State of Deep-Sea Coral and Sponge Ecosystems of the Northeast United States

Chapter 9 in The State of Deep-Sea Coral and Sponge Ecosystems of the United States Report

Recommended citation: Packer DB, Nizinski MS, Bachman MS, Drohan AF, Poti M, Kinlan BP (2017) State of Deep-Sea Coral and Sponge Ecosystems of the Northeast United States. In: Hourigan TF, Etnoyer, PJ, Cairns, SD (eds.). The State of Deep-Sea Coral and Sponge Ecosystems of the United States. NOAA Technical Memorandum NMFS-OHC-4, Silver Spring, MD. 62 p.
Available online: http://deepseacoraldata.noaa.gov/library.

An octopus hides in a rock wall dotted with cup coral and soft coral in Welker Canyon off New England. Courtesy of the NOAA Office of Ocean Exploration and Research.

STATE OF DEEP-SEA CORAL AND SPONGE ECOSYSTEMS OF THE NORTHEAST UNITED STATES

David B. Packer[1], Martha S. Nizinski[2], Michelle S. Bachman[3], Amy F. Drohan[1], Matthew Poti[4], and Brian P. Kinlan[4]*

[1] NOAA Habitat Ecology Branch, Northeast Fisheries Science Center, Sandy Hook, NJ
* Corresponding Author: Dave.Packer@noaa.gov

[2] NOAA National Systematics Laboratory Smithsonian Institution, Washington, DC

[3] New England Fishery Management Council, Newburyport, MA

[4] NOAA Marine Spatial Ecology Division, National Centers for Coastal Ocean Science, Silver Spring, MD

I. Introduction

The Northeast region extends from Maine to North Carolina ends at the U.S. Exclusive Economic Zone (EEZ). It encompasses the continental shelf and slope of Georges Bank, southern New England, and the Mid-Atlantic Bight to Cape Hatteras as well as four New England Seamounts (Bear, Physalia, Mytilus, and Retriever) located off the continental shelf near Georges Bank (Fig. 1). Of particular interest in the region is the Gulf of Maine, a semi-enclosed, separate "sea within a sea" bounded by the Scotian Shelf to the north (U.S. jurisdiction ends at the Hague Line), Georges Bank to the south, and Cape Cod to the southwest. Diverse benthic habitats are found on the rocky ledges, soft sediment banks, and within the 21 deep basins (the largest and deepest being Jordan, Wilkinson, and Georges) of the Gulf. Georges Bank, another prominent feature in the region, is a shallow elongate extension of the continental shelf bounded by the Gulf of Maine to the north, Great South Channel and Nantucket Shoals to the west and south, and the Northeast Channel/Scotian Shelf to the east and north (U.S. jurisdiction ending at the Hague Line). The central portion is shallow, consisting mostly of larger grain-sized sediments, ranging from sand to gravel to boulders depending on location. Numerous submarine canyons, found near the shelf break from Georges Bank down to Cape Hatteras (Fig. 1), cut into the slope and occasionally into the shelf. They were formed by erosion of sediments and

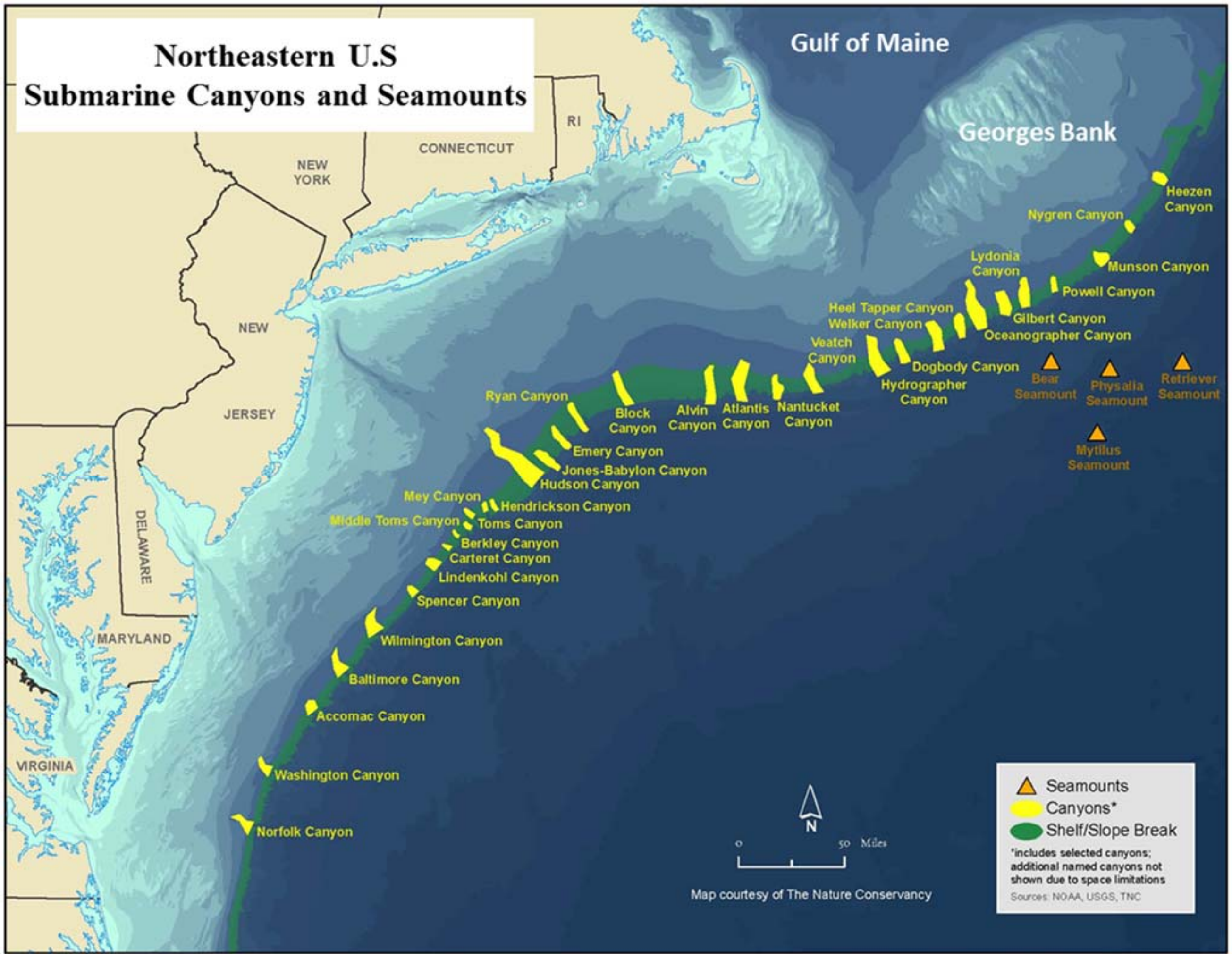


Figure 1. *The major submarine canyons and seamounts (within the EEZ) off the Northeast coast of the U.S.*

sedimentary rocks of the continental margin and are classed as deep (V-shaped from erosion by rivers, mass wasting, and turbidity currents) or shallow (shallowly eroded into the continental margin, or U-shaped canyons). The Mid-Atlantic Bight includes the shelf and slope from Georges Bank to Cape Hatteras. Many hard-bottom topographic features characteristic of other deep-sea coral habitats (e.g., boulders, bedrock, etc.) are absent here. The relatively small amount of hard substrate in deeper water available in this area occurs in conjunction with submarine canyons or is anthropogenic in origin (e.g., artificial reefs, shipwrecks). The shelf topography is relatively smooth and sediments are rather uniform, mostly consisting of sand with some gravel, with finer sediments occurring toward the outer shelf, shelf break, and deeper parts of canyons. The Hudson Shelf Valley and Canyon, off NY/NJ is the main physiographic feature in the Bight, extending from the inner shelf to slope.

Packer et al. (2007) extensively reviewed most of the major coral groups of the Northeast (the exception was sea pens or pennatulaceans; see below), including gorgonians and true soft corals (alcyonaceans), black corals (antipatharians), and certain stony corals (scleractinians). However, much of the information needed to assess the status of the deep-sea coral habitats was unavailable or incomplete at the time of that review. There was missing or inadequate information on deep-sea coral distribution, abundance, natural history, taxonomy, and overall population status and trends, as well as a lack of high-resolution bathymetry data. Available information on deep-sea corals from shelf, slope, and canyon locations was compiled from historical databases (see Packer et al. 2007). These data were mainly presence-only or occurrence records. The canyons where the majority of the survey work had been done were Heezen, Lydonia, Oceanographer, Hendrickson, Baltimore, and Norfolk canyons.

A few patterns or trends were suggested or apparent (Watling and Auster 2005; Packer et al. 2007). For the gorgonians and true soft corals, species composition varies with depth. The suite of species that occurs at depths less than 500 m (shelf and upper slope) is different than that which occurs at depths greater than 500 m (lower slope and rise) (Watling and Auster 2005). Some other species (e.g., the stony coral *Astrangia poculata*) can also be found in nearshore waters less than 50 m deep. Corals occurred in higher densities and were more diverse in canyons, and some species, such as those restricted to hard substrates, were found only in canyons while those utilizing soft substrata were found both in canyons and on the continental slope (see discussions of Hecker and colleagues surveys in Packer et al. 2007). Surveys conducted prior to 2012 (Moore, Watling, Auster, Shank, and colleagues) showed that deep-sea corals are major components of benthic communities of the New England Seamounts. At the time, the black corals (antipatharians) in this region appeared to be primarily confined to the seamounts. Sea pens (pennatulaceans) were not discussed in detail. However, the most common and widespread sea pens (*Pennatula aculeata* and *Stylatula elegans*) are found on the continental shelf in soft sediments, with most other species recorded on the slope and in canyons.

In addition, little was known about the fauna associated with deep-sea coral habitats. For example, debate continued on the role of deep-sea corals as essential fish habitat (EFH) in this region. Although redfish (*Sebastes* spp.) commonly occur in the vicinity of deep-sea corals in the Gulf of Maine and corals may provide important structural attributes of habitat that can affect the distribution and abundance of fishes, it was suggested that corals may not be functionally different from other structure available to fishes (e.g., Auster 2005). There was also little information available about associations between invertebrate species and deep-sea corals in this region, except for nearby studies in Canada (e.g., Northeast Channel: Metaxas and Davis 2005). Studies on invertebrate species associations with octocorals on the seamounts were ongoing.

The effects of fishing efforts on deep-sea corals and coral habitats in this region were not quantified. Quantitative information on the extent of other anthropogenic impacts to corals was also not available. The types of bottom-contact fishing gear used in the Northeast include fixed gear such as longlines, gillnets, pots and traps, as well as mobile gears such as trawls and dredges. Most fishing is conducted on the shelf, or along the shelf break, and in the Gulf of Maine.

The fisheries that have the highest likelihood of occurring near concentrations of known deep-sea coral habitats in canyon and slope areas are the bottom trawl fishery for monkfish (or goosefish, *Lophius americanus*) and the bottom longline fishery for tilefish (*Lopholatilus chamaeleonticeps, Caulolatilus microps)*, and the pot fisheries for Atlantic deep-sea red crab (*Chaceon quinquedens*) and offshore lobster (*Homarus americanus*). Bottom trawl fisheries for squid (*Doryteuthis* [*Amerigo*] *pealeii and Illex illecebrosus*), whiting (includes silver hake, *Merluccius bilinearis* and offshore hake, *Merluccius albidus*), and butterfish (*Peprilus triacanthus*), and pot fisheries for Jonah crab (*Cancer borealis*) occur along the shelf break. In the Gulf of Maine, lobster fishing occurs in all known coral habitats, and gillnet and bottom trawl fisheries for groundfish such as pollock (*Pollachius virens*), redfish (*Sebastes* spp.), and white hake (*Urophysis tenuis*) occur offshore.

In terms of fishery management actions, in 2005, NOAA's National Marine Fisheries Service (NMFS), on the advice of the New England and Mid-Atlantic Fishery Management Councils (NEFMC, MAFMC), closed portions of Oceanographer and Lydonia canyons indefinitely to vessels fishing with bottom trawls or bottom gillnets during a monkfish "day-at-sea" in order to minimize impacts of the monkfish fishery on EFH. Although corals were not included in the EFH descriptions for any fisheries species in the Northeast region, a number of federally-managed species had EFH defined as hard substrates in depths greater than 200 m (e.g., redfish), and the abundance of structure-forming organisms, especially deep-sea corals in these canyons was a major driver for the protection of these hard bottom habitats.

In this chapter we highlight new scientific information on deep-sea coral ecosystems that has become available since the publication of Packer et al. (2007), both from the analysis of samples collected before 2007 (e.g., seamount expeditions conducted from 2003-2005 and described in Packer et al. 2007) and major new mapping and research initiatives since 2011. This new information has resulted in major new management measures established or under development to help protect these habitats in the region. We also include information on deep-sea sponges, which were not addressed in the 2007 report.

II. Update on Scientific Information

II.1. New Research – Overview

In 2010, the Bureau of Ocean Energy Management (BOEM), in partnership with the U.S. Geological Survey (USGS) and the National Oceanic and Atmospheric Administration (NOAA) initiated a major study: Exploration and Research of Mid-Atlantic Deepwater Hard Bottom Habitats and Shipwrecks with Emphasis on Canyons and Coral Communities (BOEM 2010). Between 2012 and 2015, NOAA conducted a series of exploratory surveys of coral habitats in the Gulf of Maine, additional Northeast canyons, and New England seamounts, which have significantly expanded our knowledge of deep-sea coral and sponge habitats in the region. While analysis of information from many of these surveys is ongoing, several publications and reports have already come out (cited and discussed below), and the higher-level identification of deep-sea coral and sponge habitats has already been used by the Regional Fishery Management Councils in development of coral protection zones and by the Obama Administration to inform designation of the Northeast Canyons and Seamounts Marine National Monument (discussed below).

II.1.i – BOEM Atlantic Deep-water Canyons Study 2010-2017

This multi-year study focused on Baltimore and Norfolk canyons in the southern mid-Atlantic Bight, and was designed to understand the distribution and complexity of hard bottom communities in the region. The study was funded by BOEM and awarded to Continental Shelf Associates, Inc. Partners included NOAA, USGS, North Carolina Museum of Natural Sciences, European agencies, and several U.S. universities. The study area was originally selected based on the potential oil and gas lease sales in federal waters within the BOEM mid-Atlantic planning region.

Specific coral related objectives included characterization of the canyons' physical environments, habitats, and associated communities, and included documenting deep-sea coral distribution and diversity, developing predictive habitat models of deep-sea coral distributions, evaluating sensitivity of communities to disturbance, and understanding population connectivity between canyons. The study mapped Baltimore, Accomac, Washington, and Norfolk canyons, with subsequent remotely operated vehicle (ROV) surveys, collections, and studies focused on Baltimore canyon and Norfolk canyon.

For example, see Brooke et al. 2017 for deep-sea corals specifically, as well as other studies by Ross et al. 2015; Prouty et al. 2016; Bourque et al. 2017, etc. See also: http://oceanexplorer.noaa.gov/explorations/12midatlantic/welcome.html and http://oceanexplorer.noaa.gov/explorations/13midatlantic/welcome.html.

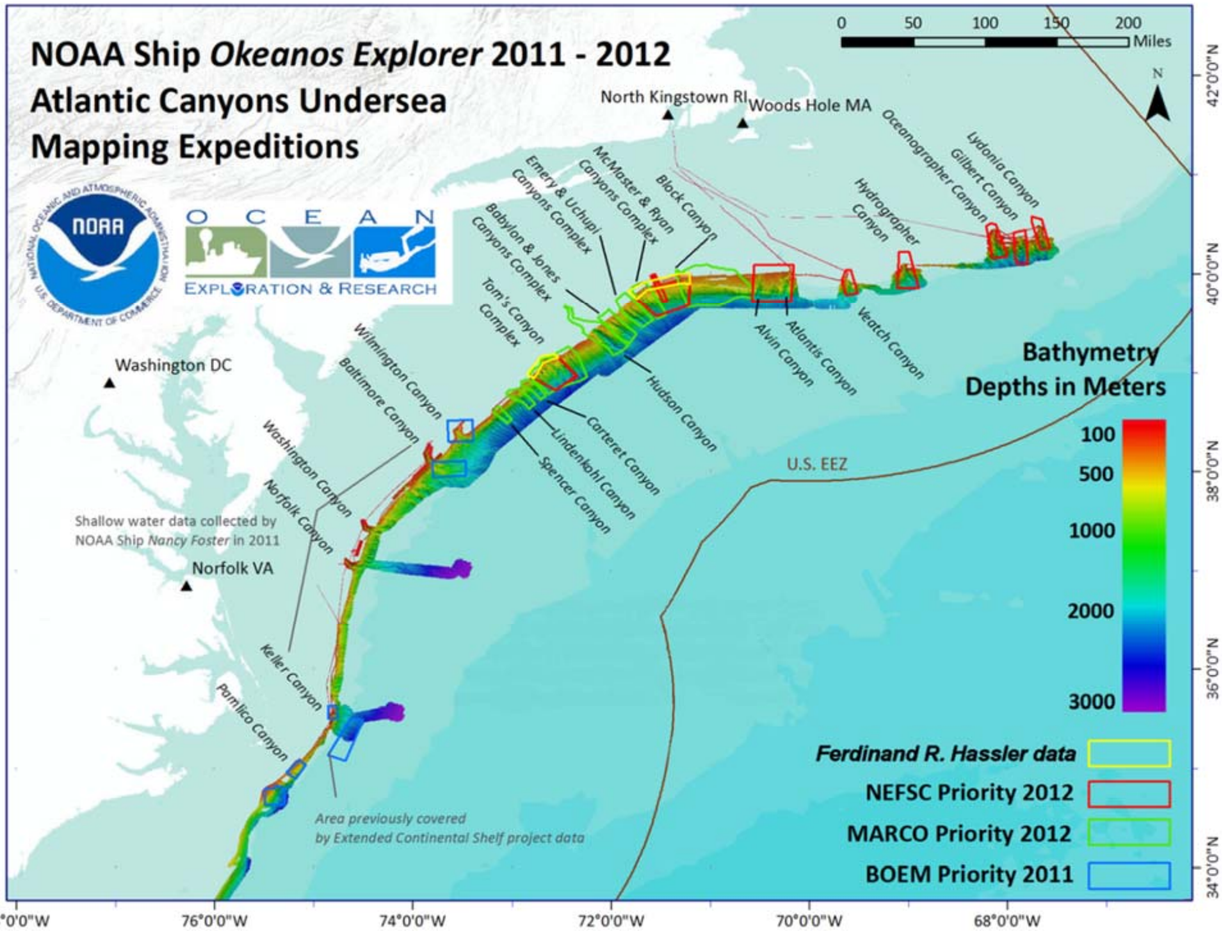


Figure 2. *ACUMEN priority areas selected by NOAA and external partners. Mapping efforts by NOAA Ship* Okeanos Explorer *depicted as color swaths; NOAA Ship* Ferdinand Hassler *as yellow boxes.*

II.1.ii – ACUMEN (Atlantic Canyons Undersea Mapping Expeditions) 2012

Because the submarine canyons on the Northeast continental shelf and slope are diverse and unique habitats that contain a variety of fauna, they are of great interest to federal and state management agencies. However, most are poorly known, due to the costs and logistical difficulties of surveying these areas. A partnership among NOAA line offices, the Atlantic Canyons Undersea Mapping Expeditions (ACUMEN) was established to make efficient use of research ships' multibeam mapping resources, allowing for effective and efficient data collection and capitalizing on complementary capabilities of NOAA assets to produce an integrated, coherent dataset. ACUMEN's goals included field efforts to support the NOAA Habitat Blueprint Northeast Regional Initiative (NOAA 2012a), support of NOAA Integrated Ocean and Coastal Mapping efforts, prioritization of canyons for conservation goals as suggested by state and regional constituents (e.g., NEFMC Habitat Plan Development Team [Habitat PDT], the Mid-Atlantic Regional Council on the Ocean [MARCO]), and sharing of data and products across platforms to guide and refine expedition plans in near real-time. A working relationship was also established with scientists in charge of the BOEM Atlantic Deep-water Canyons study mentioned above.

Priority areas along the continental shelf/slope from Virginia to Rhode Island were initially identified for exploration and mapping by ACUMEN to gather baseline information in support of science and management needs. Between February and August 2012, five expeditions conducted a mapping 'blitz' focused on the submarine canyons (Fig. 2). The expeditions highlighted the complementary capabilities of three NOAA ships: *Okeanos Explorer* (Office of Ocean Exploration and Research), *Ferdinand R. Hassler* (Office of Coast Survey), and *Henry B. Bigelow* (NMFS, Northeast Fisheries Science Center). The *Hassler* and *Okeanos Explorer* collected high-resolution bathymetry data that were quickly processed into mapping products that guided the majority of subsequent habitat modeling and deep-water surveys (discussed below).

The 2012 ACUMEN field efforts finished with a July survey aboard the FSV *Henry B. Bigelow*. Overall goals of the mission were to survey and ground-truth known or suspected deep-sea coral habitats associated with the submarine canyons off the edge of the Northeastern U.S continental shelf/slope. Activities included: (1) characterizing benthic habitats and identifying areas where deep-sea corals and sponges were present; (2) initial ground-truthing of areas predicted to be coral "hotspots" based on data and outputs from a deep-sea coral habitat suitability model; and, (3) ground-truthing newly collected high-resolution (25-50 m) continental slope bathymetric maps created from multibeam data collected during ACUMEN cruises. Using the Woods Hole Oceanographic Institution's (WHOI) towed camera system (*TowCam*), three main canyon areas were targeted: Toms Canyon complex in the mid-Atlantic (Toms, Middle Toms, and Henderickson canyons; Toms-Hendrickson inter-canyon area), Veatch Canyon and the rim of an unnamed canyon northeast of Veatch, and Gilbert Canyon off New England (Fig. 3). Gilbert Canyon in particular was identified as a deep-sea coral "hotspot" by the habitat suitability model. All three main canyon areas were either under-explored or unexplored with regards to deep-sea coral and sponge occurrences. Thus, these areas were of particular interest to the regional Fishery Management Councils.

II.1.iii – Physalia Seamount Expedition 2012

In October 2012, the Waitt Institute funded a cruise with their two REMUS 6000 autonomous underwater vehicles (AUVs; operated by Woods Hole Oceanographic Institution to investigate deep-sea corals on Physalia Seamount (summit depth approximately 1880 m), a previously unexplored member of the western New England Seamount chain within

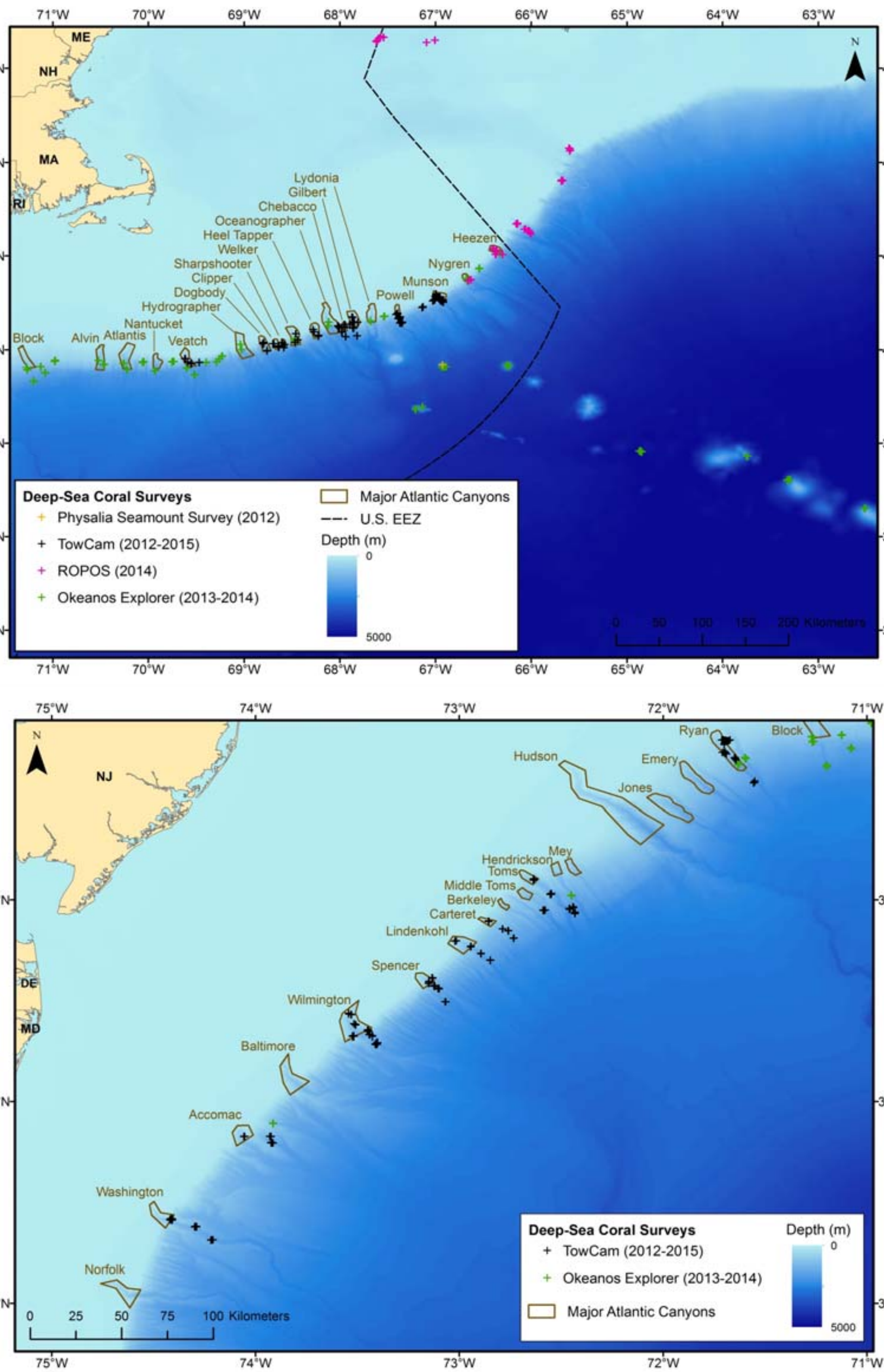


Figure 3. *Map of 2012-15 NOAA expeditions (dives and tows) of the continental slope, canyons, and Mytilus, Physalia, and Retriever Seamounts using either the Woods Hole Oceanographic Institute's TowCam towed camera system or the Canadian ROV ROPOS onboard NOAA ship* Henry Bigelow, *and exploratory surveys by ROV Deep Discoverer onboard NOAA ship* Okeanos Explorer. *BOEM funded surveys of Baltimore and Norfolk canyons are not included. A) New England region. B) Mid-Atlantic region.*

the U.S. EEZ (Kilgour et al. 2014; Fig. 3). The vehicles collected 2956 color seafloor images as well as 120 kHz (low-frequency) and 420 kHz (high-frequency) sidescan sonar. The cruise demonstrated that AUVs are suitable for the rapid assessment of the presence and distribution of deep-sea corals. This "high and fast" sampling strategy was appropriate for the spatial resolution of current management approaches that essentially propose broad geomorphic features (e.g., discrete submarine canyons, seamounts) as deep-sea coral protection zones. The geo-referenced images provided fine scale distribution information, which is optimal for surveying the large areas required for tactical management needs (Kilgour et al. 2014). This project demonstrated that AUVs could be ideal tools for linking fine-scale spatial distribution of deep-sea corals to meso-scale patterns and variation in landscape features, flow regimes and other oceanographic attributes. Such information is of particular benefit for improved deep-sea coral habitat suitability modeling to predict distribution of deep-sea coral taxa across regional landscapes (Kilgour et al. 2014). The results from the AUV deep-sea coral surveys at Physalia Seamount were provided to the NEFMC for use in their regional deep-sea coral management zone determinations.

II.1.iv – NOAA Ship Okeanos Explorer Atlantic Canyon and Seamounts Expeditions 2013 & 2014

In 2013 and 2014, NOAA Ship *Okeanos Explorer* surveyed canyons off New England and the Mid-Atlantic as well as three seamounts off New England using the ROV *Deep Discoverer* (Fig 3). Areas for exploration were prioritized prior to the cruise by resource managers, federal and state partners, and through broad participation of the marine science community. The ship also conducted additional multibeam mapping.

In 2013, surveys were conducted in 11 submarine canyons and Mytilus Seamount (Quattrini et al. 2015; also: http://oceanexplorer.noaa.gov/okeanos/explorations/ex1304/welcome.html). The New England areas surveyed in 2014 included Physalia and Retriever Seamounts, Nantucket Canyon, an unnamed, minor canyon east of Veatch Canyon. Mid-Atlantic areas surveyed in 2014 included the Mey-Lindenkohl Slope (Lindenkohl and Hendrickson canyons) and Washington, Norfolk, Phoenix, McMaster, and Ryan canyons. Full descriptions of the 2014 dives can be found at:

http://oceanexplorer.noaa.gov/okeanos/explorations/ex1404/welcome.html.

II.1.v – NOAA Northeast Deep-sea Coral and Sponge Initiative 2013-2015

The Deep Sea Coral Research and Technology Program funded a Northeast fieldwork initiative from 2013 to 2015 to locate, survey, and characterize deep-sea coral and sponge communities in this region (NOAA 2016). The fieldwork initiative was implemented by NOAA scientists in collaboration with other government agencies (including the Canadian Department of Fisheries and Oceans), and researchers from academic institutions. The projects were designed with the participation of the Regional Fishery Management Councils. The emphasis during the 3-year initiative was on baseline coral and sponge habitat characterization, while trying to survey as many areas as possible in order to provide information and contribute to management decisions by the Fishery Management Councils and other regional partners (e.g., Mid-Atlantic Regional Council on the Ocean, [MARCO]). Thus, the Initiative was designed to satisfy resource management needs while significantly increasing our understanding of the region's deep-sea coral and sponge ecosystems.

By combining Program resources with other partners within and outside of NOAA, leveraging funding, and employing a wide range of research tools, the initiative advanced deep-sea coral science and management through three major fieldwork projects:

1. Exploratory surveys of coral/sponge habitats in submarine canyons, slope areas, and seamounts off New England and the Mid-Atlantic (Fig 3). Surveys off New England and the Mid-Atlantic were conducted every summer from 2013-2015 using towed cameras, targeting areas in and around submarine canyons from approximately 300+ m to 2100 m. The Deep Sea Coral Research and Technology Program was also a partner on the *Okeanos Explorer* expeditions. Surveys contributed to groundtruthing and refining the next iterations of the Northeast's deep-sea coral habitat suitability model.

2. Characterizations of seafloor communities in the U.S. and Canadian cross-boundary Gulf of Maine region and on the U.S. and Canadian continental margin (ROV *ROPOS* dives, 2014; Fig 3).

3. Exploratory surveys of northern Gulf of Maine (U.S.) habitat areas for deep-sea corals and sponges. This component also included collecting specimens of the common sea pen (*Pennatula aculeata*) to determine if they are being used by fish larvae (perhaps redfish, *Sebastes* spp.) as nursery habitat, as has been observed in Canada (Baillon et al. 2012).

II.2. Taxonomy and Species Distributions

II.2.i – Corals

a. Coral taxonomy

Deep-sea corals in the Northeastern U.S. belong to four orders: Order Scleractinia (the stony corals), Order Antipatharia (black corals), Order Alcyonacea (including gorgonians [formerly in the order Gorgonacea], true soft corals, and stoloniferan corals), and Order Pennatulacea (sea pens) (see Packer et al. 2017 online). Sea pens were not covered in detail by Packer et al. 2007; however, they may play an important role in benthic communities (Buhl-Mortensen et al. 2016) and provide nursery habitat for some commercial fish species (see below, re: Baillon et al. 2012) Thus, sea pens are now included in the species list and summaries of deep-sea corals in this region. NOTE: Gorgonians are the most important structure-

Table 1. *Number of coral species reported from the Northeast U.S. in 2007 and in the present report (including taxa with incomplete taxonomy – e.g. taxa reported only to genus level)). Increases include new species identifications and range extensions, but principally represent species not included in the first report. The lower number of sea pen taxa reflects a number of synonymized species. Data sources and references online in Packer et al. 2017: https://deepseacoraldata.noaa.gov/library/2017-state-of-deep-sea-corals-report.*

TAXON	Packer et al. 2007	Packer et al. 2017
Black corals (Order Antipatharia)	2	6
Stony corals (Order Scleractinia)	16	17
Gorgonian corals (Order Alcyonacea – in part [formerly Order Gorgonacea])	17	32
True soft corals and stoloniferans (Order Alcyonacea)	9	9
Sea pens (Order Pennatulacea)	17	14
Total	**61**	**78**

forming corals in the Northeast region, and for the purposes of this chapter, they will generally be treated separately from other alcyonaceans. Current taxonomic recognizes gorgonians, true soft corals, and stoloniferans under order Alcyonacea (Bayer 1981; Daly et al. 2007; McFadden et al. 2010).

Packer et al. (2007) reported 61 species of corals from the Northeast region (Table 1). Since 2007, the systematic compilation of coral records in the National Deep-sea Coral and Sponge Database, along with new descriptions and range extensions, has increased this number to 78 (Table 1; see Packer et al. 2017 online). The largest increase in numbers was among the gorgonian corals, reflecting new species descriptions by Cairns (2006, 2007), Pante and Watling (2011), and Simpson and Watling (2011), as well as new additions to the species list. Many of the new species descriptions resulted from analysis of specimens collected during 2003-2005 seamount expeditions (described in Packer et al. 2007).

For sea pens, there have been several new additions and name changes; e.g., *Protoptilum aberrans* Kölliker 1880 has been removed from the current list as it is now considered a junior synonym of *Protoptilum carpenteri* Kölliker, 1872 (Mastrototaro et al. 2015), *Funiculina armata* Verrill, 1879 has been added, etc. (see Packer et al. 2017 online).

b. Coral distribution

Data Sources: The primary sources of historical (i.e., prior to 2007) deep-sea coral records and observations in this region are discussed and referenced in Packer et al. (2007). There are two main types of deep-sea coral data in the

Northeast region: geo-referenced presence records, and presence records with no accompanying geo-referenced information, or only general location information, which we call "observations." (The latter most often comes from the historical deep-sea coral survey literature.) There is too little deep-sea coral density or abundance data to be useful for either scientific or management purposes, especially in aggregate with other occurrence data. A database of Northeast deep-sea corals, based largely on historical geo-referenced presence records from the late 1800s to the present, was updated by incorporating taxonomic changes made between 2007 and 2013 and adding "new" presence records gleaned from museum collection databases (e.g., the Smithsonian Institution's National Museum of Natural History collection, which includes records of coral taxa collected from various research surveys/expeditions from 1873 through to the present), other data mining activities, the literature, and new records from expeditions in the 2000s (e.g., the NOAA-Ocean Explorer 2001 "Deep East" expeditions to Oceanographer, Hydrographer, and Hudson Canyons and 2003 "Mountains in the Sea" expeditions to the New England Seamounts). Additional records of sea pens (especially *Pennatula aculeata*) collected from 1956-1984 were compiled from various sources (e.g., Langton et al. 1990). Records of new species of octocorals, mostly from Bear and Retriever Seamounts with some from the submarine canyons off New England (e.g., *Thouarella grasshoffi* Cairns 2006 from Bear Seamount and Oceanographer Canyon) were obtained from recently published literature (Cairns et al. 2007; Thoma et al. 2009; Pante and Watling 2011; Watling et al. 2011). New records of antipatharians were also obtained from recently published seamount literature (Thoma et al. 2009). These records have now been incorporated into NOAA's National Database on Deep-Sea Corals and Sponges (www.deepseacoraldata.noaa.gov; Hourigan et al. 2015).

Deep-sea Coral Habitat Suitability Modeling: Because of the prohibitive costs and logistical difficulties of surveying for deep-sea corals and their associated habitats, geo-referenced deep-sea coral location data are often limited and patchy, and are mostly of presence-only. This makes it difficult for resource managers trying to identify and implement deep-sea coral habitat management areas to develop spatially contiguous measures for coral conservation in the absence of comprehensive surveys.

Habitat modeling for deep-sea corals has become a cost effective approach to predict locations of deep-sea corals and other benthic species, and aid managers in developing deep-sea coral management zone alternatives (Leverette and Metaxas 2005; Bryan and Metaxas 2007; Davies et al. 2008; Tittensor et al. 2009; Davies and Guinotte 2011; Guinotte and Davies 2012; Yesson et al. 2012; Vierod et al. 2013). Habitat suitability modeling examines the associations between the presence and/or absence of organisms and their relevant environmental or habitat variables such as depth, slope, temperature, and related measures.

NOAA developed a set of deep-sea coral predictive habitat models for this region for a set of taxonomic groups (Kinlan et al. 2013; Kinlan et al., in review). The spatial domain of the models includes the continental shelf and canyons in New England and the Mid-Atlantic. Seamounts are not included, because the model is based on the footprint of the coastal relief digital elevation model, which does not include the seamounts. A machine-learning technique called Maximum Entropy modeling, or MaxEnt, was used to predict suitability of unexplored habitats based on locations and environmental characteristics of known deep-sea coral presence (Guinotte et al., this volume).

The MaxEnt models were run with selected predictor (environmental) variables and presence data for four taxonomic orders of deep-sea corals represented in the Northeast historical database (Alcyonacea, [formerly] Gorgonacea, Scleractinia, and Pennatulacea). Data included in the models were: 1) Northeast coral presence records from the Cold Water Coral Geographic (CoWCoG) database (Scanlon et al. 2010; NOAA 2011a) supplemented with additional records from the region (Packer and Dorfman 2012); 2) high-resolution bathymetry data from the NOAA Coastal Relief Model (NOAA 2011b); and, 3) environmental predictors (seafloor terrain statistics; physical, chemical, and biological oceanographic data, and sediment/substrate information).

Habitat suitability maps and model evaluation methods predicted suitable habitat in the vicinity of known deep-sea coral presence locations, as well as in unsurveyed areas (for more detailed discussion of model results, see Guinotte et al. 2016, Guinotte et al., this volume, Kinlan et al., in review). Some model outputs are better predictors of coral presence than others, in part due to the number of coral records for each order in the historical database. The model outputs for alcyonacean (= gorgonian and true soft) corals is based on a sizeable number of data points and is the model with the best predictive ability. Therefore, these model outputs were used by the MAFMC and NEFMC to evaluate deep-sea coral habitat suitability of each proposed broad and discrete deep-sea coral management zone (see discussion, below). Conversely, the model for scleractinians is based on a smaller number of records, mostly of solitary, soft-sediment dwelling cup corals (e.g., *Dasmosmilia lymani* and *Flabellum* spp.). The scleractinian model is likely to under-predict the likelihood of suitable habitat for this coral taxon. Sea pens were modeled, based mostly on records from the continental shelf (e.g., *Pennatula aculeata* from New England/Gulf of Maine and *Stylatula elegans* from the Mid-Atlantic) but are not currently used by the Fishery Management Councils. These corals occur in soft bottoms, are more widespread in distribution, and the contribution of these two species, especially *P. aculeata,* as structure-forming habitat for other species is still poorly understood or open to question (see discussion below). Black corals were not included in the modeling study due to insufficient data on their distribution when the study commenced. Future incorporation of recent data for structure-forming scleractinians and black corals in the Northeast region will

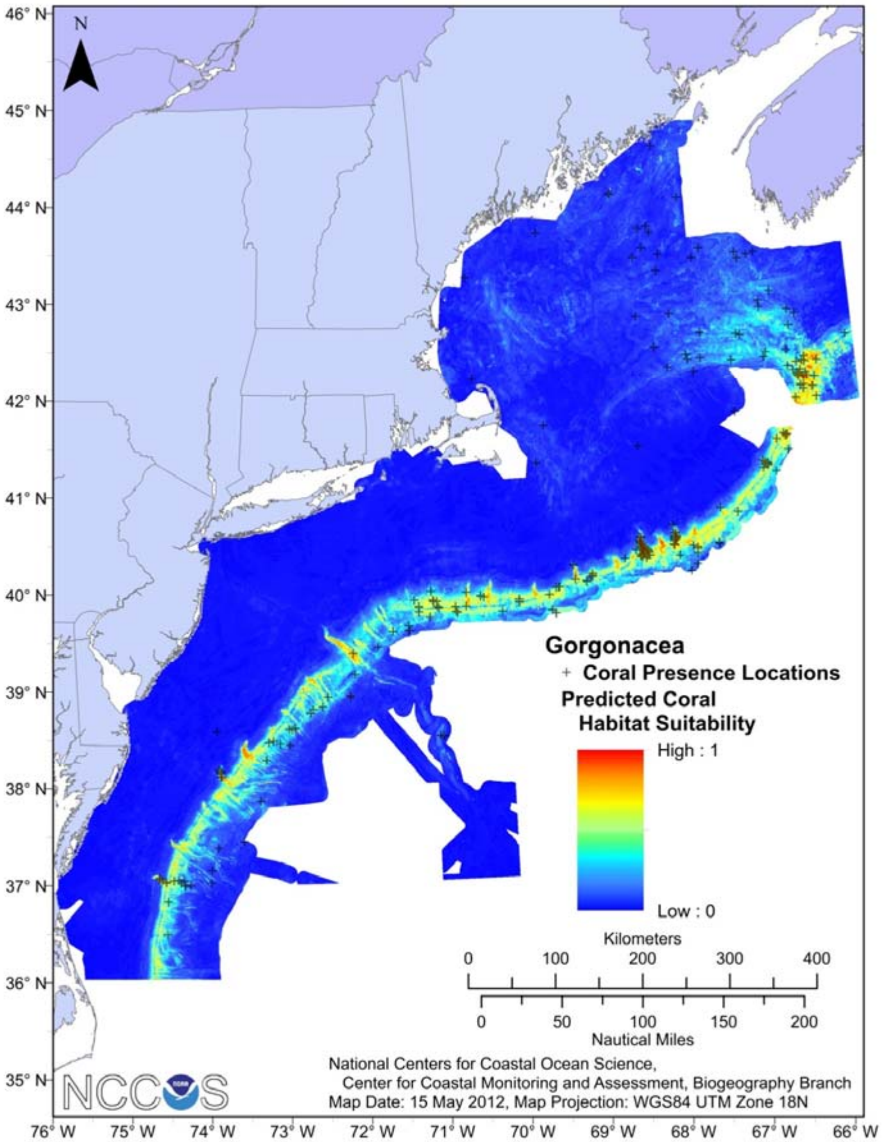


Figure 4a. *Example of MaxEnt Predictive Habitat Model (PHM) for gorgonians in the Northeastern U.S. region (Kinlan et al. 2013). Warm colors (e.g., red) denote areas predicted to be more suitable gorgonian habitat and cooler coolers (e.g., blue) denote areas predicted to be less suitable gorgonian habitat. Crosses represent coral presence records used in generating the model.*

likely improve the predictive ability of models for these taxa.

An example of model outputs for gorgonians are shown in Fig. 4a,b. The outputs show the predicted likelihood of deep-sea coral habitat in a given area. The predicted likelihood of coral habitat suitability is displayed in "thresholded logistic" maps; i.e., the likelihood values are displayed by the following likelihood scale: cooler colors (e.g., blue) denote areas predicted to be less suitable habitat for gorgonians, while warmer colors (e.g., red) denote areas predicted

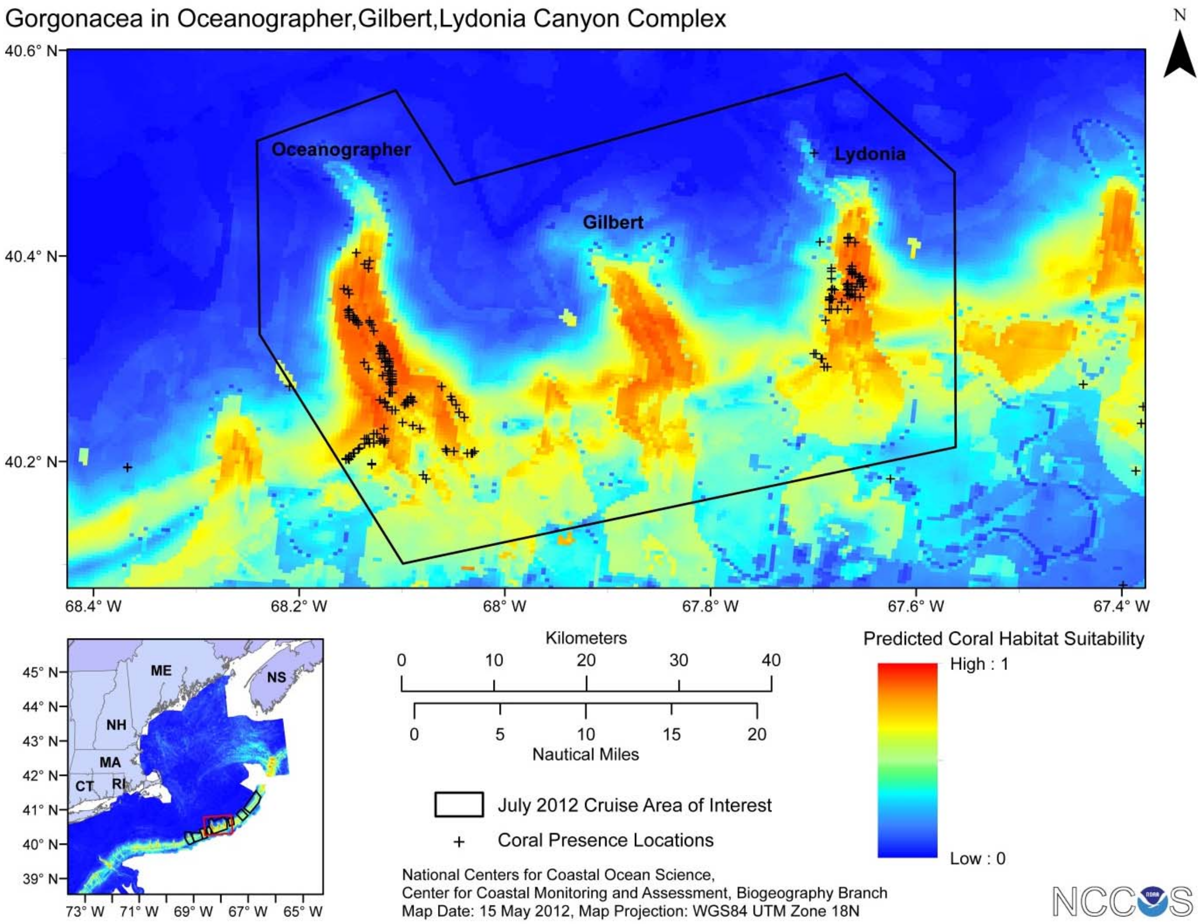


Figure 4b. *Close-up of predicted gorgonian habitat suitability in the Oceanographer-Gilbert-Lydonia canyon complex. Crosses represent historical coral presence records. Polygon boundary shows area of interest identified for exploration and groundtruthing for July 2012 DSCRTP/NEFSC R/V* Bigelow *cruise.*

to be more suitable habitat. The models predict that the canyons represent "hot-spots" for gorgonian coral presence.

After the surveys designed to ground-truth the model were conducted (see below), the Northeast's habitat suitability models, along with distribution data from historical and recent deep-sea coral surveys, became essential components of the deep-sea coral protection zone decision-making process by the two Regional Fishery Management Councils. This includes the decision by the MAFMC in 2015 to approve an amendment to protect deep-sea corals in their region from the impacts of bottom-tending fishing gear along the edge of the continental shelf and slope and in the submarine canyons (discussed, below).

Mid-Atlantic and New England Continental Slope and Canyons Exploratory Surveys: The continental slope off the Northeast U.S. is incised by numerous submarine canyons, which contain extensive hard-bottom habitat, which is needed for the attachment of most deep-sea corals (Packer et al. 2007). Prior to 2010, most information on deep-sea coral habitats within Northeast canyons came from the surveys of Hecker et al. during the 1980s (see Packer et al. 2007 for discussions and references, and B. Hecker presentation in NEFMC 2011). Based on these historical surveys, some general patterns in deep-sea coral distribution were suggested. As stated above, deep-sea corals were generally more densely distributed and diverse in the canyons than on the adjacent slope owing to steep canyon topography, accelerated currents, and heterogeneous sedimentary geology. Some species, such as those restricted to hard substrates, were only found in the canyons while other species that frequently occur on soft substrates, such as *Acanella arbuscula*, were found both in canyons and on the slope. There appeared to be two distinct distributional patterns for the gorgonians and true soft corals (Watling and Auster 2005). Most were deep-water species that occurred at depths > 500 m (gorgonians in the genera *Acanthogorgia*, *Acanella*, *Anthothela*, *Lepidisis*, *Radicipes*, *Swiftia*; the alcyonacean soft coral *Anthomastus*, and the stoloniferan *Clavularia*). Other species appeared to occur throughout shelf waters to the upper continental slope (gorgonians *Paragorgia arborea*, *Primnoa resedaeformis*, *Paramuricea* spp.) (Watling and Auster 2005). The larger northern canyons such as Lydonia and Oceanographer have hard substrates along most of their axes and walls that support many deep-sea corals and sponges. The slope south of Georges Bank appeared to be mostly soft substrate, supporting mainly solitary stony (cup) corals on the upper slope (e.g. *Flabellum* sp., *Dasmosmilia lymani*) and sea pens deeper than about 1500 m, with some exceptions (NEFMC 2011). Some harder substrate was found at depths greater than 1400 m depth on the Mid-Atlantic slope off New Jersey. Sparse coral populations were found at these deeper depths; sea pens and stony corals appeared to be sparse or common on the upper slope; sea pens and *A. arbuscula* were found on the lower slope. The larger, southern canyons like Baltimore and Norfolk canyons appeared to have less hard substrate than the northern canyons (NEFMC 2011), although some hard substrate that supports coral and sponges was found in shallower depths (300-550 m). There were also sea pens at upper slope depths and sea pens and *A. arbuscula* at lower slope depths.

Recent towed camera and ROV surveys (most without associated specimen collections) were conducted in almost all of the major canyons in the Mid-Atlantic and New England regions (Fig. 3). Several minor canyons and slope areas were also surveyed. The surveys revealed significant inter-canyon variability, even between neighboring canyons. Canyon morphology, habitat heterogeneity, the amount and type of substrate, depth, environmental conditions, and currents appear to play a role in the biodiversity of corals, sponges, and fishes observed in each canyon. Corals were observed in every canyon, however, abundance and diversity of corals varied dramatically. For example, only a few colonies of widely dispersed corals were observed in Washington

Canyon (off Virginia) whereas a "coral forest" of the bubblegum coral (*Paragorgia arborea*) was observed in Heezen Canyon (near Hague Line). The surveys also revealed unique areas; e.g., discovery of coral biodiversity hotspots in relatively shallow (300-500 m) depths at the head of Wilmington Canyon, as well as Baltimore and Norfolk canyons (Brooke et al. 2017), and observations of corals in minor canyons.

Colonial stony corals, the solitary stony cup coral *Desmophyllum dianthus*, black corals, most alcyonaceans, and the majority of sponges observed were on hard substrates, whereas other solitary stony corals (e.g., *Flabellum* sp.), sea pens, and the bamboo coral *Acanella* sp. were common on soft sediments (Fig. 5). Throughout the Mid-Atlantic and New England canyons, gorgonians were the dominant structure-forming corals. The large gorgonians, *Paragorgia arborea*, *Paramuricea* spp. (including *P. placomus*), *Primnoa resedaeformis*, and *Acanthogorgia* spp. were generally most abundant in canyons from Virginia to the Hague Line at depths shallower than 1000 m. Gorgonians in the genus *Anthothela* were also abundant. The bubblegum coral (*P. arborea*) reached the largest sizes. As for the true soft corals, *Anthomastus* is probably the numerically dominant species, while *Duva florida* can be extremely locally abundant (hundreds of colonies) but distribution is patchy (Sandra Brooke, Florida State Univ., pers. comm.). The first observations of black corals in a number of the canyons were made during recent surveys. These included species in the genera *Bathypathes*, *Parantipathes, Stauropathes*, and the recently described *Telopathes magna* (Quattrini et al. 2015; Brooke et al. 2017) (Fig. 5).

Stony corals (Order Scleractinia) were not especially abundant or diverse at large spatial scales (although they were patchy and dense within particular areas of canyons). The solitary cup coral, *Desmophyllum dianthus*, was the most often observed stony coral, usually seen on canyon walls and in dense aggregations along ledges or overhangs (Quattrini et al. 2015, Brooke et al. 2017). The branching colonial corals *Lophelia pertusa* and *Solenosmilia variabilis* were also observed in the canyons. Both corals occurred as small, individual colonies, with *L. pertusa* generally observed between 300-1000 m and *S. variabilis* generally deeper than 1000 m. *Lophelia pertusa* is the most important reef-forming deep-sea coral in the Atlantic, and forms large reefs (bioherms) in the southeast U.S. (Ross and Nizinski 2007; Hourigan et al., this volume) and the Northeast Atlantic (Roberts et al. 2009). There was no evidence of large bioherm formation by either species in the Northeast region.

Quattrini et al. (2015) reported at least 58 coral taxa representing 20 families in 11 New England canyons and adjacent slope habitats. Quattrini et al. (2015) found that the type of broad-scale habitat feature and high habitat heterogeneity in this region was an important factor that influenced the diversity of coral assemblages. There were no significant differences between deep-sea coral assemblages occurring in the two different types of canyons (continental shelf-breaching canyons vs. canyons confined to the continental slope).

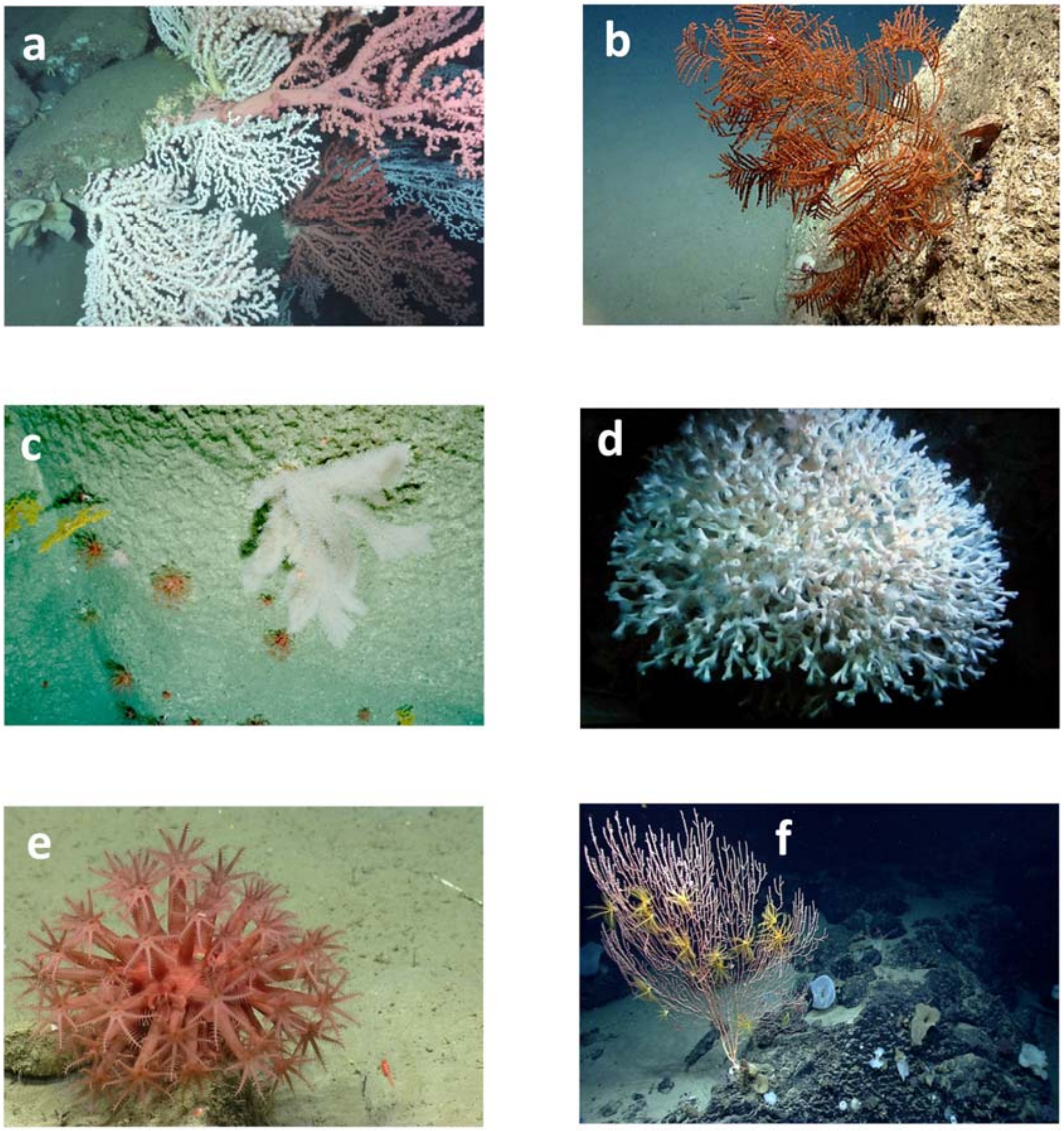


Figure 5. *Examples of Northeast deep-sea corals from the submarine canyons and seamounts during the 2012-2015 expeditions. Coral identifications in the images may be tentative. a) Various color morphs of gorgonian bubble gum coral (*Paragorgia arborea*), Heezen Canyon (656 m) (ROPOS). (b) Black coral* Telopathes magna*, Block Canyon (1345 m) (Deep Discoverer). (c) Gorgonian* Thouarella grasshoffi *(white), soft coral* Anthomastus *(red), gorgonian* Paramuricea *(yellow); Powell Canyon (1300-1770 m) (TowCam). (d) Scleractinian colonial coral* Lophelia pertusa*, Baltimore Canyon (381 m) (Kraken 2). (e) Soft coral* Anthomastus*, Oceanographer Canyon (Deep Discoverer). (f). Gorgonian bamboo coral* Jasonisis*, with numerous crinoid associates, Mytilus Seamount (Deep Discoverer).*

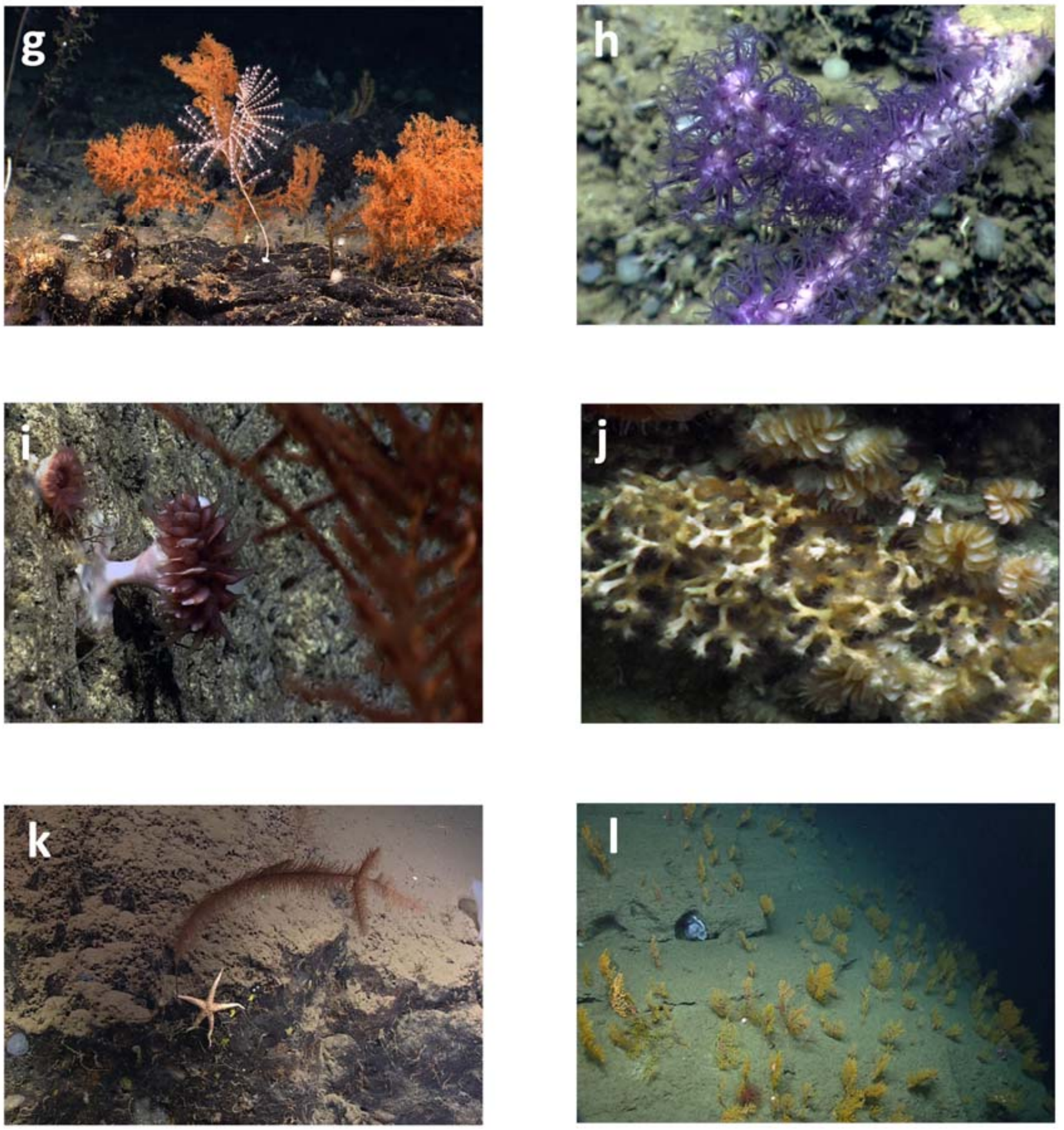


Figure 5 (cont.). *Examples of Northeast deep-sea corals from the submarine canyons and seamounts during the 2012-2015 expeditions. Coral identifications in the images may be tentative. g) Two colonies of black corals and spiraled gorgonian* Iridogorgia *sp., Retriever Seamount (Deep Discoverer). (h) Stoloniferan coral* Clavularia *sp., Nygren Canyon (Deep Discoverer). (i) Scleractinian cup corals and black coral (foreground), wall of unnamed canyon east of Veatch Canyon (1480 m) (Deep Discoverer). (j) Scleractinian colonial coral* Solenosmilia variabilis *and solitary cup coral (above)* Desmophyllum dianthus*, Baltimore or Norfolk Canyon (Brooke et al. 2017). (k) Black coral* Parantipathes *sp., Nygren Canyon (ROPOS). (l). Gorgonian* Paramuricea *sp., Welker Canyon (Deep Discoverer).*

However, different, less diverse faunal assemblages were observed at cold seeps (areas on the seafloor where hydrocarbon-rich fluid seeps up from below) and soft bottom open slope sites. The canyons often had large patches of hard bottom deep-sea coral habitat, which also included bivalves, anemones, and sponges. Stony corals (e.g., the solitary cup coral *Desmophyllum dianthus* and the colonial *Solenosmilia variabilis*) and octocorals were often abundant on long stretches of canyon walls and under and around overhangs; the colonial stony coral *Lophelia pertusa* was particularly noted in canyons at depths from 733-1030 m. Coral communities were uncommon on the open slope, except on the channel floor of Veatch Canyon where sea pens and bamboo corals in soft sediments were frequently observed. Corals and sponges were also observed on boulders and outcrops in some open slope and inter-canyon areas. At Veatch seeps and the canyon wall adjacent to the seep community in Nygren Canyon, octocorals and stony cup corals (*D. dianthus*) were found attached to authigenic carbonates (carbonate precipitated in-situ at the sediment–water interface and/or within the sediment).

Quattrini et al. (2015) also found that depth was a significant factor influencing the coral assemblages. Although species richness did not change significantly with depth over the range explored by the surveys (494-3271 m), species composition changed at ~1600-1700 m. Species composition in the canyons and other areas with hard substrates were significantly dissimilar across this depth boundary. Stony corals and the gorgonians *Anthothela* spp., *Keratoisis* sp. 1, and *Paragorgia arborea*, occurred at depths < 1700 m, whereas gorgonians from the family Chrysogorgiidae (chrysogorgiids) and sea pens were more common at depths > 1700 m. Overall, depth, habitat, salinity and dissolved oxygen explained 71% of the total variation observed in coral assemblage structure (Quattrini et al. 2015).

The surveys of both Baltimore and Norfolk canyons discovered that deep-sea corals were patchily distributed and locally abundant and large gorgonians were the dominant structure-forming species on exposed hard substrates (Brooke et al. 2017). Several species of stony corals were also present, including new records of *Solenosmilia variabilis* on deep walls (~1400 m) in Norfolk Canyon, and the structure-forming *Lophelia pertusa* on shallower (381-434 m) walls of both Baltimore and Norfolk canyons (Brooke and Ross 2014; Fig. 5d). A new record of the black coral *Telopathes magna* was also reported for Norfolk Canyon. The diversity of structure-forming corals was low, but several areas in both canyons had high coral abundances and diverse coral communities, dominated by large octocoral species (Brooke et al. 2017). Coral distribution varied within and between the two canyons, with greater abundances of the bubblegum coral *Paragorgia arborea* in Baltimore Canyon than in Norfolk Canyon, but higher occurrences of stony corals in Norfolk Canyon than in Baltimore. The gorgonians *P. arborea*, *Primnoa resedaeformis*, and *Anthothela grandiflora* had a wide distribution within these canyons, whereas *Paramuricea placomus* and the branching stony corals *L. pertusa* and *S. variabilis* were limited to certain habitat types and/or depth zones (Brooke et al. 2017).

The Northeast deep-sea coral habitat suitability models generally predict that the canyons are highly suitable habitat for the gorgonian and soft coral groups. Surveys of the canyons allowed independent ground-truthing of the models, which were qualitatively validated: all sites observed to be areas of high coral abundance and diversity were also areas predicted to have a high likelihood of suitable habitat based on the regional model. The habitat suitability models performed well in predicting areas of likely deep-sea coral habitat, as well as predicting areas where corals are unlikely to be found. However, the exact location of areas of high deep-sea coral density and diversity often depends on fine-scale seabed features (e.g., ridges or ledges of exposed hard substrate) that are smoothed over in this regional-scale model. The current resolution of the model is grid cells of approximately 370 m^2 (although there are plans to improve the model by increasing resolution to 25 m^2, as well as incorporating more recent multibeam bathymetry and coral observations with higher taxonomic specificity). Habitat suitability maps based on this model should be viewed as representing only the general locations of predicted suitable coral habitat (within a distance of approximately 350-740 m, the dimension of one to two model grid cells). For this reason, the total area of high/very high habitat suitability is an approximation using the best available data. Quantitative ground-truthing of the model includes assessment of the prediction skill of the model and correlation between predicted habitat suitability and coral frequency/abundance observations.

New England Seamounts Exploratory Surveys: Bear Seamount was discussed in Packer et al. (2007).

Physalia Seamount (summit depth ~ 1,880 m) was explored by AUVs in 2012 (Kilgour et al. 2014) and an ROV in 2014 (*Okeanos Explorer* 2014 expedition). The AUV surveys revealed the presence of octocorals, with sea pens generally found in flat, soft sediments, and most other octocorals found at either the transition between soft sediment and hard bottom, or on hard bottom features such as walls, ledges, and gravel/bedrock pavement (Kilgour et al. 2014). The more detailed ROV survey revealed relatively low abundances and low diversity of corals. The gorgonian *Chrysogorgia* sp. and sea pen *Anthoptilum* sp. were seen most commonly. Of particular note, *Anthoptilum* sp. was seen in typical sea pen habitats embedded in soft sediments but also on hard substrates; Williams and Alderslade (2011) described species in this genus from the Pacific with the unusual adaptation of the peduncle that acts as a holdfast for attachment to rocky substrata. Occasionally, the bamboo coral *Lepidisis* sp. was observed. Other corals reported from Physalia Seamount include the black corals *Telopathes* sp. and *Bathypathes* sp., the soft coral *Anthomastus* sp., and stony cup corals.

Mytilus Seamount has the deepest summit (~2,500 m) of all New England seamounts in U.S. waters. The first ROV surveys of Mytilus (Quattrini et al. 2015) revealed a diverse assemblage of taxa, including gorgonians (Fig. 5f) and especially black corals, and numerous hexactinellid sponges and demosponges. The corals observed (> 2600 m) were significantly different from those observed in Northeast canyon sites at similar depths by Quattrini et al. (2015). Differences in species composition between Mytilus Seamount and other sites were primarily due to the presence/absence of numerous species. For example, *Chrysogorgia* spp., *Convexella*? *jungerseni*, *Corallium*? *bathyrubrum*, *Paranarella*? *watlingi*, and *Paragorgia/Sibogagorgia* sp. 1 were observed on Mytilus Seamount, while *Acanthogorgia* spp., *Anthothela* spp., *Clavularia*? *rudis*, *P. arborea*, and *Paramuricea* spp. were not seen on Mytilus Seamount, but occurred at other sites. No stony corals were observed here. Quattrini et al. (2015) suggest that the deeper depths (2600 to 3200 m) are beyond the bathymetric limits of stony corals.

Retriever Seamount is the farthest-offshore seamount within the U.S. EEZ. It is about 2000 m high, 7 km in diameter, and has three main summits. Thoma et al. (2009) reported the occurrence of gorgonians in the genera *Chrysogorgia*, *Iridogorgia*, *Metallogorgia*, *Acanella*, and *Paramuricea*; as well as black corals in the genera *Bathypathes* and *Parantipathes*. A single ROV dive in 2014 (Fig. 5g) between 2142 to 2003 m depth revealed sandy slopes, boulders and a rock outcrop. Many sea pen colonies, with ?*Anthoptilum* sp. more common than *Pennatula* sp., as well as stony cup corals (*Caryophyllia* sp.) were seen in sedimented areas. Colonies of the chrysogorgiid gorgonian, *Metallogorgia melanotrichos* were very abundant on the rock outcrops; several "sub-adult" colonies were observed, suggesting multiple recruitment events in the area. Other corals observed on the outcrop included the gorgonians *Hemicorallium ?bathyrubrum (=Corallium ?bathyrubrum*) and *H. ?niobe*, *Paramuricea* sp., *Iridogorgia splendens* (at least one with shrimp associate) and *I. magnispiralis*, *Candidella imbricata* and an unidentified primnoid coral, bamboo corals (*Lepidisis* sp. and *Acanella* sp.), and black corals in the genera *Parantipathes* (branched), *Stauropathes*, and, seen further upslope on isolated rocks, *Bathypathes*.

Gulf of Maine Exploratory Surveys: Deep-sea corals in the Gulf of Maine have been reported since the 19th century, both as fisheries bycatch and from naturalist surveys. At one time, deep-sea corals may have been considered common on hard bottoms in the region. However, after a century of intensive fishing pressure using mobile bottom gear such as trawls and dredges as well as fixed gear such as lobster traps, the denser populations of deep-sea corals and coral habitats are now confined to small areas where the bottom topography makes them mostly inaccessible to these fisheries (Auster 2005; Watling and Auster 2005; Cogswell et al. 2009; Auster et al. 2013).

Previous studies, including work on the Canadian side of the Gulf (e.g., Northeast Channel: Buhl and Buhl-Mortensen 2004; Watanabe et al. 2009) do show that deep-sea corals have a patchy distribution that is correlated with environmental factors such as slope, sediment, current, temperature and depth. Nevertheless, the information needed to assess their overall status in the U.S. Gulf of Maine has been lacking. Additionally, information on deep-sea coral distribution in relation to habitat and landscape features, abundance, natural history, associated species, and human impacts has been inadequate.

Previous deep-sea coral exploratory surveys and seafloor mapping in the region guided the selection of survey sites in 2013. Initial deep-sea coral surveys using ROVs in 2002 and 2003 documented a limited number of locations in Western Jordan Basin and around Mount Desert Rock with dense coral garden communities at around 200 m (Auster 2005; Watling and Auster 2005). Deep-sea corals were found on rocks, boulders, ridges and walls extending above the surrounding fine-grained sediments. During a cruise aboard NOAA Ship *Ronald H. Brown* in 2005, multibeam bottom sonar data collected in Western Jordan Basin revealed that hard bottom in the immediate area around "114 Bump" (one of the sites surveyed for corals in 2002-2003) was more spatially extensive than previously suspected (see Fig. 2 in Auster et al. 2014). Thus, the potential for suitable deep-sea coral habitat in the area was more likely.

Results of the recent Gulf of Maine exploratory surveys (2013-15) revealed extensive coral aggregations at depths around 200-250 m in the five primary survey sites: Western Jordan Basin, Central Jordan Basin, near Mount Desert Rock, on Outer Schoodic Ridge, and on Lindenkohl Knoll in Georges Basin (Fig. 6) (Auster et al. 2013, 2014; Packer et al., unpublished data). Structure-forming corals on hard substrate at all sites were predominantly gorgonians, although a few tiny, stony scleractinian cup corals were seen on some dives. Coral occurrences were classified as either coral present (sparse to medium density) or coral garden (high density patches).

Coral gardens are defined as areas where non-reef-forming corals are among the dominant fauna and occur at densities higher than surrounding patches (Bullimore et al. 2013). Dense and extensive gorgonian coral gardens were seen in Western Jordan Basin, Outer Schoodic Ridge, and near Mount Desert Rock, especially in areas of high vertical relief. Outer Schoodic Ridge especially was a unique area, with topography reminiscent of narrow slot canyons on land (e.g., western U.S., in southern Utah). Based on preliminary analyses of 2013 images (Auster et al. 2013), these steeper areas had some of the highest densities, with about 16-39 colonies/m^2, well above the threshold of 0.1 colonies/m^2 used by ICES (2007) to define coral garden habitat. Central Jordan Basin and Georges Basin also contained coral communities, but these assemblages were more patchy, less dense, and occurred in lower relief environments than the aforementioned areas.

The dense corals on the steep vertical walls and cliffs of Outer Schoodic Ridge and Mount Desert Rock were primarily *Primnoa resedaeformis*, with lower abundances of *Paramuricea placomus* (both in two color morphs of yellow and purple color morphs). On some of the tall, narrow canyon-like walls and cliffs of Outer Schoodic Ridge, *P. resedaeformis* colonies were so densely packed it was impossible to identify and count individual colonies (Fig. 7a,b), some were likely 1 m tall.

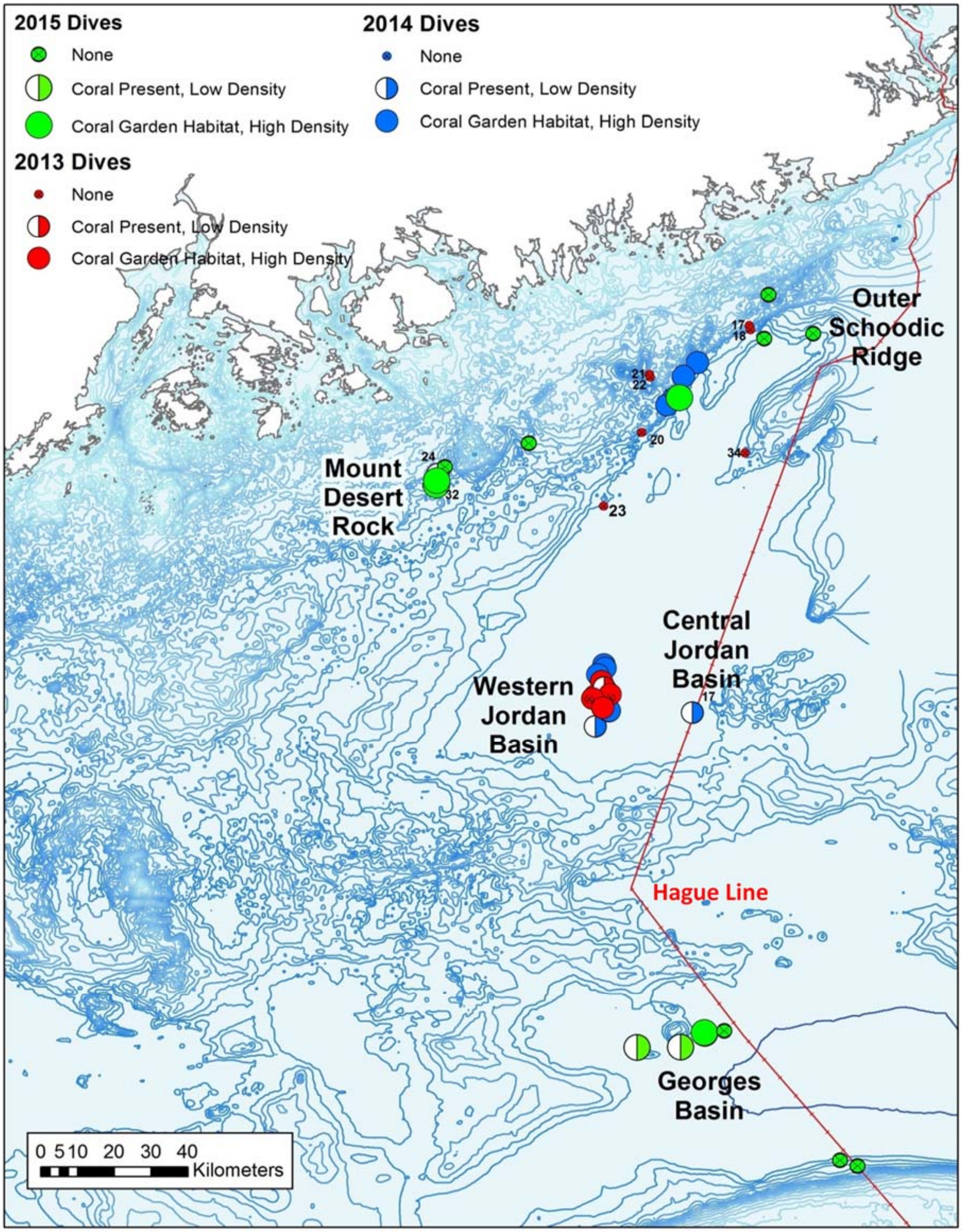


Figure 6. *Gulf of Maine deep-sea coral exploratory survey locations and results (2013-2015). Modified from Auster et al. (2014).*

Conversely, the major coral species found in Western and Central Jordan Basin and Georges Basin was *P. placomus,* with lower abundances of *P. resedaeformis* and *Acanthogorgia cf. armata* (Fig. 7c-e). *Paramuricea placomus* was found in higher densities on steeper hard-bottom areas. Open areas adjacent to steeper features including muddy areas containing gravel, sand-gravel, and emergent rock outcrop features (with shallow expressions above the fine-grain sediment horizon) supported lower densities of coral, primarily *P. placomus*. This was also true for Outer Schoodic Ridge and Mount Desert Rock. Based on multivariate analyses of eight 2013 transects in Jordan Basin with coral garden habitat (Martin 2015), temperature and depth were primary environmental factors and sediment type, rock outcrop, and topographic rise were primary sedimentary factors that correlated with coral distributions.

Of note were the first observations of *Anthothela* (*grandiflora*?) in the relatively shallow waters of the Gulf of Maine (Auster et al. 2014). A couple of colonies were seen at Outer Schoodic Ridge (Fig. 7f) around 200 m. This species is most common at 400-1600 m depth in Northeast canyons (Hecker et al. 1983; Quattrini 2016; Brooke et al. 2017) and off the Northeast Channel along the continental margin (Cogswell et al. 2009). *Paragorgia arborea*, both pink and white forms, which was noted at 114 Bump in Western Jordan Basin during the 2003 survey, was not seen in the more recent exploratory dives.

The most common and ubiquitous sea pen species found in the Gulf of Maine, *Pennatula aculeata* was also found in dense patches in mud and gravel/mud habitats adjacent to hard-bottom habitats (Fig. 8e,f). Highest densities were observed in the Mount Desert Rock region (Packer et al., unpublished data). *Pennatula aculeata* became a focus of the surveys because Baillon et al. (2012) found convincing evidence that several species of sea pens were directly utilized as shelter by fish larvae, particularly by those of redfish (*Sebastes* spp.; see below, and Dean et al. 2016).

The results from these Gulf of Maine exploratory surveys have provided the NEFMC with improved information to inform conservation and management decisions for these unique deep-sea coral and sponge habitats. Currently the Council is using these data to revise and develop new deep-sea coral management zone alternatives for the northern Gulf of Maine region. The large-sized, structure-forming gorgonians *P. resedaeformis* and *P. placomus*, occurring in such high densities in the relatively shallow waters of the Gulf of Maine, as compared to the submarine canyons and seamounts, is unique in the Northeast. The proximity of these habitats to shore and their association with commercially important fish and shellfish increases the potential role of these habitats as EFH (e.g., Auster 2005, 2007). Finding these unique deep-sea coral habitats, especially the spectacular walls of corals at some sites, for the first time after 40-plus years of previous underwater surveys, illustrates how much remains to be discovered about the Gulf of Maine ecosystem in order to better conserve and protect its living marine resources.

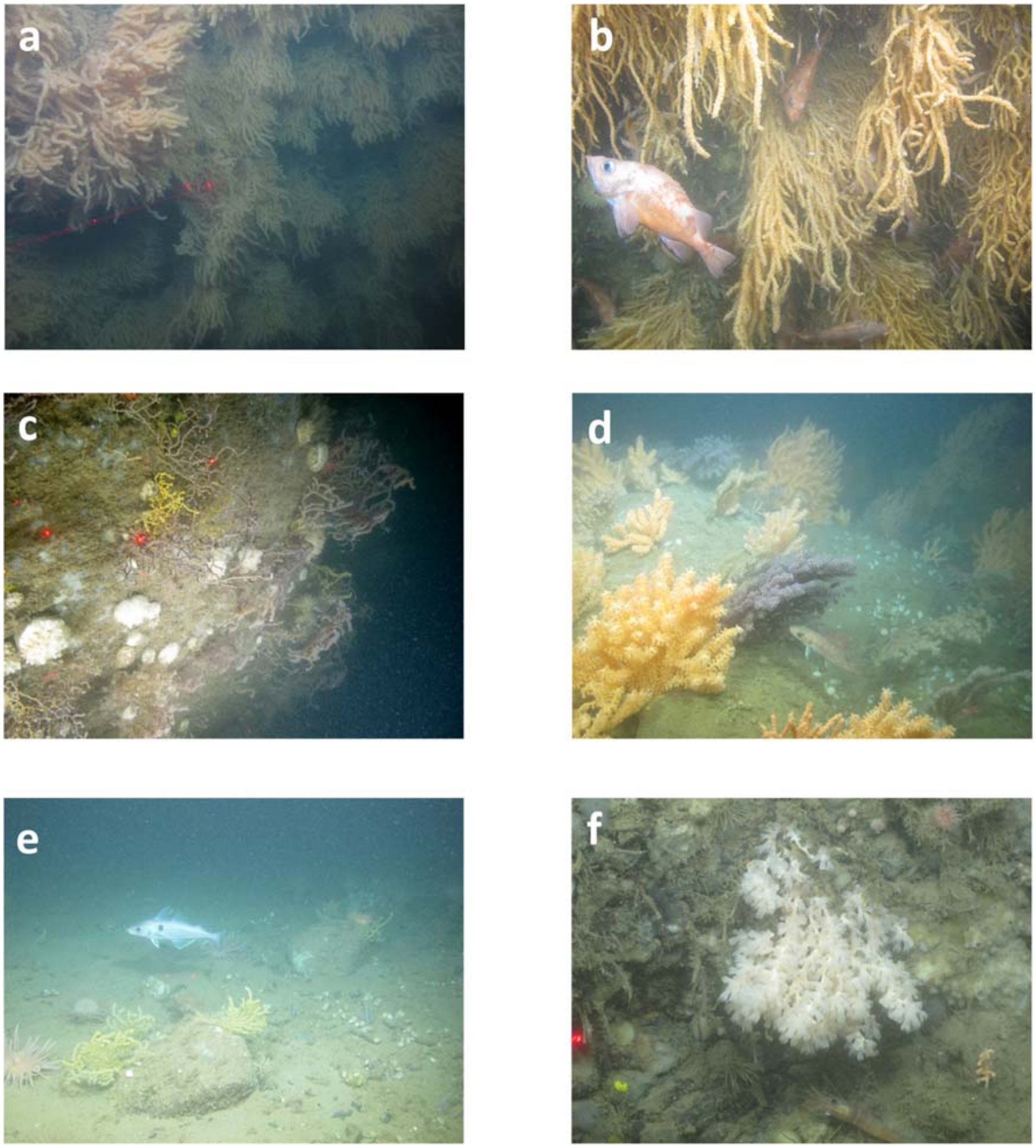


Figure 7. *Examples of Gulf of Maine deep-sea coral habitat seen during 2013-14 exploratory surveys (Auster et al. 2014 and unpublished images). (a) Dense colonies of* Primnoa resedaeformis *on a near vertical rock wall along Outer Schoodic Ridge. (b) Acadian redfish and* P. resedaeformis *on a near vertical rock wall along Outer Schoodic Ridge. (c) Purple and yellow forms of* Paramuricea placomus *and* Polymastia *sponge along a steep escarpment in Western Jordan Basin. (d)* P. placomus, P. resedaeformis, *and juvenile cod in Western Jordan Basin. (e)* P. placomus *and haddock, Central Jordan Basin. (f)* Anthothela *sp. at around 200 m on a near vertical rock wall along Outer Schoodic Ridge.*

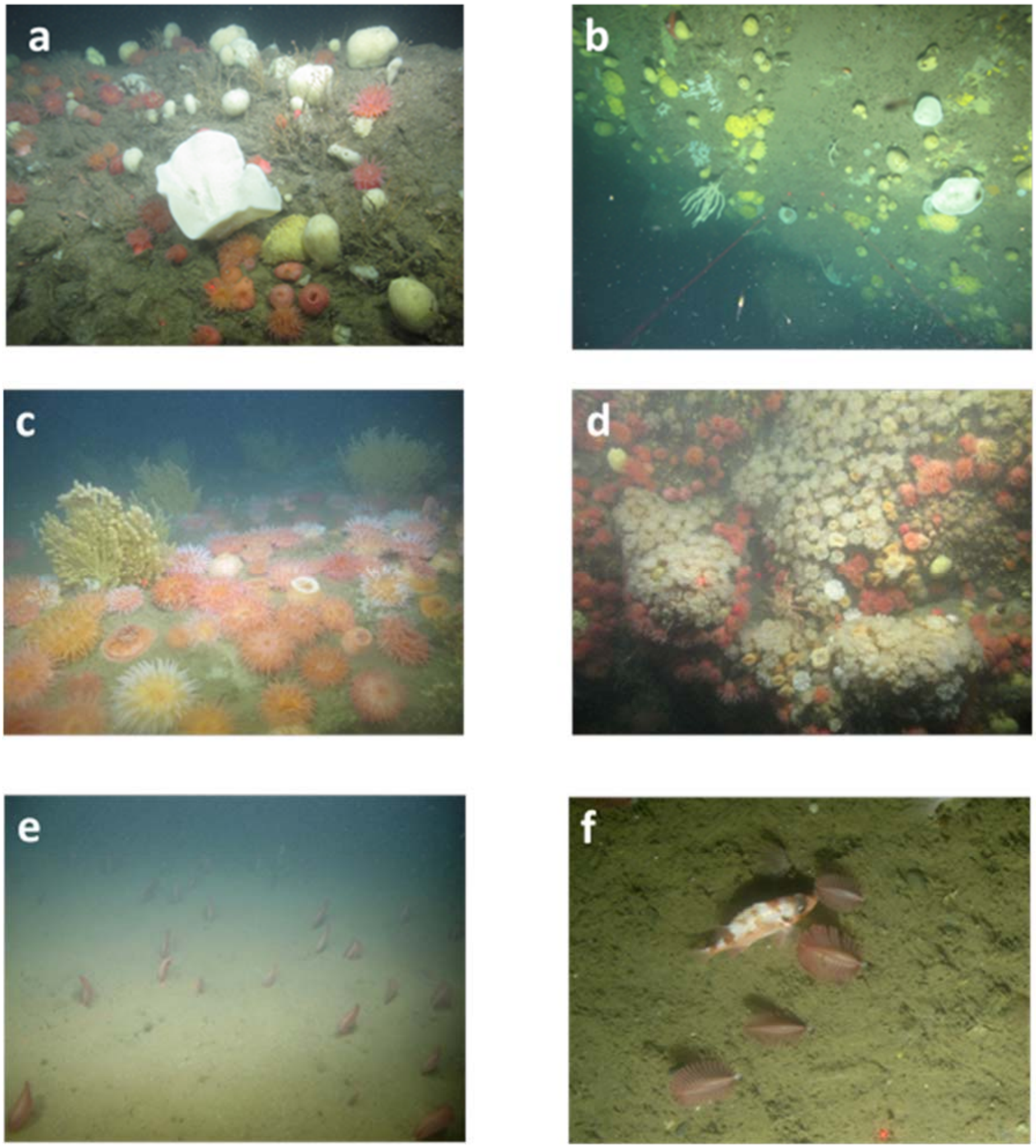


Figure 8. *Examples of dense sponge, anemone, and sea pen habitats in the Gulf of Maine (Auster et al. 2014 and unpublished images). (a) Sponge (including vase sponge* Phakellia*? sp. and* Polymastia *sponge sp.) and anemone habitat along Outer Schoodic Ridge. (b) Sponge (including vase sponge* Phakellia?, Polymastia *sponges, and finger sponges) habitat along Outer Schoodic Ridge. (c) Anemone and coral habitat in Western Jordan Basin. (d) Anemone habitat (with king crab,* Lithodes maja*) on near vertical rock walls along Outer Schoodic Ridge. (e) Sea pens,* Pennatula aculeata*, in soft substrate in Western Jordan Basin. (f)* P. aculeata *and Acadian redfish in an area of Jordan Basin known as 91 Bump.*

II.2.ii – Sponges

Information on the regional sponges and their habitats is severely lacking. Deep-sea sponges in the Northwest Atlantic in general have been the subject of relatively few studies or surveys. However, most of these studies, both historically (e.g., Lambe 1896, 1900) and more recently (e.g., Fuller 2011; Beazley et al. 2013, 2015, 2016), have been conducted in Canada. In the Northeast U.S., Theroux and Wigley (1998) reported on extensive surveys of invertebrates collected by grab samplers. They reported that sponges constituted a small proportion of the observed fauna, and were "generally uncommon on the continental shelf and uncommon to rare on the continental slope and rise." Larger specimens included *Polymastia* sp. and *Myxilla* sp. usually found on cobbles and boulders. Sponges were more abundant off Nova Scotia and in the Gulf of Maine than elsewhere in the region. However, it is likely that sponges were underrepresented in their samples, as benthic grabs cannot adequately sample hard substrates where most sponges occur, especially if they are mostly found on vertical surfaces (e.g., Miller and Etter 2011). Documenting the diversity and distributions of sponges in this region is still in the preliminary stages. Difficulties with taxonomy and identifications (especially via photographs or video alone) and lack of expertise hamper these efforts. Thus far, presence records from the Smithsonian Institution's database and other limited data have been used to create an initial species list. Most geo-referenced records that have been entered in the National Deep-Sea Coral and Sponge Database are listed simply as "Porifera." New geo-referenced records of sponges from the photographic images obtained from recent 2012-2015 surveys will be added to the database after processing.

Sponges that are of conservation interest are the large, structure-forming sponges that, like deep-sea corals, provide habitat for managed species of fish (especially juveniles that seek refuge from predators), increase biodiversity of local fauna, or are susceptible to fishing gear impacts (e.g., Auster and Langton 1999; Fuller 2011; Beazley et al. 2013; Maldonado et al. 2016). Preliminary, historical information on the geographic range (or locations where present), size, morphological form, and habitats (depth and substrates) was compiled for 12 structure-forming species that are found on the continental shelf in the region (Table 2). Encrusting species or species that would not be considered structure-forming are not included. Information sources for Table 2 include the Marine Life Information Network, the Stellwagen Bank National Marine Sanctuary (Gulf of Maine) (on-line), the European Marine Life Network, the Marine Life Encyclopedia website, Georgia Southern University (on-line), the Chesapeake Bay Program website, Hartman (1958), Gosner (1978), Witman and Sebens (1988), Fuller et al. (1998), Steimle and Zetlin (2000), and Stokesbury and Harris (2006).

On Georges Bank, species of interest include *Suberites ficus*, *Haliclona oculata*, *Halichondria panicea*, *Isodictya palmata*, *Clathria prolifera* (=*Microciona prolifera*), and *Polymastia robusta* (Almeida et al. 2000; Stokesbury and Harris 2006). The larger species are probably the most susceptible to the adverse effects of fishing. These would include *S. ficus*, *H. oculata*, *H. panicea*, and *I. palmata* as well as *Mycale lingua* and the large form of *Cliona celata*. All of these species attach to some form of hard substrate including shells. *Suberites ficus* attaches to small shell fragments on sandy bottom habitats on Georges Bank. These relatively rare microhabitats provide cover for fishes and crustaceans (Lindholm et al. 2004). As this sponge grows, the substrate on which it originally attached is covered over and the sponge often is rolled along the bottom by currents and wave action. The other species of structure-forming sponges are more common on hard bottom habitats. Based on the available information, only two of the species listed in Table 2, *C. celata* and *H. oculata,* are known to occur south of southern New England (see also Van Dolah et al. 1987). This may reflect the fact that natural rocky bottom habitats on the shelf are rare south of New York Harbor (Steimle and Zetlin 2000). Other structure-forming species of sponge are undoubtedly present in the Mid-Atlantic region, but are either found on hard substrates on the continental slope and in the canyons or on the shelf attached to gravel, scallop shells, and shell fragments in predominantly sandy habitats.

Fuller (2011) also created a species list of sponges, as documented in published reports, for the entire Gulf of Maine, including the Bay of Fundy (Fuller 2011 Appendix III). Sixty-seven species were recorded; the Gulf of Maine Census of Marine Life listing 32 in the Gulf of Maine. The North Atlantic Fisheries Organization (NAFO) also published a sponge identification guide for eastern Canada, with some overlap into the U.S. Gulf of Maine (Best et al. 2010).

The species list presented here focuses mostly on the shallower species. Thus, the list is preliminary and incomplete. Analysis of recent deep-sea surveys will add many additional species including some new to science. For example, not listed here are the vase/basket demosponges (*Phakellia/Axinella* spp.). *Phakellia ventilabrum* has been found in Stellwagen Bank National Marine Sanctuary in the Gulf of Maine (< 100 m; Tamsett et al. 2010), and several large vase/basket demosponges have been recently seen in the Gulf of Maine surveys at around 200 m (Packer et al. unpublished). However, Fuller (2011) does not list *Phakellia/Axinella* as even occurring in the Gulf of Maine. This type of conflicting information highlights just how little is truly known about the deep-sea sponges in this region.

Hecker et al. (1980, 1983) indicated that sponges, along with corals, were frequently the dominant epifaunal organisms observed during submersible surveys on exposed hard substrate in Northeast submarine canyons. Both sponges and corals were consistently more abundant in the canyons compared to adjacent slope areas. The demosponge, *Asbestopluma* sp. occurred on walls of consolidated clay in Lydonia Canyon and accounted for more than half the invertebrates observed between 800-950 m

Table 2. *Preliminary list of structure-forming sponges of the U.S. Northeast continental shelf.*

Species	Range	Height	Form	Habitats
***Cliona celata* Grant, 1826**	Gulf of Mexico to Long Island Sound, locally to Gulf of St. Lawrence	Up to 1 m, 60 cm diameter	Two growth forms, boring into shells and large "barrel" shape, firm with tough outer layer, embeds rocks and sediments into tissue	On rock to 200 m; begins life by boring into limestone, shells, or calcareous red algae
***Halichondria (Halichondria) panicea* (Pallas, 1766)**	Arctic south to Cape Cod, rarely beyond	Up to 30 cm	Encrusting, globular, or branched	Cobbles, boulders, bedrock, shells, algae down to 80 m (570 m in Europe), esp. abundant in strong tidal flows
***Haliclona (Haliclona) oculata* (Linnaeus, 1759)**	Labrador to Long Island, rarely to North Carolina, but present in Georgia	Up to 45 cm	Short stalk with flat to rounded finger-like branches, very flexible, not fragile	Sandy, rocky substrates, often attached to stones, to 150 m
Haliclona (Haliclona) urceolus (Rathke and Vahl, 1806)	Range unknown, found in Bay of Fundy	To 15 cm, stalk typically < half body length	Tubular, even bell shaped, with thin, hard, flexible stalk	On rock, shell fragments, etc.
***Isodictya deichmannae* (de Laubenfels, 1949)**	Newfoundland to Rhode Island	Often confused with *I. palmata*		To 110 m
***Isodictya palmata* (Ellis and Solander, 1786)**	Nova Scotia to Gulf of Maine, Georges Bank	Up to 35 cm	Large, palmate with finger-like branches	Deep water on rocks, 52-70 m in sand and gravel on Georges Bank
***Clathria (Clathria) prolifera* (Ellis and Solander, 1786)** (=*Microciona prolifera*)	Nova Scotia to Florida and Texas	Up to 20 cm	At first encrusting, then forms small clumps with fingerlike branches	Shells, pilings, hard surfaces, in shallow to moderate depths (52-70 m on Georges Bank)
***Mycale (Mycale) lingua* (Bowerbank, 1866)**	Range unknown, found in the Gulf of Maine	Up to 30 cm high with variable width and depth	In mounds, sometimes in erect, flattened form with base narrower than apex	Between 30-2460 m on rocky bottom
***Myxilla (Myxilla) fimbriata* (Bowerbank, 1866)**	Range unknown, found in GOM		Mounds	To 78 m
***Polymastia boletiformis* (Lamarck, 1815)** (=*Polymastia robusta*)	Range unknown, found on Georges Bank, in the Gulf of Maine and southern New England	Volume of 40 cm^3	Globular with thick base, body is soft	Most common on upward facing rock or boulder tops, as deep as 2300 m (in Europe)
***Suberites ficus* (Johnston, 1842)**	Arctic south to Rhode Island, possibly to Virginia	10-40 cm diameter	Variable, lobed or globular cushion, rolls over bottom if it outgrows its substrate	Attaches to rocks and to small stones, empty shells, in sandy or muddy bottom, from 15 to 200 m

(Hecker et al. 1983). This species was also common in Baltimore Canyon. Brooke et al. (2017) reported that sponges were commonly observed on hard substrata in Norfolk and Baltimore canyons, and that their species richness exceeded that of corals, with more than 30 different morphotypes of hexactinellid and demosponges.

Sponges are often a major component of the epibenthic organisms found on the hard substrates that dominate seamounts (Samadi et al. 2007). Cho (2008) reported that the phylum Porifera represented the most abundant megabenthic fauna in the New England Seamount chain (surveys did not include the four seamounts in U.S. waters). As noted previously, (Quattrini et al. 2015) observed numerous and diverse hexactinellid sponges and demosponges on Mytilus Seamount. Moore et al. (2003) reported six taxa of sponges on Bear Seamount, including glass sponges and the demosponge *Geodia* sp. The latter forms major sponge grounds elsewhere in the North Atlantic, including along the continental slopes of the Grand Bank and Flemish Cap and northward along the Labrador Slope to the southern Davis Strait off Canada (Murillo et al. 2012; Knudby et al. 2013; Kenchington et al. 2014), but high density aggregations have not been reported in the U.S. Northeast.

II.3. Species Associations with Deep-Sea Corals and Sponges

Packer et al. (2007) summarized information on species associations with deep-sea coral habitats off the Northeast U.S. While there were numerous examples of invertebrate associations with deep-sea corals in the region, the role of deep-sea corals as habitat for commercially important fish species was unclear.

Recent studies in this region highlight relationships of invertebrate symbionts and their octocoral hosts at deep-sea coral habitats on the seamounts (Watling et al. 2011). In an extreme case of host fidelity, Mosher and Watling (2009) showed that the ophiuroid *Ophiocreas oedipus* was found only on the chrysogorgiid *Metallogorgia melanotrichos*. The young brittle stars settle on young corals and the two species then remain together. The brittle star may receive some refuge and feeding benefits from the coral, but the coral's relationship to the brittle star appears to be neutral (Mosher and Watling 2009). Within the EEZ, these two species were collected from Bear Seamount at 1491 and 1559 m. Another ophiuroid, *Asteroschema clavigerum*, has a close relationship with *Paramuricea* sp. and *Paragorgia* sp. on both the seamounts and the continental slope (Cho and Shank 2010). The shrimp *Bathypalaemonella serratipalma* as well as the egg cases of an unknown octopus were found on *Chrysogorgia tricaulis* on the seamounts (Pante and Watling 2011). Additionally, older colonies of *Acanella arbuscula* collected from the seamounts were host to a scale worm (Watling et al. 2011). De Clippele et al. (2015) reported on associations of invertebrate fauna with three gorgonian species (*Paragorgia arborea, Primnoa resedaeformis, and Paramuricea placomus*) in Norway, which are also dominant coral species in the U.S. Northeast. All hosted numerous associates, with *P. arborea* colonies having the most associated taxa and numbers of individuals. Cho (2008) found that corals were the dominant living substrate for other macroinvertebrates on the New England Seamount chain; sponges were the second most important host. See Watling et al. (2011) for reviews and lists of known invertebrate symbionts and their octocoral hosts worldwide.

Quattrini et al. (2015) noted that the presence of certain deep-sea coral species may influence crustacean assemblage patterns. For example, the squat lobster *Uroptychus* sp. was only observed on the black coral *Parantipathes* sp. In contrast, *Munidopsis* spp. (squat lobsters in a different superfamily) utilized a variety of different coral species as habitat, particularly those with structurally complex morphologies. Many other observations suggesting possible species associations between deep-sea corals and other invertebrates are recorded in the various dive logs and summaries from the recent *Okeanos Explorer* surveys.

In all areas explored in the Gulf of Maine, sponges (e.g., in the genera *Polymastia*, *Iophon, Phakellia/Axinella*) and anemones (e.g.; *Metridium*, *Urticina*) often occurred in high-density patches amongst the more extensive corals on walls and on steep features without corals (Fig. 8a-d) (Auster et al. 2014). Crustaceans such as shrimp, amphipods, aggregations of krill (*Meganyctiphanes norvegica*), and the king crab (*Lithodes maja*; Fig. 8d) were commonly associated with coral communities along steep walls and were seen foraging amongst structure-forming organisms, including corals, on the seafloor.

A number of commercially important fish and shellfish species were observed at the Gulf of Maine coral sites, including Acadian redfish (*Sebastes fasciatus;* juveniles, adults, and pregnant females; Fig. 7b), haddock (*Melanogrammus aeglefinus*; Fig. 7e), pollock (*Pollachius virens*), cusk (*Brosme brosme*), monkfish (*Lophius americanus*), Atlantic cod (*Gadus morhua*; juveniles, adults; Fig. 7d), silver hake (*Merluccius bilinearis*), Atlantic herring (*Clupea harengus*), spiny dogfish (*Squalus acanthias*), squid (*Illex illecebrosus*), and lobster (*Homarus americanus*). The fish were observed searching for and catching prey that were also found among the coral, including shrimp, amphipods, krill, and other small fish (Auster et al. 2014). The corals also appeared to provide refuge from the strong, tidally-generated bottom currents.

A cause and effect relationship between coral/sponge presence and fish populations is difficult to determine. Our understanding of relationships between deep-sea corals and fishes is both situational and inferential (e.g., Baker et al. 2012). This may be particularly true with regard to the seamount habitats (Auster 2007), although it has been shown, for example, that false boarfish, *Neocyttus helgae*, were associated with basalt habitats colonized by gorgonian corals and sponges (on both nearly horizontal basalt sheets and steep cliffs) on Bear and other seamounts (Moore et al. 2008). Aggregates of dead coral debris on seamounts also served as habitat for juveniles of deep-sea fish, but observations have been limited (Moore and Auster 2009). In Norway, Foley et al. (2010) applied the production-function approach to estimate the link between *Lophelia pertusa* deep-sea coral reef habitat and redfish (*Sebastes* spp.). Both the carrying capacity and growth rate of the redfish were found to be functions of deep-sea coral habitat. Thus, the authors concluded that deep-sea coral reef habitat can be considered as essential fish habitat. They also estimated a facultative relationship between deep-sea coral and *Sebastes* spp. stocks. Deep-sea coral reef (bioherm) habitats do not occur in the U.S. Northeast, and comparable quantitative studies on gorgonian-dominated habitats have not been carried out.

Recent surveys in the region addressed the functional role deep-sea corals play in fish life history and ecology. Demersal fish distributions and habitat associations, including the influence of deep-sea corals and sponges, were assessed for Baltimore and Norfolk canyons (Ross et al. 2015). Although deep-sea coral and sponge presence did not significantly influence fish assemblages in the two canyons, deep-sea coral and sponges did increase habitat complexity, which is an important factor in determining habitat use for deep-sea fishes (Ross et al. 2015). Some of the fishes were closely associated with the corals, including *Dysommina rugosa* (cutthroat eel), *Benthocometes robustus* (robust cusk-eel), and *Brosme brosme* (cusk) (Ross et al. 2015). Ross et al. (2015) also noted unidentified shark egg cases were frequently entangled in octocorals, especially the bubblegum coral *Paragorgia arborea*, while eggs of snailfish (Liparidae) were also found in *Anthothela* sp. and *Acanthogorgia* sp. Quattrini et al. (2015) did find that deep-sea coral species richness was an important variable in explaining demersal fish assemblage structure. These authors hypothesized that corals may increase fish diversity because the fish use the corals as habitat, or corals may increase food resources for fishes. However, Auster (2005, 2007 and references therein) also hypothesizes that some fish co-occur with deep-sea corals because both taxa do better in areas of enhanced flows that advect food, and not because the fish need the corals per se.

Baillon et al. (2012) reported that several species of sea pens, including *Anthoptilum grandiflorum*, *Pennatula aculeata, P. grandis*, and *Halipteris finmarchica* from the Laurentian Channel and southern Grand Banks in Canada were utilized as shelter by fish larvae, mainly by those of redfish (*Sebastes* spp.). *Anthoptilum grandiflorum* may have been of particular importance to redfish larvae in that study. Both redfish and these species of sea pens also co-occur in the U.S. Northeast region (e.g., Fig. 8f). These discoveries could have significant research and management implications for sea pens and redfish in the Northeast.

The Baillon et al. (2012) study collected sea pens as trawl bycatch during their routine multispecies research surveys. A relatively small number of *P. aculeata* collected via ROV from different sites in the U.S. Gulf of Maine in July/August 2014 yielded no fish larvae. In 2015, 186 individual *P. aculeata* were collected as bycatch from the 2015 NMFS Gulf of Maine northern shrimp survey and subsequently examined in the laboratory. Redfish larvae were found on *P. aculeata* at four stations, either adhering to the exterior of the colony, or entrapped within the arms or polyps (Dean et al. 2016). However, the source of the sea pen samples for both the Baillon et al. (2012) and this study was from trawl survey bycatch. Thus, the possibility that fish larvae were actually extruded in the net by viviparous ripe and running redfish, or when the catch was emptied on the deck, and the larvae then subsequently adhered to the sea pens must be explored. In June 2016, some stations in the Gulf of Maine where a positive association had been found between redfish larvae and *P. aculeata* were resampled. This time a small beam trawl was used as the sampling gear, increasing the probability that only sea pens, and not adult redfish, would be captured, thus eliminating the potential cross contamination described above. Over 1400 sea pens were collected over two days of beam trawling over soft bottoms at 150-180 m depth. No larval redfish were found associated with the sea pens. However, ~80 to 85% of the sea pens collected were quite small, < 25-50 mm total length (adults are upwards of 200-250 mm). This suggests a recent recruitment event occurred, and therefore colonies collected were probably too small to serve as possible nursery habitat for larval redfish. Very few larger sea pens were captured, and those that were caught were generally tangled in the chain rather than caught in the net. The beam trawl likely did not dig deep enough into the sediment to dislodge these larger animals. Thus, the role of *P. aculeata* as possible nursery habitat for larval redfish in the Gulf of Maine remains uncertain.

II.4. Other new information from published studies since 2007

Other new findings from the region include information on coral growth and life history. For example, *Metallogorgia melanotrichos* colonies change form as they grow (Mosher and Watling 2009). Young colonies have lateral branches coming off the central axis, while older colonies lose these branches as the colony senesces, leaving only a dense crown of branches.

Life history studies (e.g., reproductive strategies) on several species of corals found on both the eastern Canadian shelf and slope (Newfoundland, Labrador) and off the Northeastern U.S. (e.g., *Acanella*, *Anthomastus*; see Watling et al. 2011 for review) were also conducted. The bamboo coral, *Acanella arbuscula*, which is abundant in canyons and slope areas of the Northeast U.S., has separate sexes (gonochoric) and is likely a broadcast spawner (Beazley and Kenchington 2012). Colonies reached sexual maturity at a small size (~3 cm, corresponding to an age of 3 years) and larger colonies appeared to be relatively fecund compared to other gorgonians (Beazley and Kenchington 2012). The authors nevertheless concluded that its longevity and the uncertainty surrounding its dispersal and recruitment, combined with its vulnerability to bottom-contact fishing gear, warranted considering *A. arbuscula* as an indicator species or vulnerable marine ecosystems.

Lawler et al. (2016) reported on the microbial assemblages of two species of the octocoral *Anthothela* from Norfolk and Baltimore canyons, and Kellogg et al. (2016) examined *Paramuricea placomus* bacterial community diversity in Baltimore Canyon, providing insights into the functional roles that these bacteria may play in corals.

II.5. Research Priorities

Packer et al. (2007) identified a number of deep-sea coral research priorities for the region. In 2011, NOAA convened a group of federal, state, academic, and non-governmental organization scientists to identify exploration and research priorities for deep-sea coral and sponge ecosystems in the Northeast region (NOAA 2012b). Key priorities identified, which continue to be our major priorities going forward, included the following:

- Locate and characterize deep-sea coral and sponge communities:
  - Collect and analyze existing data, and evaluate data gaps
  - Develop and refine predictive models for coral and sponge distribution
  - Conduct multibeam sonar surveys to improve bathymetry data to guide field research and for use in spatially-explicit models (canyons and deepwater areas of the Gulf of Maine)
  - Conduct site-specific research designed to locate and characterize deep-sea coral and sponge habitats
- Understand the biology, biodiversity and ecology of deep-sea corals and sponges, including:
  - Species identification
  - Population connectivity
  - Age and growth rates
  - Functional role
- Understand natural and human impacts on deep-sea coral and sponge ecosystems:
  - Disturbance effects and recovery
  - Economic and social values associated with these coral and sponge communities

New research conducted since 2011 has addressed a number of these priorities for deep-sea corals, resulting in extensive multibeam mapping of the shelf-edge and slope, the first comprehensive predictive habitat models for deep-sea corals, extensive new exploratory surveys, and studies of community ecology (trophic and population structure) and coral biology (age, growth, life histories). Studies of various aspects of the biology and ecology of key species (e.g., *Primnoa resedaeformis*) are underway. However, much additional work remains to be done. Studies on deep-sea sponges, including taxonomy, distribution, life history, and habitat functions, are almost totally lacking.

III. Update on Management of Deep-Sea Corals and Sponges

III.1. New Information on Impacts and Stressors

III.1.i – Fishing

Fishing impacts to deep-sea corals in the Northeast region were discussed previously (Packer et al. 2007), but this is an active field of research, and new field and modeling studies have been published since 2007. Much of this work is applicable to the Northeast region and informs interpretation of observations of obvious gear impacts to regional deep-sea coral and sponge habitats. In any case, the conclusions about the nature of these impacts are generally similar to earlier work. Because the predominate industrial use of the deep-sea in the Northeast is fishing, impacts from bottom-contact fishing are still considered the greatest and most immediate threat to deep-sea corals and sponges in this region. The seriousness of the threat is reflected in the proactive work of the Fishery Management Councils in pursuing the current management options, discussed below.

Most bottom-contact fisheries in the Northeast U.S. are conducted on the continental shelf, including the Gulf of Maine and Georges Bank, with some fishing effort around the shelf/slope break. Considering the major areas of coral distribution described above, the Gulf of Maine and the upper portion of canyons and slope are subject to the highest fishing pressures. Fishing for monkfish (largely by trawl, with some gillnet fishing) and tilefish (predominantly by bottom longlines) occurs predominantly on the shelf, but can extend into deeper waters, as can the squid, whiting, and butterfish trawl fisheries. Lobster pots are used to harvest American lobster, as well as Jonah crab, along the shelf break. A small deep-sea red crab (*Chaceon quinquedens*) fishery is active in deeper waters, deploying strings of 90-120 pots primarily at depths from 400-800 m (NEFMC 2002), targeting approximately the 640 m depth contour.

During the 2012-2015 Gulf of Maine exploratory surveys, areas exhibiting direct impacts from fishing activities were observed at sites in Western and Central Jordan Basin, Outer Schoodic Ridge, and Georges Basin (Auster et al. 2014). In steep areas, paths or tracks, consistent with the setting or recovery of trap gear, were denuded of corals and associated fauna (Fig. 9a). The peaks of some ridges and nearly horizontal sections of wider rock outcrops were also denuded. Tracks observed here were consistent with impacts from mobile fishing gear (Fig. 9b,c). Some coral patches exhibited damage in the form of live colonies with disjunct size class structure, suggesting past impacts (Fig. 9d). In areas such as Georges Basin, colonies of *Paramuricea placomus* and associated species were often small and virtually all occurred in physical refuges such as cracks and crevices of outcrops and along the sediment-rock interface of large cobbles and boulders. Of note is that the sea star *Hippasteria phrygiana* was observed eating or preying on *P. resedaeformis* colonies at the Outer Schoodic Ridge site. These sea stars were seen on living coral colonies that had been detached from rock walls and were laying on the seafloor, possibly due to fishing activity, as one was seen next to an abandoned fishing net. Opportunistic predation by *H. phrygiana* has also been noted in Alaska on *Primnoa pacifica* that had been injured or detached by fishing gear (Stone et al. 2015). This may indicate that coral damaged by fishing gear interactions are at an increased risk of predation by sea stars, thus further reducing the chances that a coral colony will recover from gear-related injuries and impacts.

Knight et al. (2006) analyzed recovery of epibenthic megafauna in predominantly soft-

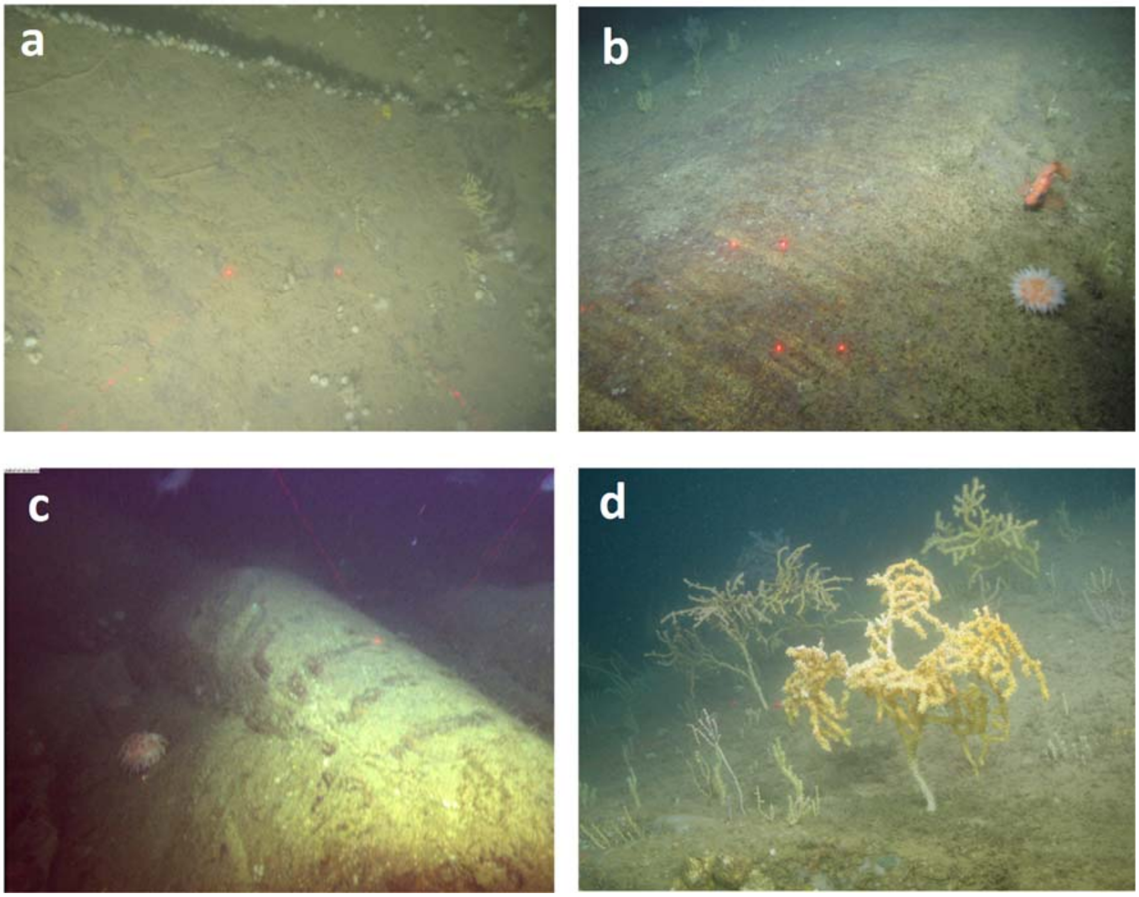


Figure 9. *Examples of fishing gear impacts to coral habitats in the Gulf of Maine (Auster et al. 2014 and unpublished images). (a) Denuded bottom (sediment covered hard bottom) in Western Jordan Basin (114 Bump) consistent with fixed gear impacts. (b) Denuded ridge in Central Jordan Basin consistent with mobile gear impacts. (c) Denuded ridge in Georges Basin consistent with mobile gear impacts. (d) Example of oddly shaped corals with disjointed size class structure, possibly due to damage, in Western Jordan Basin.*

sediment shelf areas in the Western Gulf of Maine that had been closed to fishing for 6 years. The closed sites showed higher average taxonomic abundance than fished sites – with unidentified sponges and a tunicate (*Mogula* sp.) responsible for approximately 83% of the difference. This suggests that sponges are susceptible to impacts from bottom-contact fishing, and at least certain species may recover more quickly than corals.

The annual number of interactions between fishing gear and deep-sea corals and sponges is not known, but bycatch data indicate that a relatively small number of trips interact with deep-sea corals. In 2011 NOAA's National Marine Fisheries Service (NMFS) granted the Maine Department of Marine Resources an exempted fishing permit for redfish in order to conduct a baseline catch and bycatch evaluation in and around Wilkinson Basin and elsewhere in the central Gulf of Maine. Many smaller individuals escape from the 6.5 inch mesh nets required by groundfish regulations. The experimental fishing used nets with smaller, 4.5 inch mesh liners in the cod end and targeted schools of redfish that congregate on "bumps" or pinnacles that occur in the normally deep, muddy areas in the central Gulf of Maine. Since redfish seek shelter near structure-forming organisms such as deep-sea corals and sponges, as well as boulder reefs (Packer et al. 2007), concerns were raised by NMFS that the smaller mesh nets would increase the probability of bycatch of deep-sea corals. NMFS determined that the project could have an adverse effect on EFH, particularly on any deep-sea corals found there. Therefore, they requested that deep-sea coral bycatch be carefully monitored to enhance the understanding of deep-sea coral distribution in the Gulf of Maine and the potential effects of an expanded redfish fishery on deep-sea corals. However, by the end of the project the only coral by-catch was that of a single specimen of the common sea pen, *Pennatula aculeata*, which, as stated previously, is ubiquitous in muddy areas of the Gulf of Maine. It seems that none of the project tows overlapped with any known soft coral habitats, even though the current redfish fishery appears to operate in the vicinity of these habitats.

Several years ago, NMFS Northeast Fisheries Science Center's (NEFSC) fishery independent surveys and Northeast Fisheries Observer Program (NEFOP) were assessed for potential coral bycatch. As discussed previously (Packer et al. 2007), the spring/fall NEFSC groundfish trawl and scallop dredge surveys conducted in the region do not "catch" deep corals in any meaningful quantities, nor is any deep coral that may be brought on deck recorded in a significant quantitative way. The NEFSC groundfish trawl surveys loosely describe and roughly quantify any substrate (rock, shell, etc.) or non-coded invertebrate species. Although this bycatch information could possibly be useful as presence/absence data, since deep-sea corals are not the focus of the bottom trawl surveys, these data should of course be used with caution (John Galbraith, NMFS, NEFSC, Woods Hole Laboratory, Woods Hole, MA, pers. comm.).

Outside the Gulf of Maine, the general lack of deep-sea coral in both the groundfish trawl and scallop dredge surveys may be a function of the surveys fishing in waters shallower than where the larger deep-sea coral species are likely to occur; i.e., the groundfish survey fishes from about 9-366 m depth, while nearly all the scallop surveys fish < 100 m and all are < 140 m. In some areas in the Gulf of Maine and Georges Bank, these larger corals (e.g., *Paragorgia arborea*, *Primnoa resedaeformis*) may have already been "fished out" in the survey areas during the 19th and 20th centuries (Packer et al. 2007). In Canadian waters near the Northeast Channel, but within the survey region, there is a deep-sea coral protection area that is closed to fishing. J. Galbraith (NEFSC, pers. comm.) stated that this was the only area he could remember where any amount of coral was encountered. Anecdotal accounts from the time period before the groundfish survey began

(1950s or early 1960s) reference an area on Georges Bank called "The Trees" where large corals existed in shallower water before being eventually cleared out, supposedly by foreign trawling vessels. There are also anecdotal accounts from Gloucester fishermen who said that they used bottom gear on Georges Bank to first knock down the "trees" before fishing for large adult redfish.

The fishery dependent deep-sea coral bycatch data collected from the NEFOP used to suffer many of the same problems as the groundfish trawl and scallop dredge surveys. First, it should be noted that only 10-40% of all fishing effort is observed by "observers" onboard vessels, depending on the fishery, and a grand average may be somewhere around 10%. A small NEFOP database of coral bycatch collected from 1994-2009 showed only 39 confirmed coral entries. Two of these entries were labeled '*Astrangia*' (a solitary stony cup coral) and 10 additional entries were labeled stony corals. Basic information about the haul (gear type, year, month, depth, and geographic coordinates) was included. Gear used included otter trawls, scallop dredges, and gill nets, at depths from 5.5-253 m (depths were taken at the beginning of a tow or set). Estimated or actual weights for the coral in a given haul ranged from 0.05 – 22.7 kg. No specimens or photographs were included.

In 2013, the NEFOP training curriculum and associated sampling protocols were changed to improve deep-sea bycatch identification, retention, enumeration, and documentation (Lewandowski et al. 2016). This included the use of a Northeast deep-sea coral identification guide for the onboard observers, and standardized recording, sampling, and preservation procedures. Since implementation of the new protocols, although deep-sea coral bycatch is still low, the number of recorded and verified samples has increased, and photographic records and samples are being stored via the NEFOP Species Verification Program (Lewandowski et al. 2016). These were recently reviewed and classified by Northeast deep-sea coral experts. Several structure-forming gorgonians, as well as sea pens, were documented in bycatch by at-sea observers. Improved NEFOP fishery dependent deep-sea coral bycatch data will lead to a better understanding of fisheries and deep-sea coral interactions and impacts, and guide conservation efforts of deep-sea corals habitats in the Northeast. Of course, bycatch only reveals what is not lost below the net, or not lost through the mesh, or not destroyed within the net (see Auster et al. 2011 on this issue).

III.1.ii – Other stressors

Oil and gas drilling, while currently not conducted within the region, took on an added urgency with the lifting of the ban on oil drilling off Virginia in 2010; hence, the BOEM-funded study discussed above. The Mid-Atlantic was removed from the 2017-2022 Outer Continental Shelf Oil and Gas Leasing Proposed Program (BOEM 2016), but this decision could be revisited. On June 29 2017, the Secretary of the Interior announced a review of the 2017-2022 Program to include all 26 planning areas. Ocean acidification, although not discussed in Packer et al. (2007), is obviously a major threat to all corals worldwide (e.g., for tropical coral reefs, see Kleypas and Yates 2009). Research on ocean acidification in relation to deep-sea corals has begun (e.g., Form and Riebesell 2012; Lunden et al. 2014), but has focused primarily on stony corals (i.e., *Lophelia pertusa*). There have been no studies on the dominant coral species in the Northeast region.

Other activities that impact the seafloor and pose potential threats to deep-sea corals and sponge habitats in the region include deployment of seafloor cables and offshore renewable energy installations. New York is a major hub for underwater communication cables, but there is little information on impacts to biogenic habitats. Potential offshore wind development has become a major driver for more comprehensive ocean planning within the region. The Bureau of Ocean Energy management (BOEM) has awarded leases in specific areas from Massachusetts to Virginia. In 2016, the Block Island Wind Farm off Rhode Island began operations as the nation's first offshore wind installation. This and future wind development is likely to be conducted on the continental shelf relatively close to shore, and thus less likely to impact major deep-sea coral and sponge habitats, although it could affect shallower water sponge populations.

Marine debris and trash are also a threat to corals in this region, and have been noted in some of the recent surveys. Quattrini et al. (2015) found an estimated 0.002-0.130 items/10 m^2, including derelict fishing gear (ghost traps, lines, hooks) and trash (cans, bottles, plastic bags, etc.). The highest numbers came from one of the minor, unnamed canyons. At least 12 deep-sea coral colonies were tangled in debris, including five gorgonian colonies (*Paramuricea* spp., *Thouarella grasshoffi*) that suffered varying degrees of injury or death. Brooke et al. (2017) noted marine debris on almost every dive in Baltimore and Norfolk canyons, often near the canyon heads on rock outcrops; canyon heads are where most fishing activity would take place. During the Gulf of Maine exploratory surveys, little debris was seen, which was surprising considering the number of vessels traversing the survey areas. Debris observed included lines, nets, trash, and in one instance in Western Jordan Basin, a large piece of plastic sheeting that covered a boulder with several large colonies of *Paramuricea placomus*.

Packer et al. (2007) discussed potential impacts of an invasive colonial tunicate (*Didemnum* sp. A) found on gravel and cobble substrates on Georges Bank. This species has since been identified as *Didemnum vexillum* (Lengyel 2009). The progress of this species is being monitored, as it can have a major effect on the benthic invertebrate communities of Georges Bank (Kaplan et al. 2017a, b), but it has not been reported in the primary habitats of high-density deep-sea coral or sponge communities (e.g., Bullard et al. 2007).

III.2. New or Planned Management Actions

III.2.i – Northeast Canyons and Seamounts Marine National Monument

On September 15, 2016, President Obama designated the first marine national monument in the Atlantic Ocean, the Northeast Canyons and Seamounts Marine National Monument, using his authority under the Antiquities Act of 1906. The monument consists of two units (Fig. 10), representing distinct geological features that support vulnerable ecological communities, including deep-sea coral and sponge communities. The Canyons Unit covers approximately 2,437 km^2 (941 square miles) on the edge of Georges Bank, including Oceanographer, Gilbert, and Lydonia submarine canyons. The Seamounts Unit encompasses 10,287 km^2 (3,972 square miles) and includes the four New England Seamounts in the U.S. EEZ: Bear, Mytilus, Physalia, and Retriever. The presidential proclamation specifically referenced deep-sea corals, along with "other structure-forming fauna such as sponges and anemones," as resources that "create a foundation for vibrant deep-sea ecosystems" and are extremely sensitive to disturbance from extractive activities.

The new monument will be managed jointly by the Department of the Interior and the Department of Commerce (through NOAA). The proclamation creating the Monument identifies a number of prohibitions designed to help protect monument ecosystems, including prohibiting oil, gas, and mineral exploration and development. Commercial fishing in the monument is prohibited with the exception of existing red crab and lobster fisheries, which were granted a grace period for up to seven years. Other activities, such as cable deployment and maintenance, scientific activities, and recreational fishing will be permitted as long as they are determined to be consistent with the conservation goals of the Monument. The Department of the Interior and NOAA will jointly develop a management plan for the Monument within three years. Recent marine national monument designations are undergoing review by the Department of the Interior and NOAA, in response to an April 26, 2017 Executive Order.

III.2.ii – Fisheries management

In the Northeast region, fisheries in Federal waters are primarily managed by NOAA's National Marine Fisheries Service (NMFS) under fishery management plans (FMPs) developed by the New England and Mid-Atlantic Fishery Management Councils (NEFMC, MAFMC). Recent work by both regional Councils has been facilitated by the new exploratory surveys and data on the distribution of deep-sea corals. As described above, most of these data were collected between 2012 and 2015. The Councils, in collaboration with NMFS, recommended priority targets to ensure that results would be relevant to managers. Additionally, in 2011, NMFS, in collaboration with the two regional Councils, initiated a partnership to develop and implement a strategy for deep-sea coral conservation as part of NOAA's Habitat

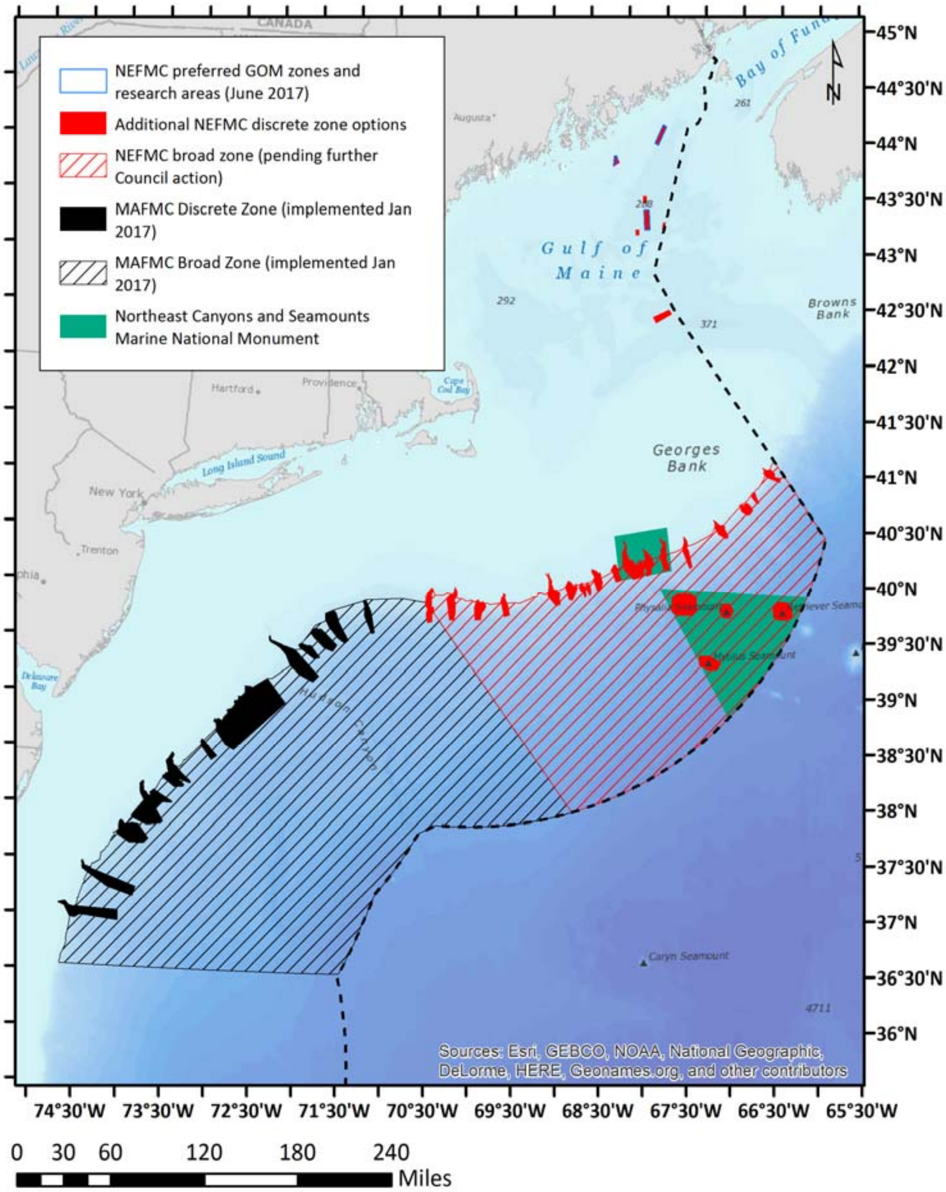


Figure 10. *Deep-sea coral protection zones for the Northeast region enacted in the Mid-Atlantic and being considered for New England. Broad zones are shaded; discrete zones on seamounts, in canyons, and in the Gulf of Maine, are outlined. Alvin Canyon straddles the New England/Mid-Atlantic inter-council boundary. New England zone boundaries will likely change as the amendment is finalized based on stakeholder feedback.*

Blueprint program. The goal was to ensure effective, long-term conservation of deep-sea coral habitats with existing management and scientific resources as well as provide a template to integrate habitat conservation and science into the Council process. This program took advantage of deep-sea coral science and management activities that were already underway in the region, including the 2013-2015 NOAA Northeast Deep-sea Coral and Sponge Initiative. Another objective of this program was to implement a coral conservation strategy with federal offshore energy licensing agencies (e.g., BOEM) using existing coordination and consultation procedures.

There are two primary authorities in the Magnuson Stevens Fishery Conservation and Management Act (MSA) that can be used to protect deep-sea coral and/or sponge habitats. Under the Essential Fish Habitat (EFH) authority, fishing restrictions should be enacted to minimize, to the extent practicable, the adverse effects of fishing on corals or sponges that are considered a component of EFH for a managed fisheries species (MSA section 305(b)). Actions taken under the EFH authority generally occur within areas that are designated as EFH. The NEFMC used this authority in 2005 to protect deep-sea corals and associated habitat features in Lydonia and Oceanographer canyons from fishing activity occurring under a monkfish "days-at-sea" permit. The MAFMC used the same authority in 2008 to close these two canyons to bottom trawling by vessels in the squid, mackerel, and butterfish fisheries via Amendment 9 to that FMP. In 2009 the MAFMC closed Lydonia, Oceanographer, Veatch, and Norfolk Canyons (as tilefish Gear Restricted Areas) to mobile bottom tending gear through Amendment 1 to the tilefish FMP, with the intention of protecting vulnerable tilefish habitat (clay outcroppings also known as "pueblo" habitats).

Areas outside designated EFH may also be managed under the EFH authority, but the scope of this authority is presumably not limitless. In the Northeast region, coral distributions extend into waters deeper than the bounds of managed species and their designated EFH. The deep-sea coral discretionary provisions (MSA Section 303(b)) from the 2007 MSA reauthorization provide an additional and more flexible mechanism by which to protect deep-sea corals from physical damage by fishing gear. This discretionary authority allows Councils to designate protection zones anywhere corals have been identified by the Deep Sea Coral Research and Technology Program and implement measures to protect corals within those zones, provided that long term sustainable use of fishery resources has been considered, and there is a nexus to Council-managed fisheries (NOAA 2010; Sutter 2014). This authority has become the primary basis for a range of coral protection measures enacted by the MAFMC and currently under development by the NEFMC (Fig. 10). The measures define the boundaries of coral protection zones and implement fishing restrictions within them. In addition to the EFH and discretionary authorities, National Standard 9 of the MSA requires federal fishery management plans to minimize bycatch to the extent practicable.

Substantial spatial overlap exists between continental slope fisheries managed by the NEFMC and MAFMC. This overlap affects the range of coral alternatives developed and their potential impacts on fishing activities. The NEFMC began development of a deep-sea coral amendment in 2010 that included coral areas from the Gulf of Maine to Norfolk Canyon, off Virginia. In 2012, the MAFMC decided to initiate their own FMP amendment to protect deep-sea corals in the Mid-Atlantic region (roughly south of Alvin Canyon). These two Councils, along with the South Atlantic Fishery Management Council, then drafted a memorandum of understanding (MOU) to coordinate deep-sea coral management activities. Also during 2012, the NEFMC decided to develop their deep-sea coral management measures in a standalone coral-focused amendment, independent from a much more comprehensive omnibus EFH amendment.

In 2015, the MAFMC recommended specific proposals to NMFS to prohibit the use of most types of bottom-tending fishing gear within a 99,000 km² (~38,000 square miles) area on the outer continental shelf, slope, and canyons to the outer boundary of the EEZ. This was approved by NOAA in 2016, marking the first use of the MSA deep-sea coral discretionary authority. The new management zones are officially known as the "Frank R. Lautenberg Deep-Sea Coral Protection Area." Senator Lautenberg, a senator from New Jersey, was responsible for, and authored, several important pieces of ocean conservation legislation, including several provisions in the reauthorized MSA, including the discretionary provisions described above.

The Frank R. Lautenberg Deep-Sea Coral Protection Area includes two types of zones. 'Discrete' zones protect defined areas of canyons and canyon complexes based on the best available information on known coral distributions or outputs of predictive models that rank the likely presence of suitable coral habitats. A precautionary 'broad' zone protects a large area of deepwater habitats extending from approximately 450 m on the slope to the outer limits of the U.S. EEZ (Fig. 10). The objective is to protect corals by limiting future expansion of bottom fishing in an area that is largely outside the footprint of current fishing activity. Both zones restrict most bottom-tending gears, but the red crab fishery is exempted for a period of at least two years in the discrete zones and indefinitely in the broad zones, and the action does not restrict lobster/Jonah crab traps in either type of coral zone. The lobster fishery is primarily managed by the Atlantic States Marine Fisheries Commission. This dual discrete/broad framework follows the approach of NOAA's *Strategic Plan for Deep-Sea Coral and Sponge Ecosystems* (NOAA 2010), and provides flexibility to revise fishing restrictions independently in the various areas.

The NEFMC is still developing and evaluating management approaches and will likely make final recommendations to NMFS during late 2017 or early 2018. The council has taken a similar approach to that of the MAFMC, including a precautionary 'broad' zone in deeper water. Discrete area options that are being considered in New England include seven areas in the Gulf of Maine, a number of submarine canyons and canyon complexes, and the four New England Seamounts in the U.S. EEZ southeast of Georges Bank.

III.2.iii – Other Resource Management and Ocean Policy Efforts

The Mid-Atlantic Regional Council on the Ocean (MARCO) was created by the Governors of five Mid-Atlantic States (NY, NJ, DE, MD, VA) to improve regional coordination of shared ocean issues and to address the ocean environment across the states as a whole ecosystem, through the principles of ecosystem-based management (Capobianco 2011). The first MARCO priority is to coordinate the protection of important habitats and sensitive and unique offshore areas, such as the submarine canyons and deep-sea coral and sponge habitats, on a regional scale. To facilitate habitat protection actions by its partners, MARCO developed an online portal (http://midatlanticocean.org/data-portal/) that displays geospatial information obtained from sources such as NOAA's deep-sea coral and sponge database to aid in identifying regionally-important habitats such as the canyons (Capobianco 2011). The high-resolution multibeam bathymetric surveys of the slope and canyons conducted by NOAA were done in part to support MARCO's habitat mapping and protection goals. MARCO has been following the work of the two Councils in protecting submarine canyon habitats, and facilitated the engagement of multiple federal entities and stakeholders with an interest in these habitats to ensure that all existing resources and authorities were leveraged. Similar planning and geospatial data gathering efforts are underway in New England as well, and coral-related data products including habitat suitability model outputs are available through the Northeast Ocean Data Portal (http://www.northeastoceandata.org). In December, 2016, the National Ocean Council certified the Northeast and Mid-Atlantic Ocean Plans.

NOAA's National Marine Sanctuary Program also received nominations from communities for new National Marine Sanctuaries for Baltimore Canyon and Hudson Canyon (http://www.nominate.noaa.gov/nominations/). In both cases, deep-sea coral resources were identified in the justification for consideration for sanctuary status. The Baltimore Canyon proposal was withdrawn in January 2017, but the Hudson proposal was moved into candidate status at NOAA during February 2017.

V. Conclusions

Mapping and exploratory surveys since 2010 have covered almost all the submarine canyons off the Northeast coast as well as areas of the continental slope, the seamounts within the EEZ, and significant areas in the Gulf of Maine. Considering the state of our knowledge of deep-sea coral and sponge habitats prior to these surveys, the results documented herein have increased our knowledge base of

Northeast deep-sea coral and sponge habitats exponentially. They have also generated much interest from the public and media (e.g., see NRDC 2014 for some 2011-2014 canyon and seamount expedition highlights). However, knowledge gaps still exist for many of these organisms, especially for the sponges, and some basic questions about distribution, abundance, taxonomy, connectivity, life history, population biology, functional role, effects and scale of disturbance, ecological resilience, etc. remain unanswered. Nevertheless, the new surveys have contributed greatly to our regional knowledge of deep-sea coral diversity, distribution, and habitat characteristics.

From a management perspective, these results prompted the NEFMC and MAFMC to revisit their previous lists of potential deep-sea coral protections zones, especially those for the submarine canyons and the Gulf of Maine. Now that most of these areas have been surveyed and deep-sea corals were observed in almost all of them, these areas can be confidently classified as "assessed" and as "suitable" deep-sea coral habitat. The Councils, therefore, were then able to recommend additional areas for consideration as deep-sea coral protection zones/ management areas. Having this information led directly to the creation of the Frank R. Lautenberg Deep-Sea Coral Protection Area in the mid-Atlantic, will support the decision-making process for the creation of deep-sea coral protected areas by the NEFMC, and was one of the major factors behind the creation of the Northeast Canyons and Seamounts Marine National Monument. In addition, a high correlation between recent coral observations and locations predicted to be suitable coral habitat has increased confidence in using the regional deep-sea coral habitat suitability model to inform current and future management decisions of the Councils. Both the NEFMC and MAFMC have used and continue to use the information and results gathered from the recent exploratory surveys, the historical database, and the habitat suitability model to draft management alternatives to designate deep-sea coral zones in the Northeast and Mid-Atlantic and implement fishing restrictions necessary to protect the deep-sea corals within those zones.

V. Acknowledgements

The authors thank those people from other NOAA Line Offices that were either part of the *Bigelow/Okeanos/Hassler* mapping/survey cruises and/or led and provided assistance/funding for modeling, surveys, etc. including Mashkoor Malik, Jeremy Potter, Elizabeth Lobecker, Nathan Keith, LCDR Ben Evans, LT Sam Greenway, and Tim Shank from WHOI. The authors also thank the Gulf of Maine survey scientists, including Peter Auster, Rhian Waller, Rich Langton, and Steve Auscavitch; the crew and engineers of the *Connecticut*, *ISIS2*, and *Kraken 2*, including Ivar Babb; and the Sandy Hook folks who help get the data out there: Donna Johnson, Jeff Pessutti, Barry Shafer, Christine Shafer, and Caren Martins. Additional thanks to Tania Lewandowski (NEFOP). Finally, we thank Rich Langton (NEFSC), David Stevenson (GARFO), Stephen Cairns (Smithsonian NMNH), Andrea Quattrini

(Harvey Mudd College), Sandra Brooke (Florida State Univ.), Rhian Waller (U. Maine), Peter Auster (U. Conn.), Kiley Dancy (MAFMC), and especially Tom Hourigan for helpful reviews and comments. Figure 5d courtesy of Source: Deepwater Canyons 2012 Expedition NOAA-OER/BOEM/USGS. Figures 5e,f,l courtesy of NOAA *Okeanos Explorer* Program, 2013 Northeast U.S. Canyons Expedition. Figures 5g,h,i courtesy of NOAA *Okeanos Explorer* Program, Our Deepwater Backyard: Exploring Atlantic Canyons and Seamounts. Gulf of Maine Figures 7-9 courtesy of NOAA/UConn. – NURTEC/UMaine.

This chapter is dedicated to the memory of Brian Kinlan, whose presence is deeply missed but whose ideas and passion live on.

Online Annex – Comprehensive list of deep-sea corals in the U.S. Northeast region link: https://deepseacoraldata.noaa.gov/library/2017-state-of-deep-sea-corals-report

VI. Literature Cited

Almeida F, Arlen L, Auster P, Cross J, Lindholm J, Link J, Packer D, Paulson A, Reid R, Valentine P (2000) The effects of marine protected areas on fish and benthic fauna: the Georges Bank Closed Area II example. Poster: Am Fish Soc 130th Ann Meet, 20-24 Aug 2000, St. Louis, MO

Auster PJ (2005) Are deep-water corals important habitats for fishes? In: Freiwald A, Roberts JM (eds) Cold-water corals and ecosystems. Springer-Verlag, Heidelberg, p 747-760

Auster PJ (2007) Linking deepwater corals and fish populations. In: George RY, Cairns SD (eds) Conservation and adaptive management of seamount and deep-sea coral ecosystems. Rosenstiel School Mar Atmos Sci, Miami:93-99

Auster P J, Gjerde K, Heupel E, Watling L, Grehan A, Rogers AD (2011) Definition and detection of vulnerable marine ecosystems on the high seas: problems with the "move-on" rule. ICES J Mar Sci 68:254-264

Auster PJ, Kilgour M, Packer D, Waller R, Auscavitch S, Watling L (2013) Octocoral gardens in the Gulf of Maine (NW Atlantic). Biodiversity 14:193-194

Auster P, Moore J, Heinonen KB, Watling L (2005) A habitat classification scheme for seamount landscapes: assessing the functional role of deep-water corals as fish habitat. In: Freiwald A, Roberts JM (eds) Cold-water corals and ecosystems. Springer-Verlag, Heidelberg, p 761-769

Auster PJ, Langton RW (1999) The effects of fishing on fish habitat. In: Benaka L (ed) Fish habitat: essential fish habitat and rehabilitation. Am Fish Soc Symp 22:150-187

Auster PJ, Packer D, Waller R, Auscavitch S, Kilgour MJ, Watling L, Nizinski MS, Babb I, Johnson D, Pessutti J, Drohan A, Kinlan B (2014) Imaging surveys of select areas in the northern Gulf of Maine for deep-sea corals and sponges during 2013-2014. Rep New England Fishery Management Council - 1 December 2014. ResearchGate DOI: 10.13140/RG.2.1.4760.0163

Baillon S, Hamel J-F, Wareham VE, Mercier A (2012) Deep cold-water corals as nurseries for fish larvae. Front Ecol Environ 10(7):351–356

Baker KD, Haedrich RL, Snelgrove PVR, Wareham VE, Edinger EN, Gilkinson, KD (2012) Small-scale patterns of deep-sea fish distributions and assemblages of the Grand Banks, Newfoundland continental slope. Deep-Sea Res Part I 65:171–188.

Bayer FM (1981) Key to the genera of Octocorallia exclusive of Pennatulacea (Coelenterata: Anthozoa), with diagnoses of new taxa. Proc Biol Soc Wash 94:902–947

Beazley LI, Kenchington EL, Murillo FJ, Sacau M (2013) Deep-sea sponge grounds enhance diversity and abundance of epibenthic megafauna in the Northwest Atlantic. ICES J Mar Sci, DOI:10.1093/icesjms/fst124.

Beazley L, Kenchington E, Murillo FJ, Lirette C, Guijarro J, Knudby A (2016) Species distribution modelling of corals and sponges in the Maritimes Region for use in the identification of significant benthic areas. Can Tech Rep Fish Aquat Sci 3172: 189 pp

Beazley L, Kenchington E, Yashayaev I, Murillo FJ (2015) Drivers of epibenthic megafaunal composition in the sponge grounds of the Sackville Spur, northwest Atlantic. Deep-Sea Res Part I: Oceanog Res Pap 98:102-114

Best M, Kenchington E, MacIsaac K, Wareham VE, Fuller SD, Thompson AB (2010) Sponge identification guide NAFO area. Sci Coun Stud 43:1–50, DOI:10.2960/S.v43.m1

BOEM (Bureau of Ocean Energy Management) (2010) Exploration and research of mid-Atlantic deepwater hard bottom habitats and shipwrecks with emphasis on canyons and coral communities. Environmental studies program AT-10-03. https://www.boem.gov/AT-10-03/

BOEM (Bureau of Ocean Energy Management) (2016) 2017–2022 outer continental shelf oil and gas leasing proposed program. U.S. DOI/ BOEM, Mar. 2016, http://www.boem.gov/2017-2022-Proposed-Program-Decision/

Bourque JR, Robertson CM, Brooke S, Demopoulos AWJ (2017) Macrofaunal communities associated with chemosynthetic habitats from the U.S. Atlantic Margin: a comparison among depth and habitat types. Deep-Sea Res Part II 137:42-55

Brooke S, Ross SW (2014) First observations of the cold-water coral *Lophelia pertusa* in mid-Atlantic canyons of the USA. Deep-Sea Res Part II 104:245–251

Brooke SD, Watts MW, Heil AD, Rhode M, Mienis F, Duineveld GCA, Davies AJ, Ross SW (2017) Distributions and habitat associations of deep-water corals in Norfolk and Baltimore canyons, Mid Atlantic Bight, USA. Deep-Sea Res Part II 137:131-147

Bryan TL, Metaxas A (2007) Predicting suitable habitat for deep-water gorgonian corals on the Atlantic and Pacific continental margins of North America. Mar Ecol Prog Ser 330:113–126

Buhl-Mortensen B, Buhl-Mortensen L (2004). Distribution of deep-water gorgonian corals in relation to benthic habitat features in the Northeast Channel (Atlantic Canada). Mar Biol 144:1223-1238

Buhl-Mortensen P, Buhl-Mortensen L, Purser A (2016) Trophic ecology and habitat provision in cold-water coral ecosystems. In: Rossi S, Bramanti L, Gori A, Orejas Saco del Valle C (eds) Marine animal forests: the ecology of benthic biodiversity hotspots. Springer International Publishing, Switzerland, p 1-26

Bullard SG, Lambert G, Carman MR, Byrnes J, Whitlatch RB, Ruiz G, Miller RJ, Harris L, Valentine PC, Collie JS, Pederson J, McNaught DC, Cohen AN, Asch RG, Dijkstra J, Heinonen K (2007) The colonial ascidian *Didemnum* sp. A: current distribution, basic biology and potential threat to marine communities of the northeast and west coasts of North America. J Exp Mar Biol Ecol 342:99–108

Bullimore RD, Foster NL, Howell KL (2013) Coral-characterized benthic assemblages of the deep Northeast Atlantic: defining 'coral gardens' to support future habitat mapping efforts. ICES J Mar Sci 70:511–522

Cairns SD (2006) Studies on western Atlantic Octocorallia (Coelenterata: Anthozoa). Part 6. The genera *Primnoella* Gray, 1858; *Thouarella*, Gray, 1870; *Dasystenella* Versluys, 1906. Proc Biol Soc Wash 119(2):161-194

Cairns SD (2007) Studies on western Atlantic Octocorallia (Gorgonacea: Primnoidae). Part 8: New records of Priminoidae from the New England and Corner Rise Seamounts. Proc Biol Soc Wash 120(3):243-263

Cairns SD, Bayer FM (2003) Studies on western Atlantic Octocorallia (Coelenterata: Anthozoa). Part 3: The genus Narella Gray, 1870. Proc Biol Soc Wash 116(2):617-648

Capobianco G (2011) Perspectives from the Mid-Atlantic Regional Council on the Ocean. In: Packer D (ed) Proceedings of the Mid-Atlantic Fishery Management Council's Habitat-Ecosystem Workshop, Virginia Beach, VA, December 13-14, 2010, p 45-46

Chaytor JD, Twichell DC, ten Brink US (2011) A reevaluation of the Munson-Nygren-Retriever submarine landslide complex, Georges Bank Lower Slope, Western North Atlantic. In: Yamada Y, Kawamura K, Ikehara K, Ogawa Y, Urgeles R, Mosher D, Chaytor J, Strasser M (eds) Submarine mass movements and their consequences: advances in natural and technological hazards research. Springer, p 135–146

Cho WW (2008) Faunal biogeography, community structure, and genetic connectivity of North Atlantic seamounts. Ph.D. Diss, Massachusetts Institute of Technology & Woods Hole Oceanographic Institution

Cho W, Shank TM (2010) Incongruent patterns of genetic connectivity among four ophiuroid species with differing coral host specificity on North Atlantic seamounts. Mar Ecol 31(suppl. 1):121-143

Cogswell AT, Kenchington ELR, Lirette CG, MacIsaac K, Best MM, Beazley LI, Vickers J (2009) The current state of knowledge concerning the distribution of coral in the Maritime Provinces. Can Tech Rep Fish Aquat Sci 2855:v + 66 pp

Cook RR, Auster PJ (2013) The biodiversity value of marine protected areas for multi-species fishery management in the Gulf of Maine. Aqua Conserv Mar Freshw Ecosys 23:429-440

Daly M, Brugler, MR, Cartwright P, Collins AG, Dawson MN, Fautin DG, France SC, McFadden S, Opresko DM, Rodriguez E, Romano SL, Stake JL (2007) The phylum Cnidaria: a review of phylogenetic patterns and diversity 300 years after Linnaeus. Zootaxa 1668:127–182.

Davies AJ, Wisshak M, Orr JC, Roberts JM (2008) Predicting suitable habitat for the cold-water coral *Lophelia pertusa* (Scleractinia). Deep-Sea Res Part I 55:1048–1062

Dean A, Langton R, Packer D, Auster P, Nizinski M, Waller R (2016) Is the common sea pen (*Pennatula aculeata*) nursery habitat for Acadian redfish (*Sebastes* spp.) in the U.S. Gulf of Maine? Poster: 6th International Symposium on Deep-Sea Corals September 11-16, 2016, Boston MA

De Clippele LH, Buhl-Mortensen P, Buhl-Mortensen L (2015) Fauna associated with cold water gorgonians and sea pens. Cont Shelf Res 105:67-78

Devictor, ST, Morton, SL 2010 Identification guide to the shallow water (0–200 m) octocorals of the South Atlantic Bight. Zootaxa 2599. 62 pp

Etter RJ, Bower AS (2015) Dispersal and population connectivity in the deep North Atlantic estimated from physical transport processes. Deep-Sea Res Part I: Oceanog Res Pap 104:159-172

Foley NS, Kahui V, Armstrong CW, van Rensburg TM (2010) Estimating linkages between redfish and cold-water coral on the Norwegian Coast. ar Resource Econ 25:105-120

Form AU, Riebesell U (2012) Acclimation to ocean acidification during long-term CO_2 exposure in the cold-water coral *Lophelia pertusa*. Global Change Biol 18:843–853

Fuller SD (2011) Diversity of marine sponges in the Northwest Atlantic. PhD Diss, Dalhousie Univ, Halifax, Nova Scotia, 215 pp

Fuller SD, Kenchington ELR, Davis D, Butler M (1998) Associated fauna of commercial scallop grounds in the lower Bay of Fundy. Mar Issues Comm Spec Pub 2. Ecology Action Centre, Halifax, Canada

Gosner K (1978) A field guide to the Atlantic seashore: invertebrates and seaweeds of the Atlantic coast from the Bay of Fundy to Cape Hatteras. Houghton Mifflin Co, Boston

Greene JK, Anderson MG, Odell J, Steinberg N, eds. (2010) The Northwest Atlantic marine ecoregional assessment: species, habitats and ecosystems. Phase one. The Nature Conservancy, Eastern U.S. Division, Boston, MA

Guinotte JM, Georgian S, Kinlan BP, Poti M, Davies A (this volume) Predictive Habitat Modeling for Deep-Sea Corals in U.S. Waters. In: Hourigan TF, Etnoyer PJ, Cairns SD (eds.). State of Deep-Sea Coral and Sponge Ecosystems of the United States. NOAA Technical Memorandum NMFS-OHC-4, Silver Spring, MD

Hartman, WD (1958) Natural history of the marine sponges of southern New England. Bull Peabody Mus Nat Hist 12:1-155

Hecker B, Blechschmidt G, Gibson P (1980) Final report for the canyon assessment study in the Mid- and North Atlantic areas of the U.S. outer continental shelf: epifaunal zonation and community structure in three Mid- and North Atlantic canyons. In: Canyon assessment study. U.S. Department of Interior Bureau of Land Management, Washington, DC, No. BLM-AA551-CT8-49, p 1-139

Hourigan TF, Etnoyer PJ, McGuinn RP, Whitmire CE, Dorfman D, Dornback M, Cross SS, Salis D (2015) An Introduction to NOAA's national database for deep-sea corals and sponges. NOAA Techn Memo NOS NCCOS 191

Hourigan TF, Reed J, Pomponi S, Ross SW, David AW, Harter S (this volume) State of Deep-Sea Coral and Sponge Ecosystems of the Southeast United States. In: Hourigan TF, Etnoyer PJ, Cairns SD (eds.). State of Deep-Sea Coral and Sponge Ecosystems of the United States. NOAA Technical Memorandum NMFS-OHC-4, Silver Spring, MD

ICES (International Council for the Exploration of the Sea) (2007) Report of the Working Group on Deep-Water Ecology (WGDEC), 26–28 February 2007. ICES Advisory Committee on Ecosystems, ICES Doc CM 2007/ACE: 01, Copenhagen, Denmark:ICES

Kanwit K, Pol M, Pingguo H (2013) REDNET - A network to redevelop a sustainable redfish (*Sebastes fasciatus*) trawl fishery in the Gulf of Maine In: Component 2— baseline catch and bycatch evaluation. Report to the Northeast Cooperative Research Partners Program, NMFS

Kaplan K, Hart, D R, Hopkins K, Gallager S, York A, Taylor R, Sullivan PJ (2017a) Evaluating the interaction of the invasive tunicate *Didemnum vexillum* with the Atlantic sea scallop *Placopecten magellanicus* on open and closed fishing grounds of Georges Bank. ICES J Mar Sci, DOI:10.1093/icesjms/fsx076

Kaplan K, Hart, D R, Hopkins K, Gallager S, York A, Taylor R, Sullivan PJ (2017b) Invasive tunicate restructures invertebrate community on fishing grounds and a large protected area on Georges Bank. Biol Invasions, DOI: 10.1007/s10530-017-1517-y

Kellogg CA, Ross SW, Brooke SD (2016) Bacterial community diversity of the deep-sea octocoral *Paramuricea placomus*. PeerJ 4:e2529 https://doi.org/10.7717/peerj.2529

Kilgour, MJ., Auster PA, Packer D, Purcell M, Packard G, Dessner M, Sherrell A, Rissolo D (2014) Use of AUVs to inform management of deep-sea corals. Mar Tech Soc J 48 (1):21-27.

Kinlan BP, Poti M, Drohan A, Packer DB, Nizinski M, Dorfman D, Caldow C (2013) Digital data: Predictive models of deep-sea coral habitat suitability in the U.S. Northeast Atlantic and mid-Atlantic regions. Downloadable digital data package. Department of Commerce (DOC), National Oceanic and Atmospheric Administration (NOAA), National Ocean Service (NOS), National Centers for Coastal Ocean Science (NCCOS), Center for Coastal Monitoring and Assessment (CCMA), Biogeography Branch. Released August 2013. Available at: http://coastalscience.noaa.gov/projects/detail?key=35

Kinlan BP, Poti M, Drohan A, Packer DB, Dorfman D, Nizinski M (In review) Predictive modeling of suitable habitat for deep-sea corals offshore of the Northeast United States. Deep Sea Res Part I: Oceanogr Res Pap

Kleypas JA, Yates KK (2009) Coral reefs and ocean acidification. Oceanogr 24(4):108-117

Knight E, Watling L, McLellan C, Kelley JT (2006) Assessment of benthic recovery in the Western Gulf of Maine Closed Area. Final Report submitted to the Northeast Consortium, University of New Hampshire, 49 pp

Lambe, L. M. (1896). Sponges from the Atlantic coast of Canada. Trans Royal Soc Can Ser 2(2):181-211

Lambe, L. M. (1900). Sponges from the coasts of Northeastern Canada and Greenland. Trans Royal Soc Can Ser 2(6):19-48

Langton RW, Langton EW, Theroux RB, Uzmann JR (1990) Distribution, behavior and abundance of sea pens, *Pennatula aculeata*, in the Gulf of Maine. Mar Biol 107(3):463-469

Lawler SN, Kellogg CA, France SC, Clostio RW, Brooke SD, Ross SW (2016) Coral-associated bacterial diversity is conserved across two deep-sea *Anthothela* species. Front Microbiol 7:458

Lengyel N (2009) The invasive colonial ascidian *Didemnum vexillum* on Georges Bank — Ecological effects and genetic identification. Aquatic Invasions 4:143-152

Leverette TL, Mexataxas A (2005) Predicting habitat for two species of deep-water coral on the Canadian Atlantic continental shelf and slope. In: Freiwald A, Roberts JM (eds) Cold-water corals and ecosystems. Springer-Verlag, Heidelberg, p 467–479

Lewandowski T, Packer D, Nizinski M (2016) The Northeast Fisheries Observer Program (NEFOP) deep-sea coral program and data analysis. Poster: 6th International Symposium on Deep-Sea Corals September 11-16, 2016, Boston MA

Lindholm J, Auster P, Valentine P (2004) Role of a large marine protected area for conserving landscape attributes of sand habitats on Georges Bank (NW Atlantic). Mar Ecol Prog Ser 269:61-68

Lunden JJ, McNicholl CG, Sears CR, Morrison CL, Cordes EE (2014) Acute survivorship of the deep-sea coral *Lophelia pertusa* from the Gulf of Mexico under acidification, warming, and deoxygenation. Front. Mar Sci 1(78): 1-12

Maciolek N, Grassle JF, Hecker B, Brown B, Blake JA, Boehm PD, Petrecca R, Duffy S, Baptiste E, Ruff E (1987a). Study of biological processes on the U.S. North Atlantic slope and rise. Vol 2, Final Report, U.S. Dept Int Minerals Management Service OCS Study MMS 87-0051

Maciolek N, Grassle JF, Hecker B, Boehm PD, Brown B, Dade B, Steinhauer WG, Baptiste E, Ruff RE, Petrecca R (1987b) Study of biological processes on the U.S. Mid-Atlantic slope and rise. Vol 2, Final Report, U.S. Dept Int Minerals Management Service OCS Study MMS 87-0050

Maldonado M, Aguilar R, Bannister RJ, Bell JJ, Conway KW, Dayton PK, Diaz C, Gutt J, Kelly M, Kenchington ELR, Leys SP, Pomponi SA, Rapp HT, Rutzler K, Tendal OS, Vacelet J, Young CM (2016) Sponge grounds as key marine habitats: a synthetic review of types, structure, functional roles, and conservation concerns. In Rossi (ed) Marine animal forests. Springer International Publishing, Switzerland, p. 1-39

Martins CJE (2015) Distribution of octocorals in Jordan Basin, Gulf of Maine NW Atlantic. MSc. Thesis, Erasmus Mundus Master Program EMBC+ 43 pp

Mastrototaro, F, Chimienti G, Capezzuto F, Carlucci R, Williams G (2015) First record of *Protoptilum carpenteri* (Cnidaria: Octocorallia: Pennatulacea) in the Mediterranean Sea, Italian J Zool 82(1):61-68, DOI: 10.1080/11250003.2014.982218

McFadden CS, Sánchez JA, France SC (2010) Molecular phylogenetic insights into the evolution of Octocorallia: a review. Integr Comp Biol 50:389-410

Metaxas A, Davis J. (2005) Megafauna associated with assemblages of deep-water gorgonian corals in Northeast Channel, off Nova Scotia, Canada. J Mar Biol Ass UK 85:1381-1390

Miller RJ, Etter RJ (2011) Rock walls: small-scale diversity hotspots in the subtidal Gulf of Maine. Mar Ecol Prog Ser 425:153-165

Moore J, Auster PJ (2009) Commensalism between juvenile cusk eels and pancake urchins on western North Atlantic seamounts. Bull Peabody Mus Nat Hist 50:381–386

Moore JA, Auster PJ, Calini D, Heinonen K, Barber K, Hecker B (2008) False boarfish *Neocyttus helgae* in the western North Atlantic. Bull Peabody Mus Nat Hist 49:31–41

Mosher CV, Watling L (2009) Partners for life: a brittle star and its octocoral host. Mar Ecol Prog Ser 397:81-88

NEFMC (2011). Habitat Plan Development Team meeting summary, October 17-18, 2011, Woods Hole, MA. New England Fishery Management Council

NOAA (2010). NOAA Strategic Plan for deep-sea coral and sponge ecosystems: research, management, and international cooperation. NOAA Coral Reef Conservation Program, NOAA Tech Memo CRCP 11: 67 pp

NOAA (2011a) Deep-sea coral National Geographic Database, version 2.0. NOAA, NMFS, Deep Sea Coral Research and Technology Program, Silver Spring, MD

NOAA (2011b) U.S Coastal Relief Model Vol 1:2 http://www.ngdc.noaa.gov/mgg/coastal/grddas01/grddas01.htm http://www.ngdc.noaa.gov/mgg/coastal/grddas02/grddas02.htm, Accessed December 9, 2011

NOAA (2012a) NOAA Habitat Blueprint. A framework to improve habitat for fisheries, marine life, and coastal communities, https://www.habitatblueprint.noaa.gov/

NOAA (2012b) NOAA Deep-sea coral and sponge ecosystems exploration and research priorities workshop for the Northeast U.S., https://deepseacoraldata.noaa.gov/library/northeast-dsc-priorities-workshop-report-2011

NOAA (2016) Report to Congress on the Deep Sea Coral Research and Technology Program, 56pp, https://deepseacoraldata.noaa.gov/library/2016-dsc-report-to-congress

NRDC (Natural Resources Defense Council) (2014). The Atlantic's deep sea treasures: Discoveries from a new frontier of ocean exploration. NRDC Issue Brief Nov 2014, IB:14-11-C, https://www.nrdc.org/sites/default/files/atlantic-deep-sea-treasures-IB.pdf

Obelcz J, Brothers D, Chaytor J, Brink Ut, Ross SW, Brooke S (2014) Geomorphic characterization of four shelf-sourced submarine canyons along the U.S. Mid-Atlantic continental margin. Deep Sea Res Part II: Topical Stud Oceanog 104:106-119

Packer DB, Boelke D, Guida V, McGee L-A (2007) State of deep coral ecosystems in the Northeastern U.S. region: Maine to Cape Hatteras. In: Lumsden SE, Hourigan TF, Bruckner AW, Dorr G (eds) The state of deep coral ecosystems of the United States. NOAA Tech Memo CRCP-3, p 195-232

Packer DB, Dorfman DS (2012) Deep sea corals. In: Menza C, Kinlan BP, Dorfman DS, Poti M, Caldow C (eds) A biogeographic assessment of seabirds, deep sea corals and ocean habitats of the New York Bight: science to support offshore spatial planning. NOAA Tech. Memo NOS NCCOS 141, p 69-86

Packer, DB, Nizinski MS, Cairns SD, Hourigan TF (2017) Deep-sea coral taxa in the U.S. Northeast region: depth and geographical distribution. https://deepseacoraldata.noaa.gov/library/2017-state-of-deep-sea-corals-report

Pante E, Watling L (2011) *Chrysogorgia* from the New England and Corner Seamounts: Atlantic – Pacific connections. J Mar Biol Assoc UK, DOI:10.1017/S0025315411001354

Pierdomenico M, Guida VG, Macelloni L, Chiocci FL, Rona PA, Scranton MI, Asper V, Diercks A (2015) Sedimentary facies, geomorphic features and habitat distribution at the Hudson Canyon head from AUV multibeam data. Deep-Sea Res Part II 121:112–125

Prouty NG, Sahy D, Ruppel CD, Roark EB, Condon D, Brooke S, Ross SW, Demopoulos AWJ (2016) Insights into methane dynamics from analysis of authigenic carbonates and chemosynthetic mussels at newly-discovered Atlantic Margin seeps. Earth Planet Sci Lett 449:332–344

Quattrini AM, Nizinski MS, Chaytor JD, Demopoulos AWJ, Roark EB, France SC, Moore, JA, Heyl T, Auster PJ, Kinlan B, Ruppel C, Elliott KP, Kennedy BRC, Lobecker E, Skarke A, Shank TM. (2015) Exploration of the canyon-incised continental margin of the Northeastern United States reveals dynamic habitats and diverse communities. PLoS ONE 10(10): e0139904, DOI:10.1371/journal. pone.0139904

Roberts JM, Wheeler AJ, Freiwald A, Cairns SD (2009) Cold-water corals: The biology and geology of deep-sea coral habitats. Cambridge University Press, Cambridge, UK

Ross SW, Nizinski MS (2007) State of the U.S. deep coral ecosystems in the Southeastern United States region: Cape Hatteras to the Florida Straits. In: Lumsden SE, Hourigan TF, Bruckner AW, Dorr G (eds) The state of deep coral ecosystems of the United States. NOAA Tech Memo CRCP-3, p 233-270

Ross SW, Rhode M, Quattrini AM (2015) Demersal fish distribution and habitat use within and near Baltimore and Norfolk canyons, U.S. Middle Atlantic slope. Deep-Sea Res Part I 103:137-154.

Samadi ST, Schlacher TA, Richer de Forges B (2007) Seamount benthos. In: Pitcher TJ, Morato T, Hart PJB, Clark MR, Haggan N, Santos RS (eds) Seamounts: ecology, fisheries and conservation. Blackwell Fish Aquat Resourc Ser, p 119–140

Scanlon KM, Waller RG, Sirotek AR, Knisel JM, O'Malley JJ, Alesandrini S (2010) USGS cold-water coral geographic database - Gulf of Mexico and Western North Atlantic ocean. Ver 1.0. USGS Open File Report 2008-1351. http://pubs.usgs.gov/of/2008/1351/

Shank TM (2010) New England and Corner Rise Seamounts. Oceanography 23:104-105

Steimle FW, Zetlin CA (2000) Reef habitats in the Middle Atlantic Bight: abundance, distribution, associated biological communities, and fishery resource use. Mar Fish Rev 62(2):24-42

Stokesbury KDE, Harris BP (2006) Impact of limited short-term sea scallop fishery on epibenthic community of Georges Bank closed areas. Mar Ecol Prog Ser 307:85-100

Stone RP, Masuda MM, Karinen JF (2015) Assessing the ecological importance of red tree coral thickets in the eastern Gulf of Alaska. ICES J Mar Sci 72:900-915

Sutter B. (2014) Protection of deep-sea corals from physical damage by fishing gear under the MSA Deep Sea Coral Discretionary Authority. Letter to Executive Directors, Fishery Management Councils, NMFS, Silver Spring, MD, http://www.mafmc.org/s/140611_MSA_DSC-DiscrAuth-nnmp.pdf

Tamsett A, Heinonen KB, Auster PJ, Lindholm J (2010) Dynamics of hard substratum communities inside and outside of a fisheries closed area in Stellwagen Bank National Marine Sanctuary (Gulf of Maine, NW Atlantic). Mar Sanctuaries Conserv Ser ONMS-10-05, 53 pp.

Theroux RB, Wigley RL (1998) Quantitative composition and distribution of macrobenthic invertebrate fauna of the continental shelf ecosystems of the Northeastern United States. NOAA Technical Report NMFS-140, 240 pp

Thoma JN (2013) Molecular and morphological diversity of sea fans with emphasis on deep-sea octocorals of the Order Alcyonacea Lamouroux, 1812. Ph.D. Diss, Univ Louisiana Lafayette

Thoma JN, Pante E, Brugler MR, France SC (2009) Deep-sea octocorals and antipatharians show no evidence of seamount-scale endemism in the NW Atlantic. Mar Ecol Prog Ser 397:25-35

Van Dolah R F, Wendt PH, Nicholson N (1987) Effects of a research trawl on a hard-bottom assemblage of sponges and corals. Fish Res 5(1):39-54

Vierod AD, Guinotte JM, Davies AJ (2013) Predicting the distribution of vulnerable marine ecosystems in the deep sea using presence-background models. Deep-Sea Res Part II 99:6-18

Watanabe S, Metaxas A, Sameoto J, Lawton P (2009) Patterns in abundance and size of two deep-water gorgonian octocorals, in relation to depth and substrate features off Nova Scotia. Deep-Sea Res I 56:2235–2248

Watling L, Auster P (2005) Distribution of deep-water Alcyonacea off the Northeast coast of the United States. In: Freiwald A, Roberts JM (eds) Cold-water corals and ecosystems. Springer-Verlag, Berlin, p 259-264

Watling L, France SC (2011) A new genus and species of bamboo coral (Octocorallia: Isididae: Keratoisidinae) from the New England Seamounts. Bull Peabody Mus Nat Hist 52:209-

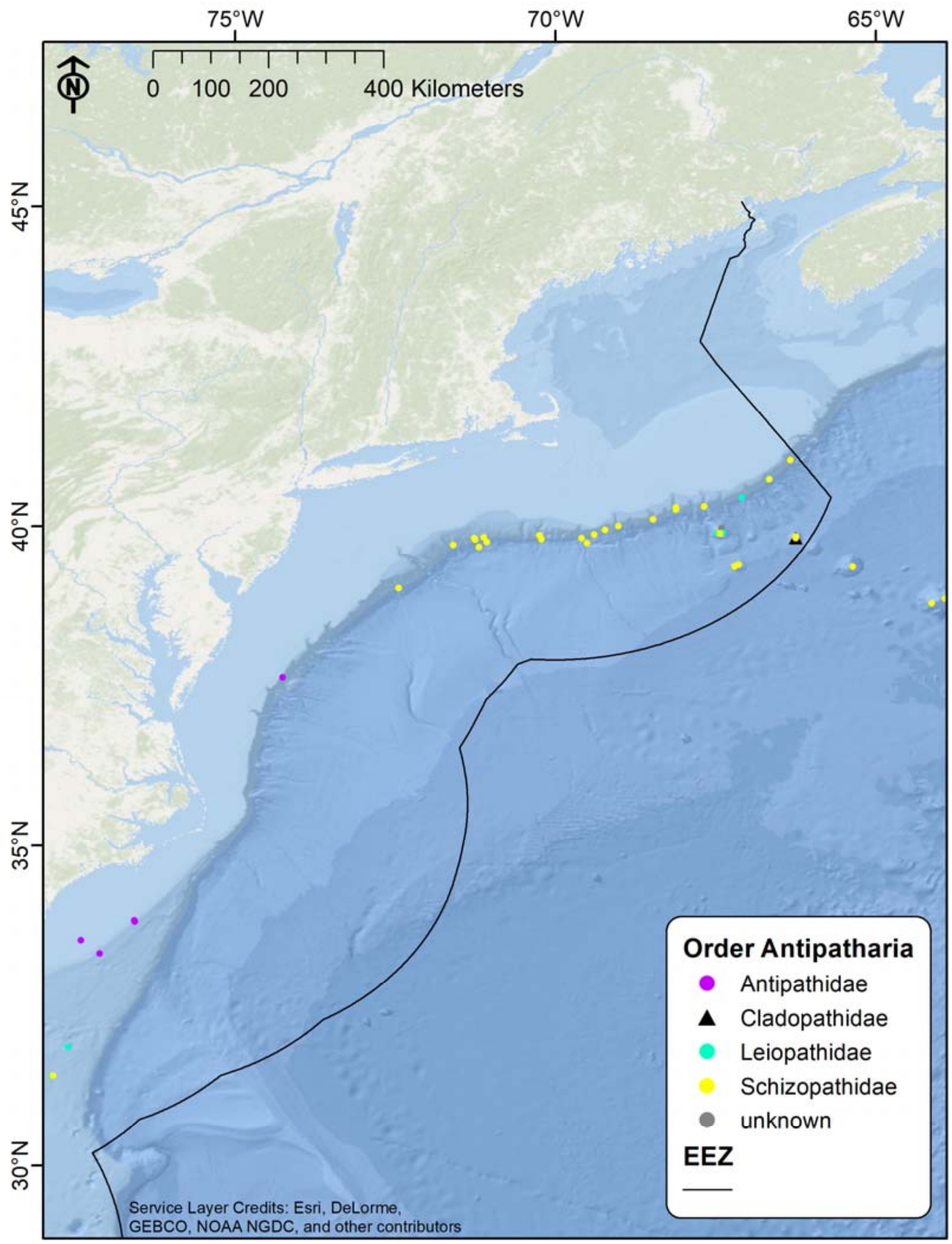
Watling L, France SC, Pante E, Simpson A (2011) Biology of deep-water octocorals. Adv Mar Biol 60:41-122

Williams LC (2009) The U.S. Atlantic commercial fishing industry and cold-water coral conservation: history, current trends and next steps. MS Marine Policy, University of Delaware

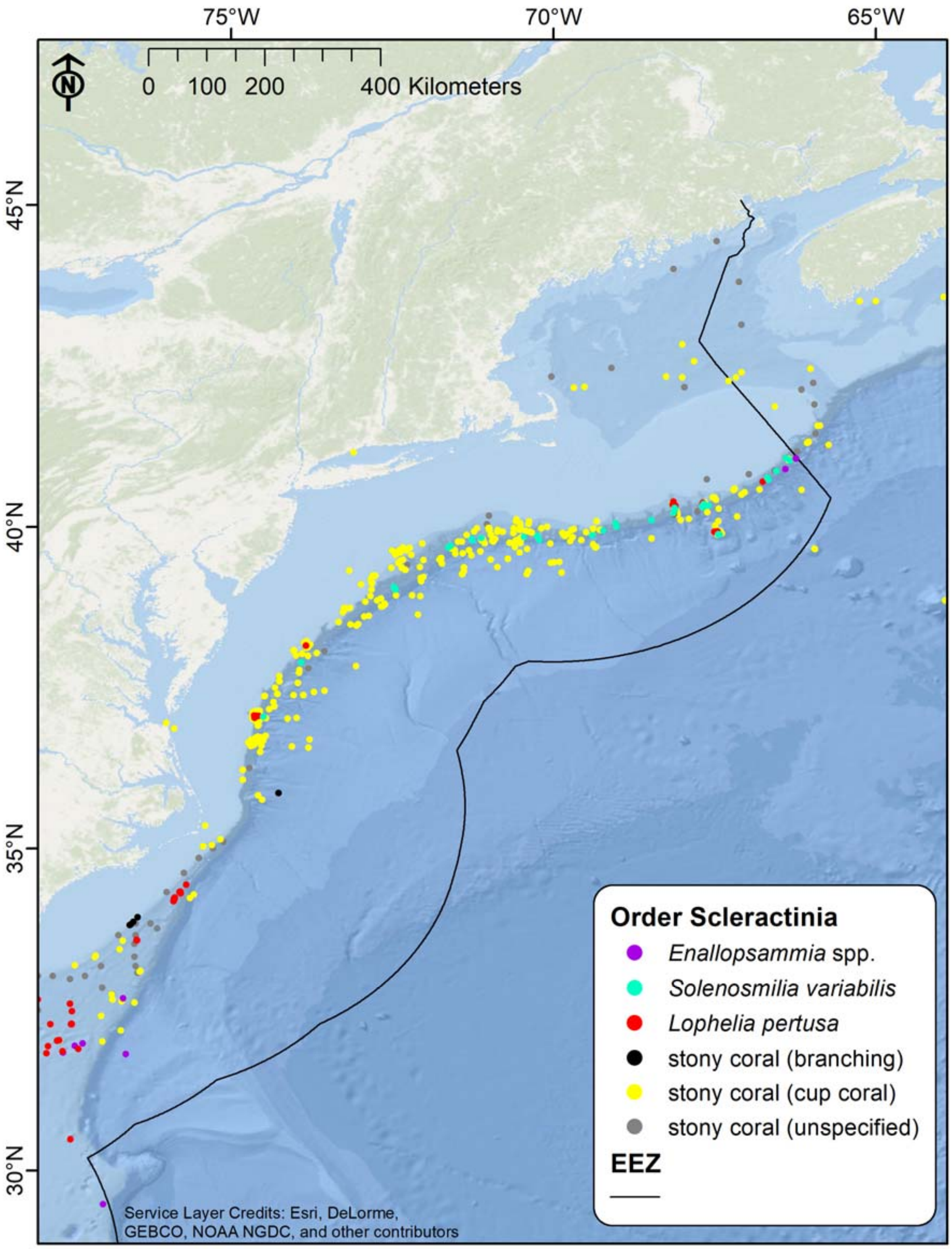
Witman JD, Sebens KP (1988) Benthic community structure at a subtidal rock pinnacle in the central Gulf of Maine. In: Babb I, DeLuca M (eds) Benthic productivity and marine resources of the Gulf of Maine. Nat Undersea Res Prog Res Rep 88-3:67-104

Online Annex 1. Deep-sea Coral Taxa in the U.S. Northeast Region: Depth and Geographic Distribution

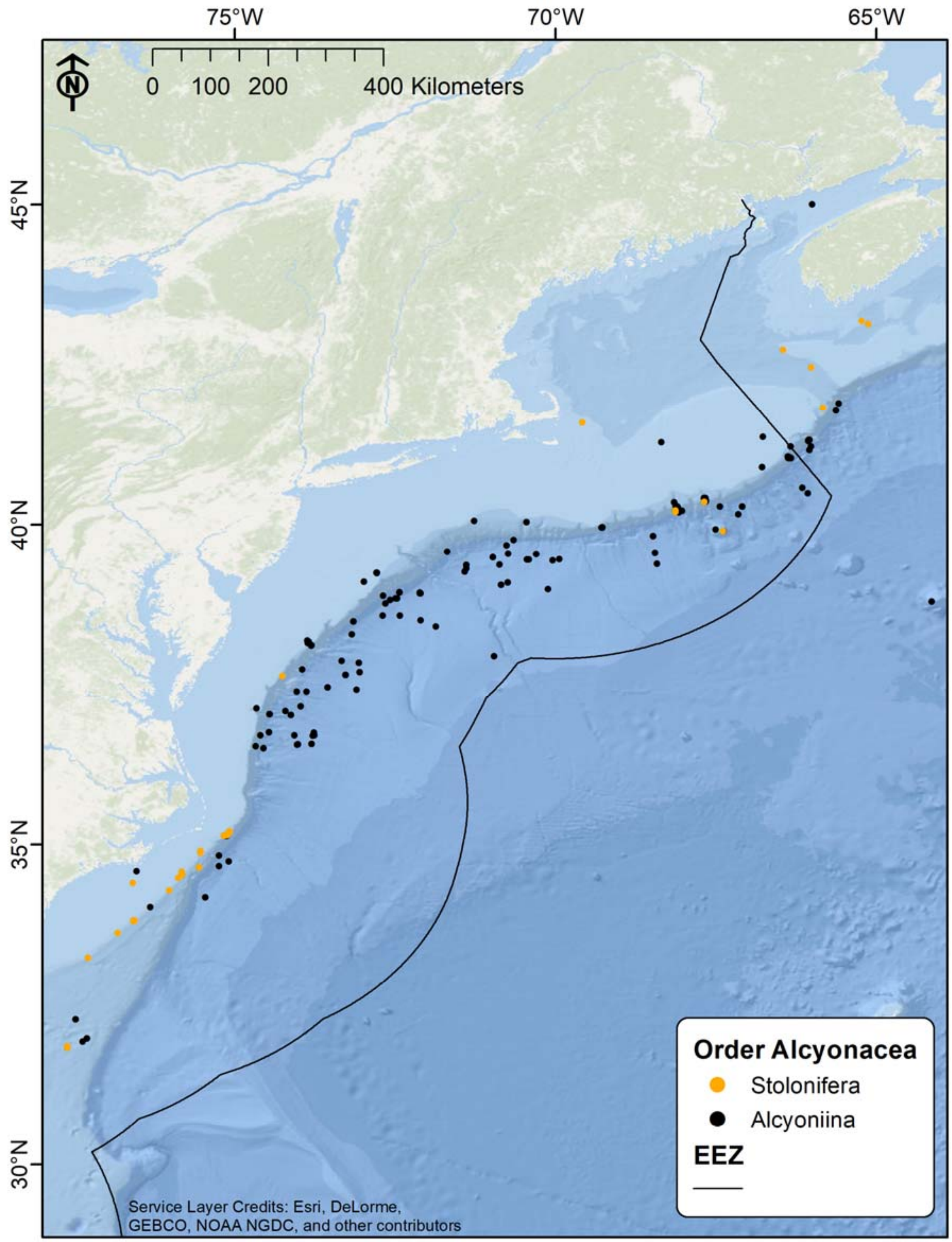
Appendix – Deep-Sea Coral and Sponge Distribution Maps



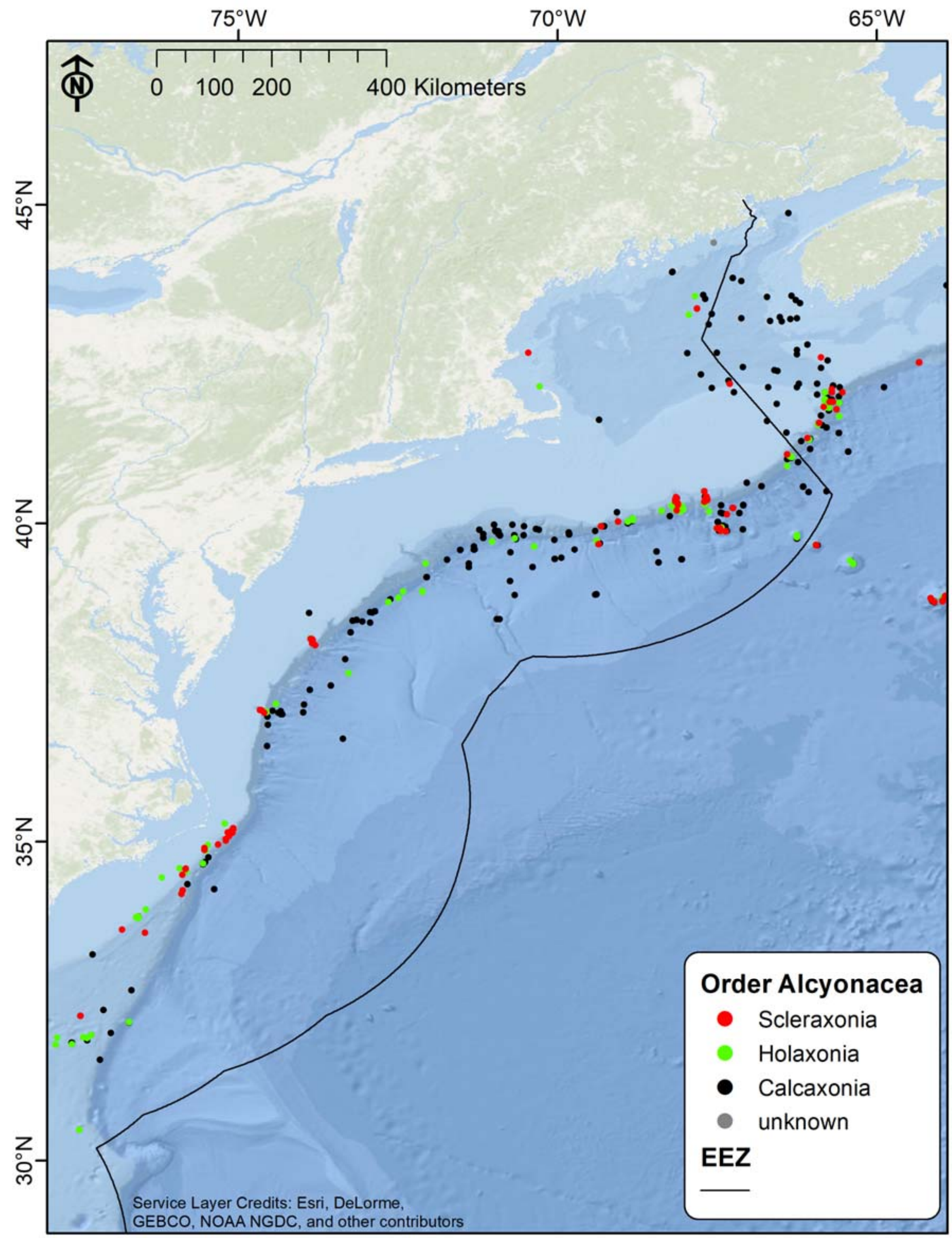
Map 1. *Locations of black corals (Order Antipatharia) recorded in the National Deep-Sea Coral and Sponge Database (as of October 2017).*



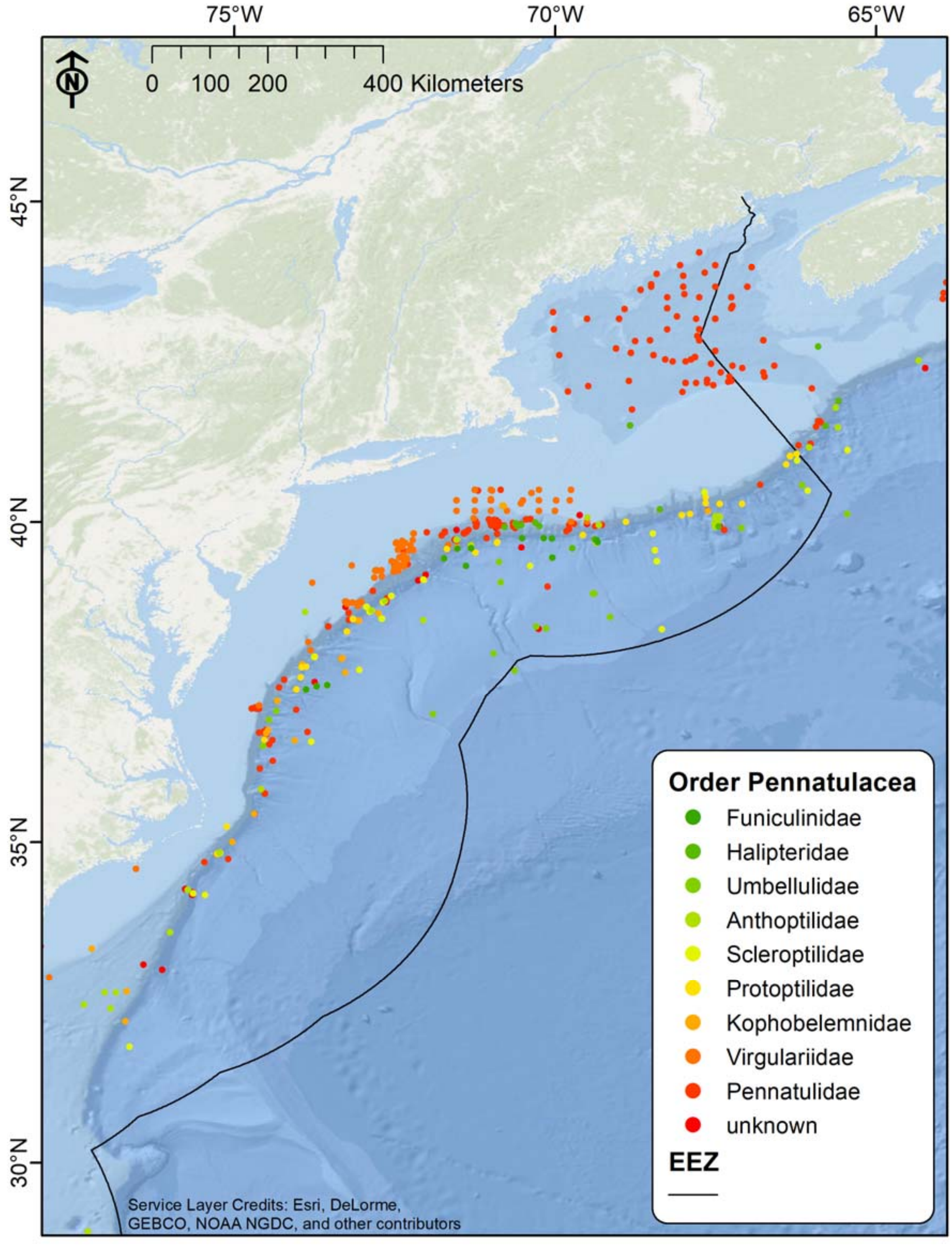
Map 2. *Locations of stony corals (Order Scleractinia) recorded in the National Deep-Sea Coral and Sponge Database (as of October 2017).*



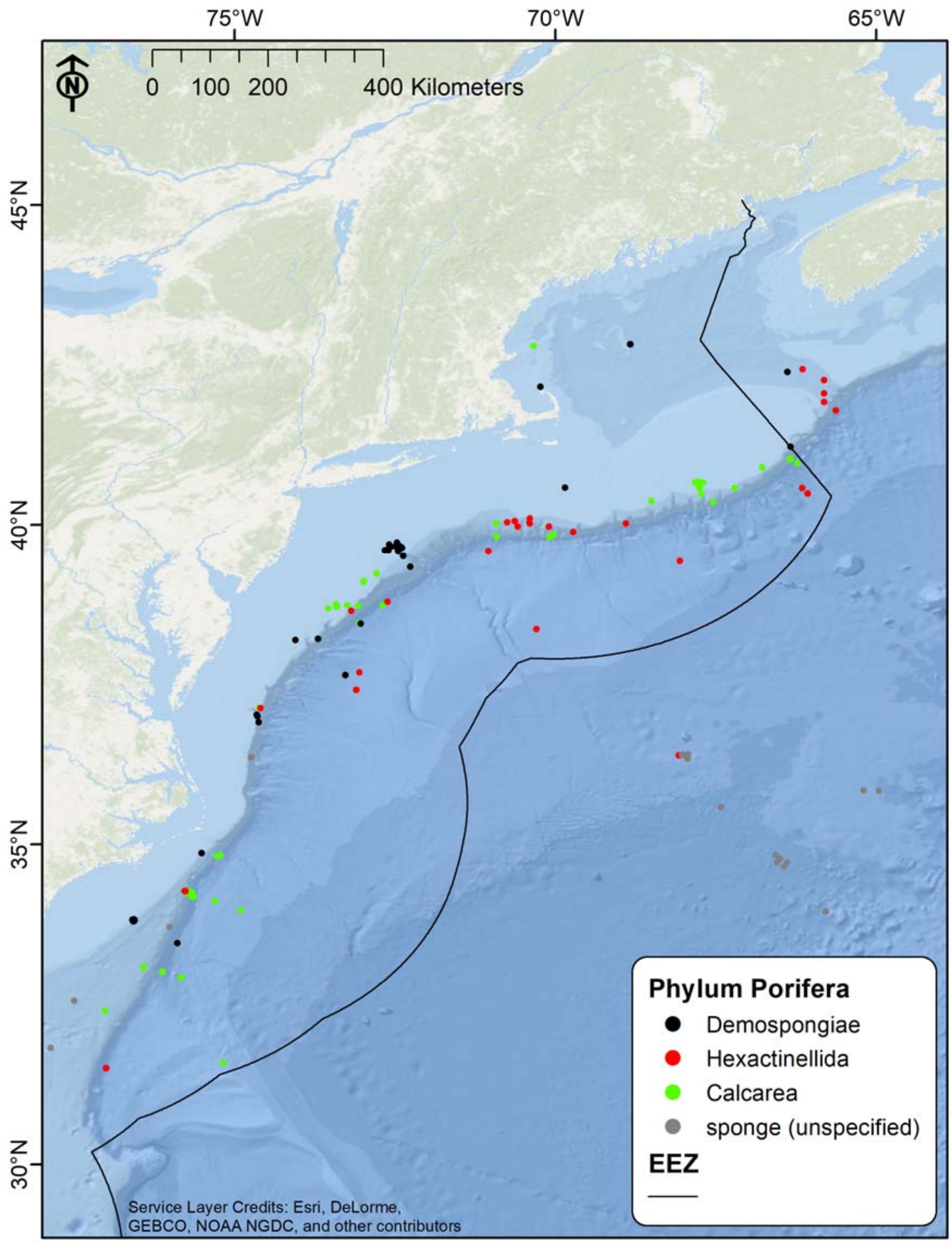
Map 3. *Locations of soft corals (Order Alcyonacea) recorded in the National Deep-Sea Coral and Sponge Database (as of October 2017).*



Map 4. *Locations of gorgonians (Order Alcyonacea, in part – formerly Order Gorgonacea) recorded in the National Deep-Sea Coral and Sponge Database (as of October 2017).*



Map 5. *Locations of sea pens (Order Pennatulacea) recorded in the National Deep-Sea Coral and Sponge Database (as of October 2017).*



Map 6. *Locations of sponges (Phylum Porifera) recorded in the National Deep-Sea Coral and Sponge Database (as of October 2017). Although sponges occur throughout the region, observations have not been systematically recorded and organized, so records in the database are currently limited.*