFSC benthic database of identified coral taxa, and observations from recent National Undersea Research Center (NURC) field studies [for further information, see Watling and Auster (2005)]. A total of 17 species in 7 families were recorded for the northeastern U.S. shelf and slope north of Cape Hatteras (Table 5.2). These 17 species in the seven gorgonian families (Acanthogorgiidae, Paramuriceidae, Anthothelidae, Paragorgiidae,

Table 5.3. Identity and distribution of Pennatulacea on the northeastern U.S. continental shelf and slope. NMNH = Smithsonian Natural Museum of Natural History; OBIS = Ocean Biogeographic Information System.

Higher Taxon	Species	Distribution	Depth Range (m)	Reference
Anthoptilidae	*Anthoptilum grandiflorum*	Newfoundland to Bahamas, Lousiana, Chile, Hawaii, Antarctica, N. Europe	274-3651	U.S. NMNH collection, OBIS
	Anthoptilum murrayi	Lydonia Canyon to Puerto Rico, Hawaii, Aleutians, Japan, W. Africa, N. Europe	430-2491 (1538 m min in NE U.S.)	U.S. NMNH collection, OBIS
Kophobelemnidae	*Kophobelemnon stelliferum*	Newfoundland to South Carolina, Japan, W. Africa, N. Europe	393-2199 (1330 m min in NE U.S.)	U.S. NMNH collection, OBIS
	Kophobelemnon scabrum	Nova Scotia to Virginia	1977-2249	U.S. NMNH collection
	Kophobelemnon tenue	Massachusetts to Virginia	2491-4332	U.S. NMNH collection
Pennatulidae	*Pennatula aculeata*	Newfoundland to Virginia, California, Iberia, N. Africa	119-3316	U.S. NMNH collection, OBIS
	Pennatula grandis	New Jersey, Bay of Biscay	1850-2140	U.S. NMNH collection, OBIS
	Pennatula borealis	Newfoundland to North Carolina, California	219-2295	U.S. NMNH collection, OBIS
Protoptilidae	*Distichoptilum gracile*	Nova Scotia to North Carolina, W. Africa, N. Europe	1211-2844 (doubtful report at 59 m)	U.S. NMNH collection, OBIS
	Protoptilum abberans	Nova Scotia to Virginia	1483-2359	U.S. NMNH collection
	Protoptilum carpenteri	Massachusetts to North Carolina, W. Africa, N. Europe	1334-2194	U.S. NMNH collection, OBIS
Scleroptilidae	*Scleroptilum gracile*	Massachusetts to Virginia	2513-4332	U.S. NMNH collection
	Scleroptilum grandiflorum	Massachusetts to North Carolina, Panama, W. Africa	1502-2505	U.S. NMNH collection, OBIS
Umbellulidae	*Umbellula guntheri*	Massachusetts to Virginia, Louisiana	2683-3740 (3166 m min in NE U.S.)	U.S. NMNH collection
	Umbellula lindahlii	Massachusetts to the Virgin Islands, Louisiana, Suriname, N. Europe, Indian O.	549-3338 (1538 m min in NE U.S.)	U.S. NMNH collection, OBIS
Virgulariidae	*Balticina finmarchica*	Newfoundland to Massachusetts, NC (doubtful), the Virgin Islands, Alaska	37-2249 (229 m min in NE U.S.)	U.S. NMNH collection
	Stylatula elegans	New York-Florida, Iberia	20-812 (51 m min in NE U.S.)	U.S. NMNH collection, OBIS



e. *True Soft Corals* (Class Anthozoa, Order Alcyonacea)

As stated above, the Watling et al. (2003) database obtained records of both gorgonian and true soft coral occurrences from a variety of sources, including Verrill, Deichmann (1936),Hecker and collaborators [e.g.; Hecker (1980, 1990), Hecker and Blechschmidt (1980), Hecker et al. (1980, 1983); see descriptions below], Yale Peabody museum collections, the NEFSC benthic database of identified coral taxa, and observations from recent National Undersea Research Center (NURC) field studies [for further information, see Watling and Auster (2005)]. A total of 9 species in 3 families were recorded for the northeastern U.S. shelf and slope north of Cape Hatteras (Table 5.2). Two species that were not common in the database, but apparently are very numerous in nearshore records, were the soft corals *Gersemia rubiformis* and *Alcyonium* species (Watling and Auster 2005). As with the gorgonians, it should be noted that, for a variety

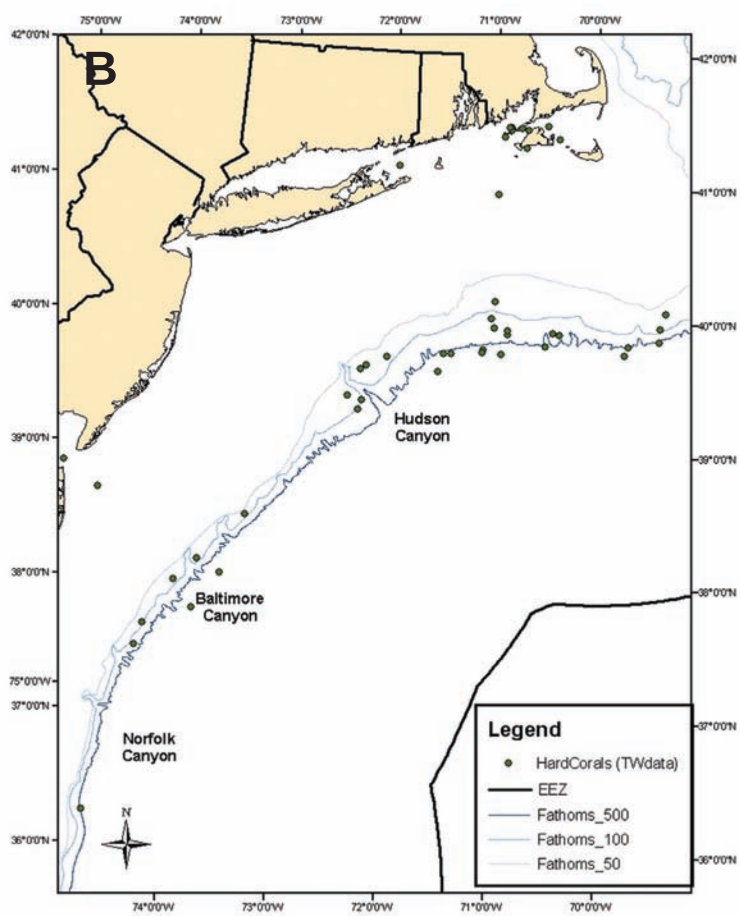


Figure 5.2 A. Distribution of stony or hard corals (*Astrangia, Dasmosmilia*, and *Flabellum*) in the Gulf of Maine and Georges Bank. B) Distribution of stony or hard corals (*Astrangia*, *Dasmosmilia*, and *Flabellum*) in the Mid-Atlantic. Source credit: Theroux and Wigley (1998) database.

Chrysogorgiidae, Primnoidae, and Isiddae) are the best documented because of their larger sizes, as well as being most abundant in the deeper waters of the continental slope (Watling and Auster 2005). It should be noted that, for a variety of reasons, there is uncertainty about the accuracy of the identifications from these various surveys (Watling and Auster 2005), so these surveys should be interpreted with caution. Gorgonians have also been collected during recent expeditions to the New England and Corner Rise Seamounts (Moore et al. 2003, 2004; Watling et al. 2005, 2006).

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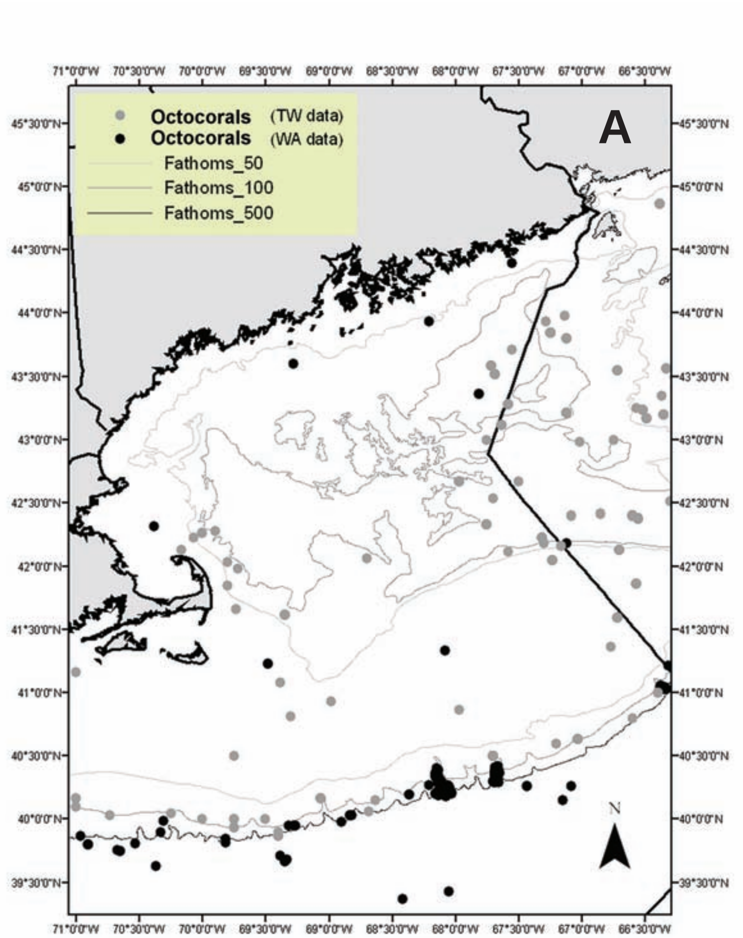
f. *Pennatulaceans* (Class Anthozoa, Order Pennatulacea)

Records of sea pens were drawn from Smithsonian Institution collections and the Theroux and Wigley benthic database. Nearly all materials from the former source were collected either by the U.S. Fish Commission (1881-1887) or for the Bureau of Land Management (BLM) by the Virginia Institute of Marine Sciences (1975-1977) and Battelle (1983-1986). These latter collections heavily favor the continental slope fauna. The Theroux and Wigley collections (1955-1974) were made as part of a regional survey of all benthic species (Theroux and Wigley 1998), heavily favoring the continental shelf fauna. A list of 17 sea pen species representing five families was compiled from these sources for the northeastern U.S. (Table 5.3). None commonly occur in shallow water, and only two species are known from the lower continental shelf depths (80-200 m) in this region: *Pennatula aculeata* (common sea pen) and *Stylatula elegans* (white sea pen). *P. aculeata* is common in the Gulf of Maine (Langton et al. 1990), and there are numerous records of *Pennatula* sp. on the outer continental shelf as far south as the Carolinas in the Theroux and Wigley database. *S. elegans* is abundant on the Mid-Atlantic coast outer shelf (Theroux and Wigley 1998). The other 15 sea pen species have been reported exclusively from the continental slope



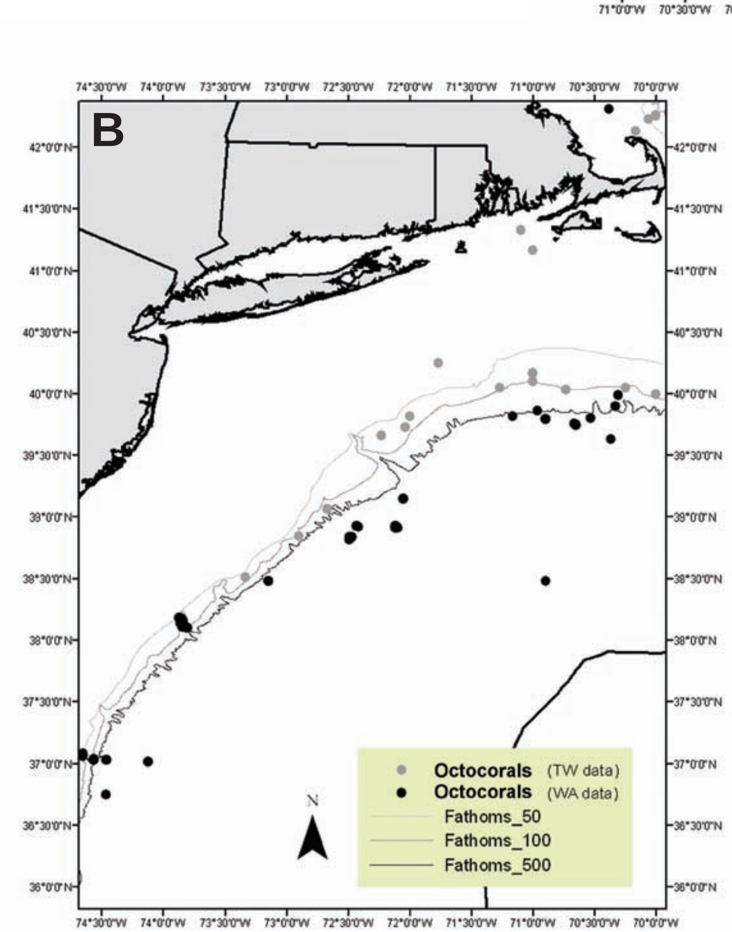
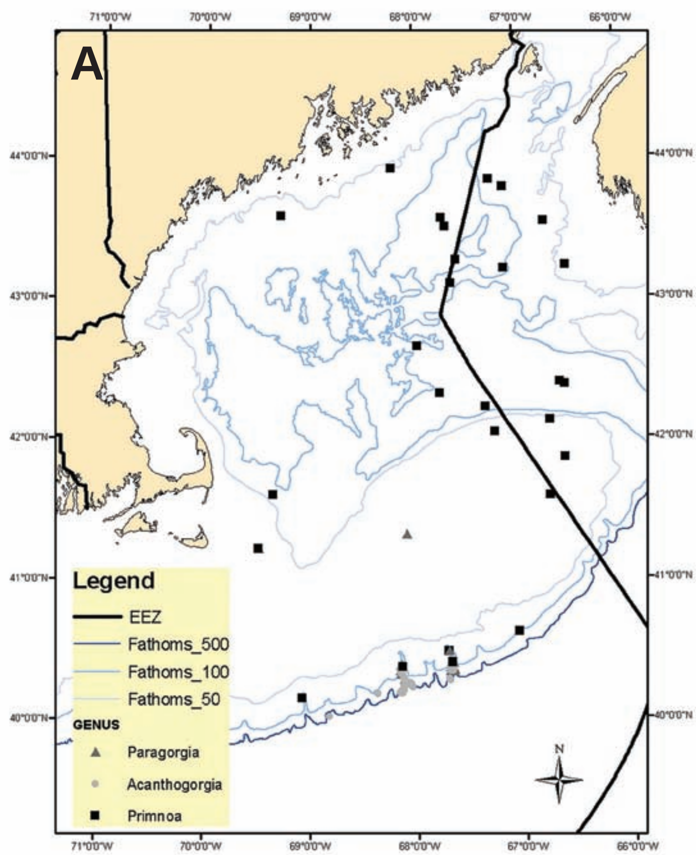


Figure 5.3 A) Distribution of gorgonians and soft corals in the Gulf of Maine and Georges Bank. B) Distribution of gorgonians and soft corals in the Mid-Atlantic. Source credits: Theroux and Wigley (1998) database, Watling et al. (2003) database.

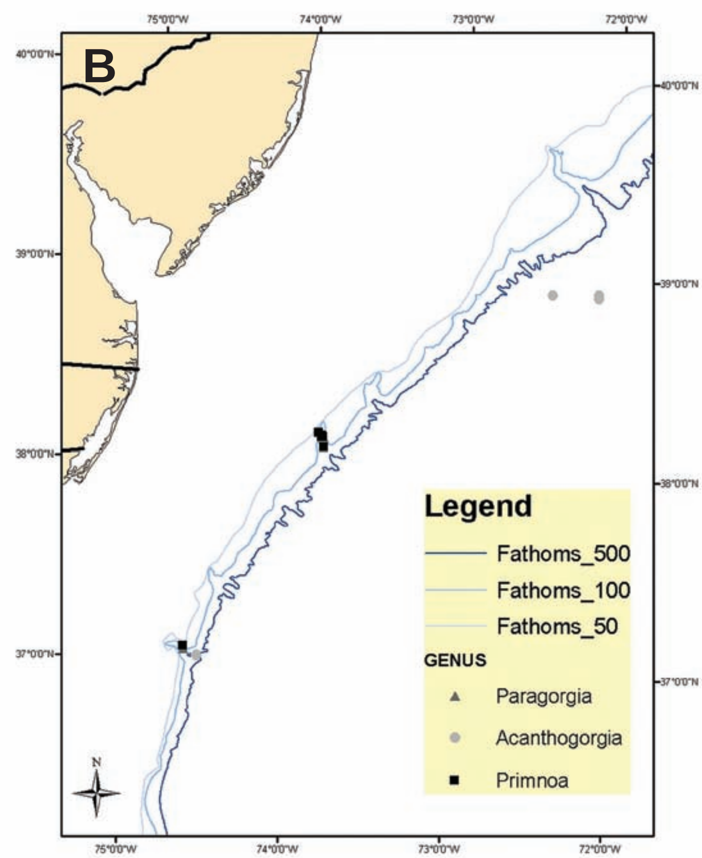


V. SPATIAL DISTRIBUTION OF CORAL SPECIES AND HABITATS

General Distribution in the Gulf of Maine, Georges Bank, and Mid-Atlantic Bight

Theroux and Wigley (1998) described the distribution of deep corals in the northwest Atlantic, based on samples taken from 1956-1965. They often do not distinguish between taxonomic groups; e.g., stony corals such as *Astrangia* sp. and *Flabellum* sp. are lumped together with the various types of anemones in the subclass Zoantharia. The distributions of only the stony corals, specifically *Astrangia*, *Dasmosmilia*, and *Flabellum*, from the Theroux and Wigley (1998) database in the Gulf of Maine/Georges Bank, and Mid-Atlantic are depicted in Figures 5.2A and B, respectively. There appears to be a general lack of stony corals on Georges Bank (Figure 5.2A), but note their presence along the continental margin (Figure 5.2A and B).

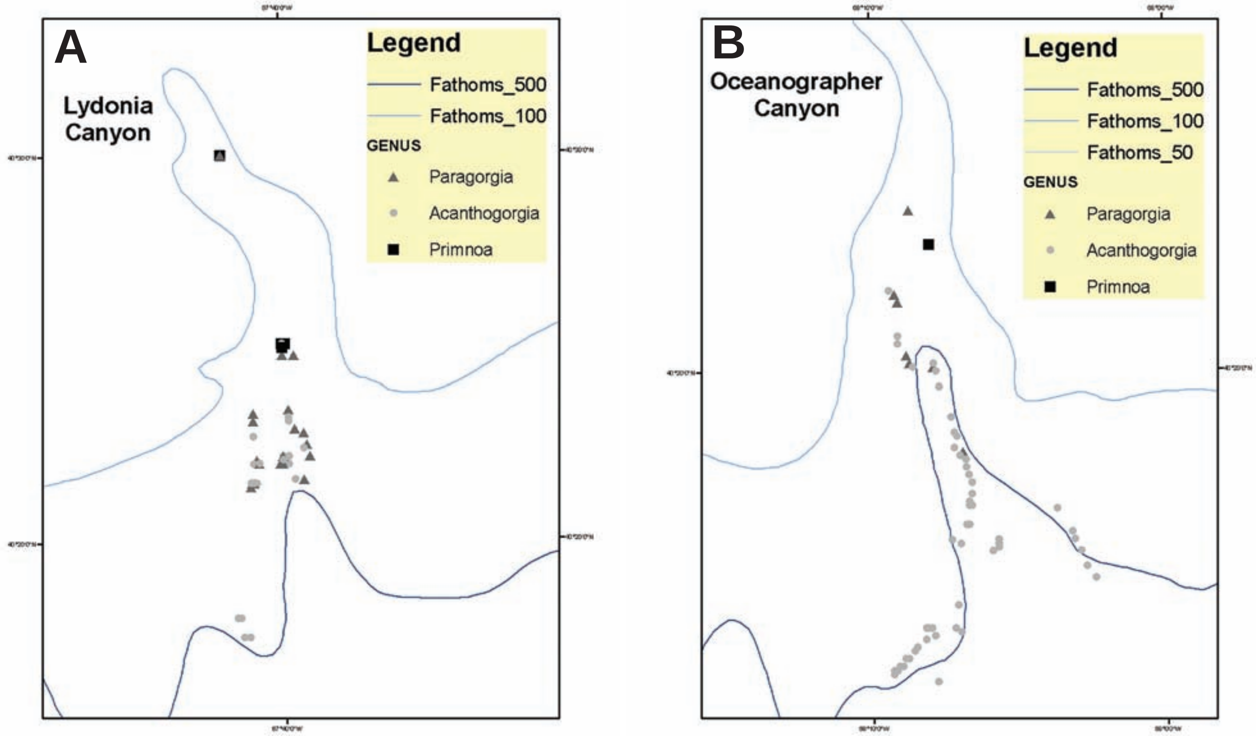
Figure 5.4 A) Distribution of the gorgonians *Acanthogorgia armata, Paragorgia arborea*, and *Primnoa resedaeformis* in the Gulf of Maine and Georges Bank. B) Distribution of the gorgonians *Acanthogorgia armata, Paragorgia arborea,* and *Primnoa resedaeformis* in the Mid-Atlantic. Source credit: Watling et al. (2003) database.



depths (200-4300 m). Unlike most other corals, sea pens live in muddy sediments, anchored in place by a swollen, buried peduncle. Some species are capable of retracting part or the entire colony into the sediment when disturbed.

g. *Stylasterids* (Class Hydrozoa, Order Anthothecatae, Suborder Filifera, Family Stylasteridae)

No records of species from this family have been found in this region (Cairns 1992).



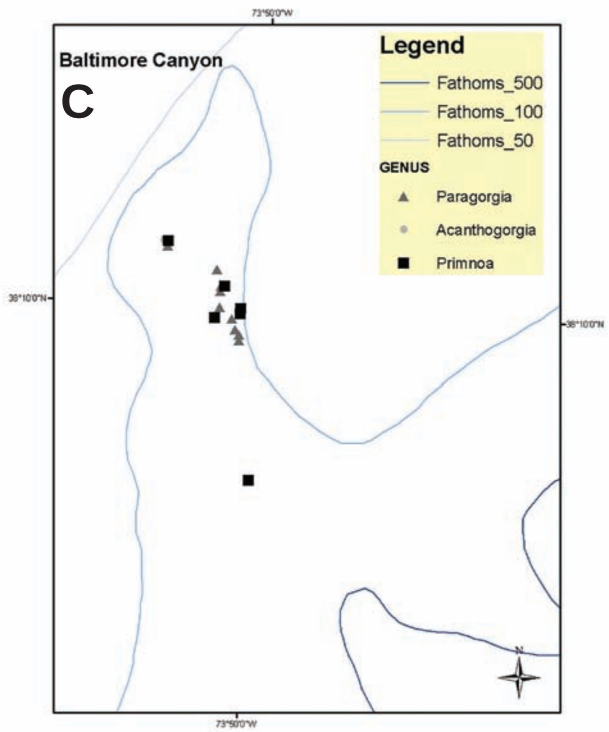


Figure 5.5 Distribution of the gorgonians *Acanthogorgia armata, Paragorgia arborea,* and *Primnoa resedaeformi*s in A) Lydonia and B) Oceanographer Canyons (Gulf of Maine) and C) Baltimore Canyon (Mid-Atlantic). Source credit: Watling et al. (2003) database.

Theroux and Wigley (1998) also discussed the soft corals, gorgonians, as well as the sea pens. They were present along the outer margin of the continental shelf and on the slope and rise, and were sparse and patchy in all areas, particularly in the northern section. Theroux and Wigley (1998) found that they were not collected in samples taken at <50 m in depth, and were most abundant between 200-500 m. Figures 5.3A and B depict the distribution of gorgonians and soft corals in the Gulf of Maine, Georges Bank, and the Mid-Atlantic, based on the Theroux and Wigley (1998) database and the Watling et al. (2003) database. Identified species include gorgonians such as *Acanella* sp., *Paragorgia arborea*, *Primnoa reseda* [now *resedaeformis*, see Cairns and Bayer (2005)] and the soft coral *Alcyonium* sp. Gorgonians and soft corals were collected from gravel and rocky outcrops (Theroux and Wigley 1998).

Watling and Auster (2005) noted two distinct distributional patterns for the gorgonians and soft corals. Most are deepwater species that occur at depths >500 m; these include species of gorgoninans in the genera *Acanthogorgia*, *Acanella*, *Anthothela*, *Lepidisis*, *Radicipes*, and *Swiftia*, and soft corals in the genera *Anthomastus* and *Clavularia*. Other species occur throughout shelf waters to the upper continental slope and include the gorgonians *P. arborea*, *P. resedaeformis*, and species in the genus *Paramuricea*. *P. arborea* was described by Wigley (1968) as a common component of the gravel fauna of the Gulf of Maine, while Theroux and Grosslein (1987) reported *P. resedaeformis*, as well as *P. arborea*, to be common on the Northeast Peak of Georges Bank. Both species are widespread in the North Atlantic (Tendal 1992); *P. resedaeformis* has been reported south to off Virginia Beach, Virginia (37°03'N) (Heikoop et al. 2002).

Figures 5.4A and B depict the distribution of three major gorgonians: *Acanthogorgia armata*, *P. arborea*, and *P. resedaeformis* in the Gulf of Maine/Georges Bank and the Mid-Atlantic, respectively, based on the Watling et al. (2003) database. All three species occur in Lydonia and Oceanographer Canyons located off Georges Bank (Figure 5.4A), and Baltimore and Norfolk Canyons in the Mid-Atlantic (Figure 5.4B). Figure 5.1 shows the locations of the major submarine canyons off the New England/Mid-Atlantic U.S. coast. The majority of records for these three species come from Lydonia, Oceanographer, and Baltimore canyons (Figure 5.5A, B, and C respectively). In addition, *P. resedaeformis* was found throughout the Gulf of Maine and on the Northeast Peak of Georges Bank (Figure 5.4A), affirming Theroux and Grosslein's (1987) observations.

It should be noted that the distribution maps presented in this chapter, based on both the Theroux and Wigley (1998) and Watling et al. (2003) databases, show presence only; i.e., they only describe where deep corals that could be identified were observed or collected. Since all areas have not been surveyed and since some specimens were not identified, the true distributions of many of these species remain unknown. However, the combination of these two databases represents the best available georeferenced data on the presence of deep corals in this region.

Continental Margin/Slope and Submarine Canyons

Dr. Barbara Hecker and her colleagues surveyed the deep corals and epibenthic fauna of the continental margin and several canyons off the northeastern U.S. in the 1980s via submersible and towed camera sled (Hecker et al. 1980, 1983). Corals were denser and more diverse in the canyons, and some species, such as those restricted to hard substrates, were found only in canyons while the soft substrate types were found both in canyons and on the continental slope (Hecker and Blechschmidt 1980). The following is a summary of their findings for several of the prominent submarine canyons and continental slope areas; the surveys of other researchers are also included.

Lydonia Canyon

In the axis of Lydonia Canyon, deep corals were a major component of the fauna, and most were restricted to hard substrates (Hecker et al. 1980). The gorgonians *Paramuricea grandis* and *A. armata* were found in the axis and on the walls, with *P. grandis* being more common in the deeper part of the axis at depths >800 m. Other gorgonians on hard substrates occurring along the axis of the canyon included *P. arborea, P. resedaeformis*, and *Anthothela grandiflora*, as well as the soft coral *Trachythela* (now *Clavularia*) *rudis* (Hecker et al. 1980). The most abundant coral found was the soft coral *Eunephthya* (now *Capnella*) *florida,* which was most common farther up the east axis between 500-700 m. Several individuals of a closely related species, *Capnella glomerata*, occurred on both the east and west walls of the canyon. The solitary stony coral *Desmophyllum cristagalli* (= *dianthus*) was found on outcrops in the deeper part of the axis and in some areas of the west wall. Other stony corals found in the canyon include *Dasmosmilia lymani*, *Flabellum* sp., *Javania cailleti* and *Solenosmilia variabilis* (Hecker et al. 1983). The availability of suitable substrate appeared to be the most important factor in determining the distribution of the corals in Lydonia Canyon; for example, *D. dianthus* and *P. grandis*, which were common inhabitants of outcrops along the canyon axis, were also found on outcrops and boulders on the slope (Hecker et al. 1983).

Oceanographer Canyon

On the west flank of Oceanographer Canyon, glacial erratics and coral rubble provide hard substrate for the attachment of several species of coral, the most common being the gorgonian *A. armata* from 650-950 m (Hecker and Blechschmidt 1980; Hecker et al. 1980). *A. armata* and *P. grandis* were also found on the east flank, and on both the east and west walls along the axis. The soft coral *C. florida* was also abundant on the east flank. The most common species in the deeper zone was the gorgonian *P. grandis* (Hecker et al. 1980). Hecker and Blechschmidt (1980) and Valentine et al. (1980) also noted the presence of the *Paramuricea borealis* (now *P. grandis*), in Oceanographer Canyon; Valentine et al. (1980) observed their greatest abundance to be from 1100-1860 m, while Hecker and Blechschmidt (1980) observed that they were dominant from 950-1350 m. *A. armata* was most common on smaller cobbles, boulders, and coral rubble while *P. grandis* was usually found on large boulders or outcrops (Hecker and Blechschmidt 1980; Hecker et al. 1980). Other deep corals on hard substrates in Oceanographer Canyon included the soft coral *Anthomastus agassizii* in the axis and on both walls, the soft coral *Clavularia rudis* on the west wall, large colonies of the gorgonian *P. arborea* in the axis above 1000 m, and numerous individuals of the small encrusting gorgonian, *A. grandiflora*, along the axis. Valentine et al. (1980) also found *A. agassizii* in a zone of greatest abundance from 1100-1860 m, while Hecker and Blechschmidt (1980) found this species mostly from 950-1350 m on glacial erratics, outcrops, and coral rubble. The solitary stony coral, *D. dianthus*, was found throughout the axis between 1500-1600 m (Hecker and Blechschmidt 1980) and on the west flank. Deep corals restricted to soft substrates included the soft coral *Anthomastus grandiflorus* on the east flank (Hecker and Blechschmidt 1980; Hecker et al. 1980) and the gorgonian *Acanella arbuscula* on both walls (Hecker and Blechschmidt 1980; Hecker et al. 1980); *A. arbuscula* was found by Hecker and Blechschmidt (1980) mostly from 950-1350 m. The gorgonian *P. resedaeformis* is also found in the canyon, with a zone of greatest abundance from 300-1099 m (Valentine et al. 1980).

Baltimore Canyon

Compared to Lydonia and Oceanographer Canyons, Baltimore Canyon in the Mid-Atlantic had the fewest corals, perhaps due to the scarcity of exposed outcrops (Hecker et al. 1980). At depths >400 m, where the canyon axis constricts and bends, outcrops and talus blocks are exposed. Several corals restricted to hard substrates were found in this area by Hecker et al. (1980). Massive colonies of the gorgonian *P. arborea* were found on the large rock outcrops. Other corals found included the gorgonians *A. armata*, *P. resedaeformis*, *A. grandiflora, A. arbuscula*, and the soft corals *C. florida* and *A. agassizii* (Hecker et al. 1980, 1983). The solitary stony coral *D. lymani* occurred in dense localized patches near the head of Baltimore Canyon, but was absent from many other areas in the Canyon (Hecker et al. 1983). Other stony corals found included *Flabellum* sp. and *D. dianthus* (Hecker et al. 1983).

Other Canyons

Hecker and Blechschmidt (1980) surveyed the deep corals and epibenthic fauna of the several other canyons off the northeastern U.S. Discrete assemblages of corals were not identified. For a complete list of species found in the historical survey of Hecker and Blechschmidt (1980) and the Hecker et al. (1980) field study, see Appendix 5.2, which includes Opresko's (1980) list of octocorals and Hecker's (1980) list of scleractinians from those two surveys.

In Heezen Canyon, the gorgonian *A. arbuscula* and the soft coral *A. grandiflorus*, both found on soft substrates, occurred at 850-1050 m; the gorgonian *P. grandis* was common from 1450-1500 m; the soft coral *A. agassizii* and the stony coral *D. dianthus* were found from 1150-1500; *D. dianthus* was also found from 1500-1550 m. The walls of Corsair Canyon were heavily dominated by corals, all of which were restricted to soft substrates. The gorgonian *A. arbuscula* was prominent from 600-800 m, and the soft coral *A. grandiflorus* dominated from 800-1000 m. In Norfolk Canyon in the Mid-Atlantic, the stony coral *D. dianthus* and the gorgonian *A. armata* were found on hard substrate at 1050-1250 m; both were also observed in this canyon by Malahoff et al. (1982). Hecker and Blechschmidt (1980) also noted that the solitary stony coral *Flabellum* sp. was seen in high concentrations at 1300-1350 m depth in Norfolk Canyon, and the soft coral *A. grandiflorus* was found between 2150-2350 m.

Deep corals have been seen on the shelf around Hudson Canyon and in the head of the Canyon (see Appendix 5.2). For example, most recently a survey by Guida (NOAA Fisheries Service,

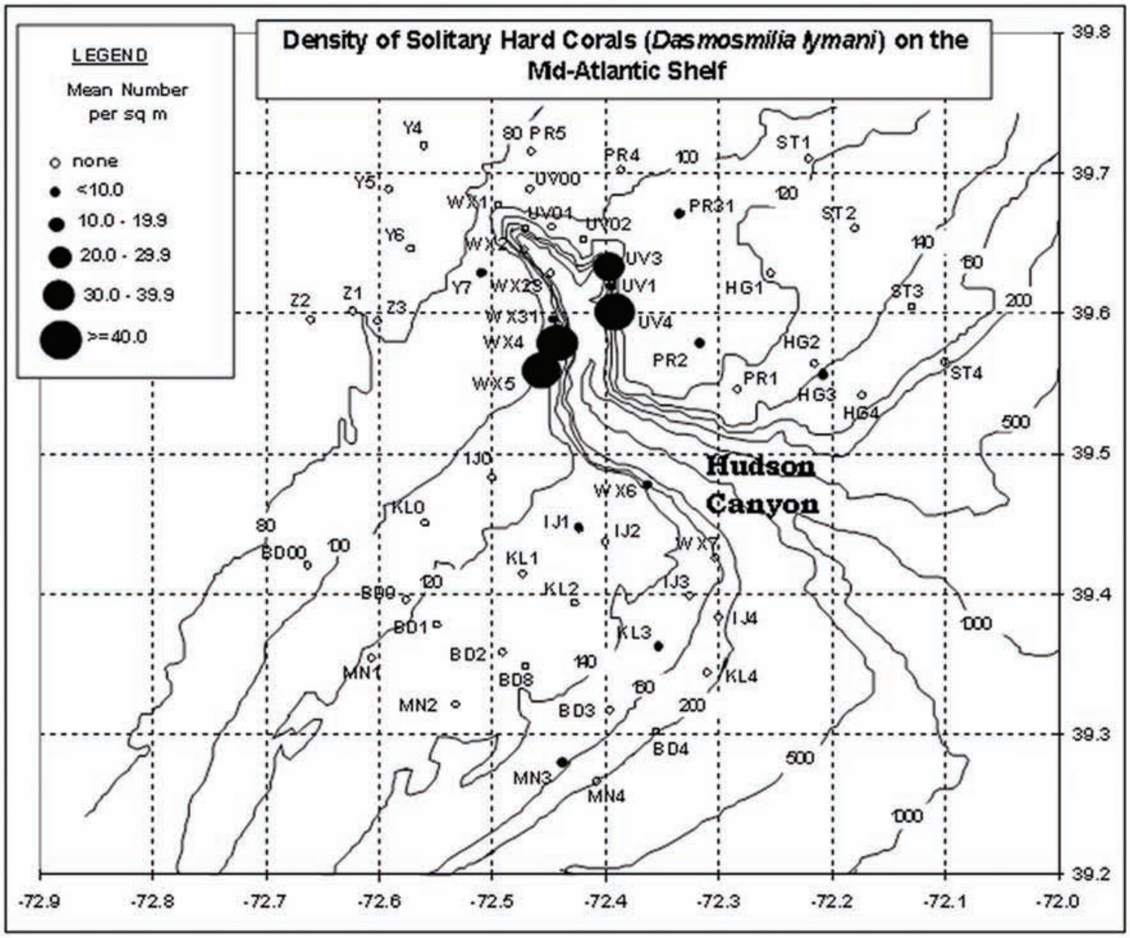


Figure 5.6. Distribution and approximate densities (polyps per square meter) of the solitary stony coral *Dasmosmilia lymani* in samples from the Mid-Atlantic shelf around Hudson Canyon (Guida, unpublished data). Data obtained from still photos and trawl samples taken during October and November 2001, 2002, 2005, August 2004, and March 2007.

NEFSC, James J. Howard Marine Sciences Laboratory, Highlands, NJ, unpublished data) of benthic habitats on the shelf around Hudson Canyon in 2001, 2002, and 2004 found the solitary stony coral *D. lymani* at a number of sites at depths of 100 to 200 m (Figure 5.6). They were particularly abundant in patches in a narrow band along the canyon's rim near its head at depths of 105-120 m; local densities within those patches exceeded 200 polyps m^{-2}, but densities elsewhere were much lower. However, the only evidence of deep corals occurring deep within the canyon itself comes from Hecker and Blechschmidt (1980), who found abundant populations of the soft coral *Eunephthya fruticosa* (same as *Gersemia fructicosa*?) only in the deeper portion of the canyon.

Other Areas of the Continental Slope

Hecker et al. (1983) surveyed an area called Slope III, a 25 mile wide section of the continental slope on the southwestern edge of Georges Bank, between Veatch and Hydrographer Canyons. In the Mid-Atlantic they surveyed two slope areas; one, called Slope Area I, was flanked by Lindenkohl Canyon on the south and Carteret Canyon on the north, and the other, called Slope II, was about 70 miles north of Slope I, and was bounded by Toms Canyon to the south and Meys Canyon to the north. Deep corals found on Slope III included the solitary stony corals *D. lymani* and *D. dianthus*, the soft coral *A. agassizii*, and the gorgonian *P. grandis*. In the Mid-Atlantic, the solitary stony coral *D. lymani* occurred in very high abundances in both slope areas at depths <500 m. Other stony corals found on Slope I included *Flabellum* sp. and *D. dianthus*; those corals, as well as *S. variabilis*, were also found on Slope II. The gorgonians *P. grandis* and *A. arbuscula* and the soft coral *A. agassizii* were also present on both slopes.

Hecker (1990), in a later survey of the megafaunal assemblages at four locations on the continental slope south of New England [including two that were surveyed as part of the Hecker et al. (1983) study] found that the solitary stony corals *D. lymani* and *Flabellum* sp. dominated the fauna on the upper slope, although *D. lymani* was absent from their transect off Georges Bank. The gorgonian *A. arbuscula* and the soft coral *C. florida*, which dominated the fauna on the shallower section of the middle slope, were found only at their transect off Georges Bank; the soft coral *A. agassizii* was also found in dense populations there.

The New England Seamounts

Deep corals are one of the dominant members of the epifaunal communities on the New England Seamount chain (Auster et al. 2005). A 2004 exploratory cruise to the New England Seamount chain revealed significant deep coral assemblages, with 27 octocoral species, 8 black coral species, and 2 stony coral species collected (Watling et al. 2005), including possible new species of gorgonians from the Chrysogorgiidae and Paragorgiidae families (Eckelbarger and Simpson 2005). A 2005 cruise to the New England and Corner Rise Seamounts sampled 39 species of octocorals, including 7 that may be new to science, and observed and collected 15 species of black coral, including 7 species that the researchers have not previously observed on the seamounts (Brugler and France 2006; Watling et al. 2006). Distributions of several species (e.g., *Paragorgia* sp., *Lepidisis* spp., *Paramuricea* spp., as well as stony corals and black corals) are currently being quantified using videotapes and digital still images (Figure 5.7). Preliminary quantitative analyses of coral species distributions indicate that community composition differs considerably between seamounts, even at comparable depths. These differences correspond to biogeographical boundaries, or they may be due to species' responses to local habitat conditions, such as substratum type or flow. Substantial variation in faunal composition occurs between sites on a single seamount (P. Auster, pers. comm.).

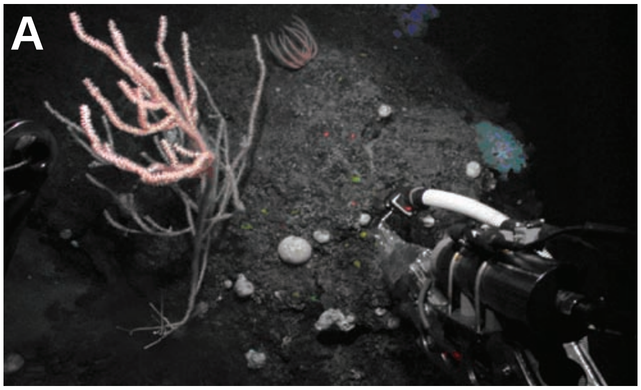
During surveys of Bear Seamount within the EEZ during 2000, Moore et al. (2003) noted the presence of several species of stony corals, including the solitary corals *Caryophyllia ambrosia*, *Flabellum alabastrum*, and, as discussed previously, *Vaughanella margaritata* and the colonial species *Lophelia pertusa*. *Desmophyllum cristagalli* (= *dianthus*) had been found on the Seamount during previous surveys. Gorgonians found by Moore et al. (2003) included *Paragorgia* sp., *Lepidisis* sp. *Swiftia* (?) sp., and *Acanthogorgia angustiflora*, although the latter species does not appear anywhere else in the deep coral records from this region. Although Moore et al. (2003) mentions that a species of *Primnoa* had been found on the Seamount during previous surveys, Cairns (Smithsonian Institution, Washington, D.C., pers. comm.) states that *Primnoa* does not occur on Bear Seamount; this record had originally been taken from Houghton et al. (1977), which is in error. Moore et al. (2003) also collected the soft coral *A. agassizii*.

Deep coral collected on Bear Seamount during a follow-up cruise in 2002 by Moore et al. (2004) included the solitary stony corals *Caryophyllia cornuformis* (this species is not mentioned elsewhere) and *F. alabastrum* and the colonial stony corals *S. variabilis* and *Enallopsammia rostrata*. Gorgonians collected included *Paragorgia* sp., *Paramuricea* sp., *Keratoisis* sp., *Swiftia pallida* (this species is not mentioned elsewhere), *Lepidisis* sp., and *Radicipes gracilis*.

VI. SPECIES ASSOCIATIONS WITH DEEP CORAL COMMUNITIES

Commercial Fisheries Species

The role of deep corals as possible habitats for fishes has only recently been addressed in the literature. The corals *Primnoa*, *Lophelia*, and *Oculina* from other regions have been the most studied. Several studies have documented that certain fish commonly occur in the vicinity of corals more often than in areas without corals. In the northwest Atlantic, this has been noted for *Sebastes* sp. (redfish) in the Northeast Channel (Mortensen et al. 2005). Redfish may take advantage of structure on the bottom as a refuge from predation, as a focal point for prey, and for other uses. However, in a survey of habitats in the Jordan Basin in the Gulf of Maine containing coral assemblages (primarily from the genera *Paragorgia, Paramuricea,* and *Primnoa*), Auster (2005) found that densities of redfish were not significantly different between dense coral habitats and dense epifauna habitats, although the density of redfish in these two habitats was higher than in the outcrop-boulder



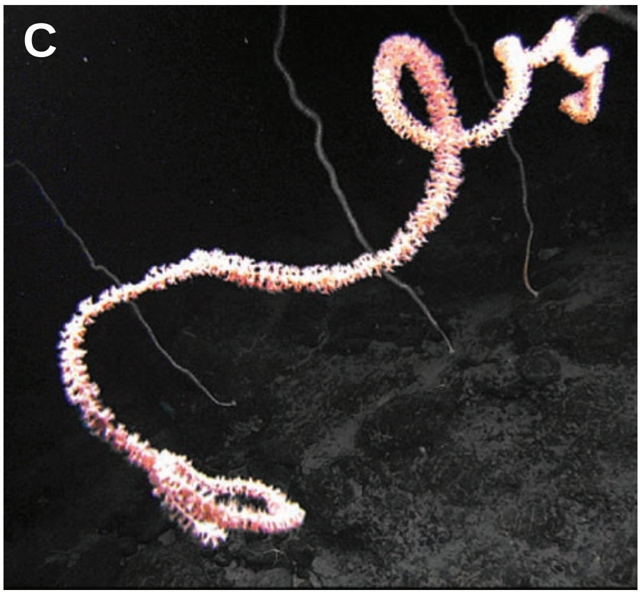


Figure 5.7. Photographic examples of variations in coral communities from the upper slope of Bear Seamount, near the summit. A) Bamboo coral (*Keratoisis* sp.) at left with globular sponge (bottom center), brisingid sea star (center top) and leafy sponge (center right). B) *Keratoisis* sp. C) *Lepidisis* sp. Photo credit: Deep Atlantic Stepping Stones Science Team, IFE, URI, and NOAA-OE

habitat containing sparse epifauna. While this study shows that a habitat without deep corals can support similar densities of fish to a habitat containing corals, Auster (2005) states that it is the actual distribution of each habitat type throughout a region that will ultimately determine the role such habitats play in the demography of particular species and communities. Deep coral habitats are fairly rare in the Gulf of Maine (Figs. 5.2A and 5.3A; Watling et al. 2003), but boulder-cobble habitats containing dense epifauna are not. Auster (2005) suggests that deep corals do have some effect on the distribution and abundance of fishes, but by themselves do not support high density, unique or high diversity fish communities. The corals do provide important structural attributes of habitat, but may not be functionally different than structures provided by other dense epifaunal assemblages.

In addition, variations in the morphological forms of the deep corals themselves within a landscape can affect how they will be used by fishes. For example, on the New England Seamounts, Auster et al. (2005) describes the gorgonian assemblage deep on the seamount flanks as a mixture of "tall and whip-like species and short fans with low density branching," with the taller species forming moderately dense stands, while near and on the seamount summits, the gorgonians (e.g., *Paragorgia* sp.) are often "large (~1 m wide) robust fans with high density branching" that are spread across the landscape. The form and density of the latter may have a different habitat value in terms of shelter or refuge from flow (Auster et al. 2005). Auster et al. (2005) did observe one fish species, *Neocyttus helgae*, that appeared to be associated with *Paragorgia* sp., perhaps utilizing them as a refuge from flow and as a foraging spot for prey associated with the coral, or perhaps they were foraging on the coral polyps themselves.

Invertebrates

There are few data available about invertebrate species associations with deep corals in this region; more is known about the species associations of deep corals and invertebrates from other regions [e.g., *Primnoa* off Alaska (Krieger and Wing 2002); *Lophelia pertusa* off Norway (Mortensen 2000)]. Off the northeastern U.S., Hecker et al. (1980) noted the frequent occurrence of shrimp on the largest gorgonians such as *Paragorgia arborea*, *Paramuricea grandis*, *Primnoa resedaeformis*, and the soft coral *Capnella florida*. An ophiuroid and an anemone appeared to have an association, possibly obligatory, as suggested by Hecker et al. (1980), with *Paramuricea grandis*. Hecker and Blechschmidt (1980) also noted several faunal associations in their study. The ophiuroids *Ophiomusium lymani* and *Asteronyx loveni* were often associated with corals; e.g., the latter with the gorgonian *A. arbuscula.* Pycnogonids were seen on the gorgonian *Paramuricea grandis*.

Current studies are looking at the species associations of the octocorals of the New England and Corner Rise Seamounts. Ophiuroids and marine scale worms were found to live commensally in and on the octocorals found on the seamounts (Watling 2005; Watling and Mosher 2006); specimens of octocorals, stony corals, and their associated species from the seamounts are also being used in population genetic studies that will assess, for example, the taxonomic relationships of the corals and associated species (Shank et al. 2006). Within the EEZ, Moore et al. (2003) noted the following invertebrates found in direct association with *Lophelia petusa* trawled from Bear Seamount: a large polychaete worm living in tubular spaces within the coral colony, the attached solitary stony coral, *Caryophyllia ambrosia*, small serpulid worm tubes, a thecate hydroid, and the gorgonian *Swiftia*.

VII. STRESSORS ON DEEP CORAL COMMUNITIES

Fishing Effects

Deep corals provide habitat for other marine life, increase habitat complexity, and contribute to marine biodiversity, and their destruction could have a significant impact on other marine species. Anecdotal data from submersible and ROV studies as well as reports from fisherman, who have brought them up as bycatch since the 19th century, suggests that deep corals have become less common or their distributions have been reduced due to the impacts of bottom fishing (Breeze et al. 1997; Watling and Auster 2005). Fishing has had significant effects on deep coral populations in other regions. Deep corals are especially susceptible to damage by fishing gear because of their often fragile, complex, branching form of growth above the bottom. Also, they grow and reproduce at very slow rates, with some estimated to be hundreds of years old (Lazier et al. 1999; Andrews et al. 2002; Risk et al. 2002), and recruitment rates may also be low (Krieger 2001), which makes their recovery from disturbances difficult over short time periods. Of the various fishing methods, bottom trawling has been found to be particularly destructive (Rogers 1999; Hall-Spencer et al. 2001; Koslow et al. 2001; Krieger 2001; Fosså et al. 2002; Freiwald 2002).

The effects of current and historic fishing efforts on deep coral and coral habitats in the northeastern U.S. have not been quantified. The types of fishing gear used here include fixed gear such as longlines, gillnets, and pots and traps, as well as trawls and dredges. Fixed gear can be lost at sea, where they can continue to damage corals. In Canada, longlines have been observed entangled in deep corals such as *Paragorgia* and *Primnoa* and may cause breakage (Breeze et al. 1997; Mortensen et al. 2005). Further, “ghost fishing” of nets entangled in coral reefs has been reported in the North Sea (ICES 2003). Bottom trawling was found to have a larger impact on deep corals per fishing unit of effort compared to longlining; e.g., damage to *Primnoa* off Alaska (Krieger 2001). The northeastern U.S. fisheries that have the highest likelihood of occurring near concentrations of known deep coral habitats (e.g., in canyon and slope areas) are the *Lophius americanus* (monkfish or goosefish) and *Lopholatilus chamaeleonticeps* (tilefish) fisheries, and the *Chaceon* (*Geryon*) *quinquedens* (red crab) and offshore *Homarus americanus* (lobster) pot fisheries.

Effects of other human activities

Invasive Species

Little is known about any existing or potential interactions between deep corals and invasive species. One invasive species that may be a threat in the northeast is the colonial tunicate (“sea squirt”), *Didemnum* sp. A. (Bullard et al. 2007). It is currently undergoing a massive population explosion and major range expansion and has become a dominant member of many subtidal communities on both coasts of North America. It was recently discovered on the northern edge of Georges Bank, and is found on hard gravel substrates, including, pebbles, cobbles, and boulders, and overgrows sessile and quasi-mobile epifauna (sponges, anemones, scallops, etc.). The species can occur on immobile sand substrates, but is not known to occur on mobile

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sand or mud substrate. On Georges Bank, *Didemnum* sp. A covers 50–90% of the substrate at numerous sites over a 230 km^2 area to a depth of 45-60 m (Bullard et al. 2007). *Didemnum* sp. A has the potential to spread rapidly by budding, and fragmentation of the mats could promote the rapid spread of the species. There are no known predators at this time, although there have been some observations of possible seastar predation (Bullard et al. 2007).

Didemnum sp. A may be a potential serious threat to deep coral that occur on hard substrates in the northeast, particularly for those corals, such as *Paragorgia* and *Primnoa*, which are known to occur on the gravel substrate of the Northeast Peak of Georges Bank. If the tunicate did colonize deep coral habitat, it could smother and kill the corals by overgrowth, or at least impede feeding (G. Lambert, University of Washington, Friday Harbor Laboratories, Seattle, WA, pers. comm.; P. Valentine, USGS, Woods Hole, MA, pers. comm.) However, Bullard et al. (2007) note that on cobble bottoms in Long Island Sound, the only epifaunal species that *Didemnum* sp. A did not appear to overgrow were the stony coral, *Astrangia poculata*, and the cerianthid anemone, *Ceriantheopsis americana*. In addition, depth, temperature, and larval dispersal may be limiting factors in the spread of the tunicate (G. Lambert, pers. comm.; P. Valentine, pers. comm.). It may be a shallow water species; so far, it has been found only at depths down to 81 m off New England on Georges, Stellwagen and Tillies Banks (Bullard et al. 2007), and even though it is found in a temperature range of -2°C to 24°C, its preferred range might be at temperatures >4°C or higher (G. Lambert, pers. comm.; P. Valentine, pers. comm.). *Didemnum* sp. A would probably have a difficult time getting from the present affected area into the submarine canyons located on the southern bank margin. The tadpole larvae that are born from sexual reproduction swim near the bottom (probably for only a few hours) before settling, so they cannot travel far on their own or by currents. However, because fragments of the colonies are viable, it could, in theory, be brought to the canyons on a boat hull or by the use of contaminated fishing gear (mobile or fixed) or the washing of contaminated boat decks (P. Valentine, pers. comm.). Even though the consensus is that *Didemnum* sp. A is probably a remote threat to deep corals, it has previously confounded researchers with its incredible rate of colonization and range expansion. So little is known about this tunicate that it is not possible to predict the limits of its further spread at this time (G. Lambert, pers. comm.). But *Didemnum* sp. A does has the potential to cause great ecological and economic damage. The species continues to expand its range and could eventually colonize large expanses of hard substrata throughout New England and eastern Canada (Bullard et al. 2007).

Other

There does not appear to be any specific current or pending oil and gas exploration/extraction, gas pipeline/communication cable, mineral mining, etc. projects that could pose a significant threat to the major deep coral species in this region; in addition, few of the coastal projects along the northeast coast of the U.S. are deep enough to affect them. There also doesn't appear to be any monitoring data or published studies from these types of projects in this region that show evidence of impacts to deep corals.

VIII. MANAGEMENT OF FISHERY RESOURCES AND HABITATS

Mapping and Research

Despite the aforementioned faunal surveys, our knowledge of the temporal and spatial distribution and abundance of deep corals off the northeastern U.S., as well as some aspects of their basic biology and habitat requirements, is severely limited, so their overall population status and trends are difficult to determine. [There is, however, more information on deep coral distribution and habitat requirements in Canadian waters; e.g., the Northeast Channel (Mortensen and Buhl-Mortensen 2004)]. NEFSC groundfish and shellfish surveys from the Gulf of Maine to Cape Hatteras have collected corals as part of their bycatch for several decades, but there are many data gaps (e.g., corals were not properly identified or quantified) which prevent using the data to clearly assess any long-term population trends.

There have been some recent, targeted surveys off of New England using trawls and remotely operated vehicles (ROVs). In 2003, 2004, and 2005, their were surveys of several seamounts in the New England and Corner Rise Seamount chains (the latter is approximately 400 km to the east of the New England Seamount chain, and nearly midway between the east coast of the U.S. and the Mid-Atlantic Ridge) funded by NOAA's Office of Ocean Exploration and National Undersea Research Program. The cruises were multidisciplinary in nature but the goals included studying the distribution and abundance of deep corals relative to the prevailing direction of currents; collecting specimens for studies of reproductive biology, genetics, and ecology; and studying species associations. Mike Vecchione (NEFSC, National Systematics Laboratory) conducted a multi-year study (2000-2005) exploring the faunal biodiversity of Bear Seamount. The multi-year program examined some of the temporal variability around the Seamount. Initial results on the biodiversity of deep corals by Moore et al. (2003) were discussed previously. Mike Fogarty (NEFSC) in spring 2004 explored the macrofaunal biodiversity of the upper continental slope south of Georges Bank from Oceanographer Canyon to Powell Canyon at depths from 400-1100 m, with the deepest stations corresponding to the shallowest depths sampled on the summit of Bear Seamount in the Vecchione survey.

Fishery Management Councils

Fishery management council jurisdiction in the northeast U.S. is primarily the responsibility of the New England Fishery Management Council (NEFMC). In addition to the 26 species under its sole management, the NEFMC shares responsibility over *Lophius americanus* (monkfish or goosefish) and *Squalus acanthias* (spiny dogfish) with the Mid-Atlantic Fishery Management Council (MAFMC). In 2005, the two Councils, with the NEFMC as the lead Council on the Monkfish Fishery Management Plan (FMP), approved the designation of Oceanographer and Lydonia Canyons (approximately 116 square nautical miles) as Habitat Closed Areas (HCA) and added these areas to the NEFMC's network of HCAs (or marine protected areas). These new HCAs are closed indefinitely to fishing with bottom trawls and bottom gillnets while on a monkfish day-at sea (DAS) in order to minimize the impacts of the directed monkfish fishery on Essential Fish Habitat (EFH[1]) in these deep-sea canyons and on the structure-forming organisms therein (Figures 5.1 and 5.8). Within these canyon habitats, a variety of species have been found which are known to provide structured habitat, including deep corals, and shelter for many species of demersal fish and invertebrates.

This action was implemented in May 2005 under Amendment 2 to the Monkfish Fishery Management Plan (FMP) (NEFMC 2004). EFH for some federally-managed species extends beyond the edge of the continental shelf and includes portions of the canyons.

The directed monkfish fishery is conducted with bottom trawls and bottom gillnets, primarily in coastal and offshore waters of the Gulf of Maine, on the northern edge of Georges Bank, and in coastal and continental shelf waters of southern New England, including offshore waters on the edge of the continental shelf and near the heads of several of the canyons. Although the current degree of overlap between the current monkfish fishing effort and the known presence of corals within the canyons is very small, one of the fishery management measures contained within Amendment 2, and which was approved by the Councils, would increase the probability that the offshore fishery for monkfish will expand in the future. Because there is documented evidence of deep corals in the canyons in the area that is identified for possible increased offshore fishing, these closures are intended as a precautionary measure to prevent any potential direct or indirect impacts of an expanded offshore monkfish fishery on EFH, offshore canyon habitats, and thus, deep corals.

Approximately 23 federally-managed species have been observed or collected within these proposed closure areas, and many of them have EFH defined as "hard substrates" at depths >200 m, which includes habitat or structure-forming organisms such as deep corals. Also, the EFH designations for juvenile and adult life stages of six of these managed species (*Sebastes* spp., redfish, is one of them) overlap with the two

[1] EFH is a provision of the Magnuson-Stevens Fishery Conservation and Management Act (1996). The EFH provision states: "One of the greatest long-term threats to the viability of commercial and recreational fisheries is the continuing loss of marine, estuarine, and other aquatic habitats. Habitat considerations should receive increased attention for the conservation and management of fishery resources of the United States." The definition of EFH in the legislation covers: "those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity." The legislation mandates that NOAA Fisheries and the Councils implement a process for conserving and protecting EFH.

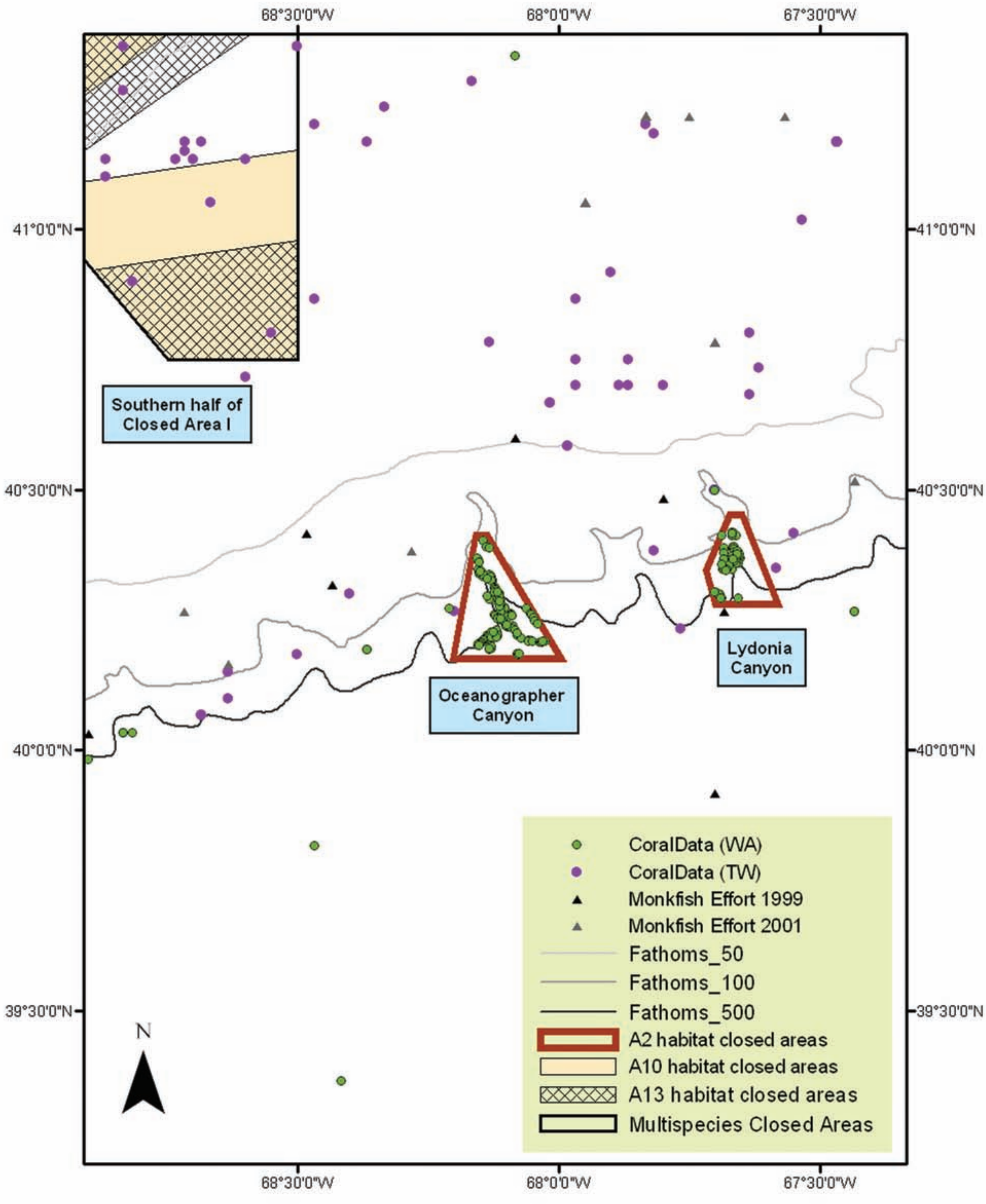

Figure 5.8. The Oceanographer and Lydonia Canyon Essential Fish Habitat closed areas, under Amendment 2 to the Monkfish Fishery Management Plan; locations of known alcyonaceans from the Theroux and Wigley (1998) and Watling et al. (2003) databases; and, 1999 and 2001 directed monkfish otter trawl trips. Source credit: 1999 and 2001 VTR).

closed areas, and EFH for all six of these species has been determined to be vulnerable to bottom trawling and perhaps also vulnerable to bottom gillnets. Although deep corals are not explicitly included in the EFH descriptions for any species in the northeast region, some deep corals are, of course, known to grow on hard substrates, and may themselves be considered a form of substrate. The rationale is that, since there are corals found within these proposed closed areas, this is indicative of areas of hard bottom. Also some coral species may provide the structural attributes of habitat similar to that provided by other dense epifaunal assemblages (as discussed above), and may be particularly vulnerable to damage or loss by trawling or gillnets. Thus, by avoiding any direct adverse impacts of bottom trawls and gillnets used in the monkfish fishery on EFH for the six species of fish and any indirect adverse impacts on hard bottom habitat and emergent epifauna, such as the deep corals, that grow in these habitats within the closed areas, adverse impacts of an expanded offshore fishery would be minimized to the extent practicable.

Protection of deep corals is a relatively new concept in this region and the NEFMC believes that there are several statutory and regulatory authorities that support the Councils' initiative to protect deep coral habitats. The NEFMC took this proactive and precautionary approach to protect these sensitive habitats through aggressive fishery management measures, which is based on sound ecological principles, as appropriate and necessary. In Amendment 2 to the Monkfish FMP, the Councils, for the same reasons and rationale discussed above, also considered a management alternative that would have closed all 12 steep-walled canyons along the continental shelf-break from the Hague Line in the north to the North Carolina/South Carolina border in the south. Although this management alternative was not ultimately chosen by the Councils for implementation due to the lack of readily available coral data and potential negative social and economic impacts, the Councils did feel that the science and data supported the closure of Oceanographer and Lydonia Canyons at that time as a precautionary measure. The Councils determined that protection of deep corals in all 12 canyons would be less certain than in just closing Lydonia and Oceanographer Canyons, until such time as additional surveys are conducted or evidence is examined which more thoroughly document the presence of corals in the other 10 canyons.

The New England Fishery Management Council alone has also indefinitely closed an additional 3,000+ square nautical miles, as Habitat Closed Areas, in the Gulf of Maine, Georges Bank, and southern New England to bottom-tending mobile fishing gear to protect EFH (Figure 5.1), which indirectly protects any deep corals in those areas. This initial suite of HCAs was created under both Amendment 10 to the Atlantic Sea Scallop Fishery Management Plan in 2003 and Amendment 13 to the Northeast Multispecies Fishery Management Plan in 2004 as "Level 3" closures, and are closed indefinitely to all bottom-tending mobile gear to protect EFH. The canyon habitat closures implemented under Amendment 2 to the Monkfish FMP should be viewed as an addition to the suite of HCAs, and in concert with the other HCAs, provides a large network of marine protected areas (MPAs) as compared to the relatively small size of the geographic region under management.

Lastly, under the current effort to update all of the EFH provisions of all of the NEFMC FMPs, the NEFMC has approved a set of new Habitat Areas of Particular Concern (HAPCs[2]) including many steep-walled canyons on the eastern seaboard extending from the Hague Line to the North Carolina/South Carolina border and Bear and Retriever Seamounts to protect sensitive EFH and the habitat and structure-forming organisms therein. These new HAPCs will need approval from the MAFMC before they can be implemented through final action sometime in late 2008. The MAFMC will likely take up the topic at one of their upcoming meetings

IX. REGIONAL PRIORITIES TO UNDERSTAND AND CONSERVE DEEP CORAL COMMUNITIES

Mapping

Deep corals have been largely unmapped off the northeastern U.S, particularly in the Mid-Atlantic. What is currently known about coral distribution

[2]HAPCs are a subset of the much larger area identified as EFH that play a particularly important ecological role in the life cycle of a managed species or that are rare and/or particularly sensitive or vulnerable to human-induced environmental degradation and development activities.

in this region is largely based on blind, random, or grid sampling with trawl gear, grab samplers, and drop cameras that was done twenty or more years ago. While the breadth of such surveys was vast, in most cases the density of data they generated is much too diffuse spatially and temporally to provide distributional data adequate for management purposes. Therefore, it is critical to identify, map, and characterize deep corals and their habitats, particularly in the canyons, utilizing more advanced technologies such as side-scan and multibeam sonars, manned submersibles and ROVs, towed camera sleds, etc. Low-resolution maps should be produced that cover large areas for purposes of identifying potential locations of deep corals, and high-resolution maps should be produced for site-specific areas where deep corals are known to exist (McDonough and Puglise 2003). Temporal/spatial changes in deep coral distribution and abundance need to be assessed, and long-term monitoring programs should be established.

Recently, Leverette and Metaxas (2005) developed predictive models to determine areas of suitable habitat for *Paragorgia arborea* and *Primnoa resedaeformis* along the Canadian Atlantic continental shelf and shelf break. Several environmental factors including slope, temperature, chlorophyll *a*, current speed and substrate were included in the analysis. Their results showed that the habitat requirements differed between the two gorgonians. *P. arborea* occurred predominantly in steeply sloped environments and on rocky substrates, while the habitat for *P. resedaeformis* was more broadly distributed and located in areas with high current speed, rocky substrates and a temperature range between 5-10°C. The use of predictive modeling to generate habitat suitability maps and to identify suitable habitat for deep coral in the northeastern U.S. would be an important step toward deep coral conservation.

Research

It was stated previously that there is uncertainty about the accuracy of the identifications of deep corals from the various historical surveys. Identifying deep corals is difficult, and their taxonomy is often in question, so as a first step, some basic taxonomic issues need to be worked out. Molecular genetics is one tool that could be used, and this line of research may provide insight into coral larval dispersal. Genetic studies may also be useful for comparing corals regionally, nationally, and on either side of the Atlantic. For example, DNA-sequencing technology is currently being used to determine whether the corals around the New England Seamounts are endemic, or simply populations of species with broader geographic distributions; e.g., whether the corals are dispersing from the New England Seamounts into the deep Gulf of Maine and submarine canyons off Georges Bank. However, it's important to note that there is a shortage of qualified coral taxonomists available to properly identify deep corals. With so few professional coral taxonomists, it will be difficult to make progress in deep coral mapping and distribution, for example. More students need to be trained in coral taxonomy at the graduate level, and more funding needs to be available for taxonomic research and to hire coral taxonomists at museums and universities.

In addition to taxonomy, basic life history studies on deep corals are needed in this region. There are fundamental questions on deep coral growth, physiology, reproduction, recruitment, recolonization rates, and feeding. Their habitat requirements need to be characterized. In addition, it is important to collect associated oceanographic, geologic, and other habitat parameter data in order to understand the physical parameters that affect the distribution and extent of deep coral habitats. Deep coral habitat biodiversity should be assessed, food web relationships need to be defined, and the role that the corals play in the life histories of associated species should be described and quantified. In terms of the latter, the possible role of deep corals as EFH for Federally managed species has to be determined. Finally, it is necessary to quantify the vulnerability or resilience of deep corals to various anthropogenic threats, especially from fishing, and to quantify the recovery rates of corals and coral habitats that have been injured or destroyed. Many of these recommendations for research on deep corals can be found in McDonough and Puglise (2003) and Puglise and Brock (2003).

The NEFSC needs to become more quantitative about their deep coral bycatch in the groundfish and shellfish surveys and fisheries observer program logs. Prior to the year 2000, for example, bycatch quantity in the NEFSC *Placopecten magellanicus* (Atlantic sea scallop) surveys were estimated by cursory visual inspection or "eyeballing" only (D. Hart, NOAA Fisheries Service, NEFSC, Woods Hole Laboratory, Woods Hole, MA, pers. comm.). The bycatch data for those surveys were divided up into 3 categories: substrate, shell, and other invertebrates; and the log sheets only recorded percent composition and total volume (bushels). In the fisheries observer program, the observers also log the presence of coral bycatch; however, they are lumped into one category ("corals and sponges"), and are not identified further. In addition, because the observer program observes thousands of trips every year in dozens of different fisheries, with each fishery having its own regulations for mesh size and configuration, a reported absence of coral at a location may simply be a function of the catchability of the gear used (D. Potter, Fisheries Sampling Branch, NOAA Fisheries Service, NEFSC, Woods Hole Laboratory, Woods Hole, MA, pers. comm.). This is also a problem with the NEFSC surveys; it is important to remember that fishing gear is not designed to "catch" corals. But at the very least, if there was an attempt made to properly identify coral bycatch from these two programs, one might come up with some form of presence data.

X. CONCLUSION

The overall quantity of deep coral habitat in the northeast region is unknown, and no systematic assessment of the distribution, abundance, and population dynamics of deep coral is available for this region. That, along with a dearth of information on their natural history, as well difficulties with their taxonomy, makes it difficult, if not impossible, to determine if there have been changes in deep coral occurrence or abundance over time. Nevertheless, even though there is no quantitative information on the extent of anthropogenic impacts to deep corals in this region, some of the areas where structure-forming deep corals are definitely known to occur (e.g., unique areas such as the submarine canyons and the New England Seamounts) are currently protected or under consideration for protection from bottom-tending fishing gear as EFH and Habitat Areas of Particular Concern.

Obviously, in order to better preserve and protect deep corals and deep coral habitat off the northeastern U.S., there needs to be 1) an increased mapping and survey effort at the Federal and academic level (including joint studies with Canada); 2) more basic research on deep coral taxonomy, life history, habitat requirements, species associations, etc.; and finally, 3) quantification on the susceptibility of deep corals to anthropogenic influences, particularly fishing.

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Appendix 5.1. List of deep coral species found in the waters off the Northeastern United States. ** = distribution information based on studies or surveys of a particular area of the Northeast Region, not on overall distribution.

Higher Taxon	Species	Distribution	Depth Range (m)	Reference
Phylum Cnidaria				
Class Anthozoa				
Subclass Hexacorallia				
Order Scleractinia				
Family Caryophillidae	*Caryophyllia ambrosia ambrosia* Alcock, 1898	Widespread (cosmopolitan) distribution; found on Bear Seamount	1487-2286	Cairns and Chapman 2001; Moore et al. 2003
	Caryophyllia ambrosia caribbeana Cairns, 1979	Endemic to western Atlantic	183-1646	Cairns and Chapman 2001
	Dasmosmilia lymani (Pourtales, 1871)	Widespread (cosmopolitan) distribution. Continental slope south of New England, Lydonia Canyon, continental shelf between Baltimore and Hudson Canyons, in Baltimore Canyon, and between 100-200 m on the shelf south of Hudson Canyon and in the head of Hudson Canyon	37-366	Hecker 1980; Hecker et al. 1983; Hecker 1990; Cairns and Chapman 2001; Guida (unpublished data)
	Deltocyathus italicus (Michelotti, 1838)	Amphi-Atlantic with a disjunct distribution	403-2634	Cairns and Chapman 2001
	Desmophyllum dianthus (Esper, 1794)	Widespread (cosmopolitan) distribution; found in several canyons (Corsair, Heezen, Lydonia, Oceanographer, Baltimore, Norfolk; near Hudson); continental slope on the southwestern edge of Georges Bank, between Veatch and Hydrographer Canyons; in the Mid-Atlantic on the slope between Lindenkohl Canyon on the south and Carteret Canyon on the north; in the Mid-Atlantic on the slope bounded by Toms Canyon to the south and Meys Canyon to the north; Bear Seamount	183-2250	Hecker 1980; Hecker and Blechschmidt 1980; Hecker et al. 1980, 1983; Malahoff et al. 1982; Cairns and Chapman 2001; Moore et al. 2003

Higher Taxon	Species	Distribution	Depth Range (m)	Reference
	Lophelia pertusa (L, 1758)	Widespread (cosmopolitan) distribution; Oceanographer Canyon wall; Bear Seamount	146-1200; 700-1300	Hecker 1980; Hecker and Blechschmidt 1980; Hecker et al. 1980; Cairns and Chapman 2001; Moore et al. 2003
	Solenosmilia variabilis Duncan, 1873	Widespread (cosmopolitan) distribution; Lydonia canyon; on the slope bounded by Toms Canyon to the south and Meys Canyon to the north	220-1383	Hecker 1980; Hecker et al. 1983; Cairns and Chapman 2001
	Vaughanella margaritata (Jourdan, 1895)	Endemic to northwestern Atlantic; Bear Seamount	1267	Cairns and Chapman 2001; Moore et al. 2003
Family Dendrophylliidae	*Enallopsammia profunda* (Pourtales, 1867)	Endemic to western Atlantic	403-1748	Cairns and Chapman 2001
	Enallopsammia rostrata (Pourtales, 1878)	Widespread (cosmopolitan) distribution	300-1646	Cairns and Chapman 2001
Family Flabellidae	*Flabellum alabastrum* Moseley, 1873	Amphi-Atlantic with contiguous distribution; Canyons (Corsair, Heezen, Lydonia Oceanographer, Alvin, Baltimore, Norfolk) and slopes; Bear Seamount. some may be *F. angularis* or *F. moseleyi*	357-1977	Hecker 1980; Hecker and Blechschmidt 1980; Hecker et al. 1980, 1983; Cairns and Chapman 2001; Moore et al. 2003
	Flabellum angulare Moseley, 1876	Amphi-Atlantic with contiguous distribution; see also *F. alabastrum*	2266-3186	Hecker 1980; Hecker and Blechschmidt 1980; Hecker et al. 1980, 1983; Cairns and Chapman 2001; Moore et al. 2003
	Flabellum macandrewi Gray, 1849	Amphi-Atlantic with contiguous distribution; see also *F. alabastrum*	180-667	Hecker 1980; Hecker and Blechschmidt 1980; Hecker et al. 1980, 1983; Cairns and Chapman 2001; Moore et al. 2003
	Javania cailleti (Duch. & Mich., 1864)	Widespread (cosmopolitan) distribution; Lydonia, Oceanographer Canyons	30-1809	Hecker 1980; Hecker et al. 1983; Cairns and Chapman 2001
Family Fungiacyathidae	*Fungiacyathus fragilis* Sars, 1872	Widespread (cosmopolitan) distribution	412-460	Cairns and Chapman 2001

Higher Taxon	Species	Distribution	Depth Range (m)	Reference
Family Rhizangiidae	*Astrangia poculata* (Ellis & Solander, 1786)	Endemic to western Atlantic	0-263	Theroux and Wigley 1998; Cairns and Chapman 2001
Order Antipatharia				
Family Antipathidae	*Leiopathes* sp.**	Near and on Bear Seamount	1643, 1754	Brugler 2005
	Cirrhipathes sp.**	Off Virginia	262	Smithsonian Institution collections
Subclass Octocorallia				
Order Alcyonacea				
Family Alcyoniidae	*Alcyonium digitatum* Linné, 1758			Watling and Auster 2005
	Anthomastus agassizii Verrill, 1922 **	Hard substrates from Corsair Canyon to Hudson Canyon; outcrops in Corsair Canyon; in Heezen, Lydonia, Oceanographer Canyons; on slope near Alvin Canyon; on slope on the southwestern edge of Georges Bank, between Veatch and Hydrographer Canyons; in Mid-Atlantic on slope flanked by Lindenkohl Canyon to south and Carteret Canyon to north and on slope bounded by Toms Canyon to south and Meys Canyon to north; Bear Seamount	750-1326	Hecker and Blechschmidt 1980; Hecker et al. 1980, 1983; Opresko 1980; Valentine et al. 1980; Hecker 1990; Moore et al. 2003; Watling and Auster 2005
	Anthomastus grandiflorus Verrill, 1878 **	Soft substrates, highest densities in canyons; found in Corsair, Heezen, Oceanographer Canyons; seen near Hudson Canyon, Toms Canyon, in Baltimore Canyon, in axis of Norfolk Canyon	700-2600	Hecker and Blechschmidt 1980; Hecker et al. 1980; Opresko 1980; Watling and Auster 2005
Family Clavulariidae	*Clavularia modesta* (Verrill, 1874)			Watling and Auster 2005
	Clavularia rudis (Verrill, 1922)**	Found in axis of Heezen, Lydonia, Oceanographer Canyons	750-1099	Hecker and Blechschmidt 1980; Hecker et al. 1980; Opresko 1980; Watling and Auster 2005

Higher Taxon	Species	Distribution	Depth Range (m)	Reference
Family Nephtheidae	*Capnella florida* (Rathke, 1806)**	Lydonia, Oceanographer, Baltimore Canyons; axis of Heezon Canyon; wall of Corsair Canyon; continental slope south of New England off Georges Bank	350-1500	Hecker and Blechschmidt 1980; Hecker et al. 1980; Opresko 1980; Hecker 1990; Watling and Auster 2005
	Capnella glomerata (Verrill, 1869)**	Several individuals found in Lydonia Canyon	200-561	Hecker et al. 1980; Opresko 1980; Watling and Auster 2005
	*Gersemia fruticosa*** (Sars, 1860)	Near and in deep portion of Hudson Canyon; at the mouth of Norfolk Canyon; seen near heads of Toms and Carteret Canyons (i.e., between Baltimore and Hudson Canyons)	600-3100	Hecker and Blechschmidt 1980; Opresko 1980; Watling and Auster 2005
	Gersemia rubriformis (Ehrenberg, 1934)			Watling and Auster 2005
Order Gorgonacea				
Family Acanthogorgiidae	*Acanthogorgia armata* Verrill, 1878 **	Found in many canyons (Corsair, Lydonia, Oceanographer, Alvin, near Hudson, Norfolk, Baltimore); seen on boulders or outcrops	350-1300	Hecker and Blechschmidt 1980; Hecker et al. 1980; Opresko 1980; Malahoff et al. 1982; Watling and Auster 2005
Family Anthothelidae	*Anthothela grandiflora* (Sars, 1856) **	Lydonia, Oceanographer, Baltimore Canyons	450-1150	Hecker et al. 1980; Opresko 1980; Watling and Auster 2005
Family Chrysogorgiidae	*Chrysogorgia agassizii* (Verrill, 1883)	Several individuals that may be *C. agassizii* found in the vicinity of Hudson Canyon.	2150	Watling and Auster 2005
	Iridogorgia pourtalesii Verrill, 1883			Watling and Auster 2005
	Radicipes gracilis (Verrill, 1884)			Watling and Auster 2005

Higher Taxon	Species	Distribution	Depth Range (m)	Reference
Family Isididae	*Acanella arbuscula* (Johnson, 1862) **	Found in Corsair, Heezen, Oceanographer Canyons; on slope near Alvin, Baltimore Canyons; in Mid-Atlantic on slope flanked by Lindenkohl Canyon to south and Carteret Canyon to north and on slope bounded by Toms Canyon to south and Meys Canyon to north; continental slope south of New England off Georges Bank; seen on soft substrates	600-2000	Hecker and Blechschmidt 1980; Hecker et al.1980; Opresko 1980; Hecker 1990; Theroux and Wigley 1998; Watling and Auster 2005
	Keratoisis grayi Wright, 1869			Watling and Auster 2005
	Keratoisis ornata Verrill, 1878			Watling and Auster 2005
	Lepidisis caryophyllia Verrill, 1883**	Bear Seamount?		Moore et al. 2003; Watling and Auster 2005
Family Paragorgiidae	*Paragorgia arborea* (Linné, 1758) **	Found in Gulf of Maine, Georges Bank, and Canyons (Lydonia, Oceanographer, Baltimore, Norfolk); probably Bear Seamount	300-1100	Wigley 1968; Hecker and Blechschmidt 1980; Hecker et al. 1980; Opresko 1980; Theroux and Grosslein 1987; Theroux and Wigley 1998; Moore et al. 2003; Watling and Auster 2005
Family Plexauridae	*Paramuricea grandis* Verrill, 1883 **	Found in Gulf of Maine and canyons from Corsair to near Hudson, seen in Corsair, Heezen, Oceanographer, Lydonia Canyons; on slope near Alvin Canyon; on slope on the southwestern edge of Georges Bank, between Veatch and Hydrographer Canyons; in Mid-Atlantic on slope flanked by Lindenkohl Canyon to south and Carteret Canyon to north and on slope bounded by Toms Canyon to south and Meys Canyon to north	400-2200	Hecker and Blechschmidt 1980; Hecker et al. 1980, 1983; Opresko 1980; Valentine et al. 1980; Watling and Auster 2005

Higher Taxon	Species	Distribution	Depth Range (m)	Reference
	Paramuricea placomus (Linné, 1758) **	Gulf of Maine		Watling and Auster 2005
	Paramuricea n. sp.			Watling and Auster 2005
	Swiftia casta (Verrill, 1883)**	Bear Seamount?		Moore et al. 2003; Watling and Auster 2005
Family Primnoidae	*Narella laxa* Deichmann, 1936			Watling and Auster 2005
	Primnoa resedaeformis Gunnerus, 1763) **	Found in Gulf of Maine, Georges Bank, and Canyons (Lydonia, Oceanographer, Baltimore, Norfolk); south to off Virginia Beach, VA; probably Bear Seamount	91-548	Hecker and Blechschmidt 1980; Hecker et al. 1980, 1983; Opresko 1980; Valentine et al. 1980; Theroux and Grosslein 1987; Theroux and Wigley 1998; Moore et al. 2003; Cairns and Bayer 2005; Watling and Auster 2005; Heikoop et al. 2002.
	Thouarella grasshoffi Cairns, 2006			Watling and Auster 2005
Order Pennatulacea				
Family Anthoptilidae	*Anthoptilum grandiflorum*	Newfoundland to Bahamas, Lousiana, Chile, Hawaii, Antarctica, N. Europe	274-3651	US NMNH collection, OBIS
	Anthoptilum murrayi	Lydonia Canyon to Puerto Rico, Hawaii, Aleutians, Japan, W. Africa, N. Europe	430-2491 (1538 m min in NE US)	US NMNH collection, OBIS
Family Kophobelemnidae	*Kophobelemnon stelliferum*	Newfoundland to South Carolina, Japan, W. Africa, N. Europe	393-2199 (1330 m min in NE US)	US NMNH collection, OBIS
	Kophobelemnon scabrum	Nova Scotia to Virginia	1977-2249	US NMNH collection
	Kophobelemnon tenue	Massachusetts to Virginia	2491-4332	US NMNH collection
Family Pennatulidae	*Pennatula aculeata*	Newfoundland to Virginia, California, Iberia, N. Africa	119-3316	US NMNH collection, OBIS
	Pennatula grandis	New Jersey, Bay of Biscay	1850-2140	US NMNH collection, OBIS
	Pennatula borealis	Newfoundland to North Carolina, California	219-2295	US NMNH collection, OBIS

Higher Taxon	Species	Distribution	Depth Range (m)	Reference
Family Protoptilidae	*Distichoptilum gracile*	Nova Scotia to North Carolina, W. Africa, N. Eurpoe	1211-2844 (doubtful report at 59 m)	US NMNH collection, OBIS
	Protoptilum abberans	Nova Scotia to Virginia	1483-2359	US NMNH collection
	Protoptilum carpenteri	Massachusetts to North Carolina, W. Africa, N. Europe	1334-2194	US NMNH collection, OBIS
Family Scleroptilidae	*Scleroptilum gracile*	Massachusetts to Virginia	2513-4332	US NMNH collection
	Scleroptilum grandiflorum	Massachusetts to North Carolina, Panama, W. Africa	1502-2505	US NMNH collection, OBIS
Family Umbellulidae	*Umbellula guntheri*	Massachusetts to Virginia, Louisiana	2683-3740 (3166 m min in NE US)	US NMNH collection
	Umbellula lindahlii	Massachusetts to the Virgin Islands, Louisiana, Suriname, N. Europe, Indian O.	549-3338 (1538 m min in NE US)	US NMNH collection, OBIS
Family Virgulariidae	*Balticina finmarchica*	Newfoundland to Massachusetts, NC (doubtful), the Virgin Islands, Alaska	37-2249 (229 m min in NE US)	US NMNH collection
	Stylatula elegans	New York-Florida, Iberia	20-812 (51 m min in NE US)	US NMNH collection, OBIS

** Distribution information based on studies of a particular area in the Northeast Region, not an overall distribution.

Appendix 5.2. Deep coral species discussed in Hecker and Blechschmidt (1980), Opresko (1980) (octocorals), and Hecker (1980) (scleractinians), as well as Hecker et al. (1980). Species names are listed exactly as stated in the literature.

SPECIES	DISTRIBUTION OR LOCATION
SCLERACTINIANS: Stony corals	
Dasmosmilia lymani	Continental shelf between Baltimore and Hudson Canyons, in Baltimore Canyon, and between 100-200 m on the shelf south of Hudson Canyon and in the head of Hudson Canyon; soft substrates.
Desmophyllum cristagalli	Same as *D. dianthus.* Outcrops and underhangs at depths from 1000-1900 m. Seen on outcrops in Corsair Canyon. Found in Heezen Canyon. Seen in deeper parts of Lydonia Canyon, and on boulders or outcrops in Oceanographer Canyon, between 650-1600 m. Found on an outcrop near Hudson Canyon. Occasionally in axis of Norfolk Canyon.
Flabellum alabastrum	Canyons and slope from 600-2500 m; some may be *F. angulare* or *F. moseleyi.* Seen in Corsair Canyon. Found in Heezen and Oceanographer Canyons on soft substrate. Seen on deep continental slope near Alvin Canyon. Found on slope south of Baltimore Canyon. Found in deeper parts of the continental slope south of Norfolk Canyon and in axis of Norfolk Canyon on soft substrate.
Lophelia prolifera	Same as *L. pertusa*. West wall of Oceanographer Canyon at 1100 m; dead rubble also found on wall at depths from 700-1300 m.
Solenosmilia variabilis	Large colony recovered from the east flank of Lydonia Canyon.
Javania cailleti	One specimen recovered in axis of Oceanographer Canyon between 935-1220 m.
ALCYONACEANS: Soft corals	
Anthomastus grandiflorus	Soft substrates, highest densities in canyons. In the northern canyons found from 700-1500 m, southern canyons from 1500-2200 m; as deep as 2600 m. Found in Corsair, Heezen (west wall), and Oceanographer Canyons. Seen near Hudson Canyon, Toms Canyon, in Baltimore Canyon, and in axis of Norfolk Canyon. Frequently seen where a species of *Pennatula* was also common.
Anthomastus agassizii	Hard substrates from Corsair Canyon to Hudson Canyon from 750-1900 m. Seen on outcrops in Corsair Canyon. Found in Heezen Canyon. Seen in deeper parts of Lydonia Canyon. On boulders or outcrops in Oceanographer Canyon; 1057-1326 m. Seen on deep continental slope near Alvin Canyon. Seen near heads of Toms and Carteret Canyons (i.e., between Baltimore and Hudson Canyons).
Eunephthya fruticosa	Same as *Gersemia fructicosa* (?). Southern part of study area at depths from 2300-3100 m. Seen near Hudson Canyon around 2250-2500 m and at the mouth of Norfolk Canyon; populations found in deep portion of Hudson Canyon. Seen near heads of Toms and Carteret Canyons (i.e., between Baltimore and Hudson Canyons). Different form seen in Corsair and Heezen Canyons between 600-1200 m may be *E. florida* (see Opresko 1980) (Same as *Capnella florida*?)
Eunephthya florida	Same as *Capnella florida* (?). Found in Lydonia, Oceanographer, Baltimore Canyons, but only high abundances in Lydonia at 350-1500 m. Axis of Heezon Canyon between 1100-1200 m; wall of Corsair Canyon between 600-1000 m.
Eunephthya glomerata	Same as *Capnella glomerata* (?). Several individuals found in Lydonia Canyon at 200 m and 562 m depth.
Trachythela rudis	Same as *Clavularia rudis*. Axis of Heezen Canyon at 1100 m, Lydonia Canyon at 900 m, Oceanographer Canyon at 750 m and 900 m.

SPECIES	DISTRIBUTION OR LOCATION
GORGONACEANS: Gorgonians	
Paragorgia arborea	Lydonia Canyon 300-900 m, Oceanographer Canyon around 300-1100 m, axis of Baltimore Canyon 400 m and 500 m, Norfolk Canyon 400-600.
Anthothela grandiflora	Found in Lydonia, Oceanographer, and Baltimore Canyons between 450-1149 m.
Acanthogorgia armata	Found in many canyons from 600-2500 m depth. Seen on boulders or outcrops in Corsair and Oceanographer Canyons; found in Lydonia and Oceanographer Canyons between 400-1299 m. Seen on deep continental slope near Alvin Canyon. Found on an outcrop near Hudson Canyon. Found at 350 m in Baltimore Canyon. Occasionally in axis of Norfolk Canyon on exposed outcrops.
Paramuricea grandis	Found from Corsair Canyon to Hudson Canyon between 750-2150 m. Found on wall and axis of Oceanographer Canyon; found at depths between 400-1349 m in Lydonia and Oceanographer Canyons.
Paramuricea borealis	Same as *P. grandis*, perhaps also *P. placomus* (?). Found from Corsair Canyon to a site near Hudson Canyon at depths of 700-2200 m on hard substrates. Seen on outcrops in Corsair Canyon. Found in Heezen Canyon. Seen in deeper parts of Lydonia Canyon. On boulders or outcrops in Oceanographer Canyon. Seen on deep continental slope near Alvin Canyon. Not seen in Norfolk Canyon.
Primnoa reseda	Same as *P. resedaeformis*. Found in Lydonia Canyon at 560 m, in Baltimore Canyon at 450 m, and Norfolk Canyon at 400 m.
Acanella arbuscula	On soft substrates from 600-1300 m depth in the north and 1500-2000 m depth in the south. Seen in Corsair, Heezen, and Oceanographer Canyons. Found in Oceanographer Canyon between 1046-1191 m. Seen on deep continental slope near Alvin Canyon. On slope just south of Baltimore Canyon. Northern and southern forms may be different species.
Chrysogorgia agassizii	Several individuals that may be *C. agassizii* were found at 2150 m in the vicinity of Hudson Canyon.