Deep Sea Corals

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5.1. SUMMARY

Deep sea corals are benthic invertebrates known to inhabit cold and deep waters throughout the globe, including the Atlantic waters offshore of the State of New York. Many are slow growing, long-lived, and exhibit complex, branching forms of growth that, while providing valuable habitat for other species, also makes them particularly susceptible to damage from fishing gear and other anthropogenic impacts. Within the New York State offshore study area there are 5,619 records of known deep sea coral locations within the deep sea coral geodatabase of NOAA's Deep-sea Coral Research and Technology Program (DSCRTP). Of these, 4,625 are of sea pens and the remaining 994 are stony corals, true soft corals, or gorgonians. The two most abundant species of sea pens are typically found in the soft sediments on the continental shelf. Most of the stony corals in this region are solitary organisms and are often found on soft substrates as well. Many of the true soft corals and gorgonians were typically found on gravel and rocky outcrops around the continental slope. Several species are found around Hudson Canyon (Figure 5.1); there are very few records from the literature of deep sea corals within the Canyon itself.

*Figure 5.1 White sea pens (*Stylatula elegans*) on muddy sand from 119 m on the outer continental shelf near Hudson Canyon (left). Solitary hard coral (*Dasmosmilia lymani*) on shelly sand from 108 m on the rim of Hudson Canyon (right). Photo credit: P.C. Valentine, USGS.*

We have a very incomplete picture of deep sea coral distribution and abundance in the northeastern U.S. region and offshore of New York, and the overall quantity and quality of deep sea coral habitat is unknown. There is also a dearth of information on their natural history, as well as difficulties with their taxonomy. Deep sea corals in this region face a range of anthropogenic threats from fishing, gas and oil drilling, and ocean acidification due to global warming.

Obviously, in order to better preserve and protect deep corals and deep coral habitat off the northeastern U.S. and offshore of New York, there needs to be: 1) an increased mapping and survey effort; 2) more basic research on deep coral taxonomy, life history, habitat requirements, species associations, etc.; and finally, 3) quantification on the susceptibility of deep corals to anthropogenic impacts. There are currently efforts underway, under the auspices of the New England Fishery Management Council (NEFMC), in coordination the Mid-Atlantic Fishery Management Council (MAFMC), to protect deep sea corals within the New York State offshore study area. Several approaches to management and conservation are being evaluated and the DSCRTP and NOAA's National Marine Fisheries Service (NMFS) Northeast Fisheries Science Center (NEFSC) will be conducting a three year regional investigation into deep sea coral distribution, biology, and ecology from fiscal year (FY) 2013 through FY2015.

5.2. INTRODUCTION

Deep sea corals are benthic invertebrates known to inhabit cold and deep waters throughout the globe, including the Atlantic waters offshore of the State of New York. While considerable attention has been given to tropical and subtropical corals and coral reefs, deep sea corals have only recently been researched and managed for

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their habitat value. Unlike shallow water corals, deep sea corals can be found in cold water habitats throughout the globe in a wide range of depths. Deep sea corals can be found from near the surface to about 3,000 m depth, although NOAA generally defines them as occurring >50 m on continental shelves, slopes, canyons, and seamounts. Deep sea corals are suspension feeders, but unlike most tropical and subtropical corals, do not require sunlight and do not have symbiotic algae (zooxanthellae) to meet their energy needs. Deep sea corals can occur as small, solitary individuals or as structure-forming corals that provide vertical structure above the seafloor that can be utilized by other species; the latter includes both branching corals that form a structural framework (e.g., reefs) as well as individual branching coral colonies. Because deep sea corals are slow-growing, long-lived, and often have complex, branching forms of growth, they are highly susceptible to anthropogenic impacts (such as from fishing gear). These life history traits also compromises their recovery from disturbances over short time periods.

Deep sea corals in the northeastern U.S. belong to three major taxonomic groups (Figure 5.2). There are the Hexacorals (or Zoantharia), which include the hard or stony corals (Scleractinia); the Ceriantipatharians which includes the black and thorny corals (Antipataria), and finally there are the Octocorals (or Alcyonaria), with flexible, partly organic skeletons that include the true soft corals (Alcyonacea), gorgonians (Gorgonacea or sea fans and sea whips), and sea pens (Pennatulacea). Scleractinians identified in the northeastern U.S. number 16 species, Anitpatharians number possibly four or perhaps more species, Alcyonaceans number nine species, Gorgonaceans number 21 species, and Pennatulaceans number 21 species. Among all three groups, there appear to be a suite of species (see below) that occurs at depths of less than 500 m (shelf and upper slope), and a separate suite that occurs at depths greater than 500 m (lower slope and rise). One species of hard coral and one alcyonacean occur in water less than 50 m deep.

Phylum	Class	Subclass	Order	Family (# species)
Cnidaria	Anthozoa (true corals and sea pens)	Ceriantipatharia	Antipatharia (black corals)	Antipathidae (1?) Leiopathidae (1?) Schizopathidae (2?)
		Hexacorallia (=Zoantharia) (true corals)	Scleractinia (stony corals)	Caryophylliidae (8) Dendrophylliidae (2) Flabellidae (4) Fungiacyathidae (1) Rhizangriidae (1)
		Octocorallia (=Alcyonaria) (octocorals)	Alcyonacea (soft corals)	Alcyoniidae (3) Clavulariidae (2) Nephtheidae (4)
			Gorgonacea (sea fans and sea whips)	Acanthogorgiidae (1) Anthothelidae (1) Chrysogorgiidae (4) Isididae (4) Paragorgiidae (1) Paramuriceidae (4) Primnoidae (6)
			Pennatulacea (sea pens and sea pansies)	Anthoptilidae (3) Funiculinidae (1) Halipteridae (1) Kophobelemnidae (3) Pennatulidae (3) Protoptilidae (3) Renillidae (1) Scleroptilidae (2) Ombellulidae (2) Virgulariidae (2)

Figure 5.2. Deep sea coral taxonomy for those species found in the northeastern U.S. from Maine to Cape Hatteras including four seamounts (Bear, Physalia, Mytilus, and Retriever) off of Georges Bank that lie within the Exclusive Economic Zone (EEZ).

5.2.1. Studies of Deep Sea Corals in the Northeast Region

Off the northeastern U.S., deep sea corals have been noted since the surveys of Verrill in the 19th century (Verrill, 1862; 1878a, b; 1879; 1884) and as fisheries bycatch since that period. Theroux and Wigley (1998) described the distribution of deep sea corals in the northwest Atlantic, based on samples taken from 1956-1965. They often do not distinguish between taxonomic groups; e.g., stony corals such as *Astrangia* sp. and *Flabellum* sp. are lumped together with the various types of anemones in the subclass Zoantharia. Theroux and Wigley (1998) also discussed the soft corals, gorgonians, as well as the sea pens. They were present along the outer margin of the continental shelf and on the slope and rise, and were sparse and patchy in all areas, particularly in the northern section. Theroux and Wigley (1998) found that they were not collected in samples taken at < 50 m in depth, and were most abundant between 200-500 m. Identified species include gorgonians, such as *Acanella* sp., *Paragorgia* *arborea*, and *Primnoa reseda* (now *resedaeformis*, see Cairns and Bayer [2005]) and the soft coral *Alcyonium* sp. Gorgonians and soft corals were collected from gravel and rocky outcrops (Theroux and Wigley, 1998).

Watling and Auster (2005) noted two distinct distributional patterns for the gorgonians and soft corals in the northwest Atlantic. Most are deepwater species that occur at depths > 500 m; these include species of gorgonians in the genera *Acanthogorgia*, *Acanella*, *Anthothela*, *Lepidisis*, *Radicipes*, and *Swiftia*, and soft corals in the genera *Anthomastus* and *Clavularia*. Other species occur throughout shelf waters to the upper continental slope and include the gorgonians *P. arborea*, *P. resedaeformis*, and species in the genus *Paramuricea*. Both *P. arborea* and *P. resedaeformis* are considered widespread off the northeastern U.S; *P. resedaeformis* has been reported south to off Virginia Beach, Virginia. The majority of records for *Acanthogorgia armata*, *P. arborea*, and *P. resedaeformis* come from Lydonia, Oceanographer, and Baltimore submarine canyons.

Dr. Barbara Hecker and her colleagues surveyed the deep sea corals and epibenthic fauna of the continental margin and several canyons off the northeastern U.S. in the 1980s via submersible and towed camera sled (Hecker et al., 1980, 1983). Corals were denser and more diverse in the canyons, and some species, such as those restricted to hard substrates, were found only in canyons while the soft substrate types were found both in canyons and on the continental slope (Hecker and Blechschmidt, 1980). For a complete discussion of Hecker's and others' surveys and research on deep sea corals as well as a thorough review of deep sea coral presence and distribution in the northeastern U.S., see Packer et al. (2007).

In the Mid-Atlantic Bight, many of the topographic features characteristic of other deep sea coral habitats are absent. The relatively small amount of hard substrate in this area occurs in conjunction with submarine canyons or are artificial reefs or shipwrecks. The main physiographic feature off of New York State is the Hudson Shelf Valley and Canyon, extending from the inner-continental shelf, at about the 40 m isobath, onto the continental slope. Sediments over the Mid-Atlantic shelf are fairly uniformly distributed, and are primarily composed of sand, with isolated patches of coarse-grained gravel and fine-grained silt and mud deposits (Stevenson et al., 2004). Deep sea corals that grow on soft bottom habitats (e.g., sea pens, some stony corals) are more common here than in other U.S. regions, especially on the shelf. Deep sea corals have been seen on the shelf around Hudson Canyon and in the head of the Canyon (discussed below).

Although the mid-Atlantic shelf is mostly soft bottom and devoid of major structure forming deep sea corals, in the relatively shallow nearshore region off Delaware and Maryland there are patch areas of hard bottom containing significant stands of the sea whip *Leptogorgia virgulata* (Gorgoniidae), which may be a northern range extension for this species. These hard bottom areas include natural rocky bottom as well as wrecks and artificial reefs, at depths as little as 8 m for the wreck/artificial reef areas, and can be less than 16 km from shore. These "shallow-dwelling" deep sea corals may not fit into the standard definition of deep sea corals, but these habitats are all known to support high densities of species that prefer structure, such as black sea bass (*Centropristis striata*) and tautog (*Tautoga onitis*), as well as flounder, so they may be important habitats in need of protection. Surveys have not yet been conducted to see if similar nearshore coral patch habitat occurs adjacent to other mid-Atlantic states like New York, but it seems unlikely that it would be restricted to Maryland and Delaware.

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

The environmental parameters of Mid-Atlantic Bight deep sea corals are also unknown, but Leverette and Metaxas (2005) developed predictive models to determine areas of suitable habitat for *P. arborea* and *P. resedaeformis* along the Canadian Atlantic continental shelf and shelf break. Several environmental factors including slope, temperature, chlorophyll *a*, current speed and substrate were included in the analysis. Their results showed that the habitat requirements differed between the two gorgonians. *P. arborea* occurred predominantly in steeply sloped environments and on rocky substrates, while the habitat for *P. resedaeformis* was more broadly distributed and located in areas with high current speed, rocky substrates and a temperature range between 5-10°C.

There have been some more recent, targeted surveys off of New England using trawls and remotely operated vehicles (ROVs). In 2003, 2004, and 2005, surveys were conducted of several seamounts in the New England and Corner Rise Seamount chains (the latter is approximately 400 km to the east of the New England Seamount chain, and nearly midway between the east coast of the U.S. and the Mid-Atlantic Ridge) funded by NOAA's Office of Ocean Exploration and National Undersea Research Program. The cruises were multidisciplinary in nature, but the goals included studying the distribution and abundance of deep corals relative to the prevailing direction of currents; collecting specimens for studies of reproductive biology, genetics, and ecology; and studying species associations.

5.2.2. The Role of Deep Sea Corals as Habitat

Deep sea corals provide habitat for other marine life, increase habitat complexity, and contribute to marine biodiversity (Lumsden et al., 2007). The role of deep sea corals as possible habitats for fishes has been studied in other regions. The corals in the *Primnoa*, *Lophelia*, and *Oculina* genera have been the most studied. Several studies have documented that certain fish commonly occur in the vicinity of corals more often than in areas without corals. In the northwest Atlantic, this has been noted for redfish in the Northeast Channel near Georges Bank (Mortensen et al., 2005). Redfish may take advantage of structure on the bottom as a refuge from predation, as a focal point for prey, and for other uses. However, in a survey of habitats in the Jordan Basin in the Gulf of Maine containing coral assemblages (primarily from the genera *Paragorgia*, *Paramuricea*, and *Primnoa*), Auster (2005) found that densities of redfish were not significantly different between dense coral habitats and dense epifauna habitats. However, the density of redfish in these two habitats was higher than in the outcrop-boulder habitat containing sparse epifauna. While this shows that a habitat without deep corals can support similar densities of fish to a habitat containing corals, Auster (2005) states that it is the actual distribution of each habitat type throughout a region that will ultimately determine the role such habitats play in the demography of particular species and communities. Deep sea coral habitats are fairly rare in the Gulf of Maine, but boulder-cobble habitats containing dense epifauna are not. Auster (2005) suggests that deep sea corals do have some effect on the distribution and abundance of fishes, but by themselves may not support high density, unique or high diversity fish communities. The corals do provide important structural attributes of habitat, but may not be functionally different than structures provided by other dense epifaunal assemblages.

There are few data available about invertebrate species associations with deep corals off the northeastern U.S. More is known about the species associations of deep corals and invertebrates from other regions. However, recent research suggests that deep corals are important components of benthic communities, providing structure and refuge for various other invertebrate species (e.g., Lumsden et al., 2007; Mosher and Watling, 2009).

5.3. OBJECTIVES

This chapter will focus on describing the distribution of those deep sea corals found off New York State, from nearshore to the continental slope, based on historical surveys and databases. When examining the information available on the distribution of corals in the area offshore from New York State it is important to note that the historical surveys are far from comprehensive and the taxonomy and identification of many of these deep sea corals are open to question, so the presence, distribution, and abundance of these deep sea corals should be interpreted with caution. The national DSCTRP and NEFSC will be conducting a three year intensive investigation on the distribution, ecology and status of deep sea corals off the northeastern U.S. beginning in FY2013.

5.4. METHODS

The primary source of data used for this analysis was the Cold-water Coral Geographic Database developed by the USGS with support from the DSCRTP. The USGS Cold-Water Coral Geographic Database (CoWCoG) consolidates the known locations of deep sea corals in the eastern US and provides a tool for researchers and managers interested in studying, protecting, and/or utilizing cold-water coral habitats in the Gulf of Mexico and western North Atlantic Ocean. The database makes information about the locations and taxonomy of deep sea corals available to the public in an easy-to-access form while preserving the scientific integrity of the data. The database includes over 1,700 entries, mostly from published scientific literature, museum collections, and other databases (Scanlon et. al., 2010).

This database was supplemented with additional records provided by the Watling et al. database (2003), the Theroux and Wigley database (1998), the Smithsonian Institution's National Museum of Natural History and NMFS NEFSC's National Systematics Lab, the archives of the former National Undersea Research Center, surveys by Dr. Barbara Hecker and her colleagues (e.g., Hecker et al., 1980, 1983), Peter Auster of the University of Connecticut, and the NEFSC. Many of these records were obtained through a data mining project sponsored by the DSCRTP. For the complete list of northeast deep sea coral references, see Packer et al. (2007). It should be noted that the distribution maps presented in this chapter show presence only; i.e., they only describe where deep corals that could be identified were observed or collected. Since all areas have not been surveyed and since some specimens were not identified, the true distributions of many of these species remain unknown. However, these combined databases represent the best available georeferenced data on the presence of deep corals in the northeast region.

5.5. RESULTS

There are a total of 5,619 records of known deep sea corals for the study area (Table 5.1). Of these, 4,625 are for sea pens (Pennatulacea; Figure 5.3). The most common and fairly widespread species found in the deeper parts of the continental shelf are *Pennatula aculeata* (common sea pen) (Langton et. al., 1990) and *Stylatula elegans* (white sea pen). *P. aculeata* has been reported down to depths of 3,300 m. *S. elegans* is abundant on the mid-Atlantic coast outer shelf (Figure 5.3) and has been found as deep as 800 m. Unlike most other deep sea corals, sea pens live in muddy or other soft sediments, anchored in place by a swollen, buried peduncle. Some species are capable of retracting part or the entire colony into the sediment when disturbed. Observation suggests that sea pens are resistant to physical disturbance, although growth and population dynamics have not been investigated, but because of their ubiquity they are generally not of concern for biodiversity or ecosystem management.

Table 5.1: Number of deep sea coral records in the study area as a total and by taxonomic order.

TAXONOMIC ORDER	COUNT
All Deep Sea Corals	5,619
Pennatulacea	4,625
Scleractinia	338
Alcyonacea	365
Gorgonacea	291

The remaining 994 records are observations of hard and soft corals, mostly from the shelf and slope. There are 338 records of stony corals (Scleractinia; Figure 5.4). These observations occur between 14 and 2,654 meters depth. Most of the stony corals in this region are solitary organisms and are often found on soft substrates. Species observed included *Dasmosmilia lymani* (Figure 5.1), *Flabellum alabastrum*, and *Astrangia* sp. (most likely *Astrangia poculata*, which can occur in very shallow water, at depths of only a few meters).

There are 365 records of true soft corals (Alcyonacea; Figure 5.5). These observations were made between 30 meters and 3,506 meters, with notable concentrations occurring at the shelf edge between 100 and 200 meters and again between 2,000 and 3,000 meters depth. Species observed included, *Capnella florida*, *Anthomastus grandiflorus*, *Anthomastus agassizii*, and *Gersemia fruticosa*. *Gersemia rubiformis* is very numerous in nearshore records throughout the northeast.

There are 291 records of Gorgonians occurring between 310 and 3,206 meters, predominantly deeper than 600 meters (Figure 5.6). Species observed included *Acanella arbuscula*, *Acanthogorgia armata*, *Anthothela grandiflora*, *Lepidisis caryophylia*, *P. arborea*, *Paramuricea grandis*, *P. resedaeformis*, *Swiftia casta*, and *Radicipes gracilis*.

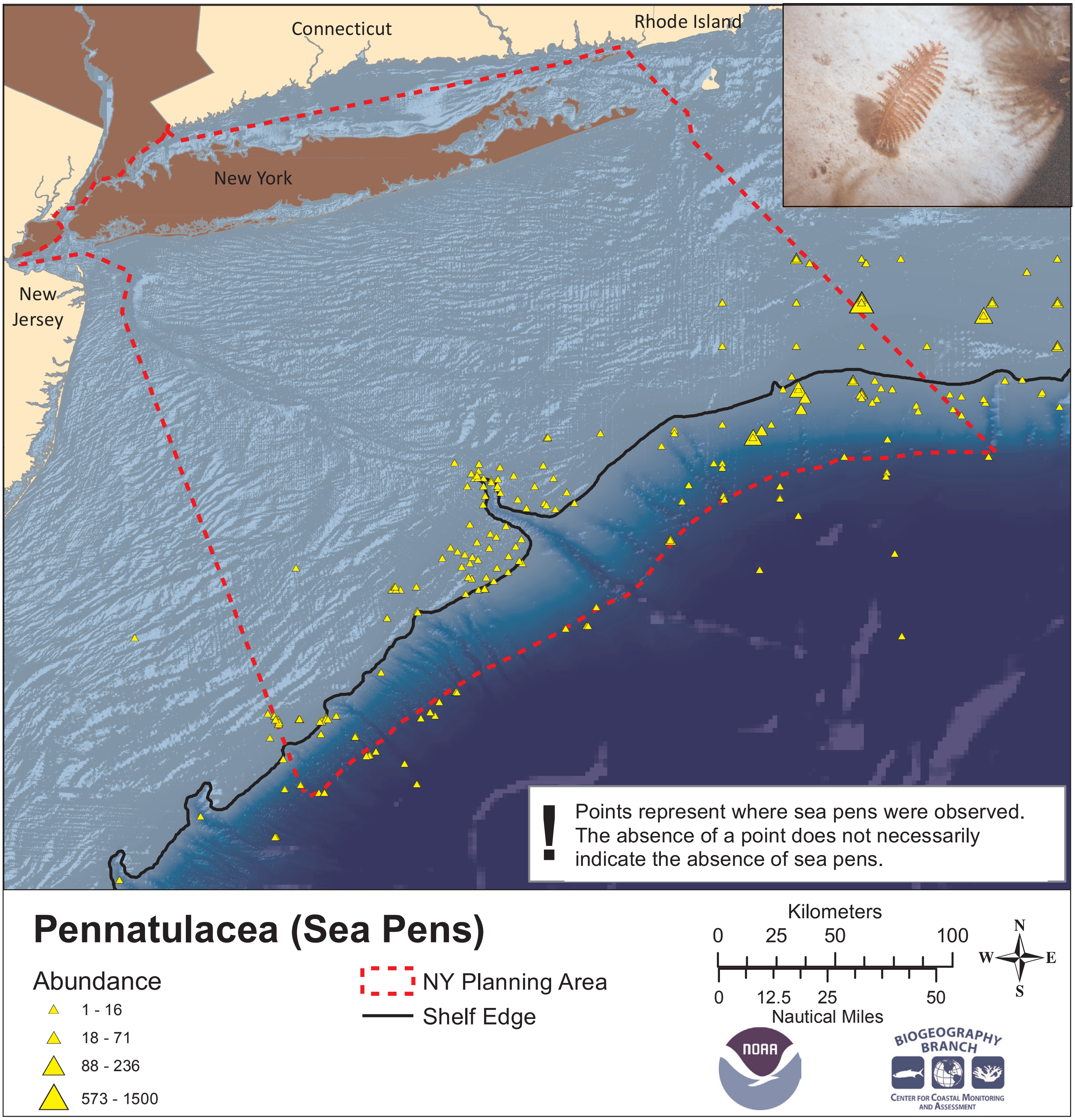

Figure 5.3. Observed Pennatulacea locations.

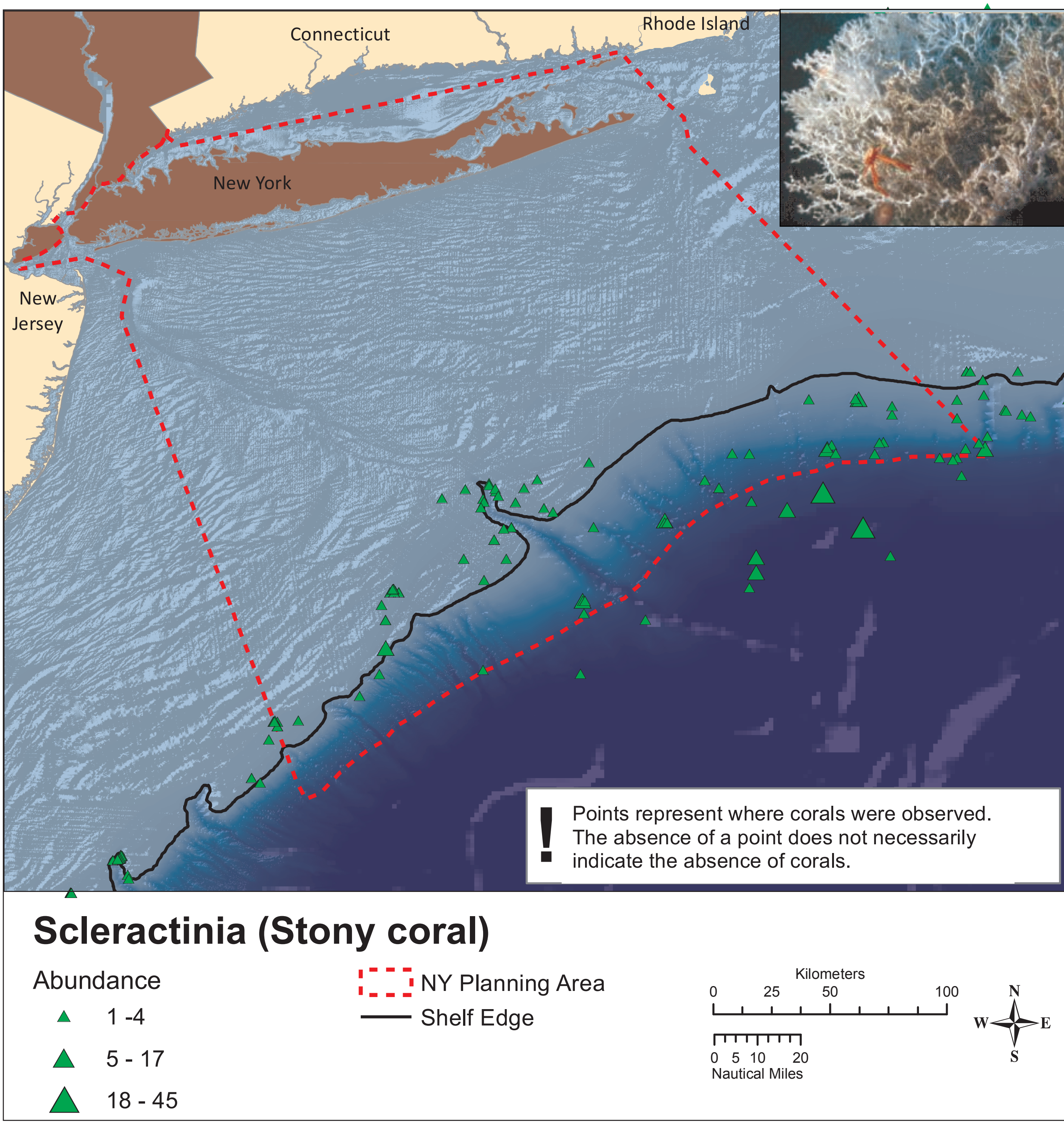

Figure 5.4. Observed Scleractinea locations.

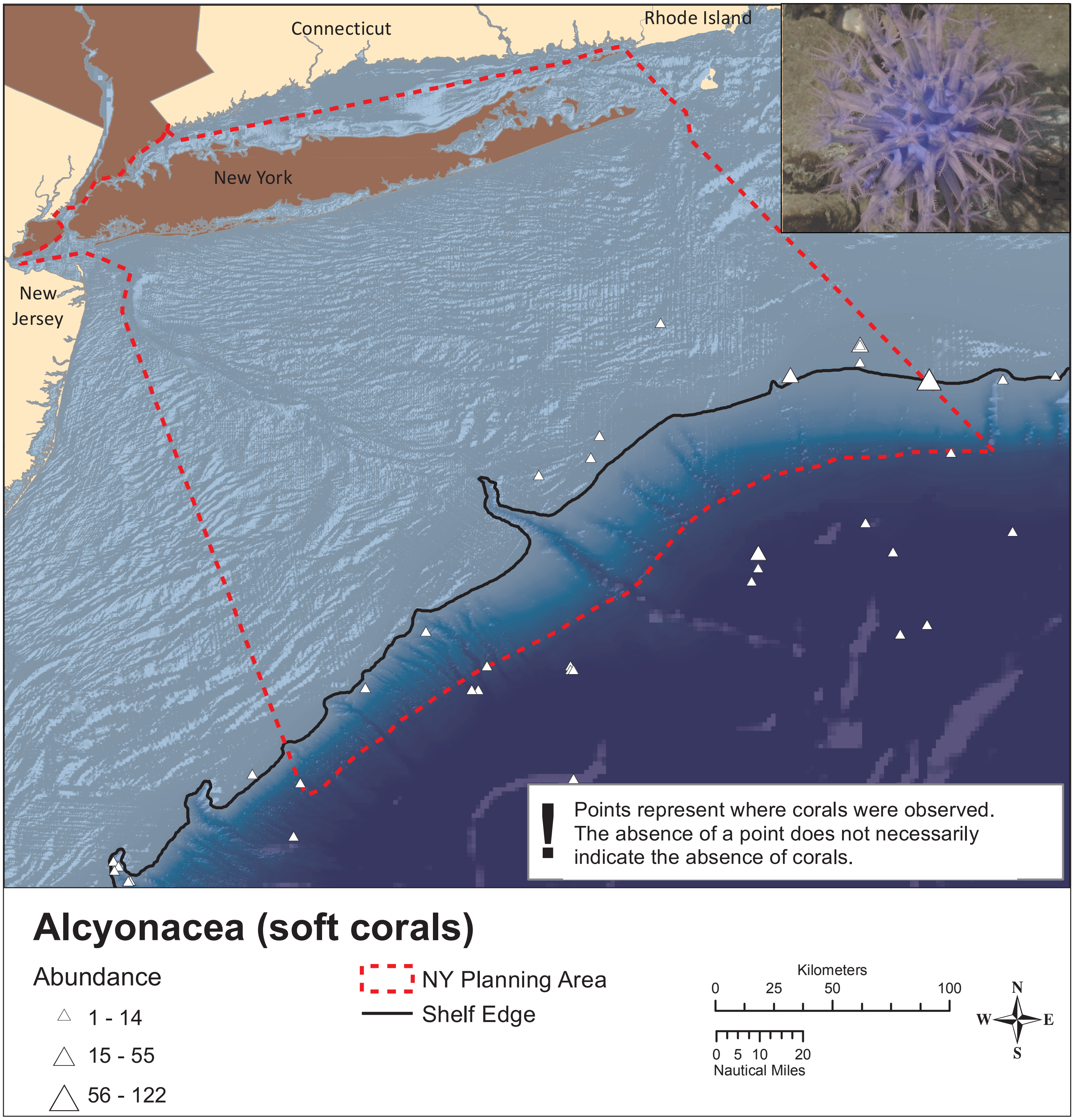

Figure 5.5. Observed Alcyonacea locations.

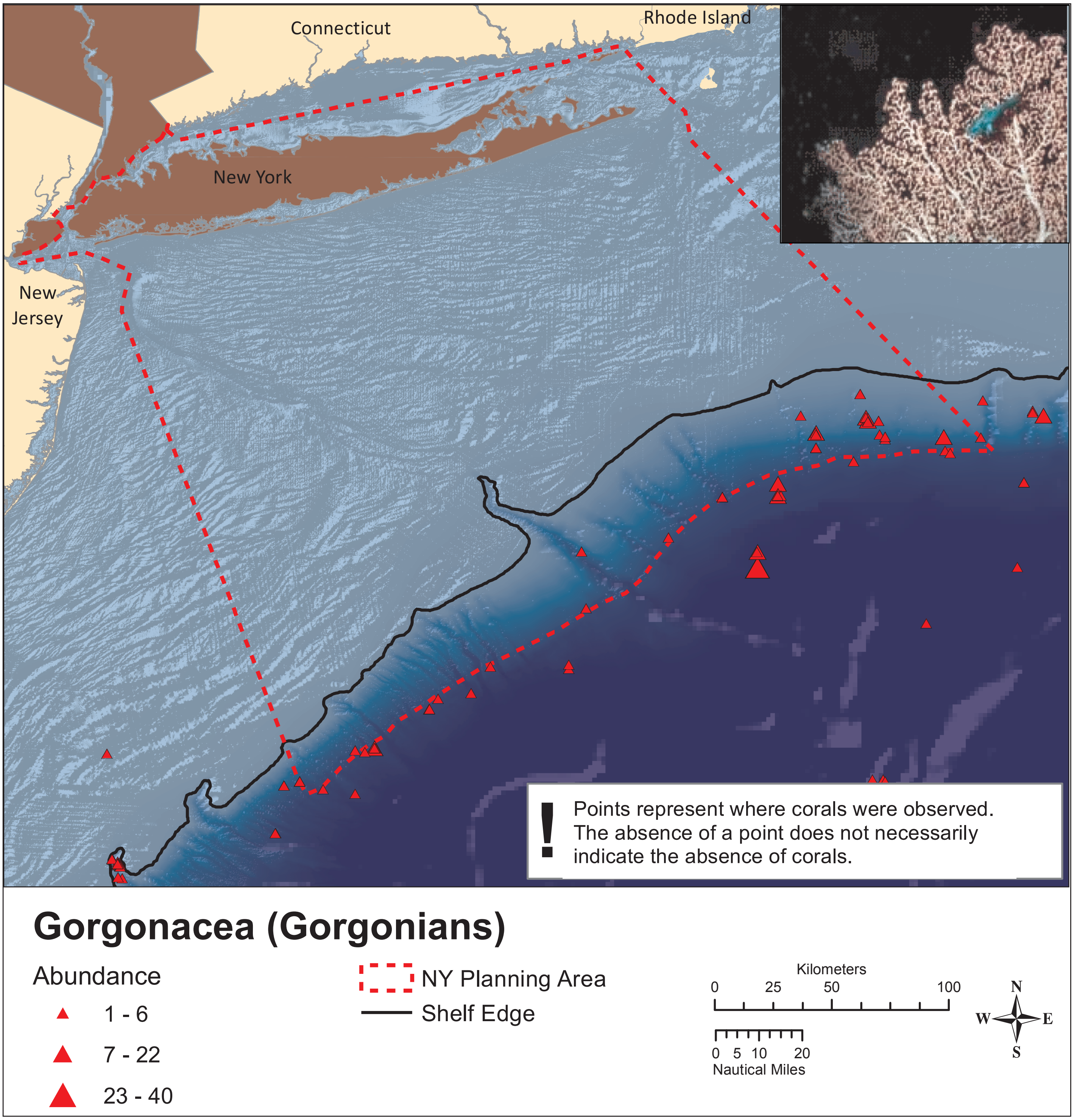

Figure 5.6. Observed Gorgonacea locations.

Hudson Canyon

Deep sea corals have been seen on the shelf around Hudson Canyon and in the head of the Canyon. For example, a survey by Guida[1] of benthic habitats on the shelf around Hudson Canyon in 2001, 2002, and 2004 found the solitary stony coral *D. lymani* at a number of sites at depths ranging from 100 to 200 m (Figure 5.7). They were particularly abundant, occurring in patches in a narrow band along the canyon's rim near its head at depths of 105-120 m; local densities within those patches exceeded 200 polyps m^2, but densities elsewhere were much lower. Other records of deep sea corals around Hudson Canyon can be found in Packer et al. (2007). However, the only evidence of deep corals occurring deep within the canyon itself comes from Hecker and Blechschmidt (1980), who found abundant populations of the soft coral *Eunephthya fructosa* (same as *G. fructosa*?), but only in the deeper portion of the canyon. This may be due to the predominance of soft substrate within the Canyon itself, although recent mapping surveys (Guida[1]) have found evidence of hard bottom areas that may serve as deep sea coral habitat.

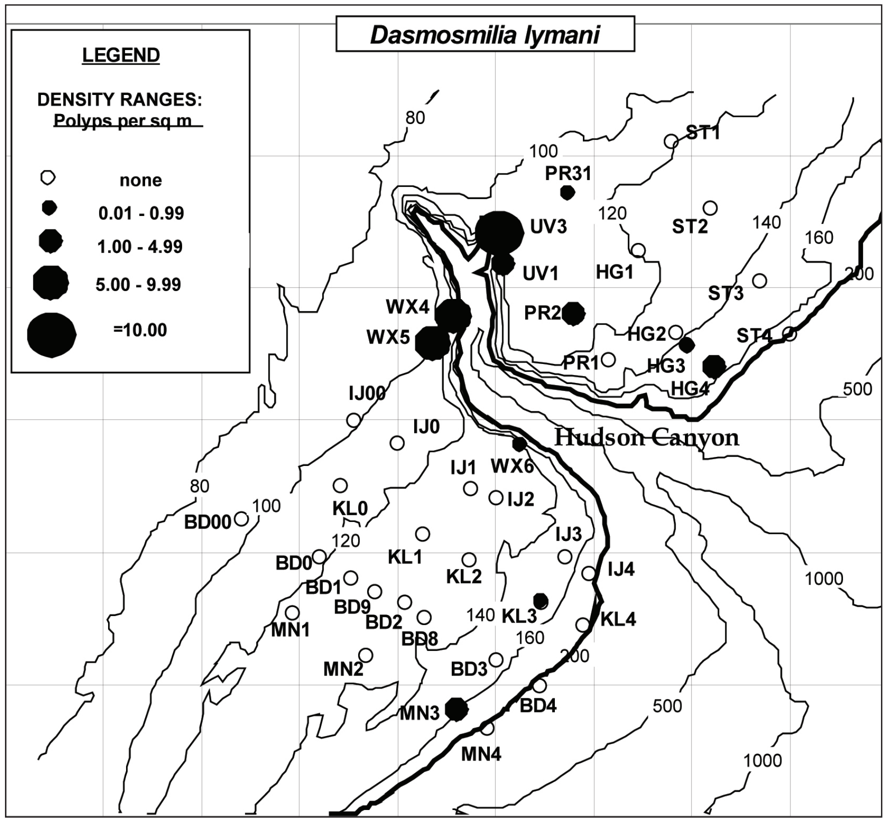

Figure 5.7. Distribution and approximate densities (polyps per square meter) of the solitary stony coral Dasmosmilia lymani *in samples from the Mid-Atlantic shelf around Hudson Canyon (Guida[1]). Data obtained from still photos and trawl samples taken during October and November 2001, 2002, and August 2004.*

In addition to deep sea corals, there are records of sponges around Hudson Canyon, a result of a single research effort by Guida[1]. Structure forming sponges are expected to play a similar role to deep sea corals by providing potential habitat for other species. Sponges were observed at 22 locations, with densities ranging from 0.1 to > 100/sq dm (Figure 5.8). An effort is currently underway to obtain and document records of sponge occurrences off the northeastern U.S. (e.g., from the Smithsonian Institution's database).

An additional map is included showing both deep sea corals and sponges in a single image. (Figure 5.9)

[1] Guida, V. 2004. Unpubl. data. NOAA, NMFS, NEFSC, James J. Howard Marine Sciences Laboratory, 74 Magruder Road, Sandy Hook Highlands, NJ 07732.

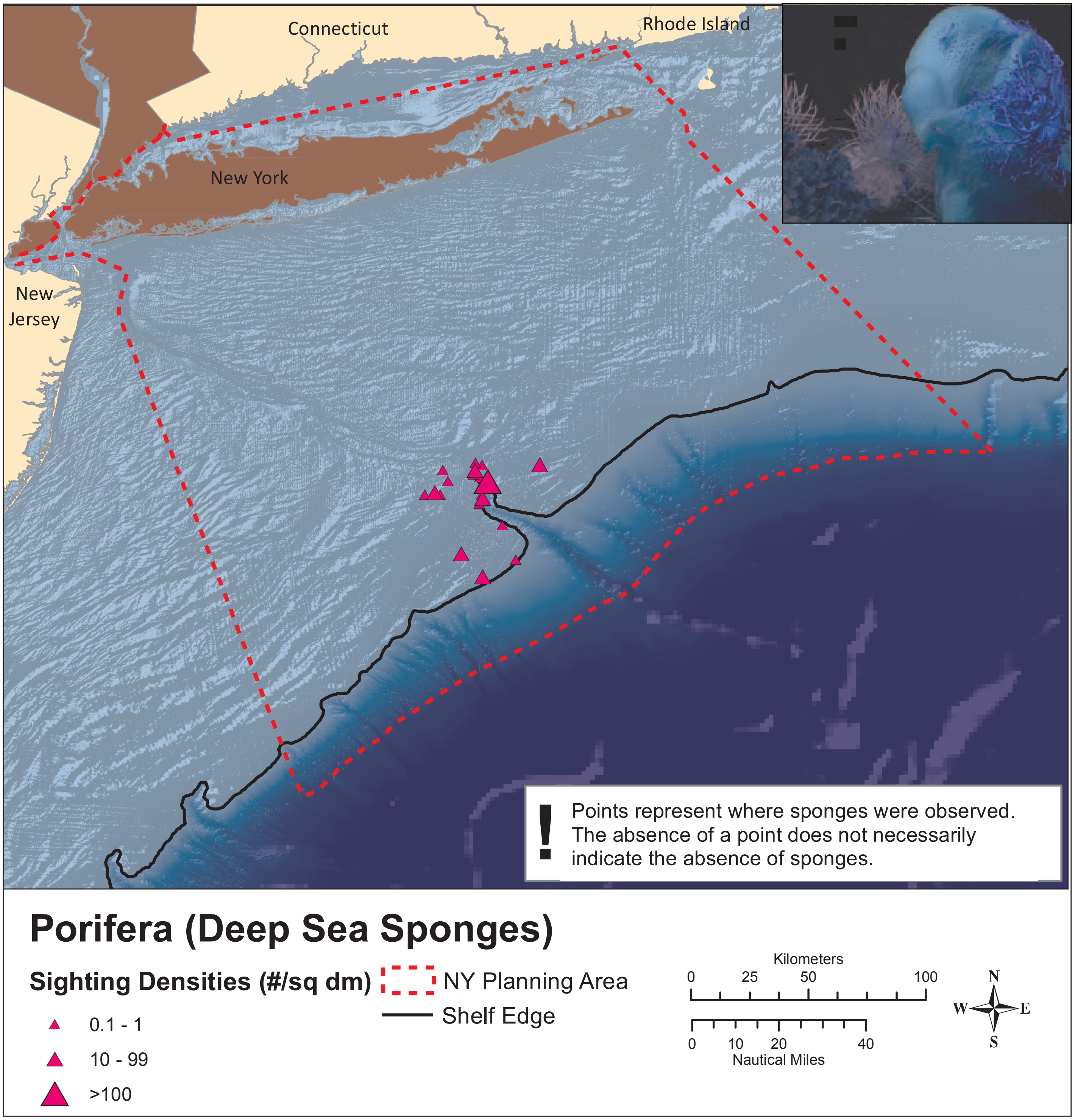

Figure 5.8. Observed deep sea sponge locations.

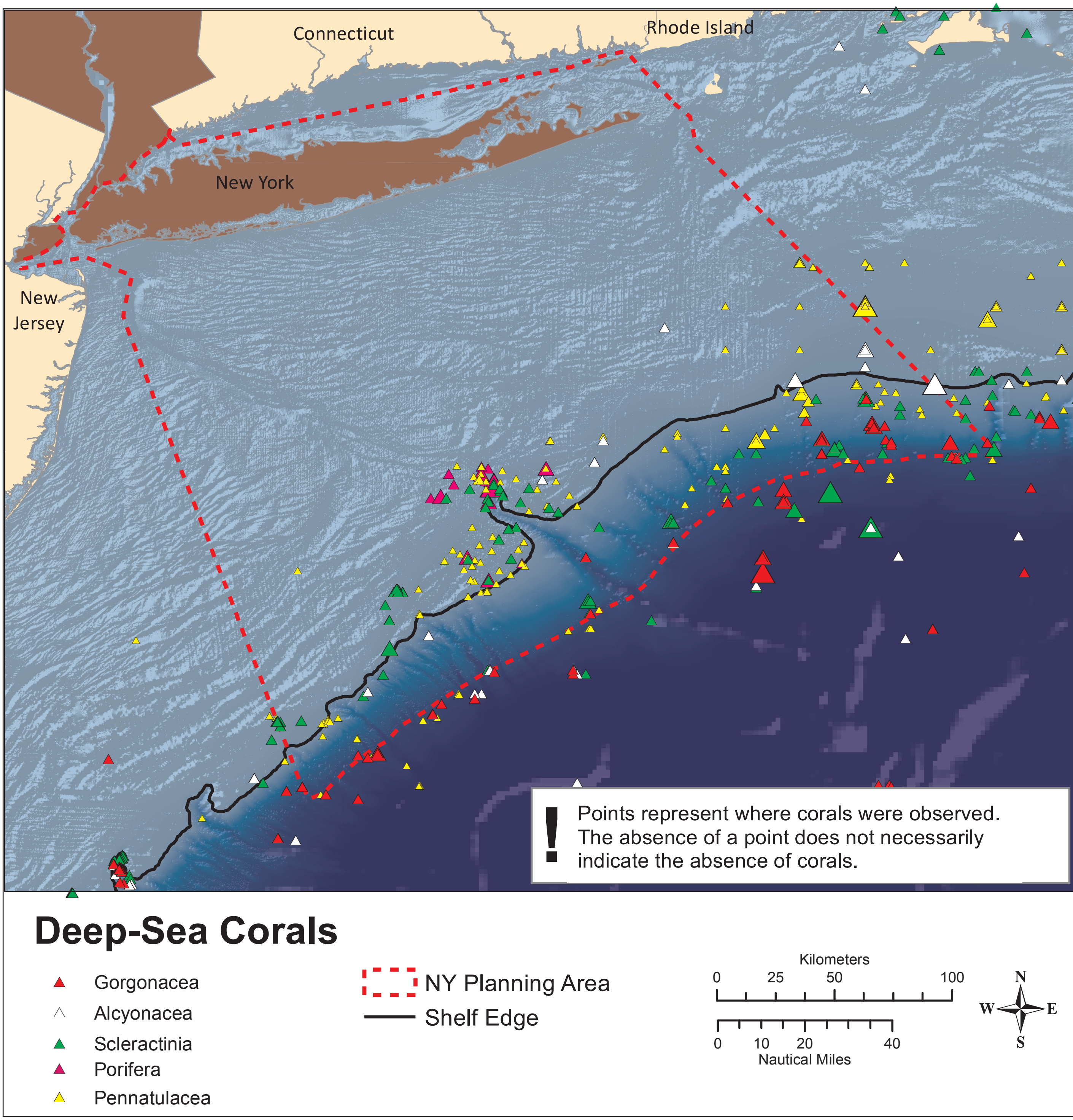

Figure 5.9. Observed deep sea coral and sponge locations.

<u>Northeast Region</u>
Our knowledge of the distribution of deep sea corals for the Northeast Region (Maine - North Carolina) is incomplete, so conclusions drawn from existing data should be considered preliminary. The known distribution of corals in the region is shown in Figure 5.10. Distribution of corals in the region is similar to the distribution found within the study area, with concentrations occurring on the shelf edge and shelf break.

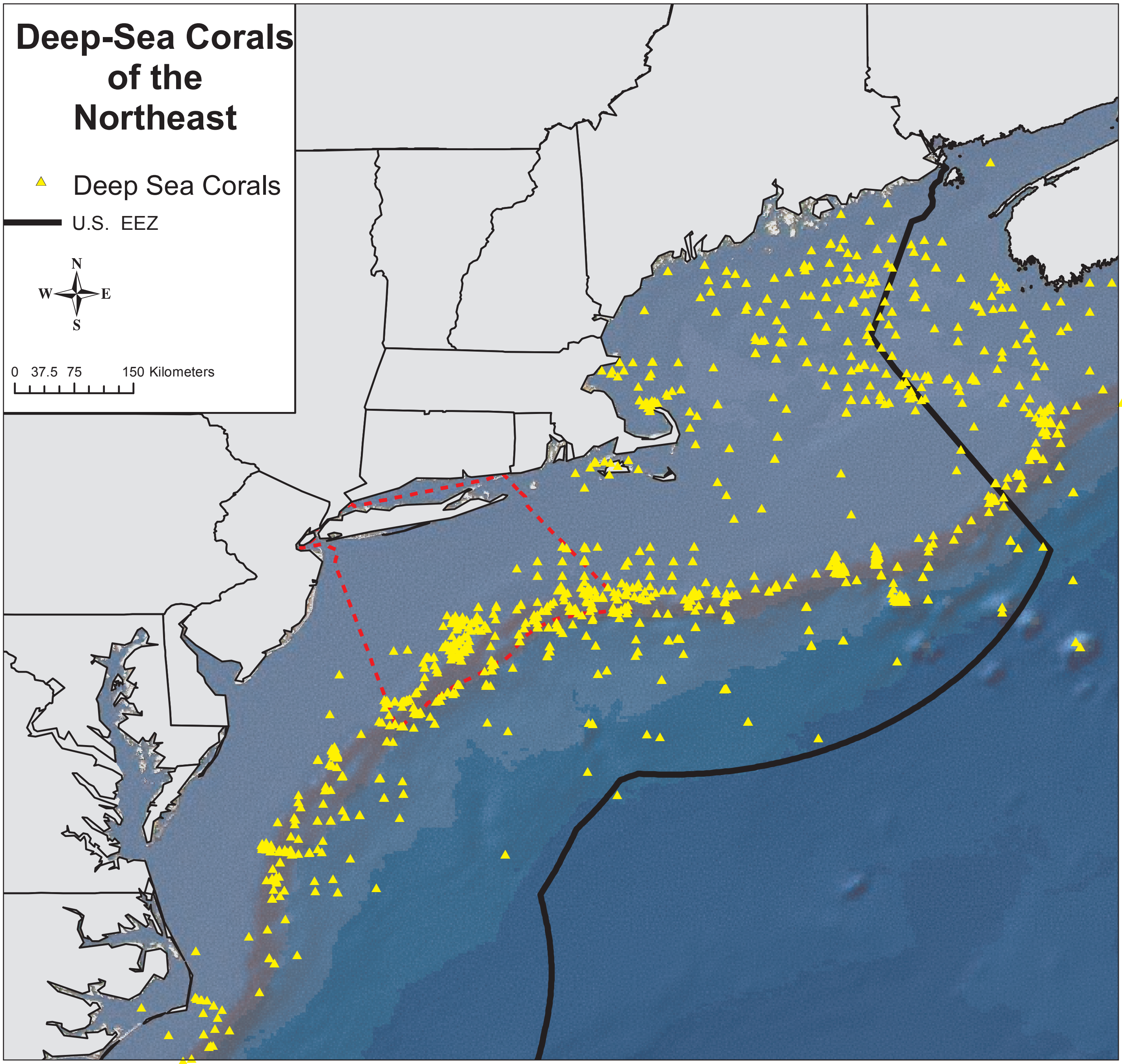

Figure 5.10. Known deep sea coral locations for the Northeast Region.

5.6. DISCUSSION

Deep sea corals provide habitat for other marine life, increase habitat complexity, and contribute to marine biodiversity, and their destruction could impact other marine species. Anecdotal data from surveys as well as reports from fishermen, who have brought corals up as bycatch since the 19th century, suggest that deep sea corals have become less common or their distributions have been reduced due to the impacts of bottom fishing (e.g., off New England); fishing has had significant effects on deep sea coral populations in other regions. Deep corals are especially susceptible to damage by fishing gear because of their often fragile, complex, branching form of growth above the bottom. Also, they grow and reproduce at very slow rates, with some estimates on the scale of hundreds of years. Recruitment rates may also be low, which makes their recovery from disturbances difficult over short time periods. Of the various fishing methods, bottom trawling has been found to be particularly destructive (e.g., Rogers, 1999; Hall-Spencer et al., 2001; Koslow et al., 2001; Krieger, 2001; Fosså et al., 2002; Freiwald, 2002).

The effects of current and historic fishing efforts on deep sea coral and coral habitats in the northeastern U.S. have not been quantified. The types of fishing gear used in the region include fixed gear, such as longlines, gillnets, and pots and traps, as well as trawls and dredges. Fixed gear can be lost at sea, where it can continue to damage corals. In Canada, longlines have been observed entangled in deep sea corals such as *Paragorgia* and *Primnoa* and may cause breakage (Breeze et al., 1997; Mortensen et al., 2005). Bottom trawling was found to have a larger impact on deep sea corals compared to longlining (e.g., damage to *Primnoa* off Alaska [Krieger, 2001]). The northeastern U.S. fisheries that have the highest likelihood of occurring near concentrations of known deep sea coral habitats (e.g., in canyon and slope areas) are the monkfish or goosefish and tilefish fisheries, and the red crab and offshore lobster pot fisheries.

Other potential threats to deep sea corals in this region include possible oil and gas drilling in the deeper parts of the shelf, and ocean acidification due to global warming. Deep sea coral communities may be uniquely vulnerable to changes in ocean chemistry associated with ocean acidification due to increased atmospheric CO_2 from the combustion of fossil fuels (Guinotte et al., 2006). The ocean acts as the largest net sink for CO_2, absorbing this gas from the atmosphere and then storing carbon in the deep ocean. Oceanic uptake of CO_2 drives the carbonate system to lower pH and lower saturation states of the carbonate minerals calcite and aragonite, the materials used to form supporting skeletal structures in many major groups of marine organisms, including corals (Kleypas et al., 2006). This change in ocean chemistry will reduce the ability of corals; i.e., stony corals, to lay down calcium carbonate skeletons (calcification). There is evidence that the rate of CO_2 increase in the deep ocean has been occurring at a pace double that of shallow waters and therefore the effect of ocean acidification on deep sea corals could be significant (e.g., Bates et al., 2002; Guinotte et al., 2006). The ability for organisms to calcify decreases in the deep ocean naturally with latitude, temperature, and pressure, causing an increased concern for deep sea corals in the near future. There are also areas in the ocean where a natural boundary, known as the 'saturation horizon', exists below which organisms may have difficulty forming calcium carbonate. This is due to the physical factors already mentioned that decrease calcification in the deep ocean, but as CO_2 levels increase the saturation horizon will become shallower. This would severely limit the distribution of deep sea corals in certain parts of the ocean (The Royal Society, 2005).

In 2005, NEFMC and MAFMC, with the NEFMC as the lead, approved the designation of Oceanographer and Lydonia Canyons (located off New England on the continental slope south of the Georges Bank fishing grounds; approximately 116 square nautical miles) as Habitat Closed Areas (HCA) and added these areas to the NEFMC's network of HCAs (or marine protected areas). These new HCAs are closed indefinitely to fishing with bottom trawls and bottom gillnets in order to minimize the impacts of the monkfish fishery on Essential Fish Habitat (EFH) in these deep sea canyons and on the structure-forming organisms therein, including deep sea corals. Veatch and Norfolk Canyons are also protected under the Tilefish Management Plan and are closed to bottom-tending gear. Recently, a working group of the NEFMC has developed a series of proposals for the designation of specific deep sea coral protection zones off the northeastern U.S. using the discretionary authorities under the Magnuson-Stevens Act Section 303(b). They have also developed a range of possible management options for those zones and suggestions for future research.

Areas where deep sea corals are present should be considered vulnerable marine ecosystems and efforts are underway to extend protection to these valuable natural resources. The NOAA Strategic Plan for Deep Sea Coral and Sponge Ecosystems encourages avoidance of adverse impacts of non-fishing activities on deep sea coral and sponge ecosystems. Impacts to deep sea corals and sponge ecosystems should be evaluated when considering off-shore development of energy facilities and infrastructure.

Packer et al. (2007) outline some of the research priorities for the deep sea corals in this region. To better preserve and protect them, first there needs to be increased mapping and survey efforts, and more basic research is needed on their taxonomy, life history, habitat requirements, water chemistry, species associations, etc. Predictive modeling for individual species of deep sea corals has assisted research and monitoring efforts in other regions (e.g., Davies and Guinotte, 2011) and is recommended for this region in order to support planning and management decisions. There needs to be a better understanding of how anthropogenic impacts (e.g., fishing, ocean acidification, oil and gas drilling) affect the deep sea corals of this region. As mentioned previously, the DSCRTP and NEFSC are planning to conduct deep sea coral fieldwork off the northeastern U.S., including the MAFMC and NEFMC regions, in 2013-15.

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