New England Fishery Management Council
50 WATER STREET | NEWBURYPORT, MASSACHUSETTS 01950 | PHONE 978 465 0492 | FAX 978 465 3116
C. M. "Rip" Cunningham, Jr., *Chairman* | Paul J. Howard, *Executive Director*

ESSENTIAL FISH HABITAT (EFH) OMNIBUS AMENDMENT

"DEEP-SEA CORALS OF THE NORTHEAST REGION: SPECIES, HABITATS AND PROPOSED CORAL ZONES, AND VULNERABILITY TO FISHING IMPACTS"

Draft: 03/28/12

Includes input from the following meetings: 10/17-18/11, 12/7/11, 1/12/12 (PDT); 1/24/12 (Advisory Panel/Committee)

This document was prepared by the following members of the NEFMC Habitat Plan Development team:

Michelle Bachman, NEFMC staff*
Nick Clifford, NEFMC staff
David Packer, NOAA NEFSC
David Stevenson, NOAA NERO
Peter Auster, UConn
Page Valentine, USGS
Kathryn Ford, MADMF

*Please forward any comments, questions, or suggestions to mbachman@nefmc.org

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1.0 Introduction

The reauthorized Magnuson Stevens Act grants Councils broad discretionary authority to close areas for coral protection. **The purpose of this document is to review the information available to support development of deep-sea coral alternatives in NEFMC's EFH Omnibus Amendment 2.** Specifically, this document:

- Summarizes the species diversity and known distribution of deep sea corals in the region, and lists coral species of particular conservation interest (section 2.0)
- Characterizes deep-sea coral habitats and coral distributions in specific areas, and identifies recommended coral protection zones (section 3.0)
- Reviews the scientific literature on the vulnerability of deep-sea corals to fishing impacts (section 4.0).

This information will form the basis for regional coral zone designations, and also inform the development of measures to minimize fishing impacts on corals in those zones. The management alternatives developed using these recommendations are summarized in the Deep-sea Coral Decision Document.

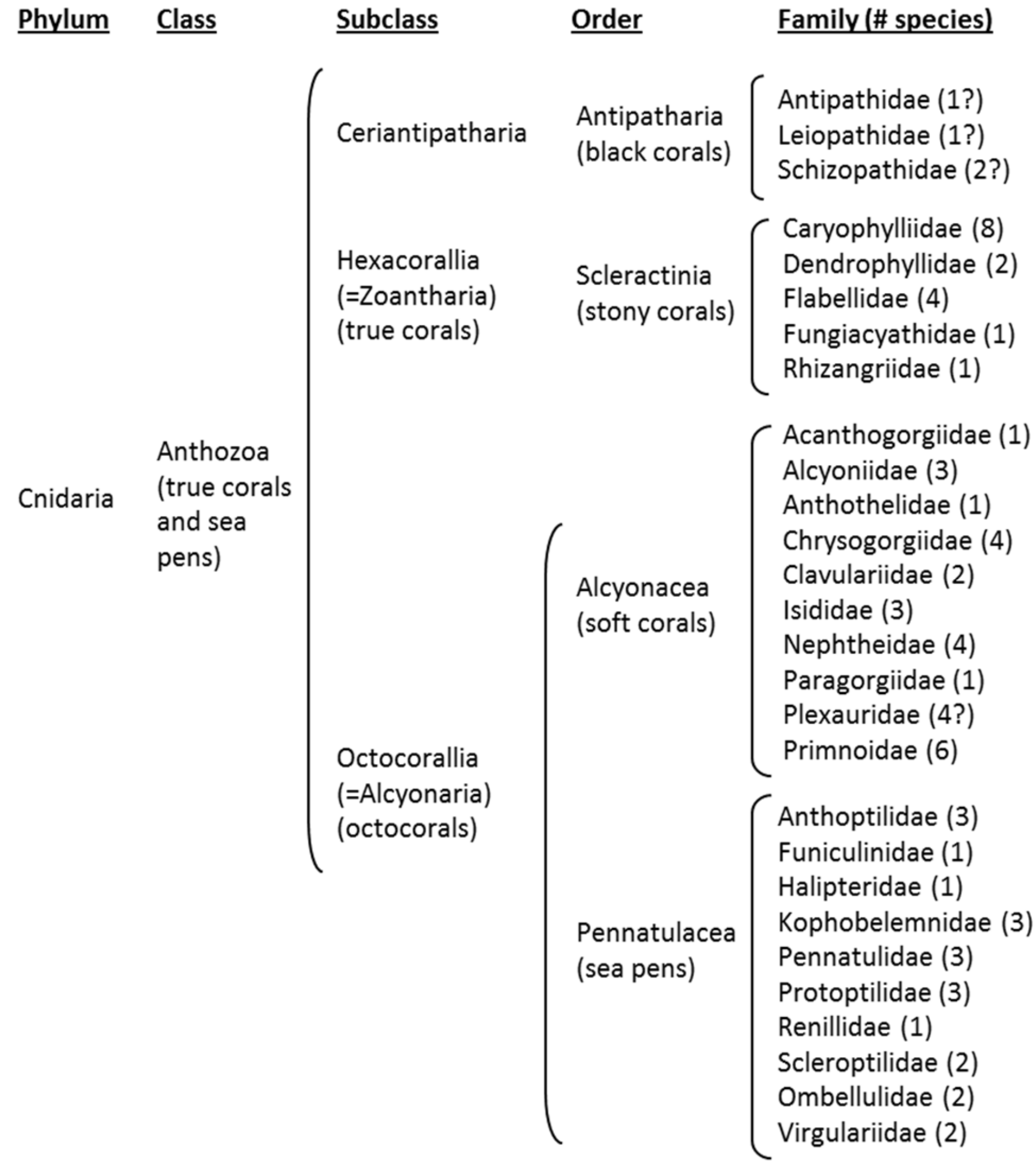
2.0 Deep-sea corals of the Northeast Region

Worldwide, deep corals can build reef-like structures or occur as thickets, isolated colonies, or solitary individuals, and often are significant components of deep-sea ecosystems, providing habitat (substrate, refugia) for a diversity of other organisms, including many commercially important fish and invertebrate species. They 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 corals can be found from near the surface to 6000 m depth, but most commonly occur between 50-1000 m on hard substrate (Puglise and Brock 2003), hence their "deep-sea" appellation.

2.1 Taxonomy

Cold-water or deep-sea corals in the northwest Atlantic are a diverse assortment of three Anthozoan subclasses (see Figure 1 for a diagram of coral taxonomy). The subclass Hexacorallia (Zoantharia) includes the hard or stony corals (order Scleractinia), the subclass Antipatharia includes the black corals (order Antipatharia), and the subclass Octocorallia (Alcyonaria or octocorals) includes the true soft corals (order Alcyonacea) and sea pens (order Pennatulacea). Previous literature on northwest Atlantic deep-sea corals; e.g., Packer et al. (2007), listed several octocoral families under a third order, the gorgonians or Gorgonacea (i.e., sea fans and sea whips). Those families have been moved to the order Alcyonacea. The following sections summarize distributional information about these corals, with a table listing all the corals found in the region (minus the black corals on the seamounts).

Figure 1 – Deep-sea coral taxonomy for those taxa found in the northwest Atlantic. Note that the order Alcyonacea now includes families previously classified in the order Gorgonacea.



2.2 Hard (stony) corals (Order Scleractinia)

Cairns and Chapman (2001) list 16 species of stony corals from the Gulf of Maine and Georges Bank to Cape Hatteras (See also Cairns 1981). Most of the stony corals in this region are solitary organisms and one species, *Astrangia poculata*, can occur in very shallow water, at depths of only a few meters.

Theroux and Wigley (1998) described the distribution of deep corals in the northwest Atlantic, based on samples taken from 1956-1965. They often do not distinguish between taxonomic groups; e.g., stony corals such as *Astrangia* sp. and *Flabellum* sp. are lumped together with the various types of anemones in the subclass Zoantharia. The distributions of only the stony corals, specifically *Astrangia*, *Dasmosmilia*, and *Flabellum*, from the Theroux and Wigley (1998) database in the Gulf of Maine/Georges Bank, and Mid-Atlantic can be found in Packer et al. (2007). There appears to be a general lack of stony corals on Georges Bank, but they are present along the continental margin. They are found mostly on hard substrates.

Moore *et al*. (2003, 2004) reported several species of solitary and colonial stony corals on Bear Seamount; one notable solitary species, *Vaughanella margaritata*, represents the first record of this species since its original description over 100 years ago, and is endemic to the northwest Atlantic (Cairns and Chapman 2001). Other recent expeditions to the New England and Corner Rise Seamounts have also found stony corals (Adkins *et al*. 2006; Watling *et al*. 2005, Shank *et al*. 2006).

Further information on the distributions of stony corals off the northeastern U.S., including the submarine canyons and the four seamounts within the EEZ (Bear, Physalia, Mytilus, and Retriever) can be found in Packer et al (2007) and Table 42, below.

Table 1 - Stony/hard corals of the Northeast Region

Coral group	*Species*	*Distribution on East Coast*	*Depth Range (m)*	*References*
Order Scleractinia, Family Caryophillidae	*Caryophyllia ambrosia ambrosia* Alcock, 1898	Cosmopolitan; found on Bear Seamount	1487-2286	Cairns and Chapman 2001; Moore et al. 2003
Order Scleractinia, Family Caryophillidae	*Caryophyllia ambrosia caribbeana* Cairns, 1979	Endemic to western Atlantic	183-1646	Cairns and Chapman 2001
Order Scleractinia, Family Caryophillidae	*Dasmosmilia lymani* (Pourtales, 1871)	Cosmopolitan. Found on soft substrates. Continental slope south of New England, Lydonia Canyon, continental shelf between Baltimore and Hudson Canyons, in Baltimore Canyon, and between 100-200 m on the shelf south of Hudson Canyon and in the head of Hudson Canyon	37-700 (the latter reported in Maciolek et al. 1987a)	Hecker 1980; Hecker et al. 1983; Maciolek et al. 1987a; Hecker 1990; Cairns and Chapman 2001; V. Guida (unpublished data, NMFS James J. Howard Marine Sciences Lab, Highlands, NJ
Order Scleractinia, Family Caryophillidae	*Deltocyathus italicus* (Michelotti, 1838)	Amphi-Atlantic with a disjunct distribution	403-2634	Cairns and Chapman 2001
Order Scleractinia, Family Caryophillidae	*Desmophyllum dianthus* (Esper, 1794)	Cosmopolitan; outcrops and underhangs from 1000-1900 m. Outcrops of Corsair Canyon. Found in Heezen Canyon. Deeper parts of Lydonia Canyon. Boulders and outcrops in Oceanographer Canyon, 650-1600 m. On an outcrop near Hudson Canyon. Hendrickson Canyon[1]. Occasionally on axis of Norfolk	183-2250. Hendrickson Canyon: Alvin dive 1119, 680-750; Alvin dive 1118 from around 1350-1430; Alvin dive 1116 around 1735-2000 (Hecker et al. 1983, p. 126)	Hecker 1980; Hecker and Blechschmidt 1980; Hecker et al. 1980, 1983; Malahoff et al. 1982; Cairns and Chapman 2001; Moore et al. 2003

[1] Near the head of Hendrickson Canyon the sea floor and axis and most of east wall consists of a silty sediment with many burrows, several glacial erratics support this coral (Hecker et al 1983, p.126). West wall of Hendrickson Canyon has white Eocene cliffs with talus slopes at their bases – skeletons of *D. dianthus* are found there; in several areas horizontal crevices up to a meter deep and a few meters long indent the surface of the cliff; on the underhangs of these crevices this coral is found (Hecker et al 1983, p.126). Entire west wall between 1735-2000 m

Coral group	***Species***	***Distribution on East Coast***	***Depth Range (m)***	***References***
		Canyon. Continental slope on the southwestern edge of Georges Bank, between Veatch and Hydrographer Canyons; in the Mid-Atlantic on the slope between Lindenkohl Canyon on the south and Carteret Canyon on the north; in the Mid-Atlantic on the slope bounded by Toms Canyon to the south and Meys Canyon to the north; Bear Seamount		
Order Scleractinia, Family Caryophillidae	*Lophelia pertusa* (L, 1758)	Cosmopolitan; west wall of Oceanographer Canyon at 1100 m, dead rubble also found on wall at depths from 700-1300 m; Bear Seamount	146-1200; 700-1300	Hecker 1980; Hecker and Blechschmidt 1980; Hecker et al. 1980; Cairns and Chapman 2001; Moore et al. 2003
Order Scleractinia, Family Caryophillidae	*Solenosmilia variabilis* Duncan, 1873	Cosmopolitan; Lydonia canyon; on the slope bounded by Toms Canyon to the south and Meys Canyon to the north, Slope Area II Alvin dive 1118 axis and west wall of Hendrickson Canyon on the underhangs of crevices of Eocene cliffs; large colony recovered from east flank of Lydonia Canyon. Bear Seamount	220-1383; Hecker et al. 1983: Slope Area II Alvin dive 1118 axis and west wall of Hendrickson Canyon. From 1350-1430 m white Eocene cliffs are found. In several areas horizontal crevices up to a meter deep and a few meters long indent the surface of the cliff; coral found on underhangs of these crevices (p. 126)	Hecker 1980; Hecker et al. 1983; Cairns and Chapman 2001; Moore et al. 2004
Order Scleractinia, Family Caryophillidae	*Vaughanella margaritata* (Jourdan, 1895)	Endemic to northwestern Atlantic; Bear Seamount	1267	Cairns and Chapman 2001; Moore et al. 2003
Order Scleractinia, Family Dendrophylliidae	*Enallopsammia profunda* (Pourtales, 1867)	Endemic to western Atlantic	403-1748	Cairns and Chapman 2001
Order Scleractinia, Family Dendrophylliidae	*Enallopsammia rostrata* (Pourtales, 1878)	Cosmopolitan; Bear Seamount	300-1646	Cairns and Chapman 2001; Moore et al. 2004
Order Scleractinia, Family Flabellidae	*Flabellum alabastrum* Moseley, 1873	Amphi-Atlantic with contiguous distribution. Bear Seamount. Canyons and slope from 600-2500 m. Seen in Corsair Canyon. Found in Heezen and Oceanographer Canyons on soft substrate. Seen on deep continental slope near Alvin Canyon. Hendrickson Canyon: Slope Area II Alvin dive 1118 axis and west wall (Hecker et al. 1983). Found on slope south of Baltimore Canyon. Found in deeper parts of the continental slope south of Norfolk Canyon and in axis of Norfolk Canyon on soft substrate. Some may be *F. angulare* or *F. moseleyi* (the latter doubtful)	347-1977, 600-2500; from 1350-1430 m silty axis lower wall of Hendrickson Canyon (Slope Area II Alvin dive 1118, Hecker et al. 1983)	Hecker 1980; Hecker and Blechschmidt 1980; Hecker et al. 1980, 1983; Maciolek et al. 1987a; Cairns and Chapman 2001; Moore et al. 2003, 2004
Order Scleractinia, Family Flabellidae	*Flabellum angulare* Moseley, 1876	Amphi-Atlantic with contiguous distribution; see also *F. alabastrum*	2266-3186	Hecker 1980; Hecker and Blechschmidt 1980; Hecker et al. 1980,

consists of a series of massive Eocene outcrops. On a vertical plane the cliffs are separated by talus strewn ledges with a light sediment veneer. Horizontally, large fractures form small tributaries of steep talus floors. Both the terraces and tributaries are littered with *D. dianthus* skeletons. Underhangs of the cliffs support dense aggregations of live coral (Hecker et al 1983, p.126).

Coral group	Species	Distribution on East Coast	Depth Range (m)	References
				1983; Cairns and Chapman 2001; Moore et al. 2003
Order Scleractinia, Family Flabellidae	*Flabellum macandrewi* Gray, 1849	Amphi-Atlantic with contiguous distribution; see also *F. alabastrum*	180-667	Hecker 1980; Hecker and Blechschmidt 1980; Hecker et al. 1980, 1983; Cairns and Chapman 2001; Moore et al. 2003
Order Scleractinia, Family Flabellidae	*Javania cailleti* (Duch. & Mich., 1864)	Cosmopolitan; Lydonia Canyon, axis of Oceanographer Canyon between 935-1220 m	30-1809	Hecker 1980; Hecker et al. 1983; Cairns and Chapman 2001
Order Scleractinia, Family Fungiacyathidae	*Fungiacyathus fragilis* Sars, 1872	Cosmopolitan	412-460	Cairns and Chapman 2001
Order Scleractinia, Family Rhizangiidae	*Astrangia poculata* (Ellis & Solander, 1786)	Endemic to western Atlantic	0-263	Theroux and Wigley 1998; Cairns and Chapman 2001

2.3 Soft corals (Order Alcyonacea)

About 29 species in 10 alcyonacean families were recorded for the northeastern U.S. shelf and slope north of Cape Hatteras and the seamounts within the EEZ. Several families (Acanthogorgiidae, Paramuriceidae, Anthothelidae, Paragorgiidae, Chrysogorgiidae, Primnoidae, and Isiddae) are the best documented because of their larger sizes, as well as being most abundant in the deeper waters of the continental slope (Watling and Auster 2005). Two species that are very numerous in nearshore records are *Gersemia rubiformis* and *Alcyonium* species (Watling and Auster 2005). It should be noted that, for a variety of reasons, there is uncertainty about the accuracy of the identifications of species from these two orders from the various historical surveys (Watling and Auster 2005; Packer et al. 2007), so these identifications and surveys should be interpreted with caution.

Theroux and Wigley (1998) found that true soft corals 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. They were not collected in samples taken at < 50 m in depth, and were most abundant between 200-500 m. Identified species include *Acanella* sp., *Paragorgia arborea*, *Primnoa reseda* [now *resedaeformis*, see Cairns and Bayer (2005)], and *Alcyonium* sp. They were collected from gravel and rocky outcrops (Theroux and Wigley 1998).

Watling and Auster (2005) noted two distinct distributional patterns for alcyonaceans. Most are deepwater species that occur at depths > 500 m; these include species in the genera *Acanthogorgia*, *Acanella*, *Anthomastus, Anthothela*, *Clavularia, Lepidisis*, *Radicipes*, and *Swiftia*. Other species occur throughout shelf waters to the upper continental slope and include *Paragorgia arborea*, *Primnoa resedaeformis*, and species in the genus *Paramuricea*. *Paragorgia arborea* was described by Wigley (1968) as a common component of the gravel fauna of the Gulf of

Maine, while Theroux and Grosslein (1987) reported *Primnoa resedaeformis*, as well as *Paragorgia arborea*, to be common on the Northeast Peak of Georges Bank. Both species are widespread in the North Atlantic (Tendal 1992); *Primnoa resedaeformis* has been reported south to off Virginia Beach, Virginia (37°03′N) (Heikoop et al. 2002). The majority of records for *Acanthogorgia armata*, *Paragorgia arborea*, and *Primnoa resedaeformis* in the Watling et al (2003) database come from Lydonia, Oceanographer, and Baltimore canyons. In addition, *Primnoa resedaeformis* was found throughout the Gulf of Maine and on the Northeast Peak of Georges Bank, affirming Theroux and Grosslein's (1987) observations.

Further information on the distributions of alcyonaceans off the northeastern U.S., including the submarine canyons and the four seamounts within the EEZ (Bear, Physalia, Mytilus, and Retriever) can be found in Packer et al. (2007); newer records from the seamounts, new species, and taxonomic changes are included in Table 2, below.

Table 2 – Soft corals of the Northeast Region (includes those species previously identified as gorgonians).

Coral group	***Species***	***Distribution on East Coast***	***Depth Range (m)***	***References***
Order Alcyonacea, Family Acanthogorgiidae	*Acanthogorgia armata* Verrill, 1878	Found in many canyons from 600-2500 m. Seen on boulders or outcrops in Corsair and Oceanographer Canyons; found in Lydonia and Oceanographer Canyons between 400-1299 m. Seen on deep continental slope near Alvin Canyon. Found on an outcrop near Hudson Canyon. Found at 350 m in Baltimore Canyon. Occasionally in axis of Norfolk Canyon on exposed outcrops	350-1300, 600-2500	Hecker and Blechschmidt 1980; Hecker et al. 1980; Opresko 1980; Malahoff et al. 1982; Watling and Auster 2005
Order Alcyonacea, Family Alcyoniidae	*Alcyonium digitatum* Linné, 1758	?	?	Watling and Auster 2005
Order Alcyonacea, Family Alcyoniidae	*Anthomastus agassizii* Verrill, 1922	Hard substrates from Corsair Canyon to Hudson Canyon from 750-1900 m; outcrops in Corsair Canyon; in Heezen Canyon. Found in depper parts of Lydonia Canyon. On boulders and outcrops in Oceanographer Canyon from 1057-1326 m. On deep continental slope near Alvin Canyon; on slope on the southwestern edge of Georges Bank, between Veatch and Hydrographer Canyons; in Mid-Atlantic on slope flanked by Lindenkohl Canyon to south and Carteret Canyon to north and on slope bounded by Toms Canyon to south and Meys Canyon to north (i.e. between Baltimore and Hudson Canyons), Slope Area II Alvin dives 1118, 1116 axis and west wall Hendrickson Canyon on cliff faces (Hecker et al. 1983); Bear Seamount	750-1900; Hendrickson Canyon axis and west wall from about 1350-1430 m on cliff faces (Slope Area II Alvin dive 1118, Hecker et al. 1983). Entire west wall between 1735-2000 m consists of a series of massive Eocene outcrops. On a vertical plane the cliffs are separated by talus strewn ledges with a light sediment veneer. Horizontally, large fractures form small tributaries of steep talus floors. This coral found on the sheer cliff faces (Slope Area II Alvin dive 1116, Hecker et al. 1983)	Hecker and Blechschmidt 1980; Hecker et al. 1980, 1983; Opresko 1980; Valentine et al. 1980; Maciolek et al. 1987a; Hecker 1990; Moore et al. 2003; Watling and Auster 2005

Coral group	***Species***	***Distribution on East Coast***	***Depth Range (m)***	***References***
Order Alcyonacea, Family Alcyoniidae	*Anthomastus grandiflorus* Verrill, 1878	Soft substrates, highest densities in canyons; found in Corsair, Heezen (west wall), Oceanographer Canyons; seen near Hudson Canyon, Toms Canyon, in Baltimore Canyon, in axis of Norfolk Canyon. In the northern canyons found from 700-1500 m, southern canyons from 1500-2200 m; as deep as 2600 m. Frequently seen where a species of *Pennatula* was also common	700-2600	Hecker and Blechschmidt 1980; Hecker et al. 1980; Opresko 1980; Watling and Auster 2005
Order Alycyonacea, Family Anthothelidae	*Anthothela grandiflora* (Sars, 1856)	Lydonia, Oceanographer, Baltimore Canyons	450-1150	Hecker et al. 1980; Opresko 1980; Watling and Auster 2005
Order Alycyonacea, Family Chrysogorgiidae	*Chrysogorgia agassizii* (Verrill, 1883)	Slope Area II Alvin dive 1116 axis and west wall of Hendrickson Canyon (Hecker et al. 1983); several individuals that may be *C. agassizii* found in the vicinity of Hudson Canyon. Genus also noted on Bear, Retriever Seamounts (Thoma et al. 2009)	2150. Hendrickson Canyon: entire west wall between 1735-2000 m consists of a series of massive Eocene outcrops. On a vertical plane the cliffs are separated by talus strewn ledges with a light sediment veneer. This coral occasionally found on the terraces (Slope Area II Alvin dive 1116, Hecker et al. 1983, p. 126). Bear: 1559, 1994–2031; Retriever: 3860	Hecker et al. 1983; Watling and Auster 2005; Thoma et al. 2009
Order Alycyonacea, Family Chrysogorgiidae	*Metallogorgia melanotrichos* (Wright and Studer, 1889)	Bear, Physalia, Retriever Seamounts. Genus also noted on Bear, Retriever by Thoma et al. 2009	Bear: 1491, 1559, (Mosher and Watling 2009); 1559, 1639 (Thoma et al. 2009). Retriever: 1983, 2012 (Thoma et al. 2009)	Mosher and Watling 2009; Thoma et al. 2009
Order Alycyonacea, Family Chrysogorgiidae	*Iridogorgia pourtalesii* Verrill, 1883	?	?	Watling and Auster 2005
Order Alycyonacea, Family Chrysogorgiidae	*Radicipes gracilis* (Verrill, 1884)	Genus noted on continental slope (38.5461, –70.7995) and on Bear Seamount by Thoma et al. 2009; species noted on Bear by Moore et al. 2004	Continental slope: 3000; Bear: 1431–1464, 1428–1650	Moore et al. 2004; Watling and Auster 2005; Thoma et al. 2009
Order Alcyonacea, Family Clavulariidae	*Clavularia modesta* (Verrill, 1874)	?	greater than 500 m?	Watling and Auster 2005
Order Alcyonacea, Family Clavulariidae	*Clavularia rudis* (Verrill, 1922)	Found in axis of Heezen (1100 m), Lydonia (900 m), Oceanographer Canyons (750 and 900 m)	750-1099	Hecker and Blechschmidt 1980; Hecker et al. 1980; Opresko 1980; Watling and Auster 2005

Coral group	***Species***	***Distribution on East Coast***	***Depth Range (m)***	***References***
Order Alcyonacea, Family Isididae	*Acanella arbuscula* (Johnson, 1862)	Found in Corsair, Heezen, Oceanographer Canyons; Oceanographer Canyon between 1046-1191 m; on deep continental slope near Alvin Canyon and just south of Baltimore Canyon; in Mid-Atlantic on slope flanked by Lindenkohl Canyon to south and Carteret Canyon to north and on slope bounded by Toms Canyon to south and Meys Canyon to north; Slope Area II Alvin dive 1116 axis and west wall of Hendrickson Canyon (Hecker et al. 1983); continental slope south of New England off Georges Bank; seen on soft substrates from 600-1300 m depth in the north and 1500-2000 m depth in the south. Northern and southern forms may be different species. Genus noted in Gilbert Canyon, on continental slope (39.7807 –70.7091) and on Retriever Seamount by Thoma et al. 2009. Maciolek et al. 1987b: between Toms Canyon to the north and Wilmington Canyon to the south: 38° 35.98N, 72° 52.97W, prefer shallower flat ridges	600-2278. Gilbert Canyon: 2097; continental slope: 1600; Retriever: 2035, 2040. Maciolek et al. 1987b: peak in abundance of 0.3 individuals per m^2 between 2000-2150. Hendrickson Canyon: entire west wall between 1735-2000 m consists of a series of massive Eocene outcrops. On a vertical plane the cliffs are separated by talus strewn ledges with a light sediment veneer. This coral occasionally found on the terraces (Slope Area II Alvin dive 1116, Hecker et al. 1983, p. 126)	Hecker and Blechschmidt 1980; Hecker et al 1980; Opresko 1980; Maciolek et al. 1987a, b; Hecker 1990; Theroux and Wigley 1998; Watling and Auster 2005; Thoma et al 2009
Order Alcyonacea, Family Isididae	*Keratoisis grayi* Wright, 1869	Genus also found on Bear Seamount	?	Watling and Auster 2005; Bear Seamount: Moore et al. 2004; Deep Atlantic Stepping Stones Science Team/IFE/URI/NOAA
Order Alcyonacea, Family Isididae	*Lepidisis caryophyllia* Verrill, 1883	Bear Seamount?	?	Moore et al. 2003; Watling and Auster 2005
Order Alcyonacea, Family Nephtheidae	*Duva florida* (Rathke, 1806)	Lydonia, Oceanographer, Baltimore Canyons, but only high abundances in Lydonia at 350-1500 m; axis of Heezen Canyon from 1100-1200 m; wall of Corsair Canyon from 600-1000 m; continental slope south of New England off Georges Bank	350-1500	Hecker and Blechschmidt 1980; Hecker et al. 1980; Opresko 1980; Maciolek et al. 1987a; Hecker 1990; Watling and Auster 2005
Order Alcyonacea, Family Nephtheidae	*Capnella glomerata* (Verrill, 1869)	Several individuals found in Lydonia Canyon	200-561	Hecker et al. 1980; Opresko 1980; Watling and Auster 2005
Order Alcyonacea, Family Nephtheidae	*Gersemia fruticosa* (Sars, 1860)	Near and in deep portion of Hudson Canyon around 2250-2500 m; at the mouth of Norfolk Canyon; seen near heads of Toms and Carteret Canyons (i.e., between Baltimore and Hudson Canyons). Southern part of study area at depths from 2300-3100 m. Different form seen in Corsair and Heezen Canyons between 600-1200 m	600-3100	Hecker and Blechschmidt 1980; Opresko 1980; Watling and Auster 2005
Order Alcyonacea, Family Nephtheidae	*Gersemia rubriformis* (Ehrenberg, 1934)	?	?	Watling and Auster 2005

Coral group	***Species***	***Distribution on East Coast***	***Depth Range (m)***	***References***
Order Alcyonacea, Family Paragorgiidae	*Paragorgia arborea* (Linné, 1758)	Gulf of Maine, Georges Bank, and Canyons [Lydonia (300-900 m), Oceanographer (300-1100 m), axis of Baltimore (400 m, 500 m), Norfolk (400-600 m)]; probably Bear Seamount	300-1100	Wigley 1968; Hecker and Blechschmidt 1980; Hecker et al. 1980; Opresko 1980; Theroux and Grosslein 1987; Theroux and Wigley 1998; Moore et al. 2003; Watling and Auster 2005
Order Alcyonacea, Family Plexauridae	*Paramuricea grandis* Verrill, 1883	Gulf of Maine and canyons from Corsair to near Hudson Canyon between 750-2150 m. On wall and axis of Oceanographer Canyon on boulders and outcrops. Depths between 400-1349 m in Lydonia and Oceanographer Canyons. Seen from Corsair Canyon to near Hudson Canyon from 700-2200 m on hard substrates. Outcrops in Corsair Canyon. Found in Heezen Canyon and deeper parts of Lydonia Canyon. Deep continental slope near Alvin Canyon; on slope on the southwestern edge of Georges Bank, between Veatch and Hydrographer Canyons; in Mid-Atlantic on slope flanked by Lindenkohl Canyon to south and Carteret Canyon to north and on slope bounded by Toms Canyon to south and Meys Canyon to north. Not seen in Norfolk Canyon. Genus also noted in Gulf of Maine, Oceanographer Canyon, and on Bear, Retriever Seamounts by Thoma et al. 2009	400-2200;Thoma et al 2009 Gulf of Maine: 220, 228, 241; Oceanographer Canyon: 814, 1078; Bear Seamount: 1378–1431; Retriever Seamount: 1981, 1984, 1985, 2040	Hecker and Blechschmidt 1980; Hecker et al. 1980, 1983; Opresko 1980; Valentine et al. 1980; Watling and Auster 2005; Thoma et al 2009
Order Alcyonacea, Family Plexauridae	*Paramuricea placomus* (Linné, 1758)	Gulf of Maine	?	Watling and Auster 2005
Order Alcyonacea, Family Plexauridae	*Paramuricea* n. sp.	?	?	Watling and Auster 2005
Order Alcyonacea, Family Plexauridae	*Swiftia casta* (Verrill, 1883)	Bear Seamount?	?	Moore et al. 2003; Watling and Auster 2005
Order Alcyonacea, Family Primnodidae	*Narella laxa* Deichmann, 1936	?	?	Watling and Auster 2005
Order Alcyonacea, Family Primnodidae	*Primnoa resedaeformis* Gunnerus, 1763)	Gulf of Maine, Georges Bank, and Canyons [Lydonia (560 m), Oceanographer, Baltimore (450 m), Norfolk (400 m)]; south to off Virginia Beach, VA; probably Bear Seamount	91-548	Hecker and Blechschmidt 1980; Hecker et al. 1980, 1983; Opresko 1980; Valentine et al. 1980; Theroux and Grosslein 1987; Theroux and Wigley 1998; Moore et al. 2003; Cairns and Bayer 2005; Watling and Auster 2005; Heikoop et al. 2002
Order Alcyonacea, Family Primnodidae	*Thouarella grasshoffi* Cairns, 2006	North Atlantic; Oceanographer Canyon, Manning and Bear Seamounts (probably common on seamounts)	814–1458 m in North Atlantic (Cairns 2006)	Watling and Auster 2005 = *Thouarella* n. sp.; Cairns 2006, 2007
Order Alcyonacea, Family Primnodidae	*Parastenella atlantica,* new species	Type Locality: Retriever Seamount, 39°48.5454'N, 66° 14.9883'W. 23 May 2004	1984	Cairns 2007

Coral group	Species	Distribution on East Coast	Depth Range (m)	References
Order Alcyonacea, Family Primnodidae	*Calyptrophora antilla* Bayer, 2001	Bear Seamount, 39°53'42"N, 66°23'07"W. 17 July 2003	1684	Cairns 2007
Order Alcyonacea, Family Primnodidae	*Paranarella watlingi,* new species	Type locality: Retriever Seamount, 39°48.0754'N, 66°14.9408'W. 23 May 2004	3855	Cairns 2007

2.4 Sea pens (Order Pennatulacea)

Records of sea pens in are drawn from Smithsonian Institution collections and the Wigley and Theroux benthic database (Packer et al. 2007). Nearly all materials from the former source were collected either by the U.S. Fish Commission (1881-1887) or for the Bureau of Land Management (BLM) by the Virginia Institute of Marine Sciences (1975-1977) and Battelle (1983-1986). These latter collections heavily favor the continental slope fauna. The Wigley and Theroux collections (1955-1974) were made as part of a regional survey of all benthic species (Theroux and Wigley 1998), heavily favoring the continental shelf fauna. A list of 21 sea pen species representing ten families was compiled from these sources for the northeastern U.S.[2] The majority of these species have been reported exclusively from continental slope depths (200-4300 m), although two uncommon species have been recorded from shallow depths (e.g., < 30 m) off the North Carolina coast. The most common and fairly widespread species found in this region in the deeper parts of the continental shelf (80-200 m) are *Pennatula aculeata* (common sea pen) and *Stylatula elegans* (white sea pen). *P. aculeata* is common in the Gulf of Maine (Langton et al. 1990), and there are numerous records of *Pennatula* sp. on the outer continental shelf as far south as the Carolinas in the Theroux and Wigley database. *S. elegans* is abundant on the Mid-Atlantic coast outer shelf (Theroux and Wigley 1998).

Table 3 - Sea pens of the Northeast Region

Coral group	Species	Distribution on East Coast	Depth Range (m)	References
Order Pennatulacea, Family Anthoptilidae	*Anthoptilum grandiflorum*	Newfoundland to Bahamas	274-3651[3]	US NMNH collection, OBIS; Hecker and Blechschmidt 1980; Opresko 1980
Order Pennatulacea, Family Anthoptilidae	*Anthoptilum murrayi*	Lydonia Canyon to Puerto Rico, Brazil (up to 75 cm in height; Pires et al 2009)	430-2491 (1538 m min in NE US)	US NMNH collection, OBIS

[2] An additional sea pen, *Virgularia mirabilis* (Müller, 1776), was mentioned in Hecker and Blechschmidt (1980): "Seven specimens of this sea pen were seen on the slope between Baltimore and Norfolk Canyons at depths from 1500 to 1800 meters." It has been recorded in Europe and is said to occur in the western Atlantic, but this is the only mention of this species in these waters that we have been able to find.

[3] Hecker and Blechschmidt 1980 note that "six individuals of this species were seen in the northern region of the study area between depths of 900-2200 m." Opresko 1980: one at 1800 m off Cape Hatteras, three at 2150 m near Atlantis Canyon, six on wall of Heezen Canyon between 850-1050 m.

Coral group	*Species*	*Distribution on East Coast*	*Depth Range (m)*	*References*
Order Pennatulacea, Family Anthoptilidae	*Benthoptilum sertum* Verrill, 1885	North Carolina, near Roanoke Island; New Jersey near Hudson Canyon	NC: 1542; NJ: 1962	US NMNH collection
Order Pennatulacea, Family Funiculinidae	*Funinculina armata* Verrill, 1879	South of Nantucket Shoals, MA; Hudson Canyon; NJ, Hog Island, VA	1538-2601	US NMNH collection
Order Pennatulacea, Family Halipteridae	*Halipteris (=Balticina) finmarchica*	Newfoundland to Massachusetts; Opresko 1980: found near Atlantis Canyon and in Heezen Canyon (as *Balticina*)	37-2249 (229 m min in NE US) as *Balticina*[4]	US NMNH collection as *Balticina*; Hecker and Blechschmidt 1980 and Opresko 1980 as *Balticina*; see Williams 1995 for current taxonomy
Order Pennatulacea, Family Kophobelemnidae	*Kophobelemnon stelliferum*	Newfoundland to South Carolina. Hecker et al. 1980: Lydonia Canyon: soft substrates, in the axis and on the east wall. Opresko 1980: common on slope north of Baltimore Canyon, off Cape Hatteras, in Heezen and Corsair Canyons (Hecker et al 1980). In Mid-Atlantic was found on slope areas by Hecker et al (1983): Slope Area I was flanked by Lindenkohl Canyon on the south and Carteret Canyon on the north; Slope II was about 70 miles north of Slope I, and bounded by Toms Canyon to the south and Meys Canyon to the north. Further north Slope III, a 25 mile wide section of the continental slope on the southwestern edge of Georges Bank, between Veatch and Hydrographer Canyons. Maciolek et al. 1987b: between Toms Canyon to the north and Wilmington Canyon to the south: 38° 35.98N, 72° 52.97W; highest densities in flat depressions	393-2350 (1330 m min in NE US)[5]	US NMNH collection, OBIS; Hecker et al. 1980, 1983; Opresko 1980; Maciolek et al. 1987b
Order Pennatulacea, Family Kophobelemnidae	*Kophobelemnon scabrum*	Nova Scotia to Virginia	1977-2249	US NMNH collection
Order Pennatulacea, Family Kophobelemnidae	*Kophobelemnon tenue*	Massachusetts to Virginia	2491-4332	US NMNH collection
Order Pennatulacea, Family Ombellulidae	*Ombellula guntheri*	Massachusetts to Virginia	2683-3740 (3166 m min in NE US)	US NMNH collection
Order Pennatulacea, Family Ombellulidae	*Ombellula lindahlii*	Massachusetts to the Virgin Islands	549-3338 (1538 m min in NE US)	US NMNH collection, OBIS

[4] Hecker and Blechschmidt 1980 note that "six individuals of this species were seen in the northern region of the study area between depths of 900-2200 m." Opresko 1980: near Atlantis Canyon and in Heezen Canyon between 900-2200 m. Found as shallow as 360-380 m off Nantucket Shoals and Martha's Vineyard based on Smithsonian records, has been found off of Brown's Ledge, off Newport R.I. at 23.8 m depth in 1880, and the NE edge of Georges Bank at 229 m by Verrill.

[5] Hecker et al. 1980: found throughout study area at depths ranging from 1300-1800 m; also seen at comparable depths in Hatteras Canyon region. Opresko 1980: states known range from 215-2369 m. Lydonia Canyon between 700-800 m, common on slope north of Baltimore Canyon between 1550-1800 m, also at 200 m north of Baltimore Canyon, between 1750-1900 m off Cape Hatteras, between 1300-1600 m in Heezen and Corsair Canyons. Hecker et al. 1983: found between 1510-2060 m on Slope III; 1140-2190 on Slope I; mostly 1460-1540 m on muddy substrate with some gravel on Slope II. Maciolek et al. 1987b: became increasingly abundant below 2200 m. Found in highest densities between 2300-2350 m.

Coral group	***Species***	***Distribution on East Coast***	***Depth Range (m)***	***References***
Order Pennatulacea, Family Pennatulidae	*Pennatula aculeata*	Newfoundland to Virginia, including submarine canyons (e.g., Lydonia, Oceanographer, Norfolk); on or around Bear Seamount	119-3316[6]	US NMNH collection, OBIS. Hecker et al. 1980, 1983; Hecker and Blechschmidt 1980; Opresko 1980; Moore et al. 2004
Order Pennatulacea, Family Pennatulidae	*Pennatula grandis*	New Jersey; Lydonia Canyon	1850-2140; Hecker et al. 1983: Lydonia Canyon Alvin dive 1263 covered the lower east wall, axis, and west wall of the canyon between 933-1145 m; *P. grandis* found on floor of canyon axis	US NMNH collection, OBIS; Hecker et al. 1983
Order Pennatulacea, Family Pennatulidae	*Pennatula borealis*	Newfoundland to North Carolina	219-2295; has been found as shallow as 360-380 m off Nantucket Shoals and Martha's Vineyard based on Smithsonian records	US NMNH collection, OBIS
Order Pennatulacea, Family Protoptilidae	*Distichoptilum gracile*	Nova Scotia to North Carolina. Near U.S. Canadian boundary, just south of Heezen Canyon on mud, middle/lower slope; lower slope south of western portion of Georges Bank (Maciolek et al. 1987a). Oceanographer Canyon: soft substrates, lower east wall and in the axis (Hecker et al 1980). Lydonia Canyon: soft substrates, especially on east wall and axis (Hecker et al. 1983). In Mid-Atlantic was found on slope areas by Hecker et al, 1983: Slope Area I was flanked by Lindenkohl Canyon on the south and Carteret Canyon on the north; Slope II, was about 70 miles north of Slope I, and bounded by Toms Canyon to the south and Meys Canyon to the north. Also Baltimore Canyon. Further north Slope III, a 25 mile wide section of the continental slope on the southwestern edge of Georges Bank, between Veatch and Hydrographer Canyons. Hecker et al. 1990: one of the dominant or common fauna/taxa of the lower continental slope south of New England	Around 600-2844 (doubtful report at 59 m)[7]	US NMNH collection, OBIS; Hecker et al 1980, 1983; Opresko 1980; Maciolek et al. 1987a; Hecker 1990
Order Pennatulacea, Family Protoptilidae	*Protoptilum aberrans*	Nova Scotia to Virginia	1483-2359	US NMNH collection
Order Pennatulacea, Family Protoptilidae	*Protoptilum carpenteri*	Massachusetts to North Carolina	1334-2194	US NMNH collection, OBIS

[6] Hecker and Blechschmidt 1980 note that the genus is "found throughout the study area, but it appeared in high concentrations only in the canyons. It was found at shallow depths in the northern canyons (600-1500 m) and deeper in the southern canyons (1500-2400 m)." Quite common near head of Lydonia Canyon between 400-600 m, soft substrates in the shallow axis and on the west wall; Hecker et al. 1983 reports high concentrations between 300-450 or 550 m in the silty axis. Opresko 1980: exceptionally high concentrations 2150-2300 m in axis of Norfolk Canyon; 1700-1799 m in Oceanographer (deep part of axis), 350-1375 in Lydonia.

[7] Opresko 1980 reports might be found 600-2500 m; Oceanographer and Lydonia Canyons between 1100-1800 m. Hecker et al. 1983: below 990 m in Lydonia, esp. 1000-1500 m; dominant on east wall 1200-1500 m, higher densities in axis at 1600 m. Found below 1200 m and common below 1600 m in Slope III; Slope I below 1330 m, mud bottom and especially below 1900 m; Slope II in Hendrickson Canyon 640 -1640 m and also common in "zone 4" between 1460-1540 m and "zone 5" between 1510-2290. Baltimore Canyon 1190-2040 m; north flank dominant between 1500-1700 m.

Coral group	***Species***	***Distribution on East Coast***	***Depth Range (m)***	***References***
Order Pennatulacea, Family Renillidae	*Renilla reniformis* (Pallas, 1766)	North Carolina to Patagonia	13-73 off NC	US NMNH collection
Order Pennatulacea, Family Scleroptilidae	*Scleroptilum gracile*	Massachusetts to Virginia	2513-4332	US NMNH collection
Order Pennatulacea, Family Scleroptilidae	*Scleroptilum grandiflorum*	Massachusetts to North Carolina	1502-2505	US NMNH collection, OBIS
Order Pennatulacea, Family Virgulariidae	*Stylatula elegans*	New York to Florida; noted in Baltimore Canyon (Hecker et al. (1980, 1983) and Lydonia Canyon (Opresko 1980); on continental shelf off NJ (Smithsonian collections) and near head of Hudson Canyon (V. Guida, unpublished data), in Mid-Atlantic was found on two slope areas by Hecker et al 1983: Slope Area I was flanked by Lindenkohl Canyon on the south and Carteret Canyon on the north; Slope II, was about 70 miles north of Slope I, and bounded by Toms Canyon to the south and Meys Canyon to the north	20-812 (51 m min in NE US)[8]	US NMNH collection, OBIS; Hecker et al. 1980, 1983; Opresko 1980; V. Guida, (unpublished data, NMFS James J. Howard Marine Sciences Lab, Highlands, NJ)
Order Pennatulacea, Family Virgulariidae	*Virgularia presbytes* Bayer, 1955	NC to Brazil and Gulf of Mexico; US NMNH collection identified species only in NC, but genus found in MA, NJ, DE	Species identified in NC: 25-31; genus in MA: 942; NJ: 65-91; DE: 84-85 with one specimen 360-410	US NMNH collection

[8] Opresko 1980: one specimen found at about 600 m in Lydonia Canyon. Hecker et al 1983: high densities found 100-300 m Slope II, 200-300 m Slope I, less in Baltimore Canyon at about 150-300 m.

3.0 Individual area characterization and coral zone assessment

This section of the document describes the approach taken to evaluate and recommend or not recommend individual discrete coral zones. Section 3.1 reviews the approach taken, section Summary of results summarizes the results of the analysis, and section 3.3 provides detailed information and maps for each discrete zone.

3.1 Approach

This section summarizes the approach taken to evaluate discrete deep-sea coral zones for recommendation to the NEFMC Habitat Committee. This approach was developed over a series of meetings, and experts outside the PDT were consulted as needed, in particular at a meeting held in Woods Hole in October 2011. While this work was not completed in the linear fashion outlined in the three sections below, this document captures the major elements of the analysis, namely:

1. Determine which coral types/species are of particular conservation interest.
2. Identify coral presence data sources and evaluate coral data.
3. Identify bathymetric and geological data sources and evaluate them to determine whether an area provides suitable coral habitat.

Overall, the purpose of the discrete zone evaluation was to group potential coral conservation areas into four categories (Table 4), based on evaluation of two data types: (1) coral presence data, and (2) bathymetric and geological data. Coral zones were recommended on the basis of relatively well documented presence of coral species (category 1), and/or based on inference of suitable coral habitat, as determined by evaluating available bathymetric and/or geological data (category 2). Areas classified as categories 3 and 4 were not recommended as coral management zones.

Table 4 - Structure of discrete zone coral assessment

	Coral presence in the area has been relatively well assessed, using either surveys where corals were the focus, or scientific studies where corals were an incidental component of the fauna assessed	***Coral presence data in the area has not been assessed, or has been relatively poorly assessed. In this case, any recommendation to define the area as a coral zone is necessarily based on inference of suitable habitat, on the basis of bathymetric data, or bathymetric and geological data.***
Coral zone recommended	(1) Coral presence has been documented. This presence of corals in a relatively well assessed area allows us to infer that habitats are suitable.	(2) Coral presence not directly assessed, but geological and/or bathymetric data do support the inference of suitable habitat.
Coral zone not recommended	(3) Coral presence has not been documented. This lack of corals in a relatively well assessed area allows	(4) Coral presence not directly assessed, geological and/or bathymetric data do not support the

	us to infer that habitats <u>are not</u> suitable.	inference of suitable habitat.

3.1.1 Step 1 – Identify NE region coral species of particular conservation interest

An array of coral species live in the northeast region, as described in section 2.0 of this document. These corals vary in terms of their size, shape, and flexibility, growth rates and reproductive strategies, and habitat associations. Some are relatively common, whereas other types are rare. All of these species have some level of vulnerability to fishing gear impacts, but the degrees of susceptibility and the rates of recovery are likely variable. The PDT focused on a few types of corals in particular when developing management alternatives for coral zones. Specifically, the PDT recommends that coral zones should focus on species that:

- Are relatively large or have other attributes that make them more susceptible to fishing-related impacts. Specifically, the gorgonians and the black corals have fairly complex physical structure that is likely to be more susceptible to damage from fishing. Taxa likely to be more vulnerable to fishing impacts are listed in Table 5.
- Require hard substrates, which are relatively rare. While there is abundant soft substrate on the continental slope, hard substrate areas are much more limited in their distribution, and should be the focus of conservation efforts because of their rarity.

Table 5 – Species of coral in the NE region that are likely to be more vulnerable to fishing gear based on their physical characteristics

Species, Order	Form	Distribution
Acanella arbuscula; soft coral	Only 15 cm high, but stiff and delicate	Canyons (Watling et al 2011), including on soft bottom, few in Oceanographer Canyon (Hecker and Blechschmidt); also on seamounts
Acanthogorgia armata; soft coral	Up to 50 cm high, usually 10-20 cm	Western N. Atlantic, including on seamounts (Appendix B in Hecker & Blechschmidt 1980 MMS Report, Watling et al 2011)
Anthomastus agassizii and A. grandiflorus, soft corals	Stalked colonial corals	Deeper areas of canyons, *A. grandiflorus* on seamounts (Watling et al 2011)
Chrysogorgia agassizi; soft coral	30 cm or more, delicate-looking with fine branches	Several in deep water in vicinity of Hudson Canyon (Appendix B in Hecker & Blechschmidt 1980 MMS Report); other species of *Chrysogorgia* on seamounts (Watling et al 2011)
Paragorgia arborea, other *Paragorgia* species; soft corals	Very large, up to 1.5 m high	*P. arborea*: western North Atlantic, including in axes of Oceanographer, Baltimore and Norfolk canyons (Appendix B in Hecker & Blechschmidt 1980 MMS Report); other species on seamounts (Watling et al 2011)
Paramuricea grandis; soft coral	Up to 80 cm, frequently 20-30 cm	Not found south of Georges Bank (Appendix B in Hecker & Blechschmidt 1980 MMS Report)

Species, Order	Form	Distribution
Primnoa resedaeformis; soft coral	Large colonies up to 1 m or more, stiff yet flexible, hard/rigid at base	Found in Norfolk, Lydonia, Baltimore canyons (Appendix B in Hecker & Blechschmidt 1980 MMS Report)
Thouarella grasshoffi, soft coral	Colonies consist of 1–3 main branches, from which numerous closely spaced (usually less than 2 mm apart) branchlets originate on all sides of the main branch in a bottlebrush arrangement. The branchlets are undivided, about 4.5 cm in length, and flexible in tension. The holotype is a single main stem 35 cm tall and 8–9 cm in width that has been broken from its base, the axis being 2.4 mm in proximal diameter and brownish in color.	Manning and Bear Seamounts of the New England Seamount Chain, and Oceanographer Canyon (Cairns, S.D. 2006, probably common on the New England Seamounts, Watling, pers. comm.).
Desmophyllum cristagalli, hard coral	Large solitary horn coral (related species *D. dianthus* up to 10 cm high)	On hard substrates in canyon axes on hard bottom (Appendix C in Hecker & Blechschmidt 1980 MMS Report)
Solenosmilla variabilis, hard coral	Forms large bushy colonies	Lydonia Canyon, Hendrickson Canyon (Appendix C in Hecker & Blechschmidt 1980 MMS Report), Bear Seamount
The black corals (order Antipatharia), genera *Antipathes, Leiopathes, Parantipathes*	Branching colonial corals	Have only been documented on seamounts, but it is possible that they exist in other areas as well which haven't been surveyed

Despite the focus on hard substrates, the PDT agreed that coral zones should encompass diverse substrate types (e.g. clay, silt, and sand) found in proximity to hard substrates. Some larger species such as the bamboo coral *Acanella arbuscula* are associated with these soft substrates. Because hard substrates occur amongst soft sediments in canyon environments, a coral zone designed around a canyon feature will inevitably encompass both hard and soft substrate areas.

The coral protection zones were not designed to focus on protection of sea pens, which typically inhabit soft substrates and might be less vulnerable to fishing disturbance than other coral types. Specifically, the white sea pen, *Stylatula elegans*, and the common sea pen, *Pennatula aculeata* possibly have lower susceptibility to fishing disturbance, and are more widely distributed than other types of corals. Other corals, fall into the category of lower susceptibility – specifically, the hard coral *Dasmosmilia lymani* was noted as being relatively common , including in shallower depths, small in size, and possibly less susceptible to fishing gear impacts.

3.1.2 Step 2 – Evaluate coral presence data

The PDT identified scientific investigations where deep-sea coral data were collected, either as a primary objective or, more often, as an incidental outcome, and catalogued this information for each of the potential discrete coral zones. A brief summary of the types of corals found in each zone was also created. The major coral data sets reviewed by the PDT are summarized in Table 6. It is important to understand that generally, these data sets show presence of corals only, and do not give absence or abundance information. Further, unlike NOAA's fish-focused trawl surveys, the various coral surveys tend to be of limited spatial extent, and the regional coverage of coral-related investigations is rather patchy. Most coral presence records are georeferenced and can be mapped, but in some cases, the literature documents coral presence or even relative abundance in a locations that are poorly georeferenced. These types of data are noted in the tables and maps prepared for each area.

For mapping coral distributions, the PDT relied on the Cold-Water Coral Geographic Database (CoWCoG) developed by the US Geological Survey and NOAA's Deep-Sea Coral Research and Technology Program (DSCRTP). A team at USGS compiled version 1 of this database, and additional records were sourced and added by the staff at NOAA's DSCRTP with the assistance of the Northeast Fishery Science Center staff and others. The data sources listed in Table 6 below constitute the bulk of the records in CoWCoG. In general, records vary in age from the 1850s through present, although most of the data were collected since the late 1970s.

Maps for this document were created using a version of this database dated 11/17/11. Corals are grouped taxonomically, and species of conservation interest are highlighted. An effort was made to identify the major contributing data sources for each of the maps, and also to note any scientific investigations in the area that did not produce geo-referenced records. Thus, the tables and maps in this document should show a high degree of correspondence.

After examining all the available coral presence data, the PDT characterized each discrete area as being relatively well assessed for corals, or not well assessed. If a relatively well-assessed area had documented coral presence, it was recommended as a coral zone. If a relatively well-assessed area had few or no corals documented, it was not recommended as a coral management zone.

Table 6 – Deep-sea coral data sources for the Northeast Region

Data set	Citation
Deichmann, 1936	Deichmann, Elisabeth, 1936, The Alcyonaria of the western part of the Atlantic Ocean: Memoirs of the Museum of Comparative Zoology at Harvard College, v. 53, 317 p.
Hecker et al., 1980, 1983	One of the primary data sources describing the deep coral fauna of the northeastern U.S. are these reports, which were prepared for Minerals Management Service in the early 1980s. Several canyons and slope areas were surveyed via submersible and towed camera sled. Hecker, B., Blechschmidt, G., and Gibson, P. 1980. Epifaunal zonation and community structure in three mid- and north Atlantic canyons—final report for the canyon assessment study in the mid- and north Atlantic areas of the U.S. outer continental shelf: U.S. Department of the Interior, Bureau of Land Management Monograph, 139 p.

	Hecker, B., et al. 1983. Final Report – Canyon and Slope Processes Study. Prepared for U.S. Department of the Interior, Minerals Management Service. Contains three volumes: Vol. I, Executive Summary; Vol. II, Physical Processes; and Vol. III, Biological Processes.
NEFSC HUDMAP	Records from 2001, 2002, and 2004 video samples taken near the head of Hudson Canyon between 100-200 m depth. Corals sampled include the sea pen *Stylatula elegans* and the stony coral *Dasmosmilia lymani*.
NEFSC Sea Pens	Records of sea pens compiled from various sources, including submersible surveys, trawl surveys, and towed camera surveys. Data collected between 1956 and 1984.
NES CR Dives	These data summarize dives locations of samples collected during NOAA Ocean Explorer "Mountains in the Sea" cruises to the New England seamounts during 2003 and 2004.
Smithsonian National Museum of Natural History	Records off all coral types from various research vessel surveys conducted from 1873 through present. Surveys conducted in GOM as well as along shelf/slope break on Georges Bank and in Mid-Atlantic Bight.
Theroux and Wigley	Theroux, Roger B. and Wigley, Roland L., 1998, Quantitative composition and distribution of the macrobenthic invertebrate fauna of the continental shelf ecosystems of the northeastern United States. NOAA Technical Report NMFS 140: 240.
US Fish Commission	Records for *Dasmosmilia lymani* off NJ/VA; collected in the 1880s
VIMS for BLM/MMS	Mostly *Dasmosmilia lymani* records; fewer records of *Stylatula elegans*; records from mid-late 1970s; collected for Minerals Management Service by Virginia Institute of Marine Science
Watling et al, 2003	Watling, L., Auster, P.J., Babb, I., Skinder, C., and Hecker, B., 2003, A geographic database of deepwater alcyonaceans of the northeastern U.S. continental shelf and slope: Groton, National Undersea Research Center, University of Connecticut, Version 1.0 CD-ROM.
Yale University Peabody Museum Collection	Yale University Peabody Museum Collection, Yale Invertebrate Zoology—Online Catalog: accessed July 2007 at http://peabody.research.yale.edu/COLLECTIONS/iz/

3.1.3 Step 3 – Evaluate bathymetric and geological data in canyons

As discussed above, the survey effort for corals is patchy, and some of the submarine canyons initially identified as prospective coral management zones have few coral data associated with them. When an area of interest had no or few scientific investigations to document the presence of corals, the PDT made a recommendation about the area on the basis of habitat suitability (the PDT also evaluated habitat suitability for canyons that had 'highly' or 'moderately' adequate coral data on which to base an assessment). As noted above, corals requiring hard substrates were determined to be a focus of conservation efforts. Thus, 'suitable habitat' refers to canyons where rock outcrops and gravel (pebbles, cobbles, boulders) are known to be or likely to be present to provide suitable attachment sites for corals.

Geology and morphology of canyon and adjacent environments

Canyons form by erosion of the sediments and sedimentary rocks of the continental margin. They can be classed as high or low relief. Canyons with high relief that are deeply eroded into the continental margin may be U-shaped or V-shaped. Erosion by glaciers produces U-shaped canyons. These include canyons in Canadian waters in the glacially-eroded Northeast Channel that separates Georges Bank and the Scotian Shelf. These U-shaped canyons contain the following sediment types:

- Glacial gravel (boulders, cobbles, pebbles) that was transported onto canyon rims, walls, and floors by glaciers and floating ice
- Gravel (boulders, cobbles, pebbles) that was transported into canyons by glaciers and floating ice
- Outcropping rocks exposed on canyon walls
- Rock rubble on canyon walls and floor from rock falls

Erosion by rivers, mass wasting, and turbidity currents produces V-shaped canyons. These include the Georges Bank canyons on the bank's southern margin. These canyons did not experience direct glacial erosion because the glaciers terminated on the bank's northern margin. These V-shaped canyons contain the following sediment types:

- Gravel in canyons that was transported by floating ice
- Outcropping rocks exposed on canyon walls
- Rock rubble on canyon walls and floor from rock falls
- Stiff Pleistocene clay exposed on canyon walls; burrowed by crabs and fish to form "pueblo villages"; burrowed clay can collapse to form rubble on canyon walls and floors
- Veneer of modern sediment partly covering canyon walls
- Modern sediment covering canyon floors
- Modern sand transported onto the canyon floor from the shelf can be formed into bedforms by strong tidal currents in some canyons

Canyons shallowly eroded into the continental margin are produced by erosion/mass wasting events such as slumping or landslides. These shallow canyons are found on the shelf edge and upper slope of the southern margin of Georges Bank. Shallow canyons are less likely than deep canyons to have a well-defined canyon axis and floor, and because their walls are not steep, they are less likely than deep canyons to have outcropping rocks. They may contain the following sediment types:

- Gravel in canyons that was transported by floating ice
- Veneer of modern sediment covering canyon walls

Inter-canyon areas on the southern margin of Georges Bank are gently sloping seabed between canyons on the continental slope. They are characterized by both erosional (mass wasting) and depositional processes. Sediment types include:

- Gravel that was transported by floating ice
- Modern sediment

Note that the inter-canyon slope area south of Hudson Canyon is regionally unique and distinct from the Georges Bank areas in that in contains limestone outcrops. This area is discussed further in section 3.3.1.2 (Mid-Atlantic canyons and surrounding slope – Mey, Hendrickson, Toms, S. Toms, Berkley, Carteret, Lindenkohl).

The continental shelf edge (shelf-slope break) represents a transition from a gently sloping shelf (1-2 degrees) to a somewhat steeper continental slope (3-6) degrees, and from coarser-grained shelf sediment to finer-grained upper slope sediment. Sediment types include:

- Modern sediment
- Gravel that was transported by floating ice
- Pebble gravel substrate in areas where sandy sediment has been eroded.

Developing the habitat inference analysis

In some cases, geological data indicating presence of suitable substrates are available for canyons and other areas of interest. When this is the case, inference about the existence of suitable coral habitat is straightforward. Specifically, qualitative assessments of various canyon and slope areas tell us that gravel (pebbles, cobbles, boulders) transported by floating glacial ice commonly occurs in canyon, shelf, and slope environments. However, the extent of these gravel deposits is poorly known and has not been adequately mapped, which limits the ability to make inferences based on substrate data alone. For example, while the presence of gravel substrates in some canyon rim environments (e.g. Oceanographer Canyon) is well documented, we are not able to infer that similar substrates occur on all canyon rims, and it is not possible to generalize about the depth intervals that contain suitable gravel substrates.

When substrate data are not available, the likelihood of the occurrence of rock outcrops (hard substrate) can be inferred by examining bathymetry data. At the October 2011 meeting in Woods Hole, the PDT discussed each canyon individually and made a recommendation as to whether suitable substrates for coral attachment were likely to occur in each canyon. At the December 2011 meeting, the PDT revisited these assessments, and decided to follow a more systematic approach. Thus, a GIS analysis of canyon morphology was completed for each canyon, and a series of measurements were reviewed to support the earlier assessment of habitat suitability.

The length, width, depth, and wall steepness of each canyon have developed in response to erosional processes during canyon formation. Measurements of these characteristics are useful for comparing the morphology of the canyons; and some of them such as canyon length and width may be indicative of the age of the canyons. **However, the best indicator of the possibility that outcropping rocks (that can serve as hard substrate for corals) are exposed on the canyon walls is the relief of the cross section at the shelf break.** The greater the relief of the canyon at the shelf break, the greater will be the likelihood that the canyon has penetrated and exposed the hard sedimentary rocks that are known to underlie the continental shelf and slope. **A relief of 450 m was used as the threshold for inferring the presence of suitable habitats.** In summary, the purpose of the analysis was to evaluate the maximum relief of all canyons, and to and compare them to see which ones most deeply incise the shelf-slope transition zone and are therefore most likely to have exposed rock outcrops that provide suitable coral habitat.

Various measurements were made for each canyon along a cross-section. The cross-section was drawn across the canyon at the shelf break perpendicular to its axis direction from one canyon rim to the opposing canyon rim. The shelf-break (transition from shelf to slope) was drawn where the upper continental slope reaches an inclination of 3 degrees. Use of a depth contour rather than a slope contour was considered, but ultimately the PDT determined that use of a slope contour was more appropriate. In particular, the 200m contour is a good approximation of the shelf-slope break south of Georges Bank and in the Mid-Atlantic, but in the transition area between the two (roughly Alvin Canyon to Hudson Canyon) the shelf break steepens to 3 degrees at deeper depths of around 400m. In this area, a slope contour better captures the shape of the canyon than the 200m depth contour, which only defines the very head of the canyon and not the cross section of greatest vertical relief.

Measurements made for the whole cross-section

- **Maximum depth** is maximum water depth of the cross-section measured from the sea surface.
- **Maximum relief** of the canyon is the difference between the maximum depth of the cross-section and the water depth of the canyon rim (3 degree slope contour). **A relief of 450 m was used as the threshold for inferring the presence of suitable habitats.**
- **Average slope** is the average slope of both canyon walls combined along the entire cross-sectional line.
- **Cross-section width** is the length of the cross-section; this is equivalent to the width of the canyon from rim to rim at the cross-section.

Measurements for each canyon wall along the cross section. For these measurements, the cross section was split at the maximum depth.

- **2D and 3D length** of the wall.

- The **minimum, maximum, and average slope** of each canyon wall**.** Minimum and maximum slope values were taken from the segment that is either closest to the horizontal or most extreme, respectively. The average slope of each canyon wall was determined by averaging the slope for all segments weighted by their 3D length.
- **Relief** of each canyon wall is the difference between the bottom of the wall (the maximum depth) and the top (the water depth of the canyon rim for that wall).

Measurements made for the axis

- **Axis length** is the straight-line distance from the head to the cross-section. It represents the distance a canyon incises the shelf-break.
- **Depth at the canyon head** is the depth of the head of the canyon at the 3-degree slope contour measured from the sea surface.

These canyon attributes were measured using GIS software. The bathymetry data set used was developed by the Nature Conservancy for their Northwest Atlantic Marine Ecoregional Assessment and is available for download at http://www.nature.org/ourinitiatives/regions/northamerica/areas/easternusmarine/explore/index.htm. NOAA's National Geophysical Data Center's Coastal Relief Model (http://www.ngdc.noaa.gov/mgg/coastal/) is the foundation for the Nature Conservancy's bathymetry coverage (and was also used in preparation of the EFH designation maps).

Table 7 - Morphological attributes for submarine canyons along the continental margin of the Northeastern United States. The critical measure for inferring whether habitats are likely to be suitable for corals is cross section relief, shown in boldface type below. Canyons are listed in alphabetical order.

Canyon name	*Maximum depth at cross-section (m)*	*Average slope at cross-section (degrees)*	*Cross-section width (km)*	*Cross-section relief (m)*	*Axis length (km)*	*Depth at head (m)*
Accomac	-861	6.4	10.6	**617**	6.9	-194
Alvin	-1530	7.1	12.2	**721**	22.6	-253
Atlantis	-753	5.3	7.1	**305**	14.1	-218
Baltimore	-949	7.4	12.3	**786**	11.2	-173
Block	-955	4.5	3.3	**151**	22.9	-206
Carteret	-391	5.3	5.3	**252**	1.7	-144
Chebacco	-641	6.5	6.3	**382**	2.7	-204
Dogbody	-625	6.4	5.9	**363**	4.2	-206
Emery	-1054	6.8	8.5	**511**	9.4	-320
Filebottom	-462	3.7	4.8	**160**	2.7	-282
Gilbert	-1209	7.7	13.8	**953**	11.5	-199
Heel Tapper	-1133	6.8	12.7	**742**	7.5	-242
Heezen	-655	6.2	10.4	**455**	5.7	-136
Hudson	-2019	6.8	15.8	**927**	57.0	-178

Canyon name	***Maximum depth at cross-section (m)***	***Average slope at cross-section (degrees)***	***Cross-section width (km)***	***Cross-section relief (m)***	***Axis length (km)***	***Depth at head (m)***
Hydrographer	-1126	10.7	9.6	**935**	18.2	-137
Jones-Babylon	-1450	4.7	11.3	**501**	17.2	-449
Lindenkohl	-814	4.9	14.6	**659**	6.3	-124
Lydonia	-1292	8.1	12.6	**971**	23.2	-154
McMaster	-988	9.2	4.6	**397**	12.0	-301
Munson	-1141	6.3	15.2	**798**	12.0	-137
Nantucket	-408	4.7	3.8	**203**	1.6	-208
Norfolk	-934	8.8	10.4	**798**	13.8	-110
Nygren	-865	5.2	10.5	**596**	4.2	-217
Oceanographer	-1344	8.7	14.4	**1089**	19.0	-160
Powell	-931	8.3	8.1	**604**	13.4	-175
Ryan	-993	7.4	5.9	**405**	11.4	-278
Shallop	-519	6.1	3.9	**211**	1.1	-310
Sharpshooter	-403	2.8	3.8	**141**	1.7	-265
Spencer	-661	6.5	7.1	**415**	4.6	-124
Toms	-686	4.1	15.7	**513**	5.1	-156
Uchupi	-871	6.7	4.4	**329**	5.0	-508
Veatch	-897	7.9	9.0	**610**	9.6	-185
Washington	-814	8.6	8.0	**637**	9.2	-113
Welker	-1333	7.1	17.6	**969**	14.7	-214
Wilmington	-1148	6.9	16.4	**989**	13.0	-152

Table 8 – Measurements for each canyon wall. Canyons are in alphabetical order. Note that the first canyon in each pair is not necessarily the northernmost/easternmost canyon.

Canyon name	***Minimum slope (degrees)***	***Maximum slope (degrees)***	***Average slope (degrees)***	***2D length (km)***	***Relief (m)***
Accomac	0.4	11.4	6.0	6.4	615.3
Accomac	0.5	19.1	6.8	4.2	492.6
Alvin	0.2	20.0	7.2	6.5	721.0
Alvin	0.7	20.4	6.8	5.7	675.7
Atlantis	0.0	13.2	5.5	4.0	304.9
Atlantis	0.7	9.9	5.1	3.1	277.2
Baltimore	0.3	16.4	5.9	7.7	700.9
Baltimore	1.7	28.2	9.8	4.6	779.1
Block	0.6	6.8	3.9	2.2	151.6
Block	1.8	10.1	5.8	1.1	109.4

Canyon name	***Minimum slope (degrees)***	***Maximum slope (degrees)***	***Average slope (degrees)***	***2D length (km)***	***Relief (m)***
Carteret	0.1	12.6	4.3	3.2	239.1
Carteret	0.8	15.5	7.1	2.1	256.3
Chebacco	1.3	20.6	8.0	3.2	381.9
Chebacco	0.3	13.2	5.0	3.1	223.5
Dogbody	1.1	16.1	7.1	3.0	362.6
Dogbody	1.8	11.9	5.7	2.9	286.6
Emery	2.3	10.7	5.4	4.6	410.7
Emery	0.0	16.3	8.6	3.9	510.7
Filebottom	0.2	11.0	3.7	3.6	157.5
Filebottom	0.4	13.7	3.7	1.3	75.2
Gilbert	0.3	26.2	6.8	7.6	879.9
Gilbert	0.9	22.4	8.9	6.2	958.8
Heel Tapper	0.0	25.1	5.9	7.2	721.8
Heel Tapper	0.0	21.7	7.9	5.5	741.6
Heezen	0.7	14.9	5.3	7.4	345.6
Heezen	1.5	23.3	8.4	3.0	440.8
Hudson	0.1	19.8	6.6	8.5	926.9
Hudson	2.4	15.4	7.1	7.2	892.0
Hydrographer	0.2	25.1	10.3	5.3	933.2
Hydrographer	0.2	32.0	11.3	4.3	830.8
Jones-Babylon	0.4	12.2	4.7	7.3	501.1
Jones-Babylon	0.0	14.6	4.9	4.0	330.7
Lindenkohl	0.9	13.0	4.4	7.8	447.7
Lindenkohl	0.2	16.9	5.5	6.8	649.7
Lydonia	0.1	23.6	8.0	8.2	970.8
Lydonia	1.5	15.1	8.4	4.4	648.2
McMaster	0.6	16.2	9.2	2.5	397.4
McMaster	3.5	18.5	9.2	2.1	343.6
Munson	0.0	13.7	6.0	7.9	794.5
Munson	0.2	21.6	6.6	7.3	788.7
Nantucket	0.9	9.5	5.7	2.0	199.2
Nantucket	0.3	9.1	3.6	1.8	107.4
Norfolk	0.2	22.3	8.1	5.7	798.1
Norfolk	1.4	18.2	9.7	4.7	780.8
Nygren	1.3	13.1	6.4	5.3	589.5
Nygren	0.0	8.1	4.0	5.2	360.9
Oceanographer	0.2	27.8	7.6	8.3	965.0

Canyon name	Minimum slope (degrees)	Maximum slope (degrees)	Average slope (degrees)	2D length (km)	Relief (m)
Oceanographer	0.9	20.8	10.2	6.1	1089.1
Powell	0.5	17.4	6.4	5.4	603.6
Powell	2.5	29.6	11.9	2.7	554.3
Ryan	0.7	19.5	7.9	3.1	404.7
Ryan	0.3	16.8	6.9	2.8	333.3
Shallop	1.1	12.6	5.5	2.2	211.4
Shallop	0.5	12.8	7.0	1.7	207.2
Sharpshooter	0.2	5.2	2.8	2.3	110.9
Sharpshooter	0.2	4.7	2.9	1.5	45.8
Spencer	0.1	12.9	5.6	4.3	414.9
Spencer	0.7	17.7	7.8	2.9	388.9
Toms	0.0	12.8	3.5	9.9	500.3
Toms	0.3	14.2	5.1	5.8	512.9
Uchupi	2.3	18.9	7.7	2.2	297.6
Uchupi	1.8	10.8	5.6	2.2	182.0
Veatch	0.8	19.8	7.4	4.9	602.1
Veatch	0.1	16.3	8.5	4.1	609.9
Washington	2.1	17.6	8.9	4.1	633.3
Washington	0.0	14.8	8.3	3.9	553.3
Welker	0.0	19.8	5.9	11.3	969.1
Welker	0.3	19.3	9.2	6.2	929.8
Wilmington	0.5	17.9	6.1	9.7	986.5
Wilmington	0.5	23.6	8.0	6.7	926.3

Note that for some canyons, higher resolution bathymetric data have been collected but are not publically available and therefore were not used in the analysis described above. This is because these data sets were collected recently (summer 2011 work by Ross and Brooke, funded by Bureau of Ocean Energy Management). The most comprehensive database of bathymetry information for the region is being compiled by scientists at USGS, and includes these more recent surveys as well as previously published information. Maps based on the most up to date version of the database were available and reviewed at the Woods Hole meeting, and hard copies were subsequently provided to the PDT. The available bathymetry data sources for each area, including these more recent sources of information, are summarized in the tables in section 3.3.

Note that factors such as water temperature and currents are known to influence distribution of some coral species (see Bryan and Metaxas 2006, 2007), and the PDT discussed including canyon-by-canyon assessments of temperature and currents in this coral zone evaluation. However, it was determined that this wasn't really realistic for our region at this time due to data/information limitations. While temperature may be limiting the distribution of some species, we don't really know the temperature range required by most species, and we don't have season-by-season temperature maps for many areas. Furthermore, coral protection zones will not be based on the distribution and abundance of individual coral species, but rather on the observed or inferred presence of a variety of species with different temperature tolerances. Regarding currents, there are some long term observations from arrays in Baltimore and Lydonia Canyons, but there isn't really sufficient information to use this parameter to infer suitable coral habitats in most locations. Predictive modeling work for regional deep-sea corals is ongoing at the Northeast Fisheries Science Center as of Spring 2012, and may be used in later stages of the Omnibus Amendment for evaluating various management alternatives.

3.2 Summary of results

Canyon areas evaluated in detail:

- Heezen
- Lydonia
- Gilbert
- Oceanographer
- Hydrographer
- Veatch
- Alvin/Atlantis
- Hudson
- Hendrickson
- Wilmington
- Baltimore
- Washington
- Norfolk

Canyon areas evaluated using GIS habitat suitability analysis:

- Heezen
- Nygren
- Munson
- Powell
- Lydonia
- Gilbert
- Chebacco
- Filebottom
- Oceanographer
- Heel Tapper
- Welker
- Sharpshooter
- Dogbody
- Hydrographer
- Shallop
- Veatch
- Nantucket
- Atlantis
- Alvin
- Block
- McMaster
- Ryan
- Uchupi
- Emery
- Jones/Babylon
- Hudson
- Toms
- Carteret
- Lindenkohl
- Spencer
- Wilmington
- Baltimore
- Accomac
- Washington
- Norfolk

Named canyon areas not evaluated using GIS habitat suitability analysis because they do not incise the shelf break significantly at the three degree slope contour. These minor canyons are not recommended as discrete coral zones, although some lie within a recommended slope coral zone:

- Clipper
- Mey
- Hendrickson
- South Heyes
- Middle Toms
- South Toms
- Berkley
- South Wilmington
- North Heyes

- South Vries
- Warr
- Phoenix
- Leonard

Slope areas evaluated:

- Slope near US/CAN border
- Slope between Veatch and Hydrographer Canyons
- Slope west of Alvin and Atlantis Canyons
- Mid-Atlantic Canyons and surrounding slope – Mey to Lindenkohl
- Slope between Baltimore and Accomac Canyons

The results of the assessment for the evaluated canyon and slope areas are presented below. To reiterate, the recommended/not recommended categories area as follows:

- **Category 1 – Recommended** based on coral data: adequate scientific observations, abundant corals.
- **Category 2 – Recommended b**ased on bathymetric and/or geologic data: highly suitable habitat inferred.
- **Category 3 – Not recommended** based on coral data: adequate scientific observations, but no or few corals.
- **Category 4 – Not recommended** based on bathymetric and/or geologic data: appropriate habitat not inferred.

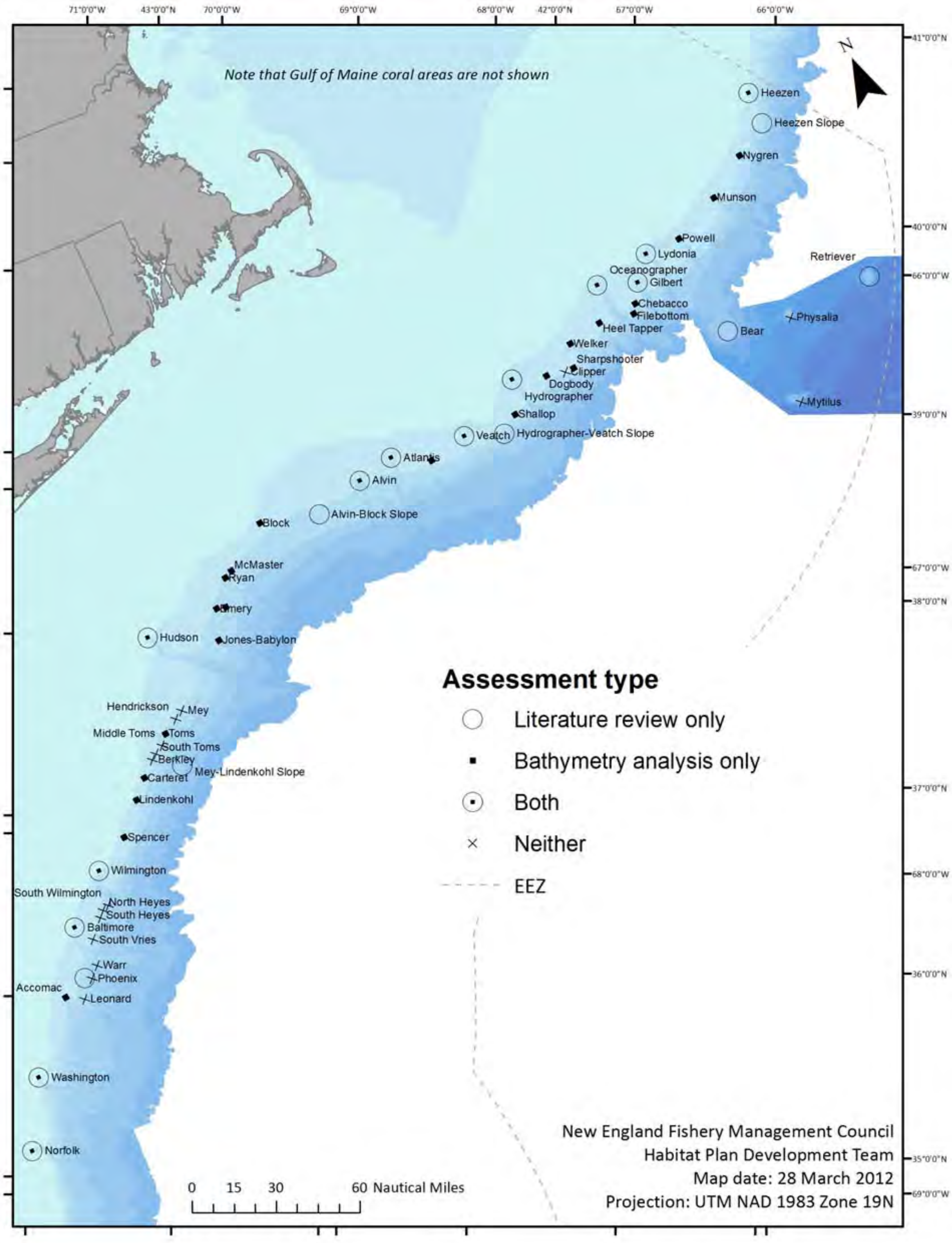
Table 9 – Coral assessment summary. These results are mapped on the following pages. Canyons are listed in north to south order.

Area	***Full literature review or bathymetry evaluation only***	***Adequacy of coral survey observations***	***Relative Abundance of corals***	***Habitat Suitability***	***Recommendation and category***
Canyons					
Heezen Canyon	Both	Moderate	High	Suitable	Yes - C1 and C2
Nygren Canyon	Bathy	Not assessed	n/a	Suitable	Yes - C2
Munson Canyon	Bathy	Not assessed	n/a	Suitable	Yes - C2
Powell Canyon	Bathy	Not assessed	n/a	Suitable	Yes - C2
Lydonia Canyon	Both	High	High	Suitable	Yes - C1 and C2
Gilbert Canyon	Both	Inadequate	n/a	Suitable	Yes - C2
Chebacco Canyon	Bathy	Not assessed	n/a	Not suitable	No - C4
Filebottom Canyon	Bathy	Not assessed	n/a	Not suitable	No - C4
Oceanographer Canyon	Both	High	High	Suitable	Yes - C1 and C2
Heel Tapper Canyon	Bathy	Not assessed	n/a	Suitable	Yes - C2
Welker Canyon	Bathy	Not assessed	n/a	Suitable	Yes - C2
Sharpshooter Canyon	Bathy	Not assessed	n/a	Not suitable	No - C4
Clipper Canyon	Bathy	Not assessed	n/a	Not suitable	No - C4

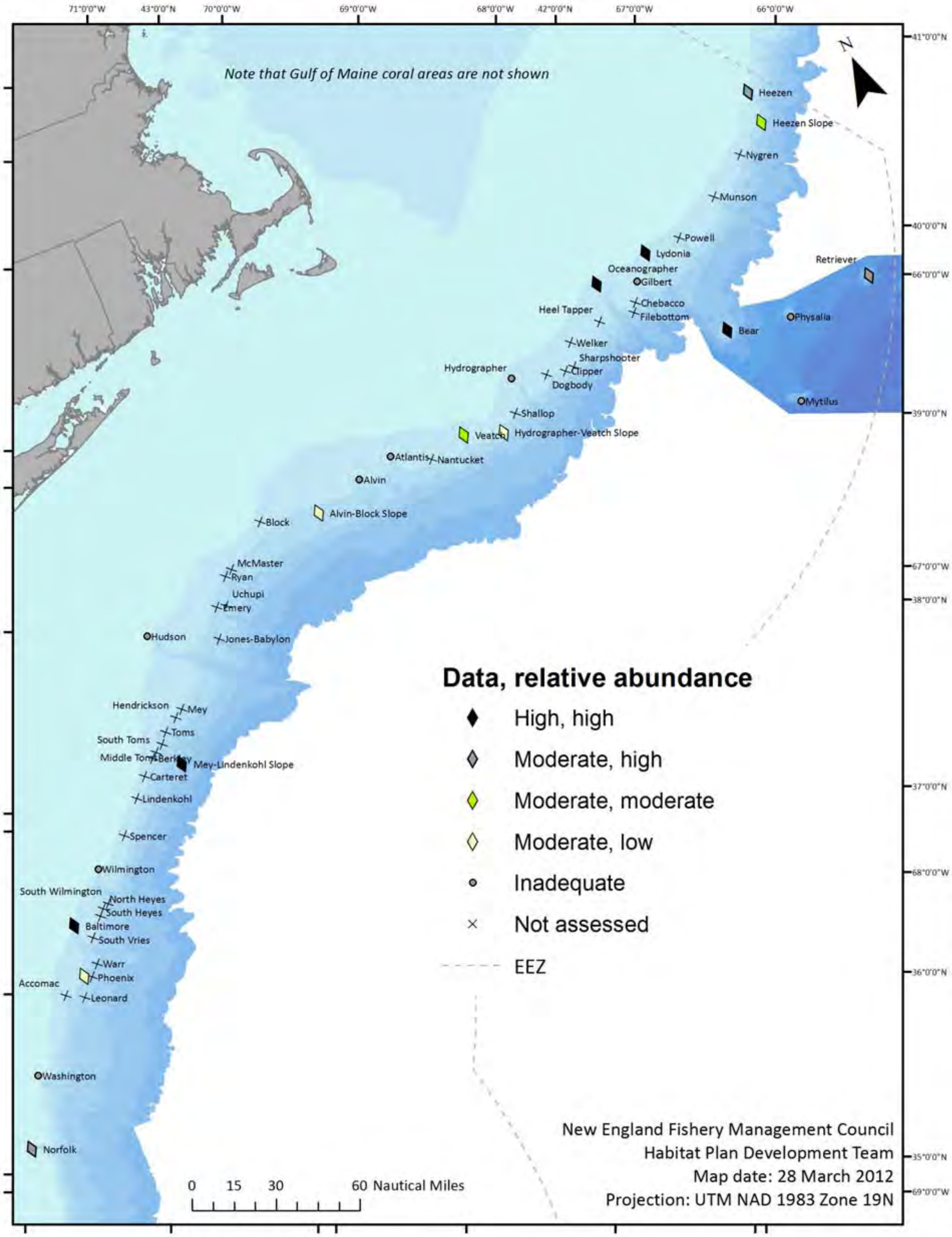
Area	*Full literature review or bathymetry evaluation only*	*Adequacy of coral survey observations*	*Relative Abundance of corals*	*Habitat Suitability*	*Recommendation and category*
Dogbody Canyon	Bathy	Not assessed	n/a	Not suitable	No - C4
Hydrographer Canyon	Both	Inadequate	n/a	Suitable	Yes - C2
Shallop Canyon	Bathy	Not assessed	n/a	Not suitable	No - C4
Veatch Canyon	Bathy	Moderate	Moderate	Suitable	Yes - C1 and C2
Nantucket Canyon	Bathy	Not assessed	n/a	Not suitable	No - C4
Atlantis Canyon	Both	Inadequate	n/a	Not suitable	No - C4
Alvin Canyon	Both	Inadequate	n/a	Suitable	Yes - C2
Block Canyon	Bathy	Not assessed	n/a	Not suitable	No - C4
McMaster Canyon	Bathy	Not assessed	n/a	Not suitable	No - C4
Ryan Canyon	Bathy	Not assessed	n/a	Not suitable	No - C4
Uchupi Canyon	Bathy	Not assessed	n/a	Not suitable	No - C4
Emery Canyon	Bathy	Not assessed	n/a	Suitable	Yes - C2
Jones Canyon	Bathy	Not assessed	n/a	Suitable	Yes - C2
Hudson Canyon	Both	Inadequate	n/a	Suitable	Yes - C2
Mey Canyon	Neither	Not assessed	n/a	Not suitable	No - C4
Hendrickson Canyon	Neither	Not assessed	n/a	Not suitable	No - C4
Toms Canyon	Bathy	Not assessed	n/a	Suitable	Yes - C2
South Heyes Canyon	Neither	Not assessed	n/a	Not suitable	No - C4
Middle Toms Canyon	Neither	Not assessed	n/a	Not suitable	No - C4
South Toms Canyon	Neither	Not assessed	n/a	Not suitable	No - C4
Berkley Canyon	Neither	Not assessed	n/a	Not suitable	No - C4
Carteret Canyon	Bathy	Not assessed	n/a	Not suitable	No - C4
Lindenkohl Canyon	Bathy	Not assessed	n/a	Suitable	Yes - C2
Spencer Canyon	Bathy	Not assessed	n/a	Not suitable	No - C4
Wilmington Canyon	Both	Inadequate	n/a	Suitable	Yes - C2
South Wilmington Canyon	Bathy	Not assessed	n/a	Not suitable	No - C4
North Heyes Canyon	Bathy	Not assessed	n/a	Not suitable	No - C4
South Vries Canyon	Bathy	Not assessed	n/a	Not suitable	No - C4
Baltimore Canyon	Both	High	High	Suitable	Yes - C1 and C2
Warr Canyon	Neither	Not assessed	n/a	Not suitable	No - C4
Phoenix Canyon	Neither	Not assessed	n/a	Not suitable	No - C4
Leonard Canyon	Neither	Not assessed	n/a	Not suitable	No - C4
Accomac Canyon	Bathy	Not assessed	n/a	Suitable	Yes - C2
Washington Canyon	Both	Inadequate	n/a	Suitable	Yes - C2
Norfolk Canyon	Both	Moderate	High	Suitable	Yes - C1 and C2
Gulf of Maine					
Mt Desert Rock Coral Zone	Lit review	High	High	Not assessed	Yes - C1

Area	***Full literature review or bathymetry evaluation only***	***Adequacy of coral survey observations***	***Relative Abundance of corals***	***Habitat Suitability***	***Recommendation and category***
W Jordan Basin Coral Zone	Lit review	High	High	Not assessed	Yes - C1
Seamounts					
Bear Seamount	Lit review	High	High	Not assessed	Yes - C1
Retriever Seamount	Lit review	Moderate	High	Not assessed	Yes - C1
Physalia Seamount	Inference	Inadequate	n/a	Not assessed	Yes - C2
Mytilus Seamount	Inference	Inadequate	n/a	Not assessed	Yes - C2
Slope Areas					
Heezen Slope	Lit review	Moderate	Moderate	Not assessed	No - C3
Hydrographer-Veatch Slope	Lit review	Moderate	Low	Not assessed	No - C3
Alvin-Block Slope	Lit review	Moderate	Low	Not assessed	No - C3
Mey-Lindenkohl Slope	Lit review	High	High	Not assessed	Yes - C1
Baltimore-Accomac Slope	Lit review	Moderate	Low	Not assessed	No - C3

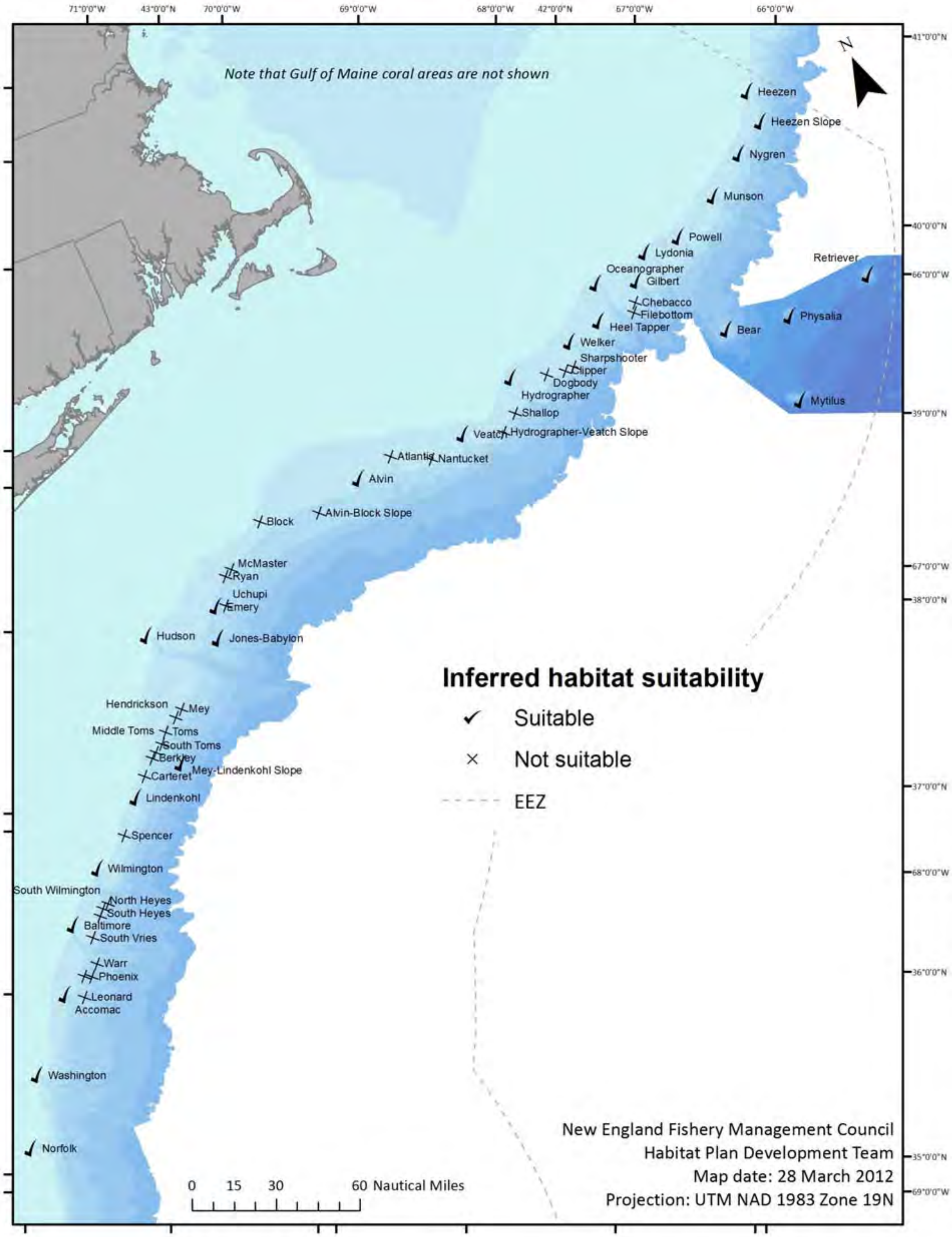
Map 1 – Type of assessment conducted.



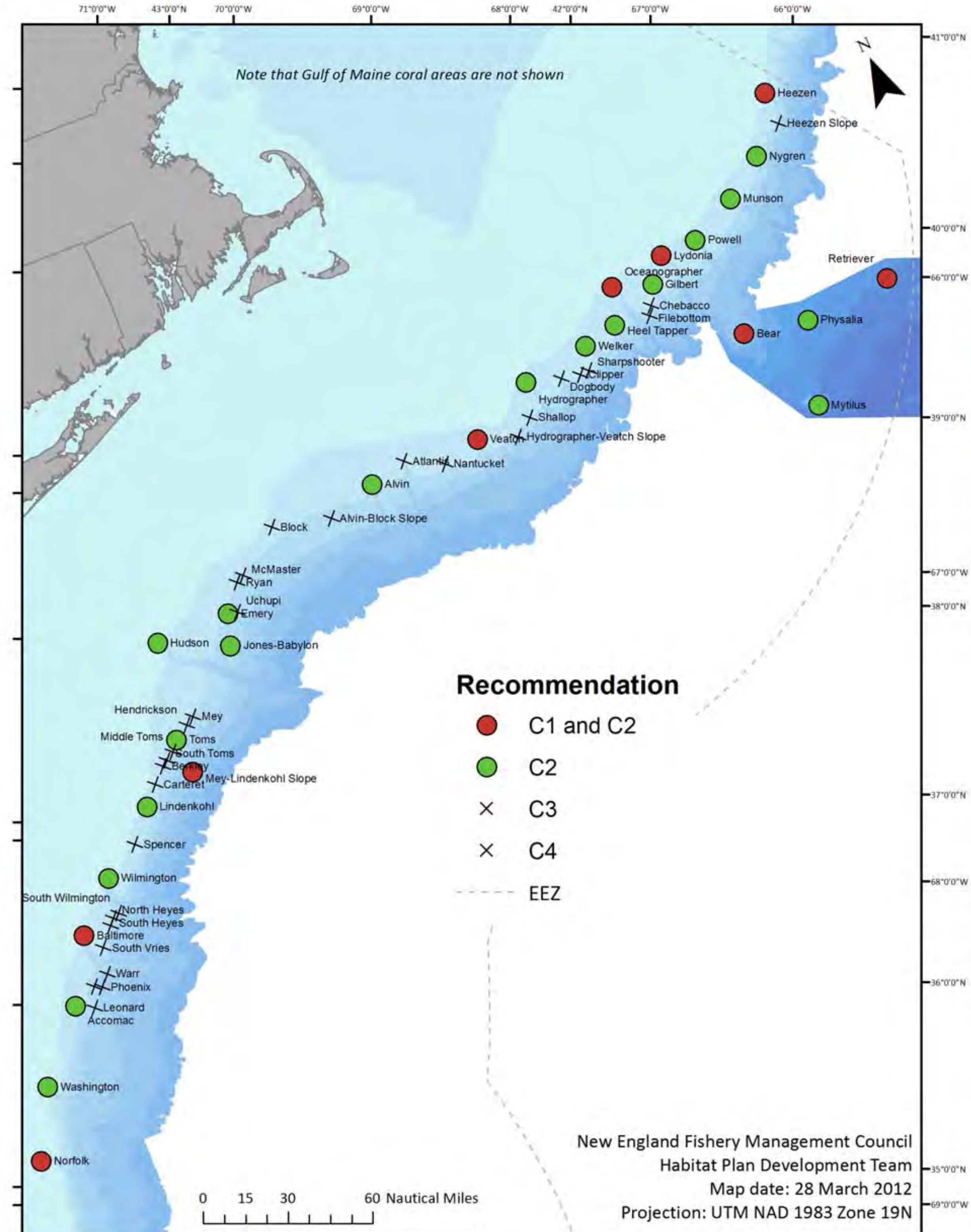
Map 2 – Suitability of coral observations for assessing each area; relative abundance of corals given available data.



Map 3 –Habitat suitability. Clockwise from top left: western Georges Bank, eastern Georges Bank, northern mid-Atlantic, southern mid-Atlantic.



Map 4 – Final recommendation. C1=Recommended based on coral data, C2=Recommended based on inferred habitat suitability, C3=Not recommended based on coral data, C4=Not recommended based on habitat suitability.



3.3 Information for individual discrete zones

This section details available information for each location, specifically: (1) morphology, bathymetry and slope, (2) substrate, and (3) coral distribution/diversity. Areas are grouped into the following categories:

- Canyons and slope areas recommended on basis of coral data and habitat suitability
- Canyons recommended on basis of habitat suitability
- Canyons and slope areas not recommended
- Other recommended zones – seamounts and Gulf of Maine

3.3.1 Canyon and slope areas recommended on basis of coral data and habitat suitability

These areas were all assessed as having adequate observations on which to base an assessment about coral abundance (either highly or moderately adequate), and coral abundance compared to other areas was found to be high to moderate. All of these canyons fell within the threshold of having at least a 450m or greater maximum relief, so likelihood of outcropping rocks and thus suitable habitats was inferred.

3.3.1.1 Heezen Canyon

Although Heezen Canyon has only moderately adequate coral observations, corals have been found during all dives conducted. Also, suitable coral habitat (bathymetry and geology) has been documented. While the maximum relief of Heezen Canyon is just equal to the 450m threshold, the walls are relatively steep in comparison with other canyons. It is recommended as a coral zone.

Table 10 – Geomorphological characterization and coral presence and distribution for Heezen Canyon

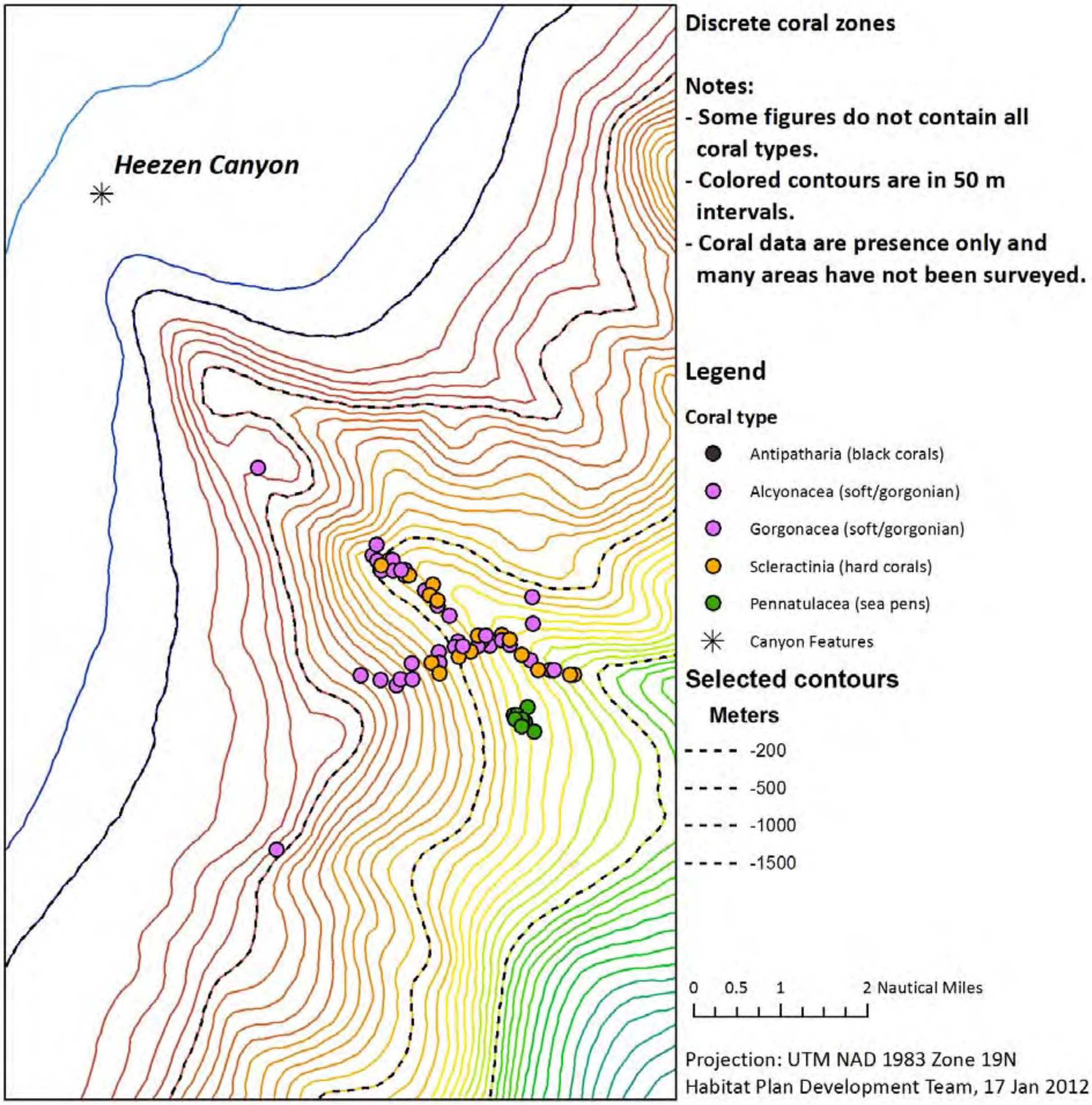
Type of information	**Data sources and methods**	**Summary of information**
Morphology, bathymetry and slope	Ryan et al 1978, also summarized in Hecker and Blechschmidt (1979) Bathymetric survey done in 1977 by Ryan et al. (no details).	Very narrow and deeply incised canyon, described as "an extremely narrow and winding gorge cut into sheer cliffs of massive chalk." See bathymetric map in Ryan et al. with location of dive transects.
Substrate	See refs above Survey effort = 3 Alvin dives, 2 up thalweg, one up SW wall in 1977, depths 850-1630 m	Muddy to sandy ripple-marked canyon floor with minor consolidated clay outcrops, axis heavily littered with large talus blocks and flanked by massive outcrops with numerous sediment dusted ledges, exposures of limestone and calcareous sandstone often cliff-like, 70 m high cliff of white chalk in canyon axis; steep, mud-covered slope (complex terrain of mud ridges and steep gullies) with some exposed bedrock outcrops and occasional glacial erratics. See cross-section geological depiction of surveyed portion of canyon in Ryan et al.
Corals	Hecker and	**Stony**: *Desmophyllum dianthus, Flabellum alabastrum*; **Soft**:

Type of information	Data sources and methods	Summary of information
documented and depths	Blechschmidt (1979); Hecker et al. (1980); Opresko (1980); also NE DSC database including Smithsonian data.	*Anthomastus agassizii, Anthomastus grandiflorus, Clavularia rudis, Duva (= Capnella) florida, Gersemia fruticosa*, *Acanella arbuscula, Paramuricea grandis*; **Sea pens**: *Anthoptilum grandiflorum, Halipteris* (=Balticina) *finmarchica, Kophobelemnon stelliferum*. *Gersemia fruticosa* between 600-1200 m. The gorgonian *Acanella arbuscula* and the soft coral *Anthomastus grandiflorus*, both found on soft substrates, occurred at 850-1050 m; the gorgonian *Paramuricea grandis* was common from 1450-1500 m; the soft coral *Anthomastus agassizii* and the stony coral *Desmophyllum dianthus* were found from 1150-1500; *Desmophyllum dianthus* was also found from 1500-1550 m. *Clavularia rudis*: axis of Canyon at 1100 m; *Duva (= Capnella) florida* axis of Heezen Canyon from 1100-1200 m. *Anthoptilum grandiflorum*: six on wall of Heezen Canyon between 850-1050 m. *Halipteris* (=*Balticina*) *finmarchica* between 900-2200 m; *Kophobelemnon stelliferum* between 1300-1600 m.

Table 11 – Coral assessment – Heezen Canyon

Attribute	Assessment			Notes
Adequacy of coral survey work relative to other areas	*High*	*Moderate*	*Inadequate*	Only three sub dives, limited depth range. Corals observed on all three dives. Note: Acanella in soft substrate
		X		
Relative frequency of occurrence of corals in comparison to other canyon areas	*High*	*Moderate*	*Low*	Assume that more surveying would probably have found more corals because corals were seen on all 3 dives
	X			
Likelihood that corals occur there based on habitat suitability	*Likely*		*Unlikely*	
	X			

Map 5 – Heezen Canyon coral observations.



Data sources of observations for Heezen Canyon:
Northwestern-most observations from 1991 Johnson Sea Link dives
Observations in axis of canyon from Hecker et al 1980
Sea pen observations from Smithsonian
Single Theroux & Wigley observation of Acanella in southwestern-most part of figure

3.3.1.2 Lydonia Canyon

Lydonia Canyon has been relatively well surveyed. It is recommended as a coral zone based on documented presence of corals and suitable coral habitat.

Table 12 – Geomorphological characterization and coral presence and distribution for Lydonia Canyon

Type of information	Data sources and methods	Summary of information
Morphology, bathymetry and slope	1. Hecker et al. (1980) 2. Thompson et al. (1980) 3. Hecker et al. (1983) 4. Pratt (1967) Bathymetric survey done in 1979 with 12kHz echo sounder	A relatively large canyon with a narrow axis (seldom >50 m wide) and steep walls incised by numerous small tributaries. This canyon cuts 20 km [15 km, Pratt] into the shelf, empties on to the continental rise at depth >2 km, and has an overall gradient running down the axis from the head >3 degrees. Joins deep-sea channel for Gilbert Canyon on continental rise. See bathymetric maps in H & B (1980) and Hecker et al. (1983) with locations of camera and dive transects, also core and dredge samples in Thompson et al. (1980).
Substrate	1. Hecker et al. (1980) 2. Hecker and Blechschmidt (1979) 3. Thompson et al. (1980) 4. Hecker et al. (1983) Three submersible dives in head of canyon (152-366 m) – see ref #2 Total 1979-1982 survey effort = 16 camera tows, 17 Alvin dives, >114K m^2 of seafloor, 130-2330 m (ref #4) Core and dredge sampling conducted in 1979 (see ref #3)	(1) Fine sediment predominates on walls and along axis; rock outcrops mainly restricted to axis with occasional exposures on walls; glacial erratics – mostly cobbles and pebbles with some shell hash – abundant on east flank above 400 m and present in reduced numbers on west flank. Heterogeneous environment is capable of supporting large populations of corals. Lydonia Canyon appears to be an area of active erosion, especially along the canyon axis. (2) Head of canyon (150-400 m) predominantly sandy interspersed with gravel, cobbles, and glacial erratics. (3) Walls of most of lower and mid canyon comprised of outcropping and subcropping[9] strata (also in small side tributaries); less exposed outcrop towards head of canyon; narrow floor sandy and rippled; broad area of cobbles and boulders on lower east flank and a small patch on west flank; surface sediment sandy on walls and along axis. (4) Both walls exhibit massive exposures of outcrop, as well as steep talus slopes, along most of their length; in middle of canyon, where it incises the shelf, well developed ridges and tributaries dominate upper walls; glacial erratics found throughout canyon.
Corals documented and depths	H & B (1980) and Hecker et al. (1983), also NE DSC database including Smithsonian data Multiple dives at two	**Stony**: *Dasmosmilia lymani, Desmophyllum dianthus, Solenosmilia variabilis, Javania cailleti*; **Soft**: *Anthomastus agassizii, Clavularia rudis, Duva (= Capnella) florida*, *Capnella glomerata*, *Paragorgia arborea, Primnoa resedaeformis, Acanthogorgia armata*, *Anthothela grandiflora*, *Acanella arbuscula, Paramuricea grandis*; **Sea pens**: *Anthoptilum murrayi*, *Kophobelemnon stelliferum*, *Pennatula aculeata*, *Pennatula grandis, Distichoptilum gracile, Stylatula elegans*. Smithsonian also lists

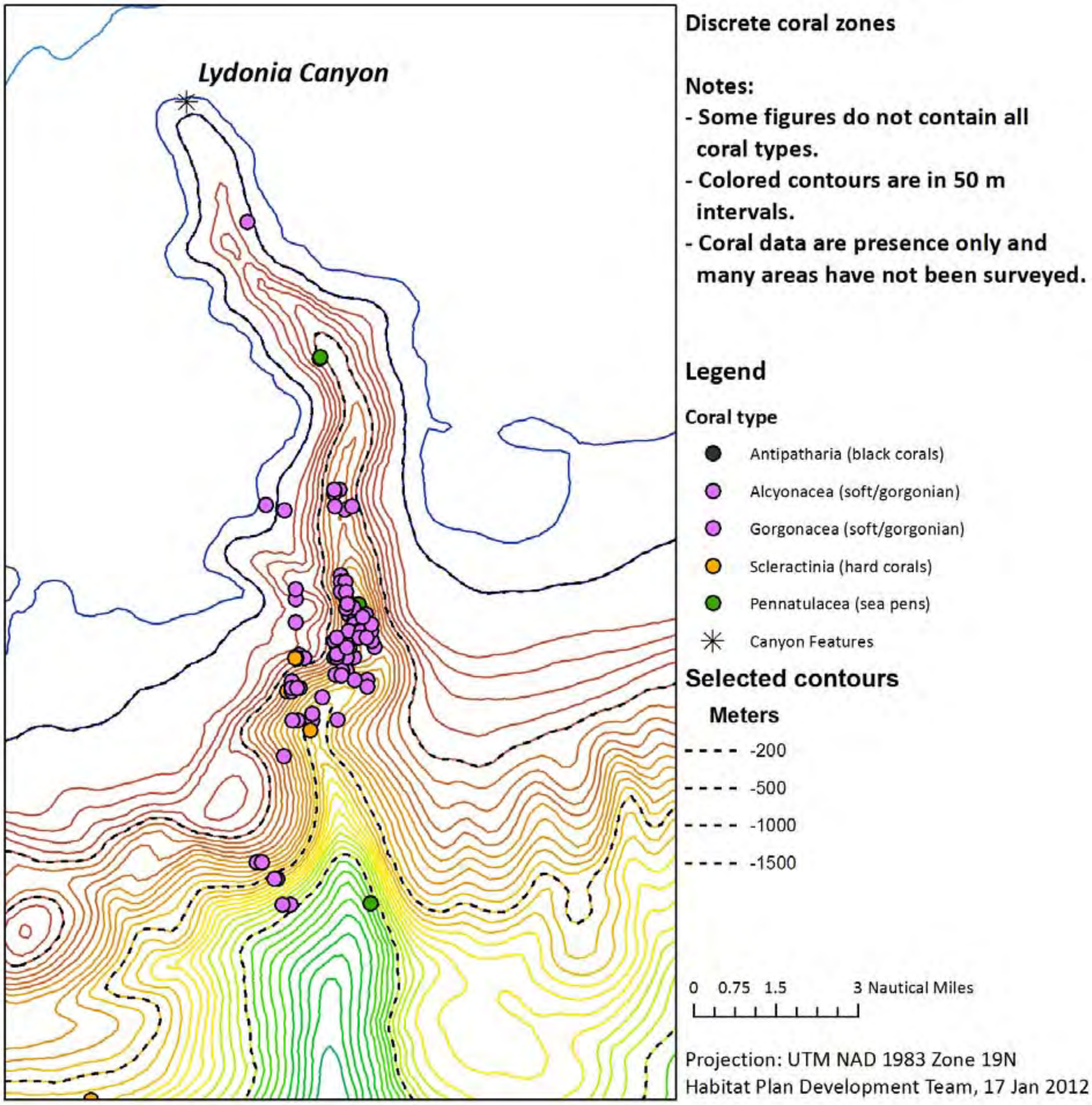
9 Subcropping refers to a rock unit that has been partially eroded and is overlain by a succeeding (younger) rock unit. Definition adapted from McGraw-Hill Dictionary of Scientific & Technical Terms, 6E, Copyright © 2003 by The McGraw-Hill Companies, Inc.

Type of information	Data sources and methods	Summary of information
	monitoring stations during 1971-1986, no available information (see Cooper et al. 1987)	*Lophelia pertusa* (**stony**), *Keratoisis* sp. (**soft**), *Scleroptilum grandiflorum* (**sea pen**). *Clavularia rudis*: 900 m. *Duva (= Capnella) florida*: 350-1500 m; most common farther up east axis between 500-700 m. *Capnella glomerata*: several individuals found at 200 m and 562 m. *Acanthogorgia armata*: 400-1299 m. *Paragorgia arborea*: 300-900 m. *Paramuricea grandis*: 400-1349 m. *Primnoa resedaeformis*: 560 m. *Paramuricea grandis*: deeper part of the axis at > 800 m. *Anthothela grandiflora*: 450-1149 m. *Paramuricea grandis*: 400-1349 m. *Pennatula grandis*: Alvin dive 1263 covered lower east wall, axis, and west wall of canyon between 933-1145 m; *P. grandis* found on floor of canyon axis. (Hecker et al. 1983). *Distichoptilum gracile*: soft substrates, especially on east wall and axis (Hecker et al. 1983); 1100-1800 m (Opresko 1980). Hecker et al. (1983) noted in Canyon (p. 34) below 990 m (p 40); especially 1000-1500 m (p. 42) or about 1300-1500 (p. 45). East wall dominant between 1200-1500 m (p. 48). In the axis reaches higher densities, with a peak of 0.7-0.9 individuals/m 2 at 1600 m, than on either of the walls (< 0.2 individuals/m2) (p. 48). Also Alvin 1265 lower west wall 900-1080 m on soft substrate a few are found (p. 130). Alvin 1263, dive covered the lower east wall, axis, and west wall of the canyon between 933-1145 m; found on floor of canyon axis (p. 131). Alvin 1267 axis and east wall 1317-1520 m, silty floor. Also above the cliffs in silt covered tributaries with small clay out crops (p. 131). Alvin 1268 axis at 2003 m (p. 132). Alvin 1264 lower west wall of silt between 2177-2190 m, plus silty axis… throughout this region it's a dominant (p. 133). *Kophobelemnon stelliferum*: 700-800 m (Opresko 1980). *Pennatula aculeata*: quite common near head of Canyon between 400-600 m, soft substrates in the shallow axis and on the west wall (Hecker and Blechschmidt 1980); high concentrations between 300-450 or 550 m in silty axis (Hecker et al. 1983.); 350-1375 (Opresko 1980). Hecker et al (1983) notes Alvin 1039 dive, a depression in axis at about 400 m, silty; *P. aculeata* dominates (p. 127). Alvin 1040: axis and east wall 170-440 m; sea pen totally dominates flat, silty axis (p. 128). Alvin 1037: axis and lower west wall 330-550 m; dominant in course-grained axis (p. 128). *Distichoptilum gracile*: 1100-1800 m (Opresko 1980); below 990 m, esp. 1000-1500 m; dominant on east wall 1200-1500 m, higher densities in axis at 1600 m (Hecker et al. 1983). *Stylatula elegans*: one specimen found at about 600 m (Opresko 1980).

Table 13 – Coral assessment - Lydonia Canyon

Attribute	Assessment		
Adequacy of coral survey work relative to other areas	*High*	*Moderate*	*Inadequate*
	X		
If surveyed, presence of corals in comparison to other canyon areas	*High*	*Moderate*	*Low*
	X		
Likelihood that corals occur there based on habitat suitability	*Likely*		*Unlikely*
	X		

Map 6 – Lydonia Canyon coral observations.



Data sources of observations for Lydonia Canyon:
Majority of observations in axis of canyon are from Hecker et al 1980
Sea pen, gorgonian, soft coral and hard coral observations from Smithsonian scattered along canyon axis and walls
Two Theroux & Wigley observations in head of canyon

3.3.1.3 Oceanographer Canyon

Oceanographer Canyon has been relatively well surveyed. It is recommended as a coral zone based on documented presence of both corals and suitable coral habitat.

Table 14 – Geomorphological characterization and coral presence and distribution for Oceanographer Canyon

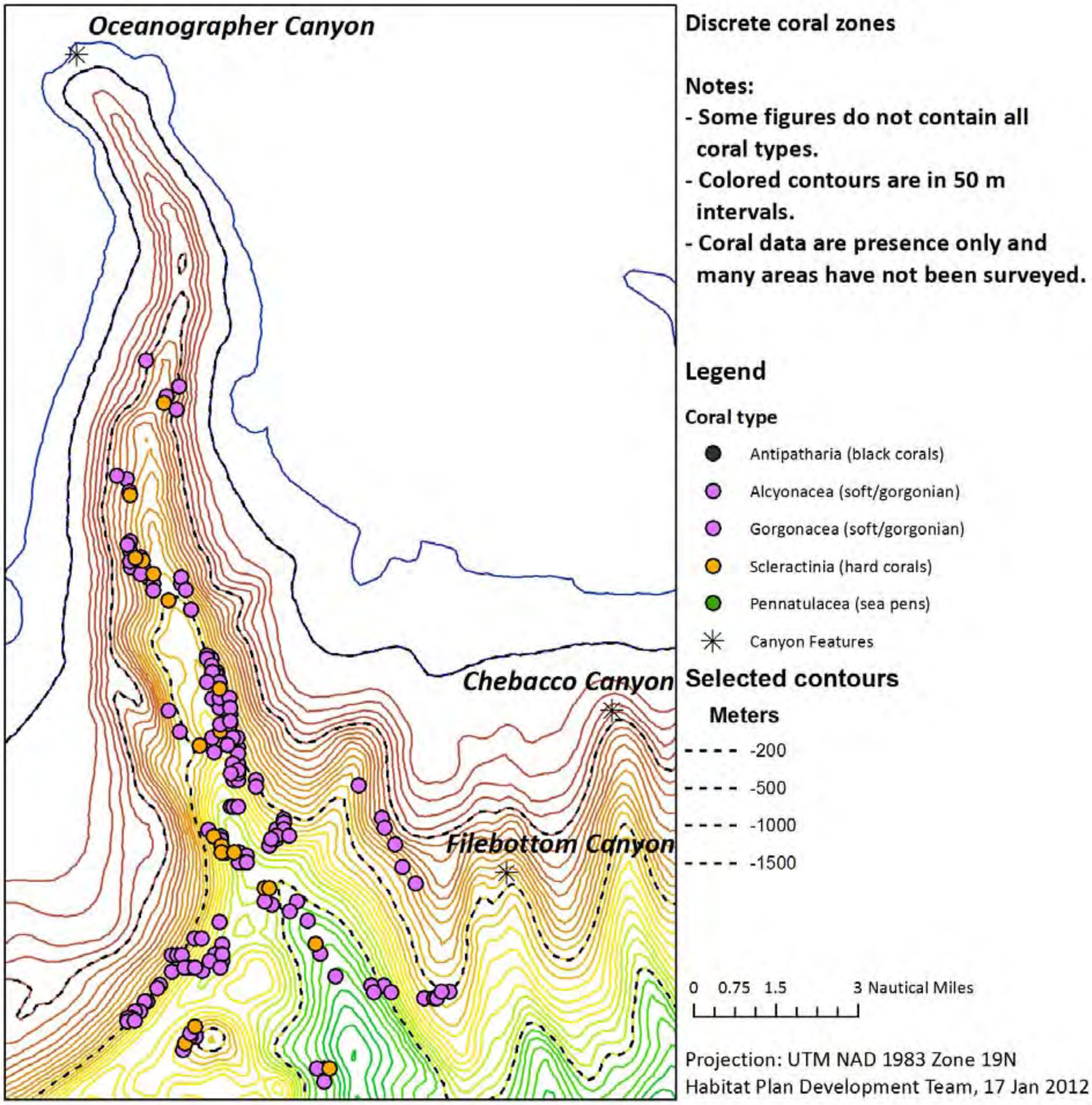
Type of information	Data sources and methods	Summary of information
Morphology, bathymetry and slope	1. Ryan et al. (1978) 2. Hecker et al. (1980) 3. Thompson et al. (1980) 4. Pratt (1967) Bathymetric survey done in 1979 with 12kHz echo sounder, also by Ryan et al.	Deeply incised canyon with steep walls with numerous lateral tributaries mostly originating below shelf edge at depths >200. This canyon cuts more than 30 km [18 km in Pratt] into the shelf, empties on to the continental rise at depth >2 km, overall axis gradient >3 degrees, floor seldom wider than 50 m. There is a large secondary channel east of the axis in the lower part of the canyon. Poorly defined in the deep sea although very precipitous and rocky where it crosses the shelf. See bathymetric maps in H & B (1980) and Ryan et al. (1978) with locations of acoustic, camera, and dive transects; also locations of dredge samples (Thompson et al. 1980).
Substrate	See above, also 5. Hecker and Blechschmidt (1979) analyzed photos taken during 3 ALVIN dives in 1977, two in axis and one up western wall, depths 500-1800 m (ref #1) 6. Valentine et al. (1980) 6 ALVIN dives in 1978, 5 in walls and one in lower canyon axis, 133-1293 m (refs 2 and 3) 8 NEKTON-GAMMA dives in 1974 to max depth of 308 m (ref #6). 4 camera sled transects in 1979 in 400-1800 m (900-1800 m in axis), area photographed = 18,433 m^2 (ref #2). Dredge samples collected in 1979 (see ref #3)	(1) Rock outcrops and talus on canyon floor, no significant rock exposures on west wall - see cross-section geological depiction of surveyed portion of canyon axis in Ryan et al. (1978). (2) High substrate variability. Silty sediment predominates on lower flanks of the canyon along with numerous glacial erratics ranging from cobbles to boulders with occasional rock outcrops on east flank and an outcrop of hard clay on the west flank; extensive outcrops of rock (e.g. siltstone) and hard clay form steep walls on both sides of canyon axis; numerous cobbles and boulders on axis walls, either talus blocks or glacial erratics; rippled mud and sand along axis. This canyon is probably undergoing active erosion. (3) Outcropping strata in along walls and in tributary channels, minor areas of exposed bedrock on east wall; floor of rippled sand; three major areas of avalanche scars near base of canyon. (5) Wall silty with some sandy areas 900-1200 meters; consolidated clay, cobbles, glacial erratics and extensive coral rubble 700-1350 m; outcrop seen at 1050-1400 m; axis silty with occasional sandy patches flanked by extensive outcrops on both sides with frequent talus blocks at base of outcrops. (6) Walls are generally smooth, but are interrupted in places by outcrops (calcareous siltstone >100 m thick exposed in east wall); large boulders on gently sloping upper canyon walls; when present, isolated erratic boulders are most prominent feature on sea floor; gravel up to cobble size present to some extent throughout northern part of canyon with isolated patches on canyon walls and in the axis; most gravel Is near shelf break in clasts of a single layer resembling a lag deposit or pavement.

Type of information	Data sources and methods	Summary of information
Corals documented and depths	1. Hecker et al. (1980) 2. Hecker and Blechschmidt (1979) 3. Opresko (1980) 4. Thoma et al. (2009) 5. Valentine et al. (1980) Also NE DSC database including Smithsonian data.	**Stony**: *Desmophyllum dianthus, Lophelia pertusa (?), Flabellum alabastrum, Javania cailleti;* **Soft**: *Anthomastus agassizii, Anthomastus grandiflorus, Clavularia rudis, Duva (= Capnella) florida*, *Paragorgia arborea, Primnoa resedaeformis, Acanthogorgia armata*, *Anthothela grandiflora*, *Acanella arbuscula, Paramuricea grandis, Thouarella grasshoffi*; **Sea pens**: *Pennatula aculeata*, *Distichoptilum gracile*. *Desmophyllum dianthus*: boulders and outcrops 650-1600 m; found throughout axis between 1500-1600 m (Hecker and Blechschmidt 1980). *Lophelia pertusa*: west wall of at 1100 m, dead rubble also found on wall at depths from 700-1300 m. *Flabellum alabastrum*: soft substrate. *Javania cailleti*: axis between 935-1220 m. *Anthomastus agassizii*: on boulders and outcrops from 1057-1326 m; Valentine et al. (1980) found them in a zone of greatest abundance from 1100-1860 m; Hecker and Blechschmidt (1980) found them mostly from 950-1350 m on glacial erratics, outcrops, coral rubble. *Anthomastus grandiflorus*: "in the northern canyons found from 700-1500 m." *Clavularia rudis*: 750 and 900 m. *Acanthogorgia armata*: boulders or outcrops between 400-1299 m; from 650-950 m (Hecker and Blechschmidt 1980; Hecker et al. 1980). *Acanella arbuscula*: 1046-1191 m; found by Hecker and Blechschmidt (1980) mostly from 950-1350 m. *Paragorgia arborea*: 300-1100 m; large colonies in the axis above 1000 m. *Primnoa resedaeformis*: zone of greatest abundance from 300-1099 m (Valentine et al. 1980). *Paramuricea grandis*: on wall and axis of on boulders and outcrops between 400-1349 m; Thoma et al (2009) 814, 1078 m; Valentine et al. (1980) observed greatest abundance from 1100-1860 m; Hecker and Blechschmidt (1980) observed they were dominant from 950-1350 m. *Pennatula aculeata*: 1700-1799 m deep part of axis (Opresko 1980). *Distichoptilum gracile*: soft substrates, lower east wall and in the axis (Hecker et al 1980); 1100-1800 m (Opresko 1980).

Table 15 – Coral assessment - Oceanographer Canyon

Attribute	Assessment		
Adequacy of coral survey work relative to other areas	*High*	*Moderate*	*Inadequate*
	X		
If surveyed, presence of corals in comparison to other canyon areas	*High*	*Moderate*	*Low*
	X		
Likelihood that corals occur there based on habitat suitability	*Likely*		*Unlikely*
	X		

Map 7 – Oceanographer Canyon coral observations.



Data sources of observations for Oceanographer Canyon:
Majority of observations are from Hecker et al 1980
A few coral observations from Smithsonian scattered along canyon walls
A few Watling & Auster database observations scattered along canyon walls

3.3.1.1 Veatch Canyon

Minor amount of survey work with some information on corals, although no images or physical samples. Substrate appears to be suitable, and habitat suitability analysis indicates sufficient relief to expose rock outcrops. Veatch Canyon is recommended as a coral zone.

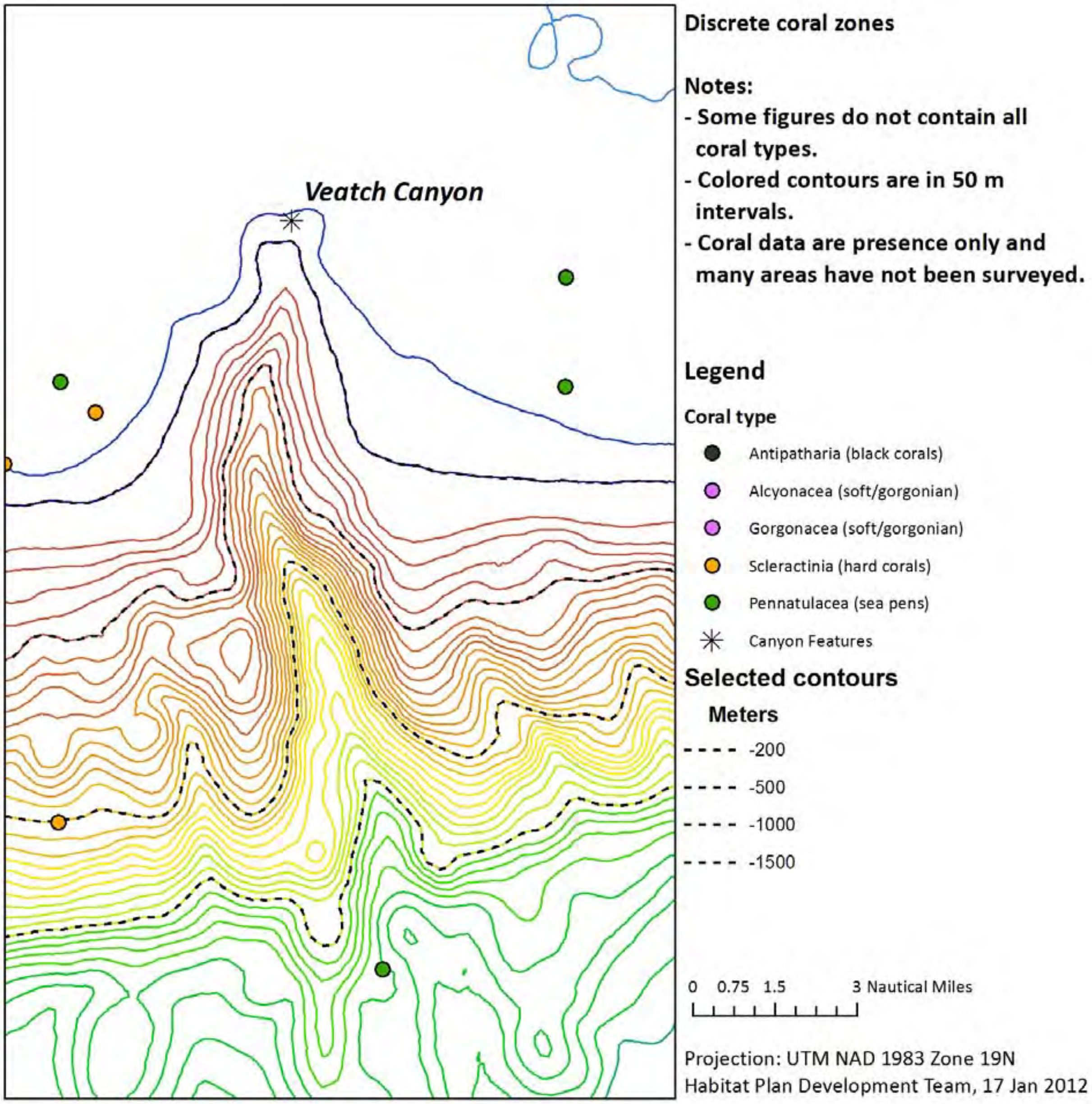
Table 16 – Geomorphological characterization and coral presence and distribution for Veatch Canyon

Type of information	Data sources and methods	Summary of information
Morphology, bathymetry and slope	Pratt (1967) Bathymetric and seismic surveys in 1975 (see Forde 1981)	Veatch Canyon has a broad leveed channel extending for about 65 km on to the continental rise; 100 km from 2000 m contour to end of channel. Moderately-sized canyon, incises shelf by 8 km.
Substrate	Hecker and Blechschmidt (1979) analyzed records from three dives done in 130-200 m	Head of canyon consists of sandy sediment between 100 and 250 m, with major clay outcrops.
Corals documented and depths	Cooper et al. (1987): observations made during sub dives at head of canyon and during nine dives on slope in or near the canyon NE DSC Database	Cooper et al. indicate that there corals were sparse in depths <300 m, but abundant >300, but these observations are not documented. According to H&B (1979), there were high concentrations of white sea pens in shallower areas. NE Database lists two **Gorgonians (now classified as Alcyonaceans)** in Veatch Canyon: GOM coral NURC = *Paragorgia arborea*; Theroux/Wigley 1998 = *Primnoa* sp. between 200-300 m; *Paragorgia arborea* between 600-700 m.

Table 17 – Coral assessment - Veatch Canyon

Attribute	Assessment			Notes
Adequacy of coral survey work relative to other areas	*High*	*Moderate*	*Inadequate*	Don't have physical samples or imagery but there has been survey work. Survey work was not focused on corals, but there have been a number of sub dives in or near this canyon.
		X		
If surveyed, presence of corals in comparison to other canyon areas	*High*	*Moderate*	*Low*	Hard to assess because of "missing" information. Database records suggest that there are gorgonians in canyon – not just sea pens.
		X		
Likelihood that corals occur there based on habitat suitability	*Likely*		*Unlikely*	
	X			

Map 8 – Veatch Canyon coral observations.



Data sources of observations for Veatch Canyon:
Two Smithsonian observations below 1500 m
Observations east and west of canyon head are from Thereoux & Wigley database, Watling et al 2003, and Yale collections
Cooper et al (1987) observations not georeferenced/mapped

3.3.1.2 Mid-Atlantic canyons and surrounding slope – Mey, Hendrickson, Toms, S. Toms, Berkley, Carteret, Lindenkohl

With the exception of Lindenkohl Canyon and Toms Canyon, the canyons in this region tend to have lower cross-sectional relief (Table 7) and are not individually recommended as coral zones (Table 9). Further, some do not noticeably incise the shelf (Map 9), and therefore were not able to be measured as part of the GIS analysis. However, this area offshore New Jersey including Mey, Hendrickson, Toms, S. Toms, Berkley, Carteret, and Lindenkohl canyons and the adjacent slope areas is recommended as a discrete coral zone because it is topographically and geologically complex, with rather unique sedimentary rock outcrop features. In particular, submersible dives near Berkley Canyon have documented exposed chalky sedimentary rocks dissected by furrows, and these same features were inferred to adjacent slope areas by comparing side scan sonar imagery between the dive site and adjacent sites (Robb et al 1983). These exposed rocks are suitable for coral attachment. Various types of corals have been found in the area, including species that inhabit soft sediments and species that require bedrock or other hard substrates for attachment (Hecker and Blechschmidt 1979), Hecker et al. 1983).

Table 18 – Geomorphological characterization and coral presence and distribution for continental slope and canyons between Mey and Lindenkohl canyons

Type of information	Data sources and methods	Summary of information
Geology	Hecker et al. (1983) 12 kHz acoustic survey of Slope II area between Toms and Mey canyons in 1980; Mey Canyon included in area of 2002 multi-beam survey (see Butman et al. 2006).	A series of small canyons on the continental slope south of Hudson Canyon that do not incise the shelf. Slope west of Carteret Canyon is smooth with parallel contours interrupted by minor gullies and ridges. To east, slope between Toms and Mey canyons is incised by Hendrickson Canyon with minor gullies and ridges on either side. Outside this canyon, sediment covered seafloor is relatively flat.
Substrate	1. Hecker and Blechschmidt (1979) - 4 submersible dives in Toms Canyon (155-336 m) and 7 in Carteret Canyon (5 in 120-330 and 2 in 1765-2507 m) – see ref #1 2. Hecker et al. (1983) - Slope Area I: 7 camera sled transects and 3 sub dives, two of each analyzed in 200-2190 m, >25K m^2 viewed. Slope Area II: 7 camera transects + 5 sub dives, 2 camera	1. Head of Carteret Canyon is mostly sandy with occasional shell fragments on its north flank. No information from ALVIN dives in deeper water. Head of Toms Canyon also sandy with shell fragments. 2. Slope Area I (to west, between Lindenkohl and Carteret canyons): Deeper part of slope is geologically active, the upper portion (200-1300m) is smooth and sediment covered. Below 1400 m massive exposures of limestone and talus-strewn slopes are prominent along axis and walls of gullies. Slope Area II (to east, between Toms and Mey canyons): Massive limestone cliffs and steep talus-strewn slopes predominate in the canyon. Slope on either side of Hendrickson is also steep. Other slope areas in vicinity also have chalk substrate. Outcrops occur to 1100 m. 3. Side scan sonar images at the mouth of, and south of, Berkley Canyon were groundtruthed during dives described in #2 above. The side scan images indicate large areas of calcareous, sedimentary claystone cut by furrows. The furrows are 10 to 50 meters apart and 4 to 13 meters deep.

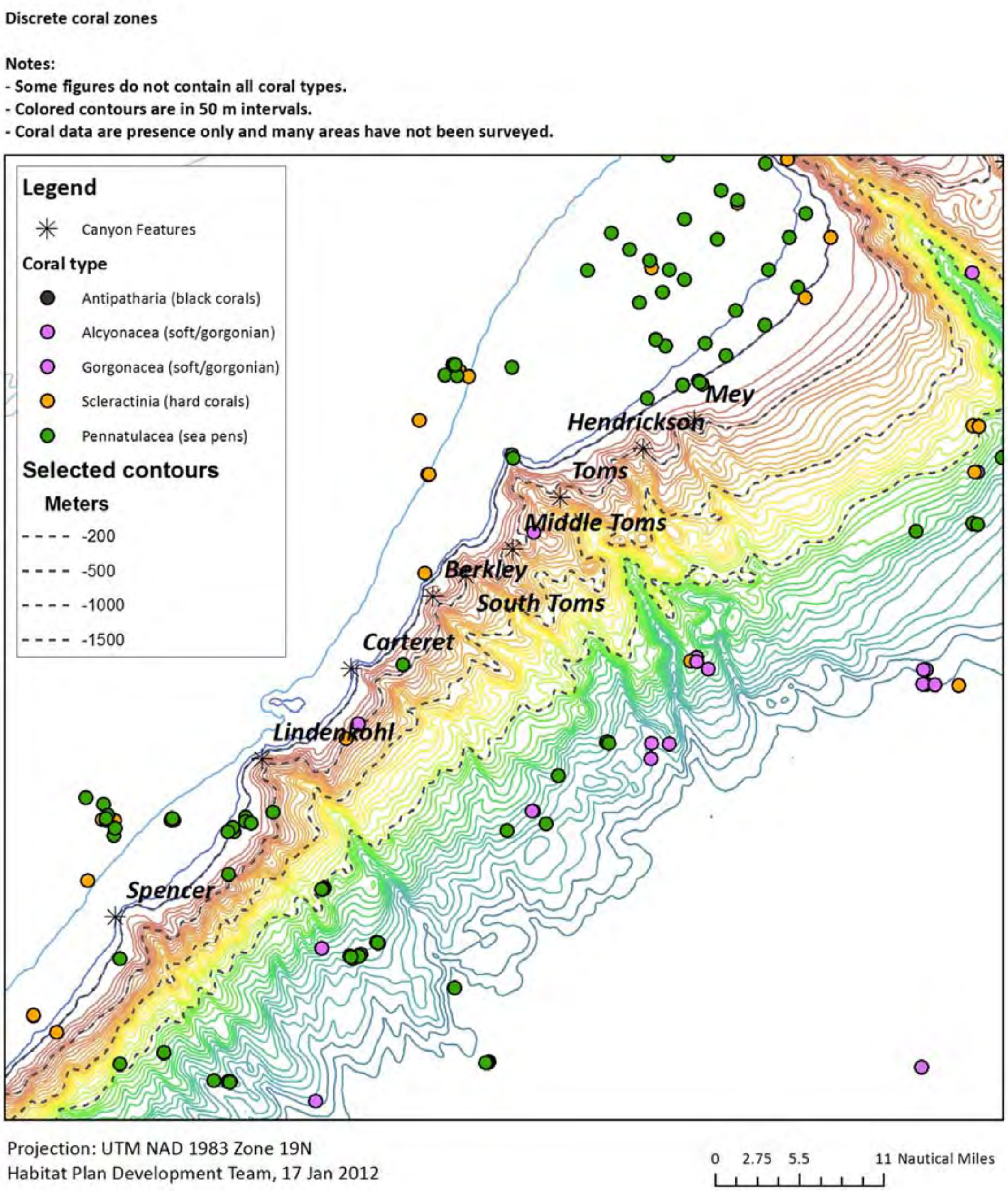
Type of information	Data sources and methods	Summary of information
	tows up axis of Hendrickson Canyon and a parallel tow up each side, 5 tows and 2 dives analyzed. Depth range = 120-2290m, >44Km^2 viewed. 3. Robb et al 1983 – side scan sonar combined with analysis of Alvin dives (see #2)	
Corals documented and depths	Hecker and Blechschmidt (1979), Hecker et al. (1983). Additional records in CoWCoG database.	**Sea pens**: *Distichoptilum gracile* in Hendrickson Canyon (Hecker et al. 1983) 640 -1640 m and also common between 1460-1540 m and between 1510-2290 m, also listed in Hecker et al (1983) from Slope Area II Alvin dive 1118 -- steep silty slope of Hendrickson Canyon between 1300-1350 m and also silty axis and lower wall 1350-1430 (p. 126) and deep axis, on hard substrate (p. 127); *Stylatula elegans* Slope II dive JSL 1082 -- slope landward of Hendrickson Canyon 145-220 m (Hecker et al 1983); *Kophobelemnon stelliferum* Slope Area II Alvin dive 1118 -- steep silty slope of Hendrickson Canyon silty axis and lower wall 1350-1430 (Hecker et al. 1983). Megafauna dominated by sea pen *Stylatula elegans* in 200-300 m and solitary scleractinian *Dasmosmilia lymani* in 100-600 m in both slope areas where they are more abundant than in Hendrickson Canyon. Other coral species observed by depth zone in Slope Area I: Sea pen *Distichoptilum gracile* and hard coral *Flabellum alabastrum* in 1330-1510 m on mud bottom; between 1440 and 2190m, sea pens *D. gracile* and *K. stelliferum* on mud bottom, horn coral *Desmophyllum cristigalli* skeletons and talus at base of an outcrop, with living polyps on cliff, soft corals *Anthomastus agassizii*, *D. cristigalli* and *Freyella* spp. on massive chalk outcrops, sea pens dominant, soft corals *Acanella arbuscula*, *Chrysogorgia agassizii*, and *Paramuricea grandis* also present.

Table 19 – Coral assessment – Continental slope between Mey and Lindenkohl canyons

Attribute	Assessment			Notes
	High	*Moderate*	*Inadequate*	
Adequacy of coral survey work relative to other areas	X			Considerable survey work on slope, including Hendrickson Canyon; only information available from dives in Carteret and Toms canyons is from shallow water at canyon heads. For entire slope area, including all canyons, survey effort is high.
If surveyed, presence	*High*	*Moderate*	*Low*	High, but deeper than currently

of corals in comparison to other canyon areas	X			defined area and also on the slope, not in the canyons
Likelihood that corals occur there based on habitat suitability	*Likely*		*Unlikely*	
	X			

Map 9 – Slope area from Mey-Lindenkohl Canyons



3.3.1.3 Baltimore Canyon

Baltimore Canyon has been relatively well surveyed for corals, and they are locally very abundant. Baltimore Canyon is recommended as a coral zone.

Table 20 – Geological, oceanographic, and biological characterization of Baltimore Canyon

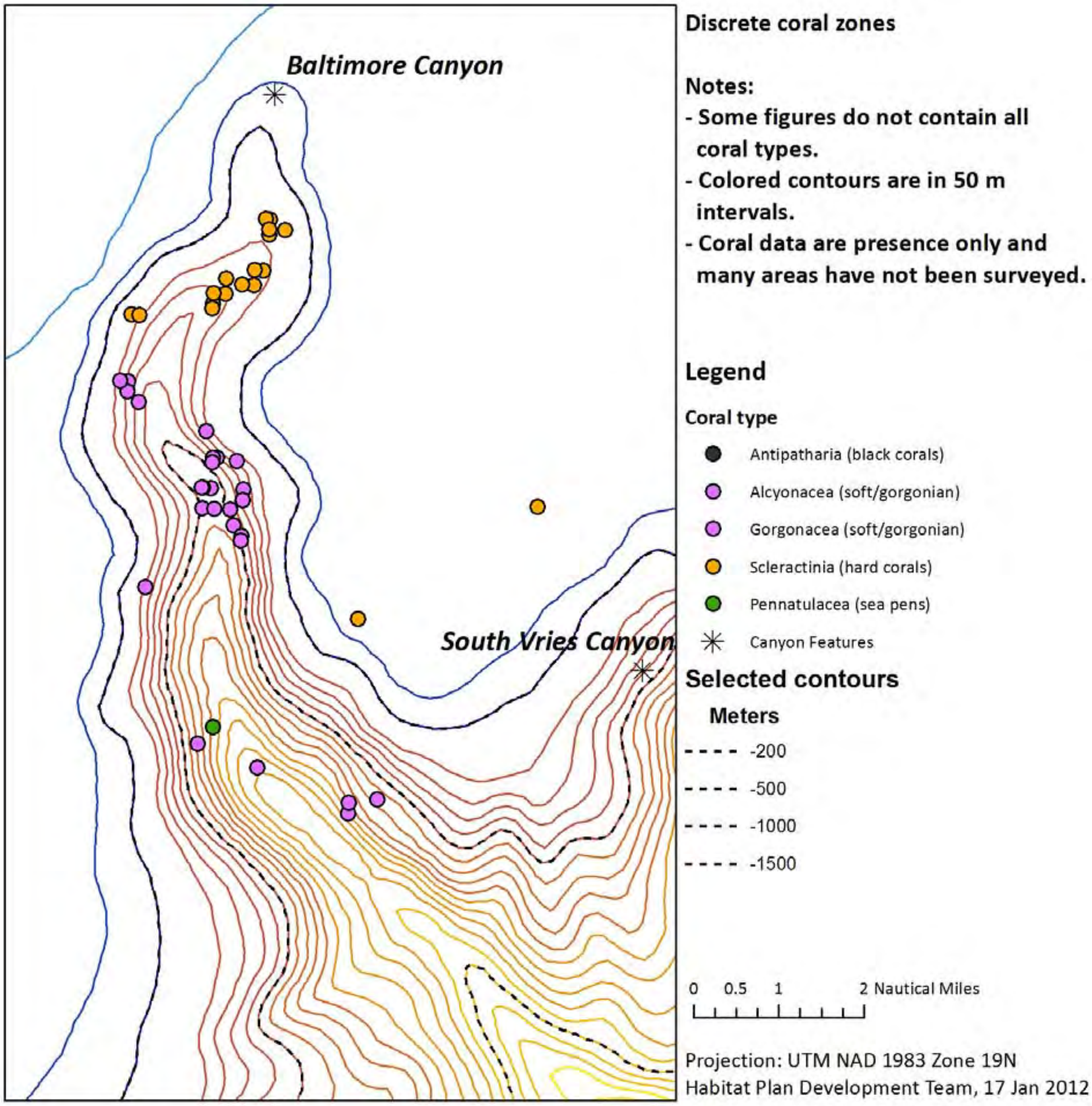
Type of information	Data sources and methods	Summary of information
Morphology, bathymetry and slope	1. Thompson et al. (1980) 2. Hecker et al. (1983) 3. Pratt (1967) Bathymetric surveys done in 1979 and 1980 with 12kHz echo sounder Multibeam survey done in 2011 by Deepwater Canyons project	(1) The upper portion of the canyon trends southward to the shelf break at about 70-80 m, then turns abruptly southeastward across the slope, emptying onto the continental rise at a depth of about 1.5 km. The floor is rather flat and wide (400-500 m) and there are several terraces up to 370 m wide on the upper walls. The overall gradient of the axis is 2.8 degrees. (2) A large canyon with a relatively broad axis, incising the shelf by 13 km [16 km in Pratt 1967]. Most of canyon is characterized by low topographic relief. (3) Does not extend very far on to continental rise - terminates at about 2500 m, on the right levee of Wilmington Canyon. Recent topographic map (based on multibeam survey) shows steep indented cliffs ("buttresses") on eastern wall in lower part of canyon down to about 800 m that have not been surveyed, no information re substrate.
Substrate	1. Hecker et al. (1980) 2. Thompson et al. (1980) 3. Hecker et al. (1983) Total 1979-1982 survey effort = 20 camera sled tows and 13 submersible dives, 125K m^2 seafloor photographed at depths of 100-2040 m (refs 1 and 3) 3 sub dives in lower canyon during 1971-1986 (see Cooper et al. 1987) – no documentation Core and dredge sampling conducted in 1979 (see ref #2)	(1) Predominant sediments are silt and sand, especially in shallower portion of canyon and on walls; floor is rippled sand along most of its length; rock outcrops at depth of 500-1000; mud in mid part of canyon with some talus blocks on walls and along axis; a number of glacial erratics ranging in size from pebbles to boulders were seen and dredged in this canyon – they are particularly common in the axis. This canyon is an area of active sediment deposition. (2) This canyon is located south of the area directly affected by Pleistocene glacial advances and in area of lesser subsidence, so exposed rocks are much younger than in northern canyons. There are abundant outcrops along deeper reaches of the walls, but not on most tributary walls, many of which are dusted by a thin layer of homogeneous sediment. Where surveyed (in 1979), the floor is covered by ripple-marked sand and silty clay. (3) Most of this canyon has a soft sediment seafloor with a limited exposure of hard substrate – the exception being near the head of the canyon where it bends around a ridge: in this area there are massive sandstone cliffs and talus-strewn slopes on both walls. In lower portion of canyon didn't find hard substrate – but did find glacial erratics and consolidated clay (B. Hecker, pers. comm.). Bottom temperature and current measurements done in 1979 (see Thompson et al. (1980).

Type of information	**Data sources and methods**	**Summary of information**
Corals documented and depths	Hecker et al. (1980, 1983); Opresko (1980).	**Stony**: *Dasmosmilia lymani* near head of Canyon *, Flabellum alabastrum* found on slope south of Canyon, *Desmophyllum dianthus;* **Soft**: *Anthomastus agassizii?, Anthomastus grandiflorus, Capnella florida*, *Acanella arbuscula* on slope just south of Canyon*, Paragorgia arborea, Primnoa resedaeformis, Acanthogorgia armata*, *Anthothela grandiflora*; **Sea pens**: *Kophobelemnon stelliferum* common on slope north of Baltimore Canyon (Opresko 1980), *Distichoptilum gracile, Stylatula elegans*. An additional sea pen, *Virgularia mirabilis* (Müller, 1776), was mentioned in Hecker and Blechschmidt (1980): "Seven specimens of this sea pen were seen on the slope between Baltimore and Norfolk Canyons at depths from 1500 to 1800 meters." It has been recorded in Europe and is said to occur in the western Atlantic, but this is the only mention of this species in these waters that we have been able to find. *Acanthogorgia armata* found at 350 m, *Paragorgia arborea* axis of Canyon at 400 m and 500 m, *Primnoa resedaeformis* 450 m, *Kophobelemnon stelliferum* common on slope north of Canyon between 1550-1800 m and also at 200 m north of Canyon (Opresko 1980), *Stylatula elegans* at about 150-300 m. *Distichoptilum gracile* 1190-2040 m and north flank dominant between 1500-1700 m. Hecker et al (1983) -- Baltimore Canyon zone 4, 1190-1690 m, and zone 5, 1610-2040 (p. 87). North flank dominant between 1500-1700 m (p. 98). Baltimore Canyon Alvin dive 1108: axis and south wall in the vicinity where it curves to the east. Lower south wall from 1140-1400 m consists of a steep consolidated clay slope with a silty sediment veneer (p. 123). Alvin 1107: dive explored axis and lower wall near mouth of canyon from 1790-1940 m; floor of axis covered by silty sediment with a hummocky topography, found in the axis and lower north wall (p. 123).

Table 21 – Coral assessment - Baltimore Canyon

Attribute	**Assessment**			**Notes**
Adequacy of coral survey work relative to other areas	*High*	*Moderate*	*Inadequate*	
	X			
If surveyed, presence of corals in comparison to other canyon areas	*High*	*Moderate*	*Low*	Not as widespread throughout the canyon as in places like Oceanographer and Lydonia – but high local abundance/density
	X			
Likelihood that corals occur there based on habitat suitability	*Likely*		*Unlikely*	
	X			

Map 10 – Baltimore Canyon coral observations.



Data sources of observations for Baltimore Canyon:
With the exception of three Smithsonian records, all observations are from Hecker et al 1980

3.3.1.4 Norfolk Canyon

Norfolk Canyon has been moderately well surveyed for corals and a diversity of species have been found. It is recommended as a coral zone.

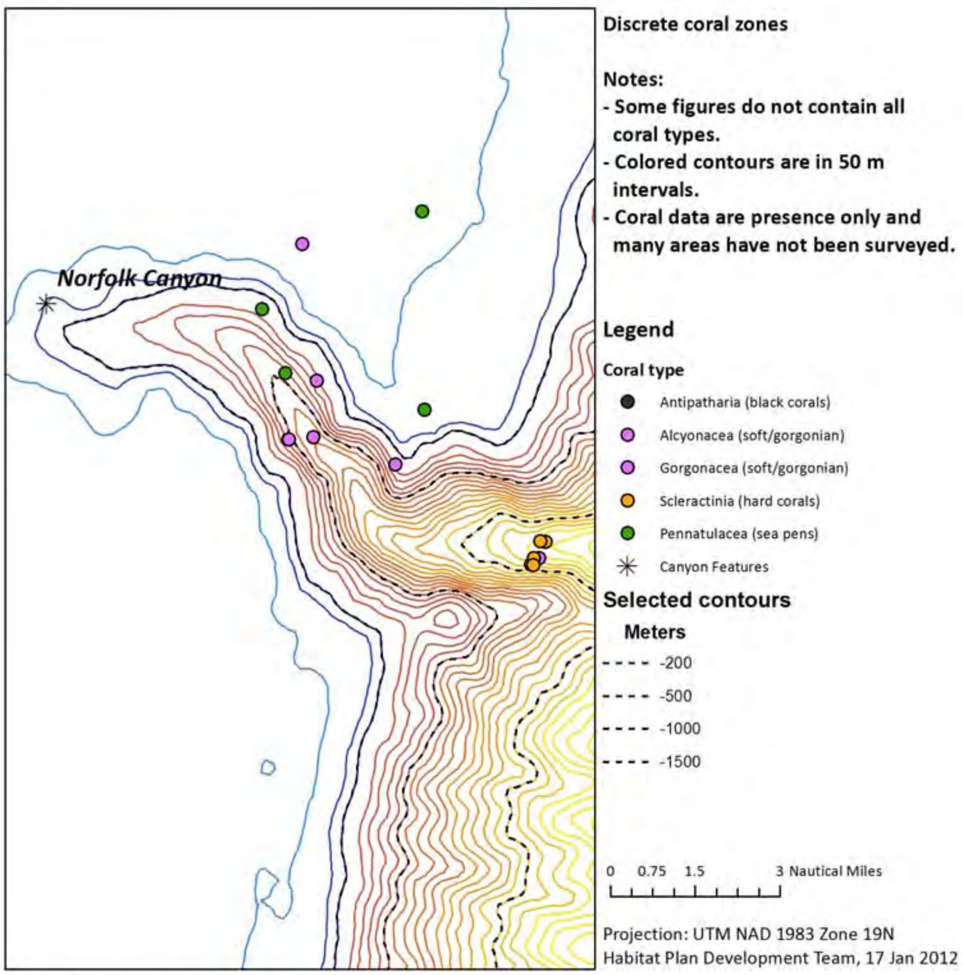
Table 22 – Geological, oceanographic, and biological characterization of Norfolk Canyon

Type of information	Data sources and methods	Summary of information
Morphology, bathymetry and slope	Bathymetric and seismic surveys in 1975 (see Forde 1981) Pratt (1967) Multibeam survey done in 2011 by Deepwater Canyons project	Incises shelf for distance of 14.5 km; mouth of canyon oriented to east, axis bends to the left with head of canyon oriented due west; large "side canyon" with tributaries on north wall near mouth. A sharper and longer canyon than Washington where it cuts across the shelf, but soon dies out in the deep sea and merges with Washington Canyon.
Substrate	Malahoff et al. (1982), summarized in Hecker and Blechschmidt (1979) 3 ALVIN dives in 1977-78 in canyon axis beyond shelf edge	Predominantly silty with substantial outcrops between 1050 and 1500 m with only occasional outcrops in deeper water (see detail below). No available information for shallower portion of canyon inside shelf break. Dive 808 (1020-1250 m, just seaward of shelf break): axis smooth, sediment covered, without outcrops or erratics; local, nearly vertical slopes on north wall with extensive outcrops of mudstones supporting various corals and anemones; south wall generally less precipitous with fewer exposures. Dive 809 (1200-1500 m, began 10 km down the canyon from dive #808): valley floor as observed in previous dive, south wall sloped gently towards canyon axis with sequence of thinly bedded mudstones. Dive 810 (2283-2315 m, started 35 down canyon from dive #809): axis channel very narrow (50-100 m) and about 70 m deep; extensive outcroppings of thin-bedded sediments on walls; very large erratic boulder at 2315 m.
Corals documented and depths	Hecker and Blechschmidt (1979); Opresko (1980); Malahoff et al. (1982). Also NE DSC database including Smithsonian data. Additional un-reviewed Johnson SeaLink dives in upper portion of canyon that documented corals (see Cooper et al. 1987)	**Stony**: *Desmophyllum dianthus* occasionally on axis of Canyon*, Flabellum alabastrum* found in deeper parts of the continental slope south of Canyon and in axis of Canyon on soft substrate*;* **Soft**: *Anthomastus grandiflorus* axis of Canyon, *Gersemia fruticosa* at the mouth of Canyon, *Paragorgia arborea, Primnoa resedaeformis, Acanthogorgia armata* occasionally in axis of Canyon on exposed outcrops; **Sea pens**: *Pennatula aculeata*. Smithsonian database: note records for *Gersemia rubiformis*, *Acanella* sp., *Stylatula* cf. *diadema* Bayer, 1959. *Desmophyllum dianthus* hard substrate at 1050-1250 m, *Flabellum* sp. high concentrations at 1300-1350 m (Hecker and Blechschmidt 1979), *Anthomastus grandiflorus* between 2150-2350 m and at 1500 m, *Acanthogorgia armata* hard substrate at 1050-1250 m (Hecker and Blechschmidt 1979), *Paragorgia arborea* 400-600 m, *Primnoa resedaeformis* 400 m, *Pennatula aculeata* exceptionally high concentrations 2150-2300 m in axis of Canyon (Opresko 1980).

Table 23 – Coral assessment - Norfolk Canyon

Attribute	Assessment			Notes
Adequacy of coral survey work relative to other areas	*High*	*Moderate*	*Inadequate*	Three Alvin dives, all beyond shelf break.
		X		
If surveyed, presence of corals in comparison to other canyon areas	*High*	*Moderate*	*Low*	
	X			
Likelihood that corals occur there based on habitat suitability	*Likely*		*Unlikely*	
	X			

Map 11 – Norfolk Canyon coral observations.



Data sources of observations for Norfolk Canyon:
Observations below 1000 m are from Hecker et al 1980
Shallower records are from Smithsonian and Watling & Auster databases

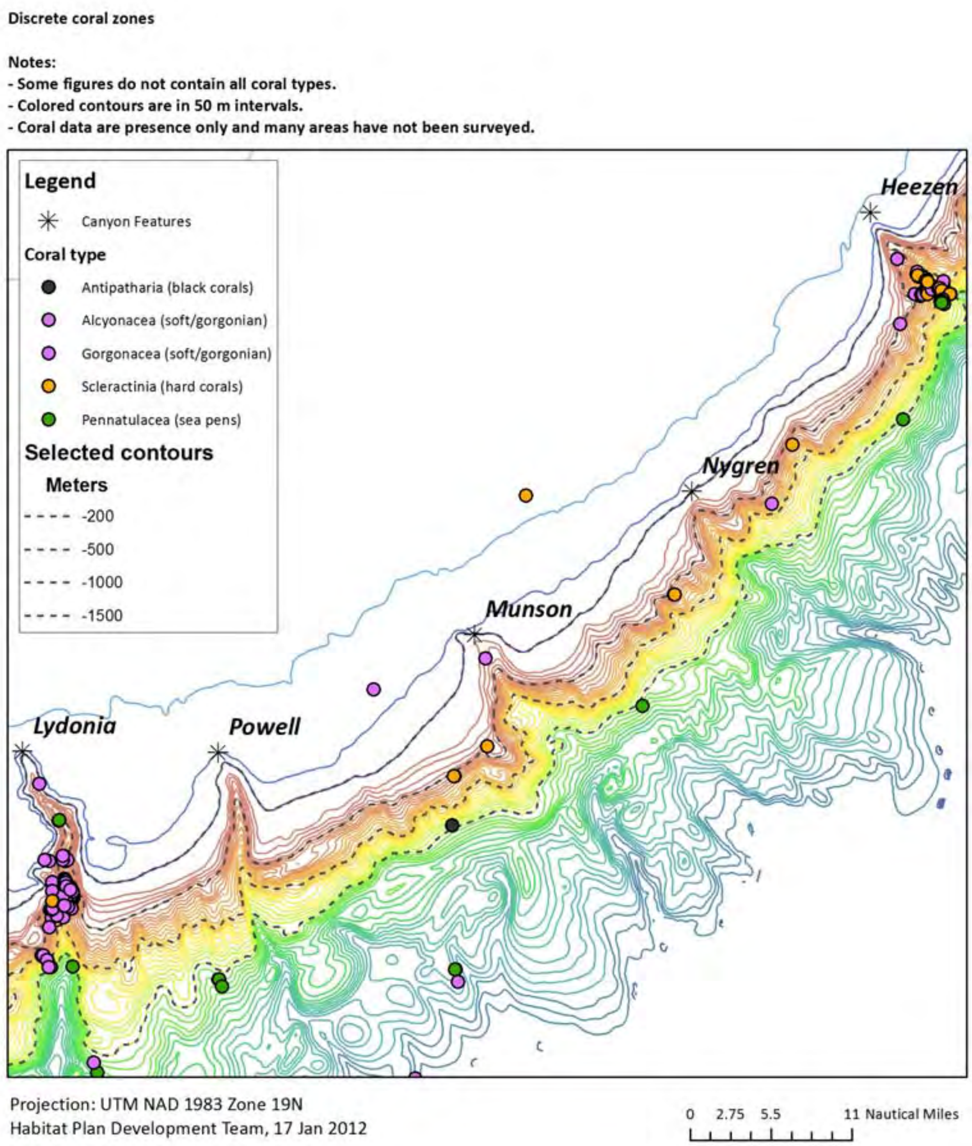
3.3.2 Canyons recommended on basis of inferred habitat suitability

All of these canyons fell within the threshold of having at least a 450 meter or greater maximum relief, so likelihood of outcropping rocks and thus suitable habitats was inferred. Relief was measured from the canyon rim to the canyon floor along the center axis.

3.3.2.1 Nygren, Munson, and Powell Canyons

Nygren, Munson, and Powell Canyons are among the smaller canyons in the shelf/slope region south of Georges Bank, and we know very little about them. However, they are relatively deep, and at the three degree slope contour have a relief from the rim of the canyon to the seafloor at that exceeds 450 m. Therefore, they are recommended as coral zones on the basis of habitat suitability.

Map 12 – Nygren, Munson, and Powell Canyons



3.3.2.2 Gilbert, Heel Tapper, and Welker Canyons

Gilbert Canyon lies between two well-studied canyons, Lydonia and Oceanographer, but has not been surveyed for corals. It is recommended on the basis of habitat suitability. Heel Tapper and Welker Canyons are also recommended on the basis of habitat suitability.

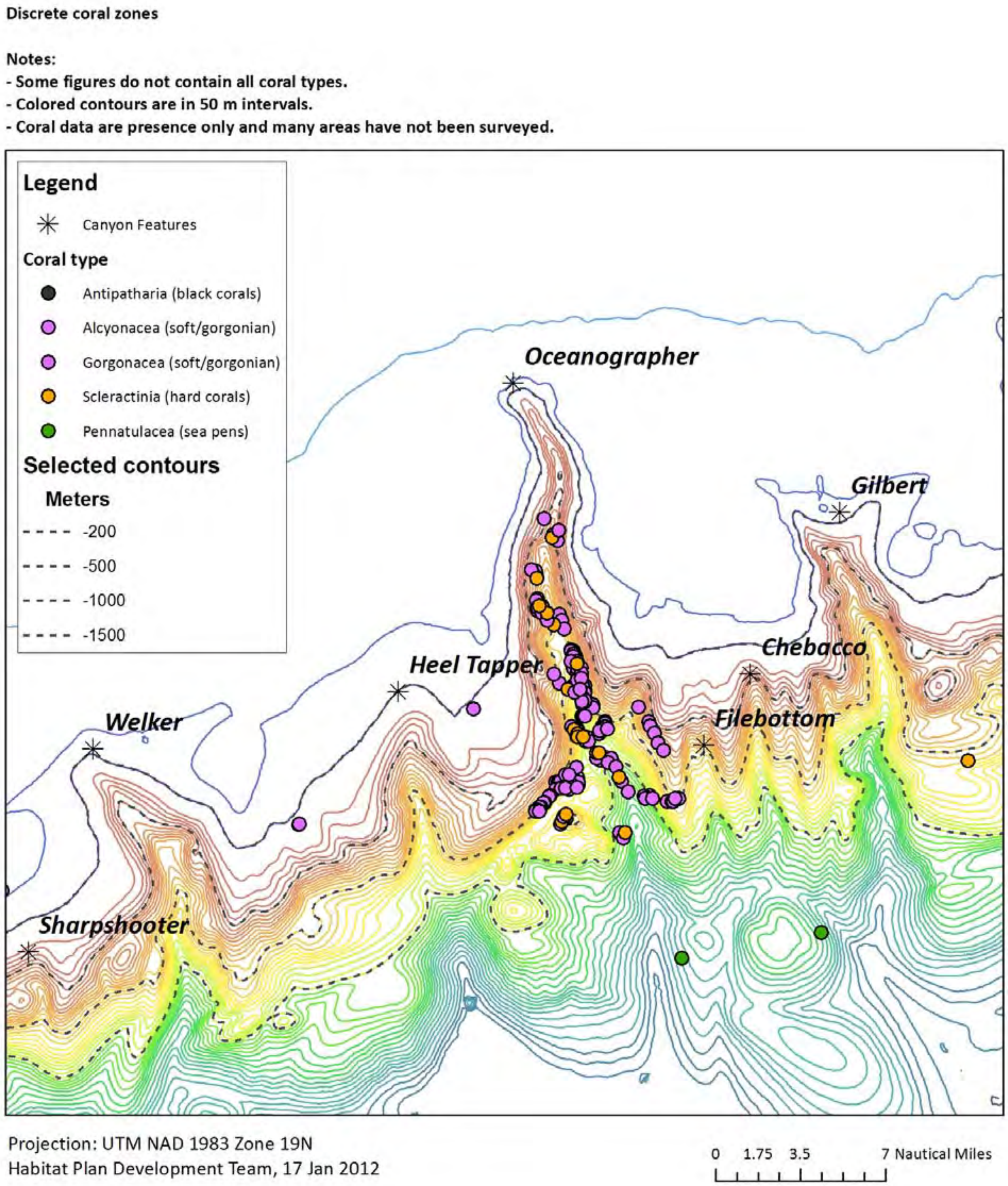
Table 24 – Geomorphological characterization and coral presence and distribution for Gilbert Canyon

Type of information	Data sources and methods	Summary of information
Morphology, bathymetry and slope	Pratt (1967) Valentine (1987	Oceanographer, Gilbert, and Lydonia canyons seem to form a canyon system; Gilbert canyon joins with Lydonia to form a well-defined channel extending seaward at least 100 km across the continental rise, with a maximum relief of about 250 m; Incises shelf to 9.5 km. Gilbert Canyon has the same width and is a little deeper at its mouth than Veatch Canyon, is deeper and wider than Oceanographer, but is not as deep as Lydonia Canyon.
Substrate	No information	No information
Corals documented and depths	Thoma et al. (2009) collected 4 specimens in Gilbert and Oceanographer canyons – no other records. Cooper et al. (1987)	Isididae: *Acanella* was found at Lat.: 40.1104, Long.: –67.8807; depth 2097 m. Corals sparse <300 m, no information in deeper water.

Table 25 – Coral assessment - Gilbert Canyon

Attribute	Assessment			Notes
Adequacy of coral survey work relative to other areas	*High*	*Moderate*	*Inadequate*	
			x	
If surveyed, presence of corals in comparison to other canyon areas	*High*	*Moderate*	*Low*	Don't know – only reference is Cooper et al. (1987), data is qualitative so this assessment is hard to make
	n/a	n/a	n/a	
Likelihood that corals occur there based on habitat suitability	*Likely*		*Unlikely*	
	X			

Map 13 – Gilbert, Heel Tapper, and Welker Canyons



3.3.2.1 Hydrographer Canyon

Very limited survey work has been conducted in Hydrographer Canyon, so a recommendation could not be made on the basis of coral or geological data. Hydrographer Canyon is narrow and steep relative to other canyons, and has a cross sectional relief value of over 900 m (canyon measurements are shown in Table 7 and Table 8). Therefore, the area is recommended as a coral zone based on the inference of suitable habitat.

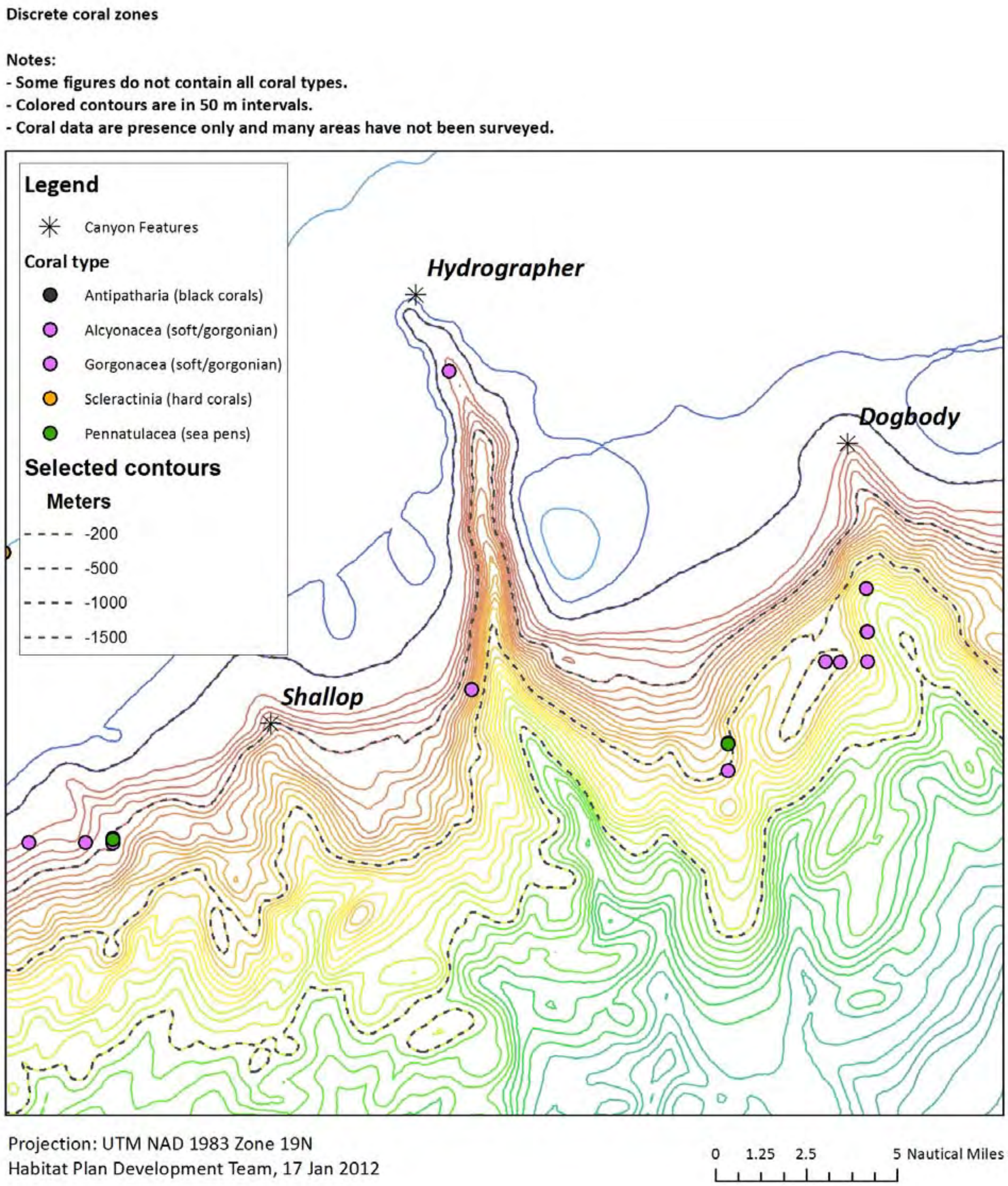
Table 26 – Geomorphological characterization and coral presence and distribution for Hydrographer Canyon

Type of information	Data sources and methods	Summary of information
Morphology, bathymetry and slope	Pratt (1967)	Large canyon, incises shelf by 15 km, extends on to continental rise, 150 km from 2000 m contour. Similar morphology at shelf break as Gilbert, but longer with steep walls.
Substrate	One ALVIN dive (see below)	Section of wall surveyed was steep with a muddy bottom; four glacial erratics also found.
Corals documented and depths	Unknown number of sub dives at 3 stations during 1971-1986 (Cooper et al. (1987) – data not available One sub dive in 2001 to 1393 m, ascended section of canyon wall (see website at right)	<http://oceanexplorer.noaa.gov/explorations/deepeast01/logs/sep14/sep14.html>. “Dr. Barbara Hecker had predicted that we would not find the same community in Hydrographer Canyon as was found in Oceanographer Canyon. Corals, she suggested, would not be well represented here because they need a rocky substrate. As the science team reviewed video footage, a rich community was revealed. Numerous individuals representing many different species were observed. Dr. Hecker's prediction was correct, however; no corals were found.” Cooper at al. (1987): Corals sparse <300 m, no info >300 m.

Table 27 – Coral assessment - Hydrographer Canyon

Attribute	Assessment			Notes
Adequacy of coral survey work relative to other areas	*High*	*Moderate*	*Inadequate*	
			X	
If surveyed, presence of corals in comparison to other canyon areas	*High*	*Moderate*	*Low*	Single Alvin dive in canyon but no corals observed; additional examination of shallow areas showed clay sediments; corals listed as “sparse” <300 m, no info >300 m (Cooper et al. 1987)
	n/a	n/a	n/a	
Likelihood that corals occur there based on habitat suitability	*Likely*		*Unlikely*	Based on canyon morphology
	X			

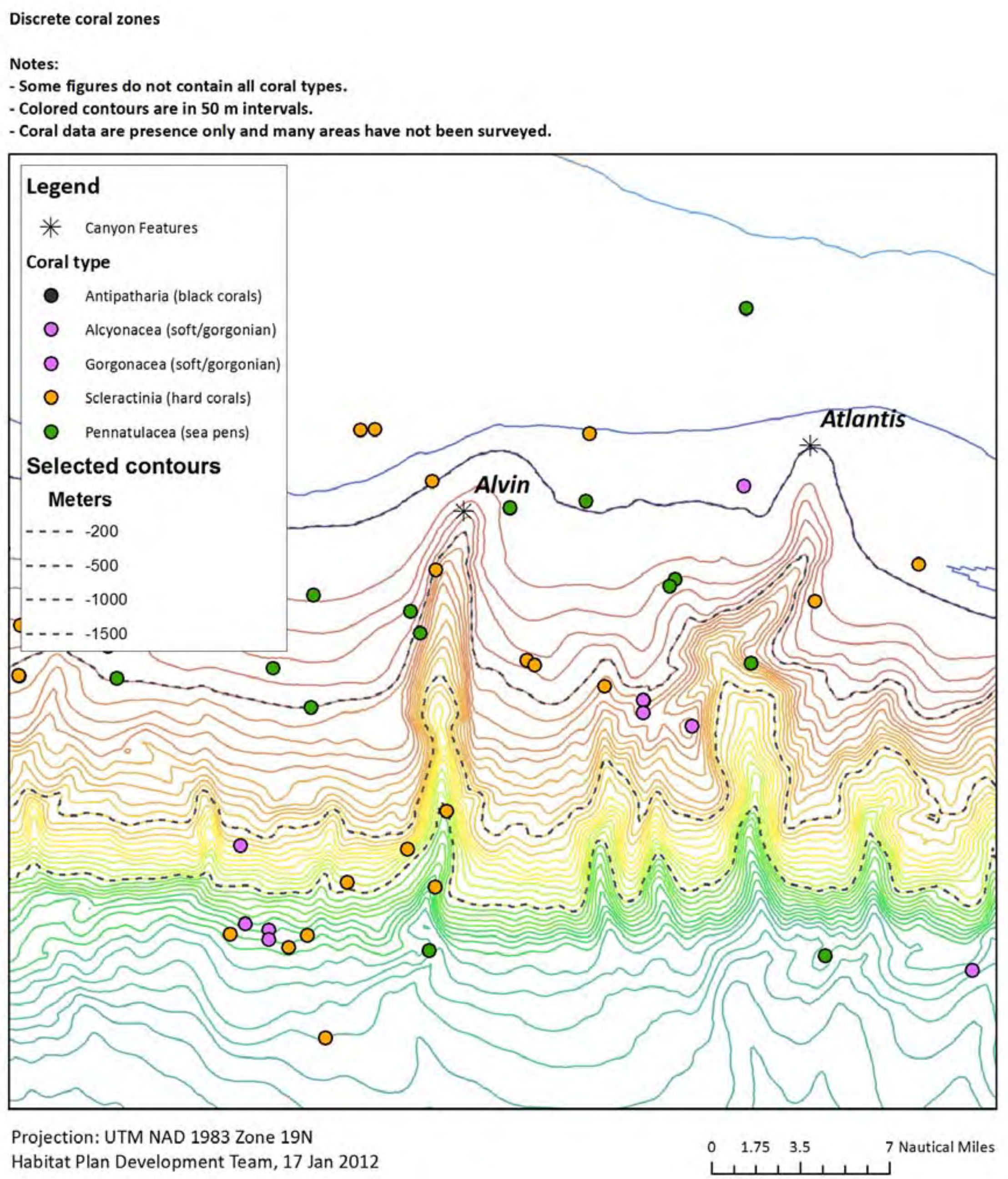
Map 14 – Hydrographer Canyon



3.3.2.1 Alvin Canyon

Coral survey work to support assessment of Alvin Canyon as coral zones is inadequate, as there have been no surveys for corals. However, the relief of Alvin Canyon from the canyon rim to the seafloor at the three degree slope contour was measured at 721 m, which is greater than the 450 m threshold for inferring suitable habitat. Therefore, Alvin Canyon is recommended as a discrete coral zone.

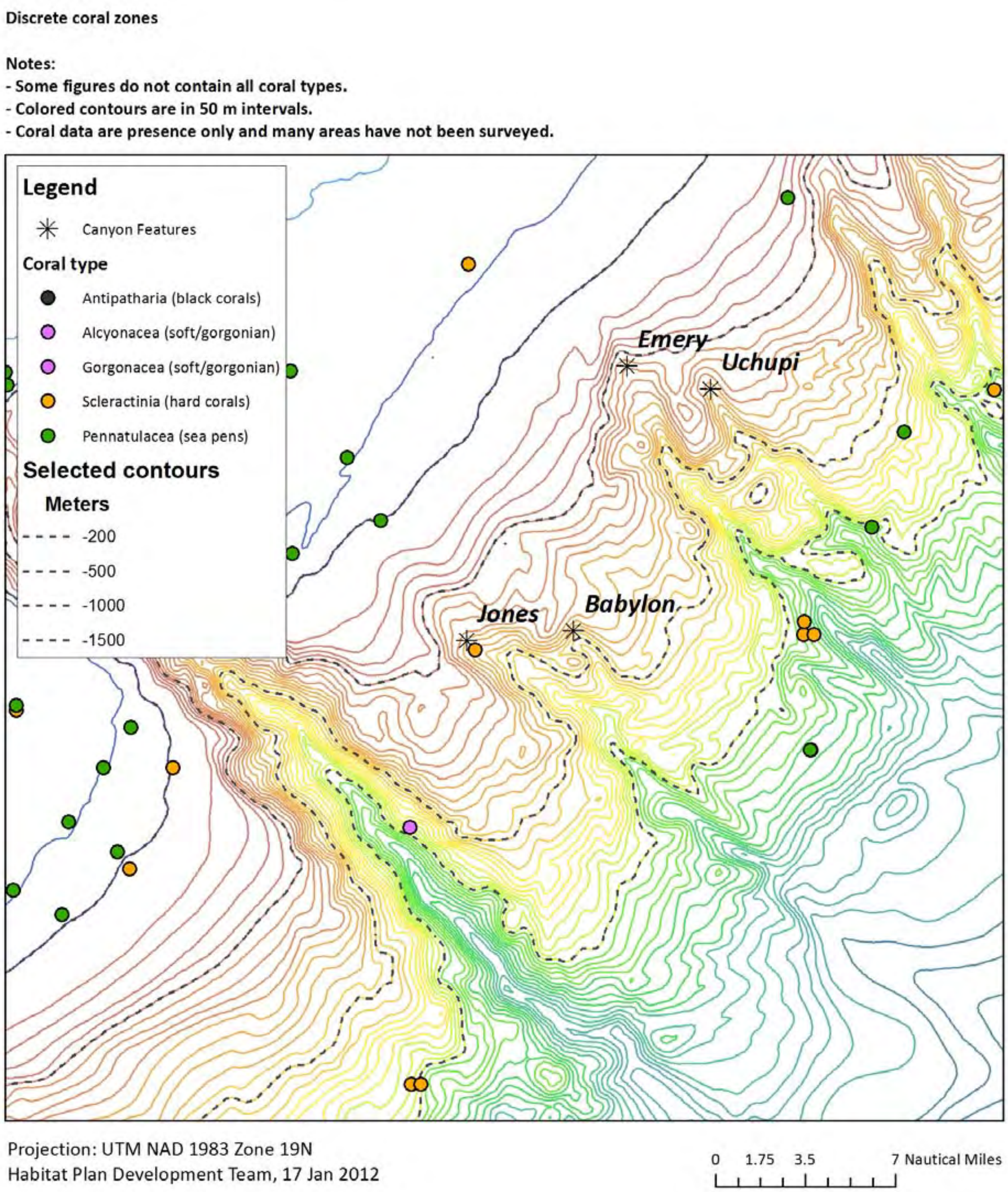
Map 15 – Alvin Canyon



3.3.2.2 Emery, Babylon, and Jones Canyons

Emery Canyon is recommended on the basis of inferred habitat suitability (Table 7). Babylon and Jones Canyons are also recommended on the basis of inferred habitat suitability (Table 7). Note that a single set of measurements was taken for both Jones and Babylon Canyons combined.

Map 16 – Emery, Babylon, and Jones Canyons



3.3.2.3 Hudson Canyon

Hudson Canyon has had lots of survey work, but relative to its very large size, there are still many areas that have not been studied. Small corals and sea pens have been observed in the canyon, but other coral types have not. However, suitable habitat may exist, particularly on the eastern wall. Hudson Canyon's cross sectional relief was measured at 926 m (Table 7), and it is therefore recommended on the basis of inferred habitat suitability.

Table 28 – Geomorphological characterization and coral presence and distribution for Hudson Canyon

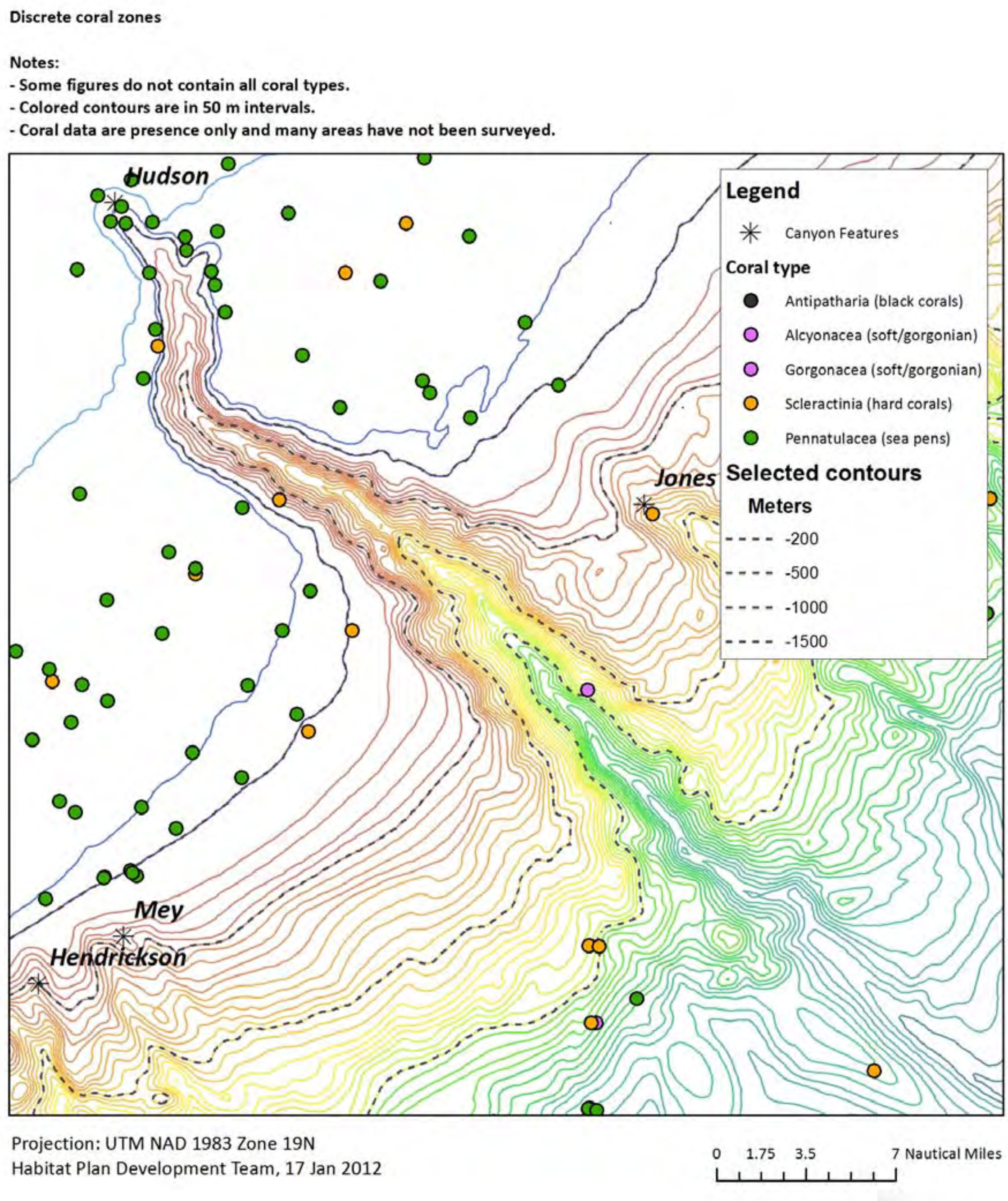
Type of information	Data sources and methods	Summary of information
Morphology, bathymetry and slope	Butman et al. (2006) Pratt (1967) Multibeam surveys of entire canyon in 2002 (USGS) and northern portion of canyon in 2007-2009 (NOAA)	By far, the largest canyon in U.S. waters of the NW Atlantic, extending for 80 km from its head to the base of the continental slope at 2200 m; over this distance, the width of the canyon rim varies from 0.8 to 12 km, with an average along-axis slope of 1.5 degrees, average slope of walls 8 degrees, canyon floor 0.2-0.9 km wide. Canyon walls are eroded with an intricate network of gullies. Incises shelf by 30 km; seaward length of 240 km beyond the 2000 m contour. Steep V-shaped canyon across the continental shelf and slope develops into a broad leveed canyon at the base of the slope. It then maintains moderate (100-200 m) depths for 65 km where it deepens into an outer gorge over 600 m in maximum depth, then makes a sharp bend to the right where it branches into two major tributaries. Note: 2002 survey revealed six small canyons on continental slope NE of Hudson Canyon with eroded walls and gullies (see Butman et al. 2006).
Substrate	See above Six ALVIN dives (835-3165 m) analyzed by Hecker and Blechschmidt (1979)	Based on map of backscatter data collected in 2007-2009, rock outcrops are assumed to exist on eastern wall of upper canyon, but their presence has not been confirmed visually (Vince Guida, pers. comm.) Primarily a silty sediment with substantial outcrops in deeper water (2900-3000 m) (B & H 1979)
Corals documented and depths	Hecker and Blechschmidt (1979) V. Guida (unpublished data, NMFS James J. Howard Marine Sciences Lab, Highlands, NJ). .	Only corals observed in main part of Hudson Canyon are sea pens, small stony coral *Eunephthya* [= *Gersemia*] *fructicosa*, and small cup coral *Dasmosmilia lymani* (Hecker and Blechschmidt (1979 and V. Guida, pers. comm.). Except for sea pens, there are no DSC observations for Hudson Canyon in NOAA DSC database. **Stony**: *Dasmosmilia lymani* in the head of Hudson Canyon, *Gersemia fruticosa* in deep portion of Canyon; **Sea pens:** *Funinculina armata*, *Stylatula elegans* near head of canyon.

Table 29 – Coral assessment - Hudson Canyon

Attribute	Assessment			Notes
Adequacy of coral survey work relative to other areas	*High*	*Moderate*	*Inadequate*	There has been survey effort but relative to the size of the canyon not very much area has been examined
			X	
If surveyed, presence	*High*	*Moderate*	*Low*	In areas that have been surveyed,

of corals in comparison to other canyon areas	n/a	n/a	n/a	few corals found and mostly small cup coral and sea pens
Likelihood that corals occur there based on habitat suitability	*Highly likely*	*Moderately likely*	*Unlikely*	May not be highly abundant – but there are areas of steep relief that may have suitable habitat
	X			

Map 17 – Hudson Canyon



3.3.2.4 Wilmington Canyon

While appropriate substrates have not been confirmed to exist, Wilmington is a large, steeply sloping canyon with a cross-sectional relief measurement of 989 m (Table 7), such that the presence of suitable habitats is inferred. In addition, if Wilmington is similar to nearby Baltimore Canyon, it seems likely that Wilmington provides suitable coral habitat.

Table 30 – Geological, oceanographic, and biological characterization of Wilmington Canyon

Type of information	Data sources and methods	Summary of information
Morphology, bathymetry and slope	Pratt (1967) Multibeam survey in 2011 as part of Deepwater Canyons project	Fairly well incised into the shelf (16 km, same as Baltimore); when including its extension into the continental rise, the second largest canyon in NE U.S., extending 312 km from the 2000 m contour, but has only about two-thirds the relief of Hudson Canyon. Multibeam data have not been analyzed
Substrate		NMFS trawl survey occasionally indicates rocks
Corals documented and depths	No literature found at present that documents the presence of corals.	Single Smithsonian record of *Pennatula aculeata*

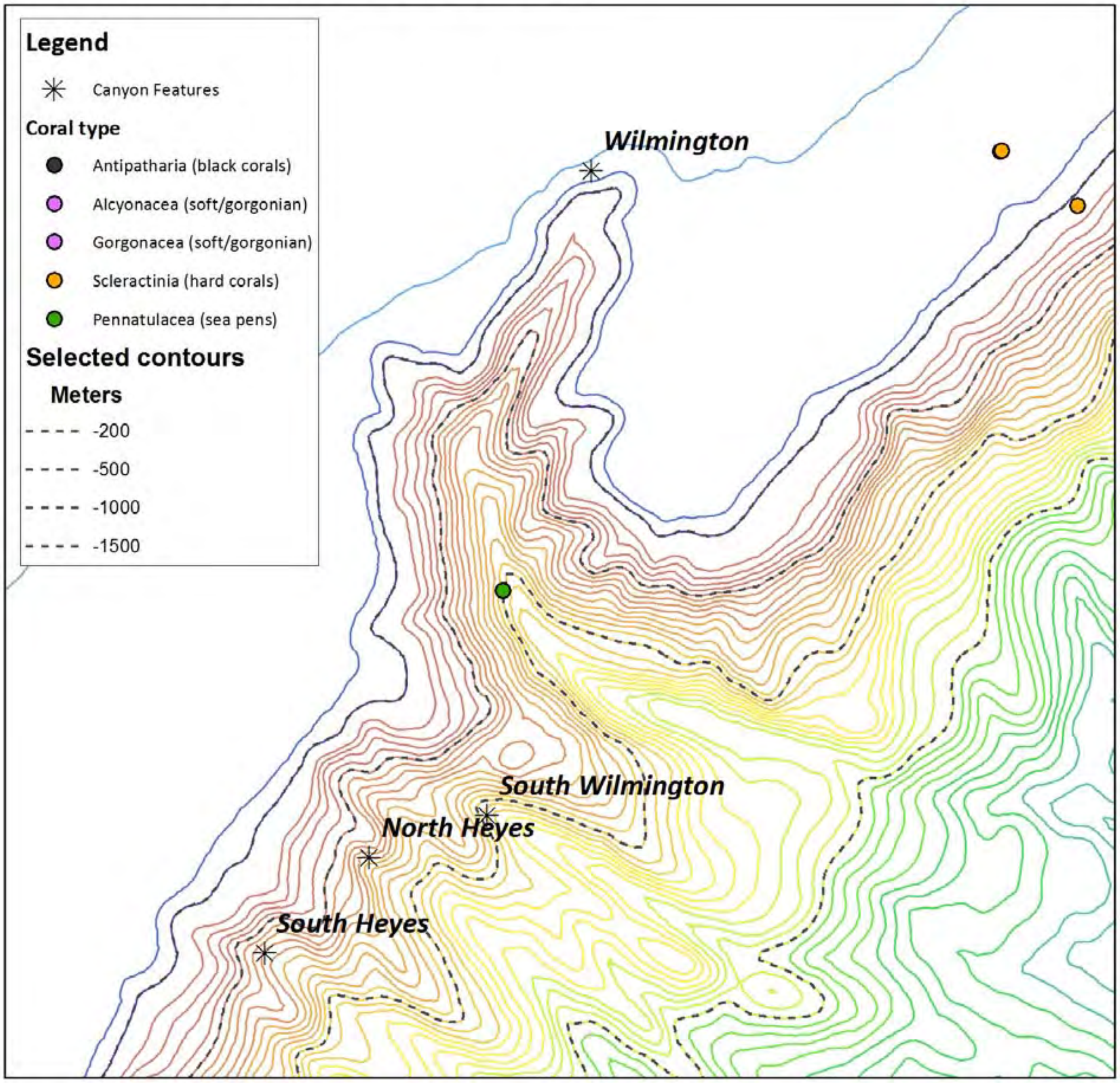
Table 31 – Coral assessment - Wilmington Canyon

Attribute	Assessment			Notes
Adequacy of coral survey work relative to other areas	*High*	*Moderate*	*Inadequate*	
			X	
If surveyed, presence of corals in comparison to other canyon areas	*High*	*Moderate*	*Low*	
	n/a	n/a	n/a	
Likelihood that corals occur there based on habitat suitability	*Likely*		*Unlikely*	Likely that corals occur in areas of hard substrate if a similarity to neighboring Baltimore Canyon is assumed. Baltimore and Wilmington similar in size, depth, and shape. Likely that both bathymetry and substrate are suitable for corals: rather deeply incised at shelf break – seems appropriate based on current understanding of topography. Pending analysis of multibeam data may strengthen or weaken this inference. Trawl survey indicates some amount of rocks – based on inference from Baltimore canyon, probably mostly soft sediment but with some outcrop areas, talus blocks, and glacial erratics.
	X?			

Map 18 - Wilmington Canyon.

Discrete coral zones

Notes:
- **Some figures do not contain all coral types.**
- **Colored contours are in 50 m intervals.**
- **Coral data are presence only and many areas have not been surveyed.**



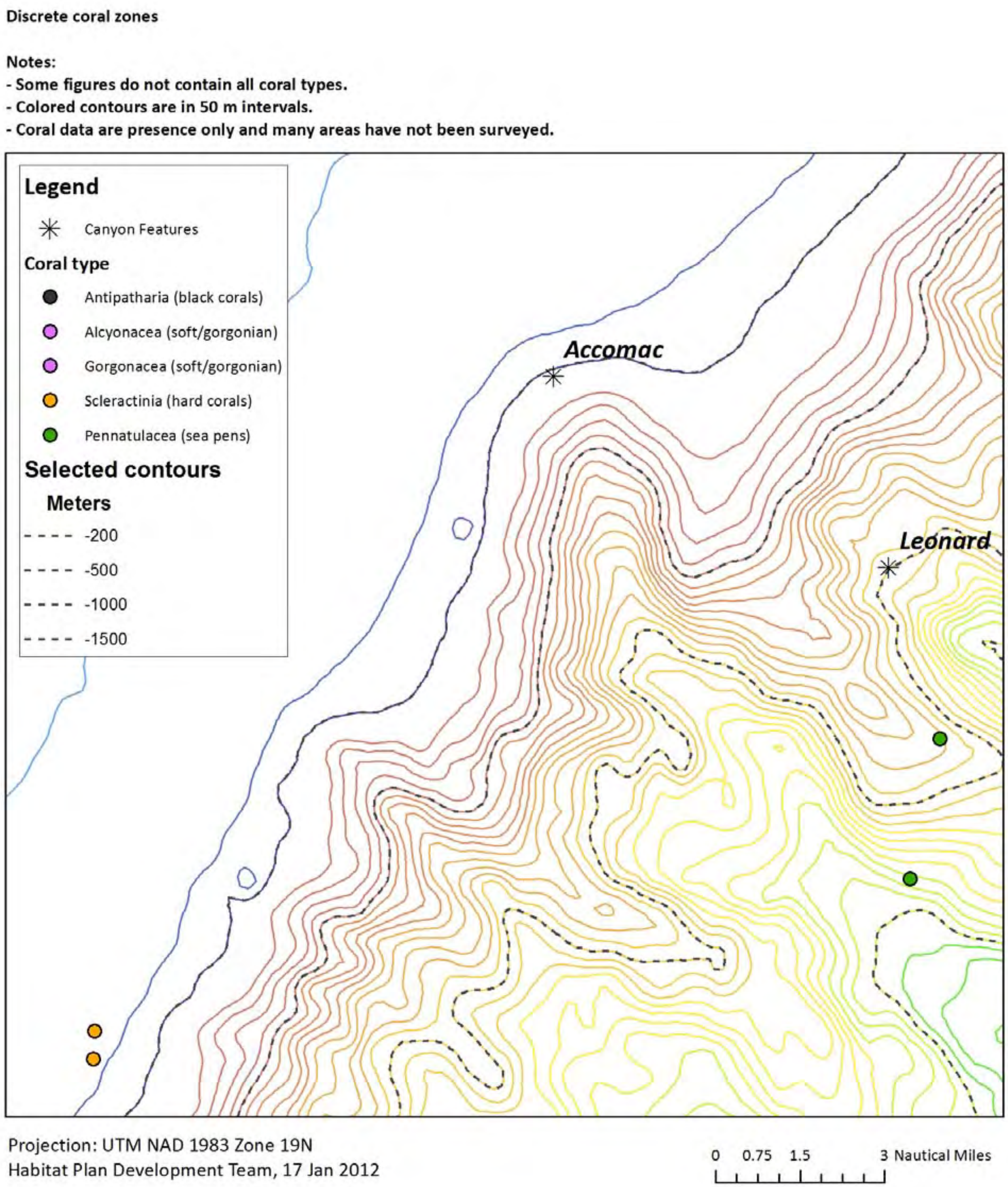
Projection: UTM NAD 1983 Zone 19N
Habitat Plan Development Team, 17 Jan 2012

0 1 2 4 Nautical Miles

3.3.2.5 Accomac Canyon

Accomac Canyon has a cross-sectional relief measurement of 617 m (Table 7), and is therefore recommended as a discrete coral zone on the basis of inferred habitat suitability.

Map 19 – Accomac Canyon



3.3.2.6 Washington Canyon

Survey work for corals in Washington Canyon is very limited, although new multibeam bathymetry data were collected in 2011. Washington Canyon has a cross-sectional relief measurement of 636 m (Table 7), and is therefore recommended as a discrete coral zone on the basis of inferred habitat suitability.

Table 32 – Geological, oceanographic, and biological characterization of Washington Canyon

Type of information	Data sources and methods	Summary of information
Morphology, bathymetry and slope	Bathymetric and seismic surveys in 1975 (see Forde 1981) Pratt (1967) Multibeam survey done in 2011 by Deepwater Canyons project – currently being analyzed	A relatively small canyon, incises shelf by about 10 km. Mouth of canyon oriented ESE, axis turns sharply to north about half way to head of canyon. North (and east) wall higher with steep sides in lower part of canyon, with one large side canyon. Third largest extension on to the continental rise of any canyon in NE U.S. (ca 170 km). It maintains a relatively constant profile in the deep sea, but, like Hudson and Wilmington canyons, has its maximum depth of 175 m about 50 km seaward of the 2000 m contour.
Substrate	Malahoff et al. (1978) One Alvin dive in canyon axis just beyond shelf edge Three undersea research sites shown by Cooper et al. (1987), but no data	Dive 811 began at 992 m in canyon axis, went down valley floor, then turned to intersect south wall at 1040 m, then up north wall to 670 m: floor relatively flat (<5˚) with soft sediment; walls slope 20-30˚; some low relief outcrops protruding several cm from north wall. (Records from this dive were reviewed by Hecker and Blechschmidt (1979) but not analyzed due to poor picture quality).
Corals documented and depths	No literature found at present that documents the presence of corals	n/a

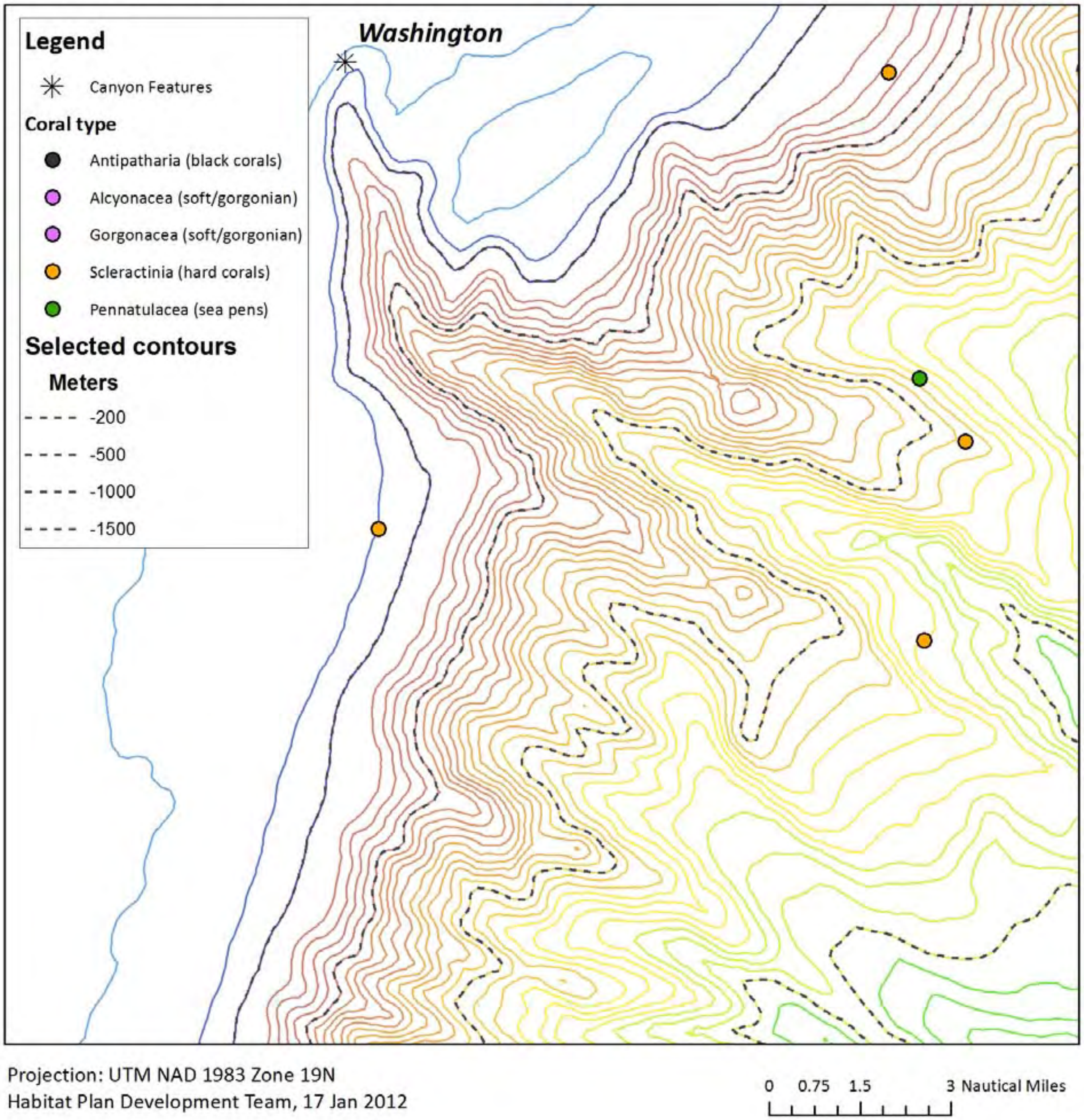
Table 33 – Coral assessment - Washington Canyon

<table>
<tr><th>Attribute</th><th colspan="3">Assessment</th><th>Notes</th></tr>
<tr><td rowspan="2">Adequacy of coral survey work relative to other areas</td><td>High</td><td>Moderate</td><td>Inadequate</td><td rowspan="2">No corals noted in single dive, but need more information. More survey work pending.</td></tr>
<tr><td></td><td></td><td>X</td></tr>
<tr><td rowspan="2">If surveyed, presence of corals in comparison to other canyon areas</td><td>High</td><td>Moderate</td><td>Low</td><td rowspan="2">n/a</td></tr>
<tr><td>n/a</td><td>n/a</td><td>n/a</td></tr>
<tr><td rowspan="2">Likelihood that corals occur there based on habitat suitability</td><td colspan="2">Likely</td><td>Unlikely</td><td rowspan="2"></td></tr>
<tr><td colspan="2">X</td><td></td></tr>
</table>

Map 20 - Washington Canyon

Discrete coral zones

Notes:
- Some figures do not contain all coral types.
- Colored contours are in 50 m intervals.
- Coral data are presence only and many areas have not been surveyed.



Projection: UTM NAD 1983 Zone 19N
Habitat Plan Development Team, 17 Jan 2012

3.3.3 Canyon and slope areas not recommended

3.3.3.1 Slope near U.S. – Canadian border

Although there are some coral observations from camera tows in this area, and some hard substrates have been documented, the PDT did not think there was enough evidence to warrant recommending this slope area as a discrete coral zone.

Table 34 – Geological and biological characterization of the slope near the US-Canadian border

Type of information	Data sources and methods	Summary of information
Geology	Hecker (1990)	Relatively steep with angles of 5.5˚ between 242 and 500m, 11.8˚ 500-1600 m, and 3.5˚ below 1600 m with variable surficial geology on upper and middle slope. The sea floor above 1300 m was frequently covered by glacial erratics (gravel to boulders) and was occasionally interrupted by low-relief outcrops.
Corals documented and depths	3 camera sled tows along one transect (?) between 242 and 2394 m in 1984, 85 and 86	Stony coral *Flabellum alabastrum* common 250-500 m, soft corals *Acanella arbuscula* and *Eunephthya florida* 700-1200 m, sea pen *Distichoptilum gracile* less common, but widespread. Note: Density (#/100 m^2) data and substrate associations for stony coral *F. alabastrum* and for soft corals *A. arbuscula and E. florida* in Hecker (1990).

Table 35 – Coral assessment for the slope area near the US-Canadian border

Attribute	Assessment			Notes
Adequacy of coral survey work relative to other areas	*High*	*Moderate*	*Inadequate*	One transect is insufficient for characterizing coral presence in this area, however, found corals even with low effort
		X		
If surveyed, presence of corals in comparison to other canyon areas	*High*	*Moderate*	*Low*	
		X		
Likelihood that corals occur there based on habitat suitability	*Likely*		*Unlikely*	Of four slope areas evaluated in Hecker (1990), this one had more hard substrate
	X			

3.3.3.2 Slope between Veatch and Hydrographer Canyons

This area is not recommended as a coral zone. Although small cup corals (hard coral *Dasmosmilia lymani*) and some sea pens are relatively common, other coral types are not. Evidence suggests that hard substrates in this area consist of glacial erratics, not rock outcrops.

Table 36 - Geological, oceanographic, and biological characterization of the slope between Veatch and Hydrographer Canyons

Type of information	Data sources and methods	Summary of information

Type of information	**Data sources and methods**	**Summary of information**
Geology	Hecker et al. (1983) and Hecker (1990)	This slope area (Slope Area III) is a 25 mile wide section of the continental slope on the southwestern edge of Georges Bank, between Veatch and Hydrographer Canyons. It is incised by numerous small gullies and tributaries. The western portion is narrow and steep, with occasional occurrences of low relief outcrop and boulders below 1500 m. Slope widens towards the east and has less vertical relief with very little outcrop. Seafloor consists of mud with occasional gravel, cobbles, and boulders. Slope is steep in its upper portion and flatter below 1800 m.
Corals documented and depths	See above 7 camera sled transects in 1981: for 4 that were analyzed depth range 290-2060 m, total area viewed 39 K m^2.	High occurrences of solitary hard coral *Dasmosmilia lymani* 290-350 m; sea pens *Distichoptilum gracile* below 1200 m and *Kophobelemnon stelliferum* 1510-1260 m; boulders in deep water with *Anthomastus agassizii*, *Paramuricea grandis*, and *Desmophyllum cristagalli*.

Table 37 – Coral assessment for the slope between Veatch and Hydrographer Canyons

Attribute	**Assessment**			**Notes**
Adequacy of coral survey work relative to other areas	*High*	*Moderate*	*Inadequate*	
		X		
If surveyed, presence of corals in comparison to other canyon areas	*High*	*Moderate*	*Low*	Aside from sea pens and small hard corals, observations were limited to corals on occasional boulders in deep water.
			X	
Likelihood that corals occur there based on habitat suitability	*Likely*		*Unlikely*	Rock outcrops apparently not very prominent or abundant.
			X	

3.3.3.3 Slope west of Alvin and Atlantis Canyons

Similar to above, this area is not recommended as a coral zone. Although small cup corals (hard coral *Dasmosmilia lymani*) and some sea pens are relatively common, other coral types are not. Evidence suggests that hard substrates in this area consist of glacial erratics, not rock outcrops.

Type of information	**Data sources and methods**	**Summary of information**
Geology	1. Hecker and Blechschmidt (1979) 2. Hecker (1990)	Gentle slope (1.7˚ 340-700m, 3.7˚ 700-1100m, 6.7˚ 1100-1600m, decreasing to 2.8˚ below 1600 m. Upper and middle slopes sediment covered with low-relief outcrops and occasional glacial erratics on lower slope.

Type of information	Data sources and methods	Summary of information
Corals documented and depths	8 sub dives on slope near Atlantis Canyon in 1265-2200 m (ref 1) 2 camera sled tows along one transect (?) in 1981, depth range 340-2100 m (ref 2) Dives made at six research sites in same area 1971-1986 (see Cooper et al. 1987) – no information	(1) *Flabellum alabastrum, Anthomastus agassizii, Paramuricea borealis, Acanella arbuscula*, and sea pens between 1750 and 2000 m; *F. alabastrum* and *A. arbuscula* and sea pens 1250-1500 m. (2) Stony corals *Dasmosmilia lymani* and *Flabellum alabastrum* 350-700 m, sea pen *Distichoptilum gracile* in deep water (1500-2050 m). Note: Density (#/100 m^2) data and substrate associations for stony corals *D. lymani* and *F. alabastrum* and for soft coral *A. arbuscula* in Hecker (1990).

Attribute	Assessment			Notes
Adequacy of coral survey work relative to other areas	*High*	*Moderate*	*Inadequate*	
		X		
If surveyed, presence of corals in comparison to other canyon areas	*High*	*Moderate*	*Low*	This area of the slope apparently has less hard substrate; most corals observed were sea pens and small stony corals. Corals that were observed in relatively deep water.
			X	
Likelihood that corals occur there based on habitat suitability	*Likely*		*Unlikely*	
			X	

3.3.3.4 Slope area between Baltimore and Accomac canyons

This area is not recommended as a coral zone. Evidence suggests that hard substrates in this area consist of glacial erratics, not rock outcrops.

Type of information	Data sources and methods	Summary of information
Geology	Malahoff et al. (1982), photos reviewed by Hecker and Blechschmidt (1979)	Dive 765 (197-545 m): upper slope and shelf break, no canyons or channels, fine sand to silty bottom with occasional cobbles and boulders; Dive 766 (1550-1790 m): traversed a slump mass, silty mud sediment; Dive 767: valley and ridge terrain (860-1300 m), occasional cobbles in valleys.
Corals documented and depths	**3 sub dives during 1977-78**	No information provided in H&B (1979) re corals.

Attribute	Assessment	Notes

<table>
<tr><td rowspan="2">Adequacy of coral survey work relative to other areas</td><td>High</td><td>Moderate</td><td>Inadequate</td><td rowspan="2"></td></tr>
<tr><td></td><td>X</td><td></td></tr>
<tr><td rowspan="2">If surveyed, presence of corals in comparison to other canyon areas</td><td>High</td><td>Moderate</td><td>Low</td><td rowspan="2">B&H (1979) reviewed photos taken during three dives in this area, but did not report any DSC observations, so presumably there were very few.</td></tr>
<tr><td></td><td></td><td>X</td></tr>
<tr><td rowspan="2">Likelihood that corals occur there based on habitat suitability</td><td colspan="2">Likely</td><td>Unlikely</td><td rowspan="2">n/a</td></tr>
<tr><td colspan="2"></td><td>X</td></tr>
</table>

3.3.3.5 Canyons not recommended based on GIS analysis: Chebacco, Filebottom, Sharpshooter, Dogbody, Shallop, Nantucket, Atlantis, Block, McMaster, Ryan Canyon, Uchupi, and Spencer Canyons

These canyons are not recommended as they are shallower and incise the shelf to a lesser degree. Specifically, their relief from canyon rim to the seafloor along the axis/thalweg were less than 450 m (Table 7).

Atlantis Canyon was discussed in the greatest detail as it was previously examined and recommended in the context of HAPC designations. It has no deep-sea extensions, and only incises the shelf 5 km (Pratt 1967). This shallow incision into the shelf edge was assumed to indicate a lesser likelihood of rock outcrops and thus suitable habitat. The GIS analysis indicated that the relief of Atlantis Canyon from the canyon rim to the seafloor at the three degree slope contour was less than 450 m, so suitable habitat was not inferred. In addition, coral survey work to support assessment of this canyon as coral zones is inadequate, as there have been no surveys for corals. Due to lack of coral data evidence and inferred lack of suitable habitats, this canyon is not recommended as a coral zone. Neighboring Alvin Canyon has greater relief and is recommended on the basis of habitat suitability.

3.3.3.6 Canyons not recommended; did not incise shelf enough to conduct GIS analysis: Clipper, South Wilmington, North Heys, South Vries, Warr, Phoenix, and Leonard Canyons

These canyons are not recommended as they do not noticeably incise the shelf. Their morphological attributes were not measured during the GIS analysis because they are smaller and shallower, and an appropriate cross section could not be readily identified for the analysis.

3.3.4 Other recommended zones

3.3.4.1 Bear Seamount

Bear Seamount is relatively well studied in terms of coral distributions, and a variety of species have been documented. It is recommended as a coral zone.

Table 38 – Biological characterization of Bear Seamount

Type of information	Data sources and methods	Summary of information
Corals documented and depths	Moore et al. (2003, 2004); Brugler (2005); Cairns (2006, 2007), Mosher and Watling (2009), Thoma et al. (2009); Deep Atlantic Stepping Stones Science Team/IFE/URI/NOAA, NE database (including Smithsonian database).	**Stony**: *Vaughanella margaritata, Caryophyllia ambrosia ambrosia*, *Lophelia pertusa, Desmophyllum dianthus, Solenosmilia variabilis Enallopsammia rostrata, Flabellum alabastrum;* **Soft**: *Anthomastus agassizii*; *Chrysogorgia* sp., *Metallogorgia melanotrichos*, *Radicipes gracilis*, *Lepidisis Caryophyllia*?, *Paragorgia arborea?, Swiftia casta?, Primnoa resedaeformis?*, *Thouarella grasshoffi, Calyptrophora antilla* (39°53'42"N, 66°23'07"W)*, Paramuricea* sp., *Keratoisis* sp.; **Sea pens**: *Pennatula aculeata;* **Black**: *Bathypathes* (Schizopathidae), *Leiopathes* sp. Smithsonian database: *Parantipathes tetrasticha* listed on summit of Bear Seamount; listed in ITIS in the family Antipathidae; Clavulariidae listed on Bear summit. *Bathypathes* (Schizopathidae) 1195–1402 and 1843–1888 m, *Leiopathes* sp. 1643 m, *Chrysogorgia* sp. 1559 and 1994–2031, *Metallogorgia melanotrichos* 1491, 1559 (Mosher and Watling 2009) and 1559, 1639 (Thoma et al. 2009), *Radicipes gracilis* 1431–1464 and 1428–1650, *Paramuricea* sp. 1378–1431, *Calyptrophora antilla* 1684 m; Smithsonian database: *Parantipathes tetrasticha* 1165 m.

Table 39 – Coral assessment – Bear Seamount

Attribute	Assessment		
Adequacy of coral survey work relative to other areas	*High*	*Moderate*	*Inadequate*
	x		
If surveyed, presence of corals in comparison to other seamounts	*High*	*Moderate*	*Low*
	x		
Likelihood that corals occur there based on habitat suitability	*Likely*		*Unlikely*
	X		

3.3.4.2 Retriever Seamount

Although it has not been surveyed as well as Bear Seamount, Retriever Seamount has been surveyed for corals and a variety of species have been documented. This area is recommended as a coral zone.

Table 40 – Biological characterization of Retriever Seamount

Type of information	Data sources and methods	Summary of information

Type of information	Data sources and methods	Summary of information
Corals documented and depths	Cairns (2007), Mosher and Watling (2009), Thoma et al. (2009)	**Soft**: *Chrysogorgia* sp., *Metallogorgia melanotrichos*, *Acanella arbuscula, Parastenella atlantica* (39°48.5454’N, 66° 14.9883’W), *Paranarella watlingi* (39°48.0754’N, 66°14.9408’W), *Paramuricea* sp.; **Black**: *Bathypathes* (Schizopathidae), *Parantipathes* (Schizopathidae). *Bathypathes* (Schizopathidae) 1983 m, *Parantipathes* (Schizopathidae) 2045 m, *Chrysogorgia* sp. 3860 m, *Metallogorgia melanotrichos* 1983, 2012, *Acanella arbuscula* 2035, 2040, *Paramuricea* sp. 1981, 1984, 1985, 2040 m, *Parastenella atlantica* 1984 m, *Paranarella watlingi* 3855 m.

Table 41 – Coral assessment - Retriever Seamount

Attribute	Assessment		
Adequacy of coral survey work relative to other areas	*High*	*Moderate*	*Inadequate*
		X	
If surveyed, presence of corals in comparison to other seamounts	*High*	*Moderate*	*Low*
	X		
Likelihood that corals occur there based on habitat suitability	*Likely*		*Unlikely*
	X		

3.3.4.3 Physalia and Mytilus Seamounts

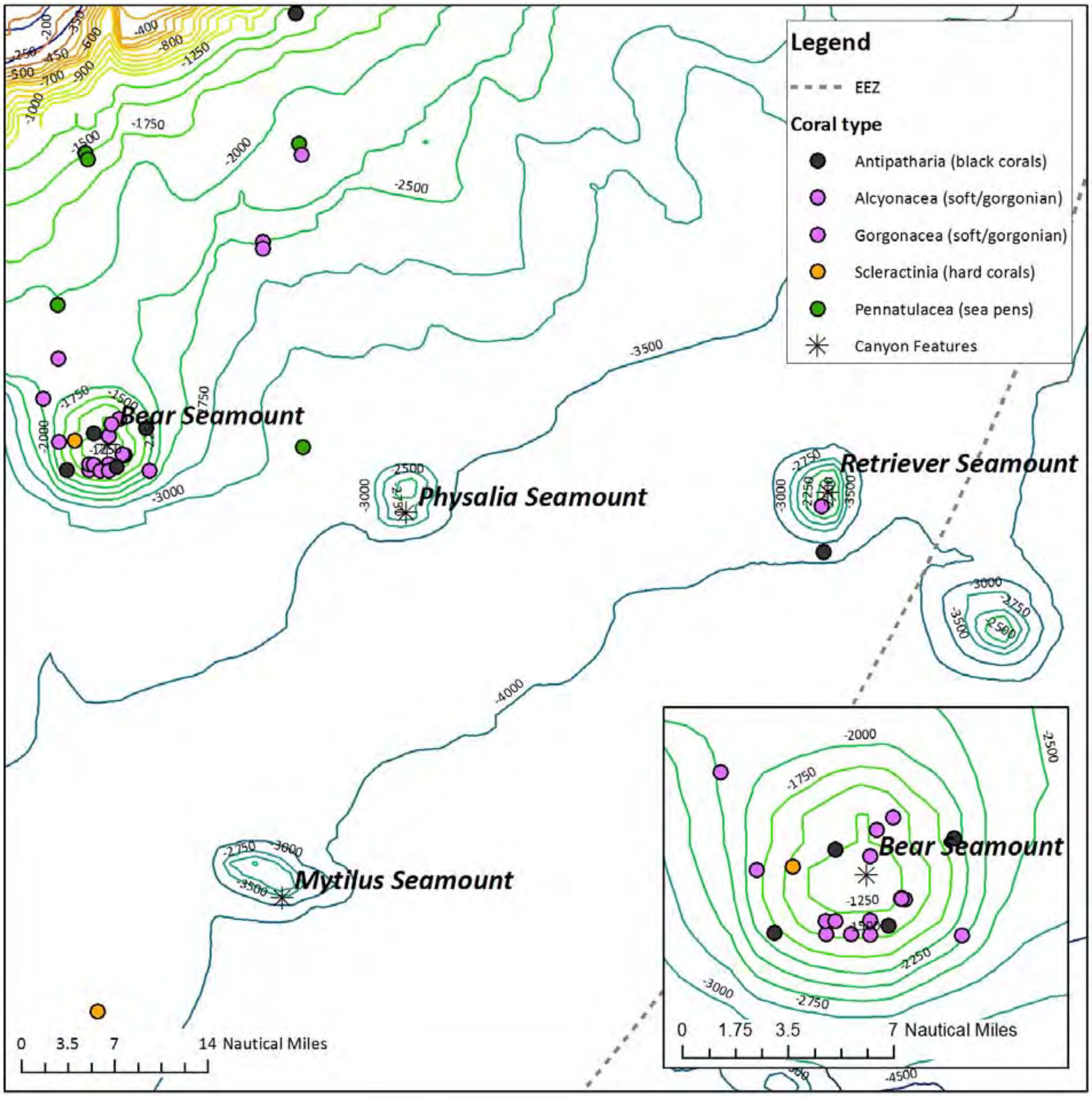
Physalia Seamount and Mytilus Seamount have not been surveyed for corals, but suitable habitat is inferred based on similarities with Bear and Retriever Seamounts.

Map 21 – Seamount coral observations.

Discrete coral zones - Seamounts

Note: Coral data are presence only and many areas have not been surveyed.
Many observations shown below represent dive locations where multiple coral types and colonies were seen.

Projection: UTM NAD 1983 Zone 19N
Habitat Plan Development Team, 17 Jan 2012



3.3.4.4 Mount Desert Rock

Mount Desert Rock is located approximately 30 km offshore of Mt Desert Island, Maine. The waters immediately surrounding the rock itself are 30-40 meters deep. The suggested coral zone area to the southwest of Mount Desert Rock has water depths ranging from approximately 100 m to 200 m.

Table 42 – Biological characterization of Mt Desert Rock area

Type of information	Data sources and methods	Summary of information
Corals documented and depths	ROV (remotely operated vehicle) video observations and sample collections at two stations during a 2002 research cruise.	Colonies of red tree coral *Primnoa resedaeformis* were found on steep surfaces in this area, with dense and diverse habitat-forming sponges found throughout the dive transects (dive details Watling and Auster, unpublished). We infer that corals are likely to be distributed in areas of similar geology and experiencing similar oceanographic conditions around these sites.

Table 43 – Coral assessment - Mt Desert Rock area

Attribute	Assessment		
Adequacy of coral survey work relative to other areas	*Highly adequate*	*Moderately adequate*	*Inadequate*
		x	
If surveyed, presence of corals in comparison to other GOM areas	*High abundance*	*Average abundance*	*Low abundance*
	x		

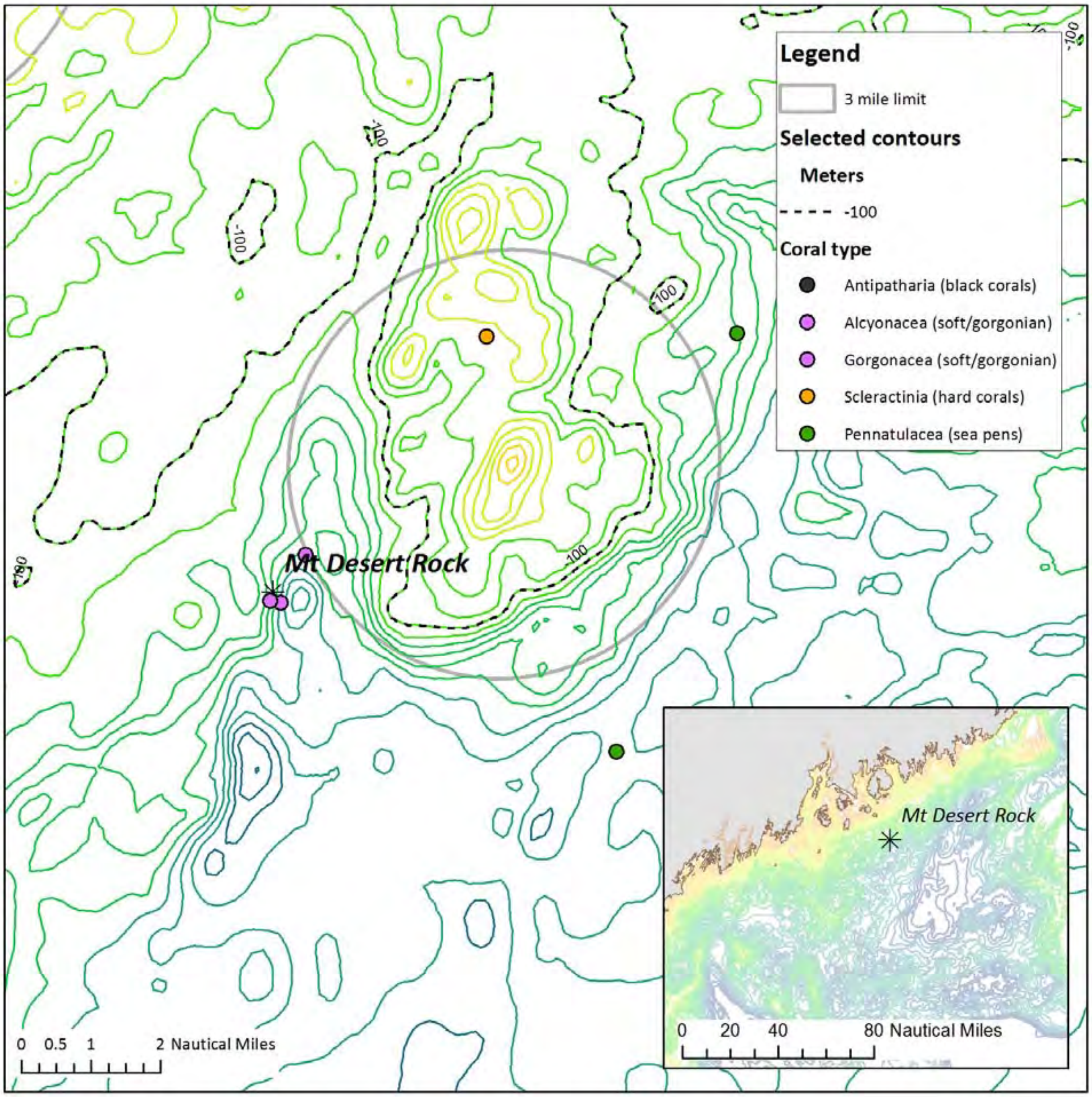
Figure 2 - Deep-sea corals observed in Mount Desert Rock area.

Map 22 – Coral observations near Mt Desert Rock, Gulf of Maine.

Discrete coral zones - Gulf of Maine

Note: Coral data are presence only and many areas have not been surveyed. Not all coral types may be represented in each figure. Observations on Mt Desert Rock represent dive locations where multiple coral types and colonies were seen.

Projection: UTM NAD 1983 Zone 19N
Habitat Plan Development Team, 17 Jan 2012



3.3.4.5 Western Jordan Basin

Jordan Basin is 200-250 m deep basin located in the eastern Gulf of Maine that straddles the US/CAN EEZ. Although much of the basin contains soft sediments, there are steep rock patches (bumps) that have been found to harbor various types of corals. An area encompassing multiple bumps is recommended as a coral zone. Corals have also been documented in eastern Jordan Basin, on the Canadian side of the EEZ.

Table 44 – Geological, oceanographic, and biological characterization of Western Jordan Basin

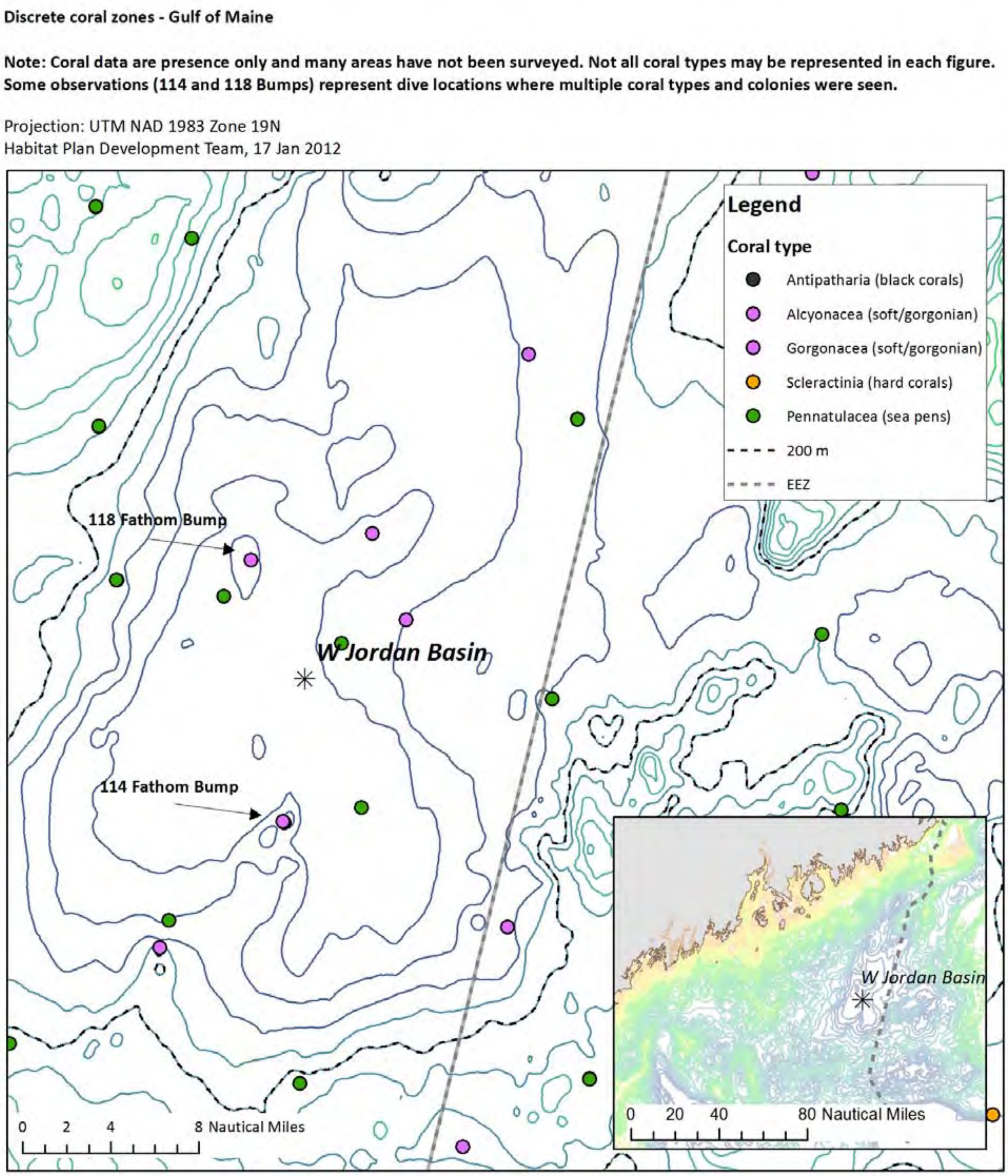
Type of information	Data sources and methods	Summary of information
Morphology, bathymetry and slope		While bathymetric charts indicate relatively moderate topographic complexity, observations and limited multibeam records indicate steep rock patches emerging from surrounding fine grain sediments.
Substrate	ROV (remotely operated vehicle) video observations and sample collections at four stations during research cruises in 2002 and 2003	See above.
Corals documented and depths	ROV (remotely operated vehicle) video observations and sample collections at four stations during research cruises in 2002 and 2003 CoWCoG coral database records that come from Watling & Auster (2005)	These patches of hard substratum support *Paragorgia arborea*, both pink and white forms, *Primnoa resedaeformis*, and a species of *Paramuricea*. Observed hard substratum communities were dominated by corals, and provided habitat for Acadian redfish and cusk (Auster 2005) as well as pandalid shrimp, an important prey taxa for species of economic importance. Thoma et al. (2009) found that *Paramuricea* in the Gulf of Maine and along the continental margin were genetically similar but different from specimens elsewhere in the North Atlantic basin, and may represent a unique species.

Table 45 – Coral assessment - Western Jordan Basin

Attribute	Assessment		
Adequacy of coral survey work relative to other areas	*Highly adequate*	*Moderately adequate*	*Inadequate*
		X	
If surveyed, presence of corals in comparison to other canyon areas	*High abundance*	*Average abundance*	*Low abundance*
	X	X	

Figure 3 - Deep-sea corals observed in Jordan Basin.

Map 23 - Western Jordan Basin coral observations.



4.0 Vulnerability of corals to fishing gear impacts

The following is a review of research studies concerned with the impacts of commercial fishing on deep water corals and coral reefs. The literature addresses several gear types as well as study locations. While the studies sites cover a variety of locations globally, the impacts of commercial fishing on the local corals and seafloor are virtually identical throughout the literature. The disturbances seen ranged from scarring left by trawl gear, to complete destruction of coral and stripping of the seafloor to underlying rock. The surviving coral in fished areas was often located on undesirable fishing terrain, or at depths not targeted by fishermen.

The conclusions drawn by these studies are that commercial fishing gear damages deep-sea corals. Trawling, specifically, is very detrimental to coral and the seafloor. The level of damage between trawled and untrawled sites is large enough to conclude that fishing has a negative impact on both the corals and the associated fauna. The substrates of heavily fished areas have been stripped to bare rock or reduced to coral rubble and sand, whereas unfished and lightly fished areas did not see such degradation (Grehan et al 2005). Passive gear, such as pots or longlines, while still affecting localized area of corals, were not as destructive as trawl gear. Coral mortality is markedly increased due to corals being crushed, buried and wounded by gear as it is dragged over the bottom (Fosså et al 2002). The degree of disturbance to the coral and seafloor ranges from lightly disturbed areas of overturned cobble with attached, living, coral, to complete stripping of the seafloor (Stone 2006).

The deep water reefs attract fauna and promote areas of high diversity in an otherwise low diversity area. Fishermen have reported that as the damage to the reefs increase, areas that were once fertile fishing grounds have seen fewer successful fishing trips (Fosså et al 2002). The fauna associated with corals are primarily "removed" along with the destruction of the coral substrate.

While much of the coral on fishing grounds was damaged or destroyed there were areas that avoided contact. As stated previously, corals growing on steep slopes had a natural protection from commercial fishing gear as a slope >20 degrees cannot be trawled. Areas of higher three dimensional complexity were also relatively untouched, as these were avoided by the fishermen for fear of damage and loss of their gear.

The studies have concluded that deep water corals are especially fragile and the greatest disturbance and destruction occurs at depths targeted by commercial fishing (Heifetz et al 2009, Hall-Spencer et al 2002). Bottom contact gear is especially detrimental and there is a correlation between the highest rates of coral damage and the depths targeted by that industry in particular. Slow growth rates and reproductive processes that are so easily disrupted result in a timely recovery period of disturbed areas.

4.1 Study methods

Each of the study sites was observed using some form of photographic or continuous video transects. Several studies mapped the area using sidescan sonar (Wheeler et al 2005, Fosså et al 2002) or multibeam sonar in conjunction with a deep camera system (Althaus et al 2009, Grehan et al 2005). This technique allowed them to determine the damage caused by dragging gear over the seafloor.

The logs of fishing trips, reports from fishermen, and other literature on fishing activities at each of the areas, were utilized by a number of the studies from each of the different regions (Althaus et al 2009, Koslow et al 2001, Heifetz et al 2009, Fosså et al 2002, Cryer et al 2002). Anecdotal reports acted as a guide to further research areas, as well as providing information about to the history of fishing and practices in the area (Fosså et al 2002).

Samples were examined in three of the studies to determine the associated fauna in the area of the corals, as well as to assess the bycatch in commercial fisheries. One study (Cryer et al 2002) used previously collected and stored samples from other research trips to determine fauna of the area. Another (Hall-Spencer et al 2002) collected samples while accompanying two French trawlers on a fishing trip to examine commercial bycatch. A third study (Koslow et al 2001) used dredge, drop line with hooks, and traps to sample benthic, as well as motile, fauna associated with the corals.

4.2 Gear types evaluated

In reviewing the research there was frequently a lack of adequate gear descriptions being examined by each study, however, three papers gave a general description of what gears are commonly employed in each of the fisheries, as well as the gear used for research. While gear descriptions can be found via other sources, the variety of gear types as well as techniques used to fish them leaves much to be inferred when the only description provided by the researcher is that a "trawl" was used. A few studies were successful at providing gear descriptions, but the dimensions of gear size can vary and a universal description and size should not be assumed for all fishing effort with each gear type. It appears that the gear could be lumped into categories, based on door size and net width for the example of trawls, however larger boats are most likely going to pull larger gear, in theory causing more damage.

The best attempt at describing the gear associated with fishing impacts provided typical gear set up and use for deep water fishing using long-lines, gill nets, traps, and trawls. It stated that for long-lines 85 hooks were typically set 3m apart on a line, and 100-120 lines were often set out (averaging 8000-9600 hooks on 28-35km of line). Gill nets in the industry were 50m long x 12m high. These were worked in stings of 700 nets. Trawls were usually fitted with rockhopper gear and held open by otter boards weighing around 1000kg each, set at a distance of 60-70m apart. The trawls are then towed for about 4 hours at a around 5-8km/h (Grehan et al 2005).

There was only one study (Cryer et al 2002) that gave a short description of the gear in use, observing that the trawl doors were set at about 40m apart, but when towing (at 5.0-5.4 km/h) the net had an effective width of around 25m. It also mentioned the use of a "Florida Flyer" net (85mm mesh and 35mm mesh) set up between "Bison" doors being used in the trawl. This at least provides a starting point for researching further descriptions of the gear used during the study.

The gear used by two 38m commercial trawlers in another study (Hall-Spencer et al 2002) was briefly described, stating that both boats used trawls with rockhopper gear and 900kg otter boards, with the boards set at approximately 22m apart. The speed was the same 4.5-5.5 km/h towing speed that appeared to be the general towing speed mentioned for fishing, or camera-towed research.

4.3 Study Sites and Findings

The research area of the studies can be broken down into larger regions. Three of the studies took place in the southern Pacific Ocean. Two of these (Althaus et al 2009, Koslow et al 2001) focused on seamounts south of Tasmania while the other (Cryer et al 2002) examined the Bay of Plenty on the north shore of New Zealand.

On the Tasmanian seamounts, areas that had never been trawled, or were lightly fished (determined via trip logs), were dominated by the coral *Solenosmilia variabilis*, making up 89-99% of coral cover in never trawled areas (Althaus et al 2009) as well as seamounts peaking below 1400m (Koslow et al 2001). It was found that active trawling at sites removed most, or all, of the coral and associated substrate, leaving bare rock in heavily trawled areas, and coral rubble and sand at the lower limits of fishing activity (Koslow et al 2001). This was supported by photographic transects by Althaus et al (2009) showing coral in less than 2% of trawled areas. "Trawling ceased" areas, where trawling had effectively stopped 5-10 years earlier, showed coral in approximately 21% of the transects. This study also found a higher abundance of the faster growing hydroids colonizing cleared areas, smaller corals and octocorals, as well as noting whip-like chrysogorgiid corals which were flexible and could presumably bend and pass under the trawls.

Two studies (Heifetz et al 2009, Stone 2006) were focused in the northern Pacific Ocean around the Aleutian Islands. In these studies, longline gear was observed on 76% of transects, but were found to only result in 5% of the disturbed area. Trawling, on the other hand, was only seen at 28% of the transects, but disturbed 32.7% of the observed seafloor, indicating a relatively greater impact of trawls. Overall, 22 of the 25 transects showed disturbance to the seafloor (approximately 39% disturbance) (Stone 2006). This was supported by the second study in this region (Heifetz et al 2009) with evidence of trawling, indicated by uniform parallel striations in the seafloor, seen on several dives. Damage caused by traps was not statistically significant between the fished and unfished areas at this site. Both studies observed that the most damage done to corals and the seafloor occurred at depths where commercial fishing intensity was the highest (100-200m), with higher population densities occurring at 200-300m.

Four studies took place in the north-eastern Atlantic Ocean. Two examined the corals on raised carbonate mounds off the western (Grehan et al 2005) and northern coasts (Wheeler et al 2005) of Ireland. The third (Hall-Spencer et al 2002) focused on the West Ireland continental shelf break, and the last study (Fosså et al 2002) dealt with deep water reefs in Norwegian waters.

The observations made off the coasts of Ireland and Norway were both similar to, and supported, findings at the Aleutian Islands. Damage at the reefs (*Lophelia pertusa*) of Norway was most severe at shallower depths where commercial fishing primarily took place. The continental shelf, at approximately 200-400m (below the highest levels of fishing), had the highest abundance of corals. These corals were intact and developed, whereas the shallower sites contained crushed coral and coral rubble, where damages were estimated at 30-50%. Accounts from local fishermen claim this is due to the fact that often the gear, chains, and otter doors of trawlers were used to crush and clear the seafloor prior to the start of fishing (Fosså et al 2002).

Another study (Hall-Spencer et al 2002) found scars from trawl doors (indicated by parallel marks or furrows on the sea floor) that were up to 4km long, as well as coral rubble on trawled areas. Locations lacking observable trawl scars contain living, unbroken, *L. pertusa*. These findings were observed at the site off the northern coast of Ireland **(**Wheeler et al 2005**)** as well. Trawl marks were located on side scan sonar records, and video showed parallel marks left by trawl doors, as well as the net and ground line gear, on the seafloor. The amount of dead coral and coral rubble increased at sites that were obviously trawled.

The various study sites of Fosså et al (2002) presented a range of disturbance due to fishing. While the deeper water corals were intact and living at one site, almost all corals were crushed or dead at another. A third demonstrated multiple stages of coral degradation, from living to dead and crushed, as well as the base aggregate the reefs often form and grow on being crushed and spread out. The percent of damage to the area was correlated with the number of reports by the fishermen of fishing activity, bycatch, and corals in the area; ranging from 5-52% damaged. More of these reports from an area indicated a larger coral community at that location, and with that, higher proportions of the area were found to be damaged.

Hall-Spencer et al (2002) also noted that fishermen avoided uneven ground due to the loss of time and money from resulting gear upkeep of tangled and damaged gear. Areas of large coral bycatch were avoided in the future, as known trouble areas for the fishermen. Because of this only 5 of the 229 trawls in the study contained large amounts of coral bycatch. Thus, the areas where corals were present and undamaged tended to have a higher topographic complexity of the seafloor.

The effect of seafloor topography on fishing and the resulting impact on corals was observed in a study site west of Ireland (Grehan et al 2005). While evidence of active trawling was seen, indicated by trawl scars in mud and non-coral habitat, there was no damage to corals on the mounds observed caused by fishing. This was due to the fact that the slope of the mounds where coral growth occurred was greater than 20 degrees. This makes the terrain is too steep to trawl and the corals were naturally protected from the gear and relatively undamaged.

One of the studies (Mortensen and Buhl-Mortensen 2004) examined the distribution of corals in the Northeast Channel in the Gulf of Maine. This site could be similar to the sites off of Ireland and Norway, however because of the distance and somewhat different environmental factors it was considered a separate region. This study was concerned with the distribution of corals relative to the benthic habitat. It found that the corals were located on the shelf break and along valleys. This habitat was subject to daily tidal water movement into and out of the Gulf of Maine, aiding in the regulation of temperature, salinity, and food supply. Similar water movement is found on seamounts and shelf breaks, as currents flow over the change in topography, providing the corals with a regulated area in which to grow (Thiem et al 2006; Pires et al 2009).

4.4 Coral growth and recovery potential

The approximate growth rates of deepwater corals have been calculated in several studies on different species of corals. *Oculina* reefs occur in waters off the east coast of Florida. By observing these corals at 6m and at 80m it was found that the corals found at the deepwater (80m) site grew relatively more quickly (16.1 mm/yr) than the same corals at the 6m site (11.3 mm/yr). When transplanted from 6m to 80m the coral polyps lost their zooxanthellae and fed off the food supply provided by the colder deep currents containing more nutrients (Reed 2002).

Two studies done off Atlantic Canada worked at finding the growth rates for *Primnoa resedaeformis*. The corals were found at approximately 200-600m and were dated to 2600-2920 years old ± 50-60 years using C^{14} dating techniques. Using the dated age and size of the colony (~0.5-0.75m in height) the average radial growth at the base of the coral was found to be 0.44 mm/yr and tip extension growth rates were around 1.5-2.5 mm/yr (Risk et al 2002), slower than the estimated rate found for *Oculina* reefs.

The difference in growth rates calculated in these studies can potentially be explained by the other study working with *P. resedaeformis*, as well as *Paragorgia arborea*. The height of colonies ranged from 5-180cm for *P. arborea* (averaging 57cm) and 5-80cm for *P. resedaeformis* (averaging 29.5cm). The maximum age of samples collected was 61 years (found by counting annual growth rings under a dissecting microscope and x-ray examination). It estimated that the rate of growth for the first 30 years was around 1.8-2.2 cm/yr. After the coral began to age (>30 years), growth slowed to 0.3-0.7 cm/yr. This shows that initially the coral grows at a speed concurrent with the first study, and then dramatically slows to only a few millimeters a year, suggested by the second study (Mortensen and Buhl-Mortensen 2005). With a growth rate of, at most, a centimeter or two year, the complete destruction and clearing of the seafloor of corals can result in very long recovery time for both the coral, and associated fauna.

Deep water coral reproduction is a subject that has not been the topic of research until recently. While the physiology of reproduction in corals has been studied, little is known about the process of timing involved and the survival of resulting offspring. Studies have, however, shown that many of the deep water corals have separate sexes (Brooke and Stone 2007; Roberts et al 2006; Waller et al 2002; Waller et al 2005). Brooke and Stone (2007) collected samples of corals (*Stylaster*, *Errinopora*, *Distichopora*, *Cyclohelia*, and *Crypthelia*) around the Aleutian Islands and discovered that the collection held a mix of females containing mature eggs, developing embryos, and planulae, males producing spermatozoa, and organisms with no reproductive material. As was pointed out the gametes within the collection were not synchronized which indicates that reproduction is either continuous, or prolonged during a certain season of the year (Brook and Stone 2007).

Waller et al (2002) also found *Fungiacyathus marenzelleri* (collected from the Northeast Atlantic at 2200m) to be gonochoric, with a sex ratio of near 1:1. The fecundity of *F. marenzelleri* was calculated to be 2892 ± 44.4 oocytes per polyp. The mean diameter of oocytes did not vary significantly from month to month and all levels of sperm development were noted. The coral was thus considered quasi-continuous reproducers, with gametogenesis for spermacysts and oocytes occurring continuously as in Brooke and Stone (2007). An interesting finding of the study was that while *F. marenzelleri* has separate sexes, it can also undergo asexual reproduction and budding was present during the study. However, this was limited to no more than one bud found on any individual and no more than two individuals were found to bud at the same time (Waller et al 2002), not nearly the kind of reproductive rate to sustain a population in highly disturbed areas.

Fecundity and reproductive traits for three other corals collected in the Northeast Atlantic were also determined in a study by Waller et al (2005). *Caryophyllia ambrosia* (collected from 1100-1300m), *C. cornuformis* (from 435-2000m), and *C. seguenzae* (from 960-1900m) were all found to be cyclical hermaphroditic. The corals possessed both sexes but only one sex was dominant at a time, corals transitioning between sexes were seen in the study and labeled as "intermediates". The fecundity of the corals was calculated at 200-2750 oocytes per polyp for *C. ambrosia*, 52-940 oocytes per polyp for *C. seguenzae* and no data due to insufficient samples of *C. cornuformis*. As with the other studies there was no significant difference in the average number of oocytes per month and continuous reproduction is assumed for both *C. ambrosia* and *C. cornuformis* (Waller et al 2005).

The effects of mechanical disturbance and trauma to the soft coral *Gersemia rubiformis* (collected from the Bay of Fundy) was examined in a lab setting by Henry et al (2003). In the study, eight colonies of soft coral, four control and four experimental, were set up in separate aquariums to determine damage and recovery rate of the organisms. The experimental colonies were rolled over and crushed every two weeks to simulate bottom contact trawling. Four days and one week after disturbance observations were recorded. It was found that crushing the corals caused retraction of the entire colony. Damaged tissue was repaired and healed between 18 and 21 days. The effect the crushing had on coral reproduction was surprising to the researchers.

Thirteen days after the initial disturbance daughter colonies were seen forming at the base of the corals, and by the end of the experiment 100% of the corals had daughter colonies at one point during the study. The mortality rate of the juveniles was 100%, however, and no colonies survived past the polyp stage. Upon testing it was determined that these colonies were sexually derived, and since they had been separated for the experiment it is assumed that the corals were brooding when collected, as they were not visibly fertile prior to the experiment. It should be noted that the control group did not have any daughter colonies during the experiment, and only after (when they were experimentally also crushed) did daughter colonies appear. It is thought that the reason for this was the expulsion of premature planulae (resulting in their ultimate death) due to stress placed on the coral and the need to allocate resources to repair damaged tissue. While adult *G. rubiformis* was able to withstand the mechanical rolling and crushing, the increased mortality of offspring due to ejecting premature planulae may have increased long term effects as the corals are repeatedly disturbed and not able to produce surviving offspring (Henry et al 2003).

While the physiology of these corals has been recently studied, more research is needed to determine the ability of corals to recolonize disturbed areas. Brooke and Stone (2007) concluded that a lightly impacted area would be able to recover via colony growth alone. However, heavily impacted areas, where the seafloor has been scoured and stripped of cover would require coral larvae to be dispersed via currents and settle the area again, which could be a slow, timely process.

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